DOLORES ARCHAEOLOGICAL PROGRAM TECHNICAL REPORTS

DAP Report: Number 066

1980 Archaeomagnetic Sampling Program

by

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Apparently Sample Type 801, Sample Number 0066 only got as far as the first draft being put on disk. Apparently no editing was accomplished This copy of the report is printed exactly as it appears on the final Micom disks.

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PREFACE

ACKNOWLEDGMENTS

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ABSTRACT

The 1980 archaeomagnetic sampling program involved the recovery of 59 archaeomagnetic samples from 13 archaeological sites excavated by the Dolores Archaeological Program. In addition, 12 samples were collected from 12 experimental hearths located within the project area. Based on the 1979 DAP refinement of the A.D. 700-900 portion of the Southwest curve, the 1978-1980 prehistoric collection sets were temporally evaluated. When these dates were compared to the original Southwest curve estimates, they were found to be more consistent with the estimated archaeological dates. Auxillary studies conducted during 1980 included several intensive analyses and studies designed to improve laboratory and field techniques. Laboratory methods changed considerably over previous years: demagnetization treatment levels for individual samples were determined based primarily on sample result parameters of previous demagnetization levels; this treatment produced better sample results. The archaeomagnetic priority system was evaluated based on the analysis results of different priority categories. Cube orientation studies were designed to determine the most accurate method for established a specimen's in situ orientation and to explain differences in the Dolores magnetic declination noted by several independent sources. The experimental hearths provided a set of data which permitted several intensive analyses correlating hearth quality with archaeomagnetic sample quality.

INTRODUCTION

Goals

The archaeomagnetic sampling program was maintained during the third year of DAP (Dolores Archaeological Program) field operations. Fifty-nine archaeomagnetic samples were recovered from various burned contexts at 13 prehistoric sites, including four (Sites 5MT0023, 5MT2854, 5MT4475, and 5MT4644) which had been partially excavated in previous years but required further investigation during 1980. Excavations at 36 sites did not produce features or contexts of incineration sufficient to warrant archaeomagnetic sampling. Twelve additional samples were collected from experimental hearths constructed within the project area.

The primary goal of the archaeomagnetic sampling program was the recovery of high-quality archaeomagnetic samples from prehistoric sites excavated by the DAP. The data obtained from this sample set served two main purposes. First, 19 independently dated prehistoric samples collected during the 1980 field season were used to refine the early portion of the current Southwest VGP (virtual geomagnetic pole) curve (for an explanationof the VGP curve and other technical terms used in archaeomagnetic research, refer to the glossary provided at the end of this report). The early work for the Southwest curve was conducted by Dr. D.L. DuBois (Watanabe and DuBois 1965; Weaver 1967; DuBois 1975; Wolfman 1979); the results of the DAP study to refine the curve were initially reported in Hathaway et al. (1979). Second, the 1980 prehistoric samples which had not been used for curve refinement were assigned temporal estimates based on the individual sample paleopole plot correlation to the current Southwest curve and to the DAP refined curve. Due to specific dissimilarities between these two curves for corresponding temporal segments, dates provided for single samples differed depending on which curve was consulted.

Secondary goals of the DAP archaeomagnetic program included the continued improvement of laboratory and field methods and an increased understanding of the remanent magnetism of burned archaeological contexts. Better understanding of the remanent directions produced by ancient firings, and what caused these magnetizations, will help solve some of the inconsistencies in archaeomagnetic research. Several intensive analyses including construction of 12 experimental hearths, were designed to promote understanding of these aspects of archaeomagnetic research, and ultimately to provide the DAP with a fully successful archaeomagnetic program.

Labor Expended

Archaeomagnetic sampling during 1980 began on 9 June and continued through 20 November. A total of 86 person-days was expended collecting the 59 archaeomagnetic samples from prehistoric sites; this included site visitation, feature evaluation, and sample collection. An additional 15 person-days was required for laboratory processing and cataloging. Experimental hearth preparation required 14 person-days, and collection and processing of the 12 samples required another 15 person-days.

METHODOLOGY

Research Orientation

Archaeomagnetic Dating

Archaeomagnetic samples are collected from features or contexts which exhibit evidence of burning during past cultural activities. Upon inceneration, the magnetic minerals present in the soil matrix orient in a direction parallel to the ambient magnetic field, and become "frozen" in this position when cooled past a critical temperature. The indensity of the "remanent" magnetization is temperature-dependent; saturation magnetization occurs only after temperatures beyond a magnetic minerals' individual curve point which generally occurs at 580° C for magnetite and 675° C for hematite (two magnetic minerals commonly found in clay soils). Remanent magnetization of archaeological contexts is, however, dependent upon many other variables, some of which are not well understood at the present time. These variables include the type, size, shape and percentage of magnetic minerals present in various contexts, the affect of soil texture and heat absrption, the affect of repeated low-temperature firings, etc. Several studies were initiated during the 1980 field season which investigated several of these factors.

Archaeomagnetic dating is dependent upon a temporally calibrated path of the VGP. A VGP path or curve records the apparent polar position of the earth's magnetic field through time. VGP curves are specific for subcontinental geographic areas; a curve calibrated for the American Southwest is inappropriate for areas in the midwestern or eastern United States. However, recent studies by Wolfman (1979) indicate that the characterization of the curve is similar for areas of the same latitude, with temporal calibration fluctuating longitudinally

A VGP curve is recorded for an area when the results of many archaeomagnetic samples are correlated with results from other absolute dating methods such as tree-ring and C-14 dating. By plotting the individual sample paleopole positions and the independent dates at which those positions occur, a sequence of pole positions can be documented and a VGP curve developed. By refering to this curve archaeomagnetists are able to date archaeomagnetic sample recovered from undated archaeological contexts. The accuracy of such a calibrated curve is dependent upon several factors: the internal consistency of paleopole positions within each sample (as measured by alpha 95 values), the internal consistency of mean paleopole positions among similarly dated samples, the number of dated samples used to characterize the curve, and the accuracy of independently dating the archaeomagnetic samples. The extensions of an archaeomagnetic curve may project only as far as independent dates of samples are available or historical observation of the ambient magnetic field is documented.

Using this method, DuBois has developed an archaeomagnetic curve for the American Southwest which extends from A.D. 1 to 1500, with best accuracy and documentation from A.D. 1000 to 1500 (Watanabe and DuBois 1965). Unfortunately, the early portion of this curve (pre-A.D. 1000) is notwell documented; less than 10 archaeomagnetic samples (independently datedpaleopole positions) were used in establishing this portion of the curve. Refinement of this portion of the curve has improved results obtained by the DAP archaeomagnetic program by providing the Southwest region with a more accurate, better-documented curve, thereby allowing the

DAP archaeomagnetic samples without independent dates to be evaluated relative to this new, refined curve. This process has reduced the discrepancy noted during 1978 and 1979 between temporal estimates based on archaeomagnetic samples and estimates based on other dating techniques (tree-ring and C-14 dating and architectural and artifact seriation).

Field and Laboratory Methods

The basic archaeomagnetic sampling procedure initiated during the 1978 field season (Hathaway 1978) and amended during the 1979 field season (Hathaway and Eighmy 1979) was followed during 1980. This procedure included collection of 12 individual specimens per sample, cube field orientation using both sun- and Brunton-compass methods, ranking of samples according to priority levels, and collection of soil specimens from sampling matrices.

Archaeomagnetic samples collected during 1980 were analyzed using the laboratory methods described by Hathaway and Eighmy (1979), with several amended procedures initiated to improve archaeomagnetic sample results. First, as previously stated, the current Southwest master VGP curve was reevaluated based on independently dated DAP archaeomagnetic samples. This refined Dolores curve provides a better representation of the VGP path for the period A.D. 700-900, and it is believed that it can provide better temporal estimates for prehistoric sites of this period. The paleopole plots presented in appendix A represent the polar positions of all dated samples collected during the 1978-1980 field seasons based on the Dolores refined curve (A.D. 700-900). In instances where a paleopole position fells away from the Dolores refined curve, the later portion of the DuBois Southwest curve (A.D. 1000-1500) was used. The current temporal estimates reported in table 1 represent a sample's relative position to both the Dolores refined curve and the later portion of the DuBois curve. It should be mentioned, however, that recent work by University of Arizona researchers (McGuire and Sternberg 1982) indicates that some revisions of the later portions of the Southwest curve are also eminent. It is important for the archaeologist to recognize that until a segment of the VGP curve is substantially documented, the characterization of that portion may fluctuate or change based on additional collections of independently dated samples. It is the academic obligation of the archaeomagnetist, then, to report not only the estimated date for an archaeomagnetic sample but to report all sample result parameters including sample demagnetization treatment, alpha 95 and paleopole position. In this manner, sample results may be reanalyzed in the event of future alterations in the VGP curve. Table 2 presents dates for DAP sites as determined by the early portions of the DuBois Southwest curve and the Dolores refined curve. Samples which fell away from <u>both</u> early curves were disregarded. The dates provided by the two curves are quite variable for a given sample. Comparison of these two estimates with the dates estimated on the basis of archaeological evidence (architecture and ceramic seriation; tree-ring and C-14 dating) supports the Dolores refined curve estimates. Samples 5MT2198-1, 5MT2198-2, 5MT4545-3, 5MT4545-4 and 5MT4545-5 represent earlier habitations that cannot be evaluated based on the Dolores refinement; however, these samples indicate that the apparent magnetic field from A.D. 600-700 may be more southerly than the apparent magnetic field from A.D. 700-900. Thirteen samples do not fall within the expected temporal range of the cultural activity as estimated by other dating methods. At the present time, these inconsistencies are not

Table 1. Archaeomagnetic sample analysis record. 1978-1980

Sample number	Year sample collected	Analysis results reported in original lab report*	Analysis results reported in site appendixes*	Analysis results reported in 1980 archaeomagnetic report*	Current temporal interpretation (date A.D.)†	Samples used in DAP curve refinement*	Date (A.D.) based on archaeological evidence
5MT0023-1	1979	Discarded	25/12/18.83	Discarded	--	--	--
5MT0023-2	1979	100/10/2.85	100/10/2.85	100/10/2.85	875, 1010, 1320, 1425 (± 45)	--	
5MT0023-3	1979	100/11/1.56	100/11/1.56	--	--	125/12/1.48	905 ± 15
5MT0023-4	1979	25/11/2.23	25/11/2.23	25/11/2.23	725, 880, 1000, 1460 (± 35)	--	
5MT0023-5	1979	25/8/3.07	25/11/3.35	25/11/3.35	700, 880, 1475 (± 50)	--	
5MT0023-6	1979	100/6/2.98	100/6/2.98	100/6/2.98	700, 875, 1460 (± 35)	--	
5MT0023-7	1979	25/11/1.99	25/11/1.99	--	--	25/12/2.34	880 ± 20 (828v)
5MT0023-8	1979	25/12/1.48	25/12/1.48	--	--	25/12/1.48	880 ± 20 (858+vv)
5MT0023-9	1979	25/10/2.54	25/10/2.54	--	--	25/10/2.54	890 ± 20 (722+vv)
5MT0023-10	1979	25/11/2.81	25/11/2.81	75/12/3.34	Falls off curve	--	
5MT0023-11	1979	25/8/3.06	25/8/3.06	75/11/3.13	790, 850 (± 40)	--	
5MT0023-12	1980	50/10/1.73	50/10/1.73	50/10/1.73	1415 (± 25)	--	
5MT0023-13	1980	50/11/2.21	50/11/2.21	--	--	50/11/2.21	870 ± 10 (852r)
5MT0023-14	1980	50/10/1.82	50/10/1.82	--	--	50/10/1.82	865 ± 10 (852r)
5MT0023-15	1980	50/12/1.00	50/12/1.00	--	--	50/12/1.00	880 ± 20 (850vv)

NOTES: "Original lab report" refers to the documents in which early analysis results were reported to the DAP; a paleoplot and estimated date were included in these reports. "Appendixes" refers to site-specific reports appearing as appendixes to individual site reports. The "1980 archaeomagnetic report" refers to the present document; the updated results reported in this column were based on three criteria: (1) the new declination determined for the Dolores area in 1980 (11.55° E), (2) additional demagnetization subsequent to original reporting, and (3) a paleoplot relative to the DuBois Southwest and Dolores refined curves.

