Geologic Map of the North Butte Area, Central Arizona

by

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Open-File Report 97-4

March, 1997

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This report is preliminary and has not been edited or reviewed for conformity with Arizona Geological Survey standards.
INTRODUCTION

The North Butte area was mapped during the 1995-1996 winter field season as part of the Arizona Geologic Survey mapping program to complete the Mesa 30 by 60 minute quadrangle. The area is one of extensive low relief pediments cut on Proterozoic and Laramide granitoid, and Tertiary conglomerate. North and South Butte are the major physiographic features of the area, both underlain by Tertiary felsic lavas. Rugged terrain is also present in the northeastern part of the map area, underlain by Tertiary hypabyssal rhyolite intrusions. Surficial geology of the North Butte Quadrangle was mapped by Huckleberry [1993], and the interested reader is referred to this map for more information on the surficial geology. Access to the area is via a good graded dirt road that connects Cochran with the Florence-Kelvin road, roads along the north and south side of the Gila River as far east as the west side of North or South Butte respectively, and a four-wheel-drive jeep trail into the northeastern part of the map area, north of the Gila River, that is accessed southwest from the Walnut Canyon Road in the Teapot Mountain Quadrangle. Donnelly Wash and Box "O" washes are both passable in a four-wheel-drive vehicle. Box "O" Wash cannot be traversed from the Florence-Kelvin Road all the way to the Gila River because of fenced private land near the south edge of the map area.

The major geologic feature of the area is an east-tilted block of pre-Tertiary igneous rocks overlain by a gently to moderately east-dipping section of Tertiary volcanic and sedimentary rocks. This block is bounded on the west by an unnamed range-bounding fault with very gently dipping or untilted Tertiary conglomerate and basalt in the hanging wall (Tsy, Tby). The eastern boundary of the tilt block is a composite fault system, consisting of the younger Cochran fault which cuts an older low-angle normal fault, the Walnut Canyon fault. The Walnut Canyon fault is interpreted to be the major fault bounding the tilt block. The footwall of this fault consists of Laramide Teacup Granodiorite, from which fission track cooling ages as young as about 15 Ma have been reported [Howard and Foster, 1996]. The hanging wall of the Walnut Canyon fault in the map area consists of Middle (?) Proterozoic porphyritic biotite granite (Yg) intruding Early Proterozoic Pinal Schist (Xp). Middle Proterozoic diabase dikes, lithologically identical to and correlated with diabase intruding the Apache Group throughout central Arizona, intrude the porphyritic biotite granite. The diabase forms north-trending, vertical dikes. If the diabase was originally intruded as subhorizontal sheets, as is typical [Howard, 1991], their present orientation suggests they have been tilted about 90° since they were intruded. An east-northeast-trending swarm of Laramide andesite to rhyolite dikes intrudes the Proterozoic granitoid and diabase. These pre-Tertiary rocks are overlain by strata correlated with the Oligocene to Early Miocene Whitetail conglomerate and a variety of Miocene sedimentary and volcanic rocks. Whitetail conglomerate strata are tilted 30-50° in the hanging wall of the Walnut Canyon fault. The Miocene sedimentary and volcanic rocks apparently overlie the Whitetail conglomerate on an angular unconformity, and are tilted 10-40°. The Miocene volcanic rocks form the southern edge of an extensive rhyolite dome field with abundant associated pyroclastic rocks, which blankets the eastern part of the Mineral Mountain quadrangle [Theodore et al., 1978], the western part of the Teapot Mountain quadrangle [Creasy et al., 1983], and the southeastern part of the Picketpost Mountain quadrangle [Spencer and Richard, 1996] in addition to the outcrops in the North Butte area. The Gila River has carved a channel across the structural grain of the Tertiary faults suggesting its present course is superimposed. Dissection related to base level drop in the river valley results in more extensive exposure of granitic rocks northward toward the river in the pedimented area south of the river.
**MAP UNITS**

**Volcanic and Sedimentary rocks**

*d* Disturbed surficial deposits (Holocene)—Gravel, broken rock and rearranged surficial deposits in mine areas.

*Qs* Undivided surficial deposits (Holocene to Pleistocene)—Unconsolidated to moderately consolidated sand and gravel. May include QTs locally.

*Qsy* Young alluvium (Holocene and late Pleistocene)—Unconsolidated sand and gravel deposits in active stream channels.

*Qo* Old alluvium (Middle to early Pleistocene)—Deposits consist of coarse gravel and cobbles to boulders, with minor amounts of finer-grained material, and are typically light reddish brown in color. Sediment is finer grained than QTs. In the northeast part of the map area, clasts include Tertiary rhyolite, various granitoids (TKtc and Yg), with sparse Paleozoic and Apache Group clasts. Apache Group quartzite cobbles (Dripping Spring?) are common to sparse but ubiquitous in rubble accumulated on surfaces developed on unit. In upper Box 'O' wash area, surfaces with a thin (1-5 m) veneer of this unit may be underlain by older alluvium (QTs).

*Qc* Pedogenic carbonate (Holocene or Pleistocene)—White, massive, fine-grained pedogenic calcite with scattered clasts of older rock.

*QTs* Weakly consolidated conglomerate (Quaternary and Tertiary)—At northwest corner of map area adjacent to bedrock, this unit consists of massive to crudely bedded, poorly sorted conglomerate with angular to subangular clasts, typically 5-50 cm diameter, of locally derived (to north) leucocratic granitoid with sparse biotite. In the northeast part of the map area, caps hills, and consists of Tertiary rhyolite boulders up to about 40 cm in diameter contained in a grussy, tan to reddish brown, poorly sorted sand matrix. Generally coarser grained than sediment mapped as Qo, and more deeply dissected.

*QTr* River gravels (Quaternary or Tertiary)—Unconsolidated pebbles and cobbles of quartzite, gray limestone, granitoids, diabase, and felsic volcanics. Clasts are typically 2-30 cm diameter, locally up to 50 cm in diameter. Carbonate clasts are commonly rounded whereas other clast types are generally subrounded. Matrix is typically very-fine grain sand. Unconformably overlies all Tertiary units. These river gravels overlie basalt (map unit Tby) along a buttress unconformity.

