GEOLOGY OF THE MORMON FLAT DAM QUADRANGLE, MARICOPA COUNTY, ARIZONA

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INTRODUCTION

The geology of the Mormon Flat Dam Quadrangle is dominated by a thick succession of Miocene volcanic rocks, and by the consequences of two important structural events: 1) formation of the Superstition Cauldron at approximately 18.6 Ma (McIntosh, personal communication, Ferguson and others, in preparation), and 2) regional extension which was active for a short period of time directly before, during, and after eruption of the Apache Leap Tuff. The Tertiary stratigraphy consists of three broadly defined sequences: 1) pre-cauldron lavas, 2) syn-cauldron units - chiefly Apache Leap Tuff, and 3) post-cauldron lavas, intrusions and volcaniclastic sedimentary rocks.

Regional extensional tectonism was active over a broad area south of the Salt River Canyon during formation of the pre-cauldron lava field (between approximately 20.5 Ma and 18.6 Ma), and then for a short time after cauldron formation, along a narrower zone along the Salt River. Areas lying to the north of Salt River remained relatively stable and unextended throughout the history of the volcanic field.

Methods

Geologic mapping was done during the fall, winter, and spring of 1996-1997. The area's topography is dominated by the Salt River which flows east to west across the middle of the map area. Several major canyons flow into the Salt River from highlands to the south (Superstition Mountains) and north (Mazatzal Mountains). Access to country south of Salt River is provided by State Highway 88 (The Apache Trial) which provides access to trail heads leading southward into the Superstition Wilderness (Figures 1, 2). Saguaro Lake and Canyon Lake are manmade reservoirs that occupy Salt River Canyon within the map area, and Apache Lake lies just upstream in the easterly adjacent Horse Mesa Dam quadrangle. Access to areas north of Salt River is provided by a network of forest roads from the northwest, reached from State Highway 87 (the Bush Highway), and by crossing Salt River using boats available from commercial outfitters at Saguaro, Canyon and Apache lakes.

Mapping silicic lavas

Most of the area's map units are silicic lava flows. The flows display a wide variety of textures related to how the lava was emplaced, and varying degrees of devitrification related chiefly to how the lava cooled and interacted with meteoric fluids. The flows may change appearance radically over short distances from massive flow-banded to lithophysal-microcrystalline to autobreccia and all of these variations may display the complete range of vitric preservation from black obsidian to white devitrified. We considered these variations in flow-related textures and devitrification as secondary in importance in terms of defining map units. We defined lava units based on phenocryst mineralogy only, and consequently our lava map units display a wide variety of flow-morphologies and degrees of devitrification which may appear inconsistent to the casual reviewer. We believe that by sticking to purely mineralogical criteria, our units have a better chance of representing chronostratigraphic units.

Almost all previous workers in the study area mapped large areas of massive devitrified lava as tuff, particularly in the First Water Creek and Boulder Canyon areas. We also did this to some degree but we endeavored to differentiate between these rocks. We found that it is often easier to differentiate between lava and tuff from a distance, and that in almost all cases, the unwelded tuffs are obviously bedded, and the devitrified lavas, although similar in appearance even at outcrop scale, are massive. At the outcrop, dark-colored, irregularly-shaped, centimeter-scale, spherulitic growths which are ubiquitous in the devitrified high-silica lava flows

are very difficult to differentiate from lithic clasts suspended in a massive lithic tuff. Important distinguishing characteristics of the devitrified autobreccias are outlines of the blocks of lava, and lack of pumice in the autoclastic matrix.

Because of their close genetic and chronostratigraphic relationship to the lava flows, many clast-supported, block and ash-flow deposits were included as part of lava flows. These block and ash-flow deposits are very similar in appearance and are commonly contiguous with the abundant autobreccias that are ubiquitous in association with the silicic lava flows. In some areas, particularly on cliff faces, basal autobreccias are crudely bedded, forming angle of repose foresets up to 50 meters thick that dip in the direction of flow. We call these autobreccias flow-front, foreset avalanche breccias and we devised a map symbol for the flow-direction indicated by the dip direction of the foresets (see Sheets 1,2). In some areas the differentiation between basal and carapace autobreccias was used to define local structures, but these contacts were largely omitted on the final version of our map for the sake of clarity and simplicity. Our map symbols for lava breccia do not differentiate between basal and carapace breccias, although it is clear in some areas, where flow direction symbols are shown, that the breccias are basal units. The more critical investigator is encouraged to examine our field sheets (on file at the Arizona Geological Survey) for additional information about some of the area's silicic lava flows.

Cauldron geology

The classic Smith and Bailey (1968) model of an ash-flow tuff caldera is a large circular volcano-tectonic depression that forms due to the eruption of a large volume (on the order of $\geq$ 500 km^3) of silicic magma from an upper crustal magma chamber. The depression is formed by collapse of the block that overlies the evacuated magma chamber. The depression fills partially with a large portion of the erupted ash-flow tuff material and the ensuing crater is referred to as a caldera. The topographic margin of the depression is referred to as the caldera margin, but this margin as it evolves through time does not necessarily coincide with the deep-seated structure or ring fractures along which the intracaldera block collapsed. Intracaldera blocks collapse in a variety of ways. The classic Smith and Bailey model (1968) depicts collapse of a piston-shaped intracaldera block along steeply dipping faults. Not all caldera's formation are so perfectly symmetric or castrophic (Walker, 1984). Some may collapse with part of the margin acting as a hinge, and the collapse may be incremental.

A cauldron is a volcano-tectonic depression whose geomorphic expression has been so modified by later structural events and/or erosion that it is unrecognizable as a caldera. The structure in the Superstition Mountains is a cauldron. In the southern Superstition Mountains, the cauldron margin coincides with the southern and western edges of the current mountain front, but this geomorphic expression of the original caldera is inverted, due primarily to the massive, intracauldron fill being more resistant to erosion. Examples of similar younger volcano tectonic depressions that are referred to as calderas because their geomorphic expressions are extant include Long Valley caldera, California, the Valles caldera of New Mexico, and Yellowstone caldera of Wyoming. The cauldron margin described in this report is a topographic margin and as such, its exact trace on the current land surface is a function of the level of erosion (Figure 3).

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implied, of the U.S. Government.

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PREVIOUS WORK

Reconnaissance geologic maps that include parts or all of the Mormon Flat Dam quadrangle include a study of the Salt River Canyon area by Scarborough (1981a,b), and a study of the Superstition Wilderness (Peterson and others, 1983). Detailed mapping and studies of more specific aspects of the geology were done by a number of graduate students, mostly under the direction of Mike Sheridan, who has also published extensively on the geology of the region. Student theses are: Stuckless (1969, 1971), Suneson (1976), Hillier (1978), Kilbey (1986), Prowell (1984), and Rettenmaier (1984). In addition, detailed studies of lavas and structures in adjacent areas by Malone (1972) and Isagholian (1983) pertain directly to the lavas that occur in the eastern parts of this map area. Sedgeley (1976) made a paleomagnetic study of some of the volcanic rocks which occur in the study area. Other works of importance include Sheridan and others (1970), Stuckless and Sheridan (1971), Stuckless and O'Neil (1973), Sheridan (1978), Sheridan (1987), and Sheridan and Prowell (1986). Trapp (1996) provides an excellent review of the complex history of stratigraphic nomenclature in the region.

STRATIGRAPHY

Proterozoic

Proterozoic rocks are exposed in only two areas of the quadrangle; along the north edge, and along an east-west striking structural arch north of Salt River in the center of the map area. All of these exposures consist of tectonically foliated, medium-grained, K-feldspar porphyritic granite or quartz monzonite. The foliations are generally steeply dipping and east-west striking. Locally, the foliation is a well-developed C-S fabric. One small exposure of tectonically foliated metafelsite occurs in the extreme northeast corner of the map area which is part of a very large area of these rocks that underlie the northern Horse Mesa Dam quadrangle (Gilbert and Ferguson, 1997) and adjoining areas of the southern Four Peaks quadrangle. The foliations in the granite and metafelsite are tentatively interpreted as being of the same generation, because they are approximately parallel.

Pre-cauldron Tertiary

Pre-cauldron volcanics in the study area are part of a 3000 km^2 lava field that extended over an area centered on and much larger than the 350 km^2 Superstition Cauldron. The area covered by this field includes the Horse Mesa area and Goldfield Mountains (Gilbert and Ferguson, 1997; Skotnicki and Ferguson, 1996), the Whitlow Canyon area and southern Superstition Mountains (Skotnicki and Ferguson, 1995; Ferguson and Skotnicki, 1995), and the Picketpost Mountain (Spencer and Richard, 1995), Superior (Peterson, 1969), and Haunted Canyon (Peterson, 1960) areas farther to the southeast. The volcanic field is part of what was originally called the Superior volcanic field (Ransome, 1903), but recent investigators more commonly refer to it as the Superstition volcanic field.

Pre-volcanic (Whitetail Conglomerate)

The oldest Tertiary rocks in the map area are pre-volcanic arkosic conglomerates exposed in the southwest corner. These strata were probably derived from the underlying Proterozoic granitoids and are part of a fairly continuous sheet of similar strata that underlie

the volcanics throughout the Superstition Mountains area. The strata are probably equivalent to the Whitetail Conglomerate. The absolute age of the conglomerates is unknown, but in adjoining areas, similar non-volcaniclastic strata at the base of the Tertiary section are, at least in part, interbedded with the oldest volcanic rocks. These range from high-silica rhyolite lava, tuff and breccia in the Apache Junction quadrangle dated at approximately 20.5 Ma by the Ar/Ar sanidine method (Skotnicki and Ferguson, 1996; McIntosh, personal communication) to basalt and dacite lavas in the Horse Mesa quadrangle dated at approximately 21 Ma by the K/Ar whole rock method (Scarborough, 1981).

