2003 ARCHAEOMAGNETIC LABORATORY RESULTS

FOR THE

INCA, SPANISH AND INDIGENOUS SILVER PRODUCTION PROJECT
PORCO, BOLIVIA

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Introduction

The following report discusses the archaeomagnetic results for four samples from burned features at Site 35 in the Porco area of Bolivia that were collected as part of the Inca, Spanish, and Indigenous Silver Production Project (Table 1). To date, only minimal archaeomagnetic research has been accomplished for South America. No archaeomagnetic reference curve for the prehistoric periods exists for the area; so, archaeomagnetic dating of prehistoric samples is not, now, possible. The goals of the archaeomagnetic research were to 1) to explore the availability of appropriate sample materials, 2) to assess the feasibility of pursuing reference curve research, and 3) to explore the application of reference curves developed from historic documents since many of the Project sites are late prehistoric and early historic in age.

Table 1. Site 35 AM Samples – 2003

CSU Lab Number	Feature Number	Expected Age
35-1	Feature E; South Side	AD 1585
35-2	Feature E, North Side	AD 1585
35-3	Feature G	AD 1585
35-4	Feature H	AD 1585

Background

In the Americas, hundreds of archaeomagnetic samples from burned features have been dated by the archaeomagnetic method. This type of dating depends on the thermoremanent magnetism (TRM) preserved by the burned feature after cooling. The basis for TRM dating is generally understood by American archaeologists, but for a review of the principles involved see Aitken (1990), Sternberg (1997), or Eighmy and Sternberg (1990). More recently, archaeomagnetism has been applied to sediments. Similar to burned features, sediments also have a detectable magnetic remanence, picked up as magnetic grains align with the earth's magnetic field during deposition and post-depositional consolidation. This type of archaeomagnetic dating depends on the depositional remanent magnetism (DRM) preserved in archaeological sediments. The theory behind DRM dating is less widely understood by American archaeologists, and an introduction to the method can be found in Wolfman (1984), in Creer, Tucholka and Barton (1983), or in Eighmy and Howard (1991). Unfortunately, very little archaeomagnetic dating research has been carried out in South America (Wolfman and Dodson 1984, 1985, and 1986). Greatest attention has been focused on the use of ceramic pottery samples to determine the paleointensity of the magnetic field in the Andean area (Bowls, J., J. Gee, and J. Hildebrand 2002; Gunn, N.M. and A.S. Murray 1980; Shaw, *et al*. 1996; Yang, S., J. Shaw, and T. Rolph 1993).

Laboratory Procedures

The analysis provided by the Colorado State University Archaeomagnetic Laboratory includes measurement of a sample's magnetic remanence in the pristine condition (referred to as natural remanent magnetization - NRM) and at a series of "demagnetization steps" to establish its primary direction of magnetization (declination and inclination) and resulting virtual geomagnetic pole position (VGP). A Schonstedt spinner magnetometer is employed for specimen measurement and an alternating current (AC) demagnetizer is used for the demagnetization. The processing of each sample is unique because of the individual qualities of each sample, but it follows general guidelines established by laboratory personnel from previous tests and experiments.

The treatment of the Porco samples followed standard procedures. After storage of the newly received sample in a Mu metal shield for several weeks, its natural remanent magnetism (NRM) is determined. Since each feature or sample may be subjected to exterior magnetic interferences that overprint, disrupt or alter the magnetic orientation acquired at the time of firing, the samples are usually "step demagnetized" in 5 millitesla (mT) steps to remove unwanted "secondary" components. Generally, secondary components acquired by the material are spurious and less stable than the primary magnetism. Therefore, these secondary components may be randomized (i.e., removed) by relatively low levels of AC demagnetization while the primary magnetism remains strong. However, occasionally samples are subjected to strong secondary influences and may require higher levels of demagnetization. The optimum demagnetization level is defined as the level at which the sample direction appears stable and the sample's directional scatter (the α_{95} is one of the indicators of scatter) is small. All the samples that were sent to us from Site 35 appeared 'clean' of secondary components by the 15 mT step, and most of the results are reported at this level. As can be seen in the individual laboratory reports included with this report, these samples exhibited very little in the way of secondary components. Sample directions were essentially stable throughout the demagnetization cleaning, and demagnetization often did not improve sample readings over the original NRM results.