*QTls* Landslide deposits (Quaternary or Tertiary)—Poorly consolidated to unconsolidated, very poorly sorted deposit, with hummocky surface littered with boulders of Tertiary felsite (Tf). Landslide is on strike with parts of the Whitetail Conglomerate that contain abundant claystone and evaporite deposits, where these are intruded by the felsite. Suspect that slope failures occurred on steep terrain underlain by fine-grained Whitetail deposits adjacent to more competent felsite masses.

*Tby* Basalt lava (Late Miocene)—Dark gray to black basalt lava that contains fresh plagioclase up to 7 mm diameter, pyroxene up to 4 mm diameter, and iron oxides that may be altered olivine. A whole rock sample from this unit, from south of the Gila River near the northwest corner of the map area, yielded a K-Ar date of 8.9±0.3 Ma [Shafiqullah et al., 1980]. Depositionally overlies Tsy. Overlain by river gravels on buttress unconformity.
**Tsy**  
**Sandstone and conglomerate (Miocene)**—Poorly sorted pebble and cobble conglomerate and gravelly sandstone. Clasts are subangular, generally 1-10 cm diameter and locally as large as 25 cm, and consist of granitoid, Pinal Schist, and Tertiary volcanic rocks. Clasts of carbonate or quartzite were not seen. Unit is overlain by basalt (map unit Tby). Base of unit not exposed.

**Tc**  
**Conglomerate (Miocene)**—Massive, crudely to locally moderately well bedded, cobble to boulder conglomerate and poorly sorted gravels. This unit overlies Proterozoic granitoids and contains volcanic rock units that were deposited in the basin during the time of conglomerate deposition.

In the basin area between South Butte and Cochran (approximately the northeastern 1/4 of the map area), the conglomerate is poorly consolidated, poorly sorted, and contains subangular to subrounded pebbles, cobbles, and boulders (locally up to 1 m diameter) of Paleozoic carbonates, Pinal Schist, Paleozoic or Proterozoic quartzite, granitoids, and Tertiary rhyolite and tuff. Dominantly volcaniclastic sandstone and sandy conglomerate (map unit Tcv) grade up-section and along strike to the southeast into arkosic conglomerate and conglomeratic sandstone. Volcanic clasts are progressively less abundant up section.

In southeastern part of map area conglomerate commonly contains boulders to 50 cm and locally to 1 m diameter (a single boulder 3-4 m diameter was seen). Virtually all clasts were of locally derived granitic rock types.

Northwest of North Butte the conglomerate is massive, non-bedded, unsorted to very poorly sorted, with a gray matrix of arkosic sand. Boulders of Proterozoic granite are up to 1 m in diameter, and boulders of Pinal Schist up to 0.7 m in diameter. Pinal Schist clasts look coarser grained and slightly more recrystallized than lithic fragments in lithic tuff unit Ttp in the same area.

North of Cochran, near the eastern contact of the unit with felsic volcanic rocks, conglomerate is crudely bedded to massive, almost a talus, and clasts up to 1 m in diameter are almost exclusively of volcanic rock.

**Tcur**  
**Conglomerate, rhyolite-lithic facies (Miocene)**—Massive boulder conglomerate consisting of clasts of intrusive or extrusive rhyolite (Tf)

**Tcv**  
**Conglomerate, volcanic-lithic facies (Miocene)**—Crudely bedded and sorted conglomerate and sparse sandstone. On both sides of Gila River southeast of North Butte, this facies of map unit Tc consists of tuffaceous sandstone and pebble conglomerate that locally includes air-fall tuff and volcanic-lithic tuff with fragments of thinly banded aphyric felsite. Ratio of volcanic to granitic clasts varies abruptly and indicates local derivation. Overlies and is interbedded with various volcanic units of North and South Butte. Grades up into map unit Tc.

**Tbd**  
**Basalt of Donnelly Wash (Miocene)**—Black aphanitic basalt with 1-2 mm spots of iron oxide that probably represent altered olivine.

**Tt**  
**Tuff, undivided (Miocene)**—Thin to thick tuff beds, locally with interbedded conglomerate. Tuffs are generally moderately to well indurated, but non-welded. Stratigraphic sequences vary in different parts of the map area. East of South Butte the sequence of tuffs includes: (1) a crystal rich tuff bed containing <2mm-diameter biotite, quartz, feldspar, and hornblende(? ) crystals, numerous pumice fragments that weather to form 1-5 cm pits on outcrop surfaces due to preferential weathering, and moderately abundant volcanic lithic fragments with a diameter of <1 cm; and (2) a tuff containing 1% 1-2 mm-diameter biotite crystals, abundant <3 mm-diameter quartz and feldspar crystals, and 10-20%, 1-3 cm volcanic-lithic fragments. Extensive exposures of tuff 1.5 miles southeast of South Butte are mostly massive, with thin, well bedded intervals. This tuff is white, weathers or-
angish brown, contains sanidine, 5-10% quartz, and <1% biotite. Marker beds indicated on the map in this area are prominent cooling breaks, along which very thinly bedded to laminated tuff is found. In southeastern corner of map area near upper Donnelly Wash tuff contains fresh biotite, quartz, and granitoid lithic fragments. West of Box O Wash in the southern part of the map area tuff contains 1-2 mm phenocrysts of quartz and biotite with sparse xenocrysts (?) of K-feldspar (?) up to 5 mm diameter. Directly south of Cochran massive, orange-weathering, volcanic lithic tuff (?) forms bold, rounded outcrops and contains abundant 2-20 cm fragments of variably flow-banded rhyolite with sparse quartz and sanidine crystals <3 mm in diameter. Biotite from tuff west of Box O Wash yielded a K-Ar date of 19.5±0.4 Ma [Damon et al., 1996].

