Geology of the Northern Kofa Mountains Owl Head and Northern Third of the Kofa Butte 7.5' Quadrangle, Yuma and La Paz Counties, Arizona v. 2.0

by

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Includes 22 pages of text and a 1:24,000 scale geologic map

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GEOLOGY OF THE NORTHERN KOFA MOUNTAINS (OWL HEAD AND NORTHERN THIRD OF 1'HE KOFA BUTTE 7.5' QUADRANGLE, YUMA AND LA PAZ COUNTIES, ARIZONA

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INTRODUCTION

The Owl Head 7.5' quadrangle and the northern third of its southern neighbor, the Kofa Butte 7.5' quadrangle, represent an 80 mile^2 area of the northern Kofa Mountains, a remote, rugged range of southwest Arizona (Figure 1). The only part of the map area covered by significant amounts of Quaternary alluvium is an 8 mile^2 area in the northwest corner which is part of a narrow, Quaternary or younger Tertiary alluvial-filled valley that separates the Kofa Mountains from the New Water and Plomosa mountains to the north.

Most of the bedrock exposures are Miocence calc-alkaline volcanic rocks of the Kofa volcanic field. They occur in three sequences: a series of outflow sheets of ash-flow tuffs that depositionally overly the crystalline basement rocks, a middle sequence of mafic to intermediate lava flows, and a younger sequence of basalt lavas. The crystalline basement rocks are exposed in the footwall of two major south-side-down normal faults which transect the north-central part of the map area. The basement consists primarily of Mesozoic(?) granitoids which intrude amphibolite-facies, Proterozoic(?), sedimentary rocks to the east. To the west, the granitoid has an indeterminate east-northeast striking contact with low-metamorphic grade argillites of probable Late Mesozoic age which underlie the northwestern peidmont of the Kofa Mountains, and which are probably correlative to extensive areas of similar rocks which make up large areas of the Plomosa Range to the north (Richard and others, 1993).

The study area represents a 20km-wide (normal to strike) northeast-tilt domain in which magnitudes of tilts for the oldest volcanic strata are nearly everywhere at least 45°. It is one of the largest and most consistently oriented tilt domains exposed anywhere in southwestern Arizona. The tilt domain is bounded to the south and north by strike-parallel antiformal and synformal (respectively) boundaries. Along strike to the southeast, an oblique synformal boundary with a steeply southwest-tilted domain is concealed by the younger basalt sequence, and to the northwest, a concealed (by alluvial deposits) transverse boundary with very weakly extended zone occurs. Along a strike-normal cross-section across the widest part of the study area, the total amount of extension is at least 62%. Locally, the oldest part of the Tertiary volcanic pile records magnitudes of extension in excess of 80%.

PHYSIOGRAPHY

Elevations range from under 1800 feet (550 meters) in Alamo Wash to an unamed 3930 foot (1200 meters) peak in the west-central part of the map area. This high point also represents the triple point along the divides between the Rangegrass Plain (northeast), La Posa Plain (west), and Palomas Plain (southeast). Most of the map area lies in the drainage basin of the Palomas Plain, which stands higher than the two northern plains. In many areas a steep north-facing erosional scarp with between one and two hundred meters of relief is present along the divide. To the east the Kofa Mountains merge with the Little Horn Mountains across Red Rock Pass, a low point along the divide between the Palomas Plain on the south and Rangegrass Plain to the north

The map area lies within a fairly arid region of the Sonoran desert with rare occurences of Arizona White Oak in some north-facing canyon bottoms. Most of the area lies within the Kofa Game Refuge which was established primarily as a refuge for Desert Big Horn Sheep in 1939. Because of the area's current Wilderness status, vehicular access is now limited to two north-south roads; the Wilbanks Road through the middle of Owl Head quadrangle, and the Kofa-Manganese Road which runs through Red Rock Pass just to the east of the map area. Despite these access limitations, there is no point within the map area that cannot be reached within 2 hours by walking from the nearest road. The presence of numerous abandoned roads, wide-open washes, and the general open nature of the vegetation make wilderness travel fairly easy.

The Kofa Game Range supports a healthy population of Mule Deer, wild Burros, and Bighorn Sheep. Although no free-flowing creeks exist, numerous seeps, springs, and natural tanks are present.

PREVIOUS AND CONCURRENT STUDIES

Geologic mapping of the study area was undertaken by the authors in the spring of 1994 and 1995 using 1:24,000 scale topographic base maps. The study area was mapped in reconnaisance as part of a USGS Wilderness Survey (Bagby and others, 1987). Shafiqullah and others (1980) reported radiometric dates of a few samples and noted that most of the tilting of the Mid-Tertiary volcanic pile occurred before the youngest mesa-capping basalt flows were erupted. The Cholla Tank and northern third of the Hoodoo Well 7.5' quadrangles which lie directly east of the study area were mapped concurrently by Skotnicki and Ferguson (1995). The New Water Mountains to the north were mapped by Sherrod and others (1990) and adjoining areas of the Plomosa Mountains to the northwest were mapped by Richard and others (1993). To the south, our mapping overlaps slightly with the mapping of Grubensky (1987) and Grubensky and others (1995).

Preliminary results of current investigations by Jim Faulds and Steve Richard of the paleomagnetic properties of regional ash-flow tuffs in southwestern Arizona and southeastern California have helped constrain some of our correlations.

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Discussions with Steve Richard, Jim Faulds, Jon Spencer, and Mike Grubensky concerning logistics and geology of the area are much appreciated. We would like to thank Jim Faulds and Steve Richard for sharing preliminary results of their paleomagnetic studies of regional ash-flow tuffs of the Kofa volcanic field, and acknowledge the Paleomagnetism Laboratory of the Geology Department at the University of Iowa, where the samples were analyzed.

Special thanks go to William C. McIntosh and the $^{40}Ar/^{39}Ar$ lab at New Mexico Institute of Mining and Technology for providing analytical results for a date of the rhyodacite lava unit in the north-central part of the map area.

STRATIGRAPHY

Pre-Tertiary units

Mid-Tertiary volcanic rocks overlie basement rocks of three general lithologies: 1) amphibolite-facies banded gniess and schist of probable Proterozoic age intruded by, 2) granitoid of probable Mesozoic age, and 3) low-metamorphic grade argillaceous sedimentary rocks of probable late Mesozoic age.

Amphibolite-facies banded gneisses and schists of probable Early Proterozoic age occur in a strike-parallel band across the north-central part of the map area. An Early Proterozoic age for these rocks is considered more likely than the Paleozoic age previously assigned to the rocks (Bagby and others, 1987; Reynolds, 1988) because their metamorphic grade is significantly higher than that of the nearby greenschist or lower fades Mesozoic metasedimentary rocks (to the west, north and southeast). The amphibolite facies rocks are polydeformed and were subdivided into two map units: paragneiss or orthogneiss. The paragneiss map unit consists of coarse-grained mica schists or compositionally banded gneiss with abundant biotite-rich melanosomes. Locally, the paragneiss map unit includes thin, intensely folded quartzites. Directly east of Owl Head (approximate UTM: 3704000N, 229000E) the paragneiss map unit consists mostly of varicolored schists, and at one small locality (approximate UTM: 3703800N, 2293 SOE) a light green colored talc or pyrophyllite schist is present.

The amphibolite facies metamorphic rocks are intruded by a medium to fine-grained, equigranular to porphyritic granitoid ranging in composition from granite to diorite, and with an average compositon of quartz monzonite to granodiorite. The plutonic rocks display a wide range of mafic mineral content from a few percent to over 25% and they are typically propyllitized. They also contain, locally abundantly, enclaves of foliated granite or banded quartzofeldspathic gneiss. The intrusive contact with metamorphic rocks in the Owl Head area is nearly horizontal, and since the overlying Tertiary strata in this fault block are tilted nearly 90°, the contact was probably originally vertical.