During the analysis of the sample from Feature H, it was considered advisable to delete a specimen from the sample's results. The specimen is considered an outlier. Outliers are defined by specimen directions that, for some reason, deviate from the sample cluster and mean direction to such a degree that they no longer are considered representative of the sample. In some cases field notes give an indication of why the specimen is an outlier; however, when a specimen direction is greater than three standard deviations from the mean of the others in the sample, it is also defined as an outlier. The direction of specimen number two from the Feature H sample was greater than three standard deviations from the remaining specimens in that sample; so, it was excluded from the mean sample calculations. Since the direction of an outlier such as specimen number two may disproportionately affect the mean sample direction and statistical measures, their exclusion should improve the accuracy of the estimate of the mean paleodirection.

Table 2. Laboratory results for archaeomagnetic samples collected from Site 35, Porco, Bolivia - 2003

Sample	N1/N2	Demag (mT)	α_{95} (degrees)	Intensity (X 10-7)	Inc (degrees)	Dec (degrees)	Plat (degrees)	Plong (degrees)	EP	EM
Feature E, South Side	12/12	15	27.71	0.121	-3.53	346.65	64.78	261.24	13.89	27.75
Feature E, North Side	6/6	15	18.10	0.159	-15.80	3.64	77.74	311.25	9.68	18.63
Feature G	12/12	15	16.90	0.182	-8.59	354.3	73.56	273.53	8.60	17.04
Feature H	12/11	10	4.81	0.472	-29.96	5.70	83.43	350.55	2.96	5.34

Goals 1 and 2 – Appropriate Material and Reference Curve Research

An important measure of the sample quality is called the α_{95} value, which is an indication of the precision with which the sample mean is determined. A small α_{95} value indicates that the specimen directions in a particular sample clustered closely about the mean. Site 35 samples had α_{95} values ranging from a low of 4.81° to a high of 27.71°. Individual sample reports are attached to this report and summarized in Table 2. Values for α_{95} larger than 10.0º are not reliable for archaeomagnetic dating or curve construction. As can be seen in Table 2, the high (i.e. poorest) α_{95} values come from features that show the weakest magnetic intensity. Feature H has a magnetic intensity approximately three times the magnetization of the Feature E and G samples. Therefore, it is not surprising that Feature H produced acceptable results while the three weaker samples are the ones that produced extremely scattered magnetic directions.

Three of the Site 35 samples had α_{95} values so large as to indicate that appropriate burned material might be difficult to locate in the Bolivian Andes. The Site 35 results are particularly discouraging in this regard since they come from well fired kiln features. It is clear

