Geologic Map of the Ninetysix Hills, Pinal County, Arizona

by

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INTRODUCTION

The Ninetysix Hills of Pinal County, Arizona, consist of a series of low hills and pediment situated about half way between the towns of Florence and Catalina, and are about 70 km (45 mi.) north of Tucson (see figure 1). The low spine of hills is underlain by at least four separate granitic plutons. The older pluton, a coarse-grained K-feldspar megacrystic granite exposed in the south, is intruded by a medium-grained granite to granodiorite. Both of these units are locally foliated, but have mineralogic and textural characteristics that suggest they do not belong to the regional suite of 1.65 to 1.7 Ga-old granites, but are younger. The quartz-porphyritic Teacup granodiorite (Krieger, 1974a, 1974b, Bradfish, 1979) comprises most of the northern part of the Ninetysix Hills, and is mapped to the north in the Grayback Quadrangle (Cornwall and Krieger, 1975) and North Butte Quadrangle (Spencer and Richard, 1997). The Teacup granodiorite appears to be intruded by a younger, medium- to coarse-grained, slightly peraluminous granite that forms the central part of the range. A correlation diagram is shown in figure 2.

This study encompasses the four USGS 7.5' quadrangles that encompass the Ninetysix Hills; they are (1) Ninetysix Hills NW, (2) Ninetysix Hills NE, (3) Ninetysix Hills SW, and (4) Ninetysix Hills SE. Most of the bedrock exposures were examined and mapped on the ground. The surficial deposits were largely mapped using approximately 1:24,000 scale black-and-white aerial photographs, dated 10/90, obtained from the US Geological Survey.

Access to the area is very good. Highway 80 cuts diagonally across the southwestern part of the map area. Branching off this road, the 96 Hills Ranch Road provides access to the northwestern part of the range. The Freeman Road is well maintained and provides excellent access to the southern and southwestern areas. The Freeman Road also crosses the range where it meets up with the Barkerville Road, which parallels the east side of the Ninetysix Hills. To the north the Barkerville Road intersects the Florence-Kelvin Highway—a well-maintained dirt road that provides good access to the northern part of the region. Several of the dirt roads that branch off these major roads are accessible even with a 2-wheel drive vehicle.

PREVIOUS WORK

Yeend and others (1977) made a reconnaissance geologic map of the Ninetysix Hills which included the same four quadrangles as the current study. Bradfish (1979) made a detailed study of the Teacup granodiorite from north of the Gila River to the south-central part of the Ninetysix Hills. His study included petrography and geochemical data. He divided the pluton into several different members, but these members were not remapped in the current study. Krieger (1974a, 1974b) mapped the Crozier Peak and Black Mountain quadrangles, respectively, to the east of the study area. To the north, Cornwall and Krieger (1975) mapped the Grayback quadrangle and Spencer and Richard (1997) mapped the North Butte quadrangle. Huckleberry (1993) mapped the surficial geology of the North Butte quadrangle as part of larger study along the middle Gila River.

GRANITES

Coarse-grained granite (Yg)

The coarse-grained granite is exposed in the southern portion of the Ninetysix Hills SE quadrangle and in the northeast corner of the Ninetysix Hills NE quadrangle. These two exposures were mapped as the same unit, although they have slight differences in the abundance of mafics. The granite in the south contains very abundant biotite (10-15%) and weathered exposures of the rock look rather dark. Exposures in the northeast do not contain as much biotite (5-10%?) and exposures overall look lighter in color. This difference may reflect variations within a single pluton or they may represent two separate intrusions. Without further work both outside the map area and by using better analytical procedures it is not possible to tell if the two are related.

The abundance of K-feldspar megacrysts and the presence of subhedral to anhedral fresh biotite books are both characteristics commonly observed in the suite of 1.4 Ga granites (Anderson, 1989; Anderson and Bender, 1989). Granites of this age have been traditionally classified as "anorogenic"

