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RAY CARROLL
COUNTY SUPERVISOR
DISTRICT 4

MEMORANDUM

TO: The Honorable Chair and Members of the
Pima County Board of Supervisors

FROM: Ray Carroll
District 4 Supervisor

DATE: January 11, 2007

RE: **Geological Survey of the Rosemont Valley**

In a memorandum released to you today by the County Administrator (for the January 16th Board of Supervisors meeting) a reference was made to a geological survey of the Rosemont Valley, which stated:

"Finally, a recent not-yet released geological survey of the mine area by the State's Geological Survey office, has called into question the stability of the high wall natural rock formation above the proposed mining pit."

I have included for your review the geological survey report in question.

The high wall rock formation stability issue is addressed on page 8 of the attached report. A color copy of the map referenced in the report in the District 4 Office which is available for your review.

cc: Chuck Huckelberry

RC:pm

Geologic Map of the Rosemont area, northern Santa Rita Mountains, Pima County, Arizona

by
Bradford J. Johnson and Charles A. Ferguson
Arizona Geological Survey

Digital Geologic Map 59 (DGM-59)
version 1.1

December 2006

Scale 1:12,000 (1 sheet)
with 10 page text

Arizona Geological Survey
416 W. Congress St., #100, Tucson, Arizona 85701
www.azgs.az.gov

Geologic Map of the Rosemont area, northern Santa Rita Mountains, Pima County, Arizona

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Introduction

Southeastern Arizona hosts one of the greatest concentrations of copper deposits on Earth. After more than a hundred years of geologic study, the porphyry-style and related copper deposits of southeastern Arizona and elsewhere remain incompletely understood. Each deposit has unique features, including typically complex structure and diverse rock types that are affected by copper mineralization and associated alteration. Commonly, much of the information about these features is lost when the deposits are mined.

The Rosemont copper-molybdenum skarn deposit is located in the subsurface of the northern Santa Rita Mountains, southeast of Tucson, Arizona. In order to evaluate the geologic setting of the deposit, the Arizona Geological Survey created a 1:12,000 scale geologic map of the rocks exposed on the surface above the deposit. This report and accompanying map are the products of that study. We thank Augusta Resource Corporation for providing access to the property and financial support.

Unit Descriptions

Hd **Disturbed areas (Holocene)** – Mine dumps, road ballast, and slag deposits. The unit is mainly represented by a set of heavily vegetated dumps downslope from the Narragansett Mine. A slag deposit in the southwest ¼ of section 29 is also included.

Qa **Younger alluvium (Holocene – late Pleistocene)** – Alluvium along active streams and washes, locally heavily vegetated. In general the unit includes all alluvium deposits and associated flood-plains incised less than 3 m.

Qc **Colluvium and talus (Holocene – late Pleistocene)** – Colluvium and talus consisting of subangular to angular pebbles, cobbles, and boulders derived from nearby upslope bedrock units. The unit is shown only in areas where deposits are extensive or where important bedrock contact relationships are buried.

Qo **Older alluvium (late Pleistocene?)** – Weakly consolidated gravel forming terraces and flat-topped interfluves. Deposits consist of medium- to thick-bedded, sandy, pebble-cobble gravel with rare boulders, ranging from clast-supported to matrix-supported, containing clasts derived from nearby upslope bedrock units. The deposits are generally incised between 4-12 m and locally form cliffs and ledges up to 3 m high. The highest terraces show little evidence of calcic soil development.