Dacite-basalt sequence and the rhyodacite of Apache Gap

A thick pile of basaltic lavas overlain by crystal-rich dacite lavas comprise the base of the Tertiary volcanic sequence in the map area. Locally, basalt lavas are interbedded with the dacite lavas. The dacite lavas are interbedded with variable thicknesses of bedded, unwelded tuff, and tuff breccia. In many areas, several distinct flows can be recognized. The dacites contain between 20% to 40% phenocrysts of plagioclase with several percent biotite. Hillier (1978) also noted alkali feldspar, pyroxene and quartz in many of these lavas, and he classified the flows as ranging from latite-andesite to latite, and rhyodacite based on major element geochemistry. We noted two petrographically distinct lava types near the top of the sequence; 1) a quartz phyric, 15-25% phenocryst lava (Tdp), and a crystal-rich rhyodacite containing both biotite and hornblende along with the ubiquitous plagioclase (Trda). The rhyodacite lava appears more felsic chiefly because of its lighter colored matrix which also tends to be more vitric (the other dacites, including the quartz-phyric variety, typically have a purplish, microcrystalline matrix). The rhyodacite is recognized as a widespread unit at the top of the dacite sequence throughout the area, although Hillier (1978) recognized several thin rhyodacite flows near the base of the sequence along highway 88. Along highway 88 at Apache Gap, the rhyodacite was originally referred to as the rhyodacite of Apache Gap (Stuckless, 1969) and interpreted as an intrusive body. We found no evidence of intrusive relationships in this area and mapped it as a lava flow. A similar lava is also present at the top of the dacite lava sequence in the westerly adjacent Apache Junction and Stewart Mountain quadrangles (Skotnicki and Ferguson, 1996; Skotnicki and Lieghty, 1997) and in the easterly adjacent Horse Mesa Dam quadrangle (Gilbert and Ferguson, 1997). The equivalent lava unit in all of these adjacent quadrangles was also mapped as Trda, although earlier (pre 1997) versions of the Apache Junction map area (Skotnicki and Ferguson, 1996) show this unit as Trd.

Shafiqullah and others (1980) report a K/Ar biotite age of 20.60 $\pm$ 0.62 Ma for the rhyodacite of Apache Gap. The dacites are bracketed by underlying and overlying rhyolite lavas and tuffs in the nearby Goldfield Mountains with sanidine Ar/Ar dates of approximately 20.5 Ma and 19.0 Ma respectively (Skotnicki and Ferguson, 1996; W. C. McIntosh, personal communication).

Rhyolite lavas

The dacite lavas and the rhyodacite of Apache Gap are overlain throughout the northern Superstition Mountains and Goldfield Mountains by a thick succession of crystal-poor rhyolite lavas interbedded with bedded, unwelded pyroclastic rocks. These units were originally referred to collectively as Geronimo Head Formation by Stuckless (1969), Stuckless and Sheridan (1971), and many later investigators. Prowell (1984) subdivided the formation into older rhyolites of Willow Creek and a younger Peters Canyon dome complex because it was apparent that the lavas on Geronimo Head and in Peters Canyon were younger than the steeply tilted flows exposed along First Water Creek. Later, Sheridan and Prowell (1986) and Sheridan (1987)

referred to the older rhyolites as rhyolites of First Water Creek, but these rocks were still considered younger than intracauldron Apache Leap Tuff.

The rhyolite lavas exposed along First Water Creek are part of a continuous blanket of lavas interbedded with variable amounts of pyroclastic rocks that covered the entire study area. The lavas contain less than 10% and typically << 5% phenocrysts of plagioclase, sanidine, biotite ± quartz and hornblende. The individual flows probably do not extend for more than 5 km in any direction, and we found it impractical to map out individual flows because of the great structural complexities south of Salt River, and difficulty of access to areas north of Salt River. To the west and east of First Water Creek the proportion of pyroclasitc rocks to lava decreases so that in the Tortilla Flat and Goldfield Mountains areas, the sequence consists of greater than 90% lava. Across the Salt River to the north, a flat-lying sequence of rhyolite lava interbedded with bedded pyroclastic rocks also overlies dacite lavas and at the far northeastern edge of the volcanic field (north of Apache Lake in the Horse Mesa Dam quadrangle) it is overlain by Apache Leap Tuff (the Superstition Tuff of Suneson, 1976; Gilbert and Ferguson, 1997). The steeply-tilted rhyolites south of Canyon Lake are also overlain by Apache Leap Tuff (Canyon Lake member of Superstition Tuff of many previous reports). We refer to the rhyolite lavas that underlie Apache Leap Tuff as pre-cauldron rhyolite lavas (Tr) and we have divided them, where possible, into three different types based purely on phenocryst content: 1) <<0.5% phenocrysts are aphyric rhyolites (Tra), 2) between 0.5% and 5% phenocrysts are crystal-poor rhyolites (Trp), and 3) >5% phenocrysts are crystal-rich rhyolites (Trx). Most of the rhyolites belong to the crystal-poor subdivision, and most of these contain only 1-2% phenocrysts. The truly aphyric rhyolites are rare and were only recognized in the extreme northeast corner of the map area. Quartz phenocrysts are notably absent or rare in these rhyolites as previously noted by Fodor (1969), Stuckless (1969; 1971), Suneson (1976), and Isagholian (1983) and for this reason rhyolitic lavas containing significant amounts of quartz phenocrysts were mapped separately. Along the Apache Trail (State Route 88) near Apache Gap, the youngest sequence of crystal-poor rhyolite lavas overlie older rhyolite lavas along an angular unconformity. It was originally thought that these younger lavas might be considerably younger, possibly even younger than the Apache Leap Tuff, but subsequent geochronology of one of these lavas suggest that the lava is older than Apache Leap Tuff. The fanning of dips is significant because it documents that tilting was active while the unit was being deposited much like a similar fanning dip sequence in the central Goldfield Mountains (Skotnicki and Ferguson, 1996).

Whitlow Canyon type rhyodacite lava

A distinctive, quartz-phyric rhyolitic lava is present locally between the pre-cauldron rhyolite lavas and the outflow sheet of the Apache Leap Tuff. This type of lava is found chiefly around the town of Tortilla Flat where it is characteristically lavender colored. The quartz phenocrysts are commonly very large (up to a cm) and typically deeply embayed. Equant to rectangular plagioclase and sanidine phenocrysts up to 0.5 cm are also ubiquitous as is biotite. Phenocryst content is generally less than 5 or 7%, but locally (directly above highway 88 about 1 km west of Tortilla Flat), crystal-rich segregations are present. The crystal-rich and crystal-poor varieties in this area are intimately swirled together, with sharp contacts, as if they were extruded together, and for this reason, a vent area for the lava is indicated in this area on the map.

Farther west, along the upper reaches of Saguaro Lake, a similar, quartz-phyric, plagioclase and sanidine phenocryst-bearing lava is present at the top of the pre-cauldron rhyolite lava sequence. These lavas are also overlain by Apache Leap Tuff, but they are

characterized by light gray colored matrix, and they appear to be more felsic than the lavas around Tortilla Flat. Because of their similar mineralogy, and stratigraphic position, these lavas are also given the Whitlow Canyon type moniker. At two other localities, intrusive bodies of rhyolite lava were mapped as Twi simply because they contain abundant, large quartz phenocrysts. These bodies may or may not be equivalent to the quartz-phyric, Whitlow Canyon type lava flows.

The Whitlow Canyon type rhyodacite lavas were originally named for an extensive series of flows that blanket much of the Whitlow Canyon area near Florence Junction in the southern Superstition Mountains (Ferguson and Skotnicki, 1995). In this area these lavas also directly underlie the outflow sheet of Apache Leap Tuff (in this area called tuff of Comet Peak by Ferguson and Skotnicki, 1995), and overlie a widespread blanket of rhyolite lavas and pyroclastic rocks (called rhyolite lavas of Tule Canyon by Ferguson and Skotnicki, 1995). The Whitlow Canyon type rhyodacite lavas represent a phase of volcanism that is distinct mineralogically from underlying units and similar to the next youngest unit; Apache Leap Tuff. The average age of 18.63 Ma for the Whitlow Canyon rhyodacite lavas in the Florence Junction quadrangle is essentially identical to that of the Apache Leap Tuff (Ferguson and Skotnicki, 1995; McIntosh, written communication; and Ferguson and others, in preparation).

Syn-cauldron units (Apache Leap Tuff)

The Apache Leap Tuff is present as both intracauldron facies and as an outflow sheet in the map area. The outflow sheet in this area was previously referred to as Canyon Lake member of the Superstition Tuff. The intracauldron facies, was previously referred to as Siphon Draw member of the Superstition Tuff to the west and Dogie Spring member of the Superstition Tuff to the east. Each member was originally considered to have been emplaced at different times (Stuckless and Sheridan, 1971). There is, however, no field evidence that these three members occur at different stratigraphic levels. In fact, all available field evidence indicate that they are time-equivalent. Previously reported zircon and sphene fission track ages for Apache Leap Tuff which indicated that the Siphon Draw and Canyon Lake members were emplaced at approximately 29 Ma and 15 Ma, respectively (Stuckless and Sheridan, 1971) are puzzling. Recent, high-precision, laser-fusion, single crystal, sanidine Ar/Ar dates for the two units are nearly identical at about 18.6 Ma (D. W. Peterson, personal communication; W. C. McIntosh, personal communication; Ferguson and others, in preparation). The sample location for Stuckless and Sheridan's (1971) fission track dates is in an area where the tuff is laced with calcite-filled fractures, and the feldspars appear cloudy in hand specimen. In thin section, the matrix and many of the phenocrysts in samples of Apache Leap Tuff along Canyon Lake are invaded by patchy growths of calcite. Ferguson and Gilbert (this report), and D. W. Peterson (personal communication) considered these rocks unsuitable for sanidine Ar/Ar geochronology sampling and we collected our samples of the unit near Mesquite Flat, and from the basal vitrophyre along La Barge Canyon. Furthermore, we disagree that the members can be distinguished on the basis of phenocryst ratios as was suggested by Stuckless and Sheridan (1971). We find that there is a consistent over-reporting of quartz and under-reporting of plagioclase in the point-counts of Table 1 in Stuckless and Sheridan (1971) based on point counts of samples from the same areas by Isagholian (1983), Prowell (1984), and Ferguson and others (in preparation). Possibly much of the plagioclase, which in the Apache Leap Tuff is commonly highly embayed and melt-inclusion rich, was misinterpreted as quartz in the thin-sections point-counted by Stuckless and Sheridan (1971). Quartz phenocrysts are also characteristically deeply embayed throughout the Apache Leap Tuff.

Intracauldron Apache Leap Tuff is found only along the southern edge of the map area in La Barge and Boulder canyons. The tuff unconformably overlies altered dacite lava along a south-dipping contact, and also includes a south-dipping mesobreccia lens near its base. The contact is interpreted as the topographic scarp of the cauldron margin, but because of poor exposure along the canyon walls, its dip is only loosely constrained between about 20° and 60° to the south. The next westerly exposure of the topographic margin is in the southerly adjacent Goldfield quadrangle (Skotnicki and Ferguson, 1995) where it consists of dacite lava overlain by massive heterolithic breccias which grade southward into poorly and then densely welded Apache Leap Tuff. The cauldron margin is presumed to strike eastward into the southern part of the easterly adjacent Horse Mesa Dam quadrangle but its projected trace is buried by younger deposits (see Gilbert and Ferguson, 1997).