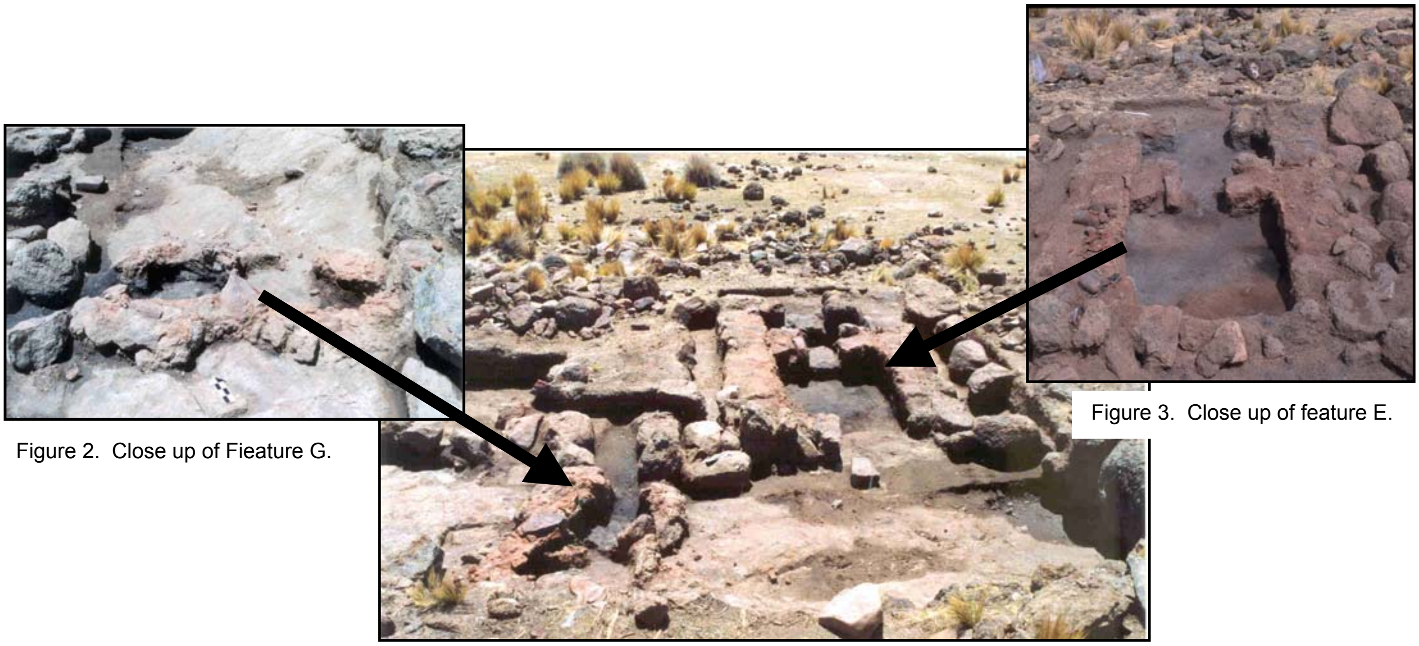


Figure 3. Close up of feature E.

Figure 2. Close up of Fieature G.

Figure 1. Structure 3 with burned Features E and G.

from the sample material and the feature contexts that these two features were highly burned (see Figures 1, 2, and 3). Kiln temperatures undoubtedly exceeded 600° C; so, thermoremanent magnetization should have been thorough. However, the lack of precise thermoremanent magnetization appears to relate to low clay content of the features (Table 3). Table 3 presents the sand/silt/clay percentages for Site 35 samples and several other samples along with their archaeomagnetic results. It can be clearly seen that high clay content tends to produce good archaeomagnetic results. It can also be seen that the Site 35 samples have a very high clay content, and that the sample with the highest clay content (that from Feature H) produced the best α_{95} value. Clayey matrices bind well during firing and will maintain a magnetic signal almost indefinitely. Without the clay, the sand and silt grains are freer to jiggle and become unoriented over the years. It is probable that the poor results from Features E and G are related to the very low clay content of the matrices even though the samples were clearly fired to high temperatures.

Table 3. Comparison of sand/silt/clay composition and archaeomagnetic results from Site 35 samples with samples from various other sites.