Dates which appear with a letter symbol were based on tree-ring sample results. These dates and the following symbol explanations were provided by the Laboratory of Tree-ring Research, University of Arizona, Tucson:

r - Less than a full section is present, but the outermost ring is continuous around available circumference.

v - A subjective judgment that, although there is no direct evidence of the true outside on the specimen, the date is within a very few years of being a cutting date.

vv - There is no way of estimating how far the last ring is from the true outside.

\+ - One or more rings may be missing near the end of the ring series whose presence or absence cannot be determined because the specimen does not extend far enough to provide an adequate check.

++ - A ring count is necessary due to the fact that beyond a certain point the specimen could not be dated.

Table 1. Archaeomagnetic sample analysis record, 1978-1980--Continued

Sample number	Year sample collected	Analysis results reported in original lab report*	Analysis results reported in site appendixes*	Analysis results reported in 1980 archaeomagnetic report*	Current temporal interpretation (date A.D.)†	Samples used in DAP curve refinement*	Date (A.D.) based on archaeological evidence
5MT0023-16	1980	50/12/3.18	50/12/3.18	50/12/3.18	1525 (± 45)	--	
5MT0023-17	1980	Discarded	75/12/3.83	Discarded	--	--	--
5MT0023-18	1980	100/11/3.53	100/11/3.53	100/11/3.53	725, 875, 1000, 1450 (± 50)	--	
5MT0023-19	1980	100/12/2.34	100/12/2.34	--	--	100/12/2.34	900 ± 20 (882++vv)
5MT0023-20	1980	50/12/2.99	50/12/2.99	50/12/2.99	760, 875, 1000, 1440 (± 40)	--	
5MT0023-21	1980	50/12/1.39	50/12/1.39	--	--	50/12/1.39	880 ± 10 (867+r)
5MT2151-1	1978	Discarded	150/12/41.03	Discarded	--	--	--
5MT2151-2	1978	Discarded	150/12/19.23	Discarded	--	--	--
5MT2151-3	1978	Discarded	150/12/17.29	Discarded	--	--	--
5MT2151-4	1978	Discarded	150/12/21.95	Discarded	--	--	--
5MT2151-5	1978	Discarded	150/12/34.03	Discarded	--	--	--
5MT2151-6	1978	Discarded	150/9/45.55	Discarded	--	--	--
5MT2151-7	1978	Discarded	150/9/50.96	Discarded	--	--	--
5MT2151-8	1978	Discarded	150/9/25.88	Discarded	--	--	--
5MT2151-9	1978	150/8/3.89	?150/8/3.89	?150/8/3.89	1050, 1220 (± 55)?	--	
5MT2151-10	1978	Discarded	25/12/8.97	Discarded	--	--	--
5MT2151-11	1979	Discarded	25/12/27.68	Discarded	--	--	--
5MT2151-12	1979	25/9/3.45	25/9/3.45	25/9/3.45	875, 1060, 1320, 1440 (± 50)	--	--
5MT2151-13	1979	25/12/2.03	25/12/2.03	--	--	25/12/2.03	750 ± 30
5MT2161-1	1980	Discarded	50/11/4.10	Discarded	--	--	--
5MT2161-2	1980	Discarded	50/8/5.12	Discarded	--	--	--
5MT2161-3	1980	Discarded	50/12/5.22	Discarded	--	--	--
5MT2161-4	1980	Discarded	50/8/7.23	Discarded	--	--	--
5MT2181-1	1980	50/12/1.88	50/12/1.88	--	--	50/12/1.88	790 ± 10 (780v)
5MT2182-1	1980	50/10/3.57	50/10/3.57	50/10/3.57	780, 860, 900 (± 50)	--	
5MT2182-2	1980	75/12/3.03	75/12/3.03	75/12/3.03	890, 1520 (± 40)	--	
5MT2182-3	1980	50/12/2.02	50/12/2.02	--	-- --	50/12/2.02	800 ± 10 (793r)
5MT2182-4	1980	50/10/2.73	50/10/2.73	50/10/2.73	700, 865, 890, 1490 (± 40)	--	
5MT2182-	1980	50/12/2.47	50/12/2.47	50/12/2.47	700, 880, 1475 (± 35)	--	
5MT2191-1	1978	150/8/3.91	150/6/3.35	150/8/3.91	1150 (± 55)	--	
5MT2191-2	1978	Discarded	150/12/11.94	Discarded	--	--	--
5MT2192-1	1979	Discarded	25/12/19.83	Discarded	--	--	--

Table 1. Archaeomagnetic sample analysis record, 1978-1980--Continued

Sample number	Year sample collected	Analysis results reported in original lab report*	Analysis results reported in site appendixes*	Analysis results reported in 1980 archaeomagnetic report*	Current temporal interpretation (date A.D.)†	Samples used in DAP curve refinement*	Date (A.D.) based on archaeological evidence
5MT2192-2	1979	Discarded	25/12/17.58	Discarded	--	--	--
5MT2192-3	1979	Discarded	25/12/25.18	Discarded	--	--	--
5MT2192-4	1979	25/9/2.69	25/9/2.69	100/12/3.13	1400 ($\pm$ 50)	--	
5MT2192-5	1979	Modern	25/11/2.68	Modern	--	--	--
5MT2192-5a	1979	Modern	25/7/2.21	Modern	--	--	--
5MT2192-5b	1979	Modern	25/8/7.35	Modern	--	--	--
5MT2192-6	1979	Modern	25/9/2.72	Modern	--	--	--
5MT2192-7	1979	Modern	25/11/1.75	Modern	--	--	--
5MT2193-1	1978	150/8/4.93	150/8/4.93	150/8/4.93	735, 875, 1090, 1429 ($\pm$ 75)	--	
5MT2193-2	1978	150/11/2.00	150/11/2.00	--	--	150/11/2.00	780 $\pm$ 20
5MT2193-3	1978	Discarded	150/12/15.13	Discarded	--	--	--
5MT2193-4	1978	Discarded	150/12/17.77	Discarded	--	--	--
5MT2193-5	1978	Discarded	150/12/13.99	Discarded	--	--	--
5MT2193-6	1978	Discarded	150/9/12.39	Discarded	--	--	--
5MT2193-15	1979	Discarded	25/12/24.76	Discarded	--	--	--
5MT2193-16	1979	Discarded	25/12/12.74	Discarded	--	--	--
5MT2193-17	1979	Discarded	25/11/25.54	Discarded	--	--	--
5MT2193-18	1979	25/12/3.46	25/12/3.46	25/12/3.46	735, 885, 1490 ($\pm$ 50)	--	
5MT2193-19	1979	Discarded	25/12/11.54	Discarded	--	--	--
5MT2193-20	1979	Discarded	25/12/6.30	Discarded	--	--	--
5MT2193-21	1979	Discarded	25/13/6.90	Discarded	--	--	--
5MT2193-22	1979	Discarded	25/12/6.51	Discarded	--	--	--
5MT2194-1	1979	Discarded	100/12/8.36	Discarded	--	--	--
5MT2198-1	1978	180Cr/7/2.85	180Cr/7/2.85	180Cr/7/2.85	1400 ($\pm$ 45)	--	
5MT2198-2	1978	150/9/4.37	150/9/4.37	150/9/4.37	875, 1100, 1280, 1410 ($\pm$ 70)	--	
5MT2199-1	1979	Discarded	25/12/5.28	Discarded	--	--	--
5MT2203-1	1979	Discarded	25/12/26.56	Discarded	--	--	--
5MT2215-1	1980	Discarded	50/11/5.57	Discarded	--	--	--
5MT2235-1	1978	180/8/4.54	150/6/3.16	150/9/3.55	1125, 1390 ($\pm$ 55)	--	
5MT2235-2	1978	Discarded	150/12/6.17	Discarded	--	--	--
5MT2235-3	1978	150/8/4.18	150/8/4.18	150/8/4.18	1100, 1225, 1340 ($\pm$ 65)	--	
5MT2235-4	1978	150/10/2.67	150/8/2.58	150/10/2.67	1140, 1370 ($\pm$ 45)	--	

Table 1. Archaeomagnetic sample analysis record, 1978-1980--Continued

Sample number	Year sample collected	Analysis results reported in original lab report*	Analysis results reported in site appendixes*	Analysis results reported in 1980 archaeomagnetic report*	Current temporal interpretation (date A.D.)†	Samples used in DAP curve refinement*	Date (A.D.) based on archaeological evidence
5MT2236-1	1979	25/7/2.73	25/7/2.73	25/7/2.73	1140 (± 45)	--	
5MT2236-2	1979	25/12/2.25	25/12/2.25	--	--	25/12/2.25	780 ± 10 (865r)
5MT2320-1	1979	25/9/1.44	25/9/1.44	--	--	25/9/1.44	880 ± 30
5MT2848-1	1979	25/10/2.70	25/10/2.70	100/11/3.51	735, 875, 1000, 1320, 1440 (± 50)	--	
5MT2848-2	1979	25/11/1.35	25/11/1.35	--	--	75/12/1.28	800 ± 10 (784r)
5MT2848-3	1979	25/7/2.98	25/7/2.98	25/7/2.98	780, 860, 900 (± 40)	--	
5MT2853-1	1979	25/10/1.52	25/10/1.52	25/10/1.52	780, 855 (± 20)	--	
5MT2854-1	1979	25/12/3.59	25/12/3.59	25/12/3.59	1100, 1400 (± 55)	--	
5MT2854-2	1979	25/7/2.68	25/7/2.68	25/7/2.68	700, 880, 1475 (± 40)	--	
5MT2854-3	1980	Discarded	50/12/6.72	Discarded	--	--	--
5MT2854-4	1980	Discarded	50/12/13.77	Discarded	--	--	--
5MT2858-1	1979	25/11/2.95	25/11/2.95	75/11/3.10	700, 875, 1000, 1460 (± 45)	--	
5MT2858-2	1979	25/11/1.46	25/11/1.46	75/11/1.79	700, 875, 1000, 1460 (± 25)	--	
5MT2858-3	1979	Discarded	25/12/11.39	Discarded	--	--	--
5MT2858-4	1979	Discarded	25/12/10.34	Discarded	--	--	--
5MT4475-1	1978	150/6/3.61?	150/10/21.25	150/6/3.61	1120, 1365 (± 55)	--	
5MT4475-2	1978	Discarded	150/10/42.86	Discarded	--	--	--
5MT4475-3	1978	150/7/2.45?	150/7/2.45?	150/8/3.01	735, 880, 1000 (± 40)	--	
5MT4475-4	1978	150/6/3.57?	150/6/3.57?	150/6/3.57?	1120, 1255, 1360 (± 55)	--	
5MT4475-5	1978	150/8/3.42?	150/8/3.42?	150/8/3.42?	780, 860 (± 45)	--	
5MT4475-6	1978	Discarded	150/10/15.02	Discarded	--	--	--
5MT4475-7	1978	Discarded	150/9/11.46	Discarded	--	--	--
5MT4475-8	1978	180/12/3.32	180/12/3.32	180/12/3.32	1415 (± 50)	--	
5MT4475-9	1978	150/8/2.70	150/7/2.47	150/8/2.70	735, 875, 1000, 1450 (± 40)	--	
5MT4475-10	1978	150/9/3.70	150/9/3.70	150/9/3.70	735, 885, 1475 (± 50)	--	
5MT4475-11	1978	150/9/3.79	150/9/3.79	150/9.3.79	1100, 1360 (± 60)	--	
5MT4475-12	1978	Discarded	150/9/9.14	Discarded	--	--	--
5MT4475-13	1978	Discarded	150/12/6.20	Discarded	--	--	--
5MT4475-14	1980	50/9/2.33	50/9/2.33	--	--	50/9/2.33	890 ± 10 (874r)
5MT4475-15	1980	50/12/2.24 100/10/1.12	100/10/1.12	--	--	100/10/1.12	890 ± 10 (874r)
5MT4475-16	1980	150/12/1.73	150/12/1.73	--	--	150/12/1.73	890 ± 10 (874r)