Outflow facies Apache Leap Tuff is exposed in two strips north of the cauldron; along Canyon Lake, and in Willow Springs basin. The tuff is poorly to moderately welded and appears white and massive in these areas. The basal portion of the tuff in the La Barge Canyon area includes a vitric interval up to 25 meters thick. This vitrophyre does not directly overlie older rocks in most areas, and it is locally discontinuous in nature. At one locality, where it crosses the La Barge Canyon hiking trail, it is strongly lineated as well as densely welded and the lineation points directly south, towards the center of the cauldron.

Bed-parallel slickened surfaces at the basal contact of the Apache Leap Tuff were recognized in the La Barge Canyon area by Sheridan (1987). We also noted slickened surfaces at the basal contact of the outflow sheet in the Willow Springs basin. The base of the Apache Leap Tuff is also characterized in most areas by an extensive regolithic breccia with fissures extending into the underlying rocks filled with jasperoid.

There is abundant evidence of syn-volcanic tectonic activity associated with emplacement of the Apache Leap Tuff. The tuff buries paleotopography (probably scarps) along two major faults. One is a complex east-side down fault zone that strikes northwest along highway 88 just west of Tortilla Flat. In this complex zone some faults cut the tuff and others appear to be mantled by vitric Apache Leap Tuff. At the north end of Willow Springs basin, Apache Leap Tuff overlaps what appears to be an abandoned strand of the basin-bounding fault. The contact here is fairly well exposed and it consists of a moderately southwest-dipping depositional contact cut by minor, steep, southwest-side-down faults. The relationships are very similar to an abandoned strand of the Elephant Butte fault, a major west-side-down fault that is buried by Apache Leap Tuff at the southern edge of the Superstition volcanic field near Florence Junction (the tuff of Comet Peak of Ferguson and Skotnicki, 1995).

Directly east of Tortilla Flat, the basal contact of the Apache Leap Tuff is cut by several northeast-side-down normal faults, and eutaxitic foliation in the tuff dips to the southwest consistently between 30° to 45°. The overlapping contact with basalt lava and volcaniclastic strata is gently dipping north of Tortilla Flat, and at the south end of the outcrop belt, the tuff is overlapped by the basal autobreccia of the crystal-rich quartz latite lava. The tuff was tilted to the southwest before deposition of the overlying basalt lava, quartz latite lava, and sedimentary rocks. The age of tilting is constrained to be between emplacement of the Apache Leap Tuff at about 18.6 Ma and the age of the overlapping volcanic rocks. A whole rock K/Ar date of 20.60 $\pm$ 0.90 Ma (Scarborough, 1981a) for the intervening basalt lava is inconsistent with the younger Ar/Ar sanidine dates of 18.6 Ma for the underlying Apache Leap Tuff. Ar/Ar sanidine dates of an ash-flow tuff within the volcaniclastic sedimentary sequence, and of the quartz latite lava are in progress.

Post-cauldron units

Post-cauldron units are classified as those which overlie Apache Leap Tuff. They consist of a variety of lavas and sedimentary rocks. Post-cauldron felsic lavas and intrusions are found chiefly within and along the margins of the Superstition Cauldron. Other post-cauldron rocks include basaltic lavas and volcaniclastic sediments which fill grabens and half-grabens that extend northwest and southeast from the cauldron along a major post-cauldron fault zone. Three different types of lava are recognized: 1) crystal-rich quartz latite lava (Tq) which forms a large dome and flow complex at Geronimo Head, 2) crystal-poor rhyolite lava or lavas which occur within a sequence of volcaniclastic sedimentary rocks in Willow Springs basin, and 3) several basalt lava flows which occur interbedded with the same volcaniclastic sequence in Willow Springs basin, north of Tortilla Flat, and at Hackberry Mesa. Post-cauldron volcaniclastic sedimentary rocks and pyroclastic rocks are also recognized in the same three areas.

Post-cauldron silicic lavas

The crystal-rich quartz latite lavas at Geronimo Head are part of an extensive post-cauldron lava flow and intrusive suite that intrude and overlie intracauldron Apache Leap Tuff along a major southeast-striking graben that transects the Superstition Cauldron (see Peterson and others, 1983; Prowell, 1984; Ferguson and Skotnicki, 1995). The lava at Geronimo Head is contiguous with the rhyodacite lavas of Coffee Flat (Ferguson and Skotnicki, 1995) which overlie intracauldron Apache Leap Tuff and intrude the southeastern cauldron margin. One of the hypabyssal intrusions to the southeast has been dated at 18.56 $\pm$ 0.06, and the associated lavas at 18.31 $\pm$ 0.04, 18.02 $\pm$ 0.09, and 18.02 $\pm$ 0.05 (W. C. McIntosh, personal communication; Ferguson and Skotnicki, 1995; Ferguson and others, in preparation). The lavas at Bluff Spring Mountain and at Weavers Needle are petrographically similar to those at Geronimo Head and Coffee Flat, and they are all considered to be part of the same magmatic event. The mineralogy of these lavas is also very similar to the Apache Leap Tuff (Prowell, 1984).

The lavas at Geronimo Head were studied extensively by Prowell (1984) and it is mostly because of her work and the work of Peterson and others (1983) that we were able to lump this complex together as a major post-cauldron lava dome complex, and concentrate our mapping efforts in other regions. Our work focused on the basal contact of this lava dome complex and its relationship to underlying rocks. Our interpretation of the geology at the base of the complex is significantly different from Prowell's (1984), but we encourage interested readers to use her map (Prowell, 1984) for a detailed look at the geology of the complex.

Post-cauldron breccia (Trd)

Within Superstition Cauldron, a thin monolithic lava breccia unit is present between the crystal-rich quartz latite lava dome complex at Geronimo Head and the underlying intracauldron Apache Leap Tuff. The breccia (Trd) is overlain by a thick unwelded tuff sequence that is probably related to formation of the overlying dome complex. The breccia (Trd) is overlain by other post-cauldron units elsewhere, but it always directly overlies Superstiton Tuff, and it is locally hydrothermally altered. The unit is present over a 30 km^2 area, mostly in the Goldfield quadrangle (Skotnicki and Ferguson, 1995), and it rarely exceeds 20 meters in thickness. It therefore can not be a simple lava flow. It is either a widespread block and ash-flow deposit or an avalanche deposit. The clasts are of a 5-10% phenocryst, feldspar-quartz-biotite lava. No vent or dome areas for the lava have been identifed. Prowell (1984) interpreted this unit as equivalent to the crystal-poor rhyolites (her Willow Creek rhyolites) that occur north of the cauldron margin, thereby supporting the long-standing interpretation that the Willow Creek rhyolites were post-Superstition Cauldron in age, and that the Canyon Lake member of the

Apache Leap Tuff, which overlies the Willow Creek lavas along Canyon Lake was younger than the intracauldron Apache Leap Tuff (originally called the Siphon Draw member of the Superstition Tuff [Stuckless and Sheridan, 1971]) farther south. Prowell's correlation based on petrographic comparison is valid, and an old age for the clasts in the breccia is supported by an 18.80 $\pm$ 0.06 Ma age for a thin lithic tuff (Ttf) which directly overlies the Trd unit and Apache Leap Tuff at the south edge of Black Mesa in the Goldfield quadrangle (Skotnicki and Ferguson, 1995; Ferguson and others, in preparation). Note that an Ar/Ar sanidine age of 18.46 $\pm$ 0.09 was obtained for the Apache Leap Tuff which underlies the apparently older lithic tuff (Ttf) unit. We interpret the Trd unit as an avalanche breccia derived from pre-cauldron rocks along the cauldron margin shortly after cauldron formation, and suggest that the old (18.80 Ma) age for the lithic tuff is because its sanidines are from lithic inclusions of the pre-cauldron rhyolite lavas. There are several similar monolithic lava breccias composed of pre-cauldron lavas interleaved with intracauldron Apache Leap Tuff along its western and southern cauldron margins (see Skotnicki and Ferguson, 1995; Ferguson and Skotnicki, 1995).

Post-cauldron basalt lavas

A basalt lava flow or flows is/are preserved within the two post-cauldron volcaniclastic sedimentary sequences which overlie outflow facies Apache Leap Tuff. Near Tortilla Flat, a basalt lava near the base of the sequence has been dated at 22.60 $\pm$ 0.90 Ma (K/Ar whole rock) by Scarborough (1981), but as mentioned previously, the basalt overlies Apache Leap Tuff which has been dated at approximately 18.6 Ma by the more precise Ar/Ar sanidine method (McIntosh (written communication), D. W. Peterson (personal communication), Ferguson and others (in preparation)). The volcaniclastic sequence of Willow Springs basin is capped by a gently northeast-dipping basalt lava dated at 18.26 $\pm$ 3.10 Ma (K/Ar whole rock) by Damon and others (1969). High precision Ar/Ar sanidine dates (in progress) of an unwelded tuff that overlies the basalt lava near Tortilla Flat and one that underlies the basalt in Willow Springs basin should shed some light on how definitive the age difference based on K/Ar whole rock dates appears to be.

A sequence of at least three basalt lava flows are interbedded with the volcaniclastic strata which buries the northern Superstition Cauldron margin at Hackberry Mesa. Scarborough (1981) reports a K/Ar whole rock age of 14.23 $\pm$ 0.47 Ma for the oldest and thickest lava in this package.

Post-cauldron sedimentary rocks

The post-cauldron sedimentary sequences in the Mesquite Flat and Willow Springs basin areas have been described in detail by Rettenmaier (1984). The sequences may be time-equivalent, but the details of each sequence's sedimentology and provenance are quite different (Rettenmaier, 1984). The Willow Springs sequence is much finer grained, it appears to be entirely volcaniclastic, and it contains abundant tuff beds. The Mesquite Flat sequence is much coarser grained and although chiefly volcaniclastic it does include large areas to the east of the quadrangle where Proterozoic detritus is fairly abundant (up to 5-10%). We found that the strata in the Mesquite Flat area are almost completely epiclastic. Only one unequivocal ash-flow tuff (about 2 meters thick) was identified within these rocks (directly north of Tortilla Flat). Rettenmaier (1984) identified numerous, relatively thick, ash-flow tuffs in the Mesquite Flat basin. The origin of these rocks is equivocal. We call the same rocks massive, pumiceous, pebbly sandstones, and interpret them as hypoconcentrated flood-flow deposits.

The Willow Springs sedimentary sequence preserves fanning dips that generally become gentler upwards, but in some areas, complex relationships with abrupt changes in dip direction

and magnitude are preserved (see Sheet 1 about 4300 feet/1300 meters north of Willow Springs Well). These relationships are interpreted as resulting from a complex interplay of syn-depositional faulting and concomitant formation of angular unconformities, locally preserving major differences in dip. Syndepositional faults that have been identified in this area are interpreted as antithetic with respect to the major, southwest-side-down basin bounding fault. In addition, a north-striking contact of indeterminate origin was mapped between east- and west-dipping strata through this area. We were unable to determine if this contact is a fault, an unconformity, or both.

