ARCHAEOMAGNETIC LABORATORY RESULTS FOR THE HONEY BEE ARCHAEOLOGICAL PROJECT

Stacey Lengyel
Illinois State Museum

Cite as:

Lengyel, Stacey
2012 Archaeomagnetic Laboratory Results for the Honey Bee Archaeological Project. <http://www.archaeologysouthwest.org/ap48>.

In all, 76 archaeomagnetic samples were collected in 2006 and 2007 from burned features at Honey Bee Village, AZ BB:9:88 (ASM), as part of the Honey Bee Archaeological Project. These samples were submitted to the Illinois State Museum archaeomagnetic laboratory for preliminary analysis in 2007 (Table 1). Based on the natural remanent magnetism measured for these samples, a subset of 29 samples was selected for complete dating analysis. The overall magnetic quality of the subset of fully analyzed samples was unusually good, and the specimen data obtained for each exhibited good to excellent internal agreement, as indicated by the samples' precision and $\alpha95$ (alpha-95) values. These results, the archaeomagnetic date ranges, and the methodologies utilized are discussed in more detail below.

ARCHAEOMAGNETIC DATING OVERVIEW

Archaeomagnetic dating is a chronometric technique that uses changes in the earth's magnetic field, through time, to date specific archaeological features. Although archaeomagnetic dating is generally well understood by American archaeologists, this discussion benefits from a short review of the technique (see Eighmy and Sternberg 1990 or Wolfman 1984 for an in-depth review). Briefly, archaeomagnetism and archaeomagnetic dating depend on two related phenomena. First, the earth's magnetic field changes in direction and strength through time. This is known as secular variation, and it is usually conceptualized as changes in the position of the north magnetic pole. Second, the soils that comprise many archaeological features contain magnetic minerals, such as hematite and magnetite, that can record the direction of the magnetic field under certain conditions. Because all the Honey Bee samples were obtained from burned cultural features, this report focuses on the magnetic signal acquired during heating, which is known as the thermoremanent magnetism.

Archaeological features acquire a thermoremanent magnetism when they are heated above several hundred degrees centigrade and then cooled to ambient temperatures. At relatively high temperatures, the ferromagnetic minerals contained within the feature matrix will become magnetized parallel with the extant magnetic field. After cooling, this alignment is locked into place, unless, and until, the feature is reheated. Thus, the direction of magnetic remanence that is measured relates to the last time the feature was heated to sufficiently high temperatures; this is usually conceptualized as the last use of the feature. The measured direction also indicates the relative position of the geomagnetic north pole at the time of magnetization.

The measured archaeomagnetic direction is used to date the respective archaeological feature by comparing it to directions of known age. For calendrical dating, this involves comparing the measured archaeomagnetic data from a feature to a calibrated reconstruction of secular variation, often referred to as a regional archaeomagnetic reference curve. Because secular variation changes randomly, these reconstructions are created from sources such as historical observations of the field (Barraclough 1995; Malin and Bullard 1981), archaeomagnetic measurements of independently dated archaeological features (Bucur 1994; Clark et al. 1988; Eighmy 1991; Kovacheva 1980, 1997; Kovacheva et al. 1998), paleomagnetic measurements of dated lake sediments (Lund and Banerjee 1985) or lava flows (Champion 1980; Doell and Cox 1965; Hagstrum and Champion 2002), or some combination of the above (Lengyel 2004; Lund 1996; Thompson 1982).

Archaeomagnetic or paleomagnetic data included in these data sets must be dated independently through other techniques, such as dendrochronology or radiocarbon dating, and precision criteria often require these data to have independent date ranges of 200 years or less (for example, Eighmy 1991:203; Eighmy et al. 1986:82, 1990:229; LaBelle and Eighmy 1997:432). Further, because secular variation is affected by regional perturbations in the magnetic field, separate curves must be developed for each archaeomagnetic region, which typically encompasses an area 1,000 km in diameter (Batt 1997:153; Noël and Batt 1990:Figures 3-4; Sternberg 1997:326). Regional reference curves are continually revised as the size and precision of the independently dated magnetic data set increases, and documentation of the curve can then be extended to both earlier and later time periods.

An archaeomagnetic sample is dated by comparing the magnetic pole position calculated for the sample to the calibrated regional reference curve. This can be done visually or mathematically. The visual method is intuitively obvious and involves plotting the sample's pole position and associated oval of confidence against the regional reference curve. Visual inspection reveals the time period(s) during which the magnetic north pole was close to the sample's pole position, indicating the best-fit date range for the associated archaeological feature's last firing event.

Of the numerous mathematical methods available for estimating a sample's date range (Lanos 2004; LeGoff et al. 2002), the statistical method developed by Sternberg (1982; also Sternberg and McGuire 1990)

Table 1. Honey Bee Archaeological Project archaeomagnetic samples collected in 2006 and 2007. (The 29 fully analyzed samples are indicated with an asterisk; natural remanent magnetism α_{95} values less than 5.0° are bolded.)

