Proterozoic rocks of the Caballo Mountains and Kingston mining district: U-Pb geochronology and correlations within the Mazatal province of southern New Mexico

Jeffrey M. Amato and Trey Becker, 2012, pp. 227-234


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PROTEROZOIC ROCKS OF THE CABALLO MOUNTAINS AND KINGSTON MINING DISTRICT: U-PB GEOCHRONOLOGY AND CORRELATIONS WITHIN THE MAZATZAL PROVINCE OF SOUTHERN NEW MEXICO

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Abstract—Basement rocks of the Caballo Mountains and Kingston mining district of south-central New Mexico are Proterozoic in age based on their exposure beneath a nonconformity with overlying Cambro-Ordovician Bliss sandstone. We used SHRIMP (sensitive high-resolution ion microprobe dating) to obtain U-Pb dates on zircon from four samples of igneous or metaigneous basement. A sample of foliated gneissic biotite granite from the Caballo Mountains yielded a date of 1681 ± 12 Ma (all uncertainties are at 2σ). Two undeformed samples from the Caballo Mountains include the Longbottom pluton, dated at 1486 ± 16 Ma, and the Caballo granite with an age of 1487 ± 24 Ma. A granophyre from the Kingston district yielded a date of 1654 ± 15 Ma. The two samples older than 1650 Ma are similar in age to other Mazatzal province basement that forms the country rock for the >1.4 Ga granites that are widespread throughout New Mexico. The samples from the Caballo Mountains are among the oldest granites that are part of the continent-wide ~1.4 Ga granite-rhyolite province. These data demonstrate the similarity of lithology and age of the Proterozoic basement of the Caballo Mountains and Kingston Mining District to other exposures of Proterozoic rocks in southern New Mexico such as the Burro Mountains of southwest New Mexico.

INTRODUCTION

Proterozoic rocks of southern New Mexico are generally exposed as relatively small outcrops along the base of uplifted fault blocks along the Rio Grande Rift, in the central part of the state, or within the Basin and Range province in the southwest New Mexico (Fig. 1). As part of an ongoing effort to understand the Proterozoic evolution of the region, we sampled and obtained U-Pb ages from two areas near Truth or Consequences, New Mexico. The Caballo Mountains of south-central New Mexico are an east-tilted normal fault block within the Rio Grande rift that exposes Proterozoic rocks along its west flank. These rocks are over lain by a Paleozoic section with the Cambrian-Ordovician Bliss Sandstone at its base. The geology of this area was previously mapped by Darton (1922), Kelley and Silver (1952), and Seager and Mack (2003) whose comprehensive treatment of the geology of the range highlighted the lack of isotopic ages of the Proterozoic basement. The only preexisting date was an unreliable and imprecise whole-rock Rb-Sr isochron age of ~1300 Ma (Muehlberger et al., 1966). The Kingston mining district is located west of the Rio Grande rift in the Black Range, where Proterozoic rocks are also over lain by the Bliss Sandstone. No ages are known to have been published from the basement rocks of this range.

The goal of this paper is to provide new U-Pb dates on the Proterozoic basement and to compare them to the ages of other Proterozoic rocks in southern New Mexico from surrounding ranges, including the Burro Mountains and Little Hatchet Mountains of southwest New Mexico (Amato et al., 2008, 2011; Amato and Mack, in press).

For this study we used primarily U-Pb zircon dates obtained by SHRIMP (Sensitive High-Resolution Ion Microprobe). Despite relatively low precision, these dates provide a framework for interpreting the history of the basement rocks and correlating these magmatic episodes to other events known from more extensively studied ranges.

REGIONAL GEOLOGY

The Caballo Mountains and Kingston mining district areas are part of the Mazatzal province that consists of igneous basement.
of likely arc origin that range in age from 1.7-1.6 Ga and have juvenile isotopic geochemical signatures (Karlstrom et al., 2004). The Mazatzal orogeny began around 1.65 Ga and records the accretion of the Mazatzal province to the Yavapai province along a NE-trending suture near the New Mexico-Colorado border (Karlstrom and Bowring, 1988; Amato et al., 2008). Rock types within the largest exposure of Mazatzal province crust in southern New Mexico, in the Burro Mountains, include amphibolite, gabbro, orthogneiss, metarhyolite, and metasedimentary rocks including schist and quartzite (Amato et al., 2008; 2011).