Sample ID	% Sand	% Silt	% Clay	Classification	Precision (α_{95})	Intensity (J)
			Site 35 Porco, Bolivia			
Unburned soil	72	19	9	Sandy-Loam	na	na
E	91	7	2	Sand	27.71 & 18.10	0.12 to 0.16×10^{-7}
G	92	6	2	Sand	16.90	0.18×10^{-7}
H	74	10	16	Sandy-Loam	4.81	0.47×10^{-7}
			Ft. Drum, NY, USA			
Feature 1	94	2	4	Sand	66.5	0.23×10^{-7}
			Experimental Hearths, Dolores, CO, USA			
1	38	44	18	Loam	1.57	0.13×10^{-2}
2	35	44	21	Loam	1.38	0.65×10^{-3}
3	31	45	24	Loam	2.16	0.29×10^{-2}
4	59	31	10	Sandy-Loam	1.32	0.13×10^{-3}
5	61	27	12	Sandy-Loam	1.95	0.26×10^{-3}
6	55	21	24	Sandy-Clay-Loam	2.16	0.17×10^{-3}
7	43	35	22	Loam	2.05	0.48×10^{-3}
8	45	32	23	Loam	2.88	0.25×10^{-3}
9	41	33	26	Loam	2.70	0.14×10^{-3}
10	28	28	44	Clay	3.08	0.16×10^{-3}
11	17	30	53	Clay	3.09	0.84×10^{-4}
12	17	29	54	Clay	4.09	0.39×10^{-4}

The encouraging results from Feature H suggest that further AM research in the Andes is warranted. Despite its relative low clay content (compared to the AM best samples), the sample from Feature H did produce a good magnetic record and demonstrates that with enough clay content, the Bolivian samples will produce good records of the magnetic field. However, the best results for the Andean area are likely to come from sites outside the High Andes where the rugged relief and low rainfall result in poorly developed, course-grained lithosols. Since radiocarbon and ceramic dating should provide independent dating with precisions less than 200 years and since burned features in the proper contexts should contain good magnetic directions, then master curve construction for this area in the prehistoric periods should be possible.

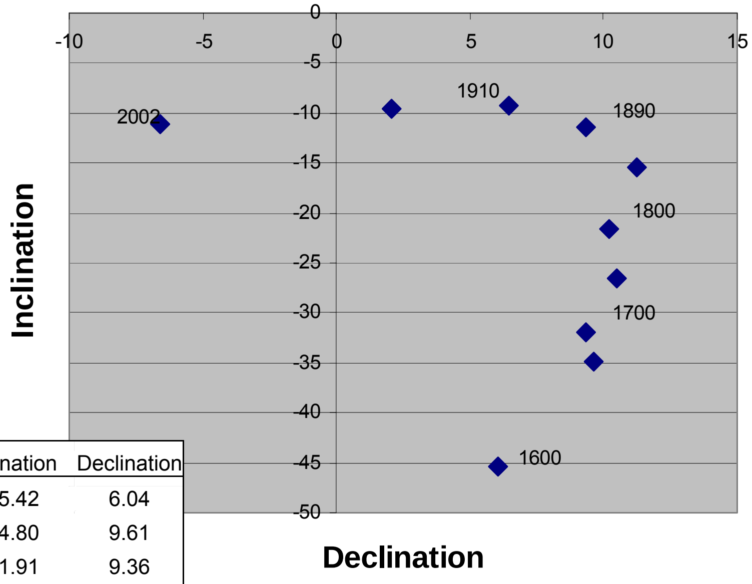
Research Goal 3 - Application of the Historic Magnetic Record

Before looking at the dating of the Feature H sample, it is useful to review archaeomagnetic dating and, especially, archaeomagnetic master curve construction. Dating an archaeomagnetic sample ultimately relies upon the sample's position relative to the regional VGP curve. The actual dating of archaeomagnetic samples may be conducted in one of two ways: visual and statistical. The visual method is intuitively obvious. The VGPs and associated ovals of 95% uncertainty in estimating the mean direction for the burned samples are plotted with a master curve. Visual inspection reveals the time periods during which the magnetic north pole was close to the observed sample pole position. The statistical method is that developed by R.S. Sternberg (1982; Sternberg and McGuire 1990a). For several reasons discussed in Eighmy, Taylor and Klein (1993:34-38), at this time we prefer the visual dates over the statistical dates.

