

# **Geologic map of the southern Roskrige Mountains (the San Pedro and the southern half of La Tortuga Butte 7.5' quadrangles), Pima County, Arizona v. 2.0**

by

Charles A. Ferguson, Wyatt G. Gilbert,  
Philip A. Pearthree, and Thomas H. Biggs

Digital Geologic Map (186)  
Formerly AZGS Open-File Report (00-06)

November 23 2022

Arizona Geological Survey  
University of Arizona  
1955 E 6st Tucson Arizona, 85721

*Research supported by the U. S. Geological Survey, National  
Cooperative Geologic Mapping Program, under USGS award  
number 99HQAG0J71.*

This report is part of a digital republication of a 2000 geologic map originally created by the Arizona Geological Survey with financial support from National Cooperative Geologic Mapping Program, (99HQAG0J71). Preparation for republication was conducted by students from the University of Arizona with financial support from the U.S. Geological Survey, National Geological and Geophysical Data Preservation Program (G21AP10428) and included the production of a new GIS geodatabase and a revised map layout. The following text report has not been altered and remains identical to the 2000 original, but there may be situations where unit names, ages, symbology, or other geologic information contained within this report do not match the information presented in the new map layout or GIS geodatabase.

**Geologic map of the southern Roskrige Mountains  
(the San Pedro and the southern half of  
La Tortuga Butte 7.5' quadrangles),  
Pima County, Arizona**

by  
Charles A. Ferguson, Wyatt G. Gilbert,  
Philip A. Pearthree, and Thomas H. Biggs

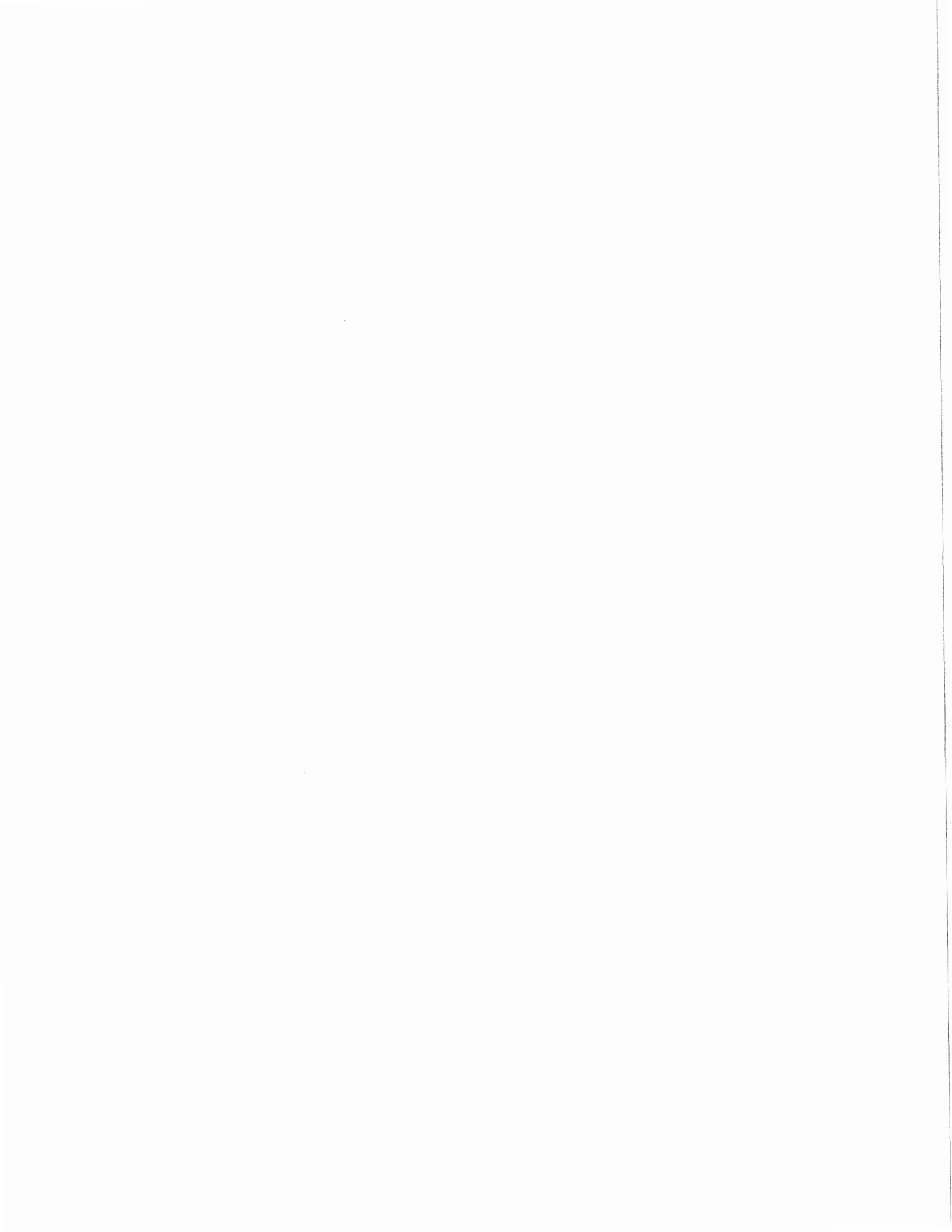
Arizona Geological Survey  
Open-File Report 00-06

September, 2000

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

**Includes 40 page text, 1:24,000 scale geologic map and cross-sections (2 sheets)**

*Research supported by the U. S. Geological Survey, National Cooperative  
Geologic Mapping Program, under USGS award number 99HQAG0171.  
The views and conclusions contained in this document are those of the authors  
and should not be interpreted as necessarily representing the official policies,  
either expressed or implied, of the U. S. Government*



## LOCATION AND ACKNOWLEDGEMENTS

The study area includes the southern Roskrige Mountains and a small area of the northernmost Coyote Mountains in Pima County, southeast Arizona (Figure 1). Elevations in the area range between 2500' and 4300'. The area lies within the sonoran desert with large areas of relatively open desert punctuated by thick brushy zones along major washes. Bedrock geology was mapped by Charles Ferguson and Wyatt Gilbert during the winter and spring of 1999-2000, and the Quaternary geology was mapped by Thomas Biggs and Phil Pearthree in the spring and summer of 2000. Some areas within the boundary of the Tohono O'Odham Nation were mapped using remote techniques.

Mapping was supported by the United States Geological Survey and the Arizona Geological Survey as part of the National Cooperative Geologic Mapping Program, under USGS award number 99HQAG0171. We wish to acknowledge Jon Spencer, Steve Richard, Steve Skotnicki, and Anne Youberg for a day of field work and for discussions. Anne Youberg helped compile some of the Quaternary geology. Charles Ferguson wrote the bedrock unit descriptions and text, and drew the structural cross-sections which were later reviewed by Wyatt Gilbert. Phil Pearthree wrote the Quaternary unit descriptions. Sheets 1 and 2 were drafted by Charles Ferguson. The report was critically reviewed by Jon Spencer and we thank Larry Fellows for continued support of geologic mapping.

## PREVIOUS STUDIES

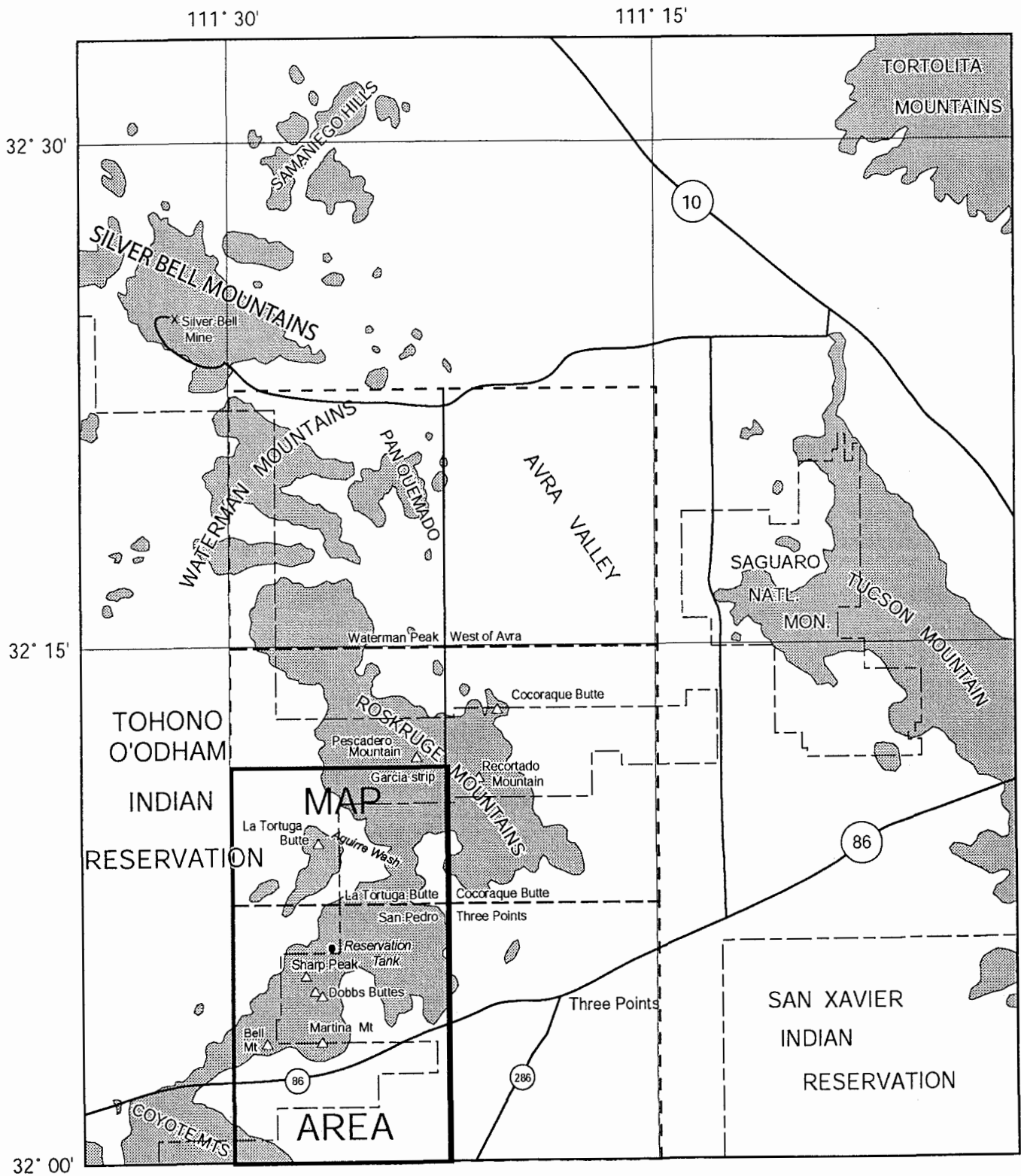
The most detailed work done in the Roskrige Mountains prior to this project was a stratigraphic study of the region by Heindl (1965), and a reconnaissance map and report of the petrology, isotope geochemistry and geochronology of the area by Bickerman (1965; 1967; 1968). Prior to this work, Bryan (1925) and Andrews (1937) briefly described the geology of the Roskrige Mountains, and a simplified version of some of Heindl's unpublished mapping is shown on the county geologic map of Wilson et al. (1960).

A detailed map and petrographic study of the Coyote Mountains and the Ajo Road detachment fault just to the west of the southwest corner of our map area was done by Gardulski (1990). The paleomagnetism of some of the Upper Cretaceous ash-flow tuff outflow sheets in the Bell Mountain area was studied by Vugtaveen et al. (1981), and Hagstrum et al. (1994). Geochemistry of the Tertiary volcanic rocks was studied by Eastwood (1970), and Hagstrum et al. (1994) report geochemical analyses of the Mesozoic ash-flow tuffs in the Bell Mountain area.

## STRATIGRAPHY

### Pre-Mesozoic rocks

Two map units are sparingly exposed that may be pre-Mesozoic in age. A leucogranite (**JYXg**) is present around the western base of La Tortuga Butte in the northwest corner of the map area. The granite appears to be intruded and or overlain by the Mesozoic volcanic/hypabyssal rocks, and we interpret it to represent exhumed crystalline basement. The granite resembles one of the plutons of the Jurassic Ko Vaya super-unit (Tosdal et al., 1989) that is exposed in the Baboquivari Mountains (S. Richard, personal communication), but it might also be Early or Middle Proterozoic in age. A potential U-Pb geochronology sample (WG-137, -138A) was collected on the north slope of La Tortuga Butte. Clasts of the same or a similar leucogranite are abundant within a Tertiary diamictite (**Tsd**) unit that appears to overlap a major east-side down normal fault



**Figure 1** Location of 7.5' quadrangles (thick dashed lines), and important geographic features in the vicinity of the study area, Pima County, Arizona.

about 6 km to the south of La Tortuga Butte. Xenoliths of the same or a similar leucogranite are also abundant in the trachyte porphyry of Martina Mountain.

A series of medium-bedded, light gray skeletal and pelletal packstone, wackstone, and micritic limestone outcrop ribs are exposed in a major wash in the center of the map area (near Reservation Tank; Figure 1) that may correlate with one of the Paleozoic units that crop out extensively in the Waterman Mountains to the north. A suite of samples was collected from the ribs (F0-1078). The limestone is very resistant, and gives a fetid odor if broken. Argillaceous interbeds, if present, are not preserved. Based on Heindl's (1965) description of some Mesozoic limestone beds in the Roadside Formation southwest of Bell Mountain, the limestone near Reservation Tank is also possibly Mesozoic in age. The skeletal grains in one of the beds resemble echinoid spines.

The limestone outcrop near Reservation Tank occurs in the footwall of a fairly major Tertiary normal fault that we interpret to be overlapped by a Tertiary diamictite unit (**Tsd**) containing abundant clasts of leucogranite. The presence of the granite clasts suggests that crystalline basement was exposed in the footwall of the normal fault. Since Paleozoic carbonate units are exposed just to the southwest of the map area in the footwall of the Ajo Road detachment fault (Gardulski, 1990), it is possible that the limestone near Reservation Tank is Paleozoic.

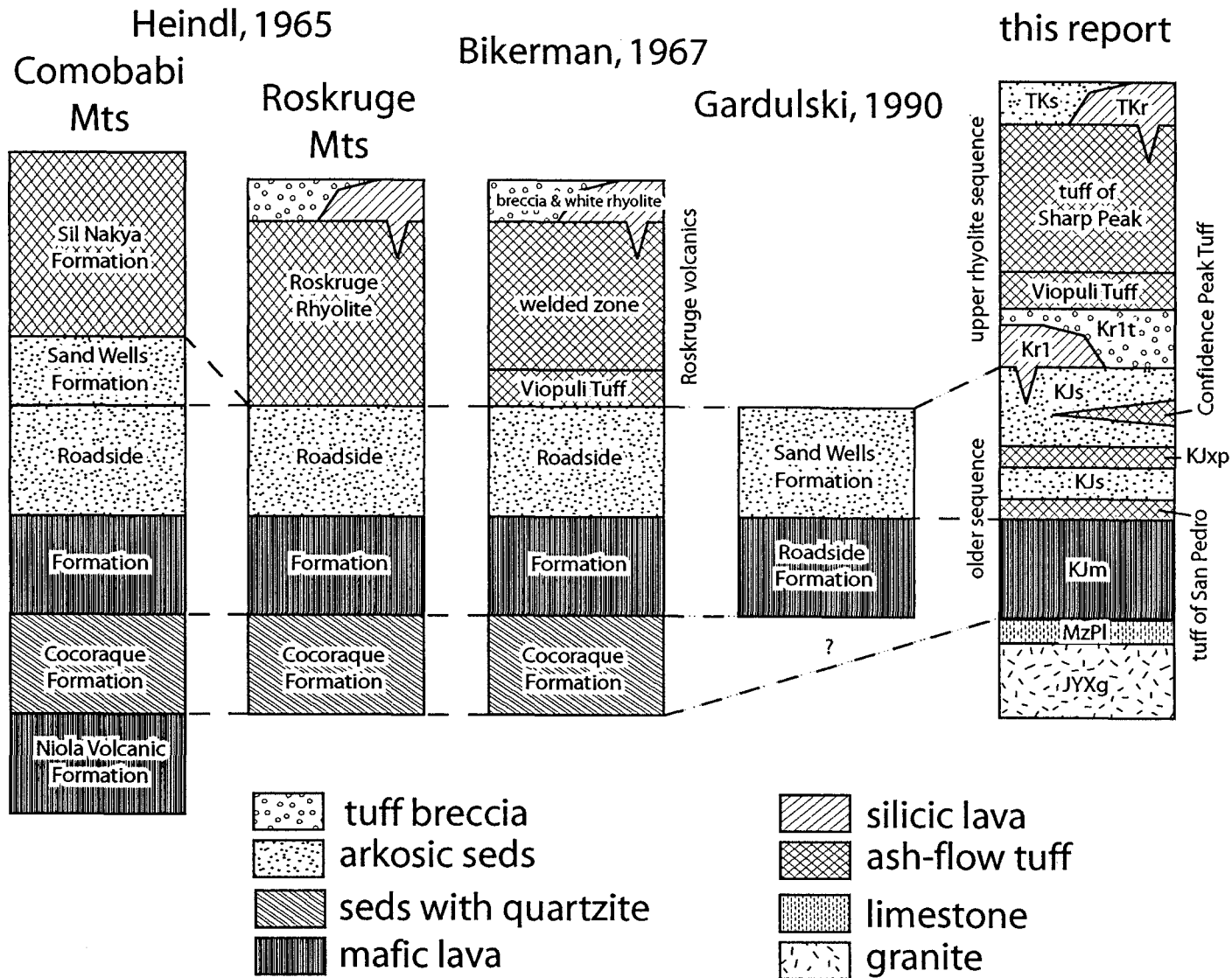
### **Mesozoic rocks**

Up to the start of our study, Mesozoic stratigraphic units in the area were described based primarily on lithostratigraphic features of the volcanic and sedimentary rocks, in particular the presence or absence of distinctive sedimentary lithologies (such as quartzite), the lithology of clasts in conglomerate, and the dominant composition of the volcanic rocks. Heindl (1965) defined three formations in the Roskrige Mountains and shows one of these units, the Cocoraque Formation in the Comobabi Mountains, along with three other formations that were believed to correlate with the units in the Roskrige Mountains based on similarities in overall lithology and the presence of specific clast types in conglomerate (Figure 2).