Granitic plutons and rhyolites ranging in age from 1490–1340 Ma are found in a wide belt across North America and have been referred to as “A-type” granites, but they are better described using the non-genetic term “ferroan” granites based on their FeO/ (FeO+MgO) (Anderson, 1989; Frost et al., 2001; Anderson and Morrison, 2005; Amato et al., 2011). Many of these plutons are described as anorogenic, but in the southwest U.S., numerous plutons have fabrics indicating syntectonic intrusion, possibly related to an orogenic event at the nearby Laurentian margin to the south (Nyman et al., 1994; Duebendorfer and Christensen, 1995; Kirby et al., 1995; Amato et al., 2011). In the Burro Mountains, variably deformed granodiorite and granite plutons yielded 1470–1460 Ma ages (Amato et al., 2011).

Evidence for the Grenville orogeny to the south comes mainly from igneous events with ages around 1.2 Ga in the Van Horn, Texas, region (Bickford et al., 2000) and in the Proterozoic Mountains (Rämö et al., 2003), and a 1080 Ma granite in the Little Hatchet Mountains (Amato and Mack, in press). Proterozoic diabase dikes inferred to be part of a 1.1 Ga dike swarm are exposed both west of the Caballo Mountains, in the Burro Mountains (e.g., Hedlund, 1980), and to the south, in the southern San Andres Mountains (Seager, 1981). Younger tectonic events relevant to interpreting the fabrics include the Grenville orogeny, the Laramide orogeny, and Paleogene magmatism and extension.

Proterozoic Rocks of the Caballo Mountains

Previous mapping in the Caballo Mountains has documented metamorphic rocks and four silicic plutons underlying the nonconformity with Paleozoic rocks (Bauer and Lozinsky, 1986; Seager and Mack, 2003). The metamorphic rocks include amphibolite-facies schists, amphibolite, and felsic orthogneiss. Amphibolite is interlayered with schists and is strongly deformed with a foliation, lineation, and boudinage (Bauer and Lozinsky, 1986; Seager and Mack, 2003). In the Burro Mountains, amphibolite was dated at ~1.68 Ga.

The Proterozoic rocks in the Caballo Mountains (Fig. 2) include the Longbottom granodiorite, the Caballo granite, a coarse-grained pink granite, and a gneissic granite, along with numerous granitic dikes (Bauer and Lozinsky, 1986; Mack et al., 1998; Seager and Mack, 2003, 2005). The Caballo granite is the largest of these plutons, with a map outcrop length of ~20 km (Seager and Mack, 2003). The Longbottom granodiorite of Bauer and Lozinsky (1986) has large K-feldspar crystals and xenoliths aligned as the result of magmatic flow (Seager and Mack, 2003).

The abundance of K-feldspar in some of the exposures indicates a granite composition based on the Quartz-Alkali Feldspar-Plagioclase diagram, so we prefer the term “Longbottom pluton” to reflect the compositional heterogeneity.

Proterozoic Rocks of the Kingston Mining District

The Kingston region of the Black Range of central New Mexico is located ~40 km due west of the Caballo Mountains, where Proterozoic rocks are exposed west of the Rio Grande rift. The area was mapped by Kuelmmer (1954), Lambert (1973), Hedlund (1977), and Seager (written communication, 2009). The Proterozoic rocks are overlain by Cambrian-Ordovician Bliss Sandstone and younger Paleozoic rocks. Granites are associated with metamorphic rocks that includes amphibolite, chlorite schist, and gneiss (Hedlund, 1977). A granophyre 4 km south of our study area yielded a U-Pb date (two-point concordia intercept age) of 1655 ± 15 Ma (Stacey and Hedlund, 1983).

METHODS

U-Pb geochronology was carried out using the SHRIMP-RG (sensitive high-resolution ion microprobe reverse geometry) at the Stanford–U.S. Geological Survey Ion Probe Facility. Beam diameter was 30 mm. All errors reported in the text are at 2σ. Details of the SHRIMP methods are in Amato et al. (2008). “Best age” refers to the most reliable age with the lowest uncertainty,
and choosing which age as “best” depends on how discordant the analyses are for each sample. Individual analyses may not be included in the weighted mean calculations if they are likely related to Pb-loss or significant (>30%) discordance. Cathodoluminescence (CL) images were obtained from all samples.