Low metamorphic grade argillites and psammitic rocks of probable Mesozoic age are exposed in the northeast part of the study area. Unfortunately, exposures are poor and the relationship between these rocks and the Mesozoic granitoid could not be conclusively determined.

Tertiary volcanics

Mid-Tertiary volcanic rocks of the northern Kofa Mountains can be divided into three chronologic sequences: 1) a lower sequence of welded ash-flow tuffs, herein referred to as the Kofa sequence, 2) a middle sequence of lavas, consisting principally of a thick pile of andesitic lavas overlain and intruded by dacite and rhyodacitic lavas, and 3) a younger sequence of basalt lavas. An untilted tuff-ring that apparently overlaps the Tertiary volcanic bedrock in the Ocotillo Mine Group area, is interpreted as a young maar volcano.

<u>The Kofa sequence, definition and correlations</u>

Seven distinctive welded ash-flow tuff outflow sheets are recognized in the northern Kofa Mountains. The six oldest occur in a series of steeply tilted fault blocks in the north-central part of the study area. The entire sequence is referred to as the Kofa sequence, because it consists of units that probably correlate with most of the major ash-flow tuffs known from the Kofa volcanic field and adjacent areas of southeastern California. A reference stratigraphic column (Figure 2) of this sequence was measured through the six oldest units near Owl Head (approximate UTM: 3704000N, 229000E). Regional correlations are based on unit descriptions published in a number of adjacent studies (Richard, 1992a; Richard, 1992b; Richard, 1992c; Grubensky and others, 1993; Ferguson and others, 1994; Grubensky and others, 1995). Preliminary paleomagnetic polarity results reported herein (Jim Faulds, personal communication) helped eliminate some of the possible regional correlations with the numerous welded ash-flow tuffs of southwestern Arizona and southeastern California. Differentiation of the units is difficult, because a phenocryst assemblage of feldspar, minor quartz, and biotite is common to four of the units. A distinctive zonation of phenocrysts in the lowermost (Tk1) unit, and the fact that two of the middle units (Tk2 and Tk3) have distinctive, crystal-poor, mafic mineral-deficient phenocryst assemblages helps considerably.

In the Owl Head area, the Kofa sequence is interrupted by only thin basalt lavas or bedded tuffaceous units. Farther south, along Hoodoo Wash most of the same outflow sheets are exposed, but vertical continuity is lacking due to shallower tilting of the fault blocks, greater thickness of the ash-flow tuff units, and the presence of thick intervening lava sequences. The youngest outflow sheet recognized in the Owl Head area forms the base of the exposed volcanic pile along the west edge and in the southwest corner of the study area, and it is in this area that the youngest welded tuff unit is found. In the southeast corner of the study area three of the older Kofa sequence tuffs; numbers one, three and four are exposed, but there is no evidence of the younger units (number 5 and 6). The number two unit, which may correlate with a unit known in the Tank Mountains nearly 30 km to the southeast, is not present in the southern part of the study area.

In this report, each unit is numbered Tk1 to Tk6 (Tk denotes Tertiary Kofa sequence) from bottom to top and the lowermost unit is locally divided into lower and upper subunits. In the following sections, the units are described, and correlations with units described elsewhere in the Kofa Mountains region are suggested. A name and type section for the oldest unit is also suggested.

Tk1, tuff of Owl Head

The lowermost unit of the Kofa sequence directly overlies granitic basement or is separated from it by a thin bedded tuffaceous and/or conglomeratic unit in the Owl Head area. A new name is proposed for this unit because it is believed to correlate with an unamed unit, recognized previously and called "older tuff" by Grubensky (1987; see also Grubensky and others, 1995) at the base of the volcanic pile in the Hoodoo Well area. The correlation is based on similarity of phenocryst assemblage (particularly the crystal-rich pumice fragments) and its position at the base of the volcanic pile in both areas. A type section is suggested along the ridge directly north of Owl Head, hence the name "tuff of Owl Head".

The tuff of Owl Head is divided into a lower and upper unit by a complex bedded tuff interval. The lower unit, by far the thickest, has normal paleomagnetic polarity (Jim Faulds, personal communication), and is normally zoned with abundant crystal-rich biotite and plagioclase-rich pumice appearing in its upper half Resorbed quartz phenocrysts are abundant in its lower part and they gradually decrease in abundance up-section.

The upper unit of the tuff of Owl Head (Tklu) has a reversed paleomagnetic polarity, and is not as crystal-rich as the lower. It has only been recognized in the northern part of the study area, where it locally consists of five alternating gray to pink-colored flow-units. Phenocryst content ranges between 10% and 15%, with plagioclase being the most abundant phase (constituting at least 85% of the total). Biotite is abundant in all thin-sections, and sanidine is present in amounts ranging from minor (<1%) to 2-3%. The sanidine is most abundant in the pink-colored varieties, where it typically occurs as rims around the larger and more abundant plagioclase, or as small solitary crystals. Plagioclase is typically strongly zoned, and full of inclusions consisting of biotite, opaque minerals or a highly birefringent alteration mineral.

Tk2 (tuff of White Tanks)

The Tk2 unit of the Kofa sequence is correlated with the tuff of White Tanks (Ferguson and others, 1994), because it is the only other crystal-poor, welded tuff without significant amounts of quartz or mafic minerals known from the Kofa volcanic field.

The Tk2 unit (tuff of White Tanks) is a simple cooling unit that is reversely zoned (based on only two thin sections). Phenocryst content ranges from about 7% to 12%. The lower part contains only sanidine phenocrysts, but higher up, inclusion-rich plagioclase is nearly as abundant as the sanidine. Biotite is very rare and was only noted at the top of the unit. The Tk2 unit has not been dated in the study area, but W. C. McIntosh (personal communication) reports $^{39}Ar/^{40}Ar$ sanidine ages of about 23 5 Ma from samples of the tuff of White Tanks at its suggested type locality in the Tank Mountains about 30 km to the southeast.

The Tk2 unit is reverse polarized in the Owl Head area, consistent with the paleomagnetic polarity of the tuff of White Tanks in its type area (Jim Faulds, personal communication).

Tk3 (tuff of Hoodoo Well)

The Tk3 tuff probably correlates with the tuff of Hoodoo Well (Grubensky, 1987; Grubensky and others, 1995) the only other extensive welded tuff know from the Kofa volcanic field with such a distinctive, crystal-poor, mafic mineral deficient, feldspar and large resorbed quartz phenocryst assemblage. The Tk3 unit is a crystal-poor normally zoned welded ash-flow tuff (2% to 7% phenocrysts) with a consistent assemblage of sanidine and resorbed quartz that picks up a few percent of inclusion-rich plagioclase and rare biotite phenocrysts up-section. The overall phenocryst content also increases upward from 2-3% to 7-8%.

Bagby and others (1987) report a sanidine, K-Ar age of 22.3 $\pm$0.4 Ma for the tuff of Hoodoo Well (Tk3 unit) in the extreme southeast comer of the study area. The Tk3 unit is reverse polarized in the Owl Head area (Jim Faulds, personal communication).

Tk4 (tuff of Yaqui Tanks)

Two feldspar, biotite, and sparsely quartz-phyric welded ash-flow tuffs occur above the tuff of Hoodoo Well in the Owl Head area. The two units are correlated with two units previously described by Grubensky and others (1995), the tuff of Yaqui Tanks and tuff of Ten Ewe Mountain. Correlations are based on stratigraphic position and petrographic (phenocryst assemblage) similarities.