Younger Tertiary

The Superstition volcanics are overlain to the north and northwest by weakly indurated conglomerates and pebbly sandstones which we have called the younger sedimentary sequence (Tsy). These strata are composed chiefly of clasts of Proterozoic rocks of the Mazatzal Mountains and to a lesser degree, clasts of Superstition volcanics. These rocks occur in two general areas: 1) capping the high ridges which connect the Mazatzal Mountains to the volcanic mesas along the north side of Salt River, and 2) in The Rolls, a topographically subdued yet deeply incised piedmont area in the northwest corner of the map area. The only outcrops of the younger Tertiary sedimentary strata are in The Rolls where the rocks are chiefly medium-bedded, plane-bedded to low-angle cross-stratified, pebbly sandstone and conglomerate. The maximum grain sizes in this area are in the cobble range. To the east, where this unit caps high-standing ridges with bedrock in the intervening gullies and canyons, the maximum grain sizes are typically in the boulder range, and meter-sized clasts are common. Unfortunately, these exposures are invariably buried by colluvium. The dominant clast type in these conglomerates changes abruptly from ridge to ridge with granitoids, quartzites and metafelsite being the main types. Metafelsite clasts are more abundant to the east (east of Cane Spring Canyon), and quartzite clasts are more abundant to the west. An abrupt change from metafelsite-clast-dominated to Tertiary rhyolite-clast-dominated conglomerates was noted from north to south between two small exposures of the unit directly north of Hells Hip Pocket, along the east edge of the map area. Other exposures of this unit south of here are also dominated by Tertiary volcanic clast types, and this boundary is tentatively interpreted as an ancient facies transition between an alluvial-fan piedmont complex to the north and ancestral Salt River axial drainage system to the south.

The absolute age of the younger sedimentary sequence is unknown, although a basalt lava flow interbedded with similar deposits in the westerly adjacent Stewart Mountain quadrangle (Skotnicki and Leighty, 1997) has been dated at 15.53 $\pm$ 0.39 Ma by Shafiqullah and others (1980). The southern edge of these strata where they onlap the Tertiary volcanics along Saguaro Lake display upward fanning of dips from over 20° to horizontal over a short distance (Skotnicki and Leighty (1977) mapped dips greater than 50° in correlative strata just to the west). It appears that the older part of the sequence was deposited while extensional tectonism affected the area.

A set of at least three generations of Quaternary terraces are developed along the Salt River and Cottonwood Creek in the western part of the quadrangle. The terraces were classified as lower, middle, and upper Pleistocene in age based on their levels relative to the current base level of the Salt River in the westerly adjacent Stewart Mountain quadrangle (see Skotnicki and Leighty, 1997).

STRUCTURAL GEOLOGY

Cauldron geology

Sheridan and others (1970), Stuckless and Sheridan (1971), and Sheridan (1978, 1987) identified two major cauldrons or cauldron margin segments in the map area; the northwestern Superstition Cauldron margin in the southwest corner of the map area, and the younger Goldfield Cauldron to the northwest. Another structure, the Tortilla Cauldron, also considered younger than the Superstition Cauldron, was also identified in areas directly east of the map area (Sheridan, 1978; 1987). The northwestern margin of the Superstition Cauldron is present in the southwest corner of the map area. The margin is defined by a dramatic southward thickening of the Apache Leap Tuff directly upstream of the confluence of La Barge and Boulder canyons. Intracauldron mesobreccia composed of clasts derived from all of the older lavas which make up the cauldron wall to the north are found within the Apache Leap Tuff directly south of the margin. The margin is buried by younger lavas (Geronimo Head quartz latite lava, Tq) to the east, and volcaniclastic strata interbedded with basalt lava to the west. The west-southwest-striking, south-dipping topographic margin steps to the right across a major, north-striking, west-side-down normal fault in the southerly adjacent Goldfield quadrangle (Skotnicki and Ferguson, 1995), and the same right-stepping relationship is thought to occur across the major, west-side-down fault that cuts across Boulder Canyon just south of the intersection of cross-section lines E-E' and D-D'.

We found no evidence of the younger Goldfield and Tortilla cauldrons as shown by previous workers. The rhyolite lavas along First Water Creek and Fish Creek Canyon which are supposed to represent cauldron-fill for these younger cauldrons predate Apache Leap Tuff. These rhyolite lavas and tuffs represent the northern and northwestern edge of a widespread (at least 2500 km^2) sheet of these rocks which covered an area centered on and much larger than the Superstition Cauldron. The rocks accumulated to a thickness of greater than 1 km over much of the area. To the north and northwest, the flows thin gradually onto Pre-Tertiary basement rocks, as do all of the pre-Apache Leap Tuff volcanics. The depression that is filled by these rocks appears to be a volcano-tectonic depression with gently inward dipping margins that encompassed the entire volcanic field. There are no abrupt "cauldron margin" bounding faults and no cauldron-margin breccia facies rocks. We interpret all of the faults that had been identified as cauldron margin faults by Sheridan (1978; 1987) in the map area as regional extension-related normal faults.

The only significant exposures of post-cauldron rocks to the north of Superstition Cauldron are the volcaniclastic sediments of Willow Springs basin and Mesquite Flat areas. These sequences were deposited in grabens and half grabens that appear to be more related to regional extension than cauldron-related volcano-tectonism.

Regional extensional tectonics

Tilt domains

The map area can be divided into two structural domains by a major fault zone which runs WNW from Tortilla Flat along lower Canyon Lake and Saguaro Lake to Bagley Flat along the west-central edge of the map area (Figure 4). To the north of this zone, all of the Tertiary strata are essentially flat-lying and relatively undeformed. A narrow zone of southwest-tilted strata is present in a graben that extends from just downstream of Mormon Flat Dam to the southeast corner of the map area (Figure 4). Southwest tilts are recorded in pre-cauldron (Td, Trp), syn-cauldron (Ts), and post-cauldron (Tcv) units. The graben is considered part of the northern structural domain as they are shown on Figure 4. Note that the northern bounding

fault of the graben changes from south-side-down to north-side down from north to south where it crosses Canyon Lake. The fault splays into a number of strands in this complex area which includes north-vergent reverse faults that die upwards into the volcaniclastic sedimentary unit (Tcv). Southwest dips in the graben are preserved in two areas. Near Tortilla Flat, eutaxitic foliation in the Apache Leap Tuff dips consistently southwest and the tuff is cut by a set of northeast-dipping normal faults. The tilting and the faults do not continue upwards into the overlying strata which consist of basalt lava and volcaniclastic sedimentary rocks to the north and crystal-rich quartz latite to the south. Just downstream of the Mormon Flat Dam, a southwest-dipping fanning dip sequence is preserved in the coarse-grained volcaniclastic sedimentary rocks that cap the mesas in the area. Some of the underlying lavas also display moderate southwest dips within a km to the northeast.

Although the northern structural domain is essential flat-lying, there is evidence of recurrent southwest tilting. Three different episodes of tilting are recognized. The oldest episode was along the northern edge of the volcanic field in the easterly adjacent Horse Mesa Dam quadrangle (Gilbert and Ferguson, 1997) where a southwest-dipping fanning dip sequence developed during eruption of pyroclastic beds related to the pre-cauldron rhyolite lava sequence. These rocks are overlain by essentially flat-lying Apache Leap Tuff (see cross-section A-A' on sheet 3 of Gilbert and Ferguson, 1997). Southwest tilting in the tilt-domain boundary graben near Tortilla Flat occurred after emplacement of the Apache Leap Tuff, but before eruption of the overlying crystal-rich quartz latite lava (Tq), basalt lava (Tbu), and the volcaniclastic sedimentary sequence (Tcv). At the northern tip of this graben, near Mormon Flat Dam, southwest-tilting and formation of a fanning dip sequence occurred during deposition of the volcaniclastic rocks which are presumably the same age as the similar strata near Tortilla Flat.

To the southwest of the tilt-domain boundary, Tertiary strata are moderately to steeply tilted to the northeast over a large area and cut by a myriad of southwest-dipping normal faults. The fault's dips range from nearly vertical to less than 20°. The tilting affects nearly all of the Tertiary section. The faulting resulted in a total of approximately 54% extension of a 12.2 km-wide area between Canyon Lake and the southern Goldfield Mountains. The restored bed length of the base of the rhyolite lava and tuff sequence for the same area, which includes parts of the southwesterly adjacent Apache Junction quadrangle (see Skotnicki and Ferguson, 1996) is approximately 7.9 km along cross-section C-C'(Sheet 3), and cross-section D-D' of the southwesterly adjacent Apache Junction quadrangle (Skotnicki and Ferguson, 1996). Upward fanning of dips from greater than 50° to nearly horizontal occurs in the Willow Springs basin. Dips are mostly to the northwest in this basin, but locally, upward fanning of dips in the opposite (southwest) direction also occurs in the Willow Springs basin, and the opposite dips are interpreted to represent development of syndepositional northeast-dipping faults antithetic to the major southwest-dipping master fault for this basin.

The tilt domain boundary

The tilt domain boundary consists of a complex array of steeply dipping faults which display abrupt changes from apparent south-side-down to north-side-down stratigraphic separation along strike near Mormon Flat Dam. Also near Mormon Flat Dam, the Apache Leap Tuff thins dramatically from several hundred meters to zero across the fault zone. The fault zone also includes several reverse faults which appear to die out upwards into coarse-grained breccias or conglomerates. A strike-slip component of offset along the fault zone is invoked to explain these relationships, but direct kinematic evidence is lacking. Kinematic indicators on the faults mostly indicate dip slip, although there are some which indicate dextral oblique normal and reverse slips. Where the fault zone runs through the Tortilla Flat area a

major north-side down normal fault is paired with a moderately southwest-dipping reverse fault in its hangingwall. The reverse fault is well exposed in the canyon that crosses highway 88 just west of town where it displays dextral oblique kinematic indicators, and is cut by a minor dextral oblique normal fault. The reverse fault is thought to die up-dip into a very coarse-grained breccia facies of the volcaniclastic sedimentary sequence (Tcv) which is interpreted as a syn-tectonic, fault-scarp, talus apron deposit. The breccia is cut by another steeper-dipping reverse fault which steepens up-dip to vertical where it eventually cuts through the quartz-latite dome to the south. Note the similarity of these complex relationships with those described along the northern bounding fault of the tilt-domain boundary graben in the previous section.