Table 1. Archaeomagnetic sample analysis record, 1978-1980--Continued

Sample number	Year sample collected	Analysis results reported in original lab report*	Analysis results reported in site appendixes*	Analysis results reported in 1980 archaeomagnetic report*	Current temporal interpretation (date A.D.)†	Samples used in DAP curve refinement*	Date (A.D.) based on archaeological evidence
5MT4475-17	1980	Discarded	50/8/4.04	Discarded	--	--	--
5MT4475-18	1980	50/11/1.43	50/11/1.43	--	--	50/11/1.43	890 ± 10 (874r)
5MT4475-19	1980	50/12/3.42	50/12/3.42	50/12/3.42	1090, 1350 (± 50)	--	
5MT4475-20	1980	50/11/1.72	50/11/1.72	--	--	50/11/1.71	880 ± 15 (825vv)
5MT4477-1	1980	50/11/3.59	50/11/3.59	50/11/3.59	750, 870, 1010, 1450 (± 50)	--	
5MT4477-2	1980	75/12/1.72	75/12/1.72	--	--	75/12/1.72	890 ± 10 (871B)
5MT4479-1	1980	50/12/1.49	50/12/1.49	50/12/1.49	700, 880, 1475 (± 20)	--	
5MT4479-2	1980	150/12/2.30	150/12/2.30	150/12/2.30	765, 890, 1490 (± 30)	--	
5MT4479-3	1980	50/12/3.14	50/12/3.14	50/12/3.14	700, 880, 990, 1480 (± 45)	--	
5MT4480-1	1980	50/11/2.54	50/11/2.54	--	--	50/11/2.54	880 ± 15 (864B, 874vv)
5MT4480-2	1980	Discarded	50/12/4.11	Discarded	--	--	--
5MT4512-1	1979	Discarded	25/12/24.06	Discarded	--	--	--
5MT4512-2	1979	25/8/3.61	25/8/3.61	25/8/3.61	1090, 1340, 1420 (± 55)	--	
5MT4512-3	1979	25/12/2.23	25/12/2.23	75/12/3.20	Falls off curve	--	
5MT4545-1	1979	Discarded	25/12/5.24	Discarded	--	--	--
5MT4545-2	1979	25/8/1.96	25/8/1.96	--	--	25/9/2.21	650 ± 30 (598vv)
5MT4545-3	1979	25/6/3.69	25/6/3.69	25/6/3.69	750, 870, 1000, 1440 (± 50)	--	
5MT4545-4	1979	100/11/2.97	100/11/2.97	125/10/3.14	700, 1475 (± 45)	--	
5MT4545-5	1979	25/12/2.98	25/12/2.98	25/12/2.98	1400 (± 50)	--	
5MT4545-6	1979	25/10/1.64	25/10/1.64	--	--	100/12/1.92	650 ± 30
5MT4545-7	1979	Discarded	25/12/5.50	Discarded	--	--	--
5MT4614-1	1979	25/12/1.72	25/12/1.72	--	--	25/12/1.72	725 ± 30
5MT4614-2	1979	25/9/2.38	25/9/2.38	--	--	25/9/2.38	750 ± 30
5MT4614-3	1979	Discarded	25/12/4.93	Discarded	--	--	--
5MT4644-1	1979	25/12/1.80	25/12/1.80	--	--	75/12/1.40	820 ± 20 (793vv)
5MT4644-2	1979	25/11/1.45	25/11/1.45	--	--	100/11/1.32	790 ± 10 (776r)
5MT4644-3	1979	25/11/2.70	25/11/2.70	--	--	100/12/2.55	790 ± 10 (776r)
5MT4644-4	1979	Discarded	25/12/11.69	Discarded	--	--	--
5MT4644-5	1979	25/11/1.25	25/11/1.25	--	--	75/12/1.65	820 ± 20 (793vv)
5MT4644-6	1979	25/10/3.35	25/10/3.35	100/12/3.46	700, 880, 980, 1460 (± 60)	--	
5MT4644-7	1980	50/12/3.24	50/12/3.24	50/12/3.24	1100, 1325, 1420 (± 50)	--	

Table 1. Archaeomagnetic sample analysis record, 1978-1980--Continued

Sample number	Year sample collected	Analysis results reported in original lab report*	Analysis results reported in site appendixes*	Analysis results reported in 1980 archaeomagnetic report*	Current temporal interpretation (date A.D.)†	Samples used in DAP curve refinement*	Date (A.D.) based on archaeological evidence
5MT4644-8	1980	50/10/2.20	50/10/2.20	--	--	50/10/2.20	760 ± 30
5MT4644-9	1980	75/11/3.37	75/11/3.37	75/11/3.37	875, 1400 (± 50)	--	
5MT4650-1	1980	50/11/2.59	50/11/2.59	50/11/2.59	765 (± 35)	--	
5MT4671-1	1980	50/10/2.07	50/10/2.07	50/10/2.07	775, 865, 890 (± 30)	--	
5MT4671-2	1980	50/11/2.49	50/11/2.49	50/11/2.49	775, 860, 900 (± 35)	--	
5MT4671-3	1980	50/11/2.04	50/11/2.04	50/11/2.04	785, 850 (± 25)	--	
5MT4671-4	1980	50/11/2.12	50/11/2.12	50/11/2.12	785, 860, 900 (± 30)	--	
5MT4671-5	1980	50/10/2.53	50/10/2.53	50/10/2.53	735, 880 (± 35)	--	
5MT4684-1	1980	125/12/1.96	125/12/1.96	--	--	125/12/1.96	690 ± 15 (669B)
5MT4684-2	1980	Discarded	50/12/4.95	Discarded	--	--	--
5MT4684-3	1980	Discarded	50/12/4.21	Discarded	--	--	--
5MT4684-4	1980	50/12/2.78	50/12/2.78	50/12/2.78	735, 880, 1485 (± 40)	--	
5MT4684-5	1980	50/11/1.93	50/11/1.93	--	--	50/11/1.93	700 ± 30
5MT4725-1	1980	Discarded	50/12/4.86	Discarded	--	--	--
5MT4725-2	1980	50/12/2.19	50/12/2.19	--	--	50/12/2.19	860 ± 15 (845r)
5MT4725-3	1980	50/12/3.48	50/12/3.48	50/12/3.48	700, 890, 1505 (± 50)	--	
5MT4725-4	1980	Discarded	50/12/4.10	Discarded	--	--	--
5MT4725-5	1980	50/12/2.77	50/12/2.77	50/12/2.77	785, 855, 900 (± 35)	--	
5MT4725-6	1980	50/11/2.28	50/11/2.28	--	--	50/11/2.28	800 ± 25

* The numbers listed in these columns are organized as follows: demagnetization level (Oe)/number of specimens/alpha 95 value "Discarded" refers to a sample which yielded an alpha 95 value too high (>3.5°) to be used for dating.
† The dates in this column are based on a sample's position relative to the DuBois Southwest and DAP refined curves.

Table 2. Archaeomagnetic sample results based on early segments of DuBois southwest curve and Dolores refined curve, 1978-1980

Sample	Date (A.D.) based on archaeological evidence*	Date (A.D.) based on DuBois southwest curve†	Date (A.D.) based on Dolores refined curve§	Error estimation (yrs)**
5MT0023-2	900 ± 25		875	± 45
5MT0023-4	890 ± 25	780	725,880	± 35
5MT0023-5	880 ± 30	775	700,880	± 50
5MT0023-6	880 ± 30	730	700,875	± 35
5MT0023-10	875 ± 30	640		± 50
5MT0023-11	870 ± 20	910	790,850	± 40
5MT0023-12	880 ± 30	690		± 25
5MT0023-16	880 ± 30	750		± 45
5MT0023-18	900 ± 25	760	725,875	± 50
5MT0023-20	900 ± 25	800	760,875	± 40
5MT2151-9	800 ± 50 or 1000 ± 50			
5MT2151-12	1050 ± 25		875	± 50
5MT2182-1	875 ± 30	820,900	780,860,900	± 50
5MT2182-2	875 ± 30	800	890	± 40
5MT2182-4	875 ± 30	800	700,865,890	± 40
5MT2182-2003	875 ± 30	760	700,880	± 35
5MT2191-1	850 ± 50			
5MT2192-4	780 ± 30	660		± 50
5MT2193-1	780 ± 20	700	735,875	± 75
5MT2193-18	775 ± 15	790	735,880	± 50
5MT2198-1	670 ± 20	660		± 45
5MT2198-2	670 ± 20	700	875	± 70
5MT2235-1	1060 ± 25	675		± 55
5MT2235-3	1075 ± 30			
5MT2235-4	1060 ± 20			
5MT2236-1	1150 ± 50			
5MT2848-1	700 ± 20	720	735,875	± 50
5MT2848-3	800 ± 20	830,890	780,860,900	± 40
5MT2853-1	775 ± 30	850	780,855	± 20
5MT2854-1	775 ± 50	675		± 55
5MT2854-2	800 ± 25	775	700,880	± 40
5MT2858-1	680 ± 30	750	700,875	± 45
5MT2858-2	680 ± 30	750	700,875	± 25
5MT4475-1	925 ± 25			
5MT4475-3	890 ± 15	790	735,880	± 40
5MT4475-5	900 ± 25	810,900	780,860	± 45
5MT4475-8	925 ± 30	690		± 50
5MT4475-9	925 ± 50		735,875	± 40
5MT4475-10	885 ± 15	795	735,885	± 50
5MT4475-11	950 ± 50			
5MT4475-19	950 ± 50			
5MT4477-1	885 ± 15	800	750,870	± 50
5MT4479-1	880 ± 25	750	700,880	± 20

Table 2. Archaeomagnetic sample results based on early segments of DuBois southwest curve and Dolores refined curve, 1978-1980--Continued

Sample	Date (A.D.) based on archaeological evidence*	Date (A.D.) based on DuBois southwest curve†	Date (A.D.) based on Dolores refined curve§	Error estimation (yrs)**
5MT4479-2	880 ± 25	805	765,890	± 30
5MT4479-3	880 ± 25	750	700,880	± 45
5MT4512-2	870 ± 30	700		± 55
5MT4512-3	870 ± 30			
5MT4545-3	675 ± 30	800	750,870	± 50
5MT4545-4	675 ± 30	715	700	± 45
5MT4545-5	675 ± 30	660		± 50
5MT4644-6	825 ± 30	760	700,880	± 50
5MT4644-7	825 ± 30	660		± 50
5MT4644-9	825 ± 30	700	875	± 50
5MT4650-1	825 ± 30		765	± 35
5MT4671-1	850 ± 30	815	775,865,890	± 30
5MT4671-2	850 ± 30	820	775,860,900	± 35
5MT4671-3	850 ± 30	875	785,850	± 25
5MT4671-4	850 ± 30	845	785,860,900	± 30
5MT4671-5	850 ± 30	805	735,880	± 35
5MT4684-4	690 ± 20	795	735,880	± 40
5MT4725-3	860 ± 20	790	700,890	± 50
5MT4725-5	860 ± 20	820,900	785,855,900	± 35

* Dates based on one or more of the following pieces of archaeological evidence; architecture, ceramic seriation, and tree-ring and C-14 dating.
† DuBois southwest curve (early portion) based on Wolfman (1979).
§ Dolores refined curve based on Hathaway et al. 1979.
** Error estimate applies to both DuBois Southwest and Dolores refined curve estimates.

understood, but it is hoped that with continuing archaeomagnetic research these problems eventually will be resolved.