In the Owl Head area, the Tk4 unit (tuff of Yaqui Tanks correlative) is light-colored, poorly to moderately welded, and moderatley crystal-poor (5-12% phenocrysts). It is normally zoned (based on only two thin-sections) and consists of at least two and commonly three distinct flow-units, separated by bedded tuff intervals. The lowermost flow-unit contains a phenocryst assemblage of resorbed quartz, sandidine and plagioclase with minor biotite. The plagioclase and sanidine, roughly equal in abundance, commonly occur together with the sanidine typically rimming the plagioclase. This assemblage is gradational between that of the uppermost Tk3 (tuff of Hoodoo Well) and the upper part of the Tk4 unit which is a plagioclase and biotite-bearing tuff with only minor amounts of quartz and sanidine. The upper part is also slightly more crystal-rich than the underlying flow-unit. In terms of paleomagnetic polarity, both of the main flow units of the Tk4 unit are reversed, but with significantly different directions (Jim Faulds, personal communication).

It is possible that the entire Tk3-Tk4 sequence represents a single, but complex, normally-zoned eruptive sequence consisting of numerous stacked cooling units. In support of this hypothesis, the tuffs of Yaqui Tanks and Hoodoo Well are their thickest in the same area of the central Kofa Mountains just to the north of the tuff of Yaqui Tank's source cauldron (Grubensky and Bagby, 1990).

Tk5 (tuff of Ten Ewe Mountain)

The uppermost tuff (Tk5 or tuff of Ten Ewe Mountain correlative) is densely welded, moderately crystal-rich (15-25% phenocrysts) and locally flow-banded. The flow-banding, recognized in the Owl Head, Ocotillo Mine Group, and Wilbanks Cabin areas, consistently plunges steeply down-dip, suggesting flow from or to the southwest, which is towards the tuff of Ten Ewe Mountain's source cauldron in the western Kofa Mountains (Grubensky and Bagby, 1990). The Tk5 unit contains abundant plagioclase (over 90% of the phenocrysts), a few percent amphibole (strongly altered), minor biotite, but only traces of quartz and sanidine. A thin section of the unit from the extreme southwest corner of the study area (sample FY-46) shows that the plagioclase phenocrysts are strongly resorbed and filled with devitrified melt inclusions, a feature that may help distinguish this unit in other areas of the Kofa volcanic field.

The plagioclase phenocrysts from the Tk5 unit in the Owl Head area are almost completely replaced by calcite, and this severe alteration may explain why its paleomagnetic sample site produced an inconsistent data set. At two other locations farther south, the Tk5 unit is normally polarized (Jim Faulds, personal communication).

Tk6 (tuff of Wilbanks Cabin)

In the southwestern corner of the study area, the oldest exposed unit is the tuff of Ten Ewe Mountain (Tk5). The Tk5 unit here is very thick, exceeding a few hundred meters with no exposed base, and it contains several discontinuous dacite to andesite brecciated lava flows that grade laterally into lithic, tuff-matrix mesobreccias. Above the tuff of Ten Ewe Mountain (Tk5), separated by less than 100 meters of andesite lava, a relatively thin, welded tuff with an identical phenocryst assemblage (based on a thin section of sample KM-10) was mapped separately as Tk6. The Tk6 unit, as we have mapped it, correlates with the tuff of Wilbanks Cabin, a thin, mafic mineral-rich, welded tuff described by Grubensky and others (1995) that directly overlies the tuff of Ten Ewe Mountain along the northern margin of the tuff of Ten Ewe Mountain's cauldron.

The Tk6 unit thins rapidly to the east, and includes a prominent flow-unit boundary which gives it a characteristic "two-toned" appearance. The lower package is poorly welded, consists of several flow units, and is tan-colored. The upper package is purplish-gray colored and more densely welded. In terms of regional correlation, the Tk6 unit was initially thought to represent the easternmost limit of the tuff of Felipe Pass, an extensive outflow sheet that blankets much of areas to the west (Trigo, Chocolate, and Middle mountains), and which is characterized in many areas (in particular the Livingston Hills) by having two flow-units. This correlation was based on similarity of phenocryst assemblages, stratigraphic position (uppermost welded tuft), and its "two flow-unit" character. However, the fact that the tuff of Felipe pass has a reversed paleomagnetic polarity and the Tk6 unit of this area has a normal polarity (Jim Faulds, personal communication) makes this correlation impossible.

The similarity of the Tk6 map unit petrographically and paleomagnetically with the tuff of Ten Ewe Mountain suggests that it is probably an uppermost flow-unit of this complex unit.

<u>Middle lava sequence</u>

The middle lava sequence consists mostly of two map units; a regionally extensive, andesite lava-dominated unit called the unit of Red Raven Wash, and a younger sequence of rhyodacite lavas restricted to the north-central part of the study area. A third map unit, basaltic andesite lava (Tba) overlies the rhyodacite lava in the north-central part of the study area.

Unit of Red Raven Wash

The most voluminous volcanic unit in the study area is an andesite-dominated sequence of lavas that overlie and locally interfinger with the upper part of the welded ash-flow tuffs of the Kofa sequence. The flows, varying in composition from basalt to dacite, are commonly separated by relatively thin unwelded tuffs and volcaniclastic sandstones. The unit is named for Red Raven Wash where the lavas attain a thickness of at least three thousand feet (900 meters). In most areas this unit was mapped as generic andesite (Ta), but where possible, flow boundaries where delineated as dashed lines and flows of differing composition were mapped separately. Two types of lavas mapped separately are: dacite (Tad) which is common in the southwest comer of the map area, and basalt (Tab).

Basalt flows (Tab) were mapped as part of the unit of Red Raven Wash only where field relationships showed that the flow was clearly older than those of the "younger basalt" sequence. The two principal field relationships used to assign a basalt flow as being within the unit of Red Raven Wash were: 1) interleaved with andesite lavas, or 2) overlain by the rhyodacite lava (Trd) map unit.

In some areas the andesites of the unit of Red Raven Wash show clear intrusive relationships with the country rock and these rocks were mapped as intrusive andesite (Tai). In some other areas, intrusive relationships are implied, but could not be conclusively determined. One of the most important of these areas is directly north of Wilkinson Seep, where much of the contact between andesite and older rocks is interpreted as intrusive. In particular, the transverse contact just to the west of Alamo Wash is thought to be an intruded fault.

Shafiqullah and others (1980) report a whole-rock K-Ar age of 21.68 ±0.57Ma for a basaltic lava flow from the Ta map unit along Alamo Wash in the northern part of the study area.

Rhyodacite lava

The rhyodacite lava map unit is restricted to the north-central part of the map area where it consists of a series of plugs and flows that occur between the unit of Red Raven Wash and the younger basalt sequence. The lava contains between 5% and 10% phenocrysts of sanidine, quartz, and minor biotite.

Bagby and others (1987) report an age of 20.4 ±0.4 Ma (K-Ar sanidine) from a sample of the rhyodacite lava unit in the vicinity of Alamo Spring. With the assistance of W. C. McIntosh (Table 1, Figure 3) we report a $^{40}Ar/^{39}Ar$ sanidine age of 22.42 ±_ 0.13 Ma from a sample of the same map unit collected farther to the west.

Basaltic andesite lava

The rhyodacite lava is overlain by a basaltic andesite lava that is apparently restricted to a small area directly southwest of Holly Seep. This mafic flow was differentiated from the overlying younger basalt sequence, because its contact with these rocks is an angular unconformity.

<u>Younger basalt sequence</u>

The youngest volcanic rocks in the study area are basalt lavas which cap most of the flat-topped mesas in the central and northern parts of the study area. The lavas occur in stacked sequences of relatively thin flows interbedded with rare reddish sandstones or thin unwelded tuffs. Although most of the flows are horizontal or gently dipping, locally dips up to and greater than 30° occur. The flows also bury significant topography and high-angle fault scarps in a number of areas, the most prominent of which is along the highest ridge of the map area, directly west of Alamo Spring.