Assuming that Mesozoic rocks of the region were deposited in a volcanic arc (eg. Tosdal et al., 1989; Lipman and Hagstrum, 1992), and given that volcanic and sedimentary rocks in volcanic environments are characterized by rapid facies change, we chose not to employ the lithostratigraphic nomenclature of Heindl (1965). Instead, we structured our stratigraphic framework around 5 time lines represented by regional ash-flow tuff sheets. The other lithologic units of mafic lava and sedimentary rock were mapped as generic units since it is probable that they were deposited locally and diachronously with little regard to time-stratigraphy throughout the Mesozoic. We were able to map some of the silicic lavas as semi-chronostratigraphic units if age relationships with the ash-flow tuffs were well exposed.

Throughout this discussion we refer to an older sequence, which probably correlates with the Sand Wells, Roadside, and possibly the Cocoraque formations of Heindl (1965), Bikerman (1965; 1967; 1968), and Gardulski (1990), and a younger rhyolite sequence, which correlates with the Roskrige Rhyolite of Heindl (1965) and the Roskrige volcanics of Bikerman (1965; 1967, 1968). These correlations are summarized in Figure 2.

The Mesozoic rocks of the southern Roskrige Mountains are dominated by at least one kilometer of the younger rhyolite. These younger rocks unconformably overlie at least 500 meters of mafic to intermediate lava, arkosic argillaceous sedimentary rocks, and lesser silicic lava breccia that crop out as subdued hills and piedmont surfaces throughout the range. The older rocks probably overlie crystalline basement at La Tortuga Butte and possibly overlie Paleozoic limestone



**Figure 2** History of stratigraphic nomenclature in the Roskruge Mountains showing correlation between the various schemes. The apparent bimodal composition of the Roadside Formation of Heindl (1965) and Bikerman (1965) is probably vastly oversimplified. The Cocoraque Formation contains clasts of volcanic rocks similar to the Niola Volcanic formation (Heindl, 1965), and seems to be characterized by the heterogenous nature of its sedimentary rocks, containing among other lithologies, quartzite beds.

near Reservation Tank. The contact between the two sequences is either poorly exposed or concealed.

### *Older Mesozoic rocks*

#### *Lithology*

Heindl's (1965) division of the older Mesozoic rocks of the Roskrige Mountains into two formations separated by an angular unconformity was based primarily on E. A. Stone's (personal communication in Heindl [1965]) description of an angular unconformity between a younger mafic lava and conglomerate unit and an older unit of sedimentary rocks at 628' depth within the Roadside Mine just to the southwest of Bell Mountain. The older unit, named the Cocoraque Formation, is defined at the surface near the Cocoraque Ranch (Heindl, 1965), and the younger unit, named the Roadside Formation, is defined in the vicinity of the Roadside Mine (Heindl, 1965). At its type section, the Cocoraque Formation includes a wide variety of siliclastic sedimentary rocks including arkose, graywacke, quartzite, mudstone, and pebble conglomerate. Bikerman (1965; 1967; 1968) adhered to the nomenclature of Heindl (1965) for the older Mesozoic rocks, but did not divide them on his geologic map. According to Heindl (1965), only the Roadside Formation is present in the southern Roskrige Mountains, and from our detailed work we agree that no strata like that which makes up the type section of the Cocoraque Formation near Cocoraque Ranch (see also Skotnicki and Pearthree, 2000) is present in the study area.

The older Mesozoic sequence in the southern Roskrige Mountains is exposed in two areas: the Sharp Peak – Dobbs Buttes area, and the Aguirre Wash area. In both areas, the older sequence consists of two main lithologies; mafic lava (**KJm**) and sedimentary rocks (**KJs**). In general, the mafic lavas are older, but the two map units are gradational and both rock types can be found throughout the section.

The best exposures of the older sequence are in the valley just north of Sharp Peak. Besides the standard mafic lava and sandstone, the older sequence here includes two previously unrecognized welded ash-flow tuffs: (1) the tuff of San Pedro (**KJp**), a two-flow-unit, approximately 60 meter-thick, crystal-rich, dark reddish brown, welded ash-flow tuff that marks the contact between the mafic lava and sedimentary rocks, and (2) an approximately 30-50 meter-thick, crystal-poor, pink to light gray, welded ash-flow tuff (**KJxp**) that is interbedded with the sedimentary rocks higher in the section. The entire sequence is unconformably overlain by the younger rhyolite sequence. The unconformity is probably slightly angular since the upper part of the older sequence wedges out to the east.

The division between the older mafic lavas of map unit **KJm** and overlying sedimentary rocks of map unit **KJs** is well-defined in the Sharp Peak - Dobbs Buttes area. This well-defined contact is also exposed in the southwest corner of the map area in the hangingwall of the Ajo Road detachment fault where Gardulski (1990) used it to divide her Roadside Formation from the younger Sand Wells Formation (Sheet 1, Figure 2).

In the Aguirre Wash area (Figure 1), exposure of the older sequence is poor and the orientation of bedding is sparingly preserved. The mafic lava (**KJm**) and sedimentary rocks (**KJs**) are invaded by multiple intrusive bodies of intermediate to dacitic composition (units **KJi**, and **KJd**) throughout much of the area, and to the north, the rocks are interbedded with lithic-rich, rhyolite-lava-clast lapilli tuff and tuff breccia lenses (**KJr**) that range in thickness from 5 to 200 meters. Along the northern edge of the outcrop belt, a steeply north-dipping sequence is preserved

that includes at least two welded ash-flow tuff sheets, but because of structural complication and poor exposure it is not possible to assign a relative age to the two units. The unit that appears to be older (no top indicators were found) is a light gray, crystal-poor, welded ash-flow tuff (**KJxp**) that is essentially identical to the crystal-poor tuff in the Sharp Peak - Dobbs Buttes area. The apparently younger tuff is a crystal-rich, quartz-phryic, light gray, welded ash-flow tuff that we correlate with the Upper Cretaceous Confidence Peak Tuff (**Kcp**) of Sawyer (1996) which fills a source cauldron in the Silver Bell Mountains to the north. The same tuff is sporadically exposed throughout the northern Roskrige Mountains and Waterman Mountains (Richard et al., 2000), and it thickens to at least 100 meters in the northeastern Waterman Mountains.

The steeply tilted section of older Mesozoic strata in the Aguirre Wash area is unconformably overlain by a moderately to gently north-dipping sequence of the younger rhyolite sequence. Just to the south of the strip of steeply, north-dipping strata discussed in the preceding paragraph, a gently south-dipping, crystal-poor, welded ash-flow tuff is also preserved below the same unconformity. This crystal-poor tuff is identical petrographically to the **KJxp** unit, but because of its opposite dip we mapped it tentatively as a younger unit (**KJxpu**). Alternatively, the **KJxpu** unit might only be a thicker section of the **KJxp** unit exposed in the south limb of an erosionally decapitated anticline, but since the two units are never juxtaposed or exposed in the same area, correlation is uncertain. Structural cross-section B-B' shows an erosionally decapitated anticline in this area, but it declines to show how the two crystal-poor tuffs relate to each other.

#### *Age of the older Mesozoic rocks*

A single K/Ar whole rock age of  $66.70 \pm 2.0$  Ma (Bikerman, 1967) was obtained from a basaltic lava flow of the **KJm** unit near Reservation Tank. The date is questionable since the lava is overlain by two ash-flow tuff sheets that have been dated at approximately 75 and 70 Ma (Bikerman, 1967). We interpret the age range of the older sequence to be Jurassic through Cretaceous based on our correlation of the older sequence in general with a folded sequence of Jurassic strata in the western Tucson Mountains that includes two crystal-poor tuffs (Jt and Jlt map units of Lipman, 1993), and a folded sequence (units Mzsv and Mzr of Sawyer, 1996) of Mesozoic undifferentiated strata in the southwestern Silver Bell Mountains that includes a "prominent light gray thin rhyolite welded tuff". In both areas, the folded sequences are overlain with angular unconformity by Cretaceous volcanic and sedimentary rocks.

The inclusion of the Confidence Peak Tuff (**Kcp**) as part of our older sequence creates an interesting problem in terms of correlation with the same unit in the Silver Bell Mountains. Sawyer (1996) describes the Confidence Peak Tuff as the basal unit that overlies an angular unconformity in the southwestern Silver Bell Mountains, whereas our Confidence Peak Tuff underlies the angular unconformity in the Aguirre Wash area. Correlating our older sequence, which includes the Confidence Peak Tuff, with Sawyer's (1996) Mzsv and Mzr units, creates an obvious problem regarding the relative age of the unconformities in the two areas, but it also allows for some intriguing possibilities. Sawyer (1996) describes another angular unconformity below the one overlapped by the Confidence Peak Tuff in the Silver Bell Mountains, and in the Aguirre Wash area, there is also the potential for more than one angular unconformity. Our younger crystal-poor tuff (**KJxpu**) appears to be bracketed above and below by angular unconformities (Sheet 2), but if so, at least one unconformity post-dates our Confidence Peak Tuff. If our correlations are correct, and the angular relationships accurately defined, the implication is that up to four angular unconformities, two preceding and two post-dating emplacement of the Confidence Peak Tuff, are present in the Mesozoic of the Roskrige - Waterman - Silver Bell mountains. Of course, the unit

we have mapped as Confidence Peak Tuff might not be the same as the Confidence Peak Tuff in the Silver Bell Mountains, and this would relieve the necessity of having so many unconformities, but it would complicate the stratigraphic framework, and create yet another outflow sheet with no known source caldera.

The age of the Confidence Peak Tuff is not precisely known since it has yet to yield reliable age dates (Sawyer, 1996). The tuff is bracketed by "well-dated" units of 72.7 and 68.6 Ma (Sawyer, 1996) and it is probably within  $\pm 1$  Ma of 72.7 Ma since it is overlain by the 72-68 Ma Cat Mountain Tuff (Lipman, 1993; Sawyer, 1996). In the Silver Bell Mountains the unit's paleomagnetic polarity is normal (Hagstrum and Sawyer, 1989).

### *Younger Mesozoic rhyolite sequence*

The younger Mesozoic rhyolite sequence consists of over 1 km of rhyolite lava, tuff breccia, and welded tuff that was originally named the Roskrige Rhyolite by Heindl (1965). Bikerman (1965; 1968) refined the stratigraphy of the Roskrige Rhyolite, renaming it the Roskrige volcanics and divided it into three units, from oldest to youngest; Viopuli ignimbrite, welded tuff, and coarse breccia intruded by white rhyolite. We recognize all of these subdivisions plus another silicic lava and tuff breccia unit at the base. The welded tuff of Bikerman (1965; 1968) is by far the thickest of these units and based on similar phenocryst mineralogy, Bikerman (1965; 1968) correlated it with the Cat Mountain Rhyolite (Bikerman, 1962) of the Tucson Mountains. Later, based on a difference in zirconium content, Hagstrum et al., 1994 (see also Lipman, 1993) concluded that the thick welded tuff in the Roskrige Mountains is not the Cat Mountain Tuff. Based on several lines of evidence to be discussed in a later section, we think that Bikerman's (1965; 1968) original correlation was correct.

### *Rhyolite lava and lapilli tuff (Kr1, and Kr1t)*

The basal unit of the younger Mesozoic rhyolite sequence throughout much of the study area is a crystal-poor, rhyolite lava clast, lapilli, lithic tuff or tuff breccia. The tuff and tuff breccia are associated locally with rhyolite lava flows and hypabyssal bodies of identical composition to the tuff and lithic clasts in the breccia. The tuff and lava are crystal-poor and characterized by the absence of quartz phenocrysts. The unit has not been dated, but according to Hagstrum et al. (1994), tuff near Bell Mountain from this unit (Sample 2) is a silicic rhyolite and its paleomagnetic polarity is reversed.

### *Viopuli Tuff (Kv)*

The Viopuli Tuff was originally defined as the Viopuli ignimbrite or red Viopuli ignimbrite by Damon et al. (1964). The tuff is present throughout the southern part of the study area, but has not been recognized north of Aguirre Wash. The tuff, which contains about 10-15% plagioclase and biotite phenocrysts, is very densely welded and its texture, described as "flamboyantly eutaxitic" by Bikerman (1965), is very similar to flow-banded lava in the main part of the flow. The tuff is thickest (110 meters) in the south near Bell Mountain where it includes two prominent flow-units. The tuff has been dated at  $75.80 \pm 1.50$ , and  $76.00 \pm 1.50$  Ma (K/Ar biotite, Bikerman, 1967, note that ages are recalculated using new constants, see Reynolds et al. 1986). Based on the chemical analyses of the tuff at the section near Bell Mountain (Hagstrum et al., 1994) the tuff is compositionally zoned from high-silica trachyte at the base to low-silica rhyolite at the top (Hagstrum et al., 1994 samples 3a, 3b and an analysis labeled "Viopuli"). Note that correlation of samples 3a and 3b with the sample labeled "Viopuli" is supported by relatively high Zr contents for

all of the analyses (Table 2 of Hagstrum et al., 1994). The tuff shows reverse zoning with respect to silica, but normal zoning with respect to the alkali elements (Figure 3). Ideally, a tuff that is normally zoned should be more silicic at the base, reflecting the evacuation of a more silicic upper zone of a magma chamber during initial phases of a pyroclastic eruption followed by more mafic material which would be emplaced later. The paleomagnetic polarity of the Viopuli Tuff is normal (Vugtaveen et al., 1981, sample RV4; Hagstrum et al. 1994, samples RT 3a,b).

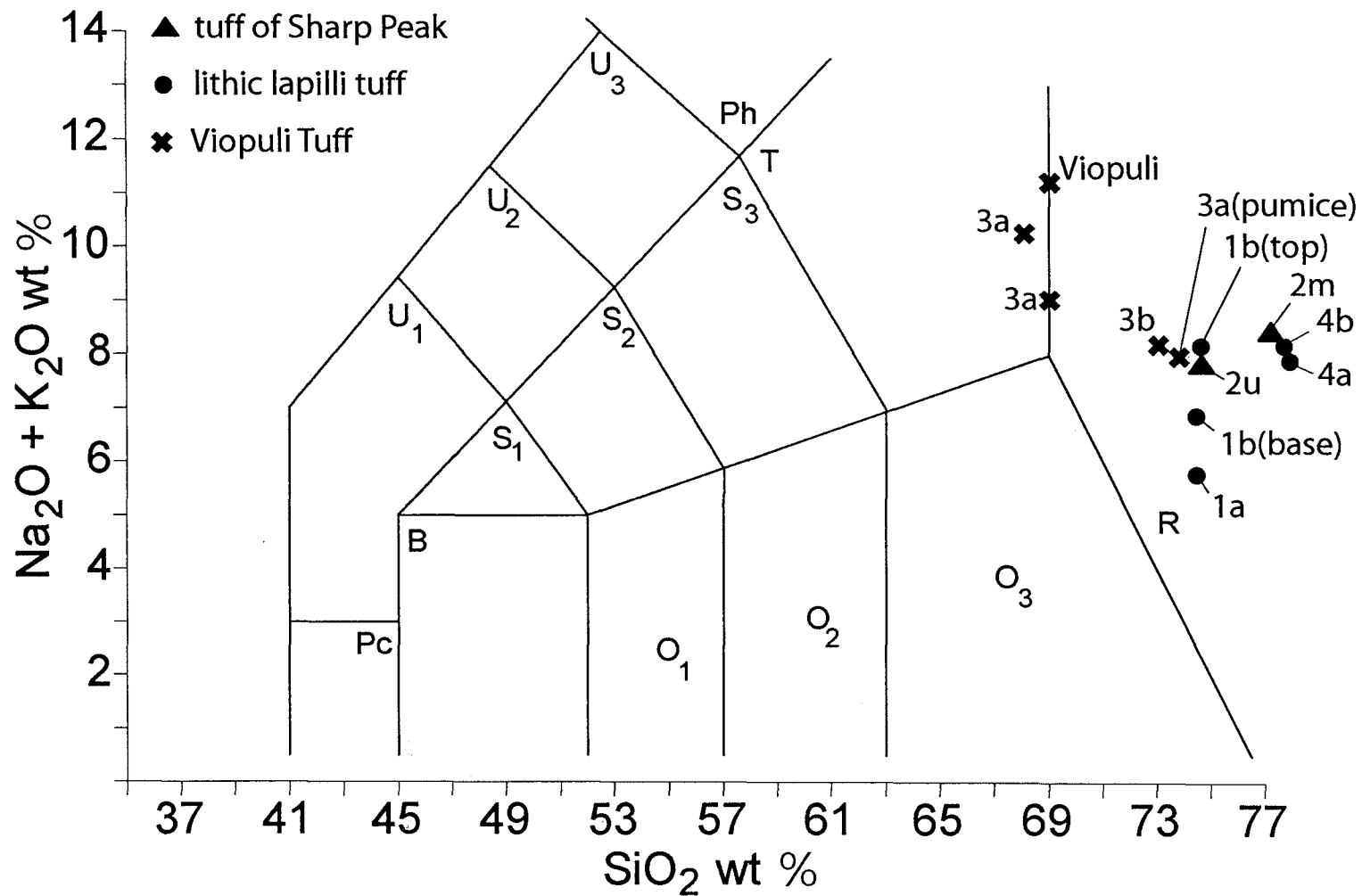
#### *Tuff of Sharp Peak (Ksp)*

The tuff of Sharp Peak (new name) is a crystal-rich, rhyolite ash-flow tuff named for a type section measured on Sharp Peak (Sheet 1) where the unit is nearly 1 km thick. The tuff contains phenocrysts of plagioclase (5-15%, 0.5-4.5 mm), quartz (4-8%, 0.7-8.0 mm), sanidine or perthitic K-feldspar (3-9%, 1.0-4.0 mm), and biotite (0.2-1.5%, 0.5-1.5 mm). The tuff is divided into a lower non-welded zone (**Kspl**) and an upper welded zone (**Ksp**). The tuff is compositionally zoned with an abrupt upward increase in plagioclase and biotite content corresponding to the gradual upward change from non-welded to welded (Table 1). Normal chemical compositional zoning of the tuff of Sharp Peak (Figure 3) is indicated by the chemical analyses of Hagstrum et al. (1994), with the lower non-welded zone (their samples 4a and 4b) being more silicic and alkaline than the upper welded zone (their samples 1a and 1b). In the basal portion, plagioclase is subordinate to equal in proportion to quartz and K-feldspar, but in the welded zone, plagioclase represents at least half of the total phenocrysts. Biotite also increases upwards from the non-welded into the welded zone from virtually nonexistent to approximately 1.5%. K-feldspar typically displays perthitic texture throughout, but at the type section, sanidine is preserved in the middle portion of the non-welded zone. Elsewhere, sanidine has been observed in the welded zone.

