GEOLOGY, MINERAL RESOURCES, AND GEOARCHAEOLOGY OF THE MONTOYA BUTTE QUADRANGLE, INCLUDING THE OJO CALIENTE NO. 2 MINING DISTRICT, SOCORRO COUNTY, NEW MEXICO

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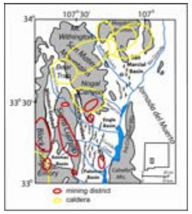
ABSTRACT

The Montoya Butte 7½ quadrangle is part of the Mogollon-Datil volcanic field in the Sierra Cuchillo and San Mateo Mountains. Cañada Alamosa is the main drainage. The purposes of mapping the quadrangle were to 1) map and describe the structures controlling the mineral resources (including the boundaries of the Nogal Canyon caldera), 2) describe geologic processes that formed the landscape, 3) determine the mineral resource potential, 4) describe the geoarchaeology, 5) provide regional correlations of the rocks, and 6) provide the data required for studies of the surface and groundwater. Geologic mapping of the quadrangle was at a scale of approximately 1:12,000, using the USGS topographic map as a base as part of the NMBGMR state geologic map and mineral resources programs. Outcrop mapping techniques were employed where the approximate extent of the outcrop of the lithology was mapped in a darker color; the lighter color was used to identify areas of the same lithology that were covered and inferred to be present. Mapping showed that at least 3 separate geothermal systems were/are present: 1) the oldest forming the volcanic-epithermal veins (~28-36 Ma), 2) the system forming the Apache Warm Springs Be deposit (~24.4-28 Ma), and 3) the current, modern system related to Ojo Caliente and other warm springs feeding Cañada Alamosa. The mineral resource potential of the Apache Warm Springs Be deposit is low to moderate. But, additional exploration drilling could locate additional Be at depth. Any potential exploration or subsequent mining would have to plan for environmental issues, especially the affects of mining on the warm and cold springs feeding the Cañada Alamosa. Most Pueblo sites are found along the Montoya (Qtm) and Victorio (Qtv) stream terraces, downstream of the intersection of Kelly Canyon with Cañada Alamosa. The Pueblo people utilized local rhyolite and tuff, andesite, basalt, and siltstone in the majority of their lithic artifacts (including stone tools, hammer stones, and projectile points) found at the Pueblo sites. Some of the lithic artifacts, including obsidian, chert, quartzite, and silicified wood, are not found in the immediate area and were imported into the canyon. Local clays were likely used in the production of common pottery, but some of the glazed pottery was made elsewhere and imported into the canyon.

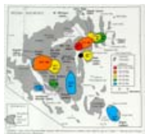
METHODS OF STUDY

- Compilation of published and unpublished data
- Areas of anomalous structural complexity, hydrothermal alteration, mineralization, and anomalous coloration were delineated, examined, mapped, and sampled
- Evaluate the NURE data (McLemore, 2010a)
- Geologic mapping of the Montoya Butte quadrangle was at a scale of approximately 1:12,000
- Outcrop mapping techniques were employed in mapping where the approximate extent of the actual outcrop of the lithology was mapped in a darker color; the lighter color was used to identify areas of the same lithology that were covered and inferred to be present
- Cross sections were constructed (McLemore, 2012a)
- Samples were collected and analyzed by a variety of methods
  - Polished thin sections of samples were examined
  - Major and trace elements by X-ray fluorescence (XRF) (McLemore, 2010a)
  - Samples of clay materials also were analyzed by instrumental neutron activation analysis (INNA). Clay mineralogy was determined by X-ray Diffraction methods (XRD) (McLemore, 2010a)
  - Age determinations of three rock samples from the Montoya Butte quadrangle were determined by $^{40}Ar/^{39}Ar$ (McLemore, 2010a; McLemore et al., 2012)
- Assesses the potential of mineral and energy resources
- Describe the geoarchaeology

LOCATION



Location of the Montoya Butte quadrangle and geographic features in central New Mexico. White box is approximate location of the Montoya Butte quadrangle.



Map of the Mogollon-Datil volcanic field showing known calderas color coded by age (from Chapin et al., 2004). The Taylor Creek Rhyolite is shown by dashed line. Ages are in millions of years. The black hexagon is the approximate location of the Montoya Butte quadrangle.

PURPOSE

- Map and describe the structures controlling the mineral resources (including the boundaries of the Nogal Canyon caldera)
- Describe geologic processes that formed the landscape
- Determine the mineral resource potential
- Describe the geoarchaeology
- Provide regional correlations of the rocks
- Provide the data required for studies of the surface water and groundwater

Features within the Montoya Butte quadrangle. Red triangles are topographic features and blue-green shading indicates areas with Pueblo sites.

