Geologic map of the Samaniego Peak 7½' Quadrangle, Pima County, Arizona

by

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Introduction

The Sierrita Mountains are a deeply eroded Basin and Range uplift located 60 km south of Tucson, Arizona. The mountains consist of a rugged inselberg core range 300 m high flanked by a bajada surface 35 km in diameter. Bedrock geology of the core range consists of Mesozoic volcanic and sedimentary successions, a subvolcanic Mesozoic intrusive suite, and early Tertiary plutons. Porphyry copper-molybdenum mineralization of the Pima mining district has been exploited at three open-pit mines in the eastern Sierrita Mountains for nearly 50 years. This district has yielded over 18 billion pounds of copper, 290 million pounds of molybdenum, and considerable lead, zinc, and silver (Keith et al., 1983; Arizona Department of Mines and Mineral Resources file data). Most previous geological studies in the Sierrita Mountains focused on the porphyry copper deposits (e.g., Kinnison, 1966; Aiken and West, 1978; West and Aiken, 1982; Barter and Kelley, 1982; Jansen, 1982; Preece and Beane, 1982; Jensen, 1998; Herrmann, 2001). The only currently active deposit, the Sierrita-Esperanza Mine, straddles the southeast corner of the map area. Mineralization at the Sierrita-Esperanza deposit is localized along the intrusive contact between the Paleocene Ruby Star Granodiorite and a Mesozoic volcanic-plutonic complex.

The Samaniego Peak quadrangle encompasses the northern half of the core range and a large area of the northern piedmont. Much of the piedmont is underlain by pediment formed on deeply weathered Ruby Star Granodiorite. The most important new conclusions based on our mapping concern the structural geometry of the Jurassic Red Boy Peak cauldron and age relationships between certain volcanic and plutonic suites. These relationships are summarized as follows: (1) the Red Boy Peak cauldron is a northwest-facing structure tilted to the southwest, (2) the Jurassic Harris Ranch Monzonite intrudes the Red Boy Rhyolite, and (3) the Sierrita Granite intrudes the Ruby Star Granodiorite and is therefore Paleocene rather than Mesozoic.

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Map Units

Quaternary Surficial Deposits

The surficial geology was mapped primarily using aerial photos taken in 1955, 1979, and 1996. Unit boundaries were spot-checked in the field, and mapping was supplemented by field observations of soils and stratigraphy. Quaternary deposits cover portions of the piedmont surrounding the northern Sierrita Mountains, although much of the piedmont area consists of exposed bedrock pediment. Most of the piedmont alluvial deposits are a few meters thick or less, and many of the areas mapped as alluvium contain very shallow or partially exposed bedrock.

dl **Mine dump (<50 years) –** Very poorly-sorted, angular rock debris ranging in size from sand to boulders (some up to 3m), but generally in the cobble to boulder size range. The rock debris, derived from Mesozoic and Paleocene volcanic and plutonic rocks, was excavated from the Sierrita-Esperanza open-pit mine and deposited mostly in 5-10m thick sequences defined by horizontal surfaces with intervening angle-of-repose foresets. The dumps cover an approximately 7 km^2 area mostly to the south and east of the mine (0-50 m thick).

Qyc **Modern channel deposits (<100 years) –** Deposits in active channels of the larger tributary drainages and the major washes, composed primarily of sand, pebbles, and cobbles. Channels are incised as much as several meters below adjacent Holocene terraces (unit Qy). Areas mapped as Qyc are prone to flooding.

Qy **Holocene alluvium (<~10 ka) –** Thin, young deposits in small channels, low terraces, and alluvial fans. Deposits generally consist of fine gravel, sand, silt and minor clay, but they contain larger proportions of gravel near the mountains. Channels generally are incised less than 2 m below Qy terraces and fans. Fairly extensive distributary channel systems exist on the northwestern Sierrita piedmont. Soil development associated with Qy deposits is weak. Soil clay accumulation is minimal, and calcic horizon development is typically stage I (see Machette, 1985, for description of stages of calcium carbonate accumulation in soils). Areas mapped as Qy may be flood prone.

Ql **Late Pleistocene alluvium (~10 to 130 ka) –** Deposits associated with moderately dissected terraces and small relict alluvial fans on the upper, middle and lower piedmont. Moderately well developed, slightly to moderately incised tributary drainage networks are typical on Ql surfaces. Active channels typically are incised less than 2 meters below Ql surfaces. Ql fans and terraces are lower in elevation than adjacent Qm and older surfaces, and generally are slightly higher and/or more eroded than adjacent Qy surfaces. Ql deposits generally consist of pebbles and finer-grained sediment, but are gravelly on the flanks of the Sierrita Mountains. Ql surfaces commonly have loose, open lags of pebbles and cobbles; surface clasts exhibit weak rock varnish. Ql surfaces appear orange on color aerial photos, reflecting slight reddening of surface clasts and the surface soil horizon. Ql soils are moderately developed, with orange to reddish brown clay loam to light clay argillic horizons and stage II calcium carbonate accumulation.

Qm **Middle Pleistocene alluvium (~130 to 500 ka) –** Moderately to highly dissected relict alluvial fans and terraces with strong soil development. Qm surfaces are drained by well-developed, moderately to deeply incised tributary channel networks; channels are typically several meters to as much as 10 m below adjacent Qm surfaces. Qm deposits typically consist of sand, pebbles and cobbles. Qm surfaces are characterized by scattered cobble to boulder lags with moderate to strong varnish. Well-preserved, planar Qm surfaces are smooth with scattered pebble and cobble lags; surface color is reddish brown and rock varnish on surface clasts is typically orange or dark brown. More eroded, rounded Qm deposits are less clay-rich and have some carbonate litter on the surface. Well-preserved Qm surfaces have a distinctive bright red color on color aerial photos, reflecting reddening of the surface soil and surface clasts. Soils typically contain reddened, clay argillic horizons, with obvious clay skins and soil structure. Underlying soil carbonate development is typically stage II to III, with abundant carbonate through at least 1 m of the soil profile.