The welded zone of the tuff of Sharp Peak is pink, gray or peach-colored and very resistant, forming nearly all of the high-standing peaks (other than those held up by resistant Mid-Tertiary igneous rocks) in the southern Roskrige Mountains. In the northern part of the map area, the transition from a lower nonwelded zone to the upper welded zone is complex due primarily to the abundance of mesobreccia (**Kspz**) and megabreccia (**Kspm**) lenses within the tuff. The lenses contain clasts up to several meters in diameter of older volcanic rocks encased within non-welded tuff. The tuff is also thickest to the north (> 1.25 km). The tuff is at least 1 km thick in the Sharp Peak – Dobbs Buttes area, but at Bell Mountain it may be as thin as 200 meters. This radical change in thickness is suggestive of a caldera margin in this area (Figure 4).

Bikerman (1967) reports a K/Ar plagioclase date of  $66.90 \pm 3.00$  Ma, K/Ar biotite dates of  $70.30 \pm 1.90$ ,  $70.40 \pm 1.70$ ,  $71.40 \pm 1.50$ ,  $71.70 \pm 1.50$ ,  $73.00 \pm 1.60$ ,  $73.80 \pm 1.60$ ,  $74.20 \pm 1.50$  Ma, and a K/Ar sanidine date of  $70.40 \pm 1.70$  Ma for this unit (note all age dates recalculated using new constants, see Reynolds et al., 1986). The paleomagnetic polarity of the tuff of Sharp Peak is reversed (Vugtaveen et al., 1981 samples RV 5-10; Hagstrum et al., 1994 samples RT1 and RT4a).

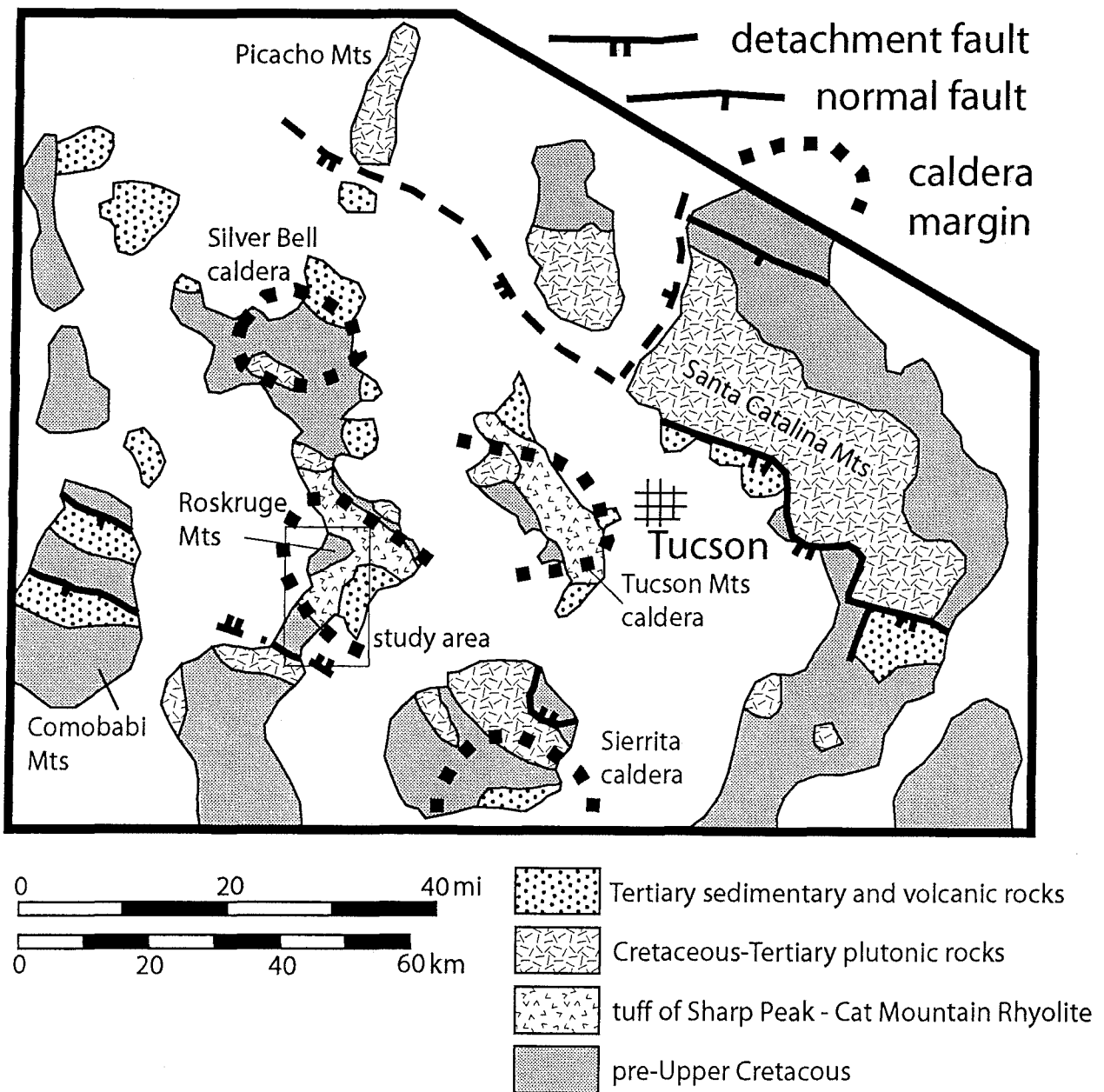
Because the tuff of Sharp Peak is at least 1 km thick throughout most of the study area, and because it includes significant zones of megabreccia and mesobreccia in the north, the conclusion that all of the study area north of Bell Mountain lies within its source caldera is practically inescapable. Relationships just to the north of the study area (Skotnicki and Pearthree, 2000; Richard et al., 2000) are suggestive of a south- to southwest-facing caldera margin. These relationships are depicted schematically in the subsurface on cross-section B-B' and the approximate location of the northern caldera margin is shown on Figure 4.



**Figure 3** Total alkali versus silica diagram of Le Bas et al. (1986) showing the analyses of Mesozoic ash-flow tuffs in the Bell Mountain area by Hagstrum et al. (1994). Sample numbers correspond to those in Hagstrum et al.'s (1994) Table 2 with samples 4b and 4b(low) averaged. Samples 4a and 4b correspond to the base of the tuff of Sharp Peak and samples 1a, 1b(base), and 1b(top) correspond to the upper welded zone of the tuff of Sharp Peak exposed on the down-thrown side of a major fault unrecognized by Hagstrum et al. (1994). All number 3 analyses are from the Viopuli Tuff which matches an unnumbered sample referred to as "Viopuli". The clustering of sample 2m near the analyses of the lower non welded zone of the tuff of Sharp Peak may be because this sample might have been collected east of the San Pedro Road from a locality that is actually within the lower non welded zone of the tuff of Sharp Peak. Field name abbreviations are Pc: picrobasalt, B: basalt,  $\text{O}_1$ : basaltic andesite,  $\text{O}_2$ : Andesite,  $\text{O}_3$ : Dacite, R: rhyolite,  $\text{S}_1$ : trachybasalt,  $\text{S}_2$ : basaltic trachyandesite,  $\text{S}_3$ : trachyandesite, T: trachyte,  $\text{U}_1$ : tephrite basalt,  $\text{U}_2$ : phonotephrite,  $\text{U}_3$ : tephriphonolite, T: phonolite.

**Table 1** Petrography of the tuff of Sharp Peak at its type section on Sharp Peak (Sheet 1) and continuing south, up-section into the Dobbs Buttes area. The first part of the section starts at the base of the unit north of Sharp Peak (UTM grid zone 12 location: 3550100N, 456170E) and ends just south of the Peak before crossing a normal fault at UTM coordinates 3549700N, 456210E. The section resumes in the hangingwall of the fault at UTM coordinates 3549625N, 456225E and continues south to UTM coordinates 3548925N, 456125E. Point counts were done using thin-section stained for K-feldspar. Samples F0-533 and F0-534 are from another fault block and probably correlate roughly with the stratigraphic levels of samples F0-531 and F0-532. Note that in sample F0-547, a large number of plucked phenocrysts were present that are interpreted to be plagioclase since the plagioclase in this sample are particularly altered and prone to plucking. 75% of the plucked counts of sample F0-547 were therefore tabulated as plagioclase for the final percentage calculations. Q=quartz, K=K-feldspar, P=plagioclase, B=biotite, O=opaque minerals, L=lithics, Mtx=matrix.

Sample	Q	K	P	B	O	Plucked	L	Mtx	Total	Q%	K%	P%	phen%	B%	Q/3%	K/3%	P/3%
F0-543	40	47	27	4	0	5	0	405	528	7.58	8.90	5.11	23.30	0.76	35.09	41.23	23.68
F0-544	42	36	47	1	3	2	0	477	608	6.91	5.92	7.73	21.55	0.16	33.60	28.80	37.60
F0-545	35	34	34	1	4	1	48	331	488	7.17	6.97	6.97	22.34	0.20	33.98	33.01	33.01
F0-546	36	38	16	2	1	27	12	426	558	6.45	6.81	6.50	21.51	0.36	40.00	42.22	17.78
F0-547	29	20	52	2	1	2	12	448	566	5.12	3.53	9.19	18.73	0.35	28.71	19.80	51.49
F0-548	46	44	90	5	4	1	13	430	633	7.27	6.95	14.22	30.02	0.79	25.56	24.44	50.00
F0-549	37	31	71	8	6	0	8	367	528	7.01	5.87	13.45	28.98	1.52	26.62	22.30	51.08
F0-531	25	28	81	6	4	1	11	422	578	4.33	4.84	14.01	25.09	1.04	18.66	20.90	60.45
F0-532	36	16	67	5	2	2	3	311	442	8.14	3.62	15.16	28.96	1.13	30.25	13.45	56.30
F0-533	40	20	77	9	4	1	20	427	598	6.69	3.34	12.88	25.25	1.51	29.20	14.60	56.20
F0-534	39	51	105	10	2	0	13	507	727	5.36	7.02	14.44	28.47	1.38	20.00	26.15	53.85



**Figure 4** Simplified geology of the Tucson area, showing the location of outcrops of the Cat Mountain Rhyolite and tuff of Sharp Peak in the Tucson and Roskrige mountains, the location of Cretaceous calderas (after Lipman, 1993; and Sawyer, 1996), and Cretaceous-Tertiary plutonic rocks. Note that the shape of the Tucson Mountains caldera in the Tucson Mountains is modified based on observations discussed in the text. Location of the caldera margin segment in the Roskrige is based on observations presented in this report and the work of Skotnicki and Pearthree (2000), and Richard et al. (2000). The location of other Cretaceous ash-flow tuffs is omitted for clarity.

### *Younger rocks*

The tuff of Sharp Peak is intruded by silicic lava in two areas along the eastern edge of the map area; a lithophysae-rich lava to the north (**TKf**) and a moderately crystal-rich rhyolite lava farther south (**TKr**). Neither silicic unit has been dated or analyzed for geochemistry. The two silicic units probably constitute the white rhyolite of the younger volcanic breccia portion of Bikerman's (1965; 1968) Roskruge volcanics. A sequence of breccia or tuff post-dating the tuff of Sharp Peak is preserved to the northeast (the Kt map unit of Skotnicki and Pearthree, 2000) and this probably represents Bikerman's (1965; 1968) breccia unit within his Roskruge volcanics.

At Martina Mountain, in the southern part of the map area, the tuff of Sharp Peak may be overlain by younger "Laramide" volcanic and sedimentary rocks (units **TKm**, **TKxp**, and **TKs**), but these units are very poorly exposed and it is possible that they predate the tuff of Sharp Peak, and are preserved in the footwall of unrecognized normal faults. The rocks might also represent Mid-Tertiary strata.

At Bell Mountain, the tuff of Sharp Peak is overlain by an ash-flow tuff that has normal paleomagnetic polarity (samples RV-11 and RV-12 of Vugtaveen et al., 1981). If this a different unit it constrains the thickness of tuff of Sharp Peak in this area to be less than 250 meters.

### *Correlation of ash-flow tuffs*

Of the five regional, welded ash-flow tuff sheets recognized in the southern Roskruge Mountains, sources for the tuff of San Pedro, crystal-poor tuff (both varieties), and the Viopuli Tuff remain unidentified, and the source of the tuff of Sharp Peak is uncertain. The only tuff whose source caldera is well known is the Upper Cretaceous Confidence Peak Tuff which was derived from the Silver Bell caldera in the Silver Bell Mountains (Sawyer, 1989; 1996).

Prior to this study the only attempt to correlate ash-flow tuffs in the Roskruge Mountains with other units in southeastern Arizona was a study by Hagstrum et al. (1994), of outflow sheets in the Bell Mountain area. Hagstrum et al. (1994) reported that five ash-flow tuff units are present in the area, but that none of them can be correlated with other tuffs in nearby mountain ranges. Hagstrum et al. (1994) mapped a small area directly east of Bell Mountain, and sampled a series of four units thought to overlie the Viopuli Tuff. The tuff units were numbered 1 through 4 from oldest to youngest, but they were unaware of normal faults in the area and they sampled two of the units twice resulting in an overly complex stratigraphy and one more paleomagnetic reversal than is necessary (Table 2). The tuff they sampled as number one is actually the top of the tuff of Sharp Peak, and the same as their tuff number 4, the youngest unit in the area. Their tuff number 2, sampled to the west of the San Pedro Road, is the rhyolite-lava-clast lapilli tuff (our Kr1t map unit) and not a regional unit. Their tuff number 2, sampled east of the San Pedro Road, is the base of the tuff of Sharp Peak, which probably explains why this sample's paleomagnetic data was discarded (see discussion on page 15,099). Hagstrum et al.'s (1994) tuff number 3 is the Viopuli Tuff, the unit they interpreted to underlie their sequence. The two older outflow sheets, tuff of San Pedro (**KJp**) and the crystal-poor tuff (**KJxp**), despite being well-exposed along San Pedro Road, were not sampled.

**Table 2.** Correlation of ash-flow tuffs in the Bell Mountain area.

This report	Hagstrum et al. (1994)
tuff of Sharp Peak ( <b>Ksp</b> ), Reversed	tuffs 1, 4, both Reversed
Viopuli Tuff ( <b>Kv</b> ), Normal	tuff 3, and Viopuli Tuff, both Normal
rhyolite lava clast lapilli tuff ( <b>Kr1t</b> ), Normal	tuff 2 (west), Normal
crystal-poor tuff ( <b>KJxp</b> ), ?	not sampled
tuff of San Pedro ( <b>KJp</b> ), ?	not sampled

### *Crystal-poor tuff and tuff of San Pedro*

The crystal-poor tuff and the tuff of San Pedro are thin outflow sheets whose source calderas have not been identified. Both tuffs thin to the north suggesting a source caldera to the south. Possible correlatives of the crystal-poor tuff are present in the Silver Bell Mountains (the prominent gray tuff within the Mzsv and Mzr map units of Sawyer, 1996), the western Tucson Mountains (the Jt, and Jlt map units of Lipman, 1993), and at Tumamoc Hill in the eastern Tucson Mountains (the Mission Road tuff of Phillips, 1976). The only local unit that might correlate with the tuff of San Pedro is a thin, crystal-rich, plagioclase biotite tuff exposed at the base of Tumamoc Hill and mapped as the Sentinel Tuff by Phillips (1976).