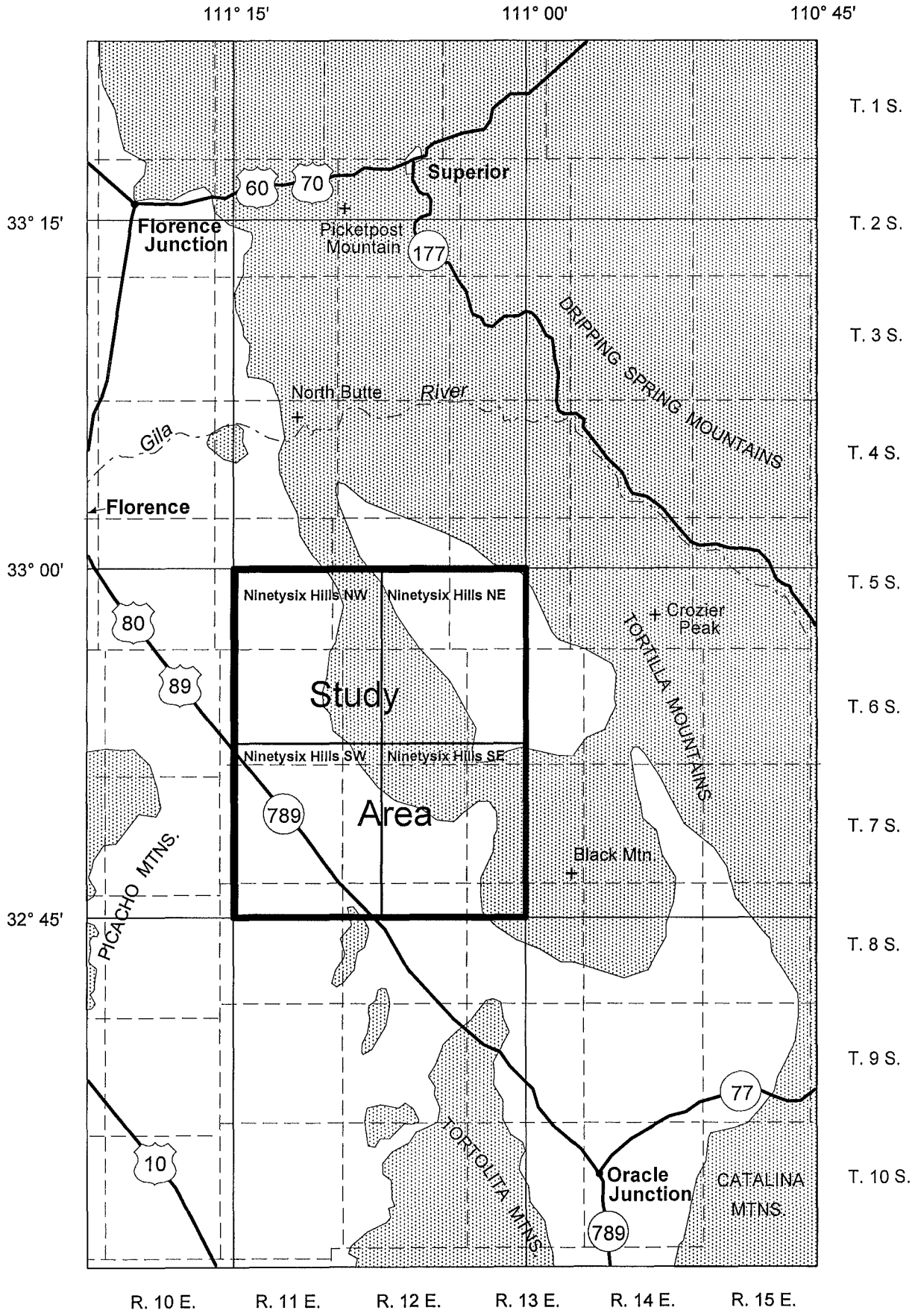

Figure 1. Location map of the Ninetysix Hills

because plutons of this age are not generally deformed. At first glance, the coarse-grained granite in the Ninetysix Hills also appears to be undeformed. However, this study has shown that this rock, particularly in the south, is actually cut by a series of widely spaced, narrow shear zones. The shear zones are from several centimeters to several meters wide with rather sharp boundaries with the surrounding unfoliated rock. Within the shear zones all of the phenocrysts are intensely sheared. Quartz is commonly stretched and elongated parallel to a prominent lineation defined by alignment of biotite. Most of the shear zones strike northeast. On the east side of the Ninetysix Hills SE quadrangle a wide, north-south-striking shear zone (width unknown) truncates the northeast-striking shear zones. Within this wider zone the coarse-grained granite as well as the medium- to coarse-grained granite/granodiorite (map unit Tyg) are both intensely sheared. On the west side of this zone, where shearing is most intense, individual phenocrysts are no longer identifiable. Instead protomylonitic and strong mylonitic fabrics have developed. Grain-size reduction during mylonitization has resulted in a sheared rock that locally appears fine-grained.

A biotite K-Ar age of 1150 ± 28 Ma for a pegmatite dike cutting this granite to the east (Shafiqullah and others, 1980)—if it is the same granite—indicates that the rock has not experienced temperatures greater than about 300°C since that time.

Medium to coarse-grained granite/granodiorite (TYg)

This granitic rock was mapped in several widely spaced exposures in all four quadrangles (in the Ninetysix Hills SW quadrangle the unit mapped as TXg may be equivalent). Yeend and colleagues (1977) mapped these different exposures as two different rock units. There are textural differences between them but they are partially masked by the overprinting of ductile deformation in the south. The mineralogy in all of the exposures is very similar—medium- to coarse-grained, biotite with minor hornblende, abundant yellow-green sphene (titanite)—and each has similar weathering characteristics. It must be pointed out, however, that it is possible the exposures in the north and south may represent different plutons.

In the Ninetysix Hills SE quadrangle this granite intrudes along the contact between coarse-grained granite (map unit Yg) and Pinal Schist (map unit Xp). The contact between TYg and Yg is almost nowhere exposed. Where the contact is exposed in section 21, T. 7 S., R. 13 E., it coincides with the boundary of a wide, north-south-striking shear zone (as described in the previous section). The contact is sharp but the true nature of the contact between the granites is ambiguous.

Like the coarse-grained granite (Yg) this pluton is also foliated. However, unlike Yg where foliation is mostly restricted to narrow, mylonitic shear zones, foliation in this granite is pervasive. Nearly every exposure observed (in the Ninetysix Hills SE quadrangle) is foliated. The foliation is not as intense as in Yg. The only mylonite observed was within the wide north-south-striking shear zone just mentioned. Instead, biotite crystals are weakly to strongly aligned. Towards the eastern side of the quadrangle an S-C fabric becomes better developed, such that the individual C-planes (spaced about 1-3 cm apart) can be measured. A lineation defined by alignment of biotite is well developed on the S-surfaces. In this area the shearing of the S-surfaces indicates a normal, near-dip-slip sense of movement.

Along Brady Wash dark biotite-rich inclusions in the granite are elongated with their long-axes aligned parallel to the plane of foliation. These foliated areas grade laterally into areas that show only a very weak foliation, but even though the foliation is weak the elongated inclusions are still oriented parallel to it. This suggests that the foliation event occurred at the same time as intrusion of the granite, so that inclusions in the melt were aligned while the rest of the rock did not yet posses enough shear strength to inherit a foliation. The widely spaced nature of the shear zones in Yg may be an indicator that the foliation event occurred after that pluton had crystallized and had cooled below a temperature of about 500 °C. It is these two observations that are the basis for concluding that TYg is younger than Yg.