Qmo **Middle to early Pleistocene alluvium (~500 ka to 1 Ma) –** Deposits associated with deeply dissected relict alluvial fans. Qmo surfaces are drained by well-developed, deeply incised tributary channel networks. Surfaces are typically rounded, and few planar remnants of the original deposition surfaces exist. Qmo surfaces are typically 10-15 m above adjacent active channels. Where Qmo surfaces are well preserved, they are smooth with pebble and cobble lags; rock varnish on surface clasts is typically orange to red. Soil carbonate development is variable, but locally is strong. Where surfaces are well preserved, soils typically contain deep reddish brown, clay argillic horizons, with obvious clay skins and soil structure. More eroded Qmo surfaces are characterized by loose cobble lags with moderate to strong varnish, ridge-and-valley topography, and carbonate litter on the side slopes.

Qc **Hillslope colluvium (Holocene and Pleistocene) –** Locally-derived colluvial and talus deposits on moderately steep hillslopes. Colluvium is mapped only where sufficiently thick and extensive as to obscure underlying bedrock. Deposits are very poorly sorted, ranging from clay to cobbles and large boulders derived from rockfalls. Clasts typically are subangular to angular.

Tertiary Rocks

Tdxi **Dacite dike (Tertiary) –** Dacite dike containing abundant phenocrysts of plagioclase, biotite, and minor hornblende (1-3 mm) in a light gray to black, aphanitic groundmass. This dike is compositionally and texturally similar to the dacites of Tinaja Peak in the Batamote Hills quadrangle to the south (Ferguson et al., 2003).

Tm **Mafic dikes (Tertiary) –** Altered dikes with pseudomorphed phenocrysts of plagioclase and mafic minerals in an aphanitic groundmass.

Th* **Helmet Conglomerate (Tertiary) –** A heterogeneous sequence of avalanche breccia, conglomerate and sandstone containing clasts derived from a wide variety of Mesozoic and Paleozoic rocks. Thin interbeds of pumiceous sandstone occur above a distinctive, coarse-grained plagioclase-porphyritic andesite lava marker unit (Tap). Damon and Bikerman (1964) reported a biotite K-Ar date of 28.6 $\pm$ 2.6 Ma from a tuff that probably correlates with one of the pumiceous sandstone beds (Richard et al., 2003). The entire sequence of Helmet Conglomerate is at least 2 km thick. * Shown on cross section only.

Tap* **Porphyritic andesite (Tertiary) –** Coarse-grained, plagioclase-porphyritic andesite lava (50-100 m thick). * Shown on cross section only.

Tph **Hornblende porphyry dikes (Tertiary) –** Fine- to medium-grained monzonite dikes with abundant, euhedral hornblende phenocrysts up to 15 mm.

Trd **Rhyodacite porphyry (Tertiary) –** In this map area, the rhyodacite porphyry is represented by a small stock in the Sierrita-Esperanza mine area. The rock contains approximately 20% phenocrysts of zoned plagioclase and potassium feldspar megacrysts in a fine-grained, dark gray to gray-green groundmass composed of quartz, orthoclase, oligoclase and biotite (Smith, 1975; West and Aiken, 1982). The unit is equivalent to the dacite porphyry of Lynch (1967).

Tns **North Sierrita Porphyry (Tertiary) –** Stocks of monzogranite pophyry containing phenocrysts of quartz, potassium feldspar, and biotite in an aphanitic groundmass. This unit intrudes the Ruby Star Granodiorite (Tgx and Tws) on the north side of the Sierrita-Esperanza mine. Herrmann (2001) obtained a concordant U-Pb zircon age of 60.5 $\pm$ 0.2 Ma from this porphyry and concluded that it was derived from a separate magmatic-hydrothermal system from that of the Ruby Star Granodiorite.

Tqv **Quartz veins (Tertiary) –** Massive, podiform quartz associated with pegmatite and aplite dikes that intrude the Ruby Star Granodiorite and the Sierrita Granite.

Tsb **Sierrita Breccia (Tertiary) –** Intrusive breccia consisting of clasts of Ox Frame volcanic rocks (units Ja and Jr), Harris Ranch Monzonite (Jh), Ruby Star megacrystic monzogranite (Tgx), and diorite (Td) in a matrix of fine-grained biotite and quartz. This strongly Cu-Mo-mineralized unit formed during emplacement of the megacrystic phase of the Ruby Star granodiorite (Tgx). According to Lynch (1967), andesite porphyry clasts were the most favorable host for supergene sulfide ore that has since been mined, with some chalcocite zones grading 4% Cu. During initial mining operations, Lynch (1967) noted that near-surface oxide mineralization gave way to chalcopyrite, pyrite, and molybdenite with increasing depth. As mining continued, West and Aiken (1982) noted that mineralization in the Sierrita Breccia decreased with depth.

Sierrita Granite

Lacey (1959) first used the name Sierrita Granite in reference to all of the granitic rocks exposed west of the Pima and Twin Buttes mines, located to the east in the adjoining Twin Buttes quadrangle (Richard et al., 2003). Cooper (1973) reassigned many of these rocks to other units and retained the name Sierrita Granite for a distinctive suite of leucocratic granite. We follow Cooper's nomenclature.

Most of the Sierrita Granite is medium- to coarse-grained and is mapped as unit Tg. A fine-grained to aplitic phase is called unit Tgf. The largest pluton of Sierrita Granite, exposed at Samaniego Peak, intrudes the Ruby Star Granodiorite and the Harris Ranch Monzonite. A lobe of this pluton southwest of Fresnal Canyon also intrudes sandstone of unit Js and Ox Frame rhyolite (Jr).

Contacts with the Harris Ranch Monzonite commonly display quartz-sericite or argillic alteration and minor faults. In some areas, notably west of the Sierrita-Esperanza mine, contacts between dikes and small stocks of the Sierrita Granite and the Harris Ranch Monzonite are obscured by intense hydrothermal alteration (quartz-sericite-jarosite-iron oxide). The symbols "Tg?" and "Tgf?" are used to designate zones where dikes of the Sierrita Granite are probably present but the original texture of the rock has been destroyed by alteration.