GEOLOGY

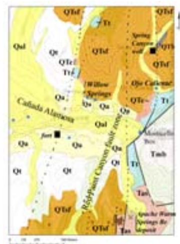
Volcanic rocks include an older sequence of andesite, lahar, and latite (around >38-36 Ma) followed by a younger sequence of ash flow tuffs and rhyolite lavas (around 22-29 Ma) associated with the formation of the Nogal Canyon (28.4 Ma) and Bear Trap Canyon (24.4 Ma) calderas in the San Mateo Mountains. Quaternary sedimentary rocks eroded from the San Mateo Mountains and Sierra Cuchillo filled the Monticello graben and formed a series of alluvial fans, pediments and stream terraces.

STRATIGRAPHY

Descriptions of geologic units in the Montoya Butte quadrangle, Socorro County, youngest to oldest (age dates, thickness, and descriptions are modified from Jahns et al., 1978; Hillard, 1967, 1969; Maldonado, 1974, 1980, 2012; McGraw, 2003; Lynch, 2003; Ferguson et al., 2007 and McLemore, 2010a, 2012a; McLemore et al., 2012).

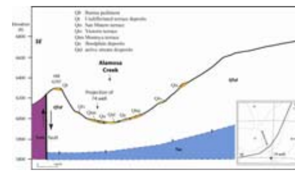
Symbol	Unit (age)	Description	Thickness (m)
af	artificial fill	areas of disturbed, excavated, or filled ground due to human activity, commonly earthen dams or stock tanks	
Qal	modern alluvium	valley bottom clays, sands, and volcanic gravel deposits found in modern and active stream channels and adjacent floodplain deposits	0-2
Qa	valley-floor alluvium	alluvium occupying the floors of modern valleys that is composed of fine-grained sediment with minor coarse channel-fills; Historical erosion has formed low terraces whose upper surface (i.e., tread) lies less than 2-3 m above adjacent major streams	2-6
Qc	colluvium and talus, undivided	colluvium and talus deposits on hill slopes that are composed of sand and volcanic gravels; these deposits conceal bedrock	0-6
QTsf	Santa Fe Group	undivided, poorly to moderately consolidated clay-silt, sand, and gravels comprising the main piedmont alluvial fans and bajadas adjacent to uplands, locally includes some terrace deposits (Qt); thickness 0-390+ m (in part after McGraw, 2003)	0-390+ (includes QTc, Qt, Qp, Qa, Qal)
Qt	terrace surfaces, undivided	clays, silts, sands and volcanic gravels forming upper terrace deposits (above active stream channels and floodplains), subdivided by age/inset relationships where possible (Qtm, Qtv, Qts) (in part after McGraw, 2003)	3-8
Qtm	Montoya terrace (youngest)	Fifth or youngest terrace, Qt5–3-15 m above modern grade of Cañada Alamosa; unit consists of silt, sand, gravel, and boulders (mostly rhyolite), generally well-developed, cemented soils; locally unconformable on Tertiary volcanic rocks; 3-8 m thick	3-8
Qtv	Victorio terrace (second youngest terrace)	Fourth terrace, Qt4–10-30 m above modern grade of Cañada Alamosa; unit consists of silt, sand, gravel, and boulders (mostly rhyolite), generally well-developed, cemented soils; 3-8 m thick	3-8
Qts	San Mateo terrace (third youngest terrace)	Third terrace, Qt3-15–45 m above modern grade of Cañada Alamosa; unit consists of silt, sand, gravel, and boulders (mostly rhyolite), generally thin soil and some caliche development; 3-8 m thick	3-8
Qp	pediment deposits	poorly to moderately consolidated sand and gravel similar to that found on terraces; larger surfaces are included in QTsf, includes the Burma pediment.	0-8
QTc	Santa Fe Group—basal conglomerate	well-cemented, orange to brown to buff, poorly sorted conglomerates and sandstones composed of volcanic material	0-9
Tb	basalt (18 Ma; McLemore et al., 2012)	fine grained, black to dark gray basalt flows and sills, <1% phenocrysts of feldspar, olivine, and late-stage calcite, vesicular to massive with local pillow-like texture	0-10
Tc	volcaniclastic sedimentary rocks	well-cemented, massive to thin-bedded, volcaniclastic conglomerate, sandstone, and siltstone; includes a white ash-fall or ash-flow tuff north of Black Mountain	0-7
Tan	andesite flows	andesite flows interbedded with volcaniclastic sedimentary rocks (Tc)	0-7
Tts	Turkey Springs Tuff (24.4 Ma; Lynch, 2003; 24.5 Ma, McLemore, 2010a)	gray, welded to nonwelded tuff containing 5-30% phenocrysts (quartz, sanidine, biotite) (Ferguson and Osburn, 2007)	0-60
Tas	rhyolite of Alum Spring	interbedded rhyolite ash-flow tuff, lava and volcaniclastic beds with strong argillic (acid-sulfate) alteration, thickness 0-350 m in drill holes	0-350?
Til	granite of Kelly Canyon (28.3 Ma; Lynch, 2003)	pinkish gray to gray holocrystalline to porphyritic granitic stocks, typically with large K-feldspar phenocrysts	intrusion
Tac	rhyolite of Alamosa Canyon (28.4 Ma; Lynch, 2003; McLemore, 2010a)	pinkish gray to gray rhyolite lava, phenocryst poor (1-3% sanidine, 1-3% quartz, locally amethyst or smokey, 1-5% biotite, pseudobrookite), with contorted flow bands, brecciated and vuggy (especially near the top), local sphereulitic texture, interbedded with local ash-flow tuffs and vitrophyre, thickness 0-300+ m	0-300+
Tvp	Vicks Peak Tuff (28.4 Ma; Lynch, 2003)	pinkish-gray, welded rhyolite ash flow tuff, phenocryst poor (1-10% sanidine, biotite), 4-15% pumice, locally columnar jointed	0-690+
Tr	rhyolite dikes	pink gray rhyolite dikes	intrusion
Tbd	andesite to basalt dikes	dark gray to black to olive green andesite to basalt dikes, locally with porphyritic texture	intrusion
Tgr	granite to quartz monzonite	pink to gray, coarse- to fine-grained granite to quartz monzonite, consisting of K-feldspar, plagioclase, quartz, and biotite (Hillard, 1963)	intrusion
Tql	Latite to quartz latite dikes	greenish gray to brown gray, porphyritic quartz latite dikes, 5-10% phenocrysts of albite, some Carlsbad twins, xenoliths common (Hillard, 1963)	intrusion
Tpl	latite of Montoya Butte (35.7 Ma, McLemore, 2010)	platy, gray to brown gray latite, up to 60% phenocrysts of sanidine, plagioclase, and biotite, locally interbedded with green to gray siltstone and sandstone	0-185
Tmbx	lahar (mudflow)	mudflow, matrix supported, contains andesite and rhyolite boulders and cobbles	0-220
Tmb	andesite of Monticello Box	black to gray, porphyritic to aphanitic andesite	0-120
Py	Yeso Formation and San Andres Limestone, undivided (Permian)	brown thin- to medium-bedded sandstone and siltstone, and dark gray, fine-grained limestone	<643 in Sierra Cuchillo

