A paleomagnetic study of extracaldera rocks associated with the Bonanza Caldera

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INTRODUCTION

The Bonanza Caldera is an early Oligocene collapse structure located in the northeast corner of the San Juan volcanic field, just west of the north-south trending Rio Grande rift system in central Colorado (Figure 1). Formed in response to the eruption of about 50km^3 of the Bonanza tuff, the caldera is thought to be centered on the remains of an older volcanic cone inferred to be the source of the Rawley Andesite (Varga and Smith, 1984). The Bonanza caldera is older than similar structures in the San Juan volcanic field and, along with two other calderas to the north, is thought to be associated with initiation of rifting in the Rio Grande system (Varga and Smith, 1984).

Previous work on the stratigraphy and petrography of the major rock units associated with the Bonanza volcanic center is summarized in Bruns et. al. (1971). The Rawley Andesite is correlated with the Conejos Formation of the San Juan volcanic field based on radiometric ages reported in Lipman et. al. (1970). The Rawley Formation is an accumulation of hornblende-biotite andesite lava flows, laharic breccias, and some minor tuffs. The overlying Bonanza Tuff consists of two distinct pyroclastic sheets, informally referred to as the Lower and Upper Bonanza tuffs. The lower sheet is a phenocryst-rich dacite ignimbrite. This unit consists of up to six ash flow cooling units outside of the caldera, which grade into a single unit inside the caldera. The Upper Bonanza is a single cooling unit of phenocryst-poor rhyolite ignimbrite. The ignimbrites are covered by hornblende andesite lava flows, collectively referred to as the Upper Andesite Sequence. The Squirrel Gulch and Brewer Creek Latites of Burbank (1932) and the Andesites of Ford Creek of Bruns et. al. (1971) are included in this andesitic sequence and are interspersed with laharic breccias in some localities west of the caldera. An Oligocene age for the caldera is indicated based on K/Ar dating in Varga and Smith (1984), which gives ages of 37.6 Ma for the Rawley Andesite, 36 Ma for the Lower Bonanza Tuff, 35.7 Ma for the Upper Bonanza Tuff, and 34.7 Ma for the Upper Andesite.

The purpose of this paper is to obtain paleomagnetic reference directions for the three units associated with the Bonanza Caldera. These are to be used for structural corrections on intracaldera rocks in a related paper by Prashad (this volume) to determine the mechanism and relative timing of caldera collapse. In addition, these data will be used to constrain the magnetostratigraphy of the units.

SAMPLING AND ANALYSIS

Five sampling localities were chosen along Saguache Creek and its tributaries about 4-12 miles west of Saguache. Stratigraphic exposure at these localities aids in positive identification of the rock units, and distance from the caldera ensures that alteration and thermal overprinting are avoided (Figure 1). Upper Andesites and Bonanza Tuff were sampled at Findley Ridge and Poison Gulch, while Rawley Andesite samples had to be obtained at three other localities: one about two miles west of Findley Ridge on Colorado State Highway 114, one about two miles west of Poison Gulch in Middle Creek, and one four miles west of Poison Gulch in Jack's Creek (Figure 1). Core samples were