ISM Lab Number	Field Number	Feature ID	Number of Specimens Collected	NRM[a] α_{95}	
ISM-17	HBA-01	632.01	12	**2.92**	*
ISM-18	HBA-02	686.02	12	23.33	
ISM-19	HBA-03	370.01	12	6.06	
ISM-20	HBA-04	215.01	12	8.38	
ISM-21	HBA-05	534.01	11	6.27	
ISM-22	HBA-06	267.01	12	**4.32**	
ISM-23	HBA-07	285.01	12	**2.26**	*
ISM-24	HBA-08	244	12	8.98	
ISM-25	HBA-09	369.01	12	**2.19**	*
ISM-26	HBA-10	490.01	12	**2.69**	*
ISM-27	HBA-11	361.01	10	9.24	
ISM-28	HBA-12	329.01	12	9.05	
ISM-29	HBA-13	228.01	12	12.75	
ISM-30	HBA-14	465.01	12	**1.66**	*
ISM-31	HBA-15	260.01	10	15.08	
ISM-32	HBA-16	261	12	11.46	
ISM-33	HBA-17	708.01	9	8.38	
ISM-34	HBA-18	710.01	12	9.52	
ISM-35	HBA-19	830.01	12	13.68	
ISM-36	HBA-20	286.03	12	**3.50**	*
ISM-37	HBA-21	1100.01	12	**4.70**	*
ISM-38	HBA-22	874.01	12	7.48	*
ISM-39	HBA-23	1088.01	11	7.72	
ISM-40	HBA-24	626.01	10	16.96	
ISM-41	HBA-25	1061.01	12	5.31	
ISM-42	HBA-26	1218.01	12	**4.29**	
ISM-43	HBA-27	541.01	12	**2.58**	*
ISM-44	HBA-28	539.01	12	**4.00**	*
ISM-45	HBA-29	588.01	12	**3.50**	*
ISM-46	HBA-30	2001.01	12	21.58	
ISM-47	HBA-31	1098.01	12	8.34	
ISM-48	HBA-32	1161.01	12	**4.08**	*
ISM-49	HBA-33	484.01	12	**3.00**	*
ISM-50	HBA-34	430.01	12	11.35	
ISM-51	HBA-35	264.01	11	10.31	
ISM-52	HBA-36	265.01	12	**3.89**	*
ISM-53	HBA-37	2080.01	9	10.37	
ISM-54	HBA-38	2041.01	12	5.43	
ISM-55	HBA-39	2042.01	9	5.43	
ISM-56	HBA-40	413.01	11	7.75	
ISM-57	HBA-41	2015.01	12	**2.91**	*
ISM-58	HBA-42	943.01	12	5.43	*
ISM-59	HBA-43	1315.01	12	11.27	
ISM-60	HBA-44	1019.01	12	**3.17**	*
ISM-61	HBA-45	775.01	12	5.73	
ISM-62	HBA-46	4020.01	12	**2.38**	*
ISM-63	HBA-47	4004.01	12	6.97	*
ISM-64	HBA-48	4014.01	12	5.45	
ISM-65	HBA-49	4015.01	12	17.27	
ISM-66	HBA-50	4015	12	17.91	
ISM-67	HBA-51	4015	12	**1.90**	*
ISM-68	HBA-52	1540.01	12	**2.98**	*
ISM-69	HBA-53	5028.01	12	8.36	
ISM-70	HBA-54	5448.01	12	**3.72**	*
ISM-71	HBA-55	5170.01	12	**3.66**	*
ISM-72	HBA-56	5150.01	12	**1.35**	*
ISM-73	HBA-57	5296.01	12	6.61	
ISM-74	HBA-58	5296.02	12	11.32	
ISM-75	HBA-59	5358.01	12	5.04	*
ISM-76	HBA-60	5158.01	12	**3.47**	*
ISM-77	HBA-61	5007.01	12	6.05	
ISM-78	HBA-62	5449.01	12	5.87	
ISM-79	HBA-63	5002.01	10	5.97	
ISM-80	HBA-64	5382.01	12	**2.00**	
ISM-81	HBA-65	5026.01	12	7.14	
ISM-82	HBA-66	5124.01	12	5.00	*
ISM-83	HBA-67	5123.01	12	19.64	
ISM-84	HBA-68	5087	12	40.07	
ISM-85	HBA-69	5089.01	12	**2.69**	
ISM-86	HBA-70	5093.01	12	9.46	
ISM-87	HBA-71	5021.01	12	**3.00**	*
ISM-88	HBA-72	5021	12	8.23	
ISM-89	HBA-73	5189.01	12	**2.79**	
ISM-90	HBA-74	5237.01	12	8.98	
ISM-91	HBA-75	5324	12	**3.39**	*
ISM-92	HBA-76	5083.01	12	**4.87**	

[a]NRM = Natural remanent magnetism.

is most commonly employed in the U.S., and it is the technique used at the Illinois State Museum Archaeomagnetic Laboratory. This method requires the use of a statistically created curve; therefore, the Honey Bee samples were dated against the Southwest reference curve SWCV595 (LaBelle and Eighmy 1997). Although the reference curve SWCV2000 (Lengyel and Eighmy 2002) is considered to offer a more accurate depiction of secular variation for this region, it lacks the statistical parameters necessary for statistical dating. However, because this curve provides a better depiction of secular variation in the Southwest, it is portrayed on each of the sample virtual geomagnetic pole polar plots herein.

In the statistical dating method, the virtual geomagnetic pole location of the undated sample is compared to the mean virtual geomagnetic pole location for each dating window along the curve (for example, A.D. 580-620 through A.D. 1986-1987) to test the null hypothesis that the two locations are the same (McFadden and Lowes 1981). If they are found to be different at the 5-percent significance level, it is concluded that the sample data were not obtained during that particular time window. The time window(s) that cannot be excluded at this significance level (that is, those not found to be statistically different from the sample location) provide the archaeomagnetic date range, or date ranges, for the sampled feature. Because the path of secular variation often loops back on itself, many sample virtual geomagnetic poles may "date" to more than one segment of the archaeomagnetic reference curve, resulting in more than one possible date range. Researchers must consider these different dating options within the context of other data from the site or project to determine the most likely date range, or ranges, for the sampled feature.

ILLINOIS STATE MUSEUM LABORATORY PROCEDURES

The treatment of the Honey Bee samples followed standard procedures established at the former Colorado State University Archaeometric Laboratory. Analysis of the measured data followed procedures established in the former University of Arizona Paleomagnetic Laboratory, including the use of principal component analysis (Kirschvink 1980) to calculate the mean directions for the individual specimens in each sample.