**Tts**

**Tuff and tuffaceous sediments, undivided (Miocene)**--Buff-colored, medium- to thick-bedded tuff, tuffaceous sandstone, and conglomeratic sandstone. Clasts in conglomerate include various granitoids (Proterozoic and Laramide ?) and Tertiary rhyolite. Low-aspect-ratio channels are present with coarse sand- to arkosic grit-matrix, cobble conglomerate filling the channels. Mapped south of South Butte. Tuffs are lithic rich in the lower part and become finer grained and lithic poor, thin to very thin bedded and vaguely laminated towards the top of the unit. Lithic fragments are of the same types as clasts in the conglomerate beds. Depositionally overlies felsite-clast-lithic tuff south of South Butte. The contact is placed at the boundary between massive lithic tuff and bedded tuffaceous sandstone. Vitrophyre breccia of South Butte depositionally overlies this unit.

**Tts²**

**Upper tuff and tuffaceous sediment (Miocene)**--Up to about 25% crystals of quartz, sanidine, plagioclase, and minor biotite. Volcanic-lithic clasts are distinctly more abundant than Pinal schist clasts. Unit has more crystals, fewer lithic fragments, and is less indurated than Pinal-clast tuff (map unit Ttp). Most lithic fragments are light lilac-gray weathering, densely welded tuff (?), maroon-brown on fresh surfaces, with ~5% crystals of quartz, sanidine, and biotite. To southwest along the south side of Martinez Canyon, granite clasts (Yg) are more abundant, and Pinal clast tuffs are interbedded with the tuffaceous sediments, such that the distinction between map units Ttf¹, Tts, Ttp and Tts² are unclear and the units are not differentiated. Depositionally overlies Pinal-clast tuff (map unit Ttp)

**Ttf**

**Felsite-lithic tuff (Miocene)**--Thin to massive non-welded tuff characterized by lithic fragments of gray, flow-banded, aphyric felsite. Marker beds on map are prominent boundaries between individual eruptive units. The lower and upper units of this tuff mapped north of the Gila River (shown as map units Ttf; and Ttf²) are lithologically indistinguishable and are differentiated based on stratigraphic position. The relationship between these units and the undivided Ttf south of South Butte is unknown. This unit depositionally overlies map unit Tc and is overlain by map unit Tts near South Butte and by volcanic-lithic conglomerate (map unit Tcv) further south.

**Ttf²**

**Upper felsite-lithic tuff (Miocene)**--Medium to thick bedded tuff with 5-10 cm diameter angular volcanic lithic clasts. Rocks of this map unit contain abundant 3-5 mm-diameter greenish white pumice fragments, and crystals of quartz, sanidine, and sparse biotite. The characteristic volcanic clasts are dense, gray to gray and maroon flow-banded, nearly aphyric, felsite with sparse 1 mm-diameter, embayed quartz crystals and rare tiny biotite flakes. Felsite lithic fragments become abundant 10-15 m above the base of the unit. Sparse white bull quartz lithic fragments are also present in the tuff. Overlies dacite of North Butte in area east of North Butte. Contact varies from conformable to a buttress unconformity with 10's of meters of relief. North and northwest of North Butte, lithologically identical tuff is interbedded in a sequence of tuffs. Grades upward into poorly exposed block tuff with
blocks of dacite of North Butte up to 1 m in diameter and blocks of aphyric felsite up to about 40 cm in diameter. This map unit grades into overlying volcanic clast conglomerate. Transition between units appears to be interbedded fanglomerate, debris-flow deposits and pyroclastic deposits.

**Ttp**

**Pinal schist-clast tuff (Miocene)**—Lithic rhyolite tuff with sparse biotite crystals less than 1 mm in diameter, and abundant 1-2 mm-diameter quartz and sparse sanidine crystals. Crystals make about 7% of rock. White on fresh surfaces, tan weathering. Contains 1-2 cm diameter pink pumice fragments, abundant 1-4 cm diameter, generally angular clasts of Pinal Schist, and clasts of aphyric gray felsite. Thick bedded to massive. Conformably overlies biotite-crystal tuff unit, conformably overlain by dacite of North Butte.

**Ttl**

**Biotite-rich crystal tuff (Miocene)**—Contains 1-2 cm volcanic rock fragments. Very light gray on fresh surfaces, weathers tan. Crystal rich, with 10-20% crystals, 2-3 mm diameter blocky feldspar predominant, also 1 mm biotite flakes. Well bedded, in beds about 1 m thick with laminated tuff partings. Dips at base near contact on underlying Trn are steeper than up section, reflecting either draping over topography on pre-existing dome, or disruption of bedding by intrusion of dome.

**Tts₁**

**Lower tuff and tuffaceous sediments (Miocene)**—Light tan to gray weathering, medium to thin bedded, crystal-poor, lithic-poor bedded tuff and tuffaceous sediment. Some beds are internally laminated. Common non-flattened pumice clasts, 2mm to 2cm diameter, weather preferentially to leave cavities on outcrop surfaces. Clasts are mostly gray aphyric felsite and very fine-grained Pinal Schist lithic fragments up to about 2 cm diameter. In epiclastic beds Pinal schist and granitoid clasts are common. Crystals are biotite and feldspar, <1mm in diameter. Deposited on Proterozoic rocks.

**Ttf₁**

**Lower felsite-lithic tuff (Miocene)**—Lithic tuff in lower Martinez Canyon, with abundant lithic fragments of aphyric felsite. Overlies conglomerate (map unit Tc) and Proterozoic rocks along probably buttress unconformity. Overlain by lower tuff and tuffaceous sediment unit (map unit Tts₁).

**Tvsb**

**Vitrophyre of South Butte (Miocene)**—Vitric lava flows (or single flow) containing phenocrysts of quartz, biotite, hornblende, and plagioclase. Glass is typically medium to dark gray in color. Mineral assemblage is same as for underlying volcanogenic breccia (map unit Tvx). Lower part of vitrophyre is massive to brecciated, upper part is crudely layered as defined by variations in resistance to weathering and by biotite orientation. East-sloping, planar surface that forms the top of South Butte is upper surface of layered upper part of vitrophyre. Hypabyssal intrusion on northwest side of South Butte appears to represent the feeder vent for this lava; the contact between intrusion and lava is difficult to define. This unit grades downward into underlying volcanogenic breccia. There are no overlying units.