**SAMPLES DATED**

Four samples were dated for this study; three from the Caballo Mountains and one from the Kingston mining district. The first sample is a gneissic granite (06CM-02). It has an igneous protolith based on texture and assemblage (Fig. 3A). Equant quartz and microcline grains are present in roughly equal proportions, and equant plagioclase grains are slightly less abundant. The strong foliation is made up of alternating wispy bands of biotite and Fe-Ti oxides alternating with quartz and feldspar. The color index is about 10-15. Accessory minerals visible in thin section include sphene, apatite, and abundant zircon.

The second sample is the coarse-grained Longbottom pluton (06CM-04). It has microcline crystals up to 2 cm in length with exsolution lamellae, plagioclase, and quartz (Fig. 3B). The abundance of K-feldspar likely makes it an alkali-feldspar granite, but modal analysis was not performed. Biotite is present in extremely low proportions (<5%), making the sample a leucogranite.

The third sample (06CM-01) analyzed is a medium- to fine-grained granite that is part of the Caballo granite pluton, with roughly equal proportions of K-feldspar with exsolution lamel-lae, plagioclase, and quartz (Fig. 3C). Biotite is the most abundant mafic mineral, with hornblende, sphene, Fe-Ti oxides, and epidote.

![Photomicrographs from the dated samples](image-url)

**FIGURE 3.** Photomicrographs from the dated samples; width of each image is approximately 1 mm. (A) Sample 06CM-02, gneiss from Caballo Mountains, plane light, dark minerals are biotite, light minerals quartz and feldspar; (B) Sample 06CM-04, Longbottom granite from Caballo Mountains, crossed polars, large mineral on the right is microcline with tartan twinning, mineral on center left is plagioclase, white minerals are quartz; (C) Sample 06CM-01, Caballo granite, plane light, biotite is the dark mineral in the center of the image, hornblende is the green mineral at upper left, and the cloudy minerals are altered plagioclase, clear colorless mineral is quartz; and (D) 06KD-02, granophyre from the Kingston District, showing granophyric intergrowth of quartz (light) in K-feldspar (extinct in crossed polars).
The sample from the Kingston mining district was collected from a locality ~4 km due north of the town of Kingston. The rock is an alkali-feldspar granite with granophytic texture (i.e., granophyre) and it has extensive intergrowths of K-feldspar and quartz with exsolution lamellae in the K-feldspar (Fig. 3D). Also present is minor plagioclase, biotite altered to chlorite, and zircon.

**GEOCHRONOLOGY RESULTS**

Eight U-Pb dates from the gneissic granite (06CM-02) were obtained (Fig. 4, Table 1). Zircons are euhedral, 100–200 μm in length, have oscillatory zonation and no observed xenocrystic cores in CL images. The zircons had U concentrations ranging from ~150-500 ppm. One of the analyses was discordant with a low $^{238}\text{U}/^{206}\text{Pb}$ age relative to its $^{235}\text{U}/^{207}\text{Pb}$ age, so this was not used in the final age calculation. The weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age of the remaining analyses is 1674 ± 16 Ma with a mean square weighted deviates (MSWD) of 1.8. The concordia upper intercept age, using all of the data, is 1681 ± 12 Ma (MSWD=1.3). The lower intercept age is 200 ± 77 Ma. We consider 1681 ± 12 Ma to be the best age.

The Longbottom pluton (sample 06CM-04) was analyzed for ten zircon ages (Table 1). Zircons have strongly metamict cores with oscillatory zonation in the rim areas. The cores do not appear to be xenocrystic, but instead have radiation damage related to high U concentrations as determined by dark areas on CL images. Several of these analyses had high common Pb, and all points were discordant with high uncertainties. U concentrations were ~500-2000 ppm. The weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age of the best eight analyses is 1466 ± 21 Ma (MSWD=1.1) and the lower intercept is 112 ± 64 Ma (MSWD=1.1). We consider 1487 ± 24 Ma to be the best age.

The Caballo granite (06CM-01) has zircons that are euhedral, 100–200 μm in length, have oscillatory zonation, and have no observed xenocrysts in CL images. Fifteen zircons have U concentrations of 300-1000 ppm and all analyses are discordant (Table 1). Several of these analyses had high common Pb concentrations. The weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age of the best 12 analyses is 1449 ± 13 Ma (MSWD=2.1). The concordia upper intercept age, using all analyses, is 1487 ± 24 Ma (MSWD=1.9). The lower intercept age is 161 ± 64 Ma. We consider 1487 ± 24 Ma to be the best age because of the discordance.