DATA MEASUREMENT

Prior to measurement, each of the 76 Honey Bee samples was stored in a Mu metal shield for at least 72 hours to allow weak, viscous magnetic components to decay. Then, the natural remanent magnetism of the individual sample specimens, or cubes, was measured on a Schonstedt spinner magnetometer. The natural remanent magnetism is simply the magnetism present prior to laboratory treatment, and it typically consists of the primary magnetization of interest overlain by weaker secondary magnetic components. These secondary components tend to distort the natural remanent magnetism enough that further analysis is necessary to obtain an accurate measurement of the primary magnetization. However, experience has shown that, in most cases, natural remanent magnetism measurements serve as fairly good indicators of magnetic strength and precision, and thus, can be used to identify samples that are likely to be useful for dating.

Given the large number of samples recovered from Honey Bee relative to the funds available for dating analysis, it was determined that the best course of action would be to measure the natural remanent magnetism of each of the 76 samples and use these results to select a subset of samples for full analysis and dating. Selection was based primarily on a sample's $\alpha95$ and magnetic strength values, as well as its preliminary virtual geomagnetic pole location with respect to the curve. Preferentially, samples with stronger magnetization (>~0.5α10-7 T), smaller $\alpha95$ values (<5.0α, and virtual geomagnetic poles locations along the curve were selected for further analysis. In a few cases, it was determined that samples with larger $\alpha95$ values most likely included one or two outlier specimens and probably would improve with further analysis; when these samples came from features of particular archaeological interest, they were considered for the final subset.

In all, 29 of the 76 samples collected from Honey Bee features were selected for full analysis and dating. This involved subjecting the individual specimens from each sample to a series of successively stronger levels of alternating field demagnetization, and remeasuring the residual magnetization after each treatment, to remove secondary components and isolate the primary magnetization of interest. The alternating fields effectively randomize the orientation of weakly magnetized grains so that they no longer contribute to the overall magnetization (Butler 1992:106-107, Figure 5.1). The Illinois State Museum Archaeomagnetic Laboratory routinely demagnetizes and measures specimens at the peak alternating field strengths of 5, 10, 20, 30 and 40 milliTesla (mT).

DATA ANALYSIS

Although it is common to select an optimal demagnetization level for a given sample and use only the specimen data obtained at that level (see Sternberg 1990:21-22), a more robust data set is obtained by incorporating all the primary magnetization data produced through the progressive demagnetization routine. This is achieved by evaluating the magnetic stability of each specimen over the demagnetization routine to isolate the primary magnetic component, and then calculating the mean strength and direction of that primary component. The mean specimen data from each sample are subsequently examined to identify and remove outlier specimens before calculating the mean for the sample. The sample mean is then used to date the archaeological feature.

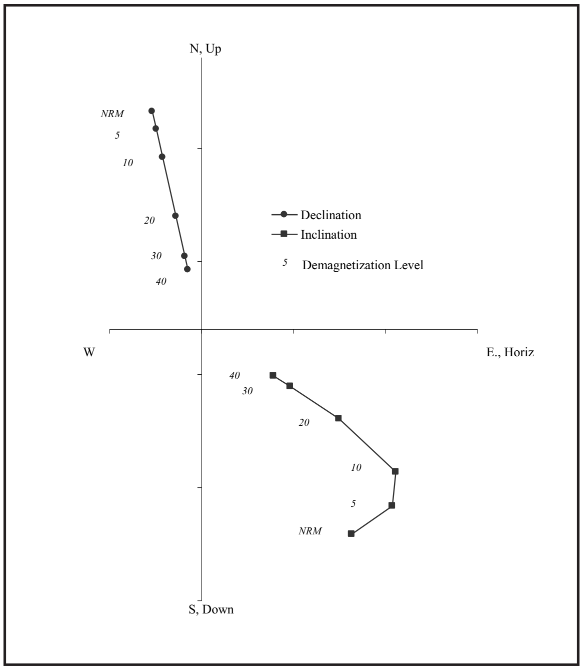

Figure 1. Vector component diagram for Specimen 6 of the sample collected from Feature 286.03 (ISM-036), Honey Bee Village, AZ BB:9:88 (ASM).

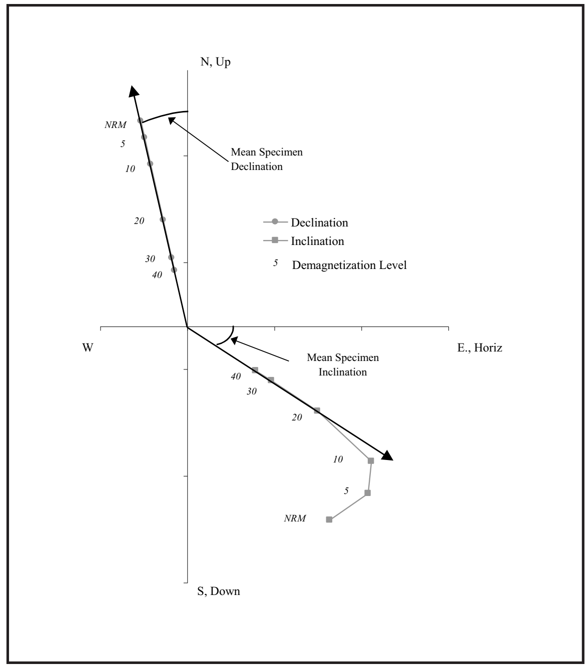

Figure 2. Principal component analysis diagram for the primary component data measured for Specimen 6 of sample ISM-036, Honey Bee Village, AZ BB:9:88 (ASM).