**Tvx**

**Volcanogenic breccia of South Butte (Miocene)**—Consists of 5-50 cm clasts of light-gray felsite in a matrix of tuff that appears to be derived from the same material. Clasts are partially to completely devitrified vitrophyre, have a notably low density, and are apparently microvesicular. Clasts contain 15 to 20% crystals of 1-3 mm-diameter hornblende and biotite, 3-7 mm-diameter feldspar (plagioclase and sanidine present), and 2-4 mm-diameter quartz. Crude bedding, defined by variable resistance to weathering, forms planar, east dipping beds discordant to top and bottom boundaries of the unit. The entire unit consists of one set of the fore-set beds, which appear to be related to a volcanic construction similar to a cinder cone. This unit pinches out abruptly on the
east flank of South Butte, and thins to the west on the south face of the butte. This unit deposition­ally overlies tuff and tuffaceous sediments and grades upward into vitrophyre of South Butte.

Trn  **North Butte rhyolite complex (Miocene)**--Two rock units with a gradational and complex contact make up this rock unit. One includes black vitrophyre, vitrophyre breccia, and gray to tan, flow­banded, lithophysal felsite and brecciated felsite. One-mm-diameter quartz and sanidine crystals, and sparse <1 to 2 mm diameter biotite crystals are present. Steep irregular flow banding possibly represents the margins of a steep magma conduit beneath a vent. The other, overlying rock type consists of massive quartz+sanidine+biotite rhyolite (biotite is <1mm diameter), which forms bold, rounded, orangish-brown outcrops. Basal zone of this upper part consists of volcanogenic breccia with cream colored, angular, 1-20 cm fragments in a tan rhyolitic matrix. Massive upper zone contains abundant 1-2 mm quartz. Together, these are probably a hypabyssal intrusion or endoge­neous dome with an auto-brecciated carapace or block and ash deposits formed during extrusion. This unit intrudes or is overlain by biotite-rich crystal tuff (map unit Ttl).

Tx  **Rock avalanche breccia (Miocene)**--Monolithologic breccia consisting of unsorted angular clasts of megacrystic biotite granite and local exposures of massive to crudely bedded conglomerate, located about 2 miles southeast of South Butte. Rock unit in parenthesis on map indicates principal com­ponent of breccia. This breccia contains local zones of iron oxide, manganese oxide, and chryso­colla staining on clast and fracture surfaces in zones up to 3 m wide. Poorly exposed rock in eastern part of the center of section 25, T. 4 S., R. 11 E., about 1.5 mi. north-northwest of Donnelly Ranch, is interpreted as a rock avalanche deposit because of the shattered character of all exposed rock. Rhyolite dikes (map unit TKq) that intruded the granite (map unit Yg) before shattering are traceable for several 10's of meters as lenses of breccia.

Td  **Dacite of North Butte (Miocene)**--Lava flows and flow breccias of medium to dark gray glassy dacite with phenocrysts of quartz, plagioclase, biotite, hornblende, and pyroxene. Conspicious plagioclase phenocrysts are up to 8 mm diameter. In some areas dacite is flow banded. Weathered surfaces develop a white alteration product. Overlies Pinal Schist clast tuff (map unit Ttp) and is overlain by upper felsite-clast tuff (map unit Ttf2) or conglomerate (map units Tc and Tcv).

Ttb  **Welded tuff (Miocene)**--Welded ash-flow tuff, pink on fresh surfaces that contains about 5-15% crystals, generally 1-2 mm in diameter, of quartz, plagioclase, sanidine and biotite. Locally this unit contains lithic fragments of Proterozoic granitoid, Pinal schist, or Laramide felsic dikes. Sparse fiamme are strongly flattened. Tuff thins and becomes less welded to southeast. Thin beds of tuff in conglomerate southeast of the Cochran road in the southeastern part of the map area may be non-welded equivalent of this tuff. This unit overlies conglomerate (map unit Tc) on an appar­ently conformable contact, and is conformably overlain by conglomerate.

Tw  **Whitetail Conglomerate (Miocene or Oligocene)**--Two small exposures of this unit about 1/4 mile southeast of Cochran consist of dark reddish brown, poorly sorted to massive conglomerate to breccia containing hematite-stained pebbles, cobbles and sparse boulders of schist, granitoids, and less abundant Tertiary(?) felsic volcanic or hypabyssal rocks. Minor copper mineralization is associated with crystal-poor rhyolite dikes (map unit Tf) that intrude the conglomerate. North of the Gila River in the northeast corner of the map area, similar conglomerate grades up section into sandstone and is contiguous with sandstone, conglomerate, mudstone, and evaporite on adjacent geologic quadrangle maps that have been mapped as Whitetail Conglomerate [Cornwall and Krieger, 1975; Theodore et al., 1978; Creasy et al., 1983]. Depositionally overlies pre-Tertiary rocks and is intruded by felsite complex of Cochran (map unit Tf).
Intrusive rocks

**Tf**  
**Intrusive or extrusive felsite (Miocene)**--Dikes and irregular intrusive masses of hypabyssal felsite.

In the northeast corner of the map area the felsite complex of Cochran consists of dikes, shallow intrusions, and massive autobreccia. The rock is light gray to white, and contains 2-4% 2-3 mm-diameter quartz phenocrysts, 3-6% 1-3 mm-diameter feldspar, and <1% (typical) to 5% 1-3 mm-diameter biotite. Textures characteristic of devitrification are apparent locally. The dike complex that forms resistant ridge crest southeast of Cochran consists of crystal-poor felsite that is very light gray to pink on fresh surfaces and contains 5-7% 1-2 mm crystals of quartz and feldspar, in sub-equal amounts, set in an aphanitic groundmass.

The intrusive felsite forming the northwest part of South Butte has a very light gray aphanitic to very fine-grained groundmass containing biotite, hornblende, 2-4 mm plagioclase, and sparse 2-4 mm quartz crystals. Biotite is in 1mm diameter flakes and books, and hornblende prisms are up to about 1mm long. The rock has a close-spaced, generally steeply dipping parting low on the mountain and weathers into plates. This felsite intrudes welded tuff (map unit Ttb) and conglomerate (map unit Tc); its field relationship to lava flows and volcanogenic breccia on South Butte (map units Tvsb and Txv) is obscure, but these are probably extrusive facies of the same rock.