Good exposures of this unit can be seen west and northwest of Coyote Peak. In these areas the granite intrudes Pinal Schist. A band of this rock extends along the west side of the Pinal Schist from Coyote Peak northward to 96 Ranch. The younger granite (map unit Tg) parallels this same contact a little farther to the west. The map pattern of TYg here suggests it may have intruded both Xp and Tg, but dikes of Tg clearly intrude TYg.

Exposures on the west side of the Ninetysix Hills NE quadrangle near Helmwheel Ranch are nonfoliated. Here, fresh rock along Box O Wash reveals fresh biotite, and hornblende crystals 2-3 mm long in conspicuous rectangular, single-crystal laths and as small clots. Here the contact with the Teacup granodiorite is sharp. These exposures are similar to rock directly west at Allens Peak in the Ninetysix Hills NW quadrangle.

Teacup Granodiorite (TKg)

The Teacup granodiorite is a Laramide-age granitic pluton recognized and mapped as far north as the Gila River (Krieger, 1974a, 1974b). In the Ninetysix Hills this pluton is characterized by conspicuous subhedral, gray quartz phenocrysts in a coarse- to medium-grained matrix of light gray feldspar and fresh subhedral to anhedral biotite. The rock defines an area in the northern parts of the Ninetysix Hills NE and NW quadrangles that is almost completely devoid of relief. Instead it underlies a broad, nearly flat pediment dissected deeply by Box O Wash. Alluvial deposits within Box O Wash show that the deep channel was first cut, then filled with sediment, and is now undergoing down-cutting a second time.

The contact with the coarse-grained granite (map unit Yg) is undulatory and sharp. Mapping the contact across the pediment southeast of Helmwheel Ranch was very difficult. In this area the two units are both coarse-grained and erode in the same manner. Exposures on the pediment are mostly mantled by a thin regolith of grus. However, in general, the Teacup granodiorite weathers into slightly lighter colored rounded boulders than does Yg. There is some variation in the amount of biotite present but not much time was devoted to determining if this variation was mappable.

The contact with the younger granite (map unit Tg) was only exposed in very tiny exposures southwest of Helmwheel Ranch below a hill of conglomerate. The contact there is sharp but it could not be determined which rock intrudes the other. Numerous east-west-striking felsic and intermediate dikes intrude the Teacup granodiorite. None of these dikes intrudes Tg. Based on this, it was concluded that Tg is younger than TKg.

Younger granite (Tg)

This rock unit forms the central part of the Ninetysix Hills and is exposed in all four quadrangles. It is medium to coarse-grained and contains mostly biotite but also appreciable muscovite (up to ~20% of total mica). In sections 4 and 9, T. 7 S., R. 12 E., this pluton contains numerous felsic dikes that have a composition slightly more leucocratic than the pluton itself. Some of the dikes are pegmatitic. However, on weathered surfaces these dikes have almost the same color and texture as the granite and are very difficult to distinguish except by carefully following the dikes. Even on aerial photos the dikes are only partially distinguishable. I did not have the time to follow the dikes on the ground, so therefore I did not map them separately. In the northwest corner of the Ninetysix Hills SE quadrangle where the granite intrudes TYg, the contact is almost everywhere sharp, although locally complex. Small dikes of Tg a meter or two thick project from the main mass of Tg and intrude TYg and Pinal Schist.

In sections 34, 35, and 36 of T. 7 S., R. 12 E. in the Ninetysix Hills SE quadrangle this pluton is foliated. A weak foliation defined by weakly aligned biotite and muscovite crystals becomes progressively stronger eastward. Here alignment of micas, elongation of quartz, and elongation of augen-shaped feldspar phenocrysts define a protomylonitic to mylonitic foliation. Thin leucocratic and pegmatitic veins are almost parallel to foliation; some veins are not foliated while some are. A prominent lineation is mostly defined by alignment of micas. Since this pluton is probably younger than the Teacup granodiorite, the foliation is probably Tertiary in age. Mylonitic foliations in granitic rocks are associated with mid-Tertiary extension of the Catalina-Rincon core complex not far to the southeast (Banks and others, 1977; Banks, 1980; Keith et al., 1980). It is possible that foliation in Tg may also be associated with that same style of deformation during the same tectonic episode.

Bradfish (1979) cites an oral communication from W. Rehrig (1978) that the granite at Middle Mountain has been dated by Richard Armstrong at the University of British Columbia who found a K-Ar muscovite age of 1280 ± 50 Ma. The date seems too old for a granite that is petrographically very similar to the main mass of granite in the Ninetysix Hills.

TERTIARY CONGLOMERATE

The alluvial plains surrounding the bedrock in the Ninetysix Hills were originally at a higher level than they are today. Remnants of older conglomerate (map unit Tc) are found along the flanks of the hills, commonly up close to the bedrock. These exposures show a style of sedimentation that was different from the style that occurred later in the Pleistocene. Deposits of Tc are commonly poorly sorted with weak bedding, and contain angular to subrounded pebble- to boulder-size clasts of granite and schist in a sandy matrix. Where good exposures exist, most deposits are clast-supported to weakly matrix supported. The clasts within the deposits are almost everywhere much fresher than the same rock in outcrop. These sediments were deposited in a high-energy environment, possibly as debris flows in the proximal facies of near-mountain alluvial fans. The greater relief that probably existed at that time was probably the result of faulting and relative uplift along the mountain front that is now the Ninetysix Hills.