Along the intrusive contact with the Ruby Star Granodiorite south of Fresnal Canyon, the medium- to coarse-grained Sierrita Granite is slightly enriched in biotite (10%) and is fractured. The contact is distinct but not chilled, suggesting that the Ruby Star was warm when the Sierrita Granite was emplaced. Both units are cut by aplite dikes of the fine-grained phase of the Sierrita Granite (Tgf) that locally grade into the medium- to coarse-grained leucogranite (Tg). Along the contact northeast of Samaniego Peak, dikes of medium- to coarse-grained Sierrita Granite also cut the Ruby Star Granodiorite. The Sierrita Granite is therefore younger, though perhaps not much younger, than the Ruby Star Granodiorite, which has been dated at 64.3 $\pm$ 0.4 Ma by U-Pb zircon method (Herrmann, 2001). Previously, the Sierrita Granite was thought to be much older. Cooper (1973) assigned a Late Jurassic age to the granite based on a Pb-alpha date of 150 Ma from near Samaniego Peak (T.W. Stern, unpublished data, 1965). Similar dates were obtained south and west of the map area by different methods. A small, altered stock in the Batamote Hills quadrangle to the south was dated by the Rb-Sr method at 137 $\pm$ 14 Ma (Damon, 1966). A K-Ar biotite date of 145 $\pm$ 5 Ma (R.F. Marvin et al., unpublished data, 1973) was reported from the Palo Alto Ranch quadrangle to the west by Drewes and Cooper (1973). Younger dates from the Samaniego Peak area, including a Rb-Sr date of 67.5 $\pm$ 6.0 Ma (Damon, 1965) and a K-Ar biotite date of 56.4 $\pm$ 3.0 Ma (Marvin et al., 1973), were previously dismissed as having been affected by isotopic resetting.

Tg **Sierrita Granite (Tertiary) –** Leucocratic, medium- to coarse-grained, equigranular syenogranite with 1-5% mafic minerals (fine-grained biotite aggregates, variably altered to white mica and hematite). A fine-grained to aplitic leucogranite phase (designated as unit Tgf where mappable) is commonly present along contacts with host rocks. Locally, this phase contains 1-5% round quartz phenocrysts (2-5 mm). Contacts between the medium- to coarse-grained and fine-grained leucogranites are sharp to gradational. Where contacts are sharp, the fine-grained phase intrudes the medium- to coarse-grained granite. A transitional phase, characterized by 10-30% medium- to coarse-grained quartz and feldspar phenocrysts in a fine- to medium-grained groundmass, is common south of Fresnal Canyon.

Tgf **Sierrita Granite, fine-grained phase (Tertiary) –** Fine-grained to aplitic leucogranite, locally containing 1-5% round quartz phenocrysts (2-5 mm). Contacts with medium- to coarse-grained leucogranite of unit Tg are sharp to gradational. Where contacts are sharp, Tgf intrudes Tg.

Ruby Star Granodiorite

The Ruby Star Granodiorite (Cooper, 1973) forms a large composite pluton that is exposed throughout the northern and eastern parts of the Samaniego Peak quadrangle and the adjacent western fringe of the Twin Buttes quadrangle. The most abundant rock type in the pluton is medium-grained, equigranular granodiorite (Tgd). Potassium feldspar-megacrystic monzogranite to granodiorite (Tgx) forms a northerly elongate zone 1-3 km wide in the core of the pluton. A transitional medium- to coarse-grained phase with up to 2% megacrysts occurs within both Tgd and Tgx, and forms a transition zone 0-100 m wide along the contact between them. The transitional phase was not mapped separately.

Tgp **Ruby Star Granodiorite intruded by pegmatite and aplite (Tertiary) –** Megacrystic to transitional monzogranite to granodiorite, similar to unit Tgx, intruded by 5-15% pegmatite and aplitic leucogranite dikes.

Near the contact with unit Tgd in the northeast corner of the Samaniego Peak quadrangle, the megacrystic component is heterogeneously foliated and contains foliated enclaves of medium-grained Tgd granodiorite and sparse, fine-grained mafic xenoliths. Biotite is evenly dispersed where the rock is not foliated but forms aggregates in foliated zones. The pegmatite and aplite dikes are generally not foliated.

In the northwestern part of the quadrangle near Soto Peak, potassium feldspar megacrysts are most abundant near pegmatite dikes and look identical to the feldspar in the pegmatite. The pegmatite and aplite dike swarms are therefore interpreted as having been derived from the megacrystic monzogranite during late stages of crystallization.

Tws **Ruby Star West Sierrita Porphyry (Tertiary) –** Porphyritic monzogranite, light gray to pinkish gray, containing up to 50% phenocrysts of plagioclase (0.5-6 mm) with subordinate potassium feldspar (1-3 cm) and quartz in an aphanitic groundmass composed of potassium feldspar, quartz, and minor plagioclase (West and Aiken, 1982).

This unit grades eastward into the megacrystic phase of the Ruby Star Granodiorite (Tgx) and is equivalent to the aphanitic phase of the Ruby Star Quartz Monzonite Porphyry described by West and Aiken (1982).

Tgx **Ruby Star Granodiorite, megacrystic phase (Tertiary) –** Megacrystic monzogranite to granodiorite, medium- to coarse-grained, with 5-25% potassium feldspar megacrysts 1-5 cm long and 10-15% medium-grained, euhedral biotite. A transitional phase is medium-grained with up to 20% coarse-grained (1 cm) potassium feldspar and up to 2% megacrysts 1-4 cm long. The megacrystic phase is called the Ruby Star Quartz Monzonite Porphyry at the Sierrita-Esperanza mine (West and Aiken, 1982). A concordant U-Pb zircon age of 63.4 $\pm$ 0.3 Ma was reported by Hermann (2001) from the Esperanza pit, just beyond the southeast corner of this map area in the Batamote Hills quadrangle.

Tgd **Ruby Star Granodiorite, equigranular phase (Tertiary) –** Granodiorite, light gray, medium-grained, equigranular, with 10-20% euhedral biotite and up to 2% sphene. Includes transitional-phase granodiorite to monzogranite, medium-grained with up to 20% coarse-grained (1 cm) potassium feldspar and up to 2% potassium feldspar megacrysts 1-4 cm long. In the northeastern part of the Samaniego Peak quadrangle, medium-grained granodiorite of Tgd contains 20-25% biotite, 2-5% hornblende, 1-2% sphene, and fine-grained mafic xenoliths. This granodiorite is weakly foliated and is intruded by medium- to coarse-grained monzogranite of the transitional phase (mapped as Tgp). Granodiorite south of Fresnal Wash is locally fine-grained near contacts with sandstone of unit Js. Fine- to medium-grained, white granodiorite or tonalite, containing 5-15% biotite and hornblende also occurs locally in the Fresnal Canyon area. This leucocratic phase apparently forms dikes that intrude the medium-grained, equigranular granodiorite, but contacts between the two phases have not been observed. Herrmann (2001) obtained a concordant U-Pb zircon date of 64.3 $\pm$ 0.4 Ma from the equigranular granodiorite at the Ocotillo pit, in the southwest corner of the Twin Buttes quadrangle.