Two radiometric dates of this map unit have been reported within the study area. Shafiqullah and others (1980) report a K-Ar whole rock age of 18.31 ±0.42Ma from a basaltic andesite in the northeast corner of the map area, and although the sample location they give is within an alluvial flat, it is assumed that the younger basalt sequence was sampled, because it constitutes the only bedrock in the area. Bagby and others (1987) report a whole rock K-Ar age of 19.9 ±0.4Ma from a basalt flow capping a mesa in the central part of the map area.

Maar volcano

An elliptically shaped ring of bedded, unwelded tuff occurs along Red Raven Wash directly southwest of the Ocotillo Mine Group camp in the west-central part of the study area. The tuffs are medium- to thin-bedded, locally low-angle cross-stratified, and bleached white in color, as if they had been altered. The tuff ring dips radially inward between 10° and 35°, and the tuffs appear to overlap a major, down-to-the-southwest normal fault, along which is concentrated the hydrothermal alteration and mineralization which characterizes the Ocotillo Mine Group mineral district .

The tuff ring is interpreted as the remnants of a young maar volcano. It is believed that the maar was emplaced into water saturated alluvial sediments of Red Raven Wash. It seems probable that phreatomagmatic activity associated with emplacement of the maar and the extensive hydrothermal alteration of rocks along the older normal fault are related.

STRUCTURAL GEOLOGY

Pre-Tertiary structure

Little is known about the Pre-Tertiary structure of the study area except that amphibolite facies metamorphic rocks of probable Proterozoic age were multiply deformed sometime prior to intrusion of a younger (probably Mesozoic) suite of plutonic rocks, and that a sequence of argillaceous sedimentary rocks of probable Mesozoic age were metamorphosed into the lower greenschist facies and deformed prior to an episode of uplift and erosion preceeding emplacement of the Mid-Tertiary volcanic pile. Unfortunately the nature (fault, depositional, or intrusive) of the contact between the Mesozoic granitoid and the Mesozoic metasedimentary rocks is unkown, even though a north-striking contact between the two can be constrained to within only a few meters at three poor exposures about a kilometer east of Jasper Spring.

Tertiary structure

The Mid-Tertiary volcanic pile of the northern Kofa Mountains is dismembered by an extensive set of northwest-striking, southwest-side-down faults. Tilts of the volcanic strata range from a few degrees to vertical and locally overturned. All of the tilting is towards the northeast, and there is a general decrease in the magnitude of the tilts upwards through the volcanic pile, and in the same units towards the south. In the north-central part of the map area, where the entire volcanic pile is exposed, the Kofa sequence dips between 90° and 40°, flows of the middle lava sequence dip between 65° and 25°, and the younger basalt sequence dips between 25° and 0°.

The distribution of rock units and orientation of structural elements within the Pre-Tertiary basement may have had some influence on the orientation of Basin and Range faults. In the Owl Head area, the low-angle synvolcanic faults that cut only lower Kofa sequence ash-flow tuffs may have been localized along planes of weakness in the underlying crystalline basement. The basement in this area consists of mica-rich banded gneisses intruded by a granodiorite of probable Mesozoic age, and the contact in many areas is nearly horizontal and northwest-striking. The contact between granitoid and gniess just to the east of Owl Head is nearly parallel to the fault planes which cut the basal-Tertiary unconformity, and although the contact was mapped as intrusive, it is possible that these kinds of discontinuities may have localized some of the Tertiary faults in this and other nearby areas.

Syn-volcanic structures

The oldest evidence of syn-volcanic tectonic activity in the map area involves dramatic thickening of the Tk1 map unit (tuff of Owl Head) across faults or fault zones in two widely separated regions of the map area. Along the ridge directly southeast of Owl Head, a south-side-down fault cutting the Tk1 unit (tuff of Owl Head) is depostionally overlain by the tuff of Hoodoo Well (Tk3). The tuff of Owl Head (Tk1) thickens from 0 to nearly 100 meters from footwall to hangingwall (north to south) across this fault.

In the southeast corner of the study area there is evidence of even greater south-side-down synvolcanic offset with respect to the Tk1 unit. Evidence of south-side-down faulting, which is best shown in the southwest corner of the adjacent map area (see Skotnicki and Ferguson, 1995), occurs across Hoodoo Wash in the vicinity of Hoodoo Well. In this area, horizontal to gently-dipping outflow facies tuff of Hoodoo Well occurs at essentially the same level on both sides of the Wash. However, to the north the tuff overlies crystalline basement, and to the south it overlies a "bottomless" (at least 300 meters thick) sequence of the tuff of Owl Head (Tk1). This stucture may represent a northern cauldron margin for the tuff of Owl Head, and in support of this interpretation, lithic mesobreccias within tuff of Owl Head occur along the south side of Hoodoo Wash.

Numerous, closely-spaced, nearly horizontal, normal faults dismember the Kofa sequence tuffs in a long strip between Owl Head (approximate UTM: 3704000N, 229000E) and the Four Peaks area (approximate UTM: 3705500N, 226000E). Although some of these faults clearly cut the entire Kofa sequence, many of the faults are erosionally truncated at the base of the tuff of Hoodoo Well (Tk3), and this constrains a fairly narrow time interval for motion along these faults. In addition to truncating faults, the tuff of Hoodoo Well also overlies some older tuffs with angular discordance in at least one other area (eg. see its basal contact near Four Peaks Dam).

In the southern part of the study area, there is a profound change in the stratigraphy of the Kofa sequence from west to east. To the west of a transverse boundary through the middle of the study area, andesite lavas of the unit of Red Raven Wash overlie and interfinger with the youngest units of the Kofa sequence (Tk5 and Tk6), but to the east only older units (Tk3, Tk1, and rarely Tk4) are preserved. The transverse boundary may continue to the south of the map area where it corresponds roughly with the northeast-striking boundary between the cauldrons for the tuff of Ten Ewe Mountain (Tk5) and the tuff of Yaqui Tanks (Tk4) along the southwestern edge of the Kofa Mountains (Grubensky and others, 1995; Grubensky and Bagby, 1990). To the north, the transverse boundary strikes into a complex transverse structural zone in the Owl Head area.

Basin and Range style regional extension

Fault geometries

There are at least three generations of normal faults in the study area. Each generation can be dated by the age of volcanic strata they cut. The oldest generation cut only strata of the Kofa sequence and some of these are overlain by the tuff of Hoodoo

Well (Tk3). Although some of these faults may be related to formation of volcanic depressions such as the south-side-down, syn-volcanic (Tk1) fault in Hoodoo Wash, most of these are believed to be the result of regional extension. The oldest generation of faults dip very gently to the southwest (less than 30°) or they are horizontal to overturned. The oldest generation of faults are only recognized in the northern part of the study area, and in several areas they are intruded by probable feeder dikes for the rhyodacite lavas of the middle lava sequence.

The second generation of faults are the most widespread, and they accomodate most of the extension recorded in the study area. These faults are moderately southwest-dipping (30° to 60°) and they cut units as young as the youngest flows of the middle lava sequence. One of the most prominent of these faults hosts the Ocotillo Mine Group mineralized veins and is herein named the Ocotillo Mine Group fault. In order to to keep the Ta map unit from attaining unreasonable thicknesses, five conjectural (not shown on the map) second generation faults were added to the structural cross-section south of the Jasper Spring-Wilkinson Seep fault. The bedding-fault plane angles (which influences the total extension calculation) for these faults were assumed to be between 70° to 85°, consistent with angles known for other second generation faults mapped in this area.