Based on the descriptions of Jurassic intracaldera ash-flow tuffs in the Hauchuca Mountains and their outflow sheets in the Mustang Mountains (Hayes, 1970; Lipman and Hagstrum, 1992) a possible correlation for the tuff of San Pedro is the crystal-rich dacite tuff that fills the Montezuma caldera of Lipman and Hagstrum (1992). Even though the tuff within Montezuma caldera is reported to contain quartz phenocrysts, hand specimens of both units are remarkably similar in appearance, and quartz phenocrysts are sparsely present in the tuff of San Pedro. In addition, the outflow sheet of the tuff that fills Montezuma caldera in the Mustang Mountains consists of two flow units separated by a thin sequence of sedimentary rocks (Lipman and Hagstrum, 1992), much like the section of tuff of San Pedro near Sharp Peak in the Roskrige Mountains. The next youngest unit in the Hauchuca Mountains is a crystal-poor tuff that fills the Turkey Canyon caldera. Petrographic descriptions of this tuff (Hayes, 1970; Lipman and Hagstrum, 1992) are consistent with correlation with the crystal-poor tuff in the Roskrige Mountains. Although 120 km is a fairly great distance for an ash-flow tuff sheet to travel, it is not unreasonable, and given the structural complexities in the area, palinspastic restorations might shorten this distance considerably.

### *Viopuli Tuff*

The Viopuli Tuff thins to the north which suggests a source caldera to the south. The texture and phenocryst mineralogy of the Viopuli Tuff is very distinctive and is remarkably similar to the main mass of the Mt. Wrightson Formation in the Santa Rita Mountains. The Mt. Wrightson Formation was defined by (1968, 1971) as a composite lava and tuff unit with interbedded sedimentary rocks. Riggs and Busby-Spera (1990) mapped large areas of the formation as hypabyssal, but our reexamination of the unit indicates that the lower 500 meters of the formation on Mt. Wrightson is a densely welded ash-flow tuff that has been intensively modified by reomorphic flow, much like the outflow sheet of the Viopuli Tuff in the Roskrige Mountains. The

sequence at Mt. Wrightson is exceptionally thick and is capped by eolian sandstone, which in turn overlain by a welded crystal-poor tuff. The map pattern and descriptions of the lower to middle parts of the Mt. Wrightson Formation (Drewes, 1968; 1971; Riggs and Busby-Spera, 1990), including odd-shaped masses of sedimentary rocks, are highly suggestive of megabreccia masses in an intracaldera sequence. Extensive areas of poorly welded mesobreccia were observed during our brief examination of the unit on the west slope of Mt. Wrightson.

Correlation of the Viopuli Tuff with the Mt. Wrightson Formation would be fairly straightforward if it were not for geochronologic discrepancies. U-Pb dates of the Mt Wrightson Formation are Jurassic, ranging in age from approximately 210 to 180 Ma (see discussion in Riggs and Busby-Spera, 1990). Two K/Ar biotite dates of the Viopuli Tuff are Upper Cretaceous, at approximately 75 Ma (Bikerman, 1967), but K/Ar dates of other Jurassic units in southern Arizona have frequently yielded metamorphic ages of around 70 Ma, and since none of the rocks it definitively overlies are reliably dated, it is possible that the Viopuli Tuff is also Jurassic in age.

#### *Tuff of Sharp Peak and the Cat Mountain Rhyolite*

The tuff of Sharp Peak was probably derived from a caldera that encompasses most of the study area, but the correlation of its outflow sheet into nearby ranges is uncertain. The tuff of Sharp Peak, which is the same as Bikerman's (1965) welded zone of the Roskrige volcanics, contains a phenocryst assemblage very similar to that of the Cat Mountain Rhyolite in the nearby Tucson Mountains (compare the petrology presented in this report with that of Bikerman, 1962). In addition, its age range of approximately 67-74 Ma is the same, within analytical error, as the Cat Mountain Rhyolite (Bikerman, 1967; Lipman, 1993), and its paleomagnetic polarity and orientation are very close (Vugtaveen et al., 1981; Hagstrum and Lipman, 1991; Hagstrum et al. 1994). Despite these similarities and based only on a difference in Zr content, Hagstrum et al. (1994) concluded that the two units do not correlate. The Cat Mountain Tuff is reported to contain up to 4 times as much Zr as the tuff of Sharp Peak (Lipman, 1993; Hagstrum et al., 1994). However, a geochemical analysis of the entire sequence of the compositionally zoned tuff of Sharp Peak has not been done, and it is possible that if a Zr-rich portion of it exists, it might not have been sampled. The Cat Mountain Tuff is also compositionally zoned such that only parts of the unit contain Zr concentrations greater than 300 ppm. In fact, most analyses of the Cat Mountain Tuff as presented in Table 2 of Lipman (1993) are well within the range of values for Zr as reported for samples of the tuff of Sharp Peak in the Roskrige Mountains (samples 1 and 4 in Table 2 of Hagstrum et al., 1994).

We suspect that the tuff of Sharp Peak and the Cat Mountain Rhyolite are the same, in agreement with Bikerman's (1965) original correlation. Except for the Zr content argument, there are no physical reasons to discount this correlation. It also seems highly unlikely that two nearly identical ash-flow tuffs could be so well represented in adjacent mountain ranges with no evidence of outflow sheets overlapping or underlying each other. The only real correlation problem is that both units exhibit abundant evidence of caldera-fill facies in each mountain range. Is it possible that the two caldera fragments were once part of a single very large caldera?

It is conceivable that the Tucson and Roskrige Mountains were much closer prior to Mid-Tertiary taphrogeny. Lipman (1993) shows a western caldera margin for the Tucson Mountains caldera just to the west of the range, but there is no direct evidence for this. In fact, there is some evidence that the eastern Tucson Mountains caldera margin is located much farther to the west than is depicted by Lipman (1993). At the eastern base of Sentinel Peak in the eastern Tucson Mountains, a small area of Mesozoic sedimentary rocks includes at least one, thin, welded ash-flow

tuff sheet (the Mission Road tuff of Phillips, 1976) and these rocks are overlain by an early Tertiary (~58 Ma) lava flow (Phillips, 1976) with significant angular unconformity. A closer examination of this critical outcrop shows that two welded ash-flow tuffs are present, a crystal-poor unit and a crystal-rich unit, the upper one being the Sentinel Tuff of Phillips (1976). Inasmuch that the Cat Mountain Tuff is considered to be the youngest regional ash-flow tuff in the area, the presence of two thin outflow sheets of probable Cretaceous or older age within the Tucson Mountains caldera is difficult to explain. There are three possible explanations for the outcrops at Sentinel Peak: (1) the two ash-flow tuffs are younger than the Cat Mountain Tuff, (2) the outcrops represent an area of uplifted caldera floor that was completely stripped of intracaldera Cat Mountain Tuff prior to 58 Ma, or (3) they represent an area outside the Tucson Mountains caldera.

Lipman's (1993) map of the Tucson Mountains shows a western caldera margin just to the west of the range and a poorly constrained eastern margin extending into the Tucson basin. Based on the evidence discussed in the previous paragraph, we suspect that the eastern margin of the Tucson Mountains caldera is west of Sentinel Peak and that it is the location of the western margin, rather than the location of the eastern margin that is really unconstrained. The Tucson Mountains caldera margin, as we suggest redefining it, and the caldera margin we describe in the Roskrige Mountains, might represent the dismembered eastern and western segments of a single caldera that was the source of the Cat Mountain Rhyolite – tuff of Sharp Peak. By closing the Avra Valley basin by a combination of restoring extension and possible left-lateral strike-slip faulting, the caldera could be as small as 600 km<sup>2</sup> (Figure 4).

### **Tertiary geology of the Roskrige Mountains**

Tertiary igneous rocks in the study area are represented by two plutonic bodies and two small volcanic fields of differing age and composition. The volcanic fields consist of an extensive (at least 110 km<sup>2</sup>) trachyandesite lava field in the southeastern part of the map area dated at  $23.91 \pm 0.70$  and  $24.08 \pm 1.40$  (K/Ar whole rock dates of Bikerman (1967), as reported in Reynolds et al., 1986), and a small (~7 km<sup>2</sup>) silicic ash-flow tuff caldera or maar volcano in the northeast corner that is the source of the approximately 13 Ma Recortado Tuff [K/Ar sanidine dates of  $12.93 \pm 0.60$ ,  $12.96 \pm 0.40$ , and  $14.25 \pm 0.50$  Ma of Bikerman (1967) as reported in Reynolds et al. (1986)]. Both volcanic fields are intruded and overlain by a xenolith-rich pyroxene megacryst basalt that has been dated at  $10.99 \pm 1.30$ , and  $9.86 \pm 1.70$  Ma (K/Ar whole rock ages of Bikerman, 1967 as reported in Reynolds, 1986). The two shallow intrusive bodies are located farther west; La Tortuga Butte porphyry dated at  $34.90 \pm 0.30$  Ma (K/Ar plagioclase date of Bikerman, 1967 as reported in Reynolds et al., 1986), and the trachyte porphyry of Martina Mountain which is dated at  $25.65 \pm 0.54$  Ma (K/Ar whole rock age of Shafiqullah et al., 1978).

### ***Plutonic rocks***

The porphyry of La Tortuga Butte (**Ttz**) is an intermediate to mafic composition intrusive complex that forms east-west striking dikes invading the Mesozoic country rock, and at least two elongate, east-west striking stocks at Tortuga Butte. Textures vary from medium-grained equigranular with very sparse plagioclase phenocrysts, to fine-grained plagioclase porphyritic. The average composition of the rock is probably quartz monzodiorite (based on thin-section estimation of mineral modes only), although Bikerman (1965) refers to the rock as a granodiorite (no chemical analyses or mineral modes reported). The rocks are dominated by euhedral to subhedral plagioclase ( $An \leq 35$ ), that is typically strongly zoned and badly altered. Interstitial quartz ( $\leq 5\%$ ,  $\leq 0.5$  mm) is present in the more equigranular varieties, along with a few percent K-feldspar.

Mafic minerals, commonly altered to felted masses of calcite, chlorite, and opaques (5-20%, 0.5-5.0 mm) are present in all samples. A few percent of the less altered mafic minerals in some specimens are clearly hornblende, opaques, and/or clinopyroxene.

La Tortuga Butte porphyry is similar to the larger east-west striking belt of porphyries in the northern Roskrige Mountains, the Dos Titos complex of Richard et al. (2000) which has been mapped as a Laramide (TK) body. The pervasive propylitic alteration and highly fractured and veined nature of La Tortuga Butte porphyry suggests that it may be Laramide in age.

The trachyte of Martina Mountain is an intrusive complex of dark-colored porphyritic trachyte porphyry containing phenocrysts of strongly zoned plagioclase (~5%, 0.5-2.0 mm, An 55 cores), euhedral hornblende (1-3%, 0.5-2.0 mm), biotite (1-3%,  $\leq 0.5$  mm), and clinopyroxene ( $\leq 0.5\%$ ,  $\leq 0.5$  mm). The unit forms the top of Martina Mountain and its map pattern suggests that the body may be the flat-bottomed remnant of a laccolith. The rock is remarkably devoid of fractures, veins, or alteration, and it weathers/erodes into non-equant, orthogonal blocks. The slightly porphyritic texture is consistent throughout, although in some areas sharp boundaries are present between slightly different textural variations of the same rock. The porphyry is also characterized by up to 1% xenoliths of medium-grained, equigranular leucogranite ranging in size from 2 cm to 30 cm. The trachyte of Martina Mountain was apparently not recognized by Bikerman (1965). Shafiqullah et al. (1978) interpreted the rock as a dacite tuff. Our chemical analyses (3a,b) show the rock to be a trachyte.

### *Volcanic and sedimentary rocks*

#### *Early Miocene lava field and sedimentary rocks*

The southeastern portion of the study area consists of an approximately 24 Ma, at least 150 meter-thick sequence of trachyandesite lava flows (**Tm**) that is at least 150 meters thick. The sequence consists of multiple flow-units of crystal-poor to moderately crystal-rich trachyandesite lava containing phenocrysts of orthopyroxene and clinopyroxene. The volume of the lava field is at least 10 km<sup>3</sup> and probably more like 20 km<sup>3</sup>. The phenocryst assemblages of the flows are variable as reported by Eastwood (1970), but we did not observe many of the units that are shown on his cross section (Eastwood's Figure 6, 1970), in particular the basaltic flows or the Cerro Prieta basalt, a distinctive unit that he defined in the Samaniego Hills 40 km to the north. The trachyandesite lava occurs in flow units ranging between 5 and 20 meters thick that are generally amalgamated with only rare occurrences of interbedded, thin sequences of pyroclastic or sedimentary rocks (**Tt**). The sequence dips gently to the west and is overlain by a sequence of lacustrine mudstone and limestone (**Tsm**), sandstone and conglomerate (**Ts**), and diamictite (**Tsd**). The sedimentary rocks coarsen to the west towards a major east-side-down normal fault.

The coarser grained facies contain clasts of the Mesozoic volcanics and granite, but little or no Tertiary trachyandesite lava. This may have influenced Bikerman (1965) to have placed these rocks below the trachyandesite lava in his stratigraphic sequence, but a west-dipping basal contact is very well exposed in the SE 1/4 of sec. 34, T15S, R9E. Elsewhere, as reported by Bikerman (1965), there is very little evidence of sedimentary rocks along the contact between the trachyandesite lava and the Mesozoic volcanic rocks. The lack of trachyandesite lava clasts in the coarse grained facies of the sedimentary unit (map units **Ts**, and **Tsd**) suggests that the down-dropped block foundered rapidly. Very large, angular to subangular clasts of the tuff of Sharp Peak and granite in the diamictite facies close to the fault zone suggest that the coarse-grained sediment was derived largely from the footwall.

### ***Recortado Tuff***

The Recortado Tuff (**Ttr**) is small volume (~1-2 km<sup>3</sup>) Late Miocene (~ 13 Ma) welded ash-flow tuff that fills a small (~ 7 km<sup>2</sup>) caldera or maar volcano whose western edge barely extends into the extreme northeast corner of the map area. The main part of the caldera is mapped by Skotnicki and Pearthree (2000). The Recortado Tuff contains abundant sanidine phenocrysts, and has a distinctive texture with black fiamme. The western part of the caldera seems to have collapsed farther than areas to the east and includes a caldera-filling sedimentary sequence (**Tsy**) that shows rapid change in facies towards the center of the small basin from coarse conglomerate to thin-bedded mudstone and siltstone. The sedimentary rocks inside the caldera are intruded by north-striking dikes (the pictograph dikes of Bikerman, 1965) of the xenolith-rich, pyroxene megacrystic basalt of Brawley Wash (**Tb**). The dikes are also present to the north (Richard et al., 2000), and they feed small areas of lava flow inside the Recortado caldera [Skotnicki and Pearthree's (2000) map unit Tbo] and a very poorly exposed lava flow to the south in Brawley Wash (Bikerman, 1965; Pearthree et al., 2000).

### ***Geochemistry***

Chemical analyses of the trachyandesite lava, the trachyte of Martina Mountain, and the basalt of Brawley Wash from this study area and the Three Points quadrangle (Pearthree et al., 2000) and representative samples from a small lava field in the eastern Waterman Mountains (Richard et al., 2000) were done as part of this study and are shown in Table 3a,b,c. All of these analyses along with Eastwood's (1970) analyses from the trachyandesite in the Roskrige Mountains, analyses of the Mid-Tertiary lava fields in the Samaniego Hills (Eastwood, 1970), and the Sawtooth Mountains (Ferguson et al., 1999), are plotted on a Le Bas et al. (1986) chemical classification diagram (Figure 5).

### ***Tertiary geology of the Coyote Mountains***

The Coyote Mountains represent the footwall of the Ajo Road detachment fault system. The fault strikes ESE-WNW and dips approximately 45° to the north. The footwall in this study area consists of a Mesozoic mafic plutonic complex intruded by the  $58.0 \pm 2$  Ma (U-Pb zircon, Wright and Haxel, 1982) Pan Tak granite. The mafic plutonic complex (**Mzd**) consists of medium- to fine-grained biotite- and/or hornblende-rich (>25%) diorite, quartz diorite, and/or quartz monzodiorite (based on visual estimation of mineral modes). The diorite is variably foliated to non-foliated and may contain a few percent quartz. According to Gardulski (1990), the mafic plutonic rocks (which she divided into three map units: biotite quartz diorite, hornblende diorite, and hornblendite) also intrude tabular bodies of middle and early Paleozoic quartzite and limestone just to the west of the study area.

In the northeastern Coyote Mountains, the Pan Tak granite is represented by a coarse-grained pegmatitic leucogranite (**Tpg**) displaying a wide range of textural variation including fine-grained aplite. The granite forms tabular, sill-like, north- to northeast-dipping bodies that invade the older dioritic rocks. The granite is locally foliated parallel to these intrusive contacts, but it is typically non-foliated in most areas.