The felsite intrusion within tuffs along the north-center margin of the map has a light gray glassy groundmass with 5-7% crystals of hornblende, biotite, quartz and plagioclase in sub-equal amounts. Crystals are about 1mm diameter. The intrusion has a brecciated contact zone 30-40 m thick, and steep contacts exposed in the walls of Martinez Canyon. Mixing of Pinal Schist clast tuff (map unit Ttp) into the felsite along the contact suggests that map unit Ttp was not fully indurated when the felsite was emplaced. In the core of the intrusion at the canyon bottom, the rock is light lilac gray and holocrystalline and aphanitic to very fine-grained, with subhorizontal flow banding.

In the northern part of the map area this unit includes several endogenous (built by inflation within) or exogenous (built by surface effusion of lava) dome complexes.

**Til**  
**Lithic-rich felsite dike (Miocene)**--Prominent north-south striking dike underlying major ridge west of North Butte, consists of reddish brown aphanitic to porphyritic (with possibly xenocrystic quartz and feldspar) felsite with abundant 1-10 cm, locally vesiculated, felsic fragments similar to matrix, and 5-15% fragments of granite rocks. North end of dike lacks lithic fragments and consists of massive to flow banded felsite with abundant 1-2 mm-diameter biotite (5-7%), 1-2 mm-diameter hornblende (1-2%), and 1-4 mm-diameter quartz (2%). Rock here is tan on fresh surfaces, reddish brown weathering, and non-vesicular. Intrudes Precambrian granitoid (map unit Yg).

**TKmd**  
**Mafic dikes (Tertiary or Cretaceous)**--Equigranular mafic dikes, grain size ranges from fine-grained in the core of thick dikes to aphanitic at chilled margins. Consist of hornblende(?) altered to biotite, chlorite and epidote, and plagioclase. Some dikes contain 0.5-1 mm long hornblende laths rimmed by anhedral white plagioclase(?). In southeastern part of map, dikes are very fine-grained, dark gray to black, and consist of mafic minerals (pyroxene or hornblende?) altered to chlorite and epidote, plagioclase, and rare quartz. Secondary calcite is common. Presence of quartz distinguished from Proterozoic diabase. Intrudes Teacup Granodiorite (map unit TKtc) in northeast part of map area. Intrudes most aplite dikes in Teacup granodiorite, but in at least one place aplite appeared to intrude a mafic dike. Dikes strike north to northwest and dip gently to moderately to the west or southwest. This unit also intrudes Teacup Granodiorite in the southeastern corner of the map area.

**TKp**  
**Pegmatite dikes (Paleocene or late Cretaceous)**--Muscovite pegmatite dikes in equigranular biotite (map unit TKte) and muscovite (map unit TKtm) phases of Teacup granodiorite.
TKap  Aplite dikes (Paleocene or late Cretaceous)—fine-grained aplite dikes; intrude equigranular Teacup granodiorite (map unit TKtc).

Teacup granodiorite (Paleocene or late Cretaceous).

TKtc  Equigranular biotite phase—Equigranular, medium-grained leucocratic granitoid. Consists of 30-40% 3-10 mm-diameter anhedral quartz, 25% pink subhedral 3-4 mm-diameter K-feldspar intergrown with 30-40% subhedral white plagioclase in 2-4 mm diameter grains, and 2-3% 1 mm diameter chloritized biotite. Very few aplite and pegmatite dikes intrude this phase. Overlain depositionally by conglomerate of map unit Tc, and intruded by mafic dikes of map unit TKmd. Intrusive contacts with Proterozoic units in the south-central part of the map area are obscure because differentiation of Laramide granodiorite and mixed igneous rocks in adjacent Proterozoic granitoid complex could not be confidently made with poor outcrop and lithologic similarity between the two granitoids.

TKtm  Muscovite granite phase—Equigranular, medium- to medium-fine-grained aplitic granitoid, consisting of 30% quartz in 2-4 mm diameter anhedral grains, 60-70% feldspar, mostly plagioclase, in 2-6 mm-diameter, anhedral grains, and 5-7% mica, with a highly variable muscovite to biotite ratio. Mica is everywhere more abundant than in the equigranular biotite phase. Pegmatite and aplite dikes are very abundant, and contain coarse-grained muscovite. Coarse grained biotite selvages were also observed along aplite dike margins. Contact with equigranular biotite granitoid phase is gradational. Tertiary rhyolite (map unit Tf) dikes intrude this phase.

TKxs  Silicified and hematite stained breccia (Paleocene or Late Cretaceous)—Alteration zone in which porphyritic biotite granite (map unit Yg) and Laramide dikes (TKq) are brecciated to locally mylonitic and pervasively impregnated with silica and earthy hematite. Locally includes fracture-filling chrysocolla.

Laramide dike swarm (Paleocene or late Cretaceous). Abundant rhyolite to andesite dikes, generally east-northeast trending, that intrude Proterozoic granitoid (Yg), especially in the Box O Wash area. Dikes have not been observed to intrude the Teacup granodiorite. This may be because the dikes are older, or because the Teacup granodiorite is in the footwall of the Walnut Canyon low-angle normal fault, and represents a deeper structural level. In this latter case, the dike swarm may be the upper crustal manifestation of the Teacup granodiorite.

TKa  Intermediate composition dikes—Compositionally variable dikes ranging from crystal poor light gray felsite with 1-3% 1-2 mm plagioclase crystals to crystal rich dikes that contain 5-25%, 1-6 mm plagioclase and generally sparse 2-4 mm quartz phenocrysts. Mafic crystals are typically chloritized, 1-2 mm in diameter, and probably were biotite, hornblende and possibly pyroxene in variable amounts. Also includes equigranular, microcrystalline to fine grained diorite to granodiorite dikes. More felsic members of this suite are gradational with felsic dikes (map unit TKq) and include dikes with a felsic core and intermediate-composition margin.