To the west, the fault zone curves into an east-west strike along Salt River and it eventually passes into Proterozoic rocks on both sides (Skotnicki and Leighty, 1997). The fault zone cuts all Middle Tertiary strata in the map area and it cuts off or appears to cut off all important moderate-angle to low-angle faults related to regional tilting on both sides. One of these is a south-dipping low-angle fault which is beautifully exposed just east of Bagley Flat along Salt River. This fault is thought to be one of the master faults for the southern structural domain.

Although the tilt-domain boundary fault zone appears to change srtike near Bagley Flat, it is important to note that the boundary of the tilt-domain does not (Figure 4). This suggests that the real boundary fault zone may be buried by the younger sedimentary sequence (Tsy) to the northwest. Volcanic rocks north of Bagley Flat and north of Saguaro Lake in the westerly adjoining Stewart Mountain quadrangle (Skotnicki and Leighty, 1997) dip moderately to the northeast as do the basal strata of the younger sedimentary unit (Tsy).

At the south end of Canyon Lake the tilt-domain boundary fault zone splits into two oppositely dipping strands or zones; a northwest-striking, northeast-side-down zone that continues through the Tortilla Flat area, and a south-striking, west-side down zone that extends up LaBarge-Boulder Canyon. The split forms a complex, triangular-shaped, 3 km^2 horst that is bounded on the south by the Superstition Cauldron margin, which is in this area overlapped by a major post-cauldron lava dome. The horst is diced up mercilessly by faults, and tilt relationships are complex. At its south edge, the horst consists of pre-cauldron lavas with northeasterly dips that range from 30° to 60° (similar to strata throughout the southern structural domain). To the north, dips change to northwesterly which is also the orientation of the contact with the overlying Apache Leap Tuff. The Apache Leap Tuff has a basal vitrophyre in this area and up-section the magnitude of northwest dips decrease from about 30° to less than 10°.

Farther to the southeast the fault zone cuts through a large post-cauldron, and largely post-tilting, crystal-rich quartz latite dome complex (Tq). In general, the tilt-domain boundary fault zone and its graben is continuous with a complex NW-SE striking graben that transects the Superstition Cauldron and which appears to merge southeast of the cauldron with the northward convergence of three major west-side-down faults which cut Apache Leap Tuff in the southeastern part of the volcanic field. From west to east these are: 1) Elephant Butte fault (Ferguson and Skotnicki, 1995), 2) Roblas Canyon fault (Spencer and Richard, 1995), and the Concentrator fault (Peterson, 1969; Spencer and Richard, 1995).

Strike-slip component

Some degree of strike-slip offset associated with extension and/or developement of the tilt-domain boundary fault zone seems to be required in the study area. One of the biggest southwest-side-down normal faults of the southern tilt-domain displays well-developed dextral oblique slickenlines. A dextral component of offset seems reasonable for the tilt-domain boundary fault zone, but almost all kinematic indicators along the faults indicate pure dip-slip.

An exception are the horizontal grooves developed on the south-striking fault that runs up La Barge Canyon. The best evidence of strike-slip across the fault zone is a 2 km offset of two markers in Apache Leap Tuff (Figure 4). One of these markers is the apparent northwestern pinch-out of the tuff, and the other is a north-striking synform defined by eutaxitic foliation in the Apache Leap Tuff (note that the presence of a synform does not require a compressional origin). The apparent 2 km of offset across the tilt-boundary fault zone in the Mormon Flat Dam quadrangle is in agreement with the offset Ferguson and Skotnicki (1995) noted was probable along the Elephant Butte fault, the probable continuation of this fault zone to the south of the Superstition Cauldron which appears to offset the cauldron margin about 1 km in a dextral sense.

Timing of extension

The record of extension in the southern part of the map area is indicated by varying magnitudes of tilting of the Tertiary strata. Upward fanning of dips from Apache Leap Tuff to the youngest strata is well documented in the Willow Springs basin and within the Superstition Cauldron at Hackberry Mesa. Note that the steeper dips (25°-40°) in the intracauldron Apache Leap Tuff which underlie the basalt lava and sedimentary rocks (5°-15°) of Hackberry Mesa are evident only in the southerly adjacent Goldfield quadrangle (Skotnicki and Ferguson, 1995). The southeast-dipping Superstition Cauldron margin is cut by at least two of the major southwest-side-down faults which accommodate the tilting of the youngest strata. The faults, one along First Water Creek, the other along Boulder Canyon, cause the margin to step to the right. This relationship is best preserved along the north edge of the southerly adjacent Goldfield quadrangle (Skotnicki and Ferguson, 1995). Pre-cauldron volcanics in the area preserve steeper dips than the overlying Apache Leap Tuff in most areas indicating that extension and tilting was active prior to cauldron formation. Fanning of dips in the pre-cauldron sequence was not documented in the southern tilt domain of the map area, but it has been in the Goldfield Mountains to the southwest (Skotnicki and Ferguson, 1996).

The oldest reliably dated volcanic rock in the Superstition volcanic field is a 20.5 Ma rhyolite lava and tuff ring that directly overlies basement and a thin layer of pre-volcanic conglomerate in the southern Goldfield Mountains (Skotnicki and Ferguson, 1996). There is no apparent change in dip between the volcanic rocks and the conglomerate, but unfortunately, no pre-Tertiary stratified rocks are present in the area, and the amount of pre-Whitetail conglomerate tilting that may have affected the area is unknown. All of the tilting of the Tertiary volcanic sequence must have occurred after 20.5 Ma.

CONCLUSIONS

Detailed mapping of the Mormon Flat Dam quadrangle has clarified important temporal relationships of the greater than 1.5 km-thick volcanic sequence which blankets most of the study area. Most of the volcanic rocks in the map area predate formation of the Superstition Cauldron at about 18.6 Ma. The pre-cauldron volcanic sequence consists primarily of a basalt and dacite lava succession overlain by rhyolite lava and pyroclastic rocks. To the southwest of the study area, in the Apache Junction quadrangle, the same basalt-dacite lava pile overlies a 20.5 Ma rhyolite dome and tuff ring which directly overlies crystalline basement. The main pulse of volcanism in the Superstition volcanic field is therefore much shorter in duration (less than 2 million years) than the 15 million years indicated by previous dating techniques. The pre-cauldron sequence is capped by a distinctive, quartz-phyric rhyolitic lava (Whitlow Canyon type rhyodacite) that directly underlies Apache Leap Tuff and it is correlated with a widespread series of petrographically identical flows that occupy the same stratigraphic position to the

southeast of the cauldron. The thick succession of rhyolite lavas and pyroclastic rocks in the pre-cauldron sequence were previously thought to postdate formation of the Superstition Cauldron. These lavas form part of the northern cauldron margin and elsewhere underlie the outflow sheet of the Apache Leap Tuff. The pre-cauldron sequence occurs on both sides of a major tilt-domain boundary which strikes WNW along lower Canyon Lake and Saguaro Lake.

The outflow sheet of the Apache Leap Tuff was previously referred to as Canyon Lake member of the Superstition Tuff (Stuckless and Sheridan, 1971) and thought to be a separate, significantly younger unit. In this report it is correlated with the intracauldron facies. This conclusion is based on field relationships and it is supported by petrographic comparisons and new precise Ar/Ar sanidine geochronology of the unit(s). The northern margin of the Superstition Cauldron sweeps across the southeast corner of the map area and continues to the east where it is buried by younger lavas and sedimentary rocks. The margin is cut and offset by major west-side-down normal faults. These faults curve to the northwest north of the cauldron margin and join a myriad of southwest-side-down normal faults which accommodate about 55% extension in a belt between Canyon Lake on the north and the southern Goldfield Mountains on the south. Most of this extension occurred during a short interval of time bracketed by emplacement of the Apache Leap Tuff at about 18.6 Ma and eruption of essentially flat-lying basalts which cap a fanning dip sequence in the Willow Springs basin area. Precise Ar/Ar, sanidine dates of key units (two of which are gently dipping ash-flow tuffs at the top of important fanning dip sequences) are in progress. A major northwest-striking, tilt-domain boundary fault zone which bisects the study area is interpreted to have accommodated 2 km of dextral slip after emplacement of the Apache Leap Tuff, based on offset of markers along Canyon Lake.

SUGGESTIONS FOR FURTHER WORK

There are three areas of the Mormon Flat Dam quadrangle that would benefit from more detailed mapping. The geology of two of these areas was generalized because we believed that the internal relationships were secondary in importance to understanding the "big picture". Upper Salt River Canyon, which consists of flat-lying rhyolite lavas and tuffs, is one of these areas. Another area is in the same rhyolite lavas where they are moderately to steeply titlted between First Water Creek and La Barge-Boulder Canyon. This area seems to have been overlooked by nearly all previous workers including ourselves. Prowell (1984) has done some detailed mapping in the eastern part of this zone, but there are some odd relationships here that suggest younger (post-cauldron) lavas may cap some of the highest ridges. In addition, there is a problem with how the rhyodacite of Apache Gap has been defined across this area. At Apache Gap, along highway 88, the lava does not contain any quartz phenocrysts, yet the lava mapped as rhyodacite of Apache Gap by Prowell (1984) to the east is quartz-phyric. The area is extremely rugged, but access is easy and a very detailed map of the area should be made.

The third area of importance is between Cottonwood Creek and the lower reach of Canyon Lake where it is confined in Salt River Canyon. A large area of Proterozoic granite is exposed in this area and the nature of its contact (fault or depositional) with the overlying volcanics is in many areas equivocal. The northern contact appears to be a fault in some areas and intrusive or depositional in others. The segments of the contact along the two talus covered slopes east and west of the creek were not visited and there are probably some exposures in these gullies that might yield important geometric and kinematic information.

Previous conclusions regarding the petrogenesis of Superstition volcanic rocks and the evolution of magmas through time have been based on an erroneous stratigraphic column. In particular, most of the high-silica, high-pottasium rhyolite lavas which were previously thought to

postdate cauldron formation are actually pre-cauldron in age, and some of these (The Bulldog Canyon rhyolite of Skotnicki and Ferguson, 1996) are actually the oldest known volcanic rock in the volcanic field. All previously acquired petrologic, geochemical, and isotopic data need to be reevaluated in light of the revised stratigraphic framework that we have established. More attention needs to be directed at the petrogenesis of the basalt lavas which are present throughout the volcanic sequence.