Vector component diagrams (see Butler 1992:110-117) were used to assess the magnetic stability of the individual specimens from the 29 demagnetized samples. These diagrams display changes in the specimen's inclination and declination over the course of progressive demagnetization (Figure 1). Ideally, these data will form a straight line toward the origin, indicating the specimen contained a single, strong magnetic component. In most cases, however, specimens exhibited two or more magnetic components, as indicated by an angled line. The progressive demagnetization data from Specimen 6 of sample ISM-036 (see Figure 1) illustrates this typical behavior. As with most archaeomagnetic specimens, the secondary component was removed over the early stages of demagnetization (by 20 mT in this case). Occasionally, a specimen exhibited erratic behavior, with no discernable pattern through the course of progressive demagnetization. These specimens were considered to be magnetically unstable, and they were usually excluded from the sample mean calculation.

After the primary magnetic component was isolated for each specimen, its mean directional and strength data were calculated through principal component analysis (Kirschvink 1980). This technique calculates the best-fit line through the primary component data points and the origin (Figure 2). The inclination, declination, and magnitude of this line indicate the mean directional and strength measurements for the specimen's primary magnetic component. Additionally, the maximum angular deviation calculated for the best-fit line provides a measure of the line's precision and the stability of the magnetic component. Very stable primary components produce data points that fall closely along the line, as indicated by small maximum angular deviations. Less stable components produce highly scattered data points or data points that do not progress toward the origin and that do not fall along the best-fit line, resulting in larger maximum angular deviations. For this project, specimens that produced a maximum angular deviation of $\geq 5.0\alpha$ were considered to be magnetically unstable and were excluded from further analysis. Six of the project's 348 fully analyzed specimens failed the maximum angular deviation criteria of $< 5.0\alpha$ (Table 2), and they were excluded from the mean calculations for the respective samples.

After completing the principal component analysis, the remaining specimen data from each sample were examined for possible outliers. These are specimen directions that deviate from the sample cluster and mean direction so that they are no longer considered to be representative of the sample. In some cases, field notes give an indication of why the specimen is an outlier, such as collector error, low oxidation, or intrusive pebbles or roots. In most cases, however, outliers are identified statistically. For this project, specimen directions that were greater than

Table 2. List of specimens that failed the maximum angular deviation and outlier tests.

ISM Lab Number	Feature Number	N1	N2	Outlier Specimens	Maximum Angular Deviation Specimens
ISM-017	632.01	12	11	4	
ISM-036	286.03	12	11	1	
ISM-044	539.01	12	10	2	5
ISM-058	943.01	12	10	2	5
ISM-063	4004.01	12	11	6	
ISM-075	5358.01	12	11	3	
ISM-076	5158.01	12	10	4	9
ISM-082	5124.01	12	10		7, 9
ISM-087	5021.01	12	10	2, 9	
ISM-091	5324	12	8	9, 11, 12	4

Note: N1 = Number of collected specimens; N2 = Number of used specimens.

three standard deviations from the mean of the remaining specimens in the respective sample were defined as outliers. In all, 12 Honey Bee specimens from nine samples were identified as outliers (see Table 2), and they were excluded from the mean calculations for the respective samples.

With the removal of the problematic specimens, the remaining Honey Bee specimen data were used to calculate the mean sample data (Table 3). The specimen data from an individual archaeomagnetic sample were averaged via Fisher statistics (Fisher 1953) to yield the mean inclination, declination, and error terms (precision [*k*] and angle of confidence [α95]) for the sample. By averaging data from at least six specimens (and preferably from 8-12), control was possible for errors derived from differences in mineralogy, weathering, and firing times and temperatures over the whole feature (Tarling and Dobson 1995).

The precision and α95 values calculated for each sample provide a measure of the dispersion among the constituent specimen directions. A small α95 value and a large *k* value indicate the specimen directions in a particular sample clustered closely about the mean. The fully analyzed Honey Bee samples constituted a very well-behaved set, with α95 values ranging from a low of 1.10α to a high of 3.80α. This set of samples has a mean α95 value of 2.28α and an interquartile range between 1.80α and 2.70α. Further, 27 of the 29 samples analyzed in this set had excellent α95 values (< 3.50α).

By convention, the mean sample directions (declination and inclination) were converted to the respective virtual geomagnetic poles for dating purposes. The location of the virtual geomagnetic poles is described by its paleolatitude and paleolongitude, and the associated error is described in terms of the major (*dm)* and minor *(dp*) axes of the associated oval of confidence. The virtual geomagnetic pole is simply the north end of the magnetic pole that would have generated the magnetic direction recovered from the archaeomagnetic sample. The location of the Honey Bee sample virtual geomagnetic poles are depicted against the archaeomagnetic reference curve SWCV2000 (Lengyel and Eighmy 2002) in Figure 3.

DATING OF THE HONEY BEE SAMPLES

All 29 samples were dated by the statistical method (Sternberg and McGuire 1990) against the archaeomagnetic reference curve SWCV595 (LaBelle and Eighmy 1997), with the results presented in Table 4. Expected age ranges were provided for 14 of the sampled features, and the archaeomagnetic dates generally agree with them, although they typically are larger than the expected age ranges. This is primarily due to the location of the sample virtual geomagnetic poles near the A.D. 1000/1250 loop in the dating curve. Virtual geomagnetic poles that plot within this loop usually agree with both arms of the loop, although, in reality, they can only date to one or the other. Thus, single long date ranges that encompass the entire loop (for example, A.D. 985-1265) are broken at the apex of the curve (circa A.D. 1125) to form two overlapping date range options (thus, A.D. 985-1150, A.D. 1100-1265). As with all multi-option archaeomagnetic date ranges, other sources of archaeological information are needed to determine which of the individual date range options provide the best age estimate for the respective feature.