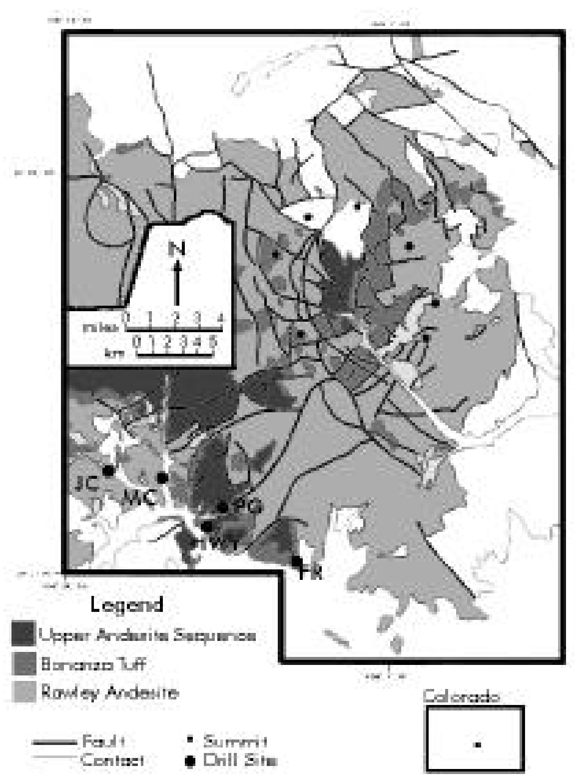

Figure 1: Sampling Localities. FR – Findley Ridge; JC – Jack's Creek; MC – Middle Creek; HWY – Highway 114; PG – Poison Gulch

drilled with hand-held, gasoline-powered drills and oriented using both magnetic and sun compass.

Standard 2.4 cm samples were measured using a Schonstedt SSM-1A spinner magnetometer. A Molspin tumbling alternating field demagnetizer was used to demagnetize the cores at peak fields of 25-1000 Oe in 6-10 steps. In most cases, such demagnetization removed secondary magnetic components in order to isolate characteristic remanent magnetic directions (ChRM). Characteristic directions were identified on the basis of decreasing magnetic intensity with little or no change in direction as displayed in Zijderveld demagnetization plots (Figure 2).

DATA

Most samples exhibited one of three types of demagnetization behavior. About 30 samples had little to no secondary vectors (Figure 2a). Another 30 had secondary magnetic components, which were removed at relatively low demagnetization levels (about 200 Oe peak field). Many of these had initial intensities of about 10^{-3} emu/cm^3 and displayed an abrupt change in direction as the secondary vector was removed, leaving 20-80% of the initial intensity (Figure 2b). Approximately 40 samples had higher intensity secondary components, which were removed at higher peak fields (400-800 Oe), usually leaving less than 10% of the NRM intensity. These samples had a higher initial NRM intensity, often on the order of 10^{-2} emu/cm^3, and exhibited a more gradual change in direction, indicating that the coercivity spectra of secondary and characteristic components overlapped slightly (Figure 2c). Four samples failed to yield stable endpoints and were discarded.

Rawley Andesite samples exhibited all three types of behavior. Demagnetization behaviors were consistent within outcrops but varied widely between outcrops. Samples from Highway 114 were greatly scattered, as expected; this locality was drilled as an intraformational conglomerate test (to be discussed later). All of the samples from Jack's Creek and Middle Creek yielded reversed ChRM directions that are approximately antiparallel to normal directions observed in other units.

Lower Bonanza directions are normal, almost all with same northerly declination and ranging from 30° to 85° inclination. The only exception is Findley Ridge flow 3 (Figure 3b, outcrop D), which has a mean of 316°, 24° (declination, inclination). This is thought to be a result of outcrop frost heaving. Mean directions for the Upper Bonanza clustered around a normal direction of about 357°, 34°, except for one sample in Poison Gulch outcrop D, which yielded a direction of 88°, 44°. The second direction from this outcrop is 2°, 51°, which is similar to the other Upper Bonanza directions. With only two samples from this outcrop, interpretation is problematic; therefore, the Upper Bonanza, Poison Gulch outcrop D was not considered further. The Upper Andesite mean directions cluster loosely about a northerly declination (Figure 3d). The clustering is slightly better before the bedding correction is applied. Uncharacteristically high bedding dips of 30° were observed in the Upper Andesite, Findley Ridge outcrops. All other beddings at Findley Ridge have dips of less than 10°, thus the Upper Andesite bedding indicators at this locality were considered to give a false measure of tilting. Consequently, bedding corrections were extrapolated from nearby tuff units.