Faults of the youngest generation cut all volcanic units of the study area (except the maar tuffs in Red Raven Wash). These faults are steeply dipping (greater than 60°) and they occur in three general zones. The first is the principal fault of the youngest generation, herein named the Jasper Spring-Wilkinson Seep fault which has a south-side-down offset of at least 600 meters (2000 feet) where it cuts across the study area parallel to regional strike. Along the eastern edge of the map area, the Jasper Spring-Wilkinson Seep fault curves sharply southward and appears to loose displacement as it runs underneath alluvium of the Palomas Plain. The second zone is along the high-standing ridge in the west-central part of the study area. The ridge is cut by several oppositely-dipping, steep faults that were apparently active during eruption of the younger basalt sequence. These faults appear to represent a zone of antithetic faulting in relation to the Jasper Spring-Wilkinson Seep fault. Faults of the youngest generation may exist farther south (a possible example is the steeply dipping fault near the south end of the structural cross-section) but because the younger basalts are not preserved in this area it is not possible, at this time, to conclusively classify all of the faults in the southern part of the study area. In the northeast, a number of steeply dipping faults with relatively minor offsets cut the mesa-capping younger basalts.

Magnitude of extension

The northern Kofa Mountains represent a 20km-wide (normal to strike) northeast-tilt domain in which magnitudes of tilts for the oldest volcanic strata are nearly everywhere at least 45°. Along a strike-normal cross-section across the widest part of the study area, the total amount of extension was calculated at 62%. A present day strike-normal length of 18.27 km along cross-section A-A' restores to 11.29 km during deposition of the Kofa sequence. Total extension was calculated using the base of the middle lava sequence as datum for areas south of the Jasper Spring-Wilkinson Seep fault, and the base of the Kofa sequence for areas to the north of this major fault. Note that the total amount of extension could be lesser or greater depending on the dip of five conjectured second generation faults in the southern half of the study area. If these faults dip shallower than depicted, the total extension would increase slightly. If they do not exist, the total extension would decrease slightly, but this would double the know thickness of the Ta map unit to over 1.5km.

Based on assumptions discussed in the preceding paragraph, the estimate of 62% total extension is actually a minimum. This is because the Kofa sequence records higher magnitudes of tilting than the middle lava sequence north of the Jasper Spring-Wilkinson Seep fault, and there is a fairly broad area between the Jasper Spring-Wilkinson Seep fault and Ocotillo Mine Group fault where only the middle lava sequence is exposed. Consequently, any extension that the Kofa sequence may have experienced prior to emplacement of the middle lava sequence in this concealed area is indeterminate. In the southern part of the study area, the middle lava sequence and the underlying Kofa sequence are conformable, and they record similar magnitudes of extension. Somewhere between the Ocotillo Mine Group fault and the Jasper Spring-Wilkinson Seep fault, the contact between the Kofa sequence and the middle lava sequence becomes an angular unconformity. It is not know if this transition is gradual or abrupt, but a likely zone for this change might be along the zone of northeast-dipping steep faults that cut the highest ridge crest. The north-dipping faults of this zone may be reactivated along a hypothetical north-dipping break-away fault that could have bounded the southwestern edge of a zone of extension that is known to have been active prior to eruption of the middle lava sequence.

Tilt domain boundaries

In reference to Tertiary strata, the northern Kofa Mountains northeast-tilted domain is one of the largest and most consistently oriented tilt domains exposed anywhere in southwestern Arizona. To the south, tilts decrease gradually towards an east-west striking antiformal boundary which corresponds roughly with the crest of the main Kofa Mountains (Grubensky and Bagby, 1990). This antiformal boundary is the northernmost of a series of alternating, strike-parallel, antiformal and synformal boundaries in a weakly extended zone that extends from the central Kofa Mountains through the Tank Mountains to the central Palomas Mountains. Along the north edge of the study area a strike-parallel, synformal boundary can be drawn through the broad valley that separates the Kofa and New Water mountains. To the northwest and west a poorly defined transverse boundary with a zone of very weakly extended Tertiary strata in the westernmost Kofa Mountains, Livingston Hills and Plomosa Mountains exists. Along strike to the southeast, tilts of the oldest Tertiary strata change fairly abruptly to steeply southwest (Skotnicki and Ferguson, 1995), but the nature of this change is concealed by the younger basalt lava sequence, and it is tenatively interpreted as an oblique synformal boundary.

Timing of extension

It has been recognized for some time that the volcanic strata of the northern Kofa Mountains record differing amounts of extension, and for this reason dating of the volcanic strata is critcal (eg. Shafiqullah and others, 1980). Each of the three progressively older volcanic sequences mentioned by Shafiqullah and others (1980) and described in detail during this study have clearly been affected by greater amounts of tilting. In the northern third of the study area the oldest part of the volcanic pile, the Kofa sequence, has been extended at least 71%. South of the Jasper Spring-Wilkinson Seep fault, the middle lava sequence was extended about 58% and the underlying Kofa sequence was extended at least as much. The younger basalt lava sequence throughout the study area has only been weakly extended (less than 5%).

The younger basalt sequence has been dated at just under 20 Ma (Bagby and others, 1987), and the rhyodacite lava unit of the middle lava sequence dated, using the high-precision, sanidine $^{40}Ar/^{39}Ar$ technique, at 22.42 ±0.13 Ma. Shafiqullah and others (1980) report a K-Ar biotite age of 23.60 ±0.62 Ma for the steeply tilted tuffs of the Kofa sequence, but the location of their sample is suspect; it lies within an outcrop of the rhyodacite lava (a unit of the middle lava sequence). The age they report, however, is in agreement with several new precise $^{40}Ar/^{39}Ar$ sanidine ages of about 23.5 Ma (McIntosh, personal communication) for several regional ash-flow tuff units from other areas of the Kofa volcanic field which almost certainly correlate with outflow sheets of the Kofa sequence. The episode of extension recorded by the Kofa sequence and the overlying middle lava sequence of this study area was fairly rapid, occuring during a less than 4 million year span of the early Miocene.

MINERALIZATION

There are a number of mineralized zones in the study area, all of which have been heavily prospected or actively mined.

Ocotillo Mine Group

The principal mining district occurs along a major northeast-side-down fault in the west-central part of the study area. This area, referred to as the Ocotillo Mine Group, is described by Wilson (1933) who visited the area while it was still marginally active. Most of the workings in the area are inclined shafts following the main Ocotillo Mine Group fault zone, and this is indeed how most of the structural attitudes for this fault were obtained. All of the rocks along the fault zone are strongly silicified, bleached and locally injected with calcite veins.

Owl Head area and granite propyllitic zone

A number of pospect pits and at least one developed mine shaft occur within the Mesozoic and probable Proterozoic crystalline rocks between Owl Head and the eastern edge of the map area near Red Rock Pass. The developed mine shaft is within a heavily propyllitized zone of the Mesozoic granitoid (approximate UTM: 3700900N, 232350£). Numerous pits and small shafts and adits occur within the amphibolite facies metamorphic rocks throughout the area, and the styles of mineralization are highly variable. For the most part the mineralized zones occur along concordant, quartz-rich veins or segregations, locally with concentrations of sulphide minerals. One of the easternmost pits occurs in a soft, light-green colored mica schist which was apparently prospected for the soft green mineral which is probably porophyllite or talc.

Midas Mine

The Midas Mine is a close grouping of prospects located in Mesozoic granite adjacent to the Jasper Spring-Wilkinson Seep fault which juxtaposes the granite with Tertiary volcanic rocks in the northwest part of the study area. Five shafts/deep pits are visible, all apparently dug into granite immediately north of the fault. At least two were dug through a shallow layer (about 1 meter) of alluvium. One shaft is inclined (with timbers in place at the top) and follows a fracture zone filled with chrysocola-hematite-quartz. The zone has fractures with an attitude of about N55E, 70W.

Southeast prospects

A prospect indicated on the Kofa Butte 7.5' quadrangle map in the southeast corner of the study area exposes two parallel, gray, carbonate veins filling a fault zone. The large vein is 0.5 m thick, and the smaller is between 10-20 cm thick. Both trend about N70W, 49S. A 5 ft-deep trench affords a good veiw of these veins.