TKm  Mixed dike—Texturally and compositionally variable dike, grades from very fine grained mafic dike rock, to porphyritic rock with quartz crystals to ~1 cm in diameter, chalky plagioclase 2-4 mm in diameter, biotite in columns up to 4 mm long and 1-2 mm in diameter, in a very fine-grained, greenish gray groundmass. Some partially resorbed xenoliths of Pinal Schist are present in the dike.
TKgp **Granite porphyry**—Tan weathering, very fine grained to aphanitic groundmass with 10-15% 4-10 mm-diameter quartz crystals, 10% K-feldspar crystals up to 4 cm long and locally zoned, 40% 2-4 mm-diameter plagioclase crystals, and 2-3% variably chloritized biotite crystals.

TKq **Felsic dikes**—Several varieties of dikes characterized by abundance of quartz crystals. Very light to dark greenish gray dikes with 2-12 mm-diameter phenocrysts of quartz (3-8%), white plagioclase (15-20%), K-feldspar (2-5%) crystals locally up to 3 cm long with plagioclase rims, 1-3 mm biotite (1-2%), and, locally, minor hornblende and an unidentified green mineral that could be altered hornblende or pyroxene. Chilled dike margins are medium gray and crystal poor. Dikes grade from those with prominent quartz to those with prominent plagioclase. Also includes fine-grained, equigranular granitoid dikes, which are so crystal rich as to appear holocrystalline. These contain ~5% mafic crystals, including acicular hornblende, locally to 1 cm long, and biotite flakes 1-2 mm in diameter, along with quartz and two feldspars. A third variety is light-gray porcelaneous, crystal-poor felsite with sparse 1-2 mm quartz crystals.

TYa **Aplite dikes** *(Tertiary, Cretaceous, or Proterozoic)*—Fine-grained equigranular aplite dikes, locally grading into pegmatite. Unit is probably Proterozoic and related to porphyritic biotite granite (Yg), but may include aplite dikes related to Teacup granodiorite.

TYd **Fine-grained diorite dike** *(Tertiary, Cretaceous, or Proterozoic)*—Fine-grained, equigranular diorite to granodiorite; light gray to light greenish gray. Typically slightly propylitized. Consists of 60-70% feldspar, 20-30% quartz, and 5-10% biotite and hornblende. All grains are anhedral and 1-2 mm in diameter. Intrudes granite of map unit Yg. Similar to intermediate composition dikes of Laramide dike swarm, but thicker, less continuous, and spatially isolated from the rest of the swarm.

TXgd **Equigranular granodiorite** *(Tertiary, Cretaceous, or Proterozoic)*—Equigranular, medium grained granodiorite consisting of 15-20% pinkish K-feldspar up to 1 cm in diameter, 50-60% anhedral plagioclase 2-6 mm in diameter, 20% quartz in 3-4 mm-diameter equant grains, 3-5% biotite in 2-4 mm diameter flakes and books up to 3 mm thick, 1-3% hornblende (variably altered to chlorite and epidote) in prisms up to 4 mm long. Honey yellow to greenish yellow sphene is an ubiquitous accessory. Intrudes (?) granite of map unit Yg along poorly exposed contact. Intruded by aplite dikes, quartz-hematite veins, and one felsic dike (map unit TKq).

Yd **Apache diabase** *(Middle Proterozoic)*—Dark gray dikes with typical sub-ophitic, diabasic texture. Consists of 35-45% 1-3 mm plagioclase laths in black groundmass of pyroxene; accessory magnetite(?) is common. Locally crude layering is defined by variation in ratio of plagioclase to groundmass and in size of plagioclase crystals. Forms north-trending dikes in the map area and intrude Proterozoic granitoid. In many places, Laramide dikes (map units TKa and TKq) appear to be cut by diabase dikes, but in detail these contacts are invariably faulted or the Laramide dike intrudes the diabase (see discussion in the structure section).

**Granitoids** *(Middle Proterozoic)*—Several varieties of granitoid, as described below. The most abundant phase is the porphyritic biotite granite. Other phases are present in a mixed zone that separates the porphyritic biotite granite from Teacup granodiorite in the southeast part of the map area. The contact between the Proterozoic granitoid and the Teacup is not exposed, and may be the southwestern continuation of the Walnut Canyon fault.
Porphyritic biotite granite (Middle Proterozoic)--Coarse-grained porphyritic biotite granite with 25-30% 2-5 mm-diameter blocky plagioclase, 20-35% 2-10 mm-diameter, anhedral, light gray quartz grains, 15-35% K-feldspar in 1-5 cm diameter, rounded-equant to elongate and blocky phenocrysts, and 5-7% biotite in 1-4 mm diameter flakes and ragged, interconnected clots. Tabular, black opaque crystals, 1-2 mm in diameter (probably ilmenite) are a sparse but ubiquitous accessory mineral in outcrops west of felsite complex of Cochran (map unit T1) in the northeast corner of map area. Quartz veins are abundant in granite; these contain epidote stringers along and within the veins. Granitoid is silicified adjacent to the veins. Thin quartz-feldspar pegmatitic veins are common, but not abundant. These commonly contain minor tourmaline. K-feldspar phenocrysts commonly contain biotite inclusions. Contact with Pinal Schist is a mixed zone. Contact between porphyritic biotite granite and Teacup granite south of the Gila River in the northeastern part of the map area is intruded by dikes (Laramide or Middle Tertiary in age), or covered by alluvium, and is suspected to be a fault. Intruded by Proterozoic (?) diabase in western part of outcrop area. Middle Proterozoic age is based on lithologic similarity to Ruin and Oracle Granites. Early Proterozoic age is possible.

Equigranular biotite granite (Middle Proterozoic)--Medium- to coarse-grained, equigranular granite that grades into megacrystic biotite granite of map unit Yg. In some areas biotite occurs as clots up to 1 cm in diameter. K-feldspar grains are mostly 1-2 cm in diameter, locally crystals become larger as rock grades into granite of map unit Yg. Southeasternmost outcrops, at edge of map (NW 1/4 of sec. 17, T. 5 S., R. 12 E.), are alkali granite with 50-60% K-feldspar in anhedral 3-5 mm-diameter grains, 15% 4-6 mm-diameter blocky plagioclase crystals, 30% quartz in equant, discrete 2-4 mm grains, and 2% biotite in 1-5 mm-diameter flakes.

