Determining the Subsidence History of the Bonanza Caldera Using Thermoremanent Paleomagnetism

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INTRODUCTION

The 36-Ma-old Bonanza caldera of the San Juan Volcanic field, Colorado, subsided after releasing 50 cubic km of dacite and rhyolite ignimbrite (Fig. 1) (Varga and Smith, 1984). There are three major stratigraphic units found within this caldera. These units are (from oldest to youngest): (1) the lower Bonanza Tuff, a phenocryst-rich dacite ignimbrite, (2) the upper Bonanza Tuff, a phenocryst-poor rhyolitic ignimbrite, and (3) upper andesite lava flows (Varga and Smith, 1984). The lower and upper Bonanza Tuff are separated by a cooling break and were both emplaced as pyroclastic flows (Varga and Smith, 1984).

Structurally, the subsidence of the caldera has been interpreted as a "trap-door" collapse, with the eastern margin of the caldera acting as a hinge and displacing the western margin by nearly 1 km (Varga and Smith, 1984). The volcanic units within the caldera have been hydrothermally altered since their emplacement. Some parts of the lower Bonanza Tuff have experienced rheomorphism and contain visible outcrop-scale folds.

This study seeks to determine whether the three caldera units cooled prior to subsidence or subsided during eruption, and when rheomorphism occurred with respect to tilting. Paleomagnetic data from the upper and lower tuff and the upper andesite were collected and analyzed to solve this problem. The units were sampled within the caldera and outside the caldera. Samples outside the caldera were used as controls to compare against the caldera samples The subsidence history of the caldera had two possibilities: 1) if the volcanic units subsided during eruption the thermoremanent magnetization (TRM) directions should be consistent with the control TRM directions or 2) if the units subsided after eruption then the TRM directions of the units within the caldera should be identical to those of the controls after a tilt correction for the amount the caldera units are dipping.

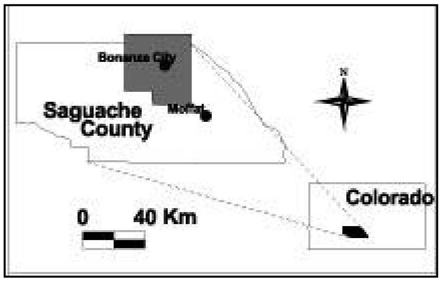

Figure 1. Location of field area in Saguache County, Colorado. The town of Bonanza is inside the caldera.

METHODS

During July 1999, paleomagnetic samples were collected at 14 sites within the caldera. The samples were taken from the lower Bonanza tuff at seven locations, the upper andesite lavas at five locations and the upper Bonanza Tuff at two locations (Fig. 2). Control samples were taken from Findlay Ridge outside the caldera to compare with the caldera sites' TRM directions.

Three of the sites within the tuff show possible rheomorphism, identified by stretched pumice or outcrop-scale folds. Site 72799-2, in particular, had two visible outcrop-scale folds that were sampled along the fold limbs. One-inch diameter cores were collected from these units in the field with a Pomeroy portable core drill. Each core was oriented for azimuth and hade with a Pomeroy orienting device. A sun compass angle was recorded to compare with the magnetic compass measurement for azimuth since there was a possibility that the rocks were magnetic. Orientations and site numbers were marked on the cores. The accuracy of this type of orientation is ± 2° (Butler, 1998). GPS positions and foliation and lineation measurements were taken at every site.