Tertiary or Older Rocks

TKq **Hydrothermal quartz veins (Tertiary – Cretaceous) –** Quartz veins and associated zones of pervasive silicification.

TKd **Diorite (Tertiary – Cretaceous) –** Fine-grained diorite, 1-2% quartz, 20-40% mafic minerals (biotite, hornblende, and opaque oxide; chlorite and epidote are present as alteration products). The unit forms stocks that intrude the Harris Ranch Monzonite and older volcanic and sedimentary rocks. Marvin et al. (1973) obtained a K-Ar biotite date of 68.5 $\pm$ 2.0 Ma (recalculated by Shafiqullah and Langlois, 1978, using modern decay constants) from the diorite 1 km west of the Sierrita-Esperanza mine. Although much of the diorite in the area appears fresh, the effects of hydrothermal alteration on the K-Ar systematics at the sample locality are unknown and, as such, this date may not be the age of the rock.

Gunsight granitoid suite

TXg **Heterogeneous granitoid rocks and schist intruded by pegmatite and aplite (Tertiary – Proterozoic?) –** A heterogeneous granitoid suite dominated by fine- to medium-grained quartz monzodiorite, monzodiorite, quartz diorite, and granodiorite containing 15-40% mafic minerals. The mafic minerals (biotite, subordinate hornblende, and traces of sphene) commonly form fine-grained aggregates up to 1cm across that are partly replaced by chlorite and epidote. Foliated inclusions of fine-grained diorite, amphibolite, and mafic schist are common, especially north of Gunsight Mountain. Amphibolite and mafic to quartzofeldspathic schist north of Gunsight Mountain have indistinct contacts with the granitoid rocks and appear to have been derived from mixed plutonic and sedimentary protoliths. In the Soto Peak area, the granitoid rocks intrude fine-grained feldspathic sandstone of unit Mzs. All of these rocks are intruded by up to 30% pegmatite and aplitic leucogranite dikes, which are Paleocene in age as they also intrude the Ruby Star Granodiorite.

The Gunsight granitoid suite is deformed by a heterogeneous, NNW-striking, steeply to moderately WSW-dipping foliation and a weak to moderate downdip mineral lineation. The foliation is subparallel to the margins of a tabular, 2-km long screen of Mzs sandstone, and to bedding in the sandstone. The sandstone generally is not foliated, implying that it was relatively stiff when the foliation formed in the granitoid rocks. West of the map area in the adjoining Palo Alto Ranch quadrangle, Drewes and Cooper (1973) mapped part of a deformed belt characterized by narrow, NNW-striking fault slivers of Proterozoic to Lower Cretaceous rocks with steeply dipping foliation and bedding. Because of the similarity in structural style, the fabric in the Gunsight granitoid suite is probably related to Cretaceous to Paleocene (Laramide) deformation.

The Gunsight granitoid suite is probably a Laramide suite of Late Cretaceous to Paleocene age. Cooper (1973) assigned a Proterozoic age to these rocks and some of the schist north of Gunsight Mountain may be as old as Proterozoic. However, the predominant granitoid rocks of the suite intrude feldspathic sandstone of unit Mzs that is most likely Mesozoic. Our observations suggest that the composition of the granitoid rocks is between those of units TKd and Tgd and they may be genetically related to either, or both of, these units.

Mesozoic Rocks

Harris Ranch Monzonite

The Harris Ranch Monzonite (Damon, 1965; Cooper, 1973) is mainly quartz monzonite in composition and forms plutons, stocks, and dikes that intrude the Jurassic volcanic and sedimentary rocks of the central Sierrita Mountains. The largest pluton in this map area extends from the head of Fresnal Canyon, southwest of Samaniego Peak, to the upper reaches of Tinaja Wash in the Batamote Hills quadrangle to the south. This pluton intrudes Ox Frame volcanic and sedimentary rocks along its southwestern margin and also along its eastern margin in the Sierrita-Esperanza mine. It intrudes the Red Boy Rhyolite northeast of Placer Peak; the contact is exposed 1 km northeast of Placer Peak near Ox Frame Tank.

Near the southwest corner of the map area, the Harris Ranch Monzonite forms a composite pluton that intrudes the Ox Frame Volcanics and sandstone of unit Js. This pluton contains three distinct varieties of granitoid that are referred to here as the Ash Creek, Tascuela, and mafic phases of the Harris Ranch Monzonite. The Ash Creek phase (Jha) is similar to the main Harris Ranch pluton (Jh) but is apparently older, because it is cut by the ENE-striking Ash Creek fault, whereas the main Harris Ranch pluton is not cut by this fault. The Tascuela phase (Jht) is exposed south of the Ash Creek fault and is in fault contact with the Ash Creek phase. The mafic phase (Jhm) intrudes the Tascuela phase and is intruded by the Ash Creek phase.

Riggs et al. (1994) reported an unpublished, concordant, U-Pb zircon age of 177 Ma for the Harris Ranch Monzonite in the Sierrita Mountains. The analytical data for the sample are included in Spencer et al. (2003) but the sample locality is not known.

Jh **Harris Ranch Monzonite (Jurassic) –** Medium-grained, equigranular quartz monzonite, greenish to pinkish gray, weathered light brown, containing 5-15% mafic minerals (biotite and hornblende variably altered to chlorite, epidote, and opaque oxides). Coarse-grained and fine-grained variations in texture occur within the main pluton. A fine-grained, porphyritic variety, common near intrusive contacts and in dikes, contains 15-40% plagioclase phenocrysts (pink to light orange, subhedral to euhedral, 1-5 mm) and up to 15% mafic minerals in a fine-grained to aphanitic, light pinkish gray to light green groundmass.