Tg Gila Conglomerate (Pliocene? – Miocene) – Light brown, generally medium- to thick-bedded, clast-supported to matrix-supported conglomerate, pebbly sandstone, and sandstone. Clasts range from rounded to subangular and consist of quartz sandstone, carbonate, argillite, hornfels, marble, granitic rock, quartz-feldspar porphyry, and quartz-feldspar phenocryst-rich, welded ash-flow tuff. The clasts reflect the composition of nearby bedrock units, including Paleozoic sedimentary rocks, felsic porphyry (TKp), ash-flow tuff (Kr), and Proterozoic quartz monzonite (YXg). In the southern part of the map area, intervals containing up to 70% subangular to subrounded clasts of potassium feldspar-megacrystic quartz monzonite (YXg) are common. These granitoid clasts are not present in the older alluvial terraces (Qo) and are an important diagnostic characteristic of the Gila Conglomerate along the mountain front. >200 m thick.

s Skarn (Paleogene – late Cretaceous?) – Skarn and vuggy, calcsilicate hornfels, characterized by intense iron-oxide and local clay alteration and strong oxide-copper mineralization. Iron oxide (typically hematite) forms dark brown lenses and layers that locally are crudely laminated. In some places, designated as sCa on the map, skarn occurs along the contact between the Bolsa Quartzite (Cb) and the Abrigo Limestone (Ca) and was clearly derived from the latter. In other places the protolith is uncertain, possibilities including the Abrigo Limestone, Bolsa Quartzite, and Willow Canyon Formation (Kw).

TKp Quartz-feldspar porphyry (Paleogene – late Cretaceous) – Light gray to pink felsic porphyry containing 8-15% phenocrysts of anhedral to subhedral quartz (1-5 mm), up to 25% subhedral to euhedral feldspar (3-5 mm, white to pink), and 1-2% biotite. The biotite forms thin 1-2 mm flakes that commonly weather out of the rock. The groundmass ranges from aphanitic to aplitic, is commonly silicified near intrusive contacts, and locally exhibits graphic intergrowths of quartz and cryptocrystalline feldspar. The porphyry forms dikes and small stocks.

TKa Andesite porphyry (Paleogene – Upper Cretaceous) – Strongly altered, fragmental, fine-grained, plagioclase-porphyritic andesite or intermediate intrusive porphyry with up to 10% green crystalline lapilli inclusions. The unit forms an elliptical outcrop belt located along the margin of the Mt. Fagan caldera. The age of the unit relative to the Mt. Fagan Rhyolite is poorly constrained. The Mt. Fagan Rhyolite contains andesitic lithic clasts that may be derived from this unit, but it is possible that the clasts were derived from andesitic lavas within the Bisbee Group (Km) or other andesitic volcanic rocks that are known to underlie the Mt. Fagan Rhyolite elsewhere.

Kr Mt. Fagan Rhyolite (Upper Cretaceous) – Phenocryst-rich ash-flow tuff containing up to 40% 1-4mm phenocrysts of quartz, feldspar, and biotite and 1-5% lithic lapilli in a welded to nonwelded, light-colored matrix. The lithic lapilli consist chiefly of feldspathic sandstone and argillite, derived from the Bisbee Group, and fine-grained andesite lava. Other clasts include limestone, and phenocryst-rich rhyolite ash-flow tuff that may have been derived from slightly older deposits of the Mt. Fagan Rhyolite. >1,000 m thick.

Kx **Mt. Fagan Rhyolite megabreccia (Upper Cretaceous)** – Zones of the Mt. Fagan Rhyolite containing more than 30% lithic blocks larger than 1 m. Lithic clasts consist mostly of feldspathic sandstone and argillite of the Bisbee Group, with subordinate fine-grained andesite. The megabreccia grades over a short distance into zones of clast-supported breccia without ash-flow tuff matrix, then into Mt. Fagan Rhyolite (Kr) with sparse lithic clasts.

Ka **Apache Canyon Formation, Bisbee Group (Lower Cretaceous)** – Medium- to thick-bedded sequences of shale and laminated silty mudstone with subordinate interbeds of dark gray, laminated to thin-bedded, micritic limestone and thin- to thick-bedded feldspathic sandstone. The limestone, which defines the formation, is typically fetid and commonly displays slump-folded laminations and beds. The sandstone is typically thin- to medium-bedded, fine- to medium-grained, and feldspathic. Many of the sandstone beds are plane-bedded with ripple-laminated tops, suggestive of turbidites. The base of the Apache Canyon Formation is defined as the lowest appearance of limestone in the Bisbee Group. >400 m thick.