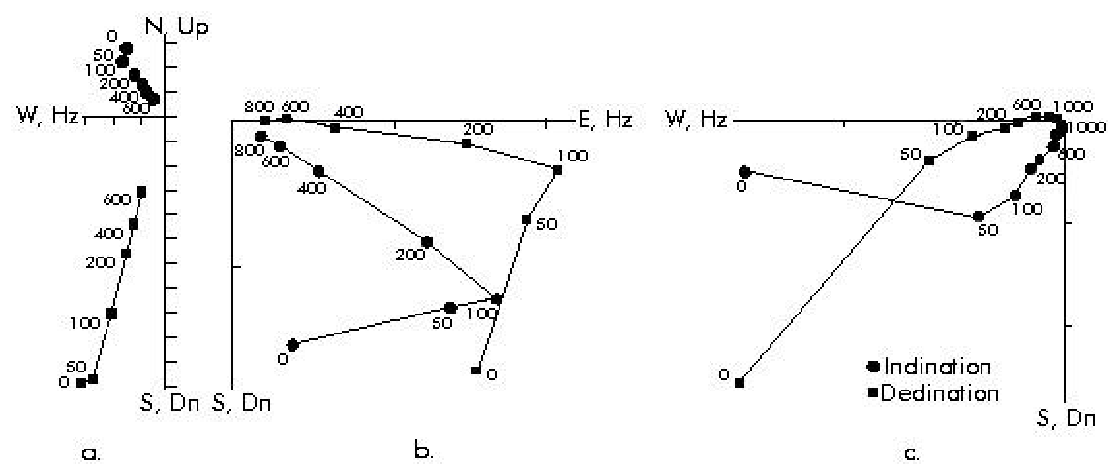

Figure 2: Representative vector diagrams showing demagnetization behavior. Declination is in N, S, E, W plane; inclination is in vertical plane (Hz – horizontal, Dn – down, Up). Numbers indicate AF demagnetization treatment in Oersteds. a. No secondary vector (from Lower Bonanza G); b. low coercivity, non-overlapping secondary vector (from Lower Andesite A); c. high-coercivity overlapping secondary vector (from Lower Andesite B)

DISCUSSION

The Rawley Andesites exhibit reversed polarity. The presence of approximately antiparallel reversals constitutes an important magnetic stability test. Although too few outcrops were sampled to attain any statistical significance, the Jack's Creek is very close to 180° from the normal directions in the other units, and the Middle Creek direction is within the realm of normal secular variation (Figure 3a, outcrop B). Thus, a positive reversal test is concluded. The reversal could be associated with the C17n or C18n polarity chrons as identified in Cande and Kent (1995) and may be a useful correlative tool. The inherent analytical uncertainty in K/Ar dating precludes any narrowing of this window at the present time.

Samples from the Highway 114 volcanic breccia outcrop have a _ of 2.8 (Table 1), which is almost low enough to qualify as a random population (Watson 1955). This is interpreted as a positive intraformational conglomerate test, which is based on the idea that clasts of a blocky lava flow reach their magnetic blocking temperature before they stop rolling. After they come to rest, the recorded magnetic directions are oriented randomly. If any overprinting has occurred, the grouping of samples will not be random, and therefore exhibit a common overprinting direction. The essentially random distribution of clast directions strongly suggests high stability of magnetic directions.

Mean directions from the Rawley Andesite outcrops B and C are separated 28° before tectonic correction and by 59° after the correction is made (Figure3a). Although stable directions of a group of outcrops are expected to cluster better after tectonic correction, this implies little about the stability of these magnetic directions because there are only two outcrops represented here. This variation may be due to the presence of an initial dip in the bedding (i.e. and erroneous structural correction), or it may be caused by secular variation.