Mylonitic fabrics in the footwall rocks are rare to nonexistent more than 500 meters south of the fault except along the higher ridge-lines. Gardulski (1990) noted a similar strain gradient in the footwall rocks, and she also noted that, in areas where the pegmatitic granite intrudes quartzite, mylonitic fabrics and multiple slip surfaces are concentrated along the contacts. We noted that near the Ajo Road detachment fault the diorite is locally pervasively foliated with a well developed

**Table 3a** Major element analyses of representative samples of Tertiary igneous rocks from the southern Roskrige Mountains, and eastern Waterman Mountains, samples located in the Waterman Peak, San Pedro, La Tortuga Butte, and Three Points 7.5' quadrangles. The samples were analyzed at the New Mexico Bureau of Mines and Mineral Resources geochemistry laboratory. The samples were crushed in a steel jaw crusher, split, and ground in a Tema mill using a WC grinding set. The samples were fused into glass disks and analyzed on a Phillips wavelength dispersive x-ray fluorescence spectrometer for major elements. A separate split of each sample was used to determine the loss-on-ignition gravimetrically.

sample	SiO <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub> -T	MnO	MgO	CaO	K <sub>2</sub> O	Na <sub>2</sub> O	P <sub>2</sub> O <sub>5</sub>	LOI	Total		Ba
	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %	wt. %		ppm
3-1-00-1	46.88	2.40	16.99	10.57	0.18	6.65	9.11	1.14	4.36	0.60	1.27	100.15		545
FO-322	64.03	0.74	15.76	4.70	0.13	1.72	3.47	4.13	3.97	0.33	1.24	100.23		1191
FO-323	71.32	0.42	13.49	3.12	0.05	1.04	2.21	5.39	2.77	0.21	0.57	100.59		1083
FO-324-CM1	65.94	0.55	15.02	3.47	0.07	1.29	2.88	4.14	3.63	0.21	3.29	100.49		929
FO-324-CM2	66.11	0.55	15.03	3.46	0.07	1.30	2.88	4.06	3.62	0.22	3.29	100.58		960
FO-324-CM3	65.99	0.55	15.00	3.45	0.07	1.28	2.87	4.13	3.61	0.22	3.29	100.46		939
FO-327	63.00	0.78	15.99	4.79	0.09	1.99	3.50	4.38	3.88	0.36	1.54	100.30		1320
FO-688	59.38	0.95	16.04	6.22	0.10	2.81	5.01	3.44	3.79	0.43	1.63	99.80		1262
FO-689	60.69	0.91	16.11	5.95	0.10	2.08	4.42	4.03	3.98	0.39	1.02	99.68		1255
FO-761	57.16	1.37	16.22	8.10	0.12	3.19	5.67	3.06	3.89	0.46	0.69	99.93		1333
FO-880	63.95	0.54	16.13	4.05	0.05	2.48	4.04	3.23	3.90	0.20	1.88	100.45		1137
FO-883	64.70	0.51	16.44	3.95	0.07	2.02	3.67	3.50	4.05	0.19	1.76	100.85		1124
FO-942	48.04	2.16	16.82	9.75	0.16	6.92	8.93	1.54	3.88	0.54	1.91	100.65		404
FO-1029	74.91	0.16	12.63	1.09	0.06	0.20	0.88	4.30	3.62	0.05	2.66	100.56		257
FO-1033	47.29	2.47	16.21	11.85	0.18	6.28	9.25	1.18	3.45	0.45	1.17	99.77		433

All values are in weight percent, except Ba, which is in parts per million.

Fe<sub>2</sub>O<sub>3</sub>-T is total iron expressed as

Fe<sub>2</sub>O<sub>3</sub>.

LOI is loss on ignition.

Sample with the extension -CM1, -CM2, and -CM3 are replicates.

**Table 3b** Trace element analyses of representative samples of Tertiary igneous rocks from the southern Roskrige Mountains, and eastern Waterman Mountains, samples located in the Waterman Peak, San Pedro, La Tortuga Butte, and Three Points 7.5' quadrangles. The samples were analyzed at the New Mexico Bureau of Mines and Mineral Resources geochemistry laboratory. The samples were crushed in a steel jaw crusher, split, and ground in a Tema mill using a WC grinding set. The samples were pressed into powder pellets and analyzed on a Phillips wavelength dispersive x-ray fluorescence spectrometer for major elements.

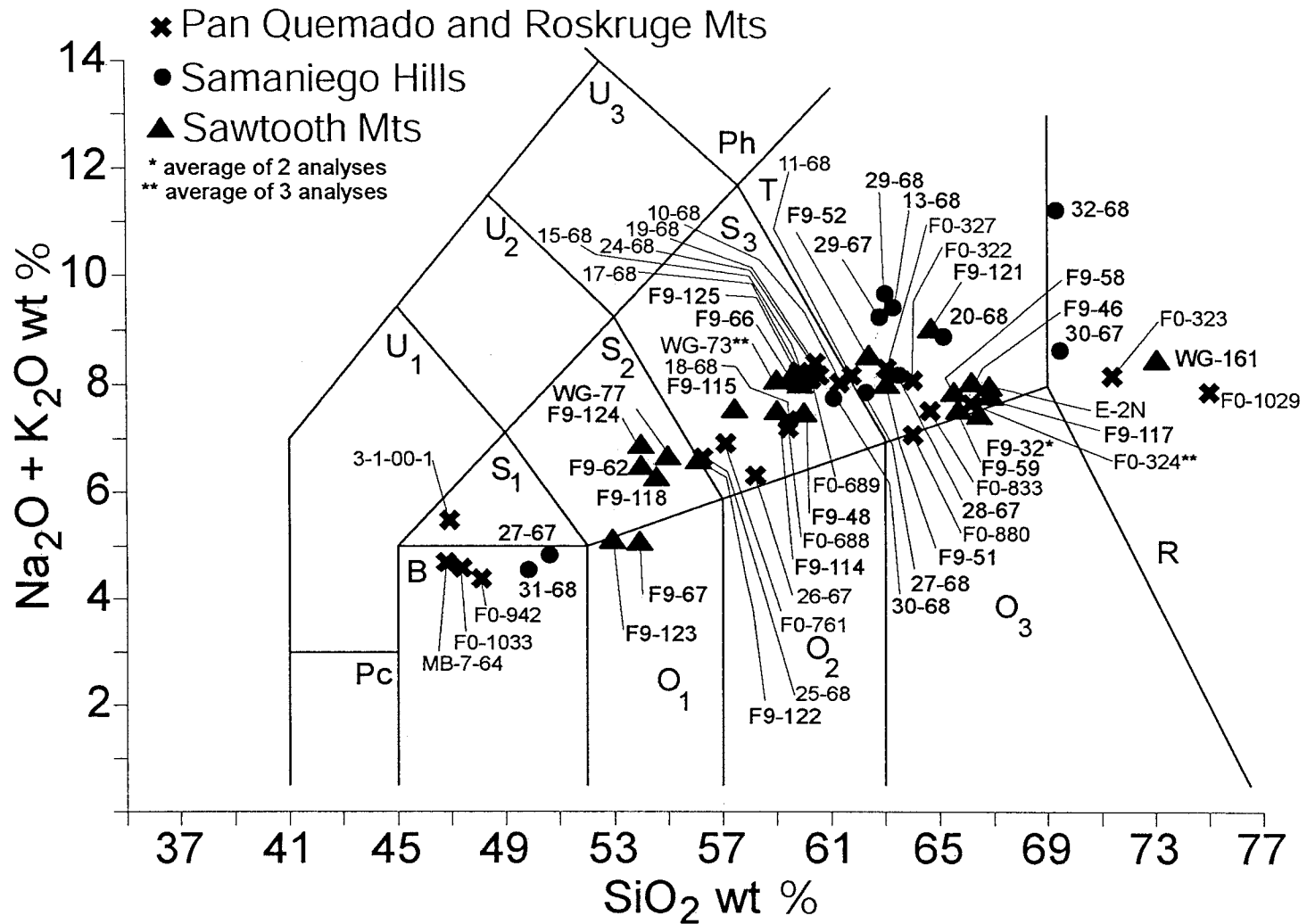
Sample	Sr	Rb	Th	Pb	Ga	Zn	Cu	Ni	Fe2O3-T	MnO	Cr	TiO2	Ba	V	As	U	Y	Zr	Nb	Mo
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	wt. %	wt. %	ppm	wt. %	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
3-1-00-1	782	11	0	4	19	70	55	80	10.73	0.19	154	2.27	407	199	2	1	28	240	74	5
FO-322-CM1	520	149	15	18	18	62	31	32	4.35	0.12	38	0.74	1170	78	3	3	25	355	22	3
FO-322-CM2	522	151	18	18	19	62	32	32	4.35	0.12	38	0.73	1187	75	2	4	25	363	22	3
FO-322-CM3	524	150	15	19	18	63	31	30	4.37	0.12	35	0.75	1186	81	2	3	25	360	23	4
FO-323	342	168	17	18	15	46	20	11	2.93	0.05	18	0.42	1087	48	1	3	16	280	16	2
FO-324	431	192	19	20	17	47	25	15	3.02	0.06	18	0.51	939	50	2	4	21	255	22	3
FO-327	528	149	13	19	19	68	36	31	4.57	0.09	34	0.79	1317	74	2	3	26	400	24	3
FO-688	563	103	17	17	20	86	52	36	6.01	0.10	43	0.94	1222	102	3	3	29	443	22	4
FO-689	531	147	18	17	20	81	40	30	5.94	0.10	48	0.93	1267	109	4	3	30	455	22	4
FO-761	584	103	12	12	21	81	43	38	7.62	0.11	39	1.21	1390	128	2	2	30	362	22	3
FO-880	632	87	10	16	19	67	32	40	3.93	0.04	58	0.52	1148	59	5	3	15	220	13	2
FO-883	586	100	13	21	19	60	36	39	3.79	0.07	61	0.50	1082	58	2	4	15	212	14	2
FO-942	631	43	0	2	19	66	49	98	9.72	0.16	223	2.05	316	187	2	2	25	233	51	4
FO-1029	85	250	27	29	15	25	6	4	0.94	0.05	9	0.15	245	8	2	8	32	109	26	4
FO-1033	591	46	0	ND	21	95	54	70	11.73	0.18	146	2.36	303	223	3	2	28	188	43	3

All values are in parts per million, except Fe2O3-T, MnO, and TiO2, which are in weight percent.

Fe2O3-T is total iron expressed as Fe2O3.

ND is below the lower limit of determination.

Samples with the extension -CM1, -CM2, and -CM3 are replicates.



**Figure 5** Total alkali versus silica diagram of Le Bas et al. (1986) showing analyses of Mid-Tertiary volcanic and hypabyssal rocks from the eastern Waterman Mountains (Richard et al., 2000) and eastern Roskruge Mountains (this report) with complete analyses and location of samples shown in Table 3a,b,c. Also shown are Eastwood's (1970) analyses from the Roskruge Mountains and Samaniego Hills (sample numbers with the -64, -67, or -68 suffix), and analyses from the Sawtooth Mountains (Ferguson et al., 1999) which includes one analysis (sample E-2N) from Banks et al. (1978). Field name abbreviations are Pc: picrobasalt, B: basalt,  $O_1$ : basaltic andesite,  $O_2$ : Andesite,  $O_3$ : Dacite, R: rhyolite,  $S_1$ : trachybasalt,  $S_2$ : basaltic trachyandesite,  $S_3$ : trachyandesite, T: trachyte,  $U_1$ : tephrite basalt,  $U_2$ : phonotephrite,  $U_3$ : tephriphonolite, T: phonolite.

**Table 3c** Location of geochemistry samples whose analyses are reported in Tables 3a,b.

Sample	UTM north	UTM east	Quadrangle	lithology	map unit
F0-322	3578040	462315	Waterman Peak	trachyte of Nessie's Mt	Ttn
F0-323	3578005	462410	Waterman Peak	rhyolite dike	Tri
F0-324	3577960	462420	Waterman Peak	crystal-rich trachyte	Ttx
F0-327	3577210	462670	Waterman Peak	trachyte of Nessie's Mt	Ttn
F0-688	3552785	460835	San Pedro	trachyandesite	Tm
F0-689	3552505	460750	San Pedro	trachyandesite	Tm
F0-761	3552165	461120	San Pedro	trachyandesite	Tm
F0-880	3546930	457410	San Pedro	trachyte porphyry of Martina Mt	Tz
F0-883	3547200	458050	San Pedro	trachyte porphyry of Martina Mt	Tz
F0-942	3560575	464540	La Tortuga Butte	xenocryst-bearing basalt dike	Tb
F0-1029	3575250	461150	Waterman Peak	crystal-rich rhyolite	Trx
F0-1033	3552160	468870	Three Points	xenocryst-rich basalt	Tb
JS-3-1-00-1	3566865	464460	La Tortuga Butte	xenocryst-rich basalt	Tb

mylonitic fabric, but in most areas, this rock is also non- to very weakly foliated. Gardulski (1990) measured lineations in the mylonitic rocks that plunge 40-60° to the NNE. The sparse measurements we collected have trends that are more to the NNW.

Ductile fabrics in the footwall of the Ajo Road detachment fault are cut by a north-striking set of lamprophyre dikes (TI) which show no evidence of ductile fabric. Gardulski (1990) is confident that the lamprophyre dikes are cut by the detachment fault, and concluded that since the lamprophyre dikes cut mylonite fabric, the lineation producing event in the footwall is older than the detachment fault.

We agree with Gardulski's (1990) age relationships of map units and her assessment of the structural history of the Ajo Road detachment. We mapped an additional post-tectonic intrusive unit, an altered plagioclase-porphyritic porphyry (Tp) which invades both footwall and hangingwall rocks and appears to intrude the fault zone of the Ajo Road detachment fault. Dates of the plagioclase porphyry and the lamprophyre dikes would therefore constrain when the Ajo Road detachment fault was active.

## STRUCTURAL GEOLOGY

### Folding

East-west striking folds of probable Laramide age are present in the Aguirre Wash area of the southern Roskrige Mountains. Two open to close, east-plunging, major anticlines are shown on the map in this area that are separated by a poorly understood curvilinear fault that is thought to be a south-dipping normal fault. The normal fault appears to have propagated in the hinge zone of the major anticline and this is probably why the axial trace of the anticline is duplicated. The normal fault may have taken advantage of weakly developed axial planar cleavage in the hinge zone or similarly oriented reverse faults. The principal evidence for this fold structure is the regional change in dip of the thick slab of tuff of Sharp Peak which dominates the structural multilayer in this area.

Older rocks in the Aguirre Wash area underlie a pronounced angular unconformity at the base of the younger rhyolite sequence, and since these older rocks do not show significant angular unconformity with the younger rhyolite sequence to the south, there must be an important phase of

structural tilting that occurred during the hiatus. We interpret this phase of structural tilting to be related to folding, but regional block faulting or localized volcanogenic structures might also be responsible.

At one locality in the Aguirre Wash area, a thin sequence of Confidence Peak Tuff is clearly folded into a series of open to close, short wavelength (<100 meters) anticlines with an intervening syncline. The folded rocks are directly overlain with angular unconformity by the younger rhyolite sequence and this discordance is one of the principal reason for our inclusion of the Confidence Peak Tuff in our older sequence. As discussed previously, there is potential for multiple angular unconformities in the Mesozoic section of the Roskruge, Waterman, and Silver Bell mountains. We speculate that multiple events of tilting and erosion are evidence of synchronous deformation and volcanism. In some areas the deformation was compressional.

### **Block faulting**

Supracrustal rocks of the Roskruge Mountains are cut by numerous normal faults of at least two orientations; N to NNW-striking east-side-down, and E-W striking mostly north-side-down. The more northerly striking set appears to be the younger since one major fault of this orientation is the only one that is known to offset the Tertiary volcanic and sedimentary rocks in the valley east of Sharp Peak and the Dobbs Buttes. Conflicting cross-cutting relationships are present elsewhere however, and the fault chronology is probably very complex.

The ~ 26 Ma trachyte porphyry of Martina Mountain appears to cut at least one of a series of east-west-striking, north-side-down normal faults that duplicate the younger rhyolite sequence repeatedly in the Sharp Peak-Dobbs Buttes area, and map patterns in the area suggest that the major NNW-striking, east-side-down fault just to the west of Martina Mountain cuts the E-W striking faults. The major curvilinear south-side-down normal fault we show in the Aguirre Wash area does not appear to offset the Mid-Tertiary trachyandesite lava field just to the east of our map area (see Skotnicki and Pearthree, 2000; Pearthree et al., 2000), and since we interpret the same fault to offset the tuff of Sharp Peak at least 1 km, we also interpret this fault as a pre- Mid-Tertiary structure. Farther to the south there is little or no evidence that the trachyandesite unit is offset by any of the E-W striking faults. Based on this evidence, we depict most of the E-W striking faults to predate intrusion and deposition of the Tertiary volcanic, hypabyssal, and sedimentary rocks.

A Mid-Tertiary diamictite unit (**Tsd**) is associated with a complex zone of north- to east-side down normal faults in the Reservation Tank area and we interpret the unit as a proximal debris-flow and talus cone deposit that overlapped the degraded footwall block(s) in the area. Because of poor exposure, it is difficult to identify which fault(s) is(are) overlapped by the diamictite unit and which one(s) (if any) cut the diamictite. The diamictite grades rapidly to the east into a sandstone-conglomerate unit (**Ts**) and eventually a lacustrine facies (**Tsm**) that overlies the trachyandesite lava field.

### **Caldera structure**

The principal evidence for a caldera in the southern Roskruge Mountains is the great thickness of the tuff of Sharp Peak throughout most of the map area, and the presence of megabreccia and mesobreccia swarms in the tuff in the Pescadero Mountain area (see also Richard et al., 2000). Structural – stratigraphic evidence on the north side of the Garcia strip strongly suggest that a NW-striking, southwest-facing caldera margin is present. A very thick northeast-dipping slab of intracaldera tuff of Sharp Peak abuts against older rocks which are locally overlapped by mesobreccia of tuff of Sharp Peak that overlies the older rocks along a gently-

dipping buttress unconformity. Restoring the regional dip to horizontal in the area would tilt the buttress unconformity so that it dips into the proposed caldera structure. These relationships shown on the map of Richard et al. (2000) are depicted schematically on structural cross-section B-B' (Sheet 2). Late Cretaceous – Early Tertiary plutonic rocks along this zone may represent post-caldera magmatism (Bikerman, 1967; Skotnicki and Pearthree, 2000; Richard et al., 2000).