In addition to the changes in the archaeomagnetic program presented above, the Colorado State University research group is providing a complete compendium of all laboratory treatment to the 1978-1980 DAP collections. The treatment levels, associated alpha 95 values, and number of specimens used in the analysis (excluding outliers), are reported in table 3.

Second, laboratory demagnetization methods were changed substantially in an attempt to improve results and provide more accurate dates for DAP sites. It had become apparent during analysis of the 1978 archaeomagnetic samples that demagnetization at 150 Oe (oersteds) was often extreme treatment for archaeomagnetic samples carrying weak remanent magnetization because much of the primary remanence in such samples was removed at this level, leaving a sample intensity too weak to accurately display the prehistoric paleodirection acquired during firing. During analysis of the 1979 samples, a step demagnetization process was introduced which subjected two to three specimens from selected samples to graduated degrees of demagnetization. A demagnetization level of 25 Oe was determined to be the optimum level based on this analysis, and the entire 1979 collection was treated and measured at this level. Although alpha 95 values remained small, this low level of demagnetization was often insufficient for removing the effects of unwanted secondary magnetizations such as VRM (viscous remanent magnetization) and IRM (isothermal remanent magnetization). Each sample apparently requires different treatment. Some samples require lower levels of demagnetization and others require higher levels depending upon their individual histories; for example, the kinds of external forces that were exerted after the acquisition of primary remanence, and the strength and duration of those forces.

Table 3. Treatment record for DAP archaeomagnetic samples. 1978-1980

Sample number	NRM (zero Oe)	Demagnetization level (Oe) 25	50	75	100	125	150	150 Cr	180	180 Cr	200	Additional sample treatment
5MT0023-1	20.42(12)	10.30(8)										
5MT0023-2	4.73(12)				2.85(10)*							SD 1,9
5MT0023-3	1.03(12)				1.56(11)	1.48(12)*						SD 1,3 ES 125.150
5MT0023-4	5.18(12)	2.23(11)*										SD 2,7
5MT0023-5	8.39(12)	3.35(11)*										
5MT0023-6	5.17(12)				2.98(6)*							SD 4,8
5MT0023-7	1.66(12)	2.34(12)*										
5MT0023-8	5.12(12)	1.48(12)*										SD 6.11
5MT0023-9	6.86(12)	2.54(10)*		3.41(12)								ES 50,75.100
5MT0023-10	9.02(12)	2.81(11)		3.34(12)*								ES 75.100
5MT0023-11	12.45(12)	3.06(8)		3.13(11)*								ES 50.75
5MT0023-12	7.89(12)		1.73(10)*									
5MT0023-13	6.61(12)		2.21(11)*									
5MT0023-14	4.85(12)		1.82(10)*									
5MT0023-15	1.02(12)		1.00(12)*									
5MT0023-16	15.00(12)		3.18(12)*		3.15(9)							
5MT0023-17	5.18(12)		3.85(12)	3.83(12)	4.08(12)							
5MT0023-18	8.71(12)		3.37(11)	2.78(11)	3.53(11)*							
5MT0023-19	2.05(12)		2.18(12)		2.34(12)*							
5MT0023-20	3.29(12)		2.99(12)*									
5MT0023-21	1.54(12)		1.39(12)*									
5MT2151-1	24.95(12)						41.03(12)					
5MT2151-2	17.97(12)						19.23(12)					
5MT2151-3	9.15(12)						14.91(8)		20.34(12)			300-18.46(12) 300Cr-15.60(12)
5MT2151-4	14.46(12)						21.95(12)					
5MT2151-5	34.87(12)						34.03(12)					
5MT2151-6	43.60(9)						45.55(9)	55.16(9)				
5MT2151-7	34.70(9)						50.96(9)					

Table 3. Treatment record for DAP archaeomagnetic samples, 1978-1980--Continued

Sample number	NRM (zero Oe)	Demagnetization level (Oe) 25	50	75	100	125	150	150 Cr	180	180 Cr	200	Additional sample treatment
5MT2151-8	19.04(9)						25.88(9)	50.37(9)				
5MT2151-9	6.43(9)						3.89(8)*	30.09(9)	3.58(7)			
5MT2151-10	6.06(12)	6.69(9)										
5MT2151-11	48.95(12)	5.65(7)										
5MT2151-12	4.41(12)	3.45(9)*										
5MT2151-13	2.15(12)	2.03(12)*										
5MT2161-1	11.12(12)		4.10(11)									
5MT2161-2	11.43(12)		5.11(8)									
5MT2161-3	5.85(12)		3.71(8)									
5MT2161-4	11.94(12)		7.23(8)									
5MT2181-1	2.97(12)		1.88(12)*									
5MT2182-1	6.74(12)		3.57(10)*									
5MT2182-2	2.74(12)		2.64(12)	3.03(12)*	3.25(12)							
5MT2182-3	2.20(12)		2.02(12)*		2.04(12)		2.08(12)				2.23(12)	
5MT2182-4	7.61(12)		2.73(10)*	4.03(11)								
5MT2182-20	3.21(12)		2.47(12)*	2.62(12)								
5MT2003												
5MT2191-1	16.17						3.91(8)*		5.23(12)			
5MT2191-2	13.88						6.13(7)		5.76			
5MT2192-1	19.10(12)	4.05(6)										
5MT2192-2	18.52(12)	17.58(12)										
5MT2192-3	24.62(12)	25.18(12)										
5MT2192-4	5.43(12)	2.69(9)			3.13(12)							ES 75,100,125, 150
5MT2192-5	3.93(16)	2.68(11)*										SD 8,9
5MT2192-5a		2.21(7)*										
5MT2192-5b		5.73(6)										
5MT2192-6	9.91(12)	2.72(9)*										
5MT2192-7	8.33(12)	1.75(11)*										
5MT2193-1	33.79(12)						4.93(8)	13.63(12)		9.81(12)		

Table 3. Treatment record for DAP archaeomagnetic samples. 1978-1980--Continued

Sample number	NRM (zero Oe)	Demagnetization level (Oe) 25	50	75	100	125	150	150 Cr	180	180 Cr	200	Additional sample treatment
5MT2193-2	8.49(12)						2.00(11)*	32.21(11)	5.49(10)	21.63(10)		
5MT2193-3	18.39(12)						7.23(8)					
5MT2193-4	27.58(12)						9.26(8)					
5MT2193-5	19.53(12)						6.51(9)		7.60(8)			
5MT2193-6	29.40(9)						8.52(7)		12.00(12)			
5MT2193-15	21.31(12)	24.76(12)										
5MT2193-16	12.66(12)	11.54(8)										
5MT2193-17	22.29(12)	25.54(11)										
5MT2193-18	5.40(17)	3.46(12)*										ES 50,75
5MT2193-19	10.97(12)	9.69(9)										
5MT2193-20	11.20(12)	5.42(9)										
5MT2193-21	7.19(13)	5.02(9)										
5MT2193-22	6.09(12)	4.21(7)										
5MT2194-1	5.76(12)				5.01(7)							SE 3,9
5MT2198-1	8.15(12)						4.61(9)	2.86(7)	7.32(7)	2.85(7)*		
5MT2198-2	9.65(12)						4.37(9)	7.13(12)	6.55(9)	8.63(12)		
5MT2199-1	7.29(12)	3.53(7)										
5MT2203-1	23.87(12)	9.67(7)										
5MT2215-1	8.22(12)	5.57(11)										
5MT2235-1	8.80(12)						3.55(9)*		4.54(8)			
5MT2235-2	31.84(12)						5.92(10)		7.21(9)			
5MT2235-3	6.56(12)						4.18(8)		4.21(8)			
5MT2235-4	3.63(12)						2.67(10)*		3.23(12)			
5MT2236-1	15.01(12)	2.73(7)*	3.94(10)									
5MT2236-2	2.10(12)	2.25(12)*		2.85(11)								ES 75,100.125
5MT2320-1	5.81(12)	1.44(9)*										SD 3,5
5MT2848-1	7.52(12)	2.70(10)			3.51(11)*							ES 75,100.125
5MT2848-2	12.95(12)	1.35(11)		1.28(12)*								ES 75,100,125, 150.200
5MT2848-3	5.65(12)	2.98(7)*										

Table 3. Treatment record for DAP archaeomagnetic samples, 1978-1980--Continued

Sample number	NRM (zero Oe)	Demagnetization level (Oe) 25	50	75	100	125	150	150 Cr	180	180 Cr	200	Additional sample treatment
5MT2853-1	15.77(12)	1.52(10)*										
5MT2854-1	3.57(12)	3.58(12)*										
5MT2854-2	9.02(12)	2.68(7)*										
5MT2854-3	8.79(12)		6.72(12)	7.49(12)								
5MT2854-4	20.08(12)		13.77(12)									
5MT2858-1	5.24(12)	2.95(11)		3.10(11)*								ES 75.100
5MT2858-2	4.87(12)	1.46(11)		1.79(11)*								ES 75.100
5MT2858-3	10.99(12)	11.39(12)										
5MT2858-4	11.39(12)	2.14(6)										SD 5,7
5MT4475-1	5.22						3.61(6)*					
5MT4475-2	31.97(12)						42.86(10)					
5MT4475-3	18.25(12)						3.01(8)*					
5MT4475-4	10.24(12)						3.57(6)*					
5MT4475-5	3.93(12)						3.42(8)*		5.17(7)			
5MT4475-6	11.07(12)						15.06(10)					
5MT4475-7	12.99(9)						5.73(7)					
5MT4475-8	13.79(9)						4.05(10)		3.32(12)*			
5MT4475-9	6.97(9)						2.70(8)*		4.87(10)			
5MT4475-10	21.87(9)						3.70(9)*		5.09(9)			
5MT4475-11	7.14(9)						3.79(9)*	31.60(9)	4.99(6)			
5MT4475-12	9.39(9)						6.49(7)		13.11(8)			
5MT4475-13	7.96(9)						4.22(7)		5.08(8)			
5MT4475-14	5.45(12)		2.33(9)*									
5MT4475-15	2.66(12)		2.24(12)		1.12(10)*							
5MT4475-16	1.75(12)		1.69(12)		1.59(12)	1.77(12)	1.73(12)*				1.84(12)	
5MT4475-17	18.23(12)		4.04(8)	8.19(10)								
5MT4475-18	6.93(12)		1.43(11)*									
5MT4475-19	4.30(12)		3.42(12)*									
5MT4475-20	11.59(12)		1.72(11)*									
5MT4477-1	5.55(12)		3.59(11)*									