Although deeply dissected, a layer of rubble mantles most of these outcrops. As a result it was difficult to find fresh exposures that revealed bedding orientation. Exposures in the stream-cuts along Bogard Wash in the southeast corner of the Ninetysix Hills SE quadrangle reveal bedding which is nearly horizontal. The best exposures are in the southeast corner of the Ninetysix Hills NW quadrangle. Here, some fresh exposures in stream-cuts reveal bedding dipping between about 20-40 degrees to the east. Here also, in section 13, T. 6 S., R. 12 E., a yellow lithic tuff is interbedded with Tc and dips about 12 degrees to the northeast. These attitudes clearly show that these deposits have been faulted and rotated.

STRUCTURE

Faults

Faults are not easily discernable in granite unless they juxtapose different rock units. The north-south-striking fault in the southeast corner of the Ninetysix Hills SE quadrangle was mapped mostly by aerial photos. On the ground there is a noticeable increase in slope across the fault but the fault itself is invisible.

As described in the section about the Tertiary conglomerate (map unit Tc) in the southeast corner of the Ninetysix Hills NW quadrangle this unit is tilted 20-40 degrees to the east. This almost certainly indicates that these rocks were cut by west-dipping normal faults that probably began as high-angle faults and subsequently tilted to lower angles. The contact between Tc and the underlying granite (map unit Tg) is ambiguous. The map pattern is consistent with both a depositional contact and a low-angle fault contact. Along the northern part of the contact there is nothing that indicates it is a fault. Along the southern part of the contact, southward into the Ninetysix Hills SW quadrangle, the granite along the contact is fractured, locally brecciated, and stained with hematite. There is also poorly exposed white quartz in a few places along the contact. This mineralization suggests the contact is a fault. Because the evidence is not definitive I drew the contact as depositional.

In the southwest corner of the Ninetysix Hills NE quadrangle the contact between map units Tg and Yg is sharp, but also ambiguous. Only at one location was there enough relief to observe the contact in a vertical section. This location is marked with an attitude arrow dipping 62 degrees north. Here both granites are fractured and locally brecciated 2-5 meters on either side of the contact, which, at this location, is almost definitely a fault. At this location, grain-size has been reduced and chlorite alteration is abundant. Tg locally forms a resistant ridge along the contact. Immediately west of this exposure the fault is filled with a 2 meter-thick quartz vein. There are no other definitive exposures anywhere else along the contact.

In the NE quadrant of section 24, T. 7 S., R. 12 E., about 1.5 cm (on the map) from the number, the contact between Tc and TYg is rather steep—about 50-60 degrees. The contact lines up across the wash and TYg is fractured, but the exposures are small and covered with much slope-wash. The contact may be depositional, but the steepness of it suggests it may be a fault.

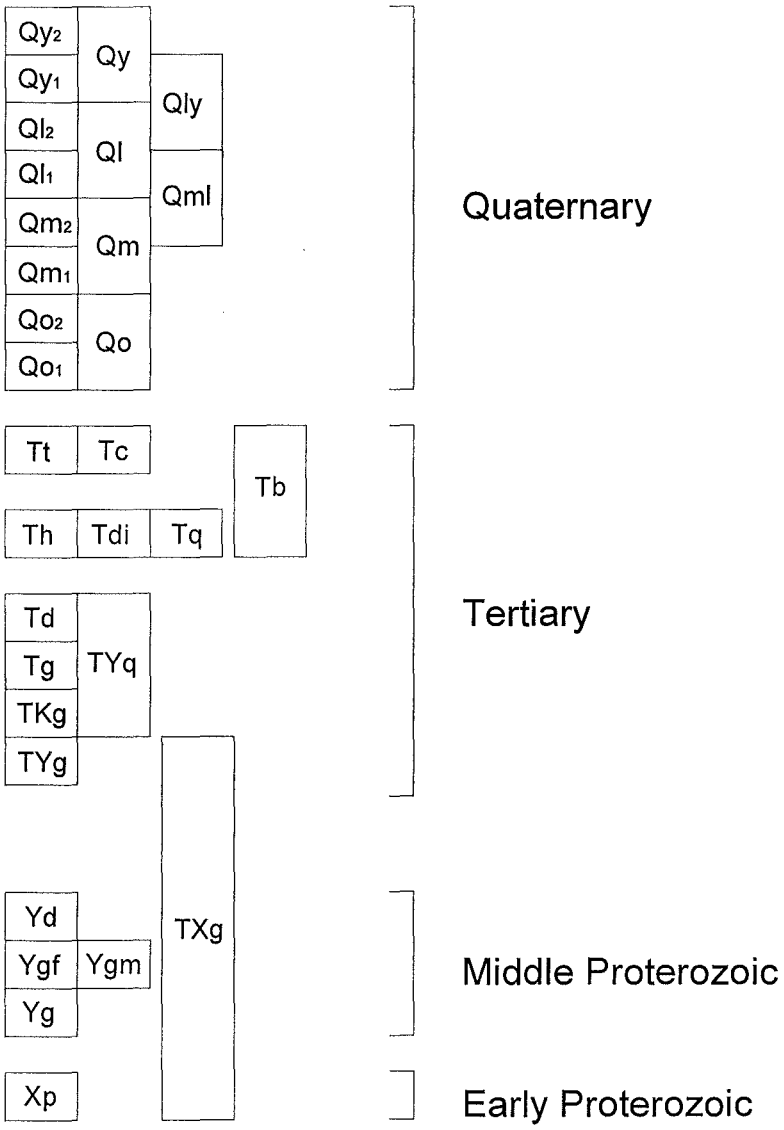

Figure 2. Correlation diagram for the Ninetysix Hills.