WATER RESOURCES



Detailed geologic map of the Monticello Box area, upper Cañada Alamosa, Montoya Butte topographic quadrangle, Socorro County, New Mexico (T9S, R7W).

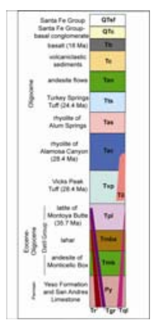
Monticello Box, looking east, where the spring-fed water flows into the box canyon. Cliffs are formed by andesite of Monticello Box.

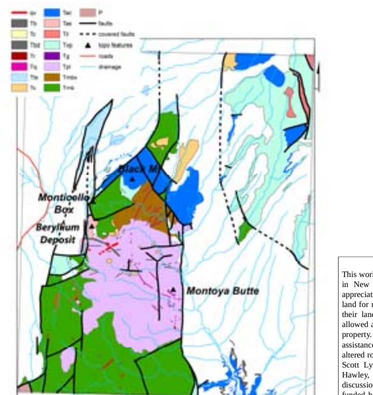


Diagrammatic cross section showing the stratigraphic relationships of the Quaternary units along Cañada Alamosa.

Estimated thickness of Quaternary-Tertiary sedimentary units in Montoya Butte quadrangle (water well data in McLemore, 2010a)

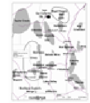
Location	Estimated thickness (m)	Source of sediment	Comments
Sim Yaten Canyon	198	San Mateo Mountains	Includes 82 m found in Sim Yaten water well
Post Canyon	213	San Mateo Mountains	Includes 27 m found in water well
Pine Canyon	198	San Mateo Mountains	
Arroyo west of Spring Canyon	73	San Mateo Mountains, volcanic rocks at Monticello Box and Red Paint Canyon	Turkey Springs Tuff exposed in the bottom of the arroyo
Spring Canyon (north of Ojo Caliente)	152	San Mateo Mountains, volcanic rocks at Monticello Box	Includes 27 m found in Spring Canyon water well
Hills west of Red Paint Canyon	6-12	Sierra Cuchillo	Includes 6 m found in Be exploration drill holes (Appendix 7)
Kelly Canyon	244	San Mateo Mountains	
San Mateo Canyon	219-262	San Mateo Mountains	Includes 18 m found in Eds water well
Cañada Alamosa (east of 74 ranch)	390	San Mateo Mountains, Sierra Cuchillo	Includes 91 m found at 74 water well
Cañada Alamosa (north of Sam Hill Canyon)	183	San Mateo Mountains, Sierra Cuchillo	From mapping, this report