Jha **Harris Ranch Monzonite, Ash Creek phase (Jurassic) –** Medium-grained, equigranular quartz monzonite and fine-grained, porphyritic quartz monzonite to monzogranite. The equigranular quartz monzonite is like that of the main Harris Ranch pluton (Jh). The fine-grained phase is leucocratic and contains medium-grained feldspar phenocrysts, 15-25% quartz (mostly in the fine-grained groundmass), and 1-10% altered mafic minerals. Contact relations between these two phases are uncertain but appear to be gradational.

Jhm **Harris Ranch Monzonite, mafic phase (Jurassic) –** Light gray, fine-grained, porphyritic quartz monzonite, containing up to 20% plagioclase phenocrysts (2-8 mm) and 15-35% mafic minerals (hornblende and fine-grained biotite, variably altered to epidote and chlorite, respectively). Unit Jhm intrudes the Tascuela phase (Jht) and sandstone of unit Js, and is intruded by the Ash Creek phase (Jha).

Jht **Harris Ranch Monzonite, Tascuela phase (Jurassic) –** Monzonite to quartz monzonite porphyry containing medium-grained phenocrysts of potassium feldspar and plagioclase in a fine-grained to aphanitic, orange-pink groundmass. The unit is exposed south of an ENE-striking fault in Ash Creek and is in fault contact with medium-grained quartz monzonite (Jha) to the north.

Jap **Andesite porphyry (Jurassic) –** Porphyritic andesite containing 10-15% euhedral plagioclase phenocrysts 1-3 mm long. The andesite is massive and has a relatively low fracture density. It intrudes the Red Boy Rhyolite just north of Keystone Peak.

Red Boy Rhyolite

The Red Boy Rhyolite is a southeast-tilted (35-60^{o}) succession of cauldron-filling ash-flow tuff preserved in a keel-shaped segment of its source cauldron, named the Red Boy Peak cauldron by Ferguson et al. (2003). The keel strikes northeast across the crest of the Sierrita Mountains and is formed by two inwardly dipping contacts that are well-exposed in the Batamote Hills quadrangle to the south of this map area. Ferguson et al. (2003) interpreted the northwestern (basal) contact as the SE-tilted caldera floor, and the gently NW-dipping southeastern contact as a buttress unconformity along the NW-facing caldera wall. At the base of the keel, a NW-side-down caldera-margin fault zone is inferred (cross-section A-A'). The northern boundary of the Red Boy Rhyolite near the southern edge of the Samaniego Peak map area is interpreted as a south-dipping fault called the Keystone fault.

All exposures of the Red Boy Rhyolite in the map area lie within or near its source caldera, and much of the unit was mapped as mesobreccia (Jbz) or megabreccia (Jbx) depending on the size and concentration of lithic fragments. Zones of monolithic megabreccia (Jbdx and Jbrx) were identified and some individual megablocks were mapped separately (Ja-Jb, Jr-Jb, and Jt-Jb). Clasts in the rhyolite porphyry megabreccia unit (Jbdx), the most voluminous unit within the caldera fill, have a similar phenocryst assemblage to the Red Boy Rhyolite and are interpreted as having been comagmatic.

The Red Boy Rhyolite overlies the Ox Frame Volcanics with angular unconformity in upper Ox Frame Canyon north of Placer Peak. Bedding, defined by alternate lapilli-rich and lapilli-poor tuff, is approximately parallel to the SE-dipping contact and is discordant with respect to NW-dipping flow foliation in the Ox Frame rhyolite lavas and bedding in the Ox Frame quartz sandstone. In this map area, the Harris

Ranch Monzonite intrudes the eastern contact of the Red Boy Rhyolite and is interpreted as a sub-caldera pluton. North of Ox Frame Canyon near Sid Simpson Spring, the Red Boy Rhyolite forms a narrow pendant intruded by the Harris Ranch Monzonite and the Sierrita Granite. Rhyolite ash-flow tuff and rhyolite porphyry in this pendant are associated with andesite and andesite breccia that form units ranging from a few meters to 500 m across, interpreted as megablocks in the Red Boy Rhyolite (Ja-Jb). Most of the Red Boy Rhyolite north of Ox Frame Canyon is therefore interpreted as megabreccia (Jbx).

Mylonite zones are common in northernmost exposures of the Red Boy megabreccia, especially north of Sid Simpson Spring. These zones are characterized by a strong, NNW-striking, near-vertically dipping foliation and a weak to moderate, gently to moderately south-plunging stretching lineation. Some contacts between large blocks and matrix within the megabreccia are sheared parallel to these mylonite zones. Of five thin sections from the mylonite that were studied, one exhibited well-preserved tails on rotated feldspar porphyroclasts indicating an oblique-dextral sense of shear.

Jb **Rhyolite ash-flow tuff, Red Boy Rhyolite (Jurassic) –** Rhyolite ash-flow tuff containing 15-30% phenocrysts of plagioclase (0.5-1.5 mm), quartz (1-4 mm), and potassium feldspar (1-3 mm) in subequal proportions, and 1-50% felsic to intermediate volcanic-lithic fragments up to 5 cm. Pumice fragments are commonly indistinguishable from lithic clasts. In the Keystone Peak and upper Ox Frame Canyon areas, the tuff is green to greenish-gray, weathers light gray to dark brownish-gray, and displays medium to thick beds defined by alternate lapilli-rich and lapilli-poor tuff. In the Sid Simpson Spring area, the tuff is light to dark gray and the lithic fragments are mostly light gray to cream felsic volcanic clasts. Some of the clasts are quartz-porphyritic and resemble Jrp; others are flow-foliated and resemble Ox Frame rhyolite (Jr).

Jbz **Mesobreccia, Red Boy Rhyolite (Jurassic) –** Rhyolite ash-flow tuff containing greater than 25% lithic fragments <1 m across.

Jbx **Megabreccia, Red Boy Rhyolite (Jurassic) –** Rhyolite ash-flow tuff containing more than 25% lithic fragments, many of which are greater than 1 m across. South and east of Samaniego Peak, megabreccia contains blocks up to 500 m across of gray andesite and andesite breccia, some of which were mapped separately (Ja-Jb). Rhyolite porphyry (Jrp) forms megablocks and also forms dikes that intrude the andesite megablocks.