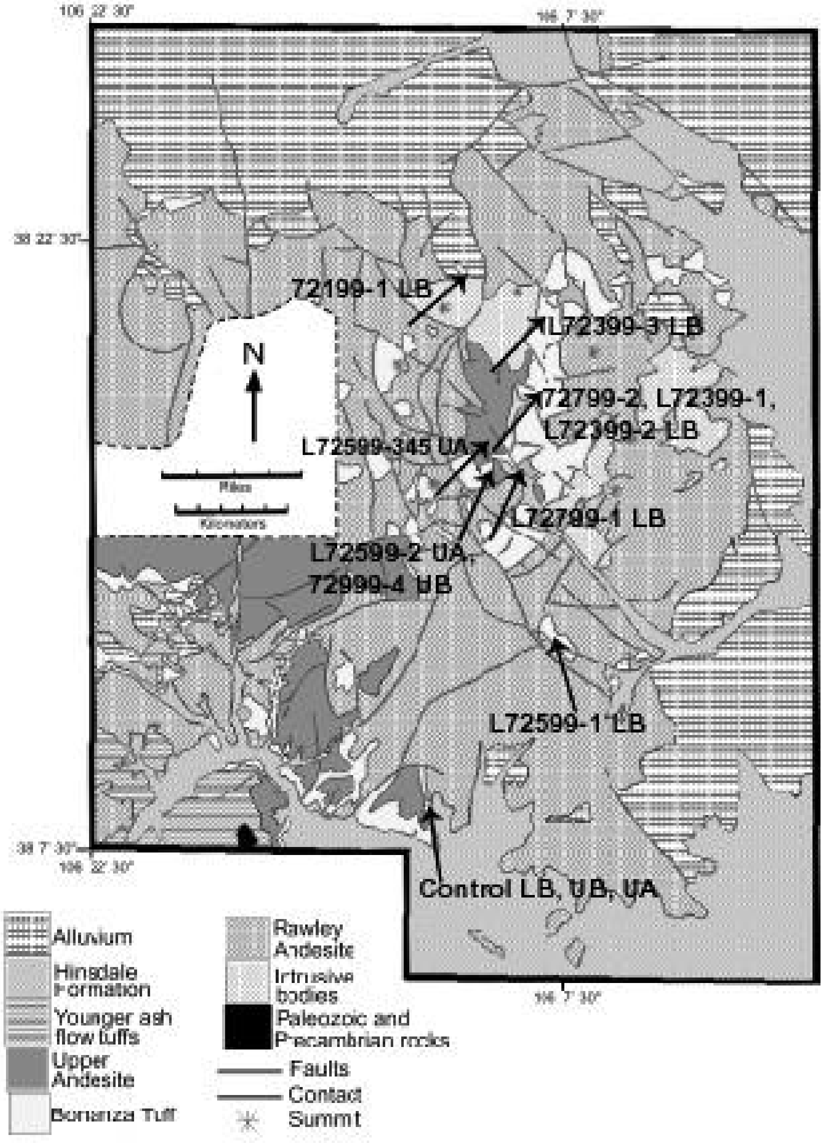

Figure 2. Map of sites within field area. Arrowheads mark the exact location of sites. Arrow directions represent the declination of the TRM at each site.

In August of 1999, thermal demagnetization was used to obtain the TRM direction of the cores at the paleomagnetics laboratory at the College of Wooster. The goal of thermal demagnetization is to obtain the TRM, which is the magnetic field that the rock first acquired when it cooled. This procedure involves heating a core to a specific temperature below the Curie temperature, which is 580°C for magnetite, then cooling the core in zero magnetic field. This results in randomizing ferromagnetic grains that have very low blocking temperatures, the temperature at which a grain is “locked in” to a magnetization. These grains have short relaxation times, which is the time it takes a grain to lose its original magnetization. Low blocking temperature grains are easily changed by magnetic influences, such as the Earth’s magnetic field, after cooling. These grains overprint the TRM and contribute to a rock’s natural remanent magnetization (NRM). Preliminary heatings of a core show a variable remanent magnetization direction but after successive heatings, the direction should start to be consistent since the grains with higher blocking temperatures have long relaxation times (Butler, 1988). This stable remanent magnetization can be interpreted as the TRM.

All cores were heated in an ASC TD48 thermal demagnetizer with a controlled field coil in increments starting at 100º C, and ending in increments of 25º C. The cores were heated to a final temperature between 600°Cand 650°C.

Cores that needed slightly higher heating temperatures to demagnetize may contain some amount of hematite which has a higher Curie temperature than magnetite. After each heating increment, the magnetism of the core was measured by a Molespin Minispin magnetometer. This device spun the core in six different orientations and measured the resulting B-field. A vector endpoint plot (Zijderveld plot) was generated for each core which plotted the remnant magnetization vector after each heating step, head to tail. Principle component analysis was performed on each plot to obtain a final TRM direction for each core. Final TRM directions from each core in a site were then plotted together on a stereonet to derive a 95% confidence circle for the mean orientation of that site's TRM.

RESULTS

Caldera site 72799-2 in the lower Bonanza has two outcrop-scale rheomorphic folds. The TRM directions derived from the 17 cores from this site cluster before the site is unfolded. The TRM directions scatter significantly after the site is unfolded. This indicates rheomorphism occurred above the Curie temperature and that the rock acquired its TRM after folding (Fig. 3).

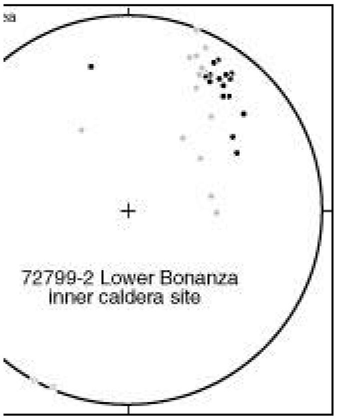

Figure 3. Fold site 7279 Black points are before unfol and grey points are after.