Kw **Willow Canyon Formation, Bisbee Group (Lower Cretaceous)** – A monotonous succession of medium- to coarse-grained, locally granular to pebbly, feldspathic sandstone and argillaceous sandstone with equal to subordinate amounts of vuggy, silty mudstone. A distinctive interval of volcaniclastic pebble-cobble conglomerate is present near the middle of the unit, below a sequence of mafic lava flows. The conglomerate (identified in the database with the symbol Kwc but not mapped separately) contains up to 70% mafic and intermediate porphyritic igneous clasts along with clasts of chert and quartzose sandstone. Sandstone throughout the formation is feldspathic (typically arkosic arenite) and is cross-stratified to plane-bedded. The sandstone is typically medium- to thick-bedded, but also forms amalgamated tabular sets. ~2,200 m thick.

Km **Mafic lava, Bisbee Group (Lower Cretaceous)** – A series of at least three mafic lava flows within the Willow Canyon Formation in the northern part of the map area, and within the Glance Conglomerate in the south. The flows are massive to amygdaloidal (calcite and quartz) and typically very fine-grained with sparse mafic phenocrysts up to 2 mm. The matrix consists of fine-grained microlites of plagioclase. Individual flows 10-100 m thick.

KJg **Glance Conglomerate, Bisbee Group (Upper Jurassic and/or Lower Cretaceous)** – Massive to very thick-bedded, clast-supported conglomerate containing pebbles, cobbles, and locally boulders that reflect the composition of underlying Proterozoic through Permian rocks. The basal contact is an angular unconformity that climbs up-section to the east. The unit is preserved in three different areas with distinctly different settings. In the southwest corner of the map area, it overlies the basal Cambrian nonconformity and consists of boulders, cobbles and pebbles of granitic rock and quartz sandstone in a sandy matrix. There the conglomerate grades upward, through a fanning dip sequence, into arkosic pebbly sandstone of the Willow Canyon Formation. In an adjacent and structurally higher fault block to the east, the Glance overlies upper Paleozoic strata and is characterized by thick-bedded, clast-supported, pebble-cobble conglomerate with clasts of limestone, argillite, and quartz sandstone. In the west-central part of the map area, an outcrop belt of clast-supported conglomerate with limestone pebbles and cobbles is exposed between the Willow Canyon Formation and the Concha Limestone, in probable faulted contact with both units. Small outcrops of monomict Glance Conglomerate can easily be mistaken for granitic basement in the south and massive limestone to the north. 0-300 m thick.

KJi **Glance Conglomerate clastic dike (Upper Jurassic and/or Lower Cretaceous)** – Clast-supported conglomerate composed of pebbles and cobbles of quartz sandstone and granitoid rock, forming a narrow, elongate outcrop approximately 40 m long in the southwest corner of the map area, surrounded by quartz monzonite of unit YXg. The exposure might represent a fault sliver, but fairly well-exposed, somewhat irregular contacts show no evidence of faulting, and the outcrop is tentatively interpreted as a clastic dike.

Prv **Rain Valley Formation, Naco Group (Permian)** – Gray, medium- to thick-bedded limestone, intercalated with subordinate thin-bedded to laminated, locally ripple-laminated, fine-grained sandstone and siltstone. The unit includes intervals of light gray, fine- to very fine-grained, thick-bedded quartz sandstone in the lower part. ~100 m thick.

Pch **Concha Limestone, Naco Group (Permian)** – Light to medium gray, medium- to thick-bedded, massive to planar-laminated, amalgamated, cherty limestone. Chert nodules are characteristically wispy and poorly formed, but locally form lenses several m long. Locally dolomitic, the limestone is mostly micritic but includes skeletal wackestone and possible packstone, which locally contain spiculite beds and brachiopod fragments. 200-250 m thick.