Obviously, then, the dating of archaeomagnetic samples from Bolivia requires the development of a master curve or, more properly, a regional virtual geomagnetic pole (VGP) curve for that area. For the prehistoric period, such a curve is created and calibrated with independently dated archaeomagnetic pole positions or virtual geomagnetic poles (VGPs). Generally, samples independently dated by tree ring, historic documentation or radiocarbon to within a 100 year range are used for building a regional VGP curve in the North America and Eurasia. As the data set of independently dated VGPs increases, the precision in estimating points along the VGP curve improves, and documentation of the curve can be extended to earlier, or later, time periods. Therefore, regional curves are continually being revised to provide the archaeological community with the most current information available (Böhnel and Molina-Graza 2002; Kovacheva, Jordanova, and Karloukovski 1998, Lengyel and Eighmy 2002, Tarling 1989).

As was mentioned earlier, no prehistoric master record of magnetic field change has been developed for the Bolivian Andes. However, since Feature H is expected to date to A.D. 1585 and since preliminary models of geomagnetic field changes for the historic period are available (Jackson, Jonkers, and Walker 2000), it will be useful to compare the thermoremanent magnetic direction recorded in Feature H with the expected field changes as they are currently understood. It should be noted, however, that direct observations for the magnetic field for the 17th century are extremely sparse; only three South American observations of inclination are known for the first half of the 17th century. Thus, even though many more observations of declination are available, our current models of the field during the 17th century are somewhat tentative. Magnetic change for the early historic period is calculated from British Geological Survey Model (1600-1910) and the International Geomagnetic Reference Field Model (1900-2002) (web site http://geomag.usgs.gov/models.html). It is depicted in Figure 4 as change in declination and inclination and in Figure 5 as a VGP path.

Feature H had declination and inclination values of 5.70° and -29.96° and a VGP plot of 83.43° N latitude and 350.55° E longitude. These directions and locations match up well with the historical record for the Bolivian Andes for the period A.D. 1650-1800 (Figure 6).



Year	Inclination	Declination
1600	-45.42	6.04
1650	-34.80	9.61
1700	-31.91	9.36
1750	-26.48	10.48
1800	-21.55	10.18
1850	-15.37	11.22
1890	-11.37	9.36
1910	-9.20	6.48
1950	-9.51	2.05
2002	-11.05	-6.60

Figure 4. Magnetic change calculated from British Geological Survey Model (1600-1910) and the International Geomagnetic Reference Field Model (1900-2002).