Shear zones

As described in the section on granites, widely spaced, northeast-striking shear zones in the coarse-grained granite (map unit Yg) and pervasive foliation in rocks of map unit TYg are truncated by a north-south-striking mylonitic shear zone on the east side of the Ninetysix Hills SE quadrangle. As described, the biotite age for Yg and the syntectonic nature of TYg both suggest that the foliation event that created the northeast-striking foliation occurred during the Proterozoic. The age of the event that created the north-south-striking foliation, however, is not well constrained. Many augen-shaped feldspar phenocrysts are broken and cataclastically reduced in size while some are locally elongated and smeared out along the foliation plane. Ductile deformation of feldspar occurred at temperatures above about 500°C, either in an area of upper crustal magmatism or at ambient temperatures in the mid-crust (depths of 15-20 km).

In the northeast corner of the Ninetysix Hills NW and in the northwest corner of the Ninetysix Hills NE quadrangle two narrow shear zones cut across the Teacup granodiorite. The shear zones are between 1-3 meters wide and are locally filled with white quartz, which is also foliated. Foliation dips moderately to steeply to the south and locally a weak lineation points to the south-southeast.

As described in the section on granites, the younger granite (map unit Tg) is strongly foliated on its southeastern side. Exposures are limited but some outcrops reveal a mylonitic foliation. Because this granite is probably younger than the Laramide-age Teacup granodiorite, this foliation is probably Tertiary in age.

MINERALIZATION

In the northeast corner of the Ninetysix Hills NE quadrangle a shaft (with an intact headframe) has been dug into a fracture zone in map unit Ygm about 10 meters south of the contact with a dacite dike (map unit Tdi). The fracture zone has an attitude of N60°E, 58°S, and contains abundant hematite, malachite, and minor chrysocolla in fractures. The dacite dike itself is not mineralized. This fracture zone is approximately parallel to mineralized joints/fractures cutting map units Ygm and Yg in the surrounding area. The joints are lined with hematite and/or chrysocolla. Many pits and trenches were dug to the northeast of the mine, in section 15, T. 5 N., R, 13 E. Most also contain hematite and chrysocolla.

Along the contact with map unit Tc in the southeast corner of the Ninetysix Hills NW quadrangle and the northeast corner of the Ninetysix Hills SW quadrangle, the younger granite (map unit Tg) is fractured and locally brecciated. Pits have been dug in places. Fractures are filled with abundant red hematite and some chrysocolla. These exposures are red to rusty orange and have been mapped with a stipple pattern on the map.

Immediately north of the intersection of Freeman Road and Highway 80 a shaft has been dug into Pinal Schist at least about 7 meters deep. White vein quartz stained with hematite was found on the mine dump but no other minerals were seen.

Northwest of Middle Mountain on the eastern side of the Cactus Forest quadrangle, two small hills underlain by what resembles TYg are pervasively fractured and altered. Most of the mafic minerals are altered to what looks like chlorite(?). Deep workings have been dug along nearly north-south-striking veins of manganese minerals (probably psilomelane). One major vein is 1-1.5 meters wide in places, but the whole west side of the larger, southern hill contains a myriad of fractures filled with black manganese and minor white calcite. The granite itself has been altered to a deep red color and is intensely brecciated locally. Spaces between breccia clasts are filled with dark manganese.

In the southeast corner of the Ninetysix Hills SW quadrangle, sitting on top of the hill of TXg are clasts of granite breccia. The matrix between clasts contains abundant red hematite. These clasts do not look in-place.

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Qy **Holocene alluvium (< 10 ka)**—Unconsolidated sand to small boulders reaching sizes up to 25 cm in diameter upstream but smaller and fewer downstream. Larger clasts are Pinal Schist and granite. Smaller clasts are subangular granitic grus. Qy deposits are characterized by stratified, poorly to moderately sorted sands, gravels, and cobbles frequently mantled by sandy loam sediment. On this surface the main channel commonly diverges into braided channels. Locally exhibits bar and swale topography, the bars being typically more vegetated. Soil development is relatively weak with only slight texturally or structurally modified B horizons and slight calcification (Stage I). Some of the older Qy soils may contain weakly developed argillic horizons. Because surface soils are not indurated with clay or calcium carbonate, these surfaces have relatively high permeability and porosity.

Qy_2 **Late Holocene alluvium.**

Qy_1 **Middle to early Holocene alluvium.**

Qly **Late Pleistocene to early Holocene alluvium.**

Ql **Late Pleistocene alluvium (10 to 250 ka)**—Moderately sorted, clast-supported sandstones and conglomerates containing much granitic grus in a tan to brown sand and silt matrix. Ql surfaces are moderately incised by stream channels but still contain constructional, relatively flat interfluvial surfaces. Ql soils typically have moderately clay-rich tan to red-brown argillic horizons. Ql soils contain much pedogenic clay and some calcium carbonate, resulting in relatively low infiltration rates. Thus these surfaces favor plants that draw moisture from near the surface. Ql soils typically have Stage II calcium carbonate development.