Pq **Quartz sandstone, Naco Group (Permian)** – Fine- to very fine-grained, white to light gray, thick- to medium-bedded quartz arenite, intercalated with carbonate tentatively identified as the Concha Limestone. 0-20 m thick.

Ps **Scherrer Formation, Naco Group (Permian)** – A unit dominated by light gray to pink, fine-grained, massive, quartzose sandstone. Laminations are rarely preserved. A transitional interval at the top of the unit, locally differentiated as the upper Sherrer (Psu), consists of distinctive, cream-colored, medium-bedded, dolomicrite, poorly preserved siltstone, and argillaceous carbonate rocks. 100-150 m thick.

Pe **Epitaph Formation, Naco Group (Permian)** – A mixed siliciclastic-carbonate unit consisting of purple to reddish, thin- to medium-bedded siltstone and silty mudstone, fine-grained, ripple-laminated sandstone, and light gray to pink, massive to laminated, medium- to thick-bedded, micritic carbonate. The siliciclastic components are commonly metamorphosed to light orange-pink or greenish hornfels, in which bedding is defined by recessive lenticular pits up to several cm long or by alternate resistant and recessive laminations. 75-120 m thick.

Pc Colina Limestone, Naco Group (Permian) – Light gray to white, medium- to thick-bedded, amalgamated, micritic carbonate and skeletal wackestone, commonly dolomitic. 50-80 m thick.

PPe **Earp Formation, Naco Group (Permian – Pennsylvanian)** – A mixed siliciclastic-carbonate unit consisting of light reddish brown to light green, thin- to medium-bedded, planar-laminated siltstone, silty mudstone, and very fine-grained sandstone, intercalated with light gray to pinkish gray, thick-bedded, micritic limestone and skeletal wackestone. The limestone locally contains spicules and is locally dolomitic. The siliciclastic components are commonly metamorphosed to light green or orange-pink hornfels. 150-200 m thick.

Ph **Horquilla Limestone, Naco Group (Pennsylvanian)** – Light gray, thin- to thick-bedded, cherty limestone with interbeds of dark gray to green silty mudstone and shale that become more abundant up-section. 200-300 m thick.

MD **Escabrosa Limestone – Martin Formation undifferentiated (Mississippian – Devonian)** – Light gray, medium- to thick-bedded, amalgamated, massive, locally cherty, recrystallized limestone. Massive dolostone or dolomitic limestone is present in the lower portion locally. Although an unconformity is present between the Martin Formation and the Escabrosa Limestone, these units are not preserved well enough in this area to distinguish them from one another. 70-170 m thick.

Ca **Abrigo Formation (Cambrian)** – A sequence of thin- to medium-bedded limestone with siliceous laminations. The lower part contains intercalated fine-grained, parallel-laminated to ripple-laminated, fine-grained sandstone, siltstone, silty mudstone and shale. In much of the map area, the unit has in part been metamorphosed to light pinkish gray to greenish yellow calcsilicate hornfels, which forms resistant outcrops with recessive thin beds, lenses, and laminations. 100-200 m thick.

Cb **Bolsa Quartzite (Cambrian)** – Light gray, medium- to fine-grained, thick- to medium-bedded, quartzose sandstone that forms cliffs and ledges. The lower part is cross-stratified, commonly coarse-grained, and locally feldspathic, with composition apparently ranging from quartz arenite to subarkosic arenite. Pebbly to granular beds occur near the base of the unit, which unconformably overlies quartz monzonite of unit YXg. The upper part of the Bolsa Quartzite is medium gray, fine-grained, commonly bioturbated with *planolites* ichnofossils, and includes up to 30% silty mudstone and shale near the gradational contact with the overlying Abrigo Formation. 80-175 m thick.