The Lower Bonanza mean directions form four groups. The Lower Bonanza Flow 3 is separated from the main grouping by 34° of declination (Figure 3b, outcrop D); this outcrop consisted of three fracture blocks that may have been frost heaved. Directions at that site separate into three distinct groups, correlating with the three blocks. This is taken as evidence of heaving and rationale for discarding the outcrop. The other means are arrayed along approximately the same declination, with inclinations varying from 30 to 85° (Figure 3b). The means from outcrops A and B from Findley Ridge are statistically the same, according to the test of McFadden and Lowes (1981) . Outcrops E and F from Findley Ridge are also statistically similar. Lower Bonanza outcrops C (Findley Ridge) and G (Poison Gulch) are not statistically the same, but are very close (Figure 3b). Each of these pairs is distinct from the other two pairs of outcrops. The directions in outcrops C and G are anomalously steep, but the similarities in the two separate localities suggests that they could be stable. The cooling units described by Varga and Smith (1984) are physically defined; that is, enough time elapsed for each flow to cool before the next was deposited. However, this does not imply a paleomagnetically useful cooling unit, in which enough time must elapse for measurable secular variation to occur.

The Lower Bonanza consists of a single physical cooling unit inside the caldera, indicating that the entire Lower Bonanza was emplaced before the intracaldera deposits cooled. This suggests that there should be no secular variation between physical cooling units. An alternate source for this variability could be related to inclination error, misrecording
of field direction by detrital magnetic carriers. This would only apply to unwelded units, as high-temperature welding

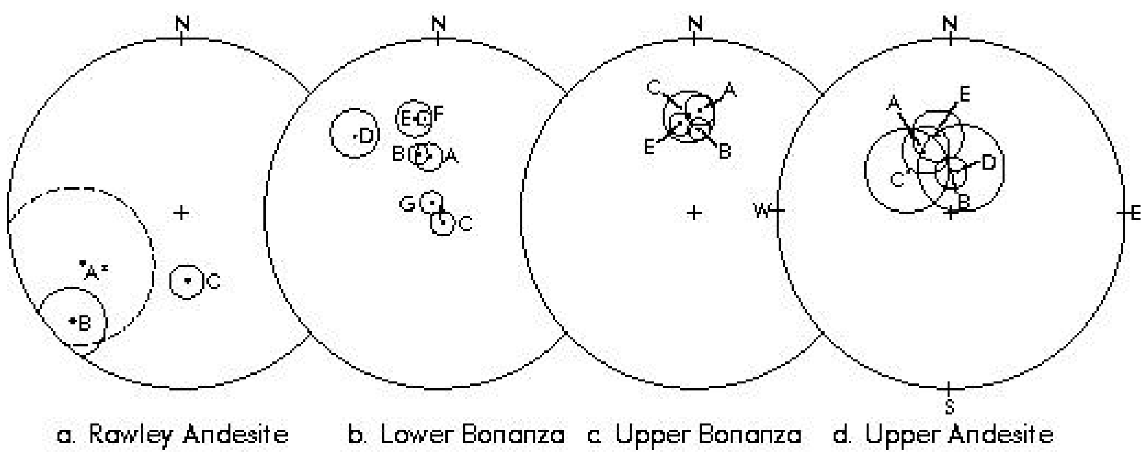

Figure 3: *Stereo plots of mean paleomagnetic directions. Solid dots are in the lower hemisphere (positive inclination); open dots are in the upper hemisphere (negative inclination). Circles are 95% confidence limits.*The unusually large circle of confidence for Lower Andesite outcrop A is due to a high dispersion of data points; these data come from individual clasts within a volcanic flow breccia (see text).*

implies a thermoremanent magnetization and accurate field recording. The mean direction of the Upper Bonanza outcrop E (Poison Gulch) is distinct from the single direction represented by Upper Bonanza outcrops A and B (both Findley Ridge). Upper Bonanza outcrop C, with its large _95 confidence circle, encompasses all of the other Upper Bonanza directions (Figure 3c). The result is two slightly different directions for the Poison Gulch and Findley Ridge localities. Since the Upper Bonanza consists of one physical cooling unit, secular variation is not a probable cause for the two directions. A more likely explanation is a slight error in bedding corrections or a small difference in paleotopography between the two localities. It is interpreted here that the Upper Bonanza means represent one direction.