Jbrx **Rhyolite lava megabreccia, Red Boy Rhyolite (Jurassic) –** Zones of megabreccia dominated by clasts of phenocryst-poor rhyolite (map units Jr, Jrl, and Jrb).

Jbdx **Rhyolite porphyry megabreccia, Red Boy Rhyolite (Jurassic) –** Zones of megabreccia dominated by clasts of quartz-feldspar rhyolite porphyry (map unit Jrp).

Jt-Jb **Megaclasts of phenocryst-rich dacite tuff, Red Boy Rhyolite (Jurassic) –** Discreet megabreccia blocks of phenocryst-rich dacite (map unit Jt).

Jr-Jb **Megaclasts of rhyolite lava, Red Boy Rhyolite (Jurassic) –** Discreet megabreccia blocks of phenocryst-poor rhyolite (map units Jr, Jrb).

Ja-Jb **Megaclasts of andesite lava, Red Boy Rhyolite (Jurassic) –** Discreet megabreccia blocks of andesite lava and lava breccia (map unit Ja), containing up to 20% phenocrysts of plagioclase <1 mm.

Jrp **Rhyolite porphyry (Jurassic) –** Rhyolite porphyry containing 20-30% phenocrysts of quartz (2-6 mm) and feldspar (1-3 mm) in a light gray, aphanitic groundmass. The unit locally displays brecciated textures reminiscent of lava autobreccia and is typically flow-foliated near contacts with the Red Boy Rhyolite ash-flow tuff. These contacts are sharp, commonly interdigitated, and apparently intrusive but the geometry of the contacts suggests that the rhyolite porphyry occurs mostly as megaclasts within the Red Boy Rhyolite. The rhyolite porphyry is interpreted as remnants of lava domes that were emplaced just prior to, and possibly shortly after, eruption of the Red Boy Rhyolite, and that were still fluid during eruption and formation of the ash-flow tuff caldera (Ferguson et al., 2003).

Ox Frame Volcanics

Jr **Rhyolite, undifferentiated (Jurassic) –** Phenocryst-poor to aphyric rhyolite containing 0-5% phenocrysts of feldspar (1-2 mm), sparse mafic minerals, and very rare quartz phenocrysts. The matrix is typically light purplish gray, aphanitic, and recrystallized. Most of this unit is coherent-facies, massive to flow-foliated lava, but the unit also includes autobreccia and intrusive rhyolite that were not mapped separately.

Jrb **Rhyolite lava breccia (Jurassic) –** Autobreccia containing clasts of unit Jr in a fine-grained, recrystallized matrix. The breccia matrix locally contains abundant quartz sand. The unit is mapped near the upper reaches of Ash Creek, where rhyolite autobreccia covers large areas. In some areas, autobreccia may grade into clast-supported block-and-ash flows.

Jri **Intrusive rhyolite (Jurassic) –** Flow-foliated to massive, phenocryst-poor to aphyric rhyolite containing 0-5% phenocrysts of feldspar (1-2 mm), sparse mafic minerals, and very rare quartz phenocrysts. The matrix is typically light gray, aphanitic, and recrystallized. The unit is shown in areas where its intrusive nature is known.

Jtq **Rhyolite ash-flow tuff (Jurassic) –** Moderately phenocryst-rich rhyolite ash-flow tuff containing 20-30% phenocrysts of quartz (0.5-2 mm), plagioclase (0.5-2 mm), and potassium feldspar (1-2 mm) in subequal proportions, plus sparse biotite phenocrysts (<1 mm). The tuff occurs as two discrete outflow sheets, 2-20 m thick, intercalated with rhyolite and andesite lava flows east of Ox Frame Canyon.

Jq **Quartz sandstone (Jurassic) –** White to medium gray, fine- to medium-grained quartz sandstone, rounded to subrounded, well sorted to moderately sorted. Much of this unit is quartz arenite but it includes thin units of pebbly, quartz-rich sandstone that contain up to 30% rhyolitic lithic clasts ranging in size from granules to pebbles (up to 3 cm). The rhyolitic clasts are commonly light colored and chalky in appearance, and the larger clasts are typically sub-angular to angular. Small amounts (1-10%) of secondary sericite, chlorite, or biotite are locally present between the framework sand grains and are interpreted as products of metamorphism or hydrothermal alteration. The quartz sandstone forms units up to 20 m thick intercalated with rhyolite and andesite lava flows throughout the Ox Frame succession.

Jas **Volcanic-lithic sandstone (Jurassic) –** Olive green, thin- to medium-bedded, fine-grained sandstone containing mafic to intermediate volcanic-lithic fragments, minor feldspar grains and traces of quartz.

Jax **Porphyritic andesite (Jurassic) –** Green andesite containing 30-40% euhedral to subhedral plagioclase phenocrysts (1-5 mm).

Ja **Andesite, undifferentiated (Jurassic) –** Andesite lava flows, autobreccia, and associated dikes. The andesite is typically a dark greenish color and contains 5-30% phenocrysts of plagioclase (1-6 mm) and 0-5% strongly altered mafic minerals (generally <2 mm) in a fine-grained crystalline matrix. Most flows contain 10-15% euhedral to subhedral plagioclase phenocrysts (1-2 mm) but some distinctive units have larger phenocrysts (3-6 mm) and are relatively phenocryst-rich (20-30%).

Jai **Intrusive andesite (Jurassic) –** Andesitic dikes containing 5-30% phenocrysts of plagioclase (1-6 mm) and 0-5% strongly altered mafic minerals (generally <2 mm) in a dark-colored, fine-grained, crystalline matrix. The unit is shown in areas where intrusive nature is known.

Js **Sandstone of upper Ash Creek (Jurassic?) –** Quartzose sandstone and siltstone exposed north of Ash Creek. The sandstone is fine-grained to very fine-grained, light gray to dark green, weathers light pinkish to light greenish gray, and is medium- to thin-bedded with argillaceous siltstone partings. Weak to moderate epidote-hornfels metamorphism is pervasive, increasing to local biotite hornfels near contacts with the Ruby Star Granodiorite. A 5m-thick section of felsic tuff and volcaniclastic sandstone occurs within this unit near the southern, faulted contact with the Ox Frame Volcanics. The tuff contains sub-angular to sub-rounded rhyolitic lithic fragments (<1 mm to 2 cm) and angular to sub-rounded, monocrystalline and polycrystalline quartz sand grains (up to 1 mm) in a light green matrix. All contacts between unit Js and other rocks are either intrusive or faulted, and therefore stratigraphic relations are uncertain. Cooper (1971, 1973) proposed correlation of this unit with the Rodolfo Formation in the Twin Buttes quadrangle but there is no substantial evidence for this correlation.