The southern margin of a caldera in the southern Roskrige Mountains is less well understood, chiefly because areas inside the Tohono O'odham nation were not mapped as part of this study. Rapid thickening from 200 meters to ~ 1 km of the tuff of Sharp Peak from south to north from Bell Mountain to the Sharp Peak – Dobbs Buttes area is implied because of paleomagnetic evidence of a younger, normally polarized ash-flow tuff that caps Bell Mountain (Vugtaveen et al., 1981). The tuff of Sharp Peak is reverse polarized. A northeast-facing buttress unconformity at the base of the tuff of Sharp Peak is also present in this area were it overlies older rocks along the old San Pedro Road.

The tuff of Sharp Peak seems to be thinner to the south where mesobreccia is rare. It is also less prone to erratic orientations of eutaxitic foliation which characterizes the unit farther north. We interpret the caldera floor within the Roskrige Mountains to be tilted to the north, and suggest that the main collapse of the caldera was in the north. It is also possible that main vent areas were also to the north, based on the presence of the multiple post-caldera plutonic complexes in the northern area.

The caldera structure in the Roskrige Mountains is folded, but it appears to post-date older phases of folding in the Aguirre Wash area.

### **Correlation of structures between the Coyote and Roskrige mountains**

Mylonitic structures in the Coyote Mountains are clearly younger than the ~ 58 Ma Pan Tak granite, but Gardulski (1990) noted that the Paleozoic rocks invaded by the Mesozoic diorite bodies are intensely folded in many areas. Gardulski (1990) interpreted these folds to be related to intrusion of the younger plutonic rocks, but she was unable to exclude an older regional tectonic folding event as a possibility.

Based simply on orientation and kinematics, we interpret the E-W striking normal faults of the Roskrige mountains to be related to formation of the Ajo Road detachment fault. Most of the faults in the southern Roskrige Mountains would be synthetic faults, but the major fault in the Aguirre Wash area would be antithetic. Based on the evidence presented in the preceding section we interpret this faulting event to pre-date emplacement of the Mid-Tertiary hypabyssal trachyte porphyry of Martina Mountain, and deposition of the Mid-Tertiary volcanic and sedimentary rocks.

The N to NNW-striking set of normal faults which cut the Tertiary volcanic and sedimentary rocks are interpreted to be related to formation of the younger, north-south striking Avra Valley – Altar basin.

### **CONCLUSIONS**

The principal volcanic unit of the southern Roskrige Mountains is a crystal-rich rhyolite ash-flow tuff that fills a caldera encompassing much of the study area. The unit has been informally named the tuff of Sharp Peak and a type section has been measured at Sharp Peak. The unit is remarkably similar to the Cat Mountain Rhyolite of the easterly adjacent Tucson Mountains and the two units are probably correlative. The tuffs are the same age (Bikerman, 1967; Lipman, 1993), have the same phenocryst mineralogy (Bikerman, 1962; this report), are vertically zoned with respect to chemistry (Hagstrum et al., 1994) and phenocrysts (Bikerman, 1962; this report),

have the same paleomagnetic polarity (Vugtaveen et al., 1981; Hagstrum and Sawyer, 1989; Hagstrum et al., 1994), and both directly overlie the Confidence Peak Tuff in several areas (Lipman, 1993; Sawyer, 1996; Richard et al., 2000; and this report). We discount a discrepancy in Zr content (Hagstrum et al., 1994) as the result of incomplete sampling. We interpret the western half of the Tucson Mountains caldera, which has been well-documented as source of the Cat Mountain Rhyolite (Lipman, 1993), to be the caldera structure in the Roskrug Mountains. Both caldera segments contain caldera-filling tuff that thickens to the north and includes abundant megabreccia swarms in the north. By opening the Avra Valley basin with a combination extensional and sinistral tear-faulting, the two segments were separated during Mid-Tertiary taphrogeny.

An older sequence of Mesozoic volcanic rocks in the Roskrug Mountains includes at least three outflow sheets of regional ash-flow tuff. The youngest is the Confidence Peak Tuff which was derived from the Silver Bell caldera to the north (Sawyer, 1987; 1989; 1996). Two older tuffs, a crystal-rich unit and a crystal-poor unit, are correlated tentatively as outflow sheets from a pair of Jurassic calderas in the Huachuca Mountains; the Montezuma and Turkey Canyon calderas, respectively, of Lipman and Hagstrum (1992).

The Viopuli Tuff, formerly the red Viopuli ignimbrite of Damon et al. (1964), and Bikerman (1965), has a distinctive texture and phenocryst mineralogy. We tentatively correlate it with a very thick (~ 500 meters) welded tuff unit that makes up the lower part of the Jurassic Mt. Wrightson Formation in the Santa Rita Mountains. If this correlation is correct, Upper Cretaceous K-Ar biotite ages of ~ 75 Ma (Bikerman, 1967) for the Viopuli Tuff in the Roskrug Mountains are metamorphic ages.

A major east-west striking anticline is present in the northern Roskrug Mountains that broadly folds rocks as young as the tuff of Sharp Peak. Older rocks in the area are more tightly folded and evidence of multiple events of folding and erosion suggest Mesozoic volcanism and compressional deformation were synchronous.

Two generations of normal faults are present in the southern Roskrug Mountains. An older generation is dominated by E-W striking faults that we interpret to be related to the north-dipping Ajo Road detachment fault and, for the most part, these faults are intruded and overlain by Mid-Tertiary volcanic, sedimentary, and hypabyssal rocks. A younger, more northerly striking set of normal faults cut the Mid-Tertiary rocks and are probably related to formation of the younger basins.

Small bodies of plagioclase porphyry are present in the hangingwall and footwall of the Ajo Road detachment and probably intrude the fault. Dates of this rock and a suite of lamprophyre dikes that are cut by the fault but which also post-date mylonitic deformation in the footwall (Gardulski, 1990) might better constrain the timing of motion along the Ajo Road detachment fault.

## REFERENCES

- Andrews, D. A., 1937, Ground water in the Avra-Altar Valley, Arizona: U. S. Geological Survey Water-Supply Paper 796-E, p. 163-180.
- Bikerman, Michael, 1962, Geologic-geochemical study of the Cat Mountain Rhyolite: Tucson, University of Arizona, M. S. thesis, 43 pp.
- Bikerman, Michael, 1965, Geological and geochemical studies of the Roskrug Range, Pima County, Arizona: Tucson, University of Arizona, Ph.D. dissertation, 112 pp.
- Bikerman, Michael, 1967, Isotopic studies in the Roskrug Mountains, Pima County, Arizona: Geological Society of America Bulletin, v. 78, no. 8, p. 1029-1036.

- Bikerman, Michael, 1968, The geology of the Roskrige Mountains--a brief summary, in Titley, S.R., ed., Southern Arizona Guidebook III: Arizona Geological Society, p. 183-191.
- Bryan, Kirk, 1925, The Papago country, Arizona; a geographic, geologic, and hydrologic reconnaissance with a guide to desert watering places: U.S. Geological Survey Water-Supply Paper 499, 436 p., scale 1:250,000 and 1:500,000, 4 sheets.
- Damon, P.E., Mauger, R. L., and Bikerman, M., 1964, K-Ar dating of Laramide plutonic and volcanic rocks within the Basin and Range province of Arizona and Sonora: Proceedings, XXII International Geological Congress, India.
- Drewes, H., 1968, New and revised stratigraphic names in the Santa Rita Mountains of southeastern Arizona: U. S. Geological Survey Open-File Report, 6 pp.
- Drewes, H., 1971, Geologic map of the Mount Wrightson quadrangle, southeast of Tucson, Santa Cruz and Pima Counties, Arizona: U. S. Geological Survey Miscellaneous Geologic Investigations Map I-614.
- Eastwood, R. L., 1970 A geochemical-petrological study of mid-Tertiary volcanism in parts of Pima and Pinal Counties, Arizona: Tucson, University of Arizona, unpublished Ph.D. dissertation, 212 pp.
- Ferguson, C. A., Gilbert, W. G., Klawon, J. E., and Pearthree, P. A., 1999, Geologic map of the Sawtooth Mountains and a portion of the West Silver Bell Mountains, Pinal and Pima Counties, Arizona: Arizona Geological Survey Open-file Report 99-16, 23 pp, 1:24,000 scale map.
- Gardulski, A. F., 1990, A structural and petrologic analysis of a quartzite – pegmatite tectonite, Coyote Mountains, southern Arizona: Tucson, University of Arizona, M. S. thesis, 69 pp., 2 sheets.
- Hagstrum, J. T., and Sawyer, D. A., 1989. Late Cretaceous Paleomagnetism and clockwise rotation of the Silver Bell Mountains, South Central Arizona: *Journal of Geophysical Research*, v. 94, p. 17,847-17,860.
- Hagstrum, J.T., Lipman, P.W., and Sawyer, D.A., 1994, Paleomagnetism, stratigraphy, and petrology of the upper Cretaceous Roskrige Volcanics at Bell Mountain, southeast Arizona: *Journal of Geophysical Research*, v. 99, no. B8, p. 15,097-15,102.
- Hayes, P.T., 1970, Cretaceous paleogeography of southeastern Arizona and adjacent areas: U.S. Geological Survey Professional Paper 658-B, 42 p.
- Heindl, L.A., 1965, Mesozoic formations in the Comobabi and Roskrige Mountains, Papago Indian Reservation, Arizona, Chapter H, in Contributions to stratigraphy: U.S. Geological Survey Bulletin 1194-H, p. H1-H15.
- Le Bas, M. J., Le Maitre, R. W., Streckeisen, A., and Zanettin, B., 1986, A chemical classification of volcanic rocks based on the total alkali-silica diagram: *Journal of Petrology*, v. 27, p. 745-750.
- Lipman, P. W., 1993, Geologic map of the Tucson Mountains caldera, southern Arizona: United States Geological Survey Miscellaneous Investigations Series Map I-2205, 2 sheets, scale 1:24,000.
- Lipman, P. W., and Hagstrum, J. T., 1992, Jurassic ash-flow sheets, calderas, and related intrusions of the Cordilleran volcanic arc in southeastern Arizona: Implications for regional tectonics and ore deposits: *Geological Society of America Bulletin*, v. 104, no. 1, p. 32-39.
- Machette, M.N., 1985, Calcic soils of the southwestern United States: in Weide, D.L., ed., Soils and Quaternary Geology of the Southwestern United States: Geological Society of America Special Paper 203, p. 1-21.
- Mauger, R. L., Damon, P. E., and Giletti, B. J., 1965, Isotopic dating of Arizona ore deposits: *American Institute of Mining, Metallurgical, and Petroleum Engineers Transactions*, v. 232, p. 81-87.
- Pearthree, P.A., Ferguson, C.A., Gilbert, W.G., and Skotnicki, S.J., 2000, Geology and geologic hazards of the Three Points Quadrangle, Pima County, Arizona: Arizona Geological Survey Open-File Report 00-xx, xx p., scale 1:24,000.
- Phillips, M. P., 1976, Geology of Tumamoc Hill, Sentinel Peak and vicinity, Pima County, Arizona: Tucson, University of Arizona, unpublished M. S. thesis, 83 pp., 1 sheet, scale 1:3,600.
- Riggs, N. R., and Busby-Spera, C. J., 1990, Evolution of a multi-vent volcanic complex within a subsiding arc graben depression: Mount Wrightson Formation, Arizona: *Geological Society of America Bulletin*, v. 102, p. 1114-1135.

- Reynolds, S. J., Florence, F.P., Welty, J.W., Roddy, M.S., Currier, D.A., Anderson, A.V., and Keith, S.B., 1986, Compilation of Radiometric Age Determinations in Arizona, Arizona Geological Survey Bulletin 197, 258 p., 2 sheets, scale 1:1,000,000.
- Richard, S. M., Ferguson, C. A., Spencer, J. E., Youberg, A., and Orr, T. R., 2000, Geologic map of the Waterman Peak 7.5' quadrangle and northern La Tortuga Butte 7.5' quadrangle, Pima County, Arizona: Arizona Geological Survey Digital Geologic Map 02
- Sawyer, D. A., 1987, Late Cretaceous caldera volcanism and porphyry copper mineralization at Silver Bell, unpublished Ph.D. dissertation: Santa Barbara, University of California, 400 pp.
- Sawyer, D. A., 1989, Field guide to the Late Cretaceous Silver Bell caldera and porphyry copper deposits in the Silver Bell Mountains: New Mexico Bureau of Mines and Mineral Resources Memoir 46, p. 127-132.
- Sawyer, D. A., 1996, Geologic map of the Silver Bell and West Silver Bell Mountains, southern Arizona: United States Geological Survey Open-file Report 96-006, 21 pp., 1 sheet, 1:48,000 scale.
- Shafiqullah, M., Damon, P. E., Lynch, D. J., Kuck, P. H., and Rehrig, W. A., 1978, Mid-Tertiary magmatism in southeastern Arizona: *in* Callender, J. F., Wilt, J. C., Clemons, R. E., and James, H. L. (eds.), Land of Cochise, southeastern Arizona: New Mexico Geological Society 29<sup>th</sup> Field Conference Guidebook, p. 231-241.
- Skotnicki, S. J., and Pearthree, P. A., 2000, Geologic map of the Cocoraque Butte 7.5' quadrangle, Pima County, Arizona: Arizona Geological Survey Open-file Report 00-08, scale 1:24,000, 28 pp.
- Tosdal, R.M., Haxel, G.B., and Wright, J.E., 1989, Jurassic geology of the Sonoran Desert region, southern Arizona, southeastern California, and northernmost Sonora: Construction of a continental-margin magmatic arc, *in* Jenney, J.P., and Reynolds, S.J., eds., Geologic evolution of Arizona: Arizona Geological Society Digest 17, p. 397-434.
- Vugteveen, R.W., Barnes, A.E., and Butler, R.F., 1981, Paleomagnetism of the Roskrige and Gringo Gulch Volcanics, southeast Arizona: *Journal of Geophysical Research*, v. 86, no. B5, p. 4021-4028.
- Wilson, E.D., Moore, R.T., and O'Haire, R.T., 1960, Geologic map of Pima and Santa Cruz Counties, Arizona: Arizona Bureau of Mines, 1 sheet, scale 1:375,000 [now available as Arizona Geological Survey Map M-3-8].
- Wright, J. E., and Haxel, G., 1982, A garnet-two-mica-bearing granite, Coyote Mountains, southern Arizona: geologic setting, uranium-lead systematics of zircon, and nature of the granite source region: *Geological Society of America Bulletin*, v. 93, p. 1176-1188.

# Unit Descriptions for the geologic map of the southern Roskrige Mountains, Pima County, Arizona

## Surficial units

### Piedmont Alluvium

Quaternary and late Tertiary deposits cover the piedmont areas around and within the Roskrige Mountains. This sediment was deposited primarily by larger 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 early Pleistocene or Pliocene. 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):** Active 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 Roskrige 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. 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. Young 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 (<10 ka):** Low terraces and broad, minimally dissected alluvial fans in the southern part of the map area. Qy1 surfaces are slightly higher and/or farther from active channels, and thus are less subject to inundation than Qy2 surfaces. Qy1 surfaces 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).

**Qy undifferentiated Holocene alluvium (0 to 10 ka):** Young stream deposit. This unit is mapped where it was not feasible to attempt to differentiate Qy2 and Qy1. It includes elements of each unit.

**Qly Holocene to Late Pleistocene alluvium (0 to 130 ka):** Broadly rounded alluvial fan surfaces approximately 1 m above active channels composed of mixed alluvium of late Pleistocene and Holocene age. Drainage networks consist of a mix of distributary channel networks associated with larger drainages and tributary channels associated with smaller drainages that head on Qly surfaces. Qly areas are mainly covered by a thin veneer of Holocene fine-grained alluvium (unit Qy), but reddened Pleistocene alluvium (unit Ql and less commonly, Qm) is exposed in patches on low ridges and in roads and cut banks of washes. The Holocene surfaces usually are light brown in color and soils have weak subangular blocky structure and minor carbonate accumulation. Qly fans support palo verde and mesquite trees along washes and low shrubs and grass in interfluvial areas.

**Ql Late Pleistocene alluvium (10 to 130 ka):** 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):** 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 Roskrige 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.

**Qlm undifferentiated middle and late Pleistocene alluvium (10 to 500 ka):** Moderately to highly dissected relict alluvial fans on fringing mountain slopes. This unit is used where Qm and Ql deposits cannot be confidently differentiated based on limited field checking.

**Qmo Middle to early Pleistocene alluvium (500 ka to 2 Ma):** Moderately to deeply dissected relict alluvial fans with strong soil development. Qmo surfaces on the south flank of the Roskrige 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):** 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 isolated locations all around the Roskrige Mountains. 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 stripped away completely 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.

### **Axial Stream Deposits**

Holocene and late Pleistocene sediment deposited by Brawley Wash covers the extreme southeastern part of the map area. 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.

**Qycr Modern river channel deposits (< 100 years):** River channel deposits of Brawley Wash. Deposits are composed primarily of sand and gravel. In the map area, 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 and continued to evolve through this century. Channel width is variable and locally the channel is braided. The 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 deposits:** Deposits in 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.

**Qy1r Holocene distal floodplain and terrace deposits (<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, but small, poorly 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 are inundated in the largest floods. They gradually merge upslope into young lowermost piedmont deposits (units Qy2 and Qy1).

**Qyr Holocene floodplain and terrace deposits (<10 ka):** The Qyr unit consists of floodplains and low terraces flanking the main channel system along Brawley Wash floodplain where 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.

## **HILLSLOPE DEPOSITS**

**Qc Quaternary hillslope colluvium:** Very poorly to poorly sorted, thin gravelly deposits mantling lower mountain slopes. Deposits are generally less than 2 m thick, and

commonly are less than 1 m thick. They typically are composed of angular clasts derived from resistant lithologies that form the higher peaks and ridges of the mountains. They typically mantle less-resistant, slope-forming bedrock units.