Table 3. Treatment record for DAP archaeomagnetic samples, 1978-1980--Continued

Sample number	NRM (zero Oe)	Demagnetization level (Oe) 25	50	75	100	125	150	150 Cr	180	180 Cr	200	Additional sample treatment
5MT4477-2	2.23(12)		1.63(12)	1.72(12)	1.76(12)							
5MT4479-1	7.37(12)		1.49(12)*									
5MT4479-2	1.74(12)		1.96(12)		2.00(12)		2.30(12)*					
5MT4479-3	8.90(11)		3.14(12)*									
5MT4480-1	12.13(12)		2.54(11)*									
5MT4480-2	5.77(12)		4.11(12)									
5MT4512-1	30.35(12)	24.06(12)										
5MT4512-2	5.67(12)	3.61(8)*										
5MT4512-3	2.94(12)	2.33(12)		3.20(12)*								ES 75,100
5MT4545-1	7.92(12)	4.23(9)										
5MT4545-2	12.83(12)	2.21(9)*	3.80(11)									ES 50,75,100
5MT4545-3	6.79(12)	3.69(6)*										SD 5,7
5MT4545-4	3.91(12)				2.97(11)	3.14(10)*						SD 2,9 ES 125,150
5MT4545-5	3.53(12)	2.98(12)*		3.82(12)								SD 1,6 ES 75,100
5MT4545-6	2.20(12)	1.64(10)			1.92(12)*							ES 75,100,125
5MT4545-7	4.95(12)	4.27(9)										
5MT4614-1	2.16(12)	1.72(12)*										SD 7,12
5MT4614-2	3.75(12)	2.38(9)*										
5MT4614-3	11.08(12)	4.93(12)										
5MT4644-1	1.73(12)	1.80(12)		1.40(12)*								ES 75,100,125, 150,200
5MT4644-2	2.03(12)	1.45(12)			1.32(11)*							ES 75,100,125
5MT4644-3	2.39(12)	2.70(11)			2.55(12)*							ES 75,100,125
5MT4644-4	11.67(12)	7.71(8)										
5MT4644-5	14.46(12)	1.25(11)		1.65(12)*		1.84(12)					1.76(12)	ES 75,100,125, 150
5MT4644-6	3.01(12)	3.35(10)			3.46(12)*							ES 75,100
5MT4644-7	6.07(12)		3.24(12)*									

Table 3. Treatment record for DAP archaeomagnetic samples. 1978-1980--Continued

Sample number	NRM (zero Oe)	Demagnetization level (Oe) 25	50	75	100	125	150	150 Cr	180	180 Cr	200	Additional sample treatment
5MT4644-8	7.53(12)		2.20(10*									
5MT4644-9	8.60(12)		3.79(10)	3.37(11)*								
5MT4659-1	4.26(12)		2.59(11)*									
5MT4671-1	11.43(12)		2.07(10)*									
5MT4671-2	3.86(12)		2.49(11)*									
5MT4671-3	9.60(12)		2.04(11)*									
5MT4671-4	5.61(12)		2.12(11)*									
5MT4671-5	4.30(12)		2.53(10)*									
5MT4684-1	3.90(12)		1.68(12)		2.04(12)	1.96(12)*						
5MT4684-2	4.52(12)		4.95(12)	5.33(12)								
5MT4684-3	4.07(12)		4.21(12)	4.35(12)								
5MT4684-4	12.22(12)		2.78(12)*									
5MT4684-5	5.19(12)		1.93(11)*									
5MT4725-1	7.60(12)		4.85(12)	6.21(12)								
5MT4725-2	3.76(12)		2.19(12)*									
5MT4725-3	4.10(12)		3.48(12)*									
5MT4725-4	5.42(12)		4.10(12)									
5MT4725-5	14.12(12)		2.77(12)*									
5MT4725-6	11.26(12)		2.28(11)*									

* Indicates the demagnetization level, alpha 95 value, and number of specimens used in the present report.

† Indicates that a cryogenic rather than a spinner magnetometer was used in analysis.

NOTES: The first number in each of the demagnetization columns is the alpha 95 value obtained at the respective demagnetization level; the number in parentheses refers to the number of specimens used.

The abbreviations used in the "Additional sample treatment" column may be explained as follows:

SE - Indicates the specimens used in a step-demagnetized treatment at 25 Oe levels up to 200 Oe.

ES - Indicates the demagnetization level (in Oe) at which all even-numbered specimens of a sample were treated.

Therefore, during 1980, analysis involved the individualized treatment of depending on the sample intensity levels, degree of specimen clustering (alpha 95), remanent direction changes between levels and stability during step demagnetization treatment. All specimens from each sample were demagnetized at levels from 50 Oe up to 200 Oe in 25 or 50 Oe steps. This individualized sample treatment resulted in an increased success rate of datable samples over previous years. The 1979 samples were then re-treated using this technique. Due to these additional treatments, many of the results reported from the 1979 collections have changed; these changes are reflected in the results reported in this document.

Third, methods of storing the archaeomagnetic samples were altered to reduce the effects of secondary magnetizations aquired subsequent to sample collection. The orientation of the 12 specimens comprising each sample were placed in opposing directions (x, y, and z axes) so that any secondary components would be acquired in a random fashion. This would aid the detection of strong secondary components acquired during storage and facilitate effective treatment measures to eliminate these unwanted components.

The Declination of the Dolores Area

During the first three years of the DAP archaeomagnetic program, a total of 158 samples were collected on 33 archaeological sites. Laboratory analyses have provided 65 percent of these samples with temporal estimates based on paleopole positions relative to a master VGP curve originally developed for the Southwest by Dr. R.L. DuBois.

During 1980, problems were encountered in the determination of the present magnetic field direction for the Dolores area. Some variation was noted between values of magnetic declination reported by various documents (table 4). In addition, results of the 1979 and 1980 sun and Brunton compass analyses strongly indicated that the reported values were incorrect. In order to check the values obtained by these analyses, North Star was sighted on 17 July 1981, and the declination of the Dolores area was determined to be 12.3° E. Based on this sighting it was determined that the 14.0° E value for magnetic declination taken from the USGS (U.S. Geological Survey) Trimble Point Quadrangle (1965) and the 13.5° E value taken from the National Oceanic and Atmospheric Administration Map, "Magnetic Declination in the United States - Epoch 1975.0," were inaccurate. The magnetic declination for the Dolores area as determined by differences in sun and Brunton compass measurements and values obtained by sighting North Star is 11.55° East. Because the present magnetic declination value is an integral part of the archaeomagnetic calculations of a samples paleopole position when specimen orientations are determined by magnetic compass methods, the paleopole positions of all dated samples from the 1978-1980 collections were recalculated based on the 11.55° East magnetic declination. The recalculated paleopole positions (i.e., paleolatitude and paleolongitude) are reported in table 5. The precision parameter, alpha 95, mean sample vector, mean sample intensity, EM, and EP were unchanged by this alteration and values reported in the individual site appendixes are applicable to the paleopole positions reported here. an exceptions to the use of 11.55° E declination is the 13.5° E declination used in the experimental hearth analyses. However, since the conclusions drawn from the results of these analyses are based on relative differences rather than absolute figures, the use of a different declination for analysis of the experimental sample set is not regarded as a serious drawback.

Table 4. Magnetic declination of the Dolores Project area as reported by several sources

Source	Year	Declination
USGS 7.5' Trimble Point Quadrangle map (1965)	1965	14.0° E*
National Oceanic and Atmospheric Administration Map "Magnetic Declination in the United States - Epoch Epoch 1975.0"	1975	13.1° E†
Declination of North Star sighted by transit at 37.52° N latitude, 251.45° E longitude on 2 September	1978	13.5° E§
Declination of North Star sighted by transit at 37.52° E latitude, 251.45° E longitude on 17 July	1980	12.3° E
Declination of North Star sighted by transit and brunton at 37.52° N latitude, 251.45° E longitude on 17 August	1981	11.1° E
Averaged sun compass-Brunton compass differences for 1979 collection set	1979	10.4° E
Averaged sun compass-Brunton compass differences for 1980 collection set	1980	11.2° E
Averaged sun compass-Brunton compass differences for 1980 experimental hearth collection	1980	11.4° E

* Since 1965 the magnetic declination has changed; if estimates of rate change at 0.2° longitude per year (E, B) are applied to this value and updated for 1980, the magnetic declination is estimated to be 11.0° E.
† 1980 declination is estimated from rate change stated on map and map value for Dolores area for 1975.
§ Unless North Star is sighted at elongation, the sighted declination value needs to be corrected for time and date of sighting. The sighted declination may change as much as 1°. Sightings after 1978 were corrected and the values provided are corrected declinations.

Table 5. Results 1978-1980 archaeomagnetic samples based on additional demagnetization treatment and 11.55° E declination for Dolores, Colorado

Sample number	Demagnetization level (Oe)	Numbers of specimens	Inclination (dip)	Declination (° E)	Paleolatitude (°)	Paleolongitude (°)
5MT0023-2	100	10	58.36	359.96	88.51	250.34
5MT0023-4	25	11	55.20	3.42	86.69	14.30
5MT0023-5	25	11	55.18	6.55	84.43	358.92
5MT0023-6	100	6	57.3	6.43	84.90	335.33
5MT0023-10	75	12	60.75	10.34	81.02	310.50
5MT0023-11	75	11	46.97	7.35	78.77	36.09
5MT0023-12	50	10	58.81	4.60	85.89	311.11
5MT0023-16	50	12	54.22	12.77	79.32	352.93
5MT0023-18	100	11	55.83	2.69	87.54	9.74
5MT0023-20	50	12	53.57	0.20	86.54	68.72
5MT2151-9	150	8	56.94	349.07	81.34	164.50
5MT2151-12	25	9	57.90	355.99	86.71	179.17
5MT2182-1	50	10	49.64	4.72	81.92	41.13
5MT2182-2	75	12	50.72	10.73	79.27	12.93
5MT2182-4	50	10	51.98	6.51	82.74	22.40
5MT2003	50	12	55.54	3.89	86.56	5.44
5MT2191-1	150	8	67.11	350.85	76.09	226.20
5MT2192-4	100	12	63.91	4.03	81.38	270.56
5MT2192-5	25	11	66.16	13.69	75.17	289.78
5MT2192-5a	25	7	64.59	14.18	76.22	296.51
5MT2192-6	25	9	66.88?	13.48	74.59	286.15
5MT2192-7	25	11	66.86	8.92	76.42	276.83
5MT2193-1	150	8	58.75	359.57	88.00	241.77
5MT2193-18	25	12	53.51	5.94	84.03	15.90
5MT2198-1	180	7	64.49	3.48	80.79	266.60
5MT2198-2	150	9	59.44	359.86	87.25	249.13
5MT2199-1	25	7	59.79	32.09	65.04	324.16
5MT2235-1	150	9	63.58	359.29	82.33	247.66
5MT2235-3	150	8	60.79	346.51	78.79	188.08
5MT2235-4	150	10	64.33	350.90	79.06	216.17
5MT2236-1	25	7	66.78	352.55	76.98	229.43
5MT2848-1	100	11	57.84	0.24	89.01	262.29
5MT2848-3	25	7	49.48	3.87	82.12	46.29
5MT2853-1	25	10	47.82	1.43	81.29	63.12
5MT2854-1	25	12	61.89	1.55	84.30	262.90
5MT2854-2	25	7	55.20	5.21	85.45	3.29
5MT2858-1	75	11	55.98	4.00	86.65	358.08
5MT2858-2	75	11	55.91	3.76	86.81	0.43
5MT2858-4*	25	6	80.06	355.66	56.78	248.85
5MT4475-1	150	6	63.07	356.09	82.37	229.98
5MT4475-3	150	8	53.73	3.82	85.52	26.59
5MT4475-4	150	6	62.38	351.21	80.91	207.08