For six of the 14 samples with prior age expectations, the archaeomagnetic dates suggested slightly different and/or more refined ages for the features. For two of these features, Feature 632.01 (ISM-017) and Feature 490.01 (ISM-026), the archaeomagnetic dates overlap with the later ends of the expected ages and suggest the features may have been used later than expected. In the case of four other features—Feature 1100.01 (ISM-037), Feature 265.01 (ISM-052), Feature 1619.01 (ISM-060), and Feature 4020.01 (ISM-062)—the archaeomagnetic dates bracketed, but did not overlap with, the expected age ranges, suggesting the features may have been used earlier or later than expected.

Prior age expectations were not provided for 15 of the features in the dated subset. Therefore, their resulting archaeomagnetic dates cannot be evalu-

Table 3. Archaeomagnetic data for the 29 fully analyzed Honey Bee Village, AZ BB:9:88 (ASM), samples.

ISM Lab Number	Feature Number	N1	N2	Inc	Dec	α95	k	Plat (N)	Plong (E)	DM	DP
ISM-017	632.01	12	11	59.09	348.89	2.7	281.18	78.37	201.91	4.08	3.05
ISM-023	285.01	12	12	61.82	344.00	2.4	331.52	73.56	203.71	3.70	2.86
ISM-025	369.01	12	12	58.49	345.67	2.2	374.00	76.58	193.38	3.33	2.47
ISM-026	490.01	12	12	60.44	352.15	1.9	548.25	79.08	216.38	2.82	2.14
ISM-030	465.01	12	12	56.27	345.38	1.1	1,630.35	77.21	183.22	1.55	1.12
ISM-036	286.03	12	11	59.36	351.44	3.2	209.78	79.65	209.81	4.74	3.55
ISM-037	1100.01	12	12	58.24	353.59	1.6	729.07	81.68	212.17	2.38	1.76
ISM-038	874.01	12	12	61.75	348.11	3.6	150.04	75.92	210.76	5.50	4.25
ISM-043	541.01	12	12	60.17	351.25	1.8	581.94	78.88	212.61	2.73	2.07
ISM-044	539.01	12	10	57.63	350.20	2.2	469.17	80.12	197.97	3.27	2.40
ISM-045	588.01	12	12	57.95	345.41	2.4	315.69	76.64	190.67	3.60	2.65
ISM-048	1161.01	12	12	58.43	340.04	2.0	485.08	72.52	187.23	2.92	2.17
ISM-049	484.01	12	12	61.08	349.01	1.7	636.19	76.96	210.33	2.64	2.02
ISM-052	265.01	12	12	61.01	354.43	2.9	232.22	79.42	226.02	4.37	3.35
ISM-057	2015.01	12	12	57.15	349.28	1.8	606.62	79.75	193.32	2.57	1.87
ISM-058	943.01	12	10	59.76	349.28	1.6	905.70	78.14	205.70	2.42	1.82
ISM-060	1019.01	12	12	56.93	339.25	3.2	181.18	72.30	181.56	4.70	3.42
ISM-062	4020.01	12	12	58.21	350.20	1.5	827.32	79.76	200.91	2.23	1.65
ISM-063	4004.01	12	11	57.38	348.70	2.2	422.43	79.24	193.34	3.25	2.38
ISM-067	4015	12	12	58.84	347.94	2.2	394.77	77.92	198.80	3.26	2.43
ISM-068	1540.01	12	12	59.53	351.04	3.0	211.55	79.30	209.36	4.49	3.38
ISM-070	5448.01	12	12	57.31	347.27	2.1	438.43	78.25	190.47	3.03	2.21
ISM-071	5170.01	12	12	53.54	347.81	1.3	1,197.33	79.68	171.59	1.75	1.22
ISM-072	5150.01	12	12	58.21	348.11	1.2	1,349.48	78.40	196.21	1.75	1.29
ISM-075	5358.01	12	11	57.66	343.84	2.8	274.12	75.61	187.63	4.05	2.97
ISM-076	5158.01	12	10	54.64	346.82	2.7	314.48	78.72	176.69	3.85	2.72
ISM-082	5124.01	12	10	49.10	8.00	3.8	163.87	82.74	356.65	5.01	3.31
ISM-087	5021.01	12	10	59.61	350.44	2.4	406.31	78.91	208.01	3.61	2.71
ISM-091	5324	12	8	44.81	2.05	2.5	489.04	83.71	52.10	3.17	2.00

Note: N1 = Number of collected specimens; N2 = Number of used specimens; Inc = Inclination; Dec = Declination; Plat = Paleolatitude; Plong = Paleolongitude.

ated in terms of how well they agreed with initial age estimates. Twelve of these features produced archaeomagnetic dates that agreed with those of the 14 features discussed above, suggesting the bulk of activities represented by this subset of features occurred between roughly A.D. 1000 and 1250. An additional feature, Feature 1161.01 (ISM-048), appears to also date to this period, although the associated virtual geomagnetic pole was located too far from the curve to produce a statistical date. The remaining two features from the dated subset, Feature 5124.01 (ISM-082), and Feature 5324 (ISM-091), produced virtual geomagnetic poles that plot at the other end of the dating curve and likely reflect much earlier occupations than the bulk of the dated features. Pairwise statistical analysis of the virtual geomagnetic poles from the two early features indicated they are different from each other as well at the 0.05 significance level, suggesting these two features reflect different periods of occupation within the history of the site. Similar analysis of the remaining 27 samples from the dated subset, however, found no discernable difference for the group, and thus, could not be used to refine the internal chronology. This is not surprising, given the relatively tight distribution of virtual geomagnetic poles illustrated in Figure 3.