**Qsl Quaternary landslide deposits:** Disrupted deposits associated with a small to moderate-sized landslide on the northwest side of Martina Mountain. The age of this landslide is unknown, but its geomorphic expression is fresh enough to make the landslide obvious on aerial photographs.

**QTs Degraded Tertiary sedimentary rocks:** Very old, deeply dissected and highly eroded deposits. The upper surfaces of the unit are alternating eroded ridges and deep valleys, with ridgecrests typically 10 to 30 meters above adjacent active channels. Even the highest surfaces are rounded, and original highest capping fan surfaces are not preserved. Deposits that overlie areas of map unit Ts or Tsd are dominated by gravel ranging from boulders to pebbles with clasts of these older conglomerate and diamictite. Where the unit overlies the Tsm unit, it consists of fine-grained, light-colored sediment. 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 typically stage V (cemented petrocalcic horizons with laminar cap) on ridgecrests. Carbonate litter is common on ridgecrests and hillslopes. On aerial photos, surfaces are gray to white, and they generally support creosote, with lesser amounts of mesquite, palo verde, ocotillo, cholla, and saguaro.

## Bedrock units

Note: all age dates of Bickerman (1967) are recalculated using new constants (see Reynolds et al., 1986).

**Tb basalt of Brawley Wash (Tertiary) 0-30 meters:** (Bickerman, 1965; 1967): Dikes of xenolith- and xenocryst-rich, pyroxene basalt occur along the northeast edge of the map area. The dikes probably feed a flow or series of flows in the easterly adjacent Cocoraque Butte and Three Points quadrangles. The basalt flow in the Three Points quadrangle was referred to as the Brawley Wash basalt and was dated at  $10.99 \pm 1.30$  Ma (K/Ar whole rock, Bickerman, 1967). One of the dikes in the Cocoraque Butte quadrangle was dated at  $9.86 \pm 1.70$  Ma (K/Ar whole rock, Bickerman, 1967). Geochemistry samples: F0-942, F0-1033 (1033 is on the Three Points quadrangle); other sample: WG-135.

**Tsy younger sedimentary rocks (Tertiary) 0-50 meters:** Volcaniclastic sandstone, pebbly sandstone, and conglomerate that overlie the Recortado Tuff. This sequence of sedimentary rocks is probably correlative to the Ts and Tsd units farther south, but it is differentiated because it occurs only in a small basin that probably fills the western portion of a small caldera or maar volcano that was the source of the Recortado Tuff. The sedimentary rock overlies the tuff, includes abundant clasts of the tuff, and is intruded by the basalt (Tb) unit. In this map area, the unit displays rapid easterly facies change from massive boulder conglomerate to fine-grained, thin-bedded sandstone and mudstone. Sample: WG-134

**Ttr Recortado Tuff (Tertiary)** (Bikerman, 1965; 1967) 0-100 meters: Moderately crystal-rich, welded ash-flow tuff containing abundant sanidine (1-5 mm), but little or no quartz phenocrysts. The description of Bikerman (1967) does not include information about the presence or absence of plagioclase, but it is probably also present along with a trace of pyroxene and opaque minerals. The tuff is characterized by abundant, black vitric pumice fragments in a light brown matrix. Three K/Ar sanidine dates of  $12.93 \pm 0.60$ ,  $12.96 \pm 0.40$ , and  $14.25 \pm 0.50$  Ma were obtained from this tuff (Bikerman, 1967).

**Ts sedimentary rocks (Tertiary)** 0-200 meters: Poorly to well-indurated sedimentary rocks ranging from thin-bedded, light-colored mudstone and siltstone to reddish-colored, conglomeratic sandstone. Clasts in the conglomerate are typically of local Mesozoic lithologies. Gradational contact with the diamictite and lacustrine facies (**Tsd**, and **Tsm**) map unit is likely. This map unit, along with the diamictite and lacustrine facies (**Tsd**, and **Tsm**) is associated with an older Quaternary map unit (**QTs**) that is interpreted to be an erosional product of the Tertiary sedimentary rocks. Samples: F0-928 (granite clast), WG-84

**Tsm lacustrine facies (Tertiary)** 0-100 meters: Thin-bedded, light-colored mudstone with silty intervals and  $\leq 30$  cm-thick beds of massive, light gray to white micritic limestone. Gradational contact with the sandstone and conglomerate of unit **Ts**. This map unit, along with the coarser grained facies (**Ts**, and **Tsd**), is associated with an older Quaternary map unit (**QTs**) that is interpreted to be an erosional product of the Tertiary sedimentary rocks.

**Tsd diamictite facies (Tertiary)** 0-50 meters: Coarse-grained, boulder-clast diamictite. The unit is very poorly exposed and its matrix is very rarely preserved. Matrix consists of red, pebble-cobble, coarse-grained arkosic sandstone. Rarely, bedding surfaces are present. The outcrop areas erode into subdued hills with reddish soil. Clasts, ranging in size from pebbles to large boulders ( $> 1$  m) are subangular to subrounded and consist of local Mesozoic lithologies, principally tuff of Sharp Peak, rhyolite clast tuff breccia, mafic to intermediate lava, plus relatively high proportions of pink leucogranite, a unit whose nearest exposed outcrop is 6 kilometers to the north at La Tortuga Butte. This map unit, along with the sedimentary rocks unit (**Ts**), and a lacustrine facies (**Tsm**) are associated with a distinctive older Quaternary map unit (**QTs**) that is interpreted to be an erosional product of the Tertiary sedimentary rocks.

**Tm trachyandesite lava (Tertiary)** 0-200 meters: Multiple flow-units of crystal-poor to moderately crystal-rich trachyandesite lava, containing phenocrysts of orthopyroxene and clinopyroxene. The lavas are dark-colored, and display flow textures typical of mafic lava. The lava occurs in flow units ranging between 5 and 20 meters thick that are generally amalgamated with only rare instances of interbedded, thin sequences of pyroclastic, or sedimentary rocks. Bikerman reports a whole rock K/Ar date of  $23.91 \pm 0.70$  Ma from one of the flows in the southern part of the map area. In the easterly adjacent Three Points quadrangle, Bikerman (1967) reports whole rock K/Ar dates of  $24.08 \pm 1.40$  and  $14.74 \pm 2.41$  Ma from this unit (the younger date is from a badly altered zone). Thin-section samples: F0-688, -689, -766, 767; geochemistry samples: F0-688, -

689, and -761; other samples: F0-653, -654, -762, -763, -768, -778, -931, -1030, -1031, -1032, WG-83, -85, -86, -87, -88, -89, -90, -91, -92, -93, -94, -95, -96, -97, -98, -99, -100, -101, -102, -103, -104, -105, -106, -107, -108, -109, -110, -111, -112, -144, -145, -146, -147, -148, -149, -150 (F0-778, -1030, -1031, and -1032, and 00-WG-98, -99, -100, -101, -102 are all on the Three Points quadrangle).

**Tt nonwelded felsic tuff (Tertiary)** 0-10 meters: A thin (<20 cm) interval of very thin-bedded, fine ash tuff, probably an ash-fall tuff. The tuff is directly overlain by bleached mafic lava scoria. The underlying contact relationship is poorly preserved, but it seems very likely that the tuff overlies older flows of the trachyandesite map unit (**Tm**). Potential Ar/Ar geochronology sample: F0-764.

**Tz trachyte porphyry of Martina Mountain (Tertiary):** Intrusive complex of dark-colored porphyritic trachyte porphyry containing phenocrysts of strongly zoned plagioclase (~5%, 0.5-2.0 mm, An 55 cores), euhedral hornblende (1-3%, 0.5-2.0 mm), biotite (1-3%,  $\leq 0.5$  mm), and clinopyroxene ( $\leq 0.5\%$ ,  $\leq 0.5$  mm). The unit forms the top of Martina Mountain and its map pattern suggests that the body may be the flat-bottomed remnant of a lacolith. The rock is remarkably void of fractures, veins, or alteration, and it weathers/erodes into non equant, orthogonal blocks. The slightly porphyritic texture is consistent throughout, although in some areas sharp boundaries are present between slightly different textural variations of the same rock. The porphyry is also characterized by up to 1% xenoliths of medium-grained, equigranular leucogranite ranging in size from 2 cm to 30 cm. Shafiqullah et al. (1978) interpreted this rock as a dacite tuff and obtained a K/Ar whole rock age of  $25.65 \pm 0.54$  Ma from a sample which appears to have been collected from the southeastern talus cone of the mountain (based on location given in their report). Thin-section and geochemistry samples: F0-880, -883; other samples: F0-899, -900.

**Ttz porphyry of La Tortuga Butte (Tertiary):** A mafic to intermediate composition intrusive complex that occurs as east-west striking dikes invading the Mesozoic country rock, and at least two elongate, east-west striking stocks in La Tortuga Butte – Aguirre Wash area. Textures vary from medium-grained equigranular with very sparse plagioclase phenocrysts, to fine-grained plagioclase porphyritic. The average composition of the rock is probably quartz monzodiorite (based on visual estimation of mineral modes only). The rocks are propylitically altered, veined, and highly fractured, much like the Mesozoic country rock. Euhedral to subhedral plagioclase ( $An \leq 35$ ) is typically strongly zoned and badly altered. Interstitial quartz ( $\leq 5\%$ ,  $\leq 0.5$  mm) is present in the more equigranular varieties, along with a few percent K-feldspar. Mafic minerals, commonly altered to felted masses of calcite, chlorite, and opaques (5-20%, 0.5-5.0 mm) are present in all samples. A few percent of the less altered mafic minerals in some specimens are clearly hornblende, opaques, and/or clinopyroxene. Bikerman (1967) reports a K/Ar plagioclase age of  $34.90 \pm 0.30$  Ma age for this unit. Thin-section samples: F0-738, F0-739, 00-WG-64, and 00-WG-66; other samples: F0-737, -740, -742, 00-WG-65, -67, -121.

**TKp plagioclase porphyry (Tertiary-Cretaceous):** Aphanitic matrix porphyry containing 20-30% phenocrysts of plagioclase (19-27%, 2-4 mm) and altered mafic minerals and/or

biotite (1-3%, 1-2 mm). This porphyry crops out in two small areas around the base of Martina Mountain. Although probably related to the trachyte porphyry of Martina Mountain, and similar in appearance to a Tertiary porphyry in the Coyote Mountains (map unit **Tp**), this unit may be Cretaceous in age. Samples: F0-879, -903.

**TKq quartz porphyry (Tertiary-Cretaceous):** Pink to gray, crystal-rich quartz porphyry with phenocrysts of quartz (2-10%, 1-5 mm), feldspar (2-15%, 1-5 mm), and mafic minerals (~1-3%, 1-3 mm). The porphyry occurs as small stocks and east west-striking dikes in the area between Aguirre Pass and La Tortuga Butte. The orientation of the dikes and the close association of one stock with La Tortuga Butte stock suggests a Mid-Tertiary age, but the similarity in mineralogy with the nearby very thick succession of the tuff of Sharp Peak makes a late Cretaceous age possible. Samples: F0-578-2, F0-744a.

**TKs sedimentary rocks (Tertiary-Cretaceous) 0-50 meters:** Brown to light-reddish colored arkosic sedimentary rocks containing clasts of Mesozoic volcanic rocks and leucogranite. This unit is sparingly exposed where it is thought to overlie the tuff of Sharp Peak in the Martina Mountain area. The unit is very poorly exposed and nearly identical to the **Ts** and **Tsd** units, except that this unit is intruded by the trachyte porphyry of Martina Mountain.

**TKxp crystal-poor tuff (Tertiary-Cretaceous) 0-30 meters:** A crumbly weathering, light tan to orange-colored, poorly to moderately welded ash-flow tuff that is only exposed on the northeast flank of Martina Mountain. The tuff is thought to overlie the tuff of Sharp Peak, but it is similar to another crystal-poor tuff (**KJxp**) that underlies the tuff of Sharp Peak, and it is possible that complex structure is responsible for this outcrop. Samples: F0-895, -896.

**TKm mafic lava (Tertiary-Cretaceous) 0-20 meters:** A crumbly weathering mafic lava exposed at one outcrop on the northeast flank of Martina Mountain. The lava is thought to overlie the tuff of Sharp Peak, but it is similar to the mafic lava unit (**KJm**) that underlies the tuff of Sharp Peak, and it is possible that complex structure is responsible for this outcrop.

**TKf felsic lava (Tertiary-Cretaceous) 0-200 meters:** A dark-colored, plagioclase-phyric, crystal-poor, lithophysal lava. The lava is characterized by a dark bluish gray sugary matrix with ubiquitous 1-2 cm lithophysae cavities that have lighter, cream-colored rinds. Small (1-2 mm) plagioclase phenocrysts make up less than 10% of the rock. The lava intrudes the tuff of Sharp Peak in the northeast corner of the map area. Potential geochronology sample from the Cocoraque Butte quadrangle: F0-937. Other sample: 00-WG-25.

**TKr rhyolite lava (Tertiary-Cretaceous) 0-200 meters:** Moderately crystal-rich (10-15% phenocrysts), flow-banded rhyolite lava, containing K-feldspar (4-5%, 0.6-1.5 mm), plagioclase (2-3%, 0.2-0.7 mm), and quartz (2-3%, 0.3-4.0 mm) phenocrysts. This unit is recognized as a large body along the eastern edge of a wide outcrop belt of the tuff of Sharp Peak (section 23, T16S, R9E), and as a single small dike intruding the tuff of Sharp Peak (section 3, T15s, R9E). Judging from the dominant vertical flow-banding, and its outcrop pattern, the large body of rhyolite is interpreted to be hypabyssal, intruding the

tuff of Sharp Peak. Thin-section sample: F0-791; potential Ar/Ar geochronology sample: F0-792; other sample: WG-35.

**Ksp welded zone of the tuff of Sharp Peak (Cretaceous)** 200-1,200 meters: Formerly the Roskrige rhyolite of Heindl (1965) and the middle member of the Roskrige volcanics of (Bikerman, 1965; 1967; 1968). Moderately crystal-rich (18-30%) rhyolite, welded ash-flow tuff, containing phenocrysts of plagioclase (5-15%, 0.5-4.5 mm), quartz (4-8%, 0.7-8.0 mm), sanidine or perthitic K-feldspar (3-9%, 1.0-4.0 mm), and biotite (0.2-1.5%, 0.5-1.5 mm). At its type section (Sheet 1) the tuff is divided into a lower non-welded zone (**Kspl**), and an upper welded zone (**Ksp**), and the tuff is compositionally zoned with an abrupt increase in plagioclase and biotite content corresponding to the gradual upward change from non-welded to welded. In the basal portion, plagioclase is subordinate to equal in proportion to quartz and K-feldspar, but in the welded zone, plagioclase represents at least half of the total phenocrysts. Biotite also increases upwards in the welded zone from virtually nonexistent to approximately 1.5%. K-feldspar typically displays perthitic texture throughout, but at the type section, sanidine is preserved in the middle portion of the non-welded zone. Elsewhere, sanidine has also been observed in the welded zone. The welded zone of the tuff of Sharp Peak is pinkish, gray or peach colored and very resistant, forming nearly all of the high-standing peaks (other than those held up by resistant Mid-Tertiary igneous rocks) in the southern Roskrige Mountains. In the northern part of the map area, the transition from a lower nonwelded zone to the upper welded zone is complex due primarily to the abundance of mesobreccia (**Kspz**) and megabreccia (**Kspm**) lenses within the tuff. The paleomagnetic polarity of the tuff of Sharp Peak is reversed (Vugtaveen et al., 1981 samples RV 5-10; Hagstrum et al., 1994 samples RT1 and RT4a). Bikerman (1967) reports a K/Ar plagioclase date of  $66.90 \pm 3.00$  Ma, K/Ar biotite dates of  $70.30 \pm 1.90$ ,  $70.40 \pm 1.70$ ,  $71.40 \pm 1.50$ ,  $71.70 \pm 1.50$ ,  $73.00 \pm 1.60$ ,  $73.80 \pm 1.60$ , and  $74.20 \pm 1.50$  Ma, and a K/Ar sanidine date of  $70.40 \pm 1.70$  Ma for this unit. Thin-section samples: F0-531, -532, -533, -534, -548, -549, -589 - 694, 758; potential Ar/Ar geochronology samples: F0-660, -694, -758; potential U-Pb geochronology sample: F0-927; other samples: F0-586, -591, -728, -882, -943, WG-1, -19, -22, -23, -24, -26, -34, -38, -56, -59, -114, -115.

**Kspl non-welded base of the tuff of Sharp Peak (Cretaceous)** 0-300 meters: In many areas, the basal portion of the tuff of Sharp Peak is a non-welded, crudely thick-bedded, light-colored, multiple flow-unit, ash-flow tuff. The lower nonwelded zone is light-colored, tan or buff near the bottom and light reddish colored upwards into the welding transition. In areas where the lower zone directly overlies the non-welded, thick-bedded lithic tuffs of the rhyolite lithic tuff unit (**Kr1t**), the two units can be easily distinguished because the younger unit always contains a few percent quartz phenocrysts. The older unit is characteristically void of quartz phenocrysts and significantly more lithic rich (30-60% lithics versus <10% for the tuff of Sharp Peak). Thin-section samples: F0-543, -544, -545, -546, -547. Other samples: F0-671, WG-2, -20, -21, -27, -28, -54, -57, -58, -68, -118, -119, -120.

**Kspz tuff of Sharp Peak, mesobreccia (Cretaceous)** 0-250 meters: Swarms of lithic-rich (>25%), poorly to non-welded tuff of Sharp Peak, typically found near the base of the

unit. Clasts of older Mesozoic volcanics are generally less than 1 meter. The mesobreccia map unit can be distinguished from the underlying rhyolite lithic tuff unit (**Kr1t**), because it contains abundant, small quartz phenocrysts.