Table 5. Results 1978-1980 archaeomagnetic samples based on additional demagnetization treatment and 11.55° E declination for Dolores, Colorado--Continued

Sample number	Demagnetization level (Oe)	Numbers of specimens	Inclination (dip)	Declination (° E)	Paleo-latitude (°)	Paleo-longitude (°)
5MT4475-11	150	9	61.81	354.41	82.88	216.38
5MT4475-19	50	12	60.32	354.89	84.56	206.54
5MT4477-1	50	11	53.73	359.08	86.67	84.66
5MT4479-1	50	12	56.14	4.87	86.03	352.07
5MT4479-2	150	12	52.47	3.45	84.73	38.14
5MT4479-3	50	12	55.88	6.56	84.65	351.32
5MT4512-2	25	8	60.18	2.09	86.08	275.10
5MT4512-3	75	12	64.20	4.71	80.86	272.46
5MT4545-3	25	6	54.15	359.81	87.17	74.65
5MT4545-4	125	10	57.99	6.24	84.96	326.39
5MT4545-5	25	12	63.68	1.90	82.07	261.28
5MT4644-6	100	12	55.75	3.39	87.02	5.06
5MT4644-7	50	12	64.35	4.26	80.81	270.24
5MT4644-9	75	11	59.42	1.62	87.02	275.92
5MT4650-1	50	11	52.55	356.50	84.72	105.18
5MT4671-1	50	10	51.41	2.83	84.05	47.78
5MT4671-2	50	11	50.34	3.64	82.88	45.55
5MT4671-3	50	11	46.73	2.11	80.26	60.39?
5MT4671-4	50	11	48.60	3.39	81.52	51.03
5MT4671-5	50	10	52.90	3.08	85.21	38.94
5MT4684-4	50	12	53.55	4.02	85.28	26.62
5MT4725-3	50	12	52.01	8.54	81.47	13.91
5MT4725-5	50	12	48.57	5.21	80.91	41.45

INTENSIVE ANLAYSES

Investigations conducted during 1980 included the continuation of several analyses initiated in 1979 as well as the implementation of studies designed during the 1980 season. Studies were conducted on two main sample groups: the 1980 prehistoric sample set and the experimental hearth sample set. A study of the sun and Brunton compass methods was performed on both the prehistoric and experimental samples and served as a basis for comparison between the two collection sets.

Two analyses were conducted on the prehistoric collection set. First, the priority system devised during the 1979 field season (Hathaway and Eighmy 1979) was evaluated. In this analysis the success rates of the various priority levels were examined. The results permitted evaluation of the visual attributes considered important in selecting superior archaeomagnetic samples in the field. Second, the sun compass and Brunton compass specimen orientation methods were evaluated. This study, which provided important information on the relative accuracies of the two methods, and was used to evaluate the declination for the present magnetic field in Dolores, Colorado.

The experimental hearths provided controlled data for three variables: soil texture, firing temperature, and duration and frequency of firing. Several intensive analyses, including studies of ferromagnetic content and hearth temperature gradients, were also conducted. The directions of samples collected from the experimental hearths were evaluated based on the 13.5° E declination reference location. Other parameters of sample results, such as alpha 95, mean sample intensity, and sample mean direction, could also be analyzed as they relate to various archaeomagnetic conditions such as soil texture, firing temperature, and repeated firings of a context. Better understanding in these areas will contribute valuable information for interpreting archaeomagnetic results from samples from prehistoric sites.

The Prehistoric Sample Set

Priority System Evaluation

The priority system initiated during the 1979 field season (Hathaway and Eighmy 1979:16-18) was continued during the 1980 field season and recommendations resulting from the 1979 analysis were incorporated into the 1980 priority system. The success rate, alpha 95 value, and mean sample intensity of the archaeomagnetic results were compared and correlated with the field assigned priority designation. The effectiveness of the priority system was thereby evaluated, and the priority criteria were examined.

During 1980, 59 archaeomagnetic samples were collected; 57 of these were analyzed.[1] Seventy-five percent of the analyzed samples yielded results which were adequate for dating the burned cultural media. The alpha 95 value is the single most important criterion for establishing whether or not a sample may be dated. This value becomes smaller as

[1]Two samples collected from Site 5MT2182, Area 3 (sample numbers 2001 and 2002) were never received at the Colorado State University Archaeomagnetic LAboratory and are believed to have been misplaced in storage.

sample direction clustering becomes tighter, and only values below 3.5° are considered to be adequate for dating purposes (values below 2.5° are considered superior).

In the field, priority numbers 1-5 were assigned to samples based on soil texture, oxidation, hardness and preparation, intrusive qualities (contamination), and collection quality of the samples (Hathaway and Eighmy 1979:16). Priority 1 designated high probability of archaeomagnetic sample success, and priority 5 designated poor success probability. Table 6 summarizes the productivity of samples assigned to the five priority levels. Sample productivity refers to the percentages of dated samples within each priority category. The priority 1 samples consitute 24.6 percent of the 1980 collection set, yet represent only 20.9 percent of the dated samples. The sample productivity of this category was only 64.3 percent. Priority 2 and 3 samples were both more productive than priority 1 samples, and priority 4 samples were only slightly less productive. This pattern is quite similar to that found in the 1979 priority system. The priority 1 samples, although predicted to be the most successful, were notably unsuccessful.

Table 6. Comparison of priority level and productivity of 1980 samples

Priority level	Dated samples N	Dated samples %	Undated samples N	Undated samples %	Total samples N	Total samples %	Category productivity* (%)
1	9	20.9	5	35.7	14	24.6	64.3
2	20	46.5	3	21.4	23	40.4	87.0
3	11	25.6	4	28.6	15	26.3	73.3
4	3	7.0	2	14.3	5	8.8	60.0
5	0	0	0	0	0	0	-
Total	43	100.0	14	100.0	57	100.0	

* "Category productivity" refers to the percentage of dated samples within each priority level category.

Two analyses were conducted in attempts to understand the factors involved in the unexpectedly low success rate of the priority 1 samples. First, the mean sample intensity and alpha 95 values were correlated among priority levels 1-4 (fig. 1). Although higher mean sample intensity values were expected for higher priority levels, there does not appear to be any correlation between the two. Similarly, very little correlation is noted between alpha 95 values and priority groups, although there does tend to be a greater clustering of priority 2 samples around 2.0° alpha 95 levels. It appears, however, that a slight negative correlation does exist between alpha 95 and intensity.

Second, the samples in the various priority categories were grouped according to the archaeological contexts from which they were collected (structure walls, structure floors, pitstructure hearths, "other hearths," etc.) in an effort to determine which contexts are most likely to yield superior samples at the different priority levels. Table 7 is a comparison of the contextual groups as a whole and the associated productivities. It is apparent from this analysis that samples from firehardened floors and hearths in pitstructure fill were the most successful in the lot; however, both of these categories are represented by only a single sample. Of the categories represented by more than one sample, central pitstructure hearths and "other hearths" were the most successful. Firehardened walls yielded samples which were much less successful than either central pitstructure hearths or "other hearths." This relationship is notably different from the 1979 results of a similar study. Central pitstructure and "other hearth" success has increased by as much as 25 percent, and firehardened wall success has decreased by over 40 percent. An evaluation of these contexts by priority level (tables 8-11) indicates fig. 1

priority 2 and 3 central pitstructure hearth contexts were more successful than the priority 1 central pitstructure hearth context. The firehardened wall contexts from priorities 1-3 had approximately equal success rates. Again, this indicates that the critical properties of superior archaeomagnetic contexts are not being selected in the field evaluations.

In summary, it is apparent from laboratory analyses that a correlation is noted between low alpha 95 values and high intensity values. However, the system devised to discriminate the more intense, highly-fired matrices in the field was ineffective at selectively determining productive samples. This ineffectiveness is noted particularly in the prority 1 category. Further research is needed to determine why sample contexts which are rated highly in the field do not meet expected productive standards.

Sun Compass and Brunton Compass Cube Orientation Methods

Sun compass orientation for archaeomagnetic samples was initiated during the 1979 field season and continued during the 1980 field season. Twenty-four samples collected from prehistoric contexts during the 1980 field season served as a study group for which both sun and Brunton compasses were used to determine specimen orientation. The remaining 33 samples in the 1980 archaeomagnetic collection were collected using only the Brunton compass orientation method.

The Brunton compass is a magnetically sensitive instrument which orients to the magnetic field lines within an area (i.e., magnetic declination). Conversely, the sun compass operates independently of magnetic influences. This instrument detects the angular relationship between a specimen and the sun's position in the sky. For a known location and time this relationship may be converted to the specimen's

Table 7. Comparison of sampled context and productivity of 1980 samples

Cultural context	Dated samples N	%	Undated samples N	%	Total samples N	%	Context productivity* (%)
Fire hardened wall	6	14.0	5	35.7	11	19.3	54.5
Central Pitstr hearth	27	62.8	5	35.7	32	56.1	84.4
Other hearth†	8	18.6	3	21.4	11	19.3	72.7
Fire hardened floor	1	2.3	0	0	1	1.8	100.0
Burned pit feature	0	0	1	7.1	1	1.8	0
Hearth in fill of pitstr	1	2.3	0	0	1	1.8	100.0
Total	42	100.0	14	100.0	57	100.0	

Table 8. Comparison of priority 1 contexts and productivity of 1980 samples

Cultural context	Dated samples N	%	Undated samples N	%	Total samples N	%	Context productivity* (%)
Fire hardened wall	2	22.2	2	40.0	4	28.6	50.0
Central Pitstr hearth	6	66.7	3	60.0	9	64.3	66.7
Surface hearths	1	11.1	0	0	1	7.1	100.0
Total	9	100.0	5	100.0	14	100.0	

* "Category productivity" refers to the percentage of dated samples within each cultural context category.
† "Other hearths" refers to hearths not located in pitstructures.

Table 9. Comparison of priority 2 contexts and productivity of 1980 samples

Cultural context	Dated samples N	%	Undated samples N	%	Total samples N	%	Context productivity* (%)
Fire hardened walls	3	15.0	2	66.7	5	21.7	60.0
Central Pitstr hearths	11	55.0	1	33.3	12	52.2	91.7
Surface hearths	5	25.0	0	0	5	21.7	100.0
Fire hardened floors	1	5.0	0	0	1	4.3	100.0
Total	20	100.0	3	100.0	23	100.0	

Table 10. Comparison of priority 3 contexts and productivity of 1980 samples

Cultural context	Dated samples N	%	Undated samples N	%	Total samples N	%	Context productivity* (%)
Fire hardened wall	1	9.1	1	25.0	2	13.3	50.0
Central pitstr hearth	8	72.7	1	25.0	9	60.0	88.9
Surface hearth	2	18.2	2	50.0	4	26.7	50.0
Total	11	100.0	4	100.0	15	100.0	

Table 11. Comparison of priority 4 contexts and productivity of 1980 samples

Cultural context	Dated samples N	%	Undated samples N	%	Total samples N	%	Context productivity* (%)
Central Pitstr hearth	2	66.7	0	0	2	40.0	100.0
Surface hearth	0	0	1	50.0	1	20.0	0
Burned pit feature	0	0	1	50.0	1	20.0	0
hearth in fill of pitstr	1	33.3	0	0	1	20.0	100.0
Total	13	100.0	2	100.0	5	100.0	

* "Category productivity" refers to the percentage of dated samples within each cultural context category.

orientation to true north. The formula used to convert sun compass measurements is presented in Tarling (1975:59). The difference between Brunton compass and sun compass orientations should correspond to the magnetic declination recorded for an area.