Upper Andesite samples from outcrops A (Findley Ridge) and outcrop E (Poison Gulch) represent a single mean direction, according to the statistics in McFadden and Lowes (1981). This direction is distinct from outcrop B (Findley Ridge). The low number of samples in outcrops C and D render these two outcrops statistically unreliable. Therefore, it is likely that two distinct directions exist in the Upper Andesite at 353°, 53° and at 7°, 64° (Table 1).

CONCLUSION

The purpose of this project is to obtain reference directions for the three units associated with the Bonanza caldera and the underlying Rawley Andesite, as well as to produce a magnetic stratigraphy of the four units for use in correlation. A conglomerate test of volcanic breccia clasts confirms the stability of the ChRM directions, as does the reversed direction of the Rawley Andesite. The reversal revealed in the Rawley Andesite is likely associated with magnetic polarity chron C17n or C18n of Cande and Kent (1995), dated around 38 Ma. The Lower Bonanza gives at least three separate directions, at 351°, 31° at 348°, 50° and 21°, 88°, the dispersion of which is likely due to differential compaction or a detrital inclination error and which reduces the utility of these directions for structural correction. The Upper Bonanza gives a tight cluster of directions that are interpreted here as one mean direction of 359°, 34°. The Upper Andesite Sequence gives two distinct directions at 347°, 48° and 7°, 64°; both directions are thought to be in the Squirrel Gulch Latite.

	Loc	Strat. Dec.	Inc.	Geog. Dec.	Inc.	κ	à95	N	R
Upper Andesite									
A	FR	336.4	52.2	338.1	50.9	71.1	14.7	3	2.972
B	FR	5.0	66.3	6.7	64.4	70.4	9.2	5	4.943
C	PG	324.1	52.7	300.9	34.0	175.3	19.0	2	1.994
D	PG	18.1	62.1	11.0	63.6	86.6	27.2	2	1.988
E	PG	355.4	42.0	351.8	42.4	25.5	13.5	6	5.800
Combined means = 346.5, 50.7 (A, C, D, E); 6.7, 64.4 (B)									
Upper Bonanza									
A	FR	2.4	28.4	3.4	28.4	154.1	7.4	4	3.981
B	FR	1.8	37.7	3.3	38.5	154.8	5.4	6	5.968
C	PG	0.1	46.3	357.3	33.5	38.0	12.6	5	4.895
D*	PG	55.4	57.2	42.4	56.4	5.7	145.4	2	1.846
E	PG	359.2	47.7	351.9	34.9	196.1	5.5	5	4.980
Combined mean = 359.0, 34.6; Outcrop D discarded (see text)									

	Loc	Start. Dec.	Inc.	Geog. Dec.	Inc.	κ	à95	N	R
Lower Bonanza									
A	FR	349.9	51.8	352.2	50.8	219.9	8.3	3	2.991
B	FR	345.5	48.0	344.2	49.9	94.0	5.3	9	8.915
C	FR	300.9	74.7	130.2	84.1	66.4	8.3	6	5.925
D*	FR	314.2	33.9	315.5	24.3	32.1	10.8	7	6.813
E	FR	350.2	21.7	348.6	31.0	33.3	9.7	8	7.790
F	FR	354.3	30.5	352.6	31.5	288.1	3.6	7	6.979
G	PG	33.0	85.7	341.3	81.2	118.1	7.1	5	4.966
No mean calculated; Outcrop D discarded (see text)									
Rawley Andesite									
A*	HW	245.3	-65.2	242.2	-26.2	2.8	44.9	7	4.868
B	MC	220.0	-53.4	224.8	-8.3	17.4	13.7	8	7.597
C	JC	175.3	-47.0	175.3	-48.0	78.5	8.7	5	4.949
No mean calculated; A is volcanic breccia (see text)									

Table 1: Paleomagnetic Directions and Statistics.

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