**Kspm tuff of Sharp Peak, megabreccia (Cretaceous)** 0-200 meters: Swarms of lithic-rich (>25%) poorly to non-welded tuff of Sharp Peak, typically found near the base of the unit. Clasts of older Mesozoic volcanics are generally less than 1 meter, but abundant clasts >> 1 meter are also present. The unit is characterized by the large lithic blocks that are commonly > 10 meters. The megabreccia map unit can be distinguished from the underlying rhyolite lithic tuff unit (**Kr1t**), because it contains abundant, small quartz phenocrysts.

**Kv Viopuli Tuff (Cretaceous)** Damon et al. (1964) 0-150 meters: Formerly the Viopuli red ignimbrite or red Viopuli ignimbrite of Damon et al. (1964). Moderately crystal-poor (5-15%) plagioclase, biotite densely welded ash-flow tuff. This unit is characterized by abundant, extremely flattened, light pink to light gray fiamme in a darker colored, pink to lavender, densely welded matrix. Plagioclase phenocrysts (5-7%, 1-5 mm) tend to be equant, euhedral, and unbroken. Biotite is fairly abundant (1-2%, 1-4 mm). The scarcity of lithic clasts in the main body of the flow, the extreme eutaxitic foliation, and the euhedral character of the plagioclase phenocrysts gives the appearance of a lava flow in some areas. Near the base, lapilli-sized, mafic lava lithic clasts are abundant (up to 10%), and pumice fragments are less compacted giving the unit a distinctive pyroclastic texture. The unit consists of two flow units (compound cooling unit) in the south, and the contact between the two is defined by a thin interval of poorly to moderately welded, light gray, faintly thin-bedded, fine-grained tuff. Bikerman (1967) reports K/Ar biotite ages of  $75.80 \pm 1.50$ , and  $76.00 \pm 1.50$  Ma for this unit. The tuff is zoned from a high-silica trachyte near the base to a low-silica rhyolite higher in the unit (Hagstrum et al. 1994), and its paleomagnetic polarity is normal (Vugtaveen et al., 1981, sample RV4; Hagstrum et al. 1994, samples RT 3a,b). Thin section samples: F0-714 (mislabelled F0-797 on section), F0-929; potential U-Pb geochronology sample: F0-929; other samples: F0-500, -514, -542, -1006, WG-3A, -3B, -3C, -4, -11, -44, -45, -48, -123A, -123B, -124, -129, -130.

**Kr rhyolite lava (Cretaceous)** 0-100 meters: Crystal-poor rhyolite lava containing 5 % phenocrysts of euhedral plagioclase (0.4-1.0 mm) and a trace of small biotite (1.0 mm). This unit is recognized at La Tortuga Butte where it intrudes granitic basement and it appears to intrude some of the older Mesozoic mafic and intermediate lava units (**KJm**, and **KJi**). Texturally, and mineralogically, the lava is similar to the **Kr1** unit, and the exposures at La Tortuga Butte are mapped separately only because no age relationship with the tuff of Sharp Peak is preserved. Thin-section sample: F0-746, other samples: WG-82, -113, -116, -117.

**Kr1 rhyolite lava (Cretaceous)** 0-150 meters: Crystal-poor flow-banded and autobrecciated rhyolite lava that underlies the tuff of Sharp Peak. Locally this rhyolite may be partially hypabyssal. The lava contains ~5% phenocrysts of plagioclase (0.5-1.0 mm) and a trace of biotite, but little or no quartz. Samples: WG-41, -42, -62.

**Kr1t rhyolite lithic tuff (Cretaceous)** 0-200 meters: Lapilli, rhyolite lava clast, lithic tuff and tuff breccia. This is a widespread unit in the southwestern part of the study area that is closely associated with several smaller exposures of crystal-poor rhyolite lava and hypabyssal rhyolite of map unit (**Kr1**). The lithic tuffs and tuff breccias are typically thick-bedded to very thick-bedded, but in some areas the unit occurs in massive units thicker than 30 meters. The unit is dominated by thick-bedded, lithic-rich tuff, and the size of the lithic clasts is very consistently within the lapilli range (between 2 and 64 mm). Locally, the bedded tuffs are interbedded with lesser amounts of volcanoclastic, conglomeratic sandstone. The phenocryst assemblage of the ash matrix is identical to that of the lava clasts; a few percent feldspar, but no quartz. The unit has not been dated, but according to Hagstrum et al. (1994), tuff near Bell Mountain from this unit (Sample 2) is a silicic rhyolite and its paleomagnetic polarity is reversed. Thin section samples: F0-515, F0-720, other samples: F0-499, F0-575, WG-5, -6, -43, -46, -125, -126.

**Kcp Confidence Peak Tuff (Cretaceous)** (Sawyer, 1996) 0-50 meters: Crystal-rich (20-30%), quartz (10-15%, 0.5-10.0 mm), plagioclase (10-15%, 0.6-4.0 mm), K-feldspar (2-5%, 0.5-3.0 mm), biotite (1-3%, 0.5-2.0 mm) -phyric, welded ash-flow tuff. K-feldspar phenocrysts are typically perthitic, but in some samples, sanidine may be preserved. The Confidence Peak Tuff can be differentiated from the tuff of Sharp Peak because it is older, because its quartz phenocrysts are much larger (up to 1 cm), and because it contains very abundant biotite phenocrysts. Biotite K/Ar ages of approximately 57 and 59 Ma (Mauger et al., 1965) are too young based on stratigraphic constraints in the Silver Bell Mountains (Sawyer, 1996). Sawyer (1996) indicates a probable age range between 72.7 and 68.6 Ma based on bracketing between "well dated" units. In the Silver Bell Mountains the unit's paleomagnetic polarity is normal (Hagstrum and Sawyer, 1989). Thin-section samples: F0-730; potential Ar/Ar geochronology sample: F0-1077. Thin-section samples from the Waterman Peak quadrangle (Richard et al., 2000): SMR-12-21-99-2, -12-21-3; potential U-Pb geochronology sample from the Waterman Peak quadrangle: F0-1027.

**KJi intermediate composition lava and hypabyssal rocks (Cretaceous-Jurassic):** A heterogeneous suite of plagioclase phyric crystal-poor to moderately crystal-rich (5-25% phenocrysts), dark gray to greenish gray intermediate composition lava, and hypabyssal rocks. Larger bodies of the unit are probably extrusive, and narrow bands of this unit are clearly dikes, but contact relationships are typically vague and poorly preserved. Thin-section samples: F0-610, -736. Other samples: F0-580 -732, -735, -1012, WG-14, -15, -17, -31, -32, -33, -36, -37, -39, -50, -51, -57, -60, -61, -76, -77, -79.

**KJd dacitic dikes (Cretaceous-Jurassic):** Crystal-rich (40-50%) plagioclase (1-3 mm), biotite-phyric, dark reddish brown dikes that intrude the **KJm** and **Kjs** map units in the Aguirre Wash area. Samples: F0-665, -734.

**KJxpu upper crystal-poor tuff (Cretaceous-Jurassic)** 0-100 meters: Pink, crystal-poor (3-7%) quartz (1-2%, 1.0-3.0 mm), plagioclase-phyric (4-5%, 1.0-6.0 mm), K-feldspar (~1%, 2.0-3.0 mm) -phyric, welded ash-flow tuff. This tuff occurs as a relatively gently dipping sheet that appears to unconformably overlie a sequence of older sedimentary rocks (**KJs**), and mafic lava (**KJm**), with thin intervening sheet(s) of crystal-poor tuff (**KJxp**) and

rhyolite tuff (**KJr**). Although it appears to be younger than the **KJxp** unit, there is no area where this relationship can be observed, and the two tuff units may be the same. This tuff and the crystal-poor tuff (**KJxp**) may correlate with one or both of two, thin outflow sheets of crystal-poor, lithophysal, welded tuffs in the western Tucson Mountains (map units Jt, and Jlt of Lipman, 1993), and/or a thin crystal-poor welded tuff in the easternmost Tucson Mountains mapped as the Mission Road Tuff (Phillips, 1976). The tuff may also correlate with a thin tuff or sequence of tuffs mapped by Sawyer (1996) in the southwestern Silver Bell Mountains (unit Mzr). Thin-section sample: F0-578-3.

**KJxp crystal-poor tuff (Cretaceous-Jurassic)** 0-30 meters: Pink or light gray, crystal-poor (3-7%) quartz (1-2%, 0.5-3.0 mm), plagioclase (1-5%, 0.5-6.0 mm), K-feldspar (1-2%, 0.5-3.0 mm), and sparsely biotite (trace, < 1.0 mm) -phyric, welded ash-flow tuff. The tuff(s) is(are) distinctively pumice poor and can be identified most readily by conspicuous, small quartz phenocrysts. The tuff(s) is(are) preserved in two areas and they may represent different outflow sheets in these areas. In the southwest, near Bell Mountain and Sharp Peak, a pink tuff with this phenocryst assemblage occurs near the top of the sedimentary rocks map unit (**KJs**). In the northeast, near Pescadero Mountain, a thin sequence of gray tuff with this phenocryst assemblage occurs within the same sedimentary rock unit (**KJs**) below a pronounced angular unconformity with the tuff of Sharp Peak. Despite the color difference, both of these sequences are correlated with each other. The tuff(s) is(are) similar to two, thin outflow sheets of crystal-poor, lithophysal, welded tuffs in the western Tucson Mountains (map units Jt, and Jlt of Lipman, 1993), and/or a thin crystal-poor welded tuff in the easternmost Tucson Mountains mapped as the Mission Road Tuff (Phillips, 1976). The tuff(s) may also correlate with a thin tuff or sequence of tuffs mapped by Sawyer (1996) in the southwestern Silver Bell Mountains (unit Mzr). Thin-section samples: F0-523, F0-597, and F0-1011; potential Ar/Ar samples: F0-597, F0-1011; potential U-Pb sample: F0-1011; other samples: F0-724, -878.

**KJs sedimentary rocks (Cretaceous-Jurassic)** 0-250 meters: Dark-colored mudstone with thick- to medium-bedded volcanoclastic conglomerate, and thin- to medium-bedded arkosic, argillaceous sandstone and siltstone. The map unit may also include lesser amounts of mafic lava and lava breccia, and the unit is gradational into the **KJm** map unit. Samples: WG-29, -47.

**KJp tuff of San Pedro (Cretaceous-Jurassic)** 0-60 meters: Crystal-rich (20-40%), plagioclase, biotite-phyric, welded ash-flow tuff. This unit is typically dark red, but may be gray in some exposures. The tuff contains up to 35% plagioclase phenocrysts (1-8 mm, average 2-4 mm), and 1-3% biotite (0.5-2.0 mm), but no quartz or K-feldspar. In the southwest, the tuff of San Pedro occurs at the contact between the mafic lava (**KJm**) and sedimentary rocks (**KJs**) map units. In the valley immediately north of Sharp Peak, the westernmost exposure of this unit includes two flow units that may be separated by a thin sequence of sedimentary rocks. The two flow units are virtually indistinguishable except that the base of the upper unit is light gray in color, possibly because it is poorly welded, and it contains about 15-20% phenocrysts. Thin-section samples: F0-524, -525, -998; potential U-Pb geochronology sample: F0-998. Other samples: WG-127, -132.

**KJm mafic lava (Cretaceous-Jurassic)** 0-500 meters: Fine-grained, plagioclase phyric mafic lava interbedded with lesser amounts of dark-colored basaltic conglomerate, arkosic sandstone, mudstone, and argillaceous sandstone. The lava flows of this unit are typically dark gray, and erode easily into subdued hills and pediment surfaces. Plagioclase phenocrysts are typically small (0.5-2.5 mm). Altered equant grains (0.5-1.5 mm) of felted opaque minerals with calcite and chlorite are probably pseudomorphs of olivine and/or pyroxene phenocrysts. Most of the mafic lavas in this map area correlate with the Roadside Formation of Heindl (1965) which was dated at  $66.70 \pm 2.00$  Ma (K/Ar whole rock, Bikerman, 1967) in the central part of the map area. It is possible however, that parts of this map unit may belong to an older unit, the Cocoraque Formation (Heindl, 1965) which was dated at  $111.0 \pm 2.4$  Ma (Bikerman, 1967) in the easterly adjacent Cocoraque Butte 7.5' quadrangle. However, the andesite lava dated in the Cocoraque Butte quadrangle has been interpreted as a plutonic rock (Skotnicki and Pearthree, 2000). Thin-section samples: F0-502, -723, -744; other samples: F0-501, -578-1, -664, -721, -876, -932, -933, -977, WG-7, -8, -9, -10, -12, -16, -18, -30, -55, -69, -78, -80, -81, -133, -136.

**MzPl limestone (Mesozoic-Paleozoic)** 0-50 meters: Medium-bedded, light gray, partially recrystallized, skeletal and pelletal packstone, wackstone, and micrite. This unit is sparingly exposed as a series of three or four small, strike-parallel ribs in a major wash in the extreme southeast corner of section 20, T16S, R9E. The limestone is very resistant, and gives a fetid odor if broken. Argillaceous interbeds if present, are not preserved. Based on the description of Heindl (1965) of some Mesozoic limestone beds in his Roadside Formation, this unit is also possibly Mesozoic in age but the rocks are very similar to some of the younger Paleozoic limestone units in the area. The skeletal grains in one of the beds resemble echinoid spines. Sample: F0-1078.

**JYXg granite (Jurassic-Middle or Early Proterozoic):** Slightly K-spar porphyritic, medium-grained to coarse-grained, leucocratic granite. The granite is intruded by Mesozoic and Mid-Tertiary hypabyssal rocks at Tortuga Butte, and is abundantly represented as clasts in the diamictite unit (**Tsd**), and as xenoliths in the trachyte porphyry of Martina Mountain (**Tz**). The granite may be as old as Early Proterozoic, but is similar in appearance to a major pluton of the Jurassic Ko Vaya super unit (Tosdal et al., 1989) that is exposed in the Baboquivari Mountains (S. Richard, personal communication). Potential U-Pb geochronology sample: WG-137, -138; other sample: F0-928.

### **Plutonic rocks of the Coyote Mountains (footwall of the Ajo Road detachment fault)**

**Tp intrusive porphyry (Tertiary):** Plagioclase porphyritic intermediate composition porphyry. The rock is pervasively altered with limonite stained fractures and white, chalky plagioclase phenocrysts (1-3 mm, 25-40%) in a bleached, light brown, crumbly, fine-grained matrix. The porphyry intrudes footwall rocks directly adjacent to the Ajo Road detachment fault but no evidence of the porphyry intruding hangingwall rocks was observed. The intrusive porphyry may be related to the lamprophyre dikes (**TI**). Sample: F0-980; potential U-Pb geochronology sample: F0-996.

**Tfb fault breccia (Tertiary):** Tectonic breccia along the Ajo Road detachment fault composed of variably calcareous, comminuted, light brownish-colored gouge with small (< 30 cm) angular clasts of quartzite and calc-silicate. In some areas the gouge includes < 20 cm thick bands of dark red to purple fine-grained siliceous rock. The gouge appears to be intruded by dikes and stocks of the **Tp** unit. According to Gardulski (1990), the fault breccia cuts the lamprophyre dikes just to the west of the map area.

**Tl lamprophyre dikes (Tertiary):** Sparse, north-striking dikes of dark-colored plagioclase (2-4 mm) and hornblende (20%, clumps up to 7 mm) porphyritic diorite with abundant biotite in the matrix. The dikes cut all older rocks in the footwall of the Ajo Road detachment fault, and show no evidence of penetrative ductile fabric. These dikes correlate with the lamprophyre dikes of Gardulski (1990) directly to the west of this map area where one of the dikes is truncated by the Ajo Road detachment fault. The lamprophyre dikes may be related to the intrusive porphyry (**Tp**). F0-961, WG-141, -143.

**Tpg pegmatitic granite (Tertiary):** Coarse-grained pegmatitic leucogranite displaying a wide range of textural variation including fine-grained aplite. This unit is part of the Pan Tak Granite, dated at  $58.00 \pm 2.00$  Ma (U-Pb zircon, Wright and Haxel, 1982). The unit forms, tabular, sill-like, northeast-dipping bodies that invade older dioritic rocks. The pegmatite is locally foliated parallel to these intrusive contacts, but it is typically non foliated. The unit is finer grained along intrusive contacts and in narrow dikes that infiltrate the dioritic country rock. Just to the west, the pegmatite also intrudes northeast-dipping tabular masses of quartzite and limestone interpreted to be Paleozoic in age (Gardulski, 1990). Gardulski (1990) reports that intense mylonitic foliation occurs in the pegmatitic granite directly adjacent to the quartzite bodies which are also strongly deformed. Sample: WG-142.

**Mzd diorite (Mesozoic):** Medium- to fine-grained biotite- and/or hornblende-rich (>25%) diorite, quartz diorite, and/or quartz monzodiorite (based on visual estimation of mineral modes only). The diorite is variably foliated to non foliated and may contain a few percent quartz. The diorite is clearly intruded by the pegmatitic granite (Tpg). According to Gardulski (1990), these mafic plutonic rocks (which she divided into three map units: biotite quartz diorite, hornblende diorite, and hornblendite) also intrude tabular bodies of middle and early Paleozoic quartzite and limestone just to the west of this map area. Near the Ajo Road detachment fault the diorite is locally pervasively foliated with a well developed mylonitic fabric, but in most areas, the rock is non to weakly foliated. Oriented samples showing mylonitic fabric: F0-964, F0-976; potential U-Pb geochronology sample: F0-966; other samples: WG-139, -140.