The 1979 evaulation of these two methods indicated a difference of 3.0° between the averaged sun and Brunton compass declination differences (10.4° E) and magnetic declination as reported by several independent sources (13.5° E) (table 4). No correlation was found between samples associated with intensely burned areas (areas of magnetic disturbance; e.g., burned pitstructures) and large deviations from the recorded magnetic declination based on Brunton and sun compass value differences. The discrepancy noted in the 1979 material and the recorded magnetic declination of the Dolores area was therefore unexplained. The 1980 archaeomagnetic program was directed towards resolving this discrepancy; however, results from twostudies designed to address the problem were inconclusive.

First, declination differences between the two methods were determined for the 1980 material. In order to determine this difference, sun compass values for sample specimens were converted to a declination representing their orientation to true north. The difference between this value and the Brunton compass declination was then calculated for each specimen. A sample mean difference and a standard deviation were calculated for each of the 24 samples. Specimens that were exceedingly divergent from the mean value, that is, if they fell beyond two standard deviations, were excluded; a new mean and standard deviation were then calculated. Table 12 summarizes the mean sample declination differences between sun and Brunton compass declinations of corresponding samples. Figure 2

figure 2

graphically illustrates the variation between the observed mean sample declination differences. The average declination difference for the 24 study samples is 11.2° E. This value is 0.8° E of the average difference calculated in 1979.

Table 12. Sun compass-Brunton compass mean sample declination differences, 1980

Sample numbers	Sun compass-Brunton compass declination mean sample difference	Standard deviation of mean sample differences	Comments
5MT0023 - 12	10.02	1.18	Based on eight specimens due to inability in field to collect full suite of sun compass azimuths and recognization of outlier*
5MT0023 - 13	11.00	1.23	One specimen defined as outlier
5MT0023 - 14	11.12	0.94	Based on 11 specimens due to inability in field to collect full suite of sun compass azimuths
5MT0023 - 17	13.18	1.93	No outliers identified
5MT2161 - 2	9.95	1.89	Based on six specimens due to inability in field in collect full suite of sun compass azimuths
5MT2182-5MT2003	11.76	1.66	No outliers identified
5MT2215 - 1	13.95	1.12	No outliers identified
5MT2854 - 3	11.22	0.44	One specimen defined as outlier
5MT2854 - 4	9.56	1.26	No outliers identified
5MT4475 - 15	13.13	1.80	No outliers identified
5MT4475 - 19	12.02	1.22	No outliers identified
5MT4475 - 20	11.74	2.40	Based on 11 specimens due to inability in field to collect full suite of sun compass azimuths
5MT4477 - 1	10.93	1.77	No outliers identified
5MT4479 - 1	11.04	1.96	No outliers identified
5MT4479 - 2	9.91	1.91	No outliers identified
5MT4479 - 3	9.75	2.02	No outliers identified
5MT4644 - 8	8.07	1.28	Two specimens defined as outliers
5MT4644 - 9	10.81	2.14	Two specimens defined as outliers
5MT4671 - 1	10.43	1.80	One specimen defined as outlier
5MT4671 - 2	10.59	2.23	No outliers identified
5MT4671 - 3	16.18	5.82	No outliers identified
5MT4671 - 4	11.72	2.69	No outliers identified
5MT4684 - 1	12.24	1.05	No outliers identified
5MT4684 - 4	10.07	1.72	Based on 10 specimens due to inability in field to collect full suite of sun compass azimuths and recognization of outlier

* Outliers were defined in the following manner: a sample mean (of sun compass-Brunton compass differences) was calculated from the full compliment of specimens. Specimens which fell two standard deviations from the mean were defined as outliers and excluded. A new mean and standard deviation was then calculated.

For comparison purposes, magnetic declination as determined by various agencies are represented in table 4. Although estimates given in this table indicate considerable variability, some consistency is apparent. The three estimates calculated from sun and Brunton compass differences over several years are fairly consistent, ranging from 10.4° to 11.4° E. Also, the estimate determined from the 17 August 1981 sighting of North Star indicates this more westerly location of the magnetic declination. The major discrepancy, then, occurs between these estimates and estimates calculated from the map values and the 1978 and 1980 sightings of North Star. The most deviant North Star sighting may be discarded as the observed declination was not corrected for seasonal rotation of North Star (this correction can be as large as 1°). The difference between the map values and the values established by DAP archaeomagnetic analyses might be explained by several factors: (1) a local anomalous deviation affecting the Dolores region which is not indicated on continental-size maps, (2) inaccuracies in the original magnetic surveys, or (3) a higher rate of change in westward drifting components than indicated by map values (National Oceanic and Atmospheric Administration maps). Yukatake (1967) has noted that the rate of westward drift may be subject to slight variations over time, and Tarling (1971:98) has indicated that the westerly drift components may move between 0.2° and 0.3° of longitude per year. If a 0.2° change of the present field is assumed, the declination of 14.0° given on the USGS Trimble Point Quadrangle map of 1965, by 1980 would have changed to 11.0° E, which is very similar to the values obtained by the archaeomagnetic analyses.

It was therefore presumed that the estimates for magnetic declination of the Dolores Project area needed to be reevaluated in light of current data. Based on the sun compass/Brunton compass value differences and the North Star sighting of 1981, magnetic declination is presumed to be 11.55° E of true north.

The second study of sun and Brunton compass orientation methods entailed comparison of the corresponding alpha 95 values for each method. Differences between alpha 95 values obtained using Brunton compass values and alpha 95 values obtained by sun compass values were then used as indicators of the inherent inaccuracies of the two methods. This was possible because the remanent direction measured for each specimen is constant, whereas the orientation values change depending on the compass method used. The sample results for each method were "cleaned" independently of outliers (see Hathaway and Eighmy 1979:12). The alpha 95 values determined for the two compass methods are presented in table 13; the values for each method were then averaged. Sample 5MT2161-2 was deleted from the averaging due to a significantly lower number of specimen declination values collected in the field using the sun compass method. The average alpha 95 value of sun compass declinations was 3.39° and of Brunton compass declinations, 3.25°. These values do not appear significant, and indeed, a paired-comparison test of the two corresponding values among the 23 samples indicated no significant difference between the alpha 95 values of the two groups.

The Experimental Hearth Sample Set

Twelve hearths designed to resemble prehistoric hearths and imitate different archaeomagnetic conditions of small archaeological features encountered in the field were constructed in the Dolores Project area. Three variables were considered in these studies: soil texture, firing temperature, and frequency and duration of firing. A gradient for each variable was devised while the other two variables remained unchanged. Subsequent to all firing experiments, the 12 hearths were archaeomagnetically sampled, thus allowing researchers to evaluate the effects of various known parameters on the sample quality. The variables examined for each hearth are presented in table 14.

Firing temperature and soil composition are thought to be the two most important factors in determining archaeomagnetic sample quality. A very high temperature is necessary to produce a total TRM (thermoremanent magnetization); this temperature may range from 580° to 675° C depending on the constituent magnetic materials of a matrix. Tarling (1975:186) and Eighmy (1980:20) have suggested that clay-based soils are crucial for good

Table 13. Alpha 95 values as determined by sun and Brunton compass methods (1980 samples)

Sample number	Alpha 95 as determined by sun compass	Alpha 95 as determined by Brunton compass
5MT0023 - 12	3.39	1.73
5MT0023 - 13	3.23	2.20
5MT0023 - 14	1.85	1.82
5MT0023 - 17	3.85	3.83
5MT2161 - 2*	15.95	7.57
5MT2182-5MT2003	2.68	2.47
5MT2215 - 1	5.48	5.57
5MT2854 - 3	5.20	6.72
5MT2854 - 4	13.79	13.80
5MT4475 - 15	1.86	2.42
5MT4475 - 19	3.32	3.42
5MT4475 - 20	2.00	1.72
5MT4477 - 1	3.64	3.59
5MT4479 - 1	1.58	1.49
5MT4479 - 2	1.95	1.96
5MT4479 - 3	3.79	3.14
5MT4644 - 8	1.94	2.20
5MT4644 - 9	3.50	3.36
5MT4671 - 1	2.99	2.10
5MT4671 - 2	2.33	2.49
5MT4671 - 3	2.63	2.04
5MT4671 - 4	2.05	2.12
5MT4684 - 1	1.88	1.96
5MT4684 - 4	2.97	2.78

* For this sample, 6 specimens were used for the sun compass analysis, and 12 specimens were used for the Brunton compass analysis.

Table 14. Experimental hearth variables

Experimental hearth No.	Location No.	Experimental Archaeomagnetic sample No.	Firing temperatures (° C)	Duration of firing (hrs)	Soil composition
1	1	1	600-700 (high)	3	Predominantly silt
2	1	2	300-400 (low)	15	Predominantly silt
3	1	3	300-400 (low)	3	Predominantly silt
4	2	4	600-700 (high)	3	Predominantly sand
5	2	5	300-400 (low)	15	Predominantly sand
6	2	6	300-400 (low)	3	Predominantly sand
7	3	7	600-700 (high)	3	Very sandy
8	3	8	300-400 (low)	15	Very sandy
9	3	9	300-400 (low)	3	Very sandy
10	4	10	600-700 (high)	3	Predominantly clay
11	4	11	300-400 (low)	15	Predominantly clay
12	4	12	300-400 (low)	3	Predominantly clay

archaeomagnetic sample results. This may be due to a tendency for ferromagnetic minerals to accumulate in these soils and retain a sturdy composition. In order to imitate the apparent use pattern of prehistoric central pitstructure hearths, several hearths were repeatedly fired at low temperatures. Archaeomagnetic samples were collected from these experimental hearths and the natural remanent magnetization of the samples was obtained. These results, correlated with the various controlled hearth parameters, led to important conclusions about the type of matrices required for good archaeomagnetic sample results.

One further study consisted of a magnetometer survey of six hearths in two localities to determine the degree of remanent intensity necessary for detection by magnetic reconnaissance.

Experimental Design

Twelve hearths were constructed in four preselected locations in the Dolores Project area (fig. 3). The locations, all of which fall within the USGS Trimble Point Quadrangle, were selected to represent a gradient of sediment matrices within the geographic range of the Dolores valley. The DAP soils map (Leonhardy and Clay 1979) and project geologists were consulted to ensure sediment variability among the four locations. Soil samples were collected from each of the hearths in the four localities to provide laboratory verification of the sediment variability among the locations, and to provide a basis for testing the amount of variation in archaeomagnetic results as caused by variation in clay textures. These samples would also permit a ferric content count and an examination of the ferromagnetic minerals in the various soils.

Location 1 (hearths 1-3) was established east of Site 5MT4644 in the SE 1/4 of the SW 1/4 of sec. 19, T38N, R15W. The hearth in this location fig. 3

were constructed at an approximate depth of 0.25 m below present ground surface in an area which had been bladed to remove the plow zone. The soil in this area is classified as a Witt loam, a fine silty soil. Location 2 (hearths 4-6) is in the NW 1/4 of the NW 1/4 of sec. 36, T38N, R16W, just south of Site 5MT2192. The soil in this area is classified as a Sagehen Paleosol and is characterized by fine sandy soils at the surface. Location 3 (hearths 7-9) is in the SE 1/4 of the SE 1/4 of sec. 18, T38N, R15W, 50 m north of Site 5MT4671. The soil in this area is classified as a Cheyenne sandy loam which has very sandy, mixed textural characteristics. The hearths in this location were constructed in the topsoil. Location 4 (hearths 10-12) is in the NE 1/4 of the NW 1/4 of sec. 31, T38N, R15W, southwest of Site 5MT4684. The soil in this area is classified as a Hesperus loam which is deep and well drained. Hearths manufactured in this area were constructed at the bottom of a 10-by 4-by 2-m trench, where there was a high proportion of clay in the matrix.