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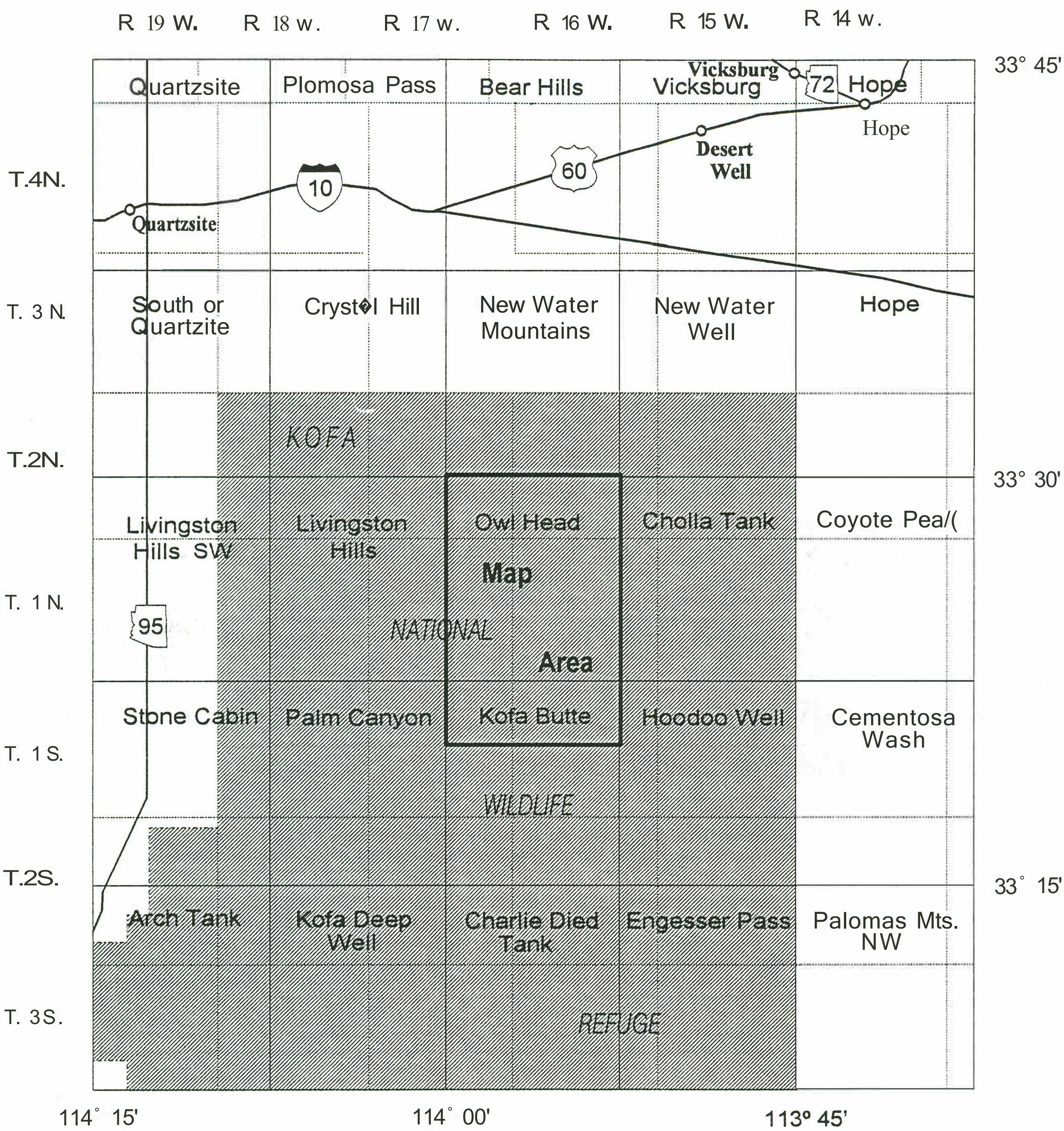

Figure 1. Location of the study area.

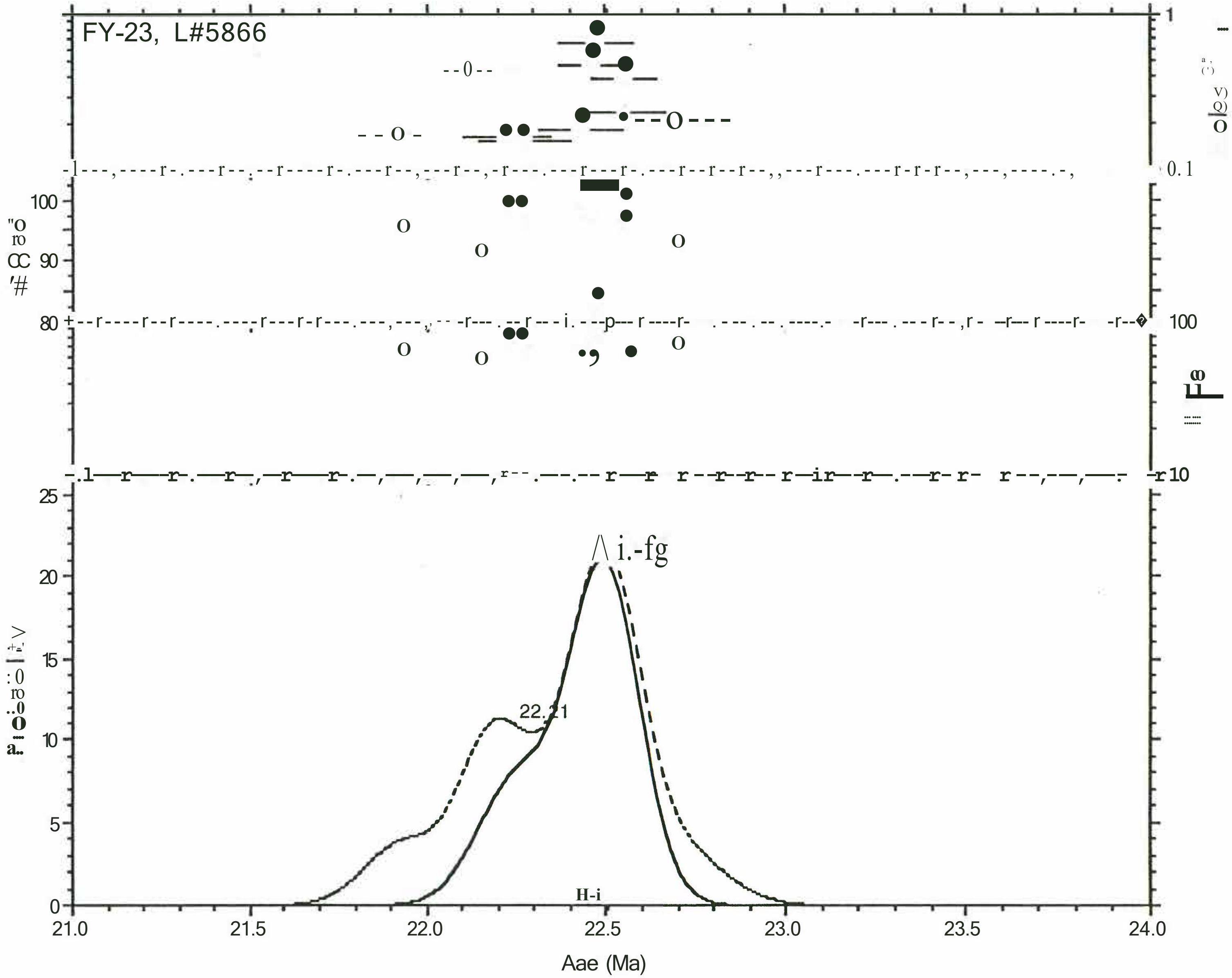

Figure 3. Graphical representation of analytical data for each sanidine crystal, $^{39}Ar/^{40}Ar$ analysis of sample FY-23. Figure courtesy W. C. McIntosh, New Mexico Bureau of Mines and Mineral Resources, Socorro. Solid dots represent crystals used to calculate age of 22.42 ±0.13 Ma.