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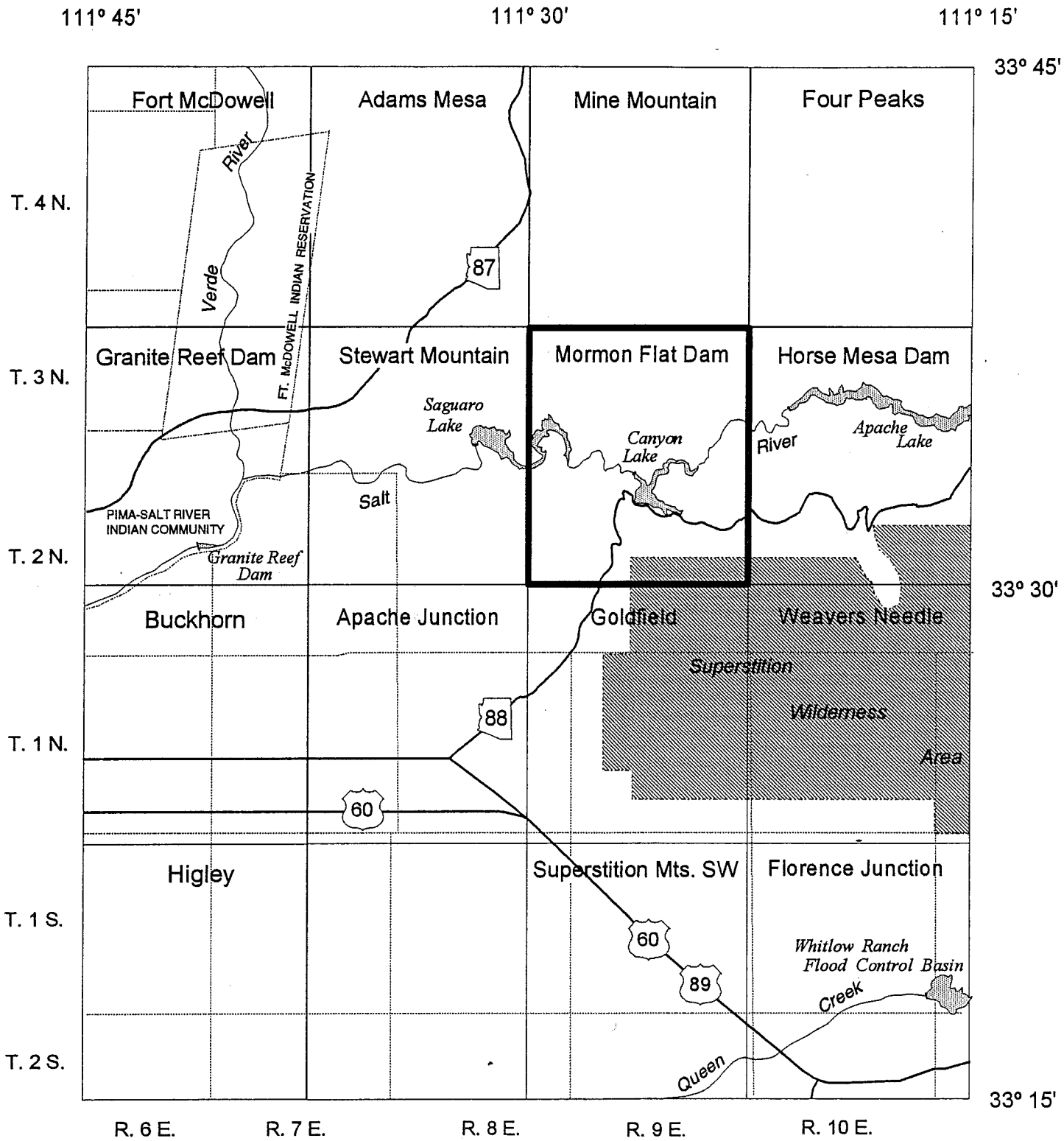

Figure 1 Location of the study area.

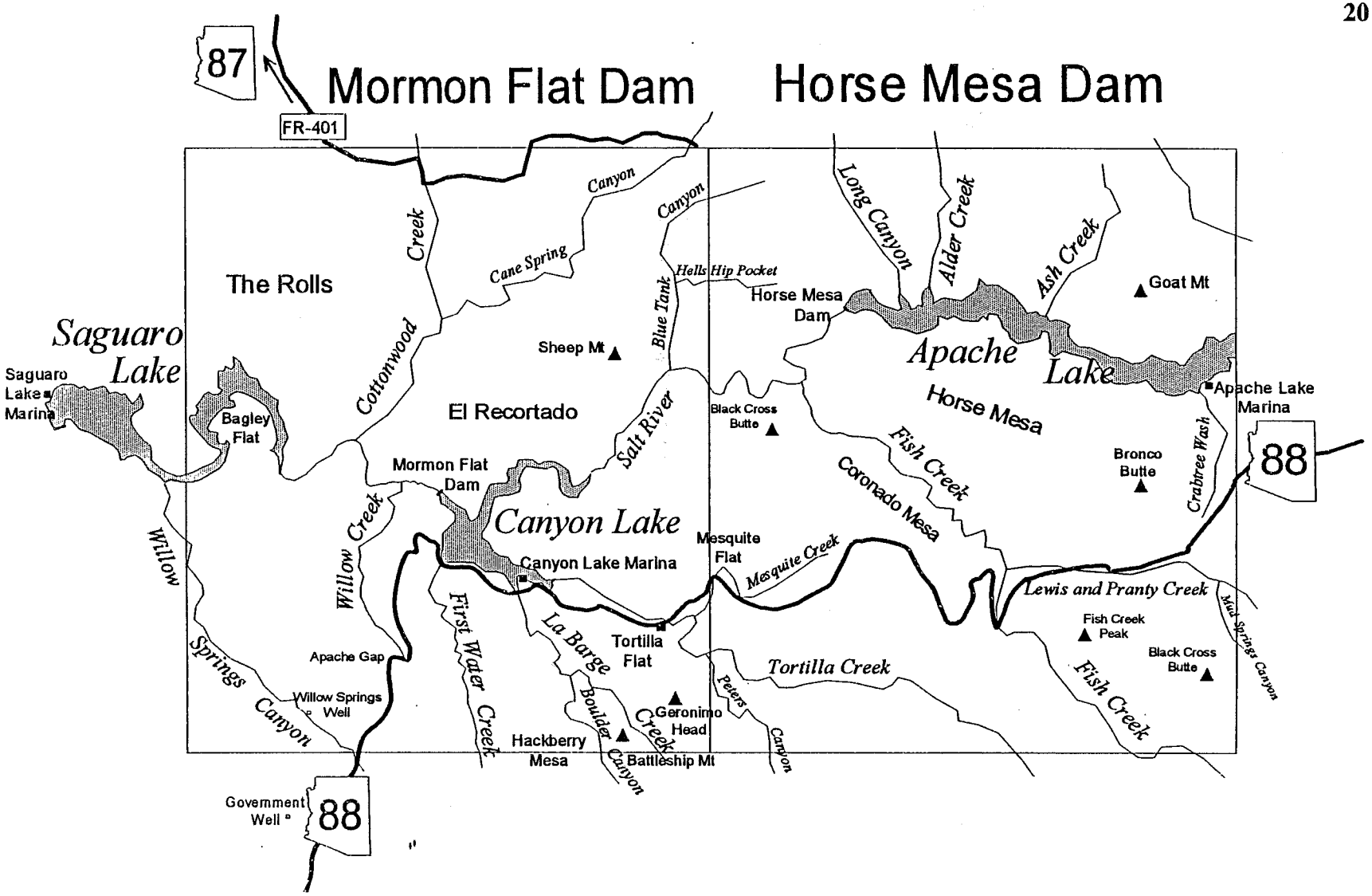

Figure 2 Location of roads, important place names, and geographic features in the Mormon Flat Dam and Horse Mesa Dam quadrangles.

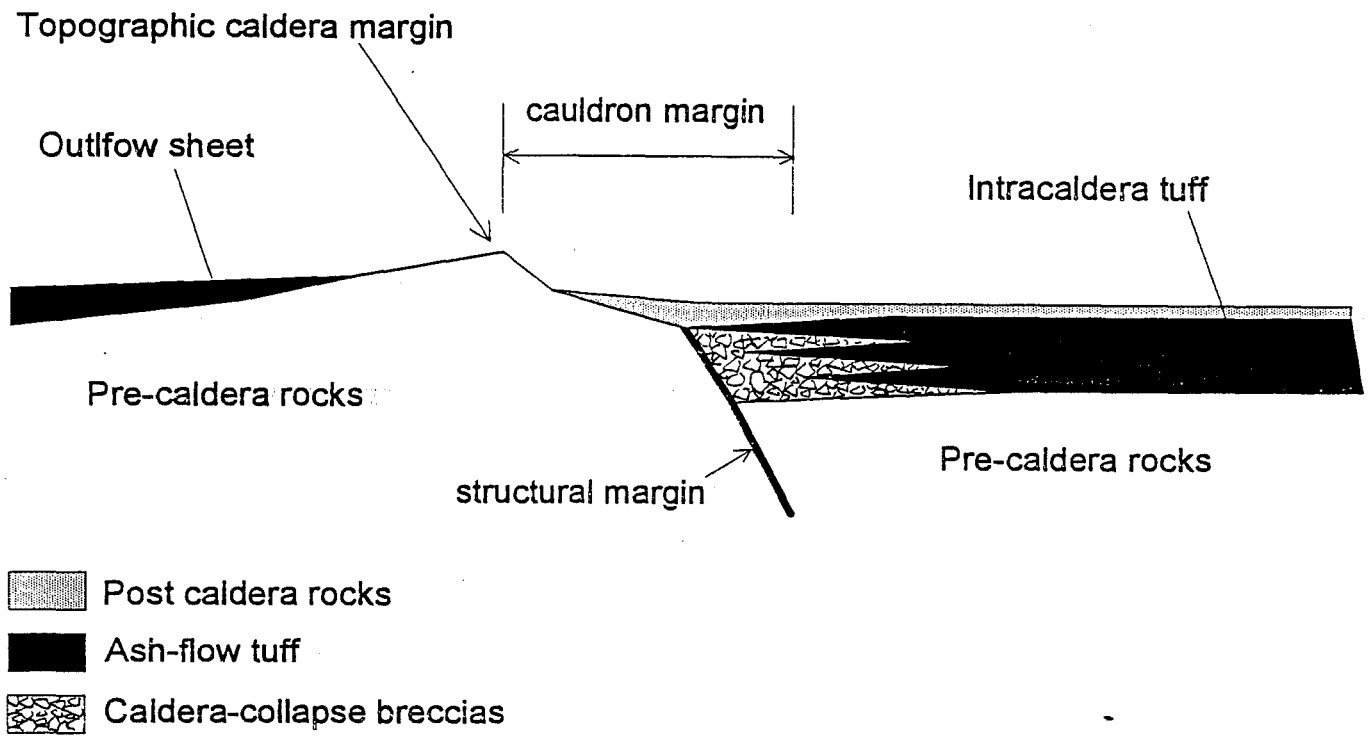

Figure 3 Schematic cross-section of a caldera margin soon after collapse of the intracaldera block. Note the difference between topographic and structural margin. As the caldera erodes, and its geomorphic expression diminshes, the location of the cauldron margin will migrate inwards, its exact location depending on the level of erosion.