Ql_2 **Late Pleistocene alluvium, younger member.**

Ql_1 **Late Pleistocene alluvium, older member.**

Qml **Middle to late Pleistocene alluvium.**

Qm **Middle Pleistocene granitic alluvium (250 to 750 ka)**—Sandy to loamy, tan-colored sandstones and minor conglomerates. The deposits are moderately consolidated and locally weakly indurated by carbonate. Argillic horizons typically are weak to moderate, probably because they have been eroded. The unit is fairly deeply dissected and forms much of the piedmont in the western part of the study area where it is best exposed as proximal fans. Argillic horizons are strongly developed where original depositional surfaces are well preserved, particularly two miles southwest of Coyote Peak on the north side of the larger hill. These argillic horizons are much weaker or nonexistent on ridge slopes. These deposits are well exposed in cross-section along the wide Brady Wash and along Paissano Wash where it overlies granite. Along the washes the deposits are only about 5-8 meters thick and are poorly to moderately consolidated with minor carbonate in the matrix. Locally, well-developed caliche horizons are visible. Soils are tan to red.

Qm_2 **Middle Pleistocene alluvium, younger member.**

Qm_1 **Middle Pleistocene alluvium, older member.**

Qo **Early Pleistocene alluvium (750 ka to 1.6 Ma)**—The composition of this unit varies slightly, but it is dominantly composed of granite grus in a sandy to silty matrix. Pebble- and larger-size clasts up to 50 cm are subangular to subrounded and are composed mostly of fine- to medium-grained granites and less abundant Pinal Schist (map unit Xp). The coarser-grained granites crumble easily and are under-represented in these deposits. A dark red-brown soil is commonly developed over a stage II pedogenic caliche horizon about 1.5 to 2 meters below the original constructional surface. In some places the unit contains clasts of tan to purple argillite and well-rounded quartzite cobbles. In the Ninetysix Hills NE quadrangle this unit is deeply dissected by Cottonwood and Box O Washes. The sediments below the caliche horizon have the same sedimentology as those above, but they are much thicker. In this area they could justifiably be mapped as QTs.

Qo_2 **Early Pleistocene alluvium, younger member.**

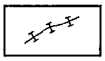
Qo_1 **Early Pleistocene alluvium, older member.**

Tt **Lithic tuff (middle to late Tertiary)**—Light yellow, bedded lithic tuff. This tuff is fine- to medium-bedded. Some beds are lithic-rich and contain sand, pebbles, and subrounded cobbles of granite (TKg, Tg, and even Yg). Lithic-poor beds contain some sand but are nearly massive. The tuff appears to contain very small phenocrysts of subhedral biotite, quartz, and possibly feldspar; however, it is difficult to distinguish between phenocrysts and lithics. Forms a yellow ledge interbedded with conglomerate in the southern part of the Ninetysix Hills NW quadrangle.

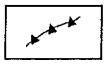
Tc **Conglomerate (middle to late Tertiary)**—This unit is composed of interbedded coarse sandstone and conglomerate that weathers into rounded, mantled hills with few fresh exposures with visible bedding. Most weathered exposures are tan to gray and fresh cuts are almost steel gray. Deposits are characteristically very poorly sorted and contain large bounders of various types of granite and Pinal Schist in a sandy to pebbly matrix. Strongly to moderately consolidated by carbonate cement. Most clasts are subrounded to angular. Granite clasts are commonly much fresher in these deposits than they are in outcrop. In some fresh exposures bedding is very faint and exposures look mostly massive. Limited exposures east of Coyote Peak in the Ninetysix Hills SE quadrangle contain abundant clasts of fossiliferous limestone, lesser gray to dark red quartzite and tan argillite, orange granite and granite porphyry, as well as granite and schist.

Tb **Basalt (middle Tertiary)**—This dark gray rock contains phenocrysts of faint gray feldspar 2-5 mm long, and locally dark rusty orange phenocrysts that my be altered pyroxene and/or olivine, all in a dark gray to gray-green aphanitic matrix. This unit is similar to mafic dikes shown as a hatchured line on the map.

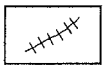
Th **Hypabyssal dacite (Middle Tertiary)**—Light gray, crystal-rich felsite containing conspicuous phenocrysts of subhedral quartz 5-8 mm wide, local K-feldspar the same size, light gray feldspar 2-4 mm wide, and biotite 1-2 mm across, all in a gray aphanitic matrix. This rock has the same mineralogy as the dacite dikes (map unit Tdi) but is more nearly holocrystalline, more coherent, and more resistant. This rock intrudes TKg in the northwest corner of the Ninetysix Hills NE quadrangle where it forms tabular, east-west-striking dike-like bodies.



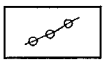
Dacite dikes (Tertiary)—Crystal-rich, coarse-grained dikes containing subhedral, light gray plagioclase 3-4 mm long (and commonly up to 1 cm), and subhedral to euhedral, fresh biotite books 2-8 mm across, all in a medium to dark gray aphanitic matrix. On weathered surfaces feldspars are bleached white. In some dikes all of the crystals and the matrix are altered to fine-grained serricite.



Granitic dikes (Tertiary)—These dikes are mapped as offshoots of both the Teacup Granodiorite (map unit TKg) and the younger Tertiary granite (map unit Tg).

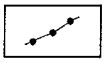


Mafic dikes (Tertiary)—Dark gray dikes containing phenocrysts of gray plagioclase 1-2 mm long, and locally hornblende or pyroxene also 1-2 mm long, in a dark gray aphanitic matrix.



Biotite-feldspar porphyry dikes (Tertiary)—Rocks of this unit contain subhedral feldspar and biotite phenocrysts 1-3 mm long and less abundant round quartz phenocrysts, in a light gray to locally vitric aphanitic matrix. Crystals comprise about 2-5% of the rock and are locally aligned parallel to the sides of the dikes in what is probably a flow foliation. These dikes are very similar to the quartz-porphyry dikes and the two appear to grade into one another.