Run ID#	40/39	37/39	36/39	39K moles	K/Ca	%40*	Age	± Err	SEM
FY-23 Q1 :41, APE,	**J=0.001445443+0.000002**								
5866-05	*8.87*	*7.83E-03*	*1.37E-03*	*1.1E-15*	*65.2*	*95.4*	*21.934*	*0.107*	
5866-10	*9.35*	*8.83E-03*	*2.71E-03*	*4.4E-15*	*57.8*	*91.4*	*22.155*	*0.082*	
5866-09	8.73	7.00E-03	5.08E-04	1.6E-15	72.9	98.3	22.224	0.105	
5866-08	8.90	7.84E-03	1.05E-03	1.5E-15	65.1	96.5	22.275	0.107	
5866-06	8.84	7.72E-03	6.31 E-04	1.8E-15	66.0	97.9	22.432	0.097	
5866-02	8.83	7.25E-03	5.62E-04	4.7E-15	70.3	98.1	22.461	0.070	
5866-04	10.48	6.66E-03	6.12E-03	6.5E-15	76.6	82.7	22.473	0.087	
5866-01	8.77	7.73E-03	2.40E-04	3.9E-15	66.0	99.2	22.551	0.072	
5866-07	9.13	7.95E-03	1.46E-03	2.3E-15	64.2	95.3	22.551	0.096	
5866-03	*9.42*	*7.17E-03*	*2.25E-03*	*2.0E-15*	*71.1*	*93.0*	*22.702*	*0.126*	
			mean	n=7	68.7	4.7	22.424	0.128	0.048

Tabl 1. ^{39}Ar/^{40} analytical data for each sanidine crystal from sample FY-23. Table courtesy W. C. McIntosh, New Mexico Bureau of Mines and Mineral Resources, Socorro. Data in *italics* excluded in calculation of age.

UNIT DESCRIPTIONS
FOR THE OWL HEAD AND NORTHERN
KOFA BUTTE 7.5' QUADRANGLES

ARIZONA GEOLOGICAL SURVEY
OPEN-FILE REPORT 96-3

QUATERNARY

Qa, Qao, Qt Alluvium, older alluvium, and talus: Surficial deposits of unconsolidated to poorly consolidated alluvium (Qa), and partially lithified, older alluvium (Qao). Younger alluvium (Qa) locally includes tongues of talus along steep mountain sides, and in some areas talus deposists were mapped separately as Qt. The older alluvium along Red Raven Wash near the head of Palomas Plain probably represents abandoned channels of ancestral Red Raven Wash and locally, semiconsolidated sandstone and pebbly sandstones are found near the base of these outcrop areas. Older alluvium in northwest comer of the quadrangle forms relatively high-standing buttes and hills.

TERTIARY

Ttm maar tuff: unwelded, low-angle cross-stratified to parallel-bedded, and massive, thin to medium-bedded, bleached, ash-fall tuff, ash-flow tuff and surge deposits. The *tufts* form an approximately 1 km-diarneter, inwardly dipping ring, the center of which is filled with alluvium. The *tufts* and the ring they form are interpreted as the remnants of a maar volcano.

Tby Younger basalt lava: Moderately crystal-rich olivine and pyroxene bearing basalt with abundant plagioclase phenocrysts. Unit consists of numerous thin flows accumulating to a thickness of over 200 meters in some areas. The uppermost lava flows locally overlap high-angle faults which truncate older flows of the same map unit. Shafiqullah and others (1980) report a K-Ar whole rock age of 18.31 ± 0.42Ma from a basaltic andesite in the northeast comer of the map area. Bagby and others (1987) report a whole rock K-Ar age of 19.9 ± 0.4Ma from a basalt flow capping a mesa in the central part of the map area.

Tba basaltic andesite: A crystal-poor, red-weathering, thin mafic lava flow that directly overlies the Trd lava. This lava is similar in appearance to some of the flows of the Thy unit, and it is differentiated from these only where flows of this variety are disrupted by moderately-dipping normal faults which are in tum overlapped by basal flows of the Thy unit.

Trd Rhyodacite lava: A moderately crystal-poor, quartz, feldspar, and biotite-bearing felsic lava displaying a wide variety of megascopic textures. The three principal morphologic types of lava are: crystalline-matrix flow-banded, vitric flow-banded, and vitric auto-breccia. A K-Ar sanidine age of 20.4±0.4Ma (Bagby and others (1987), and an $^{39}Ar/^{40}Ar$ sanidine age of 22.42±0.13Ma (McIntosh, personal communication) have been reported for this unit.

Ta, Tab, Tad, Tat, Tas, Tai Unit of Red Raven Wash: A composite unit oflavas which may exceed 300 meters in some areas. It is dominated by flows of andesitic composition, most commonly a plagioclase-rich, pyroxene, and arnphibole-bearing andesite with 10-25% phenocrysts. Fine-grained, crystal-poor basaltic andesites, olivine and pyroxene bearing basalts, and biotite-bearing dacitic lavas are also present. The andesite lavas and all undifferentiated lavas of this unit are shown as **Ta.** In some areas individual lava flows were differentiated as Tab-basalt to basaltic andesite, or Tad-dacite. Lavas of this unit are also interbedded with thin (less than 20 meter-thick) lithic-rich, unwelded, bedded *tufts* **(Tat),** and sandstones or pebbly sandstones **(Tas).** To the west, lavas of this unit are interbedded with west-thickening, welded ash-flow tuffs of the Tk5 unit. In some areas, in particular in the Ocotillo Mine Group area and areas directly east of the study area, andesites of this composition show clear intrusive relationships with the country rock. These intrusive rocks were mapped as **Tai.**

Tbi intrusive basaltic rocks: One small sill of gabbroic rock that intrudes the crystalline basement-Kofa sequence contact in the northeast corner of the map area.

Tb older basalt: Olivine, pyroxene-bearing basalt lava flows interbedded with the ash-flow tuffs of the Kofa Sequence.

Tt, Ts Unwelded tuff (Tt), volcaniclastic sedimentary rocks (Ts): Generic, unwelded, bedded and typically lithic-rich tuffaceous rocks interpreted as (in decreasing order of abundance) ash-flow tuffs, subaerial ash-fall tuffs, volcaniclastic sandstone (locally eolian), or surge units. This generic unit occurs within and between volcanic units throughout the map area.

Tk Kofa sequence, undifferentiated: The Kofa sequence is a succession of at least 6, and probably 7 welded ash-flow tuffs separated by bedded tuffaceous sequences (both pyroclastic and epiclastic), and lava flows. Most, if not all, of these tuffs can be correlated with other welded ash-flow tuffs that have been described in the Kofa Mountains region. Most of the welded tuffs can be identified by their phenocryst assemblage, and the sequence can usually be broken into its individual units. Unfortunately, the phenocryst assemblage of feldspar, manor quartz with relatively abundant biotite and hornblende is fairly common, and the distinguishing phenocryst abundances and ratios are subtle enough that severly altered or areally limited exposures of these tuffs may not be assignable to individual units.

Tku upper Kofa Sequence: Undifferentiated ash-flow tuffs of the Kofa sequence, which are believed to overlie, its most distinct unit, the tuff of Hoodoo Well.