Fine-grained biotite granite (Middle Proterozoic)--Fine-grained, equigranular, aplitic biotite granite, 1-2 mm grain size, with sparse biotite. Relative abundance of aplitic biotite granite and porphyritic and equigranular biotite granite (map units Yg and Yge) on pediment could not be confidently determined because even a small amount of aplite dominates the float and masks the biotite granite, which tends to form grus.

Aplitic porphyry (Middle Proterozoic)--Aplitic fine-grained, equigranular granite with 1-3 cm diameter K-feldspar and 2-5 mm diameter quartz phenocrysts. Grades into fine-grained aplitic biotite granite (map unit Ygf).

Biotite granitoids, undivided (Middle Proterozoic)--Includes (1) megacrystic biotite granitoid (map unit Yg); (2) fine- to coarse-grained, equigranular biotite granite (map unit Yge); (3) fine grained aplitic biotite granite (map unit Ygf); and (4) aplitic porphyry (map unit Ygp). Some of these phases may be related to Teacup granodiorite (map unit TKte). Contacts with porphyritic biotite granite (map unit Yg) are gradational.

Mixed granitoid and schist (Middle and Early Proterozoic)--Mixed medium grained equigranular to porphyritic biotite granitoid border phase of porphyritic biotite granite (map unit Yg) and medium to medium-fine grained hornfelsed Pinal Schist. Mapped in contact zones on margins of porphyritic biotite granite.

Pinal schist (Early Proterozoic)--Dark gray muscovite-biotite schist to semi-schist. Crops out in small area in northeastern corner of quadrangle, where is generally consists of highly fractured and iron-stained hornfels due to proximity of contact with Ruin Granite of map unit Yg and Tertiary (?) mineralized zone adjacent to contact with Whitetail Conglomerate (map unit Tw). Schist ranges
from fine-grained with a well defined differentiated foliation (layering defined by segregation of mineral phases) and schistosity (layering defined by alignment of mica minerals) to a massive, medium-fine-grained hornfels with 2-4 mm muscovite porphyroblasts in proximity to intrusive contacts.

GEOCHRONOLOGY

Table 1 summarizes age dates available for the map area. The dates obtained from the tuff of North Butte (12-01-95-03) and from the non-welded tuff in the southern part of the quadrangle (UAKA 72-68) are concordant, suggesting that scattered outcrops of non-welded tuff mapped as Tt in the southern part of the map area are at least in part distal fall-out tephra related to the tuff of North Butte. The fission track cooling age from the muscovite phase of the Teacup granodiorite near the western edge of the map area (15.2±1.8, sample H90 To-7, Howard and Foster, 1996) is younger than the age of the tuff of North Butte (~19 Ma, samples 12-01-95-03 and UAKA 72-68) and probably younger than the dacite of North Butte (sample M76-15). Sample H90 To-7 was collected about 100 m from the southern end of the felsite complex of Cochran (map unit Tf) of probable Miocene age. The cooling age of this apatite is concordant with another sample collected about 2 km to the northeast on the Grayback Quadrangle, also in the Teacup granodiorite (phase is uncertain). The concordance of these two cooling ages indicates that heating from the felsite complex is not responsible for the young cooling age. Thus, it appears that the Teacup granodiorite in the northeastern part of the quadrangle was still at temperatures above ~110° C as the Proterozoic granite west of South Butte was being overlain by volcanic rocks. This discrepancy in cooling ages supports the interpretation that a major west- to southwest-dipping normal fault separates the crystalline rocks between these two locations.

STRUCTURE

Tertiary faults

The western edge of the granite pediment area west of North and South Buttes is bounded by a north to northwest-trending fault system. Flat-lying or gently tilted Tertiary basin fill deposits (map unit Tsy) and basalt (map unit Tby) occupy the hanging-wall block of this fault. The fault zone contains hydrothermal carbonate (+ barite) where it is exposed just south of the Gila River. Hydrothermal carbonate rock is present along the edge of outcrops north of the river as well, but the range-bounding fault is not exposed.

The fault zone bounding the eastern margin of the Donnelly Wash basin in the northeastern part of the map area is named the Cochran fault. The fault zone is blanketed by a zone of pedogenic carbonate near the edge of the map area. Springs present along the fault, together with the pedogenic carbonate formed over the fault zone, suggest that the Cochran fault is channeling ground water in this area. North of the Gila River, the Cochran fault is apparently intruded by the felsite complex of Cochran (map unit Tf). The fault is inferred to have separated Whitetail conglomerate (map unit Tw) from tuff (map unit Tt) north of the river before intrusion of the felsite.

The major normal fault in the map area, referred to here as the Walnut Canyon fault, is exposed at the northeastern edge of the map area. Moderately to steeply tilted Whitetail conglomerate in the hanging-wall block is superposed on Teacup granodiorite. The fault is gently north-northwest-dipping where it is exposed. Where the fault crosses into the North Butte quadrangle from the east, it is interpreted to turn abruptly to the south and is intruded by a felsite sill south of the Gila River (map unit Tf). The southwest part of the Walnut Canyon fault is interpreted to separate Proterozoic rocks that underlie the Whitetail conglomerate in its hanging-wall block from Teacup granodiorite in the footwall block. The fel-
site complex of Cochran intrudes most of the fault zone within the map area, and the fault bounding the Donnelly Wash basin truncates the felsite and the Walnut Canyon Fault.

Crystalline rocks exposed in the central part of the map area, west of Donnelly Wash, are interpreted to be in the hanging wall of the Walnut Canyon fault. Diabase dikes that trend north and dip near 90° are interpreted to have been intruded as horizontal dikes, typical of Proterozoic diabase in the region [Howard, 1991]. If this is the case, then crystalline rocks in the hanging wall of the Walnut Canyon fault have been tilted about 90° since Proterozoic time. Conglomerate and the 19 Ma (Table 1) tuff of North Butte dip 15-20° to the east where they overlie these crystalline rocks, indicating that much of the tilting occurred before 19 Ma.