YXg **Quartz monzonite (Early or Middle Proterozoic)** – Medium-grained quartz monzonite containing 20-35% megacrysts of potassium feldspar up to 5 cm long, 30-40% plagioclase, 10-15% quartz, and 15-20% altered mafic minerals (epidotized hornblende?).

Map Notes

Along the western edge of the map area, Proterozoic granitic rocks are overlain unconformably by Lower Cambrian sandstone of the Bolsa Quartzite. The Bolsa Quartzite is in turn overlain by the Abrigo Limestone and a structurally attenuated succession of Devonian through Permian strata. Partially coherent Paleozoic sections are preserved locally. However, the Paleozoic rocks are cut by faults that strike at low angles to formational contacts and that omit parts of the section. Intervals of mixed carbonate and siliciclastic rocks, common in many parts of the Paleozoic section, have been metamorphosed to calcsilicate hornfels, making it difficult or impossible to identify and trace marker beds in many parts of the map area. As a result, the assignment of Paleozoic rocks to specific formations may not be entirely correct in some places, notably in the north half of section 36.

The Upper Jurassic – Lower Cretaceous Bisbee Group underlies more than half of the mapped area, and understanding its stratigraphic and structural relationships with respect to the Paleozoic rocks is important for both regional and local geological interpretations. Regionally, the Bisbee Group is a very thick (>2,500 m) succession of immature quartzofeldspathic sedimentary rocks that occupies a series of fault-bounded basins throughout southeastern Arizona (e.g., Bilodeau et al., 1987; Dickinson et al., 1987). Locally, the group is represented by the Glance Conglomerate, the Willow Canyon Formation, and the Apache Canyon Formation. The Upper Jurassic – Lower Cretaceous Glance Conglomerate is overlain by the Willow Canyon Formation, a thick succession of feldspathic sandstone and argillite that contains several mafic lava flows. These rocks are overlain gradationally by the Apache Canyon Formation, a shale-dominated succession that includes interbedded feldspathic sandstone and distinctive, dark-colored, thin-bedded limestone with cryptalgal lamination. The character of the limestone and its association with feldspathic sandstone distinguish it from Paleozoic limestones in the region. The upper part of the Bisbee Group is not exposed in the area.

In the southwest corner of the map area, Proterozoic and Paleozoic rocks are overlain unconformably by the Glance Conglomerate. This unconformity is well exposed in both the footwall and the hanging wall of an important east-dipping fault, which cuts the unconformity. In the footwall of the fault, the Glance Conglomerate overlaps the Lower Cambrian nonconformity, and is composed of clasts derived from the Proterozoic granitic rocks and the Bolsa Quartzite. In the hanging wall, the conglomerate overlies upper Paleozoic strata of the Naco Group, and contains clasts of limestone, argillite and sandstone, reflecting the composition of those strata. The basal contact of the conglomerate is an angular unconformity that overlies progressively younger units within the Naco Group to the east, indicating that the Paleozoic section was tilted before the latest Jurassic.

In the north-central part of the map area, the Willow Canyon Formation surrounds, and structurally overlies, an inlier of the Permian Rain Valley Formation. The poorly exposed contact between these two units has been interpreted previously as a thrust fault (Drewes, 1971) or depositional contact (Hardy, 1997), and is interpreted here as a depositional unconformity, cut by an east-west striking, north-side-down fault along the northern boundary of the inlier.