SUMMARY

The Illinois State Museum Archaeomagnetic Laboratory measured the natural remanent magnetism of 76 samples collected from Honey Bee Village, and a subset of 29 of these samples was fully

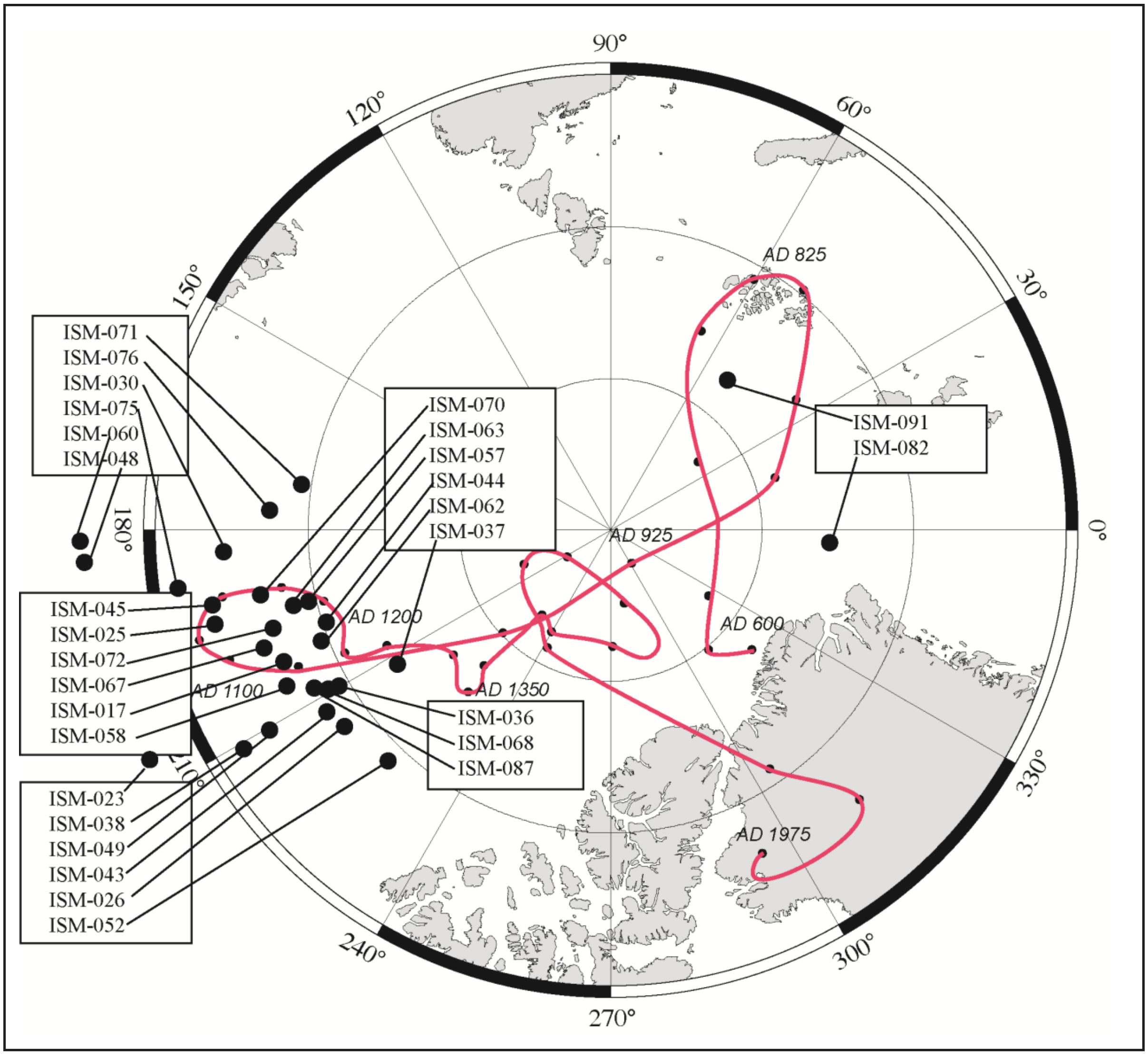

Figure 3. Honey Bee Village, AZ BB:9:88 (ASM), sample virtual geomagnetic poles plotted against the archaeomagnetic reference curve SWCV2000. (Although the samples were dated statistically against SWCV595, SWCV2000 provides a better representation of secular variation in the Greater Southwest.)

Table 4. Date range options for 29 Honey Bee Village, AZ BB:9:88 (ASM), archaeomagnetic samples.

Illinois State Museum Lab Number	Feature Number	α95	Date Ranges	Expected Age	Agreement
ISM-017	632.01	2.7	A.D. 1010-1040 A.D. 1110-1140	A.D. 950-1150	Archaeomagnetic date options agree with later half of expected age
ISM-023	285.01	2.4	A.D. 985-1150 A.D. 1100-1215	None given	N/A
ISM-025	369.01	2.2	A.D. 985–1150 A.D. 1100-1265	A.D. 1000-1150	Archaeomagnetic date range encompasses expected age
ISM-026	490.01	1.9	A.D. 985-1040 A.D. 1235-1315 A.D. 1335-1365	A.D. 850-1000	Archaeomagnetic date overlaps late end of expected age

Table 4. Continued.