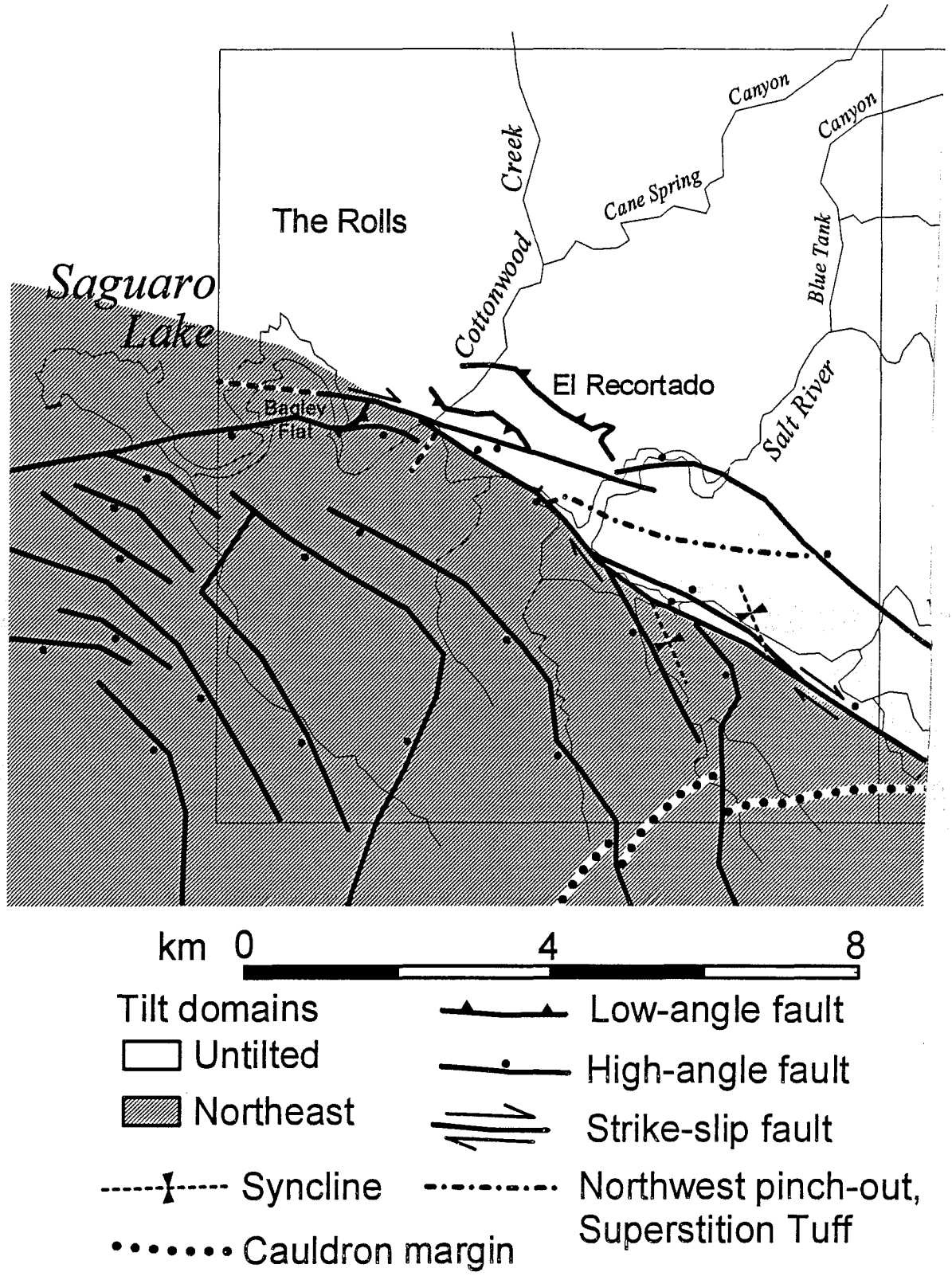

Figure 4 Tectonic map of the Mormon Flat Dam quadrangle, and adjoining areas of the Goldfield and Apache Junction quadrangles from Skotnicki and Ferguson (1995; 1996).

UNIT DESCRIPTIONS
FOR THE MORMON FLAT DAM 7.5'QUADRANGLE, MARICOPA COUNTY, ARIZONA

by
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August, 1997

QUATERNARY UNITS

Qa Younger alluvium

Qc Colluvium, talus and colluvium-covered slope deposits

Qls Landslides and other mass-movement or avalanche deposits

Qac Younger alluvium and colluvium undifferentiated

Qoa Older alluvium undifferentiated, typically preserved along terraces of Salt River and its major tributaries.

Ql_2 Younger lower Pleistocene alluvial terraces, preserved along Salt River, Cottonwood Creek, and in The Rolls.

Ql Lower Pleistocene alluvial terraces, preserved along Salt River, Cottonwood Creek, and in The Rolls.

Qm Middle Pleistocene alluvial terraces, preserved along Salt River, Cottonwood Creek, and in The Rolls.

Qo Older Pleistocene alluvial terraces, preserved along Salt River and in The Rolls.

TERTIARY UNITS

Tsy Weakly indurated conglomerate, sandy conglomerate, and pebbly sandstone. Unit is found north of Salt River in The Rolls, and capping ridges connecting the Mazatzal Mountains and mesas composed of mid-Tertiary volcanics along north side of Salt River. In The Rolls, the unit consists chiefly of medium-bedded, plane-bedded to low-angle cross-stratified sandy conglomerate and pebbly sandstone with rare, medium- to thick-bedded, massive, boulder clast diamictites. The clasts are chiefly Mazatzal Mountains Proterozoic rocks, but a significant amount of Tertiary volcanics are also present. East of Cottonwood Creek, where the unit is typically buried by colluvium, the clast size is generally greater. Locally, rhyolite lava clasts make up to 50% of the total.

Tby Younger basalt. Lavas contain a few percent plagioclase, pyroxene and olivine (typically altered to iddingsite) phenocrysts. Lavas in Hackberry Mesa locally contain nepheline phenocrysts. At Hackberry Mesa, three flows are interleaved with volcaniclastic conglomerate (Tcv). The younger two are barely exposed along the southern edge of the

map. Near Tortilla Flat, a thin basalt flow occurs at or near the base of the Tcv unit, and in the Willow Springs area, a basalt flow caps the Tcv unit.

Ttx A single, thin, crystal-rich tuff interbedded within the upper part of the Willow Springs basin sequence of volcaniclastic sedimentary rocks (see geochron sample 14 on Sheet 1 for location).

Tct Volcaniclastic conglomerate, pebbly sandstone, and sandstone interbedded with abundant, unwelded, bedded, lithic tuffs. This map unit occurs along the southeastern edge of the Willow Springs basin and is considered a transitional facies of the Tcv unit where it interfingers with the younger rhyolite lava flows and related pyroclastic rocks (Trpy, Tty) that occur within this basin.

Tcv Volcaniclastic conglomerate, pebbly sandstone, sandstone, silty mudstone, and sedimentary breccia. These strata range from plane-bedded and cross-stratified to massive, and from thin- to thick-bedded. Most of the strata are clast-supported, and the beds internally stratified; and these are interpreted as fluvial deposits. Locally, thin- to medium-bedded laminated siltstones and mudstones are abundant, some of which may be lacustrine deposits. Massive, matrix supported, medium and thick-bedded diamictites are locally abundant, and these rocks are interpreted as debris-flow and hypoconcentrated flood flow deposits. The northernmost parts of this unit in the Canyon Lake area and the lowermost strata at Hackberry Mesa include extremely thick-bedded, and very coarse-grained (over 3 meter clasts) sedimentary breccia. The map unit occurs in three areas: 1) capping ridges and mesas above Canyon Lake and around Tortilla Flat, 2) in the Willow Springs basin, and 3) Hackberry Mesa. The Willow Springs strata are thin to medium-bedded and contain a high percentage of siltstone and mudstone, whereas the Canyon Lake area strata are coarser-grained and more thickly bedded. The lowermost strata at Hackberry Mesa are dacite lava clast monolithic and change upwards to rhyolite and dacite lava clast heterolithic.

Trpy Crystal-poor rhyolite lava that overlies other crystal-poor rhyolite lava along an angular unconformity in the Apache Gap area. No age relationship preserved with the Apache Leap Tuff.

Tty Generic, unwelded, bedded or massive, crystal-poor, rhyolitic tuff that overlies other crystal-poor rhyolite lava along an angular unconformity in the Apache Gap area. No age relationship preserved with the Apache Leap Tuff.

Tq Quartz latite lava. Crystal-rich (>35%), plagioclase, sanidine, quartz, biotite, $\pm$ hornblende bearing lava. Typical of the Geronimo Head massif. Quartz phenocrysts are typically large (up to 1 cm) and embayed.

Tqb Brecciated quartz latite lava. In most cases these are basal, flow-front, foreset avalanche autobreccias, but they may include other breccias (chiefly carapace) in some areas.

Trd Quartz phyric, 5-10% phenocryst, rhyodacite lava breccia. Correlates with the **Trd** map unit of the southerly adjacent Goldfield quadrangle. The lava breccia occurs in a relatively thin layer (<30 m) over a 30 km^2 area of the northern Supserstition Cauldron.

Its thin, brecciated nature implies that it represents a major block and ash-flow or an avalanche breccia that spread out across the cauldron floor. Its source dome(s) have not been identified. Two discrete sequences of crudely bedded **Trd** lava breccia occur with overlapping, angular unconformable relationship at the base of a small box-shaped butte directly north of Battleship Mountain.

Tcx A mixed unit consisting of volcanic and epiclastic, monolithic to heterolithic breccia, conglomerate, and bedded, unwelded tuff. The breccia and conglomerate are typically massive or thick-bedded, and the tuff medium- to thin-bedded. The unit is preserved along a south-dipping erosional unconformity which represents the south-facing Superstition Cauldron margin. Clasts of all lava types older than Apache Leap Tuff have been identified in the breccias, but Superstiton Tuff and Geronimo Head type quartz latite lava have not. The clast population is similar to that found within the Apache Leap Tuff mesobreccia unit, and these two units may be in part correlative.