Soto Assemblage

Mzsp **Sandstone intruded by aplite and pegmatite (Tertiary – Mesozoic?) –** Subarkosic to arkosic arenite of unit Mzs intruded by abundant aplite and pegmatite dikes. The dikes are Paleocene in age as they also intrude the Ruby Star Granodiorite.

Mzs **Sandstone (Mesozoic?) –** Subarkosic to arkosic arenite, fine-grained, moderately well sorted, subrounded. The unit forms thick, tabular beds with planar lamination. It is preserved in a tabular, NNW-elongate pendant or screen intruded by the Gunsight granitoid suite.

Mzc **Limestone (Mesozoic?) –** Limestone, marble, and epidote calcsilicate skarn.

Paleozoic and Older Rocks

Ps **Sandstone (Permian) –** Fine- to medium-grained, thin- to medium-bedded quartz sandstone, locally ripple cross-laminated, typically in tabular-planar sets. The unit is exposed in small pendants in the Sierrita Granite west of Soto Peak. The contact with limestone of unit Pl is faulted.

Pl **Limestone (Permian) –** Medium- to thick-bedded skeletal packstone and grainstone. The unit is exposed in small pendants in the Sierrita Granite west of Soto Peak. The contact with sandstone of unit Ps is faulted.

Y-Pz-Mz* **Pre-Tertiary rocks (Mesoproterozoic – Paleozoic – Mesozoic) –** Undifferentiated granitic, volcanic, and sedimentary rocks. * Shown on cross section only.

Structural and magmatic framework

The Sierrita Mountains are most simply interpreted as a SSE-tilted fault block that exposes an inclined cross section through the upper crust. Deeper structural levels are exposed in the northern part of the Sierrita Mountains and are dominated by the Ruby Star Granodiorite. Mesozoic and Tertiary volcanic and sedimentary rocks are exposed in the southern part of the range, at higher structural levels. The Sierrita-Esperanza and Twin Buttes porphyry copper deposits are located at the upper contact of the Ruby Star Granodiorite. Tilting of 40^{o} to 60^{o} is suggested by consistent SSE dips of the youngest

Mesozoic volcanic rocks throughout the range and the dip of the basal Cenozoic unconformity (Seedorff, 1983). Preliminary paleomagnetic data from dikes that cut the Ruby Star Granodiorite (W. J. A. Stavast and R. F. Butler, 2003) corroborate this assertion.

The San Xavier fault, originally interpreted as a thrust (Cooper, 1973; Jansen, 1982), is shown schematically on our cross section as a low-angle normal fault with approximately 9 km of top-to-the-north displacement (see also Ferguson et al., 2003). This estimate of displacement is based on the interpretation that the Mission mine, in the hanging wall, correlates with the Twin Buttes mine in the footwall (Cooper, 1960; Jansen, 1982; Titley, 1982; Williamson and Poulton, 1995). The position of the fault on our cross section is based on extrapolation of structure contours of the fault surface (Figure 22.1 of Jansen, 1982). The positions of the Oligocene Helmet Conglomerate (Th) and porphyritic andesite lava (Tap) in the hanging wall were projected along strike. The Helmet Conglomerate was deposited during early stages of movement on the San Xavier fault. Some of the regional tilting may have been caused by rebound of the footwall of the San Xavier fault. If not, the fault must have had a steeper original dip.

Belts of Proterozoic to Lower Cretaceous rocks deformed by NNW-trending faults and folds are exposed on the western and northeastern flanks of the Sierrita Mountains (Cooper, 1973; Drewes and Cooper, 1973; Barter and Kelly, 1982; Jansen, 1982; Richard et al., 2003). To the west in the Palo Alto Ranch map area, NNW-striking faults form narrow fault-bounded slices several kilometers in strike length (Drewes and Cooper, 1973). Screens of Paleozoic and Mesozoic sedimentary rocks near the western edge of the Samaniego Peak map area (units Mzs, Mzc, Ps, Pl) display a similar style of deformation. The Gunsight granitoid suite, which intrudes the Mesozoic rocks, is deformed by a steeply dipping foliation that is approximately concordant to tabular screens of unit Mzs. Sandstone in the screens is bedded but not foliated. This suggests that the granitoid suite was emplaced syntectonically, the folation forming as the intrusions cooled. The Sierrita Granite is weakly foliated near the contact with the Gunsight granitoid suite, implying that the foliation is at least in part of Paleocene or younger age. In the northeast corner of the map area, NNW-striking, steeply dipping foliations along the contact between phases Tgd and Tgp of the Ruby Star Granodiorite must also be of Paleocene or younger age. Restoration of a moderate amount of SSE tilt indicates that the steeply dipping fault-bounded slices continued as such to several kilometers depth. Although the faults were mapped as thrusts by Drewes and Cooper (1973), this geometry is more akin to that typical of strike-slip faults and merits further investigation.

The northernmost exposures of the Red Boy Rhyolite, located in the south-central part of the map area, exhibit a NNW-striking, steeply dipping mylonitic foliation and a shallow to moderate southerly plunging stretching lineation. The mylonitic fabric indicates an oblique dextral sense of shear. Assuming that the stretching lineation represents the movement direction, restoration of a moderate amount of SSE tilt results in a movement vector that is horizontal (strike slip) to moderately north-plunging (oblique slip). The Harris Ranch Monzonite is not foliated near intrusive contacts with foliated

Red Boy Rhyolite. The Sierrita Granite intrudes the foliated Red Boy Rhyolite, locally displaying thin chilled zones or a weak magmatic foliation along the contact. Rare remnants of a possible tectonic foliation in the granite along the contact are overprinted by small brittle faults. The mylonitic fabric in the Red Boy Rhyolite probably formed during, or following, the collapse of the Red Boy Peak caldera and before sub-caldera plutons of the Harris Ranch Monzonite were emplaced. Our assignment of a Jurassic age to the Red Boy Rhyolite is based on the 177 Ma date from the Harris Ranch Monzonite reported by Riggs et al. (1994). However, the sample locality is unknown and it is possible that the dated pluton is not the same as the Harris Ranch Monzonite that we have mapped. Previous workers have considered the Red Boy Rhyolite to be Late Cretaceous in age (Cooper, 1973; Lipman and Fridrich, 1990). If the Red Boy Rhyolite and Harris Ranch Monzonite are of Late Cretaceous age, structural and magmatic relationships can be interpreted in the context of Laramide tectonics. NNW-striking faults, shear zones, and foliations may all be related to oblique dextral shearing with an ENE component of flattening, suggesting transpression. Variation in the orientations of mineral and stretching lineations in the Gunsight granitoid suite, the Red Boy Rhyolite, and Ruby Star unit Tgp may be due to strain partitioning or different amounts of Oligocene tilt.