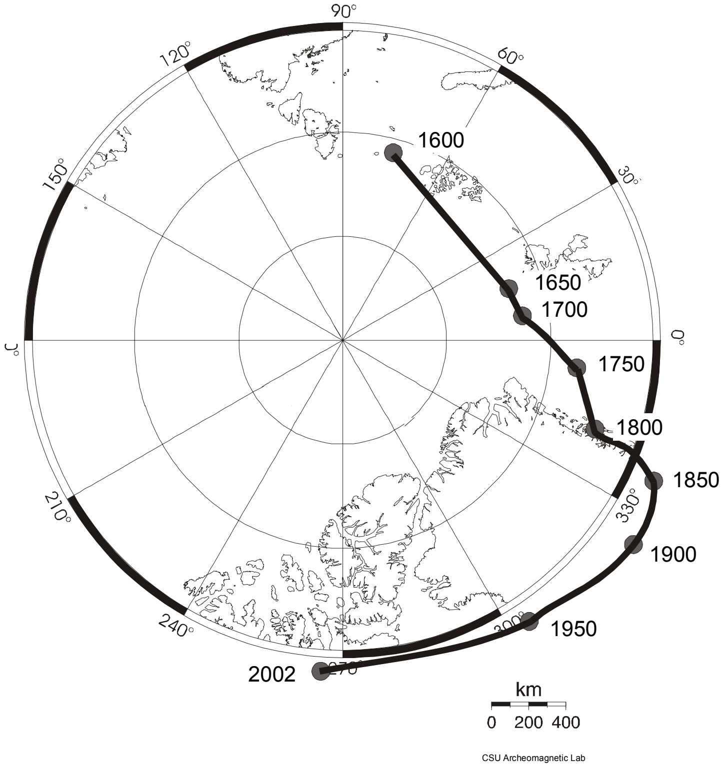


Figure 5. Polar wander path for Bolivian Andes during the early historic period. Path calculated from British Geological Survey Model (1600-1910) and the International Geomagnetic Reference Field Model (1900-2002) for 19.79º S lat and 65.98 W longº.

Year	Latitude	Longitude
1600	80.98	77.20
1650	80.92	21.67
1700	80.78	9.83
1750	78.42	355.57
1800	76.95	344.18
1850	73.83	337.84
1890	73.26	328.20
1910	73.58	317.47
1950	74.87	301.87
2002	74.40	268.84

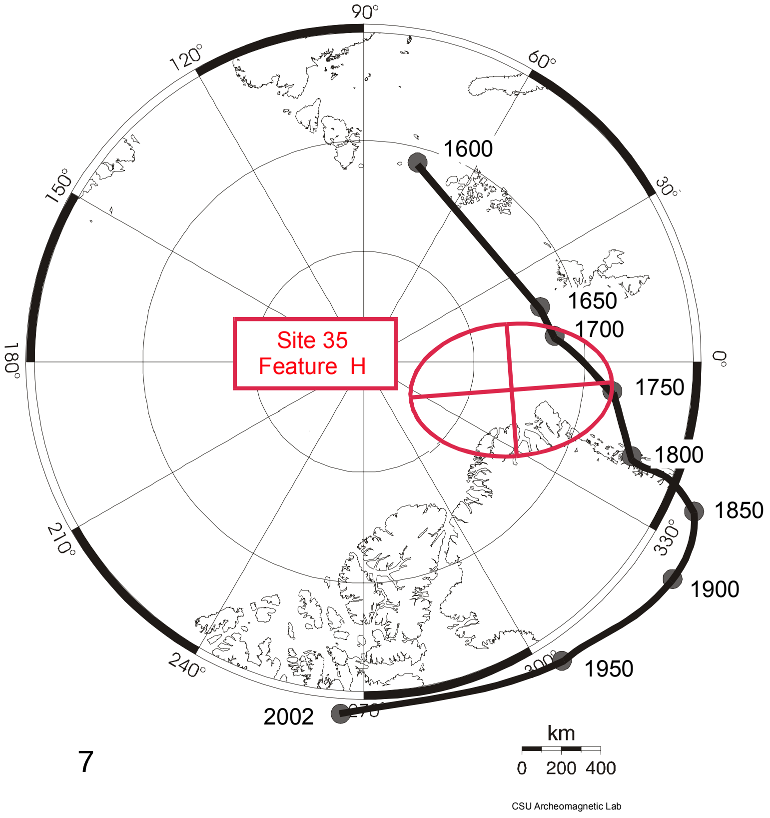


Figure 6. Plot of the paleopole position for the sample from Feature H with the early historic curve for the Bolivian Andes. The magnetic direction of Feature H is similar to the historical record for the period A.D.1600-1650 and for the period A.D. 1650-1800.

Summary

The CSU Archaeomagnetic Lab ran four samples collected from Site 35. Three of the samples appeared to contain too little clay to provide reliable results, while a fourth sample produced acceptable results. The results suggest that appropriate sampling material can be found in the Andes, but collectors must be careful to avoid features composed of the lithosols so common at high elevations there. A three century long master curve for the Bolivian Andes was constructed for the early historic period, and there is no reason to avoid further research into extending this master curve into the prehistoric periods. An early historic curve was used to provide a “date” for the Feature H kiln. This sample suggests the feature was last fired sometime between the mid-17th century and the end of the 18th century.

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