Quartz porphyry dikes (Tertiary)—Dikes of this unit contain 2-4 mm subhedral gray quartz in a very fine-grained matrix of feldspar and quartz. Less than 1% biotite and muscovite(?), <1 mm diameter, are aligned near-vertically. The dikes are light gray to tan and erode into small angular blocks and resistant light gray ridges. Possibly these are the same dikes that Spencer and Richard (1997) mapped as aplite dikes.



Pegmatite dikes (Tertiary)—These coarse-grained and locally medium-grained dikes contain quartz, K-feldspar, muscovite, and locally very minor red garnet and black tourmaline. They intrude Pinal Schist and coarse-grained granite (map unit Yg) in the Ninetysix Hills SE quadrangle. Where they intrude Yg they form a swarm of northeast-striking dikes.

Tdi **Dacite dikes (Tertiary)**—This crystal-rich, quartz-porphyritic rock contains subhedral gray quartz 5-8 mm wide, light gray subhedral feldspar 2-5 mm wide, and subhedral to euhedral dark green biotite with minor dark green hornblende. A minor accessory mineral visible in hand sample is a long, green mineral that may be epidote or sphene (titanite). Quartz phenocrysts are prominent on weathered surfaces. Locally the color and texture of these dikes are similar to those of map unit Ygm and the two rocks are sometimes difficult to distinguish. Intrudes rocks of map unit Ygm and TKg. In the northeast corner of the Ninetysix Hills NE quadrangle, hematite, malachite, and chrysocolla have been dug from a mine about 10 meters south of a wide, northeast-striking dacite dike. The dike, however, is not mineralized.

Tq **Vein quartz (Tertiary)**—Light gray to white quartz veins within the Teacup Granodiorite in the Ninetysix Hills NE and NW quadrangles. In this area the quartz veins occur as a discontinuous vein filling a mylonitic shear zone in the granite. The quartz itself is sheared and fractured with the fractures locally filled with hematite.

Td **Fine-grained diorite (Tertiary)**—Fine-grained, dark green dioritic intrusions contain light gray feldspar (plagioclase) 1-2 mm long, and biotite and hornblende almost completely altered to dark green chlorite. Biotite is both disseminated and forms clumps up to 5 mm wide that appear as dark spots in hand sample. Intrudes map unit Yg in the Ninetysix Hills NW quadrangle.

Tg **Granite (Tertiary)**—This granite contains light gray anhedral to subhedral phenocrysts of feldspar up to ~8 mm, dark clear-gray quartz, and 5-10% mica (biotite ~80%, muscovite ~20%,

but varies with location). At Middle Mountain on the south side of the Ninetysix Hills NW quadrangle the granite appears to contain mostly muscovite (could biotite be weathering to look like muscovite?). K-feldspar and plagioclase are difficult to distinguish in hand-sample. Feldspars give outcrops a light gray color. The darker anhedral quartz gives the rock a spotted appearance. Micas occur both as thin individual sheets and as subhedral books 2-5 mm wide. This granite is cut by pegmatitic and leucocratic granite dikes, particularly near the contacts with older rocks. These dikes are also light gray and are difficult to distinguish from the granite itself. Because of this similarity the dikes were not mapped separately except where they cut across older rocks. In at least one location the rock contains very sparse, dark, subhedral, red garnet 5-10 mm wide. The rock is generally unfoliated except on the southeastern side of the pluton where augen-shaped feldspars, elongate quartz, and aligned micas define a protomylonitic fabric. Fresh surfaces of this granite are light gray and weathered surfaces are light tan to orange. Jointing is locally prominent. Weathered rock forms steep, smooth granular exposures. The contact with the Teacup granodiorite is very poorly exposed, but since dikes cutting TKg do not cut Tg, Tg is inferred to be younger.

TKg **Teacup Granodiorite (Late Cretaceous to Early Tertiary)**—This rock unit contains conspicuous, abundant, gray, anhedral, quartz phenocrysts 0.5 to 1.5 cm wide, surrounded by light gray anhedral to subhedral feldspar and 2-5% biotite and locally minor muscovite. Biotite is relatively fresh and locally altered to hematite. Biotite occurs as anhedral to subhedral crystals and thin books commonly 3-4 mm wide but locally as large as 1 cm. This rock contains much less biotite than the coarse-grained granite (map unit Yg) and does not contain any large conspicuous K-feldspar megacrysts. The unit everywhere crumbles into low relief, light gray, grus-covered hills and pediment. It is difficult to find fresh, competent rock. The rock is intruded by dacite dikes, quartz-feldspar porphyry dikes, and mafic dikes.

TYq **Vein quartz (Middle Proterozoic or Tertiary)**—This white quartz occurs as 1-4 meter-wide veins exposed in two places: (1) on the east side on the Ninetysix Hills NE quadrangle where it cuts rocks of map unit Ygm, and (2) on the east side of the Ninetysix Hills SE quadrangle where it crops out in small isolated hills surrounded by alluvium but is presumably hosted by granitoids of map unit TYg. Exposures are everywhere brecciated with fracture surfaces coated with hematite.