The Bisbee Group and all older strata in the area have been deformed by a train of broad to open, locally close to tight, generally southeast-plunging folds. The Bisbee Group in the eastern and central part of the Rosemont area is folded by an open, upright, moderately southeast-plunging anticline. Along the west side of the map area, the Bolsa Quartzite outlines open, box-like folds with steeply east- to southeast-plunging axes. Interlayered carbonate and siliciclastic Paleozoic units, such as the Abrigo Limestone, are deformed by open to close, southeast- to northeast-plunging folds with angular hinges and planar limbs. Folds in the Abrigo are disharmonic with respect to those in the Bolsa Quartzite, with wavelengths of the order of tens to hundreds of meters, in contrast with the km-scale folds in the Bolsa Quartzite. Regionally, the Bisbee Group and older Mesozoic and Paleozoic strata in the northernmost Santa Rita and Empire mountains were deformed by east-vergent folds and thrusts and a later phase of north-vergent folds and reverse faults before emplacement of an extensive suite of Upper Cretaceous volcanic and plutonic rocks (Ferguson et al., 2001). After the volcanic and plutonic suite was emplaced, the entire Santa Rita range was tilted to the east-southeast approximately 30-40 degrees. This tilting is recorded by the Upper Cretaceous volcanic sequence, including the Mt. Fagan Rhyolite of this map area, and a pre-Gila Conglomerate sequence (Pantano Formation) of Paleogene – Neogene conglomerate that is not preserved in this area.

The Neogene Gila Conglomerate is exposed in a wedge-shaped graben in the southern part of the Rosemont map area and is gently tilted to the south-southeast. The graben is bounded on the northwest by a northeast-striking, southeast-side-down, high-angle normal fault, and is inferred to be bounded on the east by an unexposed, northwest-striking, southwest-side-down normal fault. The latter, inferred, fault may be linked to an array of west- to northwest-striking, high-angle normal faults that cut the contact between Proterozoic quartz monzonite and the Bolsa Quartzite north of Weigles Butte. Separation of the contact suggests that most of these faults have a south- or southwest-side-down component of displacement, possibly with a dextral strike-slip component as well.

Significant problems remain concerning the nature of northerly striking faults in the western part of the map area, and their ages relative to regional folding and tilting. An important fault has juxtaposed Paleozoic Horquilla Limestone on the Glance Conglomerate in the southwest corner of the map area. Farther north, the same fault has juxtaposed Horquilla Limestone with the Cambrian Bolsa Quartzite and Abrigo Limestone, putting younger rocks on older and omitting part of the Paleozoic section. Still farther north, this fault has cut out the lower part of the Naco Group and placed the Permian Sherrer Formation and Concha Limestone against the Cambrian units. This fault was mapped as a thrust by Drewes (1971) and as a fault of unspecified origin by Hardy (1997). Duplication of the Glance Conglomerate and the older-over-younger relationship in the southwest corner of the map area are consistent with thrust geometry. Considering that the Paleozoic rocks were deformed before deposition of the Glance Conglomerate, the observation that this fault omits part of the Paleozoic section does not rule out the possibility that it formed as a thrust.

The contact between the Paleozoic rocks and the Bisbee Group along the western part of the map area is another major fault of uncertain origin. In the south, this fault apparently dips steeply eastward or is nearly vertical. In the north, the contact locally dips moderately southward. The fault was mapped and interpreted previously as a normal fault by Drewes (1971) and as an east-vergent thrust by Hardy (1997). The age and original dip of the fault are not certain but it is clear that the Bisbee Group has been displaced down relative to the Paleozoic rocks.

Recommendations for future work

Conodont biostratigraphic analysis of a few key carbonate outcrop belts could quickly and definitively identify the belts as either Mississippian – Pennsylvanian (Escabrosa – Horquilla) or Permian (Colina – Concha). Such definition would help constrain the location of the major fault that omits the middle Paleozoic section through a problematic central portion of the map area.

The Bisbee Group in the map area is exceptionally thick. At least 2,500 m of strata are present and the upper two formations, the Shellenberger Canyon and the Turney Ranch, are not even preserved. Unlike most other areas where volcanic rocks are absent or present only near the base of the Bisbee Group, the section in the Rosemont area includes at least three sequences of mafic lava that span over 1 km of section. Petrographic, geochemical, and geochronologic study of these volcanic rocks might yield information pertinent to the tectonic origin of the Bisbee basin(s) in southeastern Arizona.

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