Illinois State Museum Lab Number	Feature Number	α95	Date Ranges	Expected Age	Agreement
ISM-030	465.01	1.1	A.D. 935-1040 A.D. 1060-1190	None given	N/A
ISM-036	286.03	3.2	A.D. 935-1415 A.D. 1435-1690	None given	N/A
ISM-037	1100.01	1.6	A.D. 935-1040 A.D. 1160-1390 A.D. 1435-1565 A.D. 1660-1690	A.D. 1100-1150	Archaeomagnetic date options suggest an earlier or later date than expected
ISM-038	874.01	3.6	A.D. 935-1265 A.D. 1335-1365 A.D. 1435-1565 A.D. 1660-1690	None given	N/A
ISM-043	541.01	1.8	A.D. 985-1040 A.D. 1160-1215 A.D. 1235-1315	None given	N/A
ISM-044	539.01	2.2	A.D. 935–1150 A.D. 1100-1335	None given	N/A
ISM-045	588.01	2.4	A.D. 985-1215	A.D. 1100-1200	Archaeomagnetic date encompasses expected age
ISM-048	1161.01	2.0	Near A.D. 1125/1150	None given	N/A
ISM-049	484.01	1.7	A.D. 1010-1065 A.D. 1085-1140 A.D. 1160-1190 A.D. 1235-1265	A.D. 1000-1100	Two of the archaeomagnetic date options agree with the expected age
ISM-052	265.01	2.9	A.D. 935-1040 A.D. 1160-1190 A.D. 1235-1415 A.D. 1435-1690	A.D. 1000-1100	One of the archaeomagnetic date options overlaps the early half of the expected age
ISM-057	2015.01	1.8	A.D. 985–1150 A.D. 1100-1315	A.D. 950-1150	Archaeomagnetic date encompasses the expected age
ISM-058	943.01	1.6	A.D. 1010–1150 A.D. 1100-1215 A.D. 1235-1265	A.D. 1100-1150	Archaeomagnetic date encompasses the expected age
ISM-060	1019.01	3.2	A.D. 985-1040 A.D. 1135-1165	A.D. 1000-1150	Archaeomagnetic date options bracket the expected expected age, suggesting the feature is earlier or later than expected
ISM-062	4020.01	1.5	A.D. 1010-1115 A.D. 1160-1350	A.D. 1100-1150	Archaeomagnetic date options bracket the expected expected age, suggesting the feature is earlier or later than expected
ISM-063	4004.01	2.2	A.D. 985–1150 A.D. 1100-1290	A.D. 1100-1150	Archaeomagnetic date encompasses the expected age
ISM-067	4015	2.2	A.D. 935–1150 A.D. 1100-1315 A.D. 1335-1365 A.D. 1435-1465 A.D. 1660-1690	A.D. 1100-1150	Archaeomagnetic date encompasses the expected age
ISM-068	1540.01	3.0	A.D. 935-1150 A.D. 1100-1390 A.D. 1435-1640 A.D. 1660-1690	A.D. 1100-1150	Archaeomagnetic date date encompasses the expected age

Table 4. Continued.

Illinois State Museum Lab Number	Feature Number	α95	Date Ranges	Expected Age	Agreement
ISM-070	5448.01	2.1	A.D. 985-1150 A.D. 1100-1265	None given	N/A
ISM-071	5170.01	1.3	A.D. 985-1015 A.D. 1200-1250	None given	N/A
ISM-072	5150.01	1.2	A.D. 985–1150 A.D. 1100-1265	None given	N/A
ISM-075	5358.01	2.8	A.D. 985-1190	None given	N/A
ISM-076	5158.01	2.7	A.D. 935-1040 A.D. 1060-1215	None given	N/A
ISM-082	5124.01	3.8	A.D. 660-740 A.D. 910-1015 A.D. 1435-1615 A.D. 1660-1890	None given	N/A
ISM-087	5021.01	2.4	A.D. 985-1150 A.D. 1100-1315 A.D. 1335-1365	None given	N/A
ISM-091	5324	2.5	A.D. 710-865	None given	N/A

analyzed. This was a very well-behaved data set, and all but one of the fully analyzed samples produced statistically derived archaeomagnetic dates against the reference curve SWCV595. Further, all but two of the samples dated to the A.D. 1000-1250 loop in the curve, indicating the majority of activities represented by this subset occurred during this time frame. Two other features within the dated subset produced much earlier date ranges in the seventh and eighth centuries, and likely reflect two additional periods of occupation within the history of the site. These findings should be verified by other archaeological data.

REFERENCES CITED

Barraclough, David Rex
1995 Observations of the Earth's Magnetic Field Made in Edinburgh from 1670 to the Present Day. *Transactions of the Royal Society of Edinburgh: Earth Sciences* 85:239-252.

Batt, C. M.
1997 The British Archaeomagnetic Calibration Curve: An Objective Treatment. *Archaeometry* 39:153-168.

Bucur, Ileana
1994 The Direction of the Terrestrial Magnetic Field in France, During the Last 21 Centuries. Recent Progress. *Physics of the Earth and Planetary Interiors* 87:95-109.

Butler, Robert F.
1992 *Paleomagnetism: Magnetic Domains to Geologic Terranes*. Blackwell Scientific Publications, Boston

Champion, Duane E.
1980 *Holocene Geomagnetic Secular Variation in the Western United States: Implications for the Global Geomagnetic Field*. OpenFile Report No. 80824. U.S. Geological Survey, U.S. Department of the Interior, Washington, D.C.

Clark, A. J., D. H. Tarling, and M. Noël
1988 Developments in Archaeomagnetic Dating in Britain. *Journal of Archaeological Science* 15:645-667.

Doell, R. R., and Allan Cox
1965 Paleomagnetism of Hawaiian Lava Flows. *Journal of Geophysical Research* 70:3377-3405.

Eighmy, Jeffrey L.
1991 Archaeomagnetism: New Data on the U.S. Southwest Master Curve. *Archaeometry* 33:201-214.

Eighmy, Jeffrey L., and Robert S. Sternberg (editors)
1990 *Archaeomagnetic Dating*. University of Arizona Press, Tucson.