TYg **Medium to Coarse-grained granite/granodiorite (Tertiary, Mesozoic, or middle Proterozoic)**—This pluton is mostly medium-grained, locally coarse-grained, and contains subhedral phenocrysts of light gray feldspar, abundant clear-gray quartz, and biotite. Locally contains small, dark tabular inclusions of biotite and magnetite(?) from about 5 to 20 centimeters long. Locally, the rock contains large phenocrysts of K-feldspar up to 3 cm long and superficially resembles granite of map unit Yg. Both the long axes of these inclusions and the long axes of the K-feldspar megacrysts are nearly everywhere aligned parallel to the foliation (marked with a symbol on the map). This unit is deformed by a pervasive weak to strong foliation. In some areas the foliation is so strong the rock is gneissic and contains leucosomes of medium-grained quartz and feldspar and melanosomes of biotite and feldspar. In some exposures a slightly more felsic variety of granite is in sharp contact with a more mafic variety. On the east side of the Ninetysix Hills SE quadrangle north of the road, the rock is locally only weakly deformed and contains minor hornblende crystals up to about 5 mm long and abundant yellow-green sphene (titanite) phenocrysts that look like small yellow spots on fresh surfaces. On the south side of the road the unit exhibits a prominent foliation with evidence of both shear and flattening fabric elements (S-C fabric). Two-to-five-cm-wide leucocratic granitic dikes locally intrude the rock. The dikes are oriented parallel to the foliation plane in the granite and are themselves foliated.

TXg **Granite (Tertiary, Mesozoic, or middle Proterozoic)**—This equigranular medium- to fine-grained granite contains anhedral gray quartz, subhedral light gray to pink feldspar, and biotite, all 2-4 mm. Biotite is abundant, partially to mostly altered to chlorite, and is evenly distributed throughout the rock. The unit is pervasively foliated. Foliation is mostly weak but is much stronger in shear zones tens of centimeters wide. In the shear zones strongly lineated mylonitic fabric is common, with the stretching lineation defined by elongation of biotite and quartz. The rock is intruded by rare leucocratic granite dikes and quartz veins (both foliated) and younger quartz vein (unfoliated) several centimeters wide. Some of the shear zones are very fine-grained and contain large amphibole and rare epidote porphyroblasts(?) up to about 5 mm. Some of the shear zones may have followed dikes of intermediate composition. The boundary between these amphibole-rich zones and the granite is sharp. This unit was mapped as only one hill at the southern boundary of the Ninetysix Hills SW quadrangle, where it weathers into steep rounded outcrops covered by subangular boulders. It is possible this is the same as map unit TYg.

Yd **Diabase (middle Proterozoic)**—This dark green rock contains abundant, gray, tabular phenocrysts of plagioclase 2-8 mm long and gray-green altered pyroxene in a dark gray-green aphanitic matrix. Just south of Helmwheel Ranch in the Ninetysix Hills NE quadrangle the unit contains yellow-green pyroxene(?) 1-2 mm long. Forms dark-colored, low crumbly hills. Intrudes map units Yg and TYg.

Ygf **Fine-grained granite (middle Proterozoic)**—This mostly equigranular granite contains small 1-2 mm wide phenocrysts of quartz, feldspar and biotite. Locally, the rock contains large subhedral K-feldspar phenocrysts 1-3 cm long and anhedral quartz 2-5 mm across. The rock erodes into small angular pieces and is locally slightly darker than the coarse-grained granite (map unit Yg). This is equivalent to map units Ygf and Ygp of Spencer and Richard (1997).

Ygm **Medium-grained granite (middle Proterozoic)**—Medium- to fine-grained and locally slightly coarse-grained granite. Mostly equigranular with local, uncommon, large subhedral quartz and/or K-feldspar phenocrysts up to 1 cm across. Contains gray quartz, light gray to pink feldspar and fresh anhedral to subhedral biotite. Biotite is locally partially altered to hematite. Quartz has been weakly stained by hematite and gives the rock a light orange color. On the west-central side of the Ninetysix Hills NE quadrangle slightly more leucocratic granitic veins (not mapped separately) locally cut the unit. In the northeast corner of the same quadrangle the rock has been intruded by northeast-striking dacite dikes. The dikes are parallel to a prominent jointing locally mineralized with hematite and minor chrysocolla. Most exposures are light orange and weather into small angular blocks on rocky outcrops. In the northeast corner of the Ninetysix Hills NE quadrangle there appear to be two varieties—a biotite-rich variety and a muscovite-rich variety, with uncertain relationships. In the same area Ygm appears to complexly intrude map unit Yg in a myriad of irregularly shaped veins and bodies. In this area the two rocks were not mapped separately.

Yg **Coarse-grained granite (middle Proterozoic)**—This coarse-grained granite contains phenocrysts of clear-gray quartz, light gray subhedral plagioclase, fresh anhedral to subhedral biotite in small books, and subhedral light gray to light pink K-feldspar. The K-feldspar crystals are commonly 1-1.5 cm across, but megacrysts up to 4 cm are locally abundant. Foliation in this unit is confined to narrow, intensely sheared zones several centimeters to meters wide. In these zones a prominent lineation is defined by alignment of biotite. In the southeast corner of the Ninetysix Hills SE quad the long axes of the K-feldspar phenocrysts are locally weakly aligned and marginally resembles a flow foliation (marked with a symbol on the map). Also in this area the rock is cut by thin foliated aplite dikes, and pegmatite dikes that do not appear to be foliated.

This unit weathers into rounded boulder-covered hills and dissected pediment. Most outcrops crumble after a few blows with a rock hammer.

Xp **Pinal Schist (early Proterozoic)**—This schist contains mostly coarse-grained muscovite and quartz, with less abundant biotite (mostly altered to chlorite), minor feldspar and opaques, and trace tourmaline and red garnet. Where finer-grained the dark opaque minerals (<1 mm) contrast with the lighter gray serricitic matrix. In many areas the rock contains segregated bands of quartz and mica, some of which are highly contorted. These bands are generally parallel to the primary foliation, but locally are folded and are cut by it. Locally a secondary foliation forms kinks in the primary foliation spaced millimeters to centimeters apart. The schist weathers into dark hills covered with angular outcrops that appear smooth when viewed from a distance.