A NNW-trending structural grain is also expressed by steeply dipping Mesozoic and Tertiary intrusive contacts, the long dimensions of plutons, and zonation within the Paleocene Ruby Star Granodiorite. Upon restoration of SSE tilt, this indicates that the plutons initially had steep walls and may have been steeply elongate. The Harris Ranch Monzonite (Jh) intrudes the Ox Frame Volcanics near the southern edge of the map area. The contact continues to the SSE into the Batamote Hills map area, where dike swarms of Harris Ranch Monzonite in the volcanics are subparallel to the NNW-striking, steeply dipping contact of the pluton (Ferguson et al., 2003). The Ruby Star Granodiorite is a steep-sided composite pluton. The Gunsight granitoid suite (TXg), which may be an early phase of the Ruby Star pluton, is intruded by younger granites along steep contacts. The megacrystic phase of the Ruby Star Granodiorite (Tgx) is a steep-sided inner spine of the Ruby Star pluton. The northeastern margins of Sierrita Granite plutons strike NNW and dip steeply. The western and northern margins are irregular and appear more gently dipping but may have been steep before regional tilting. At deep structural levels, the Sierrita Granite is weakly foliated parallel to the steep contact with the Gunsight granitoid suite and to the pervasive, steeply dipping foliation in the Gunsight suite. At higher structural levels, the northeastern contacts of the Sierrita Granite line up along strike with older, steep contacts of Harris Ranch Monzonite and Ruby Star Granodiorite plutons. These contacts are poorly exposed and locally faulted but are, at least in part, intrusive. The older intrusive contacts may have provided anisotropy that was exploited by the Sierrita Granite and subsequent minor faults.

The southern margins of the main Sierrita Granite pluton and its southwest lobe are aligned with the Ash Creek fault and were mapped by Cooper (1973) as truncated by it. The Ash Creek fault is part of an array of ENE-striking, moderately to steeply SSE-dipping brittle faults. Our mapping suggests that these faults are younger from south to north and they may have accommodated significant displacements before intrusion of the Harris Ranch Monzonite, yet were only locally reactivated after emplacement of the

Harris Ranch and younger plutons. The Keystone fault cuts the Red Boy Rhyolite and Ox Frame Volcanics and is intruded by the Tascuela phase of the Harris Ranch Monzonite (Jht). This fault marks the base of the exposed section of Red Boy Rhyolite and may be the tilted cauldron floor. The Ash Creek fault juxtaposes Ox Frame Volcanics with sandstone of upper Ash Creek, distinct pre-caldera assemblages between which stratigraphic relationships are unknown. The Ash Creek fault cuts the western plutons of the Harris Ranch Monzonite (Jht and Jha) but the eastern Harris Ranch pluton (Jh) is not offset by it. The southern contacts that define the roofs of the Sierrita Granite plutons are therefore interpreted as locally faulted intrusive contacts. In particular, the fine-grained phase of the granite (Tgf) appears to plug, rather than to be cut by, faults. Farther north, the Fresnal Wash fault cuts the mafic phase of the Harris Ranch Monzonite (Jhm) and the Ruby Star Granodiorite (Tgd). The crosscutting relationships outlined above lead to the conclusion that the ENE-striking set of faults probably formed during collapse of the Red Boy Peak caldera. Portions of the faults were reactivated during and after emplacement of the subcaldera Harris Ranch Monzonite, with minor reactivation thereafter. Restoration of a moderate amount of Tertiary SSE tilt indicates that the ENE-striking faults dipped gently to the SSE or were nearly horizontal. They may have fed into more steeply dipping caldera-margin faults.

The Sierrita Granite intrudes the equigranular phase of the Ruby Star Granodiorite (Tgd) but its age relative to the megacrystic phase (Tgx, Tgp) is not well constrained. Pegmatite and aplite dike swarms intrude the Ruby Star pluton and the Gunsight granitoid suite. Some of the pegmatite and aplite appear to have been segregated from the megacrystic phase of the Ruby Star Granodiorite during its final stages of crystallization. The aplite is indistinguishable in the field from the fine-grained phase of the Sierrita Granite (unit Tgf) and, locally, is associated with medium- to coarse-grained leucogranite that resembles the Sierrita Granite (unit Tg). The Sierrita Granite west of the Gunsight granitoid suite is not cut by pegmatite dikes but is intruded by thin aplite dikes of unit Tgf that appear to have been derived from the Sierrita Granite. Pegmatite dikes have only been observed in the Sierrita Granite near the north end of the main pluton, north of Samaniego Peak, and these appear to have been derived from the Sierrita Granite. Massive quartz veins (Tqv) are associated with pegmatites in the Ruby Star Granodiorite and similar veins occur, but are rare, in the Sierrita Granite. Veins, small faults, and associated zones of quartz-white mica alteration are common in the Ruby Star Granodiorite, especially at the north end of the mountain range north of Samaniego Peak. Similar veins and alteration have also been observed in the Sierrita Granite but only north of Samaniego Peak. Considering the intrusive relationships outlined above, the Sierrita Granite is inferred as having been emplaced shortly after, or at approximately the same time as, the megacrystic phase of the Ruby Star Granodiorite (~63 Ma). Pegmatites derived from the Ruby Star are associated with aplites that may have been derived in part from the Ruby Star and in part from the Sierrita Granite. Associated hydrothermal systems outlasted crystallization of both plutonic suites.

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