Ta Apache Leap Tuff undifferentiated; a crystal-rich (40-50%), plagioclase, embayed quartz, sanidine, biotite-bearing ash-flow tuff. The unit includes large areas of ash-flow tuff previously referred to as Canyon Lake member of the Apache Leap Tuff, and a small area along the southeast edge of map previously referred to as Siphon Draw member of the Apache Leap Tuff. The tuff ranges from unwelded to densely welded, and it rarely contains more than a few percent lithic fragments. Pumice fragments are also sparse and generally difficult to see in outcrop. The base and top of this unit are locally, crudely thick-bedded, but the unit generally appears massive. A lower vitrophyre is present in the Boulder Canyon area. Flow-banding is recognized in a few places along Boulder Canyon trail just south of Canyon Lake. Locally near the top, especially in the Willow Springs and Tortilla Flat areas, accretionary lapilli-rich intervals are present.

Tav Apache Leap Tuff vitrophyre. Thin bands of vitric matrix welded tuff that occur near the base of the unit along Boulder Creek.

Tax Apache Leap Tuff mesobreccia; a heterolithic, Apache Leap Tuff matrix, clast- and matrix-supported mesobreccia. Maximum clast size is about 5 meters, except for one >15m block of dacite lava which was mapped as a separate block. The clasts are composed of a wide variety of mafic to felsic lava, including basalt, crystal-rich dacite, porphyritic dacite, and rhyodacite (Td, Tdp, Trd), crystal-poor and crystal-rich rhyolite (Trp, Trx), and Whitlow Canyon type rhyodacite (Tw). The phenocryst mineralogy of these lava clasts can be matched directly with those of the older lava flows which crop out below Apache Leap Tuff to the north of the cauldron margin.

Tw Whitlow Canyon type rhyodacite lava. A mineralogically distinctive, gray or lavender-colored, moderately crystal rich (10-15%), and crystal-poor ($\leq$ 5%) lava containing sanidine, plagioclase, embayed quartz, and biotite. Feldspars are typically equant, euhedral and fairly large (up to 0.5cm), and the quartz phenocrysts are also large (0.5 to 1.0 cm) and characteristically embayed. The map unit is found in two areas. Along the south side of Canyon Lake, it is dark purple in color and it locally consists of alternating phases of crystal-rich and crystal-poor lava with complex, sharp, interfingering contacts. Along the upper reaches of Saguaro Lake the lava is light-colored. The lavas are mineralogically similar and are found in the same stratigraphic position (directly below

the outflow sheet of the Apache Leap Tuff) as a voluminous and areally extensive unit south of the Superstition Cauldron referred to as the rhyodacite of Whitlow Canyon (Ferguson and Skotnicki, 1995).

Twb Monolithic lava breccia composed of Whitlow Canyon type rhyodacite lava.

Twi Two intrusive plugs of Whitlow Canyon type rhyodacite lava that crop out north of El Recortado and along the west edge of the map area along Willow Springs Canyon.

Trw A hybrid map unit consisting of quartz-phyric and quartz-absent rhyolitic lavas. The quartz-phyric lavas are similar petrographically to the Whitlow Canyon type rhyodacite lava (Tw) and they also have relatively large blocky sanidine and quartz phenocrysts. Some of the lavas mapped as part of this unit are petrographically more akin to the quartz-absent or quartz-poor rhyolite lavas (Trp, Trx).

Tr Rhyolite lava undifferentiated. Plagioclase, sanidine, biotite, and rarely quartz-phyric lavas. Numerous flows of rhyolite lava occur throughout the area, many exposed on cliff faces and other inaccessible areas so that petrographic characteristics could not always be determined. Three divisions of rhyolite lava map units were recognized based on phenocryst content only: crystal-rich: **Trx** (15-5%), crystal poor: **Trp** (0.5-5%), and aphyric: **Tra** (<0.5%). Phenocryst contents were visually estimated in the field and (where possible) compared to quantitative modal analyses reported by previous workers. Further subdivisions are possible and were used locally to help define structure, but are not portrayed on the map. In general, the more crystal-rich lava is the older in a sequence of rhyolites, and this holds true for the First Water, La Barge Canyon, and Fish Creek Canyon (easterly adjacent Horse Mesa Dam quad) areas. However, this is not the case north of El Recortado where aphyric lavas underlie crystal-rich lavas, and a crystal-rich intrusive plug intrudes a crystal-poor flow.

Except for the aphyric varieties, phenocrysts in the rhyolite lavas consist of sanidine and plagioclase, biotite, $\pm$ quartz . In general, the size of the phenocrysts depends on content; small (<2mm) in the more crystal-poor, and bigger (2-5mm) in the more crystal-rich varieties. Plagioclase is generally tabular and sanidine equant.

Tra Aphyric (<0.5% phenocrysts) rhyolite lava.

Trp Crystal-poor (between 0.5 and 5% phenocryst) rhyolite lava.

Trx Crystal-rich (between 5 and 10% phenocryst) rhyolite lava.

Trxx Very crystal-rich (15-20%), plagioclase, biotite-bearing felsic lava that occurs between the precaldera rhyolite and dacite lavas of the La Barge Canyon area. The lava occurs in the same stratigraphic position as the rhyodacite of Apache Gap, and because it has similar phenocryst mineralogy, the two lavas may be time-equivalent.

Tri Intrusive, crystal-poor rhyolite in part continuous with rhyolite lava flows. The unit occurs primarily as plugs and dikes, and it locally grades into outflow facies lava (Tr, Trp, and Trx). Contacts are not always shown between these units.

Trb Brecciated rhyolite lava undifferentiated. Breccias of crystal-rich (**Trxb**) and crystal-poor rhyolite lava (**Trpb**) are also recognized. In most cases this unit consists of basal, flow-front, foreset avalanche autobreccia, but it may also include other types (such as carapace breccia) in some areas.

Trpb Brecciated crystal-poor rhyolite lava.

Trxb Brecciated crystal-rich rhyolite lava.

Tt Crystal-poor, rhyolitic unwelded tuff. These pyroclastic rocks are mainly associated with felsic lava flows. The tuffs are almost everywhere bedded, ranging in thickness from a few cm to several meters. The unit consists mostly of lapilli tuff deposited as ash-flow tuff, ash-fall tuff, and surge deposits. The unit also consists locally of massive, clast-supported, block and ash-flow deposits, but these deposits were usually mapped along with the lava flows and domes with which they are associated.

Tbm Middle basalt. A single lava flow interbedded with rhyolite lava and tuff in the extreme northeast corner of the map area. The flow is deeply eroded and a vent is located directly to the east of the map in the upper part of Blue Tank Canyon. Lava contains a few percent plagioclase, pyroxene and olivine phenocrysts.

Trda Apache Gap type rhyodacite lava (Suneson, 1976). Crystal-rich (30-60%) lava containing phenocrysts of plagioclase and biotite. Sanidine and quartz are rare to absent. This unit is differentiated from the underlying dacite lava (Td) on the basis of lighter color and its tendency to have more vitric matrix, and from the porphyritic dacite lava (Tdp) on the basis of higher phenocryst content and because the rhyodacite does not contain quartz.

Tdp Porphyritic dacite lava. Moderately crystal-rich (15-30%), plagioclase, biotite, quartz-phyric dacite lava. These flows are more sparsely porphyritic than other dacite lavas (Td) and rhyodacite (Trda) in the area, and they are characteristically quartz-phyric. Phenocrysts of blocky, euhedral plagioclase, blocky embayed quartz, and biotite occur in a dark lavender matrix.

Td Dacite lava, undifferentiated. Crystal-rich (30-60%) lavas containing plagioclase, biotite, $\pm$ hornblende. A wide variety of colors and degrees of vitric preservation and microcrystalline matrix appearance are displayed by a thick pile of dacite lavas that occurs at or near the base of the pre-caldera volcanics. In general, the lavas appear more mafic or andesitic towards the base and more felsic or rhyodacitic towards the top, but in terms of diagnostic field characteristics (phenocryst petrology), they are virtually indistinguishable. In the Horse Mesa area of the easterly adjacent quadrangle (Gilbert and Ferguson, 1997) some of the flows contain abundant dioritic magma clots, and these flows are generally the youngest in the thick pile of dacite lavas of that area. Thick sequences of dacite autobreccia and tuff breccia (interpreted as block and ash-flow material) were locally differentiated as dacite breccia (**Tdb**), and in some areas the contact between these breccias and tuffs (**Tdt**) is gradational.

Ttd Dacitic, crystal-rich tuff, typically rich in dacite lava clasts. The unit is associated with the crystal-rich dacite and rhyodacite lava map units (Td, Trda).

Tdb Dacite lava breccia, differentiated were possible. Monolithic, tuff matrix and autoclastic matrix breccia of crystal-rich dacite lava.

Tdh A small body of fine-grained, hornblende-rich dacite (?) at the west end of El Recortado that appears to be cogenetic with a large mass of dacite (Td). Both the dacite and this hornblende-rich dacite may be in part hypabyssal in this area.

Tb Older basalt. Lavas containing a few percent plagioclase, pyroxene and olivine (typically altered to iddingsite) phenocrysts. The unit is present in two areas. North of Salt River thin flows directly overlie granitic rocks in the footwall of a major south-side-down fault. Farther south, basalt lavas overlie arkosic conglomerate (Tc) and underlie a thick pile of dacite lava (Td). In the southerly adjacent Goldfield quadrangle, basalt is interbedded with the same dacites (Tdc of Skotnicki and Ferguson, 1995), and at two localities in this map area, thin basalt occurs in association with the rhyodacite of Apache Gap (Trda).

Tbi Basalt dikes and other hybabyssal bodies in the Cottonwood Creek area that are probably related to the older basalt lava. The plugs which intrude granitic rocks contain abundant, felsic xenoliths and xenocrysts of K-feldspar.

Tbu Basalt lava, undifferentiated. Basalt lavas whose age relationships to other volcanic rocks is unknown. They occur only in the north-central part of the map area where they overlie Proterozoic granitoid (YXg) and underlie younger Tertiary sedimentary rocks (Tsy).

Tc Arkosic conglomerate, pebbly sandstone, and sandstone. These strata are dominantly plane-bedded or cross-stratified, medium- to thin-bedded, and clast-supported. Lithic clasts are mostly granitic.

EARLY AND MIDDLE(?) PROTEROZOIC UNITS

YXg Variably foliated, sparsely K-feldspar porphyritic granite, quartz monzonite or quartz monzodiorite. Foliations are consistently east to northeast-striking and steeply to moderately north-dipping. Foliation is interpreted as tectonic. C-S fabrics and shear sense were recognized locally.

Xv Metafelsite. Tectonically sheared quartz and feldspar porphyroblastic schist. Crystals are generally less than 5mm and range in abundance from 5 to 40%. The unit is interpreted as a felsic volcanic rock because it locally contains inclusions that appear to be lithic and pumice clasts. In the easterly adjacent Horse Mesa Dam quad, the map unit includes thin, tectonically interleaved argillaceous schist, some of which appears to be metaconglomerate.