Eighmy, Jeffrey L., J. Holly Hathaway, T. Kathleen Henderson, and Randall H. McGuire
1986 Secular Change in the Direction of the Geomagnetic Field, A.D. 900 to 1100: New U.S. Southwest Data. *MASCA Journal* 4:81-85.

Eighmy, Jeffrey L., J. Holly Hathaway, and Allen E. Kane
1990 Archaeomagnetic Secular Variation in the American Southwest, A.D. 700-900: Final Results from the Dolores Archaeological Project. In *Archaeomagnetic Dating*, edited by J. L. Eighmy and R. S. Sternberg, pp. 226-236. University of Arizona Press, Tucson.

Fisher, R. A.
1953 Dispersion on a Sphere. *Proceedings of the Royal Society of London Series A* 217:295-305.

Hagstrum, Jonathan T., and Duane E. Champion
2002 A Holocene Paleosecular Variation Record from 14C-Dated Volcanic Rocks in Western North America. *Journal of Geophysical Research* 107(B1):EPM 8-1-EPM 8-14.

Kirschvink, J. L.
1980 The Least Square Line and Plane and the Analysis of Paleomagnetic Data. *Geophysical Journal of the Royal Astronomical Society* 62:699-718.

Kovacheva, Mary
1980 Summarised Results of the Archaeomagnetic Investigation of the Geomagnetic Field Variation for the Last 8000 Years in Southeastern Europe. *Geophysical Journal of the Royal Astronomical Society* 61:57-64.

1997 Archaeomagnetic Database from Bulgaria. *Physics of the Earth and Planetary Interiors* 102:145-151.

Kovacheva, Mary, Neli Jordanova, and Vassil Karloukovski
1998 Geomagnetic Field Variations as Determined from Bulgarian Archaeomagnetic Data. Part II: The Last 8000 Years. *Surveys in Geophysics* 19:413-460.

LaBelle, Jason M., and Jeffrey L. Eighmy
1997 Additional Archaeomagnetic Data on the South-West USA Master Geomagnetic Pole Curve. *Archaeometry* 39:431-439.

Lanos, Phillipe
2004 Bayesian Inference of Calibration Curves: Application to Archaeomagnetism. In *Tools for Constructing Chronologies: Crossing Disciplinary Bouldaries*, edited by C. E. Buck and A. R. Millard, pp. 43-82. Springer, New York.

LeGoff, Maxime, Yves Gallet, Agnès Genevey, and Nicolas Warmé
2002 On Archaeomagnetic Secular Variation Curves and Archaeomagnetic Dating. *Physics of the Earth and Planetary Interiors* 134:203-211.

Lengyel, Stacey N.
2004 *Archaeomagnetic Research in the U.S. Midcontinent*. Ph.D. dissertation, University of Arizona, Tucson. University Microfilms International, Ann Arbor, Michigan.

Lengyel, Stacey N., and Jeffrey L. Eighmy
2002 A Revision to the U. S. Southwest Archaeomagnetic Master Curve. *Journal of Archaeological Science* 29:1423-1433.

Lund, Steve P.
1996 A Comparison of Holocene Paleomagnetic Secular Variation Records from North America. *Journal of Geophysical Research* 101:8007-8024.

Lund, Steve P., and Subir K. Banerjee
1985 Late Quaternary Paleomagnetic Field Secular Variation from Two Minnesota Lakes. *Journal of Geophysical Research* 90(B1):803-825.

Malin, Stuart R. C., and Edward Bullard
1981 The Direction of the Earth's Magnetic Field at London, 1570-1975. *Philosophical Transactions of the Royal Society of London* A299:357-423.

McFadden, Phillip L., and F. J. Lowes
1981 The Discrimination of Mean Directions Drawn From Fisher Distributions. *Geophysical Journal of the Royal Astronomical Society* 67:19-33.

Noël, M., and C. M. Batt
1990 A Method for Correcting Geographically Separated Remanence Directions for the Purpose of Archaeomagnetic Dating. *Geophysical Journal International* 102:753-756.

Sternberg, Robert S.
1982 *Archaeomagnetic Secular Variation of Direction and Paleointensity in the American Southwest*. Ph.D. dissertation, University of Arizona, Tucson. University Microfilms International, Ann Arbor, Michigan

.
1990 The Geophysical Basis of Archaeomagnetic Dating, In *Archaeomagnetic Dating*, edited by J. L. Eighmy and R. S. Sternberg, pp. 5-30. University of Arizona Press, Tucson.

1997 Archaeomagnetic Dating. In *Chronometric and Allied Dating in Archaeology*, edited by R. E. Taylor and M. J. Aitken, pp. 323-356. Plenum Press, New York.

Sternberg, Robert S., and Randall H. McGuire
1990 Techniques for Constructing Secular Variation Curves and for Interpreting Archaeomagnetic Dates. In *Archaeomagnetic Dating*, edited by J. L. Eighmy and R. S. Sternberg, pp. 109-134. University of Arizona Press, Tucson.

Tarling, D. H., and M. J. Dobson
1995 Archaeomagnetism: An Error Assessment of Fired Material Observations in the British Directional Database. *Journal of Geomagnetism and Geoelectricity* 47:5-18.

Thompson, Roy
1982 A Comparison of Geomagnetic Secular Variation as Recorded by Historical, Archaeomagnetic and Palaeomagnetic Measurements. *Philosophical Transactions of the Royal Society of London* A306:103-112.

Wolfman, Daniel
1984 Geomagnetic Dating Methods in Archaeology. In *Advances in Archaeological Method and Theory*, vol. 7, edited by M. B. Schiffer, pp. 363-458. Academic Press, San Francisco.