The lower Bonanza control samples from Findlay Ridge produced a good 95% confidence circle orientation but the upper Bonanza and upper andesite controls did not. This was because only two cores from each unit were thermally demagnetized and their demagnetization plots showed significant scatter. Cores from Findlay Ridge that were demagnetized using an alternating field method by Fratesi (this volume) were used as the controls for these units.

The caldera TRM directions were dip corrected for comparison to the control TRM directions. The TRM directions acted as lines in the units' planes and were rotated by the amount required to rotate the units to horizontal. This procedure assumes the units started as horizontal, which is a reasonable estimate but may not be exact. After the caldera TRM directions were dip corrected, they all plotted significantly nearer to the control TRM directions. This indicates that much of the TRM was acquired before subsidence (Fig. 4).

Although dip corrected caldera TRM directions plot near the controls, some are overcorrected. The sites that show overcorrection are L72599-1, L72599-2, L72599-345, and 72999-4 (Fig. 2,4). There are two possible explanations for this overcorrection: 1) subsidence was ongoing during cooling or 2) the units were deposited on an already dipping surface. There is some geographic pattern to this overcorrection. The northern sites and one central site display overcorrection, whereas the southern and three central sites do not. It is unlikely that different parts of the caldera have different cooling histories so this pattern suggests that a dipping surface existed in the southern part of the caldera.

DISCUSSION

Paleomagnetic data from our fold site show that rheomorphism occurred above the Curie temperature. The caldera data suggest that most tilting, and therefore subsidence, occurred below the Curie temperature when the magnetization was already acquired. The geographic pattern of overcorrection of TRM directions suggest that the southern part of the caldera may have already begun to subside prior to the eruptions that produced these units.

REFERENCES CITED

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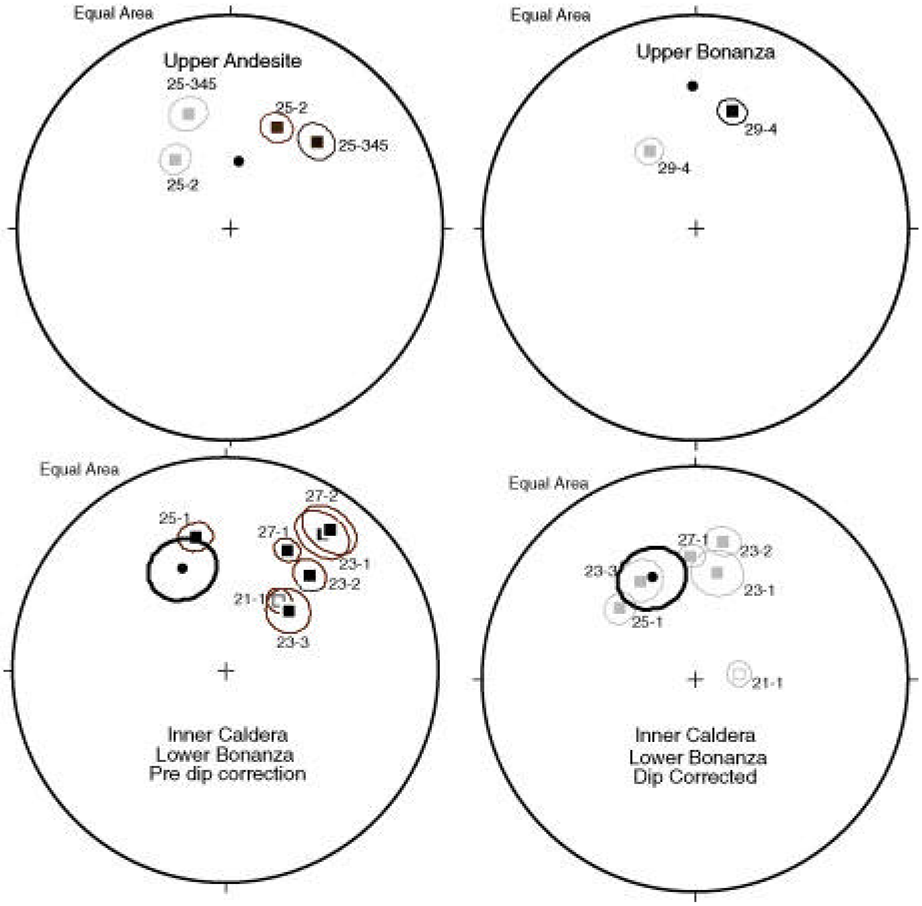

Figure 4. Stereonets show pre-dip corrected TRM directions in black and dip corrected TRM directions in grey. Control TRM directions are shown as black dots. The black dot in the center of the 95% confidence circle is the thermally demagnetized lower Bonanza control from Findlay Ridge. Other dots are controls from altenating field technique. Site Ids are shortened for space. For example, site 72599-1 is shown as 25-1.