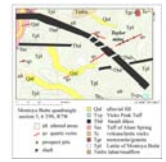
Simplified geologic map (simplified from McLemore, 2012a).

MINERAL RESOURCES



Geothermal system–type of deposit	Estimated age	Resource Potential (defined in McLemore, 2010a)
Volcanic-epithermal veins	~28-36 Ma	low with a moderate to high degree of certainty
Apache Warm Springs beryllium deposit and associated alteration	24.4-28 Ma	low to moderate with a moderate to high degree of certainty
Geothermal system related to Ojo Caliente, Willow Springs, and other warm springs feeding Cañada Alamosa	modern	low with a high degree of certainty

VOLCANIC-EPITHERMAL DEPOSITS



Detailed geologic map of the Taylor mine area, Ojo Caliente No. 2 mining district

Taylor shaft, looking east

MODERN GEOTHERMAL SYSTEM

Ojo Caliente, looking south. Ojo Caliente is approximately 27.5°C with a pH of 7.9 and Alum Spring is approximately 16°C with a pH of 7.9 (Myers et al., 1994).

VOLCANOGENIC BERYLLIUM DEPOSITS

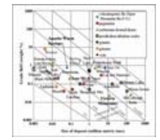
Detailed geologic map and cross section of the Apache Warm Springs beryllium deposit and adjacent area (N section 6, T9S, R7W

Alteration map of the Apache Warm Springs beryllium deposit. The western fault (between BE27 and BE24) is identified from drilling data (McLemore, 2010a).

Clay zone with red hematite-kaolinite and white kaolinite surrounding the Apache Warm Springs beryllium deposit (N section 6, T9S, R7W). A sample collected from the site shown on the left contains kaolinite, quartz, and hematite (McLemore, 2010a). A sample collected from the white clay shown in the photograph on the right contains quartz, kaolinite, illite, smectite and mixed layered clays (McLemore, 2010a).

Apache Warm Springs beryllium deposit (Be), as delineated by P and E Mining Consultants, Inc. (2009) as determined from trenching and drilling, looking northeast (N section 6, T9S, R7W).

Silicified zone, looking southwest. The Apache Warm Springs beryllium deposit is to the right (N section 6, T9S, R7W).



Grade and tonnage of selected beryllium deposits, including the Apache Warm Springs deposit (modified from Barton and Young, 2002 using references in McLemore, 2010b). Deposits in bold are located in New Mexico. Note that size of deposits includes production and reserves/resources and are not always NI 43-101 compliant and subject to change.

GEOARCHAEOLOGY

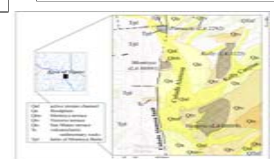
Geoarchaeology is the study of geological processes that effect archaeological sites, or how the geology relates to the mineral resources and archaeologic features.

QUESTIONS

- What geomorphic surfaces are the Pueblo sites found?
- What mineral resources were used?

Possible clay pit at the Victorio and Kelly Canyon sites.

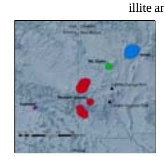
Clay suitable for pottery, blue-gray clay (contains illite and smectite). Pot made from the clay.



Location of Pueblo occupation sites in Cañada Alamosa area. Kelly and Victorio sites that show evidence of local farming are on the Qtm and Qtv terraces. Montoya site is on the Montoya (Qtm) terrace. Units are described in Table (from McLemore, 2012a).

LITHICS

The Pueblo people utilized local rhyolite and tuff, andesite, basalt, and siltstone in the majority of their lithic artifacts (including stone tools, hammer stones, and projectile points) found at the Pueblo sites. Some of the lithic artifacts, including obsidian, chert, quartzite, and silicified wood, are not found in the immediate area and were imported into the canyon.



Locations of obsidian sources regions of artifacts from Cañada Alamosa (Ferguson et al., 2009).

Walls of a room block at the Victorio site made of rhyolite boulders with mortar made from local clay.

ACKNOWLEDGEMENTS

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