Howard and Foster [1996] interpret that tilting of the Grayback block, which is the footwall of the Walnut Canyon fault, started between about 28 and 23.5 Ma. Fission track cooling ages of 15-16 Ma from the footwall of the Walnut Canyon fault suggest that cooling related to faulting and exhumation continued until about 15 Ma [Howard and Foster, 1996]. Some of this young cooling may be related to the Cochran fault, but felsite that intrudes the Walnut Canyon and Cochran faults is similar to rhyolite in the Mineral Mountain, Teapot Mountain and Picketpost Mountain quadrangles, none of which have yielded K-Ar apparent ages younger than about 16 Ma [Reynolds et al., 1986]. It seems likely that major faulting was over by about 16 Ma, and the younger fission track ages record rapid post-tectonic cooling.

Slip on the Walnut Canyon fault is not well constrained. We suggest that the belt of north-south striking diabase dikes in the Grayback quadrangle [Cornwall and Krieger, 1975] was originally part of a group of sheet intrusions contiguous with similarly oriented diabase dikes in the North Butte area, and that the east-west striking Laramide dike swarm in the North Butte area was originally contiguous with the east-west striking dike swarm along the northern margin of the Grayback quadrangle. The intersection of the horizon of the top of the diabase sheets and the Laramide dikes provides a piercing point to estimate fault slip. This assumes that all tilting of the diabase sheets is middle Tertiary, and that the Walnut Canyon fault is sub-horizontal. Based on these assumptions, rocks in the hanging wall of the Walnut Canyon fault have been translated 17 km towards 250° relative to rocks in the footwall. Restoration of slip by this amount and direction also brings the exposure of equigranular granodiorite (map unit TXgd) in the map area (which resembles the granodiorite phase of the Teacup granodiorite in the central Grayback quadrangle) back to near the eastern (and inferred originally upper) part of the Teacup granodiorite in the Grayback quadrangle.

Laramide dikes

Dikes within the east-northeast-trending Laramide dike swarm west of South Butte appear to be cut by Proterozoic diabase dikes in a number of places. In detail, the dikes are found to intrude diabase along contacts that parallel the trend of the diabase dikes (north-south), or the dikes are truncated by faults parallel and coincident with the diabase dikes. Fault zones mapped along the trend of diabase dikes commonly have scraps of diabase too small to map scattered along the fault zones. These relationships are interpreted to indicate that the diabase dikes were activated as transform-fault structures during the intrusion of the Laramide dike swarm. Slip along the dike-fault surfaces allowed differential dilation of slabs of Proterozoic granite between the diabase dikes as the Laramide dikes were intruded.

MINERALIZATION

Two major areas of mineralization are present in the study area: the Red Hills prospect (informal name) and the Cochran area. In both areas the principal structures are quartz-hematite veins and mineralized joints. Specular hematite is most common in the veins, but earthy red-brown hematite is also pres-
ent. The veins and joints are typically oriented nearly parallel to nearby dikes of the Laramide dike swarm, suggesting that they are coeval. Veins commonly contain open space with drusy quartz crystals.

**Cochran area**

Mineralization in the Cochran area is localized along an east-northeast-trending zone in the vicinity of the contact between porphyritic biotite granite and Pinal Schist. Pinal Schist in this zone is weakly silicified and moderately to strongly iron stained. Secondary copper minerals are locally present on fractures in the schist. Mineralized clasts were observed in Whitetail conglomerate, and Tertiary felsite dikes (map unit Tf) intrude the mineralized rock and apparently post-date the mineralization. A few veins in the most altered part of the zone (SE 1/4 of the NE 1/4 of sec. 5 and SW 1/4 of the NW 1/4 of sec. 4, T. 4 S., R. 12 E.) contain spongy red-brown and yellow ochre stockwork after unidentified sulfide minerals. Many of the veins in this area have been brecciated after emplacement. Measured veins and mineralized structures in this area trend 090° to 125°, dipping moderately to steeply south and southwest.

**Red Hills prospect**

In the Red Hills area, quartz-specular hematite veins and mineralized shear zones are parallel to abundant Laramide rhyolite dikes. Secondary copper minerals are present on fractures throughout the zone, but are not especially abundant. The porphyritic biotite granite host for the dikes and veins is strongly iron stained, and plagioclase is moderately to strongly sericitized, especially in selvages adjacent to veins. The granite is strongly silicified adjacent to the veins. Some development has taken place on the prospect, including some excavation, grading, and construction of a heap leach pad, but the site had been abandoned when mapping was being done in spring of 1995. A zone of relatively strong fracturing, and iron staining extends ENE from the Red Hills area to the base of the Tertiary conglomerate in the Donnelly Wash Basin. Earthy and specular hematite along fractures and mineralized shears are the most common manifestations of mineralization; secondary copper minerals are sparse but ubiquitous.

**REFERENCES**


Table 1. Summary of age dates shown on map.

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<th>Sample ID</th>
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<th>Unit</th>
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<td>UAKA-76-89</td>
<td>basalt</td>
<td>Florence basalt</td>
<td>33° 5.14', 111° 17.15'</td>
<td>KA, wr</td>
<td>8.87±0.26</td>
<td>Basalt overlies Tsy, overlain by OTr.</td>
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<td>Dacite of North Butte</td>
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<td>KA, hbld, KA, biot</td>
<td>15.8±0.5, 17.4±0.5</td>
<td>biotite apparent age is older than hornblende apparent age</td>
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<td>granite</td>
<td>Teacup granodiorite, muscovite phase</td>
<td>33° 5.083', 111° 7.583'</td>
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<td>AA, san</td>
<td>18.97±0.09</td>
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<td>W. McIntosh, Written Communication, 1996</td>
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<td>tuff</td>
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<td>19.1±0.4</td>
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Correlation of Map Units, North Butte Area

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<td>Yd</td>
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1. S.M. Richard
2. J.E. Spencer
3. W.A. Gilbert
4. photogeologic interpretation
5. Huckleberry [1993]

Sources of Data