KOFA SEQUENCE, UNIT DESCRIPTIONS

Tk6 tuff of Wilbanks Cabin: Moderately crystal-rich, welded tuff that occurs between andesititc lava flows in the lower part of the unit of Red Raven Wash along the western edge of the map area. The tuff contains phenocrysts of melt inclusion-rich plagioclase, abundant biotite, and hornblende and very little or no quartz. Throughout the map area, the tuff occurs in two subdivisions defined by welding characteristics and coloration. No mineralogical zonation has been recognized (yet). The lower subsivision is poorly welded, light-colored (yellowish to tan) and consists of numerous flow-breaks, giving it a bedded appearance. The upper zone is densely welded, locally flow-banded, massive, and purplish gray in color. The unit is correlated with the tuff of Wilbanks Cabin (Grubensky and others, 1995), and it is normally polarized (Jim Faulds, personal communication).

TkS tuff of Ten Ewe Mountain: A moderately crystal-poor to moderately crystal-rich (5-10% to 15-20%), densely welded, locally flow-banded ash-flow tuff containing phenocrysts of melt inclusion-rich plagioclase, and very abundant (up to 1-2%) biotite, and hornblende. The tuff is characteristically grayish-purple in color, and its pumice fragments commonly display evidence of axiolitic devitrification textures. The only discernible zonation of this tuff is a general upwards increase in phenocryst content, and it is normally polarized (Jim Faulds, personal communication).

Tk4 tuff of **Yaqui Tanks:** A moderately crystal-poor to moderately crystal-rich, feldspar, quartz, biotite-bearing, poorly to moderately welded ash-flow tuff. This tuff is characteristically light-colored, recessive-weathering (because of its poorly welded nature), and its pumice fragments are small (less than 10 cm long) and typically greenish in color. The tuff consists of at least two, and locally three, welded flow units separated by 1 to 5 meter-thick, unwelded, bedded tuff intervals throughout much of the Alamo Wash area. The unit as a whole is normally zoned with the lower flow unit containing nearly equal amounts of resorbed quartz, plagioclase,and sanidine phenocrysts, and the upper containing mostly plagioclase, and more abundant biotite. The unit is reverse polarized (Jim Faulds, personal communication).

Tk3 tuff of Hoodoo Well: A crystal-poor, pumice-poor, vertically zoned, sanidine, plagioclase, and large resorbed quartz phenocryst-bearing tuff with a very sparse population of ma:fic phenocrysts. The unit is vertically zoned from only a few percent phenocrysts and pumice near its base to 5% to 10% phenocrysts, and up to 10-15% pumice near its top. The unit is normally zoned with lower parts containing very little plagioclase and virtually no ma:fic minerals and the upper parts containing plagioclase and sanidine in nearly equal proportions. Resorbed quartz phenocrysts are abundant and ubiquitous throughout and rare ma:fic minerals are present only near the top. The tuff is characteristically light-gray or pink-colored on fresh surfaces, massive and red-colored in outcrop, and typically high-standing relative to adjacent units. The more densely welded portion typically has a mottled appearance due to the presence of spherulites, many of which grow around phenocrysts. The unit is reverse polarized (Jim Faulds, personal communication).

Tk2 tuff of White Tanks?: A welded tuff that occurs between the tuff of Owl Head and tuff of Hoodoo Well in the Alamo Wash area. In many areas it is separated from these two tuffs by thin basalt lava flows and/or bedded tuffaceous sequences. The tuff is normally zoned from very crystal-poor at the base to moderately crystal-poor at the top, and its phenocryst assemblage changes from all sanidine at the base to a mixture of sanidine and plagioclase near the top. The tuff is easily distinguished from the overlying tuff of Hoodoo Well (Yk3) because it contains only traces or minor amounts of quartz, and a very sparse population of ma:fic minerals distinguishes it from the other welded tuffs. An upwards increase in biotite, from virtually absent to trace amounts, occurs at the top of some sections. In the Alamo Wash area the densely welded upper portion is typically dark reddish-brown colored with a mottled appearance due to the presence of cm-scale spherulites, and it contains abundant elliptical, lithopysal cavaties up to 10 cm long. Tk2 is tenatively correlated with the tuff of White Tanks (Ferguson and others, 1994), a poorly to moderately welded tuff with a similar phenocryst assemblage. The unit is reverse polarized (Jim Faulds, personal communication).

Tklu upper tuff of Owl **Head:** A moderately crystal-rich (10-20%) feldspar (mostly plagioclase), sparse quartz, biotite and hornblende-bearing, welded ash-flow tuff. The tuff is separated from the lower tuff of Owl Head by a fairly thick (several meters) sequence of bedded tuffs, and from Tk2 by a 2-5 meter-thick, dark-colored, bedded tuffaceous sequence. This unit is differentiated only in the Four Peaks Dam area, and in a small area directly north of Owl Head. The unit is reverse polarized (Jim Faulds, personal communication).

Tkl tuff of Owl Head: A moderately crystal-rich (15%) to crystal-rich (30-40%), normally zoned, welded ash-flow tuff. The phenocryst assemblage of feldspar (mostly plagioclase), quartz, and biotite changes from a quartz-rich, biotite-poor assemblage at the base to a quartz-poor, plagioclase and biotite-rich assemblage at the top. The appearance of very crystal-rich, plagioclase and biotite-bearing, dark-colored pumice in the upper half of the unit is also fairly diagnostic. Near its type locality at Owl Head, the welded tuff overlies a bedded tuff and volcaniclastic sandstone or cobbly sandstone sequence up to 15 meters thick, and the welded portion is capped by a complex, bedded, subaerial ash-fall tuff sequence. The outflow sequence in the Owl Head area ranges from Oto 75 meters thick. In the Hoodoo Well area (Hoodoo Well and Kofa Butte 7.5' quadrangles), tuff of Owl Head fills a volcano-tectonic depression where it is at least 300 meters thick with no exposed base, suggesting that this area lies within its source cauldron. The tuff in this area grades upward from a moderately to densely welded, quartz-poor, plagioclase and biotite-rich sequence with numerous prominent and sharp flow-breaks to a sequence dominated by medium-bedded ash-fall tuffs overlain by a basalt lava. The breaks are expressed as recessive zones and are interpreted as basal 2a layers. Normally polarized (Jim Faulds, personal communication).

Td dacite porphyry: Irregular-shaped intrusive bodies, locally flow-banded, of porphyriticdacite containing about 25% phenocrysts of feldspar (mostly plagioclase), biotite, and hornblende. The bodies commonly intrude along low-angle normal faults that cut the Kofa sequence east of Alamo Wash.

Tf felsic lava: A felsic lava or intrusive body mapped only in the extreme southeast comer of the map area.

MESOZOIC

Ms sedimentary rocks: Undifferentiated dark greenish gray colored, low-metamorphic-grade sedimentary rocks consisting mostly of argillite with rare sandy and silty intervals.

Ma amphibolite: Unfoliated amphibolite dikes

Mg granitoid: Medium to fine-grained, equigranular to porphyritic granitoid(s) ranging in composition from granite to diorite, and with an average compositon of quartz monzonite or granodiorite. The granitoids display a wide range of mafic mineral content from a few percent to over 25% and they are typically propyllitized. They also contain, locally abundantly, enclaves of foliated granite or banded quartzofeldspathic gneiss.

PROTEROZOIC

Xo banded orthogneiss: Compositionally banded quartzofeldspathic gneiss with melanosome generally constituting less than 30% of the rock. These gneisses are tenatively interpreted as igneous in origin.

Xp banded paragneiss, coarse-grained schist: Banded gneisses and coarse-grained biotite and/or amphibole-rich schists interpreted to have had a sedimentary or mafic volcanic precurssor, because of their relatively high (greater than 30%) percentage of melanosome. In the Owl Head area the map unit also consists of banded calc-silicate schists, amphibolitic schists or gneisses and a thin band of light green (pyrophyllite or talc-bearing) schist.

Xq quartzite: Massive, but relatively thin (less than 10 meters wide) band of quartzite within the paragneiss unit about 3 km southeast of Owl Head.