We dated eight zircons from the Kingston granite, sample 06KD-02 (Table 1). Zircons are euhedral, 50-150 μm long, have oscillatory zonation, and no obvious xenocrystic cores. They had low U concentrations (~75-300 ppm) and the analyses were all concordant except one that was slightly discordant. All had fairly large uncertainties. The weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age is 1654 ± 15 (MSWD=0.55) and the concordia upper intercept age is 1659 ± 25 Ma (MSWD=0.58). We consider 1654 ± 15 Ma to be the best age for this sample.

**CONCLUSIONS**

The four samples from this study include two samples at 1.68-1.65 Ga and two samples at 1.48–1.45 Ga. The older samples are part of the Mazatzal province basement. Because all of these samples are pervasively deformed, and because the ~1.4 Ga rocks intruding them are only locally deformed, the main phase of deformation probably occurred during the Mazatzal orogeny sometime after 1630 Ma but before the ~1.4 Ga granites. Regionally, the Mazatzal orogeny is thought to have ended by ~1600 Ma (Karlstrom et al., 2004; Luther et al., 2006).

The remaining samples are part of the ~1.4 Ga granite-rhyolite province. In the Caballo Mountains, the two samples are 1486 ± 16 Ma and 1487 ± 24 Ma. Despite large uncertainties, the data are consistent with both intrusions having been intruded during the same intrusive episode. A similar relationship was observed in the Burro Mountains, where plutonic rocks with different compositions and textures were intruded within ~7 m.y. of each other (Amato et al., in press).

Critical questions remain concerning the age (or ages) of metamorphism within Proterozoic metasedimentary rocks. In the Burro Mountains, the main episode of metamorphism was inferred to be coeval with 1.46 Ga magmatism (Amato et al., 2011). Evaluating the timing and age of any pre-1.4 Ga metamorphism is difficult given the widespread heating of the crust during 1.4 Ga magmatism. Nonetheless, areas with exposed Proterozoic metasedimentary rocks, regardless of their outcrop volume, should be evaluated carefully to determine the crustal conditions at the time of metamorphism.

**ACKNOWLEDGMENTS**

The SHRIMP data were collected at the Stanford/U.S.G.S. facility at Stanford University and made possible by Joe Wooden.
FIGURE 4. Geochronology data shown on weighted mean plots and standard concordia plots, created using Isoplot 3.6 (Ludwig, 2008).
TABLE 1. Complete U-Pb zircon data collected by SHRIMP.

<table>
<thead>
<tr>
<th>Spot</th>
<th>Caballo Mountains gneiss (13, 288588, 3649171)</th>
<th>Caballo Mountains Longbottom granite (13, 289799, 3648809)</th>
<th>Caballo Mountains Longbottom granite (13, 288663, 3647322)</th>
<th>Kingston Mining District gneiss (13, 245990, 3648969)</th>
</tr>
</thead>
<tbody>
<tr>
<td>06CM-02:</td>
<td>7.52 ± 0.52</td>
<td>7.52 ± 0.52</td>
<td>7.52 ± 0.52</td>
<td>7.52 ± 0.52</td>
</tr>
<tr>
<td>06CM-04:</td>
<td>7.52 ± 0.52</td>
<td>7.52 ± 0.52</td>
<td>7.52 ± 0.52</td>
<td>7.52 ± 0.52</td>
</tr>
<tr>
<td>06CM-01:</td>
<td>7.52 ± 0.52</td>
<td>7.52 ± 0.52</td>
<td>7.52 ± 0.52</td>
<td>7.52 ± 0.52</td>
</tr>
</tbody>
</table>

a) Analyzes are listed in increasing age. All localities are in UTM coordinates using the NAD27 CONUS datum.
b) Common Pb component (% of total 206Pb) determined using measured 204Pb
c) Error Correlation coefficient
d) Ratio was corrected for common Pb using measured 204Pb
e) 207Pb/206Pb ages are not included for samples <300 Ma because of low precision
f) Concordance (%) = (207Pb/238U age) (206Pb/207Pb age) × 100
The New Mexico Geological Society provided funding to Trey Becker, who worked on this study as part of an undergraduate research project at New Mexico State University in a program headed by Nancy McMillan. Bill Seager and Greg Mack introduced Amato to the Caballo Mountains in 1999. The paper benefited from reviews by Greg Mack and Peter Davis.

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Bob Eveleth and Bob Osburn pose near a record (?) sized yucca, east side of Caballos. Time delay photograph by Bob Osburn.