Each of the 12 hearths was constructed 50 cm in diameter and 20 cm in depth. The three hearths within each area were placed approximately 2-4 m apart. One hearth from each location was fired for three hours at or above the Curie temperature of magnetite (580°). During temperatures of this magnitude were probably reached only in prehistoric time kilns or possibly during conflagration of pitstructures. A second hearth in each locality was fired for three hours at approximately 400° C. Comparison of laboratory results from these eight hearths (four high temperature, four low temperature) provided considerable information regarding temperature constraints on archaeomagnetic samples. The temperatures attained during the firings were expected to be directly related to the quality of the archaeomagnetic samples recovered from the hearths--as the temperature increases, archaeomagnetic success increases (alpha 95 values decrease). Also, the visual qualities of hearths heated to differing temperature gradients and under a variety of soil conditions were examined; this evaluation combined with the final archaeomagnetic results, has provided better guidelines for field evaluation of archaeomagnetic samples from prehistoric sites.

The third hearth from each location was heated to temperatures below the Curie temperature of magnetite for a total of 15 hours. These hearths were fired for three hours at a time, allowed to cool, and reheated on five separate occasions. These hearths probably best simulate the prehistoric use of domestic fires, i.e., frequently used hearths heated to low temperatures. Archaeomagnetic results from these three hearths provided an experimental basis for comparing refired, low-temperature hearths and once-fired low- and high-temperature hearths. It was hypothesized that the samples from the refired hearths would be of higher quality (as measured by intensity and alpha 95 values) than the samples from once-fired, low-temperature hearths, but would not be superior to samples from once-fired, high-temperature hearths.

In order to ensure that temperatures were maintained at the desired levels, the hearths were prepared with thermocouple wires (Type K Chromel-Alumel AGH #24) and temperatures were monitored by a WAHL Heat Prober Thermometer (Model 1370 CP) which has a liquid crystal digital readout and a range of 0-1370° C with a 1° C resolution. Once-fired hearths were wired similarly to record heat absorption in various soils at different temperatures and to record temperature variation around the hearth rim and base. Eight thermocouple wires were positioned around the hearth in various locations (fig. 4) allowing measurement of temperature gradients

figure 4

from the exposed rim surface to 2-4 cm in from the rim surface, and from the top of the hearth to the bottom of the hearth. The refired hearths in each location were monitored by thermocouples placed in two positions near the top of the hearth (fig. 5). This allowed for temperature comparison between hearths but did not permit recording of temperature gradients within the refired hearths. Because measurements of temperature gradients were recorded within the low- and high-temperature hearths, and because the former were fired at similar temperatures to the refired hearths, it was not thought necessary to reproduce this information for low fired hearths.

After the hearths were fired, and the matrices had cooled sufficiently, archaeomagnetic samples were collected from each hearth. Archaeomagnetic sampling procedures followed standard practices described by Hathaway (1978). In addition to the Brunton compass orientation method, a sun compass was used to obtain each specimen's orientation. As previously stated, sun compass measurements provide a specimen orientation relative to true north, whereas the Brunton compass measures declination relative to magnetic north. The difference between the two measurements should equal the magnetic declination determined for the Dolores area. Individual specimen's declinations, as determined by the two different methods, were then used with laboratory results to obtain the remanent magnetic direction for each specimen. Two remanent directions, one based on sun compass measurements and the other on Brunton compass measurements, were obtained for each specimen. Due to a fired hearth's own magnetic orientation and the sensitivity of the Brunton compass to such magnetic influences, it was hypothesized that the sun compass would produce more accurate results, as measured by the location of mean sample direction

figure 5

declination to a reference location and by sample alpha 95 values, than the Brunton compass.

After construction and firing of the experimental hearths, and collection of the samples, the latter were analyzed in the laboratory to determine the direction of magnetism acquired, the degree of sample clustering about the mean direction, and the intensity of acquired magnetization.

The laboratory procedure consists of two processes: demagnetization of the sample and measurement of archaeomagnetic samples on a Schonstedt Spinner Magnetometer. Demagnetization, which is commonly conducted by thermal or AC (alternating current) demagnetization, is necessary due to the apparent acquisition of secondary components of magnetism, such as VRM, subsequent to the acquisition of TRM. Large-grained particles with low coercivities are affected by low-magnitude magnetic fields (such as the Earth's ambient field) and, over time, tend to parallel the direction of that field. The affects of VRM, however, may be randomized by AC demagnetization which imposes an alternating magnetic field on the sample at increasing magnitudes. By allowing the field to degrade slowly, the "soft" magnetic particles of a sample spinning on three axes in that field will then pick up a random magnetic direction, permitting the isolation of the magnetization acquired at the time of firing. This process may be accomplished in "steps" or "levels" of demagnetization whereby higher and higher magnitudes of magnetic fields are reached. The higher the field, the more grains of higher coercivity are affected; thus, the greater the effect on primary remanence acquired during firing. Therefore, with AC demagnetization, the appropriate level of a sample's demagnetization is defined by the level at which the least effect on primary remanence is noticed, but a maximum randomization of secondary (VRM) components is noticed.

With these principles in mind, the experimental hearth samples were AC demagnetized to 200 Oe at 25 Oe levels. At each level the sample was measured on the spinner magnetometer and archaeomagnetic sample parameters (alpha 95, mean sample intensity, and mean sample direction) were determined. Then the appropriate level of demagnetization was determined based on these parameters. It was hypothesized that samples with similar textures (grain size) would require similar demagnetization treatment.

<u>*Soil Texture Analyses*</u>

Tests conducted on soil samples recovered from the post firing matrices of the 12 hearths permitted laboratory verification of the soil textures noted in the field. The laboratory analysis would provided quantification of soil texture which allowed comparison of the textures of hearths within the same locality and comparison of the textural variation among hearths in the four different localities. The laboratory analysis was conducted at the Colorado State University Soil Testing Laboratory in Fort Collins, Colorado, and consisted of hydrometer testing of soil percentages as determined from less than 2 mm fractions. These results were then compared to archaeomagnetic sample results (alpha 95 and intensity) from untreated samples (table 15) to examine the correlation between soil texture and archaeomagnetic sample quality. Sand, silt, and clay percentages are plotted against NRM values of alpha 95 and intensity for the 12 samples in figures 6-11.

An analysis of variance was conducted for the clay, silt, and sand percentages of the 12 hearths to determine if a significant variability exists among location groups. Only the silt percentages of locations 2

Table 15. Texture percentages and archaeomagnetic results of 1980 experimental hearth samples

Experimental sample No.	Percent Sand	Percent silt	Percent Clay	Texture	NRM* alpha 95	NRM* mean sample intensity
1	38	44	18	loam	1.57	$.13 \times 10^{-2}$
2	35	44	21	loam	1.38	$.65 \times 10^{-3}$
3	31	45	24	loam	2.16	$.29 \times 10^{-3}$
4	59	31	10	sandy-loam	1.32	$.13 \times 10^{-2}$
5	61	27	12	sandy-loam	1.95	$.26 \times 10^{-3}$
6	55	21	24	sandy-clay-loam	2.16	$.17 \times 10^{-3}$
7	43	35	22	loam	2.05	$.48 \times 10^{-3}$
8	45	32	23	loam	2.88	$.25 \times 10^{-3}$
9	41	33	26	loam	2.70	$.14 \times 10^{-3}$
10	28	28	44	clay	3.08	$.16 \times 10^{-3}$
11	17	30	53	clay	3.09	$.84 \times 10^{-4}$
12	17	29	54	clay	4.09	$.39 \times 10^{-4}$

* NRM (natural remanent magnetism) refers to untreated samples.

figure 6

figure 7

figure 8

figure 9

figure 10

figure 11

and 4 and 3 and 4 and the clay percentages of localities 1 and 2 and 1 and 3 indicated insignificant variability at the 95 percent confidence level.

The correlation coefficient (r) between texture and archaeomagnetic sample qualities (alpha 95 and mean sample intensity) were determined for each set of variables. This statistic measures the linear covariation between two variables. A positive value indicates an increase in both values, while negative values indicate an increase in one variable when the other variable is decreasing. A value of plus or minus 1.0 denotes perfect correlation (either positive of negative). The r^2 value indicates the amount of total variation in the dependent variable (y) which can be explained by variation in the independent variable (x).

The correlations between sand, silt, and clay percentages and alpha 95 values for untreated samples (NRM) are displayed below:

x y	r	r^2
sand/alpha 95	-.650	.422
silt/alpha 95	-.423	.179
clay/alpha 95	+.864	.747

These values indicate an opposite relationship than expected. Sand and silt percentages display a negative correlation; as sand and silt percentages increase, alpha 95 values decrease, indicating better archaeomagnetic sample quality. Clay percentages exhibit a positive relationship; as clay percentages increase, so do alpha 95 values, indicating poorer archaeomagnetic sample quality. The r^2 value indicates that 74.7 percent of the variation in alpha 95 values may be explained by variation in clay percentages. These values indicate a very predictive relationship between soil texture and archaeomagnetic sample quality; however, the relationship is opposite to that expected.

If these correlations are compared to a similar study conducted on 22 archaeomagnetic samples collected during the 1979 field season from prehistoric contexts (table 16), very few similarities are noted. In the 1979 study clay percentages and alpha 95 values had a slightly negative correlation; however, very little of the variation in alpha 95 could be explained by variation in clay percentages. Sand percentages and alpha 95 values had a slightly positive correlation with very little (1.7 percent) of the variation in alpha 95 explained by variation in sand. This relationship changed, however, when the different priority levels were examined individually: priorities 1-3 were positively correlated and priority 4 was negatively correlated; priority 2 had the highest percentage of alpha 95 variation explained by sand percent variation. Silt percentages appeared to be the strongest determinant of alpha 95 values when observing the various priority categories; priority 1 and 2 categories correlated negatively and priority 3 and 4 categories correlating positively. The discrepancy in correlation among priority levels is most likely explained by the assessment criteria of the priority levels corresponding to lower confidence levels of archaeomagnetic sample success based on evaluations of soil, oxidation, erosion, and intrusive elements.

The results from the 1980 experimental hearth and 1979 prehistoric sample studies are at first confusing. It appears from initial evaluation that the data is inconsistent and contradictory. First, as is apparent from the 1980 experimental group, soils containing coarse-grained material (i.e., sand) acquire a more intense and more homogeneous magnetic remanence (as indicated by lower alpha 95 values) than finer grained materials with a high degree of correlation noted for both (sand and clay percentages to alpha 95 values). This indicates a high degree of predictability

Table 16. Correlation coefficients (r) and r^2 values of soil texture percentages of 22 prehistoric archaeomagnetic samples as compared against the sample alpha 95 values (1979 sample data)

Variables	All priority categories r	All priority categories r^2	Priority 1 category r	Priority 1 category r^2	Priority 2 category r	Priority 2 category r^2	Priority 3 category r	Priority 3 category r^2	Priority 4 category r	Priority 4 category r^2
sand%/alpha 95	+.132	.017	+.112	.013	+.533	.284	+.270	.073	-.387?	.150
silt%/alpha 95	-.100	.010	-.330	.109	-.542	.294	+.401	.161	+.555	.308
clay%/alpha 95	-.089	.008	+.129	.017	-.169	.026	+.015	.002	-.158	.025

* NRM (natural remanent magnetism) refers to untreated samples.

for archaeomagnetic sample success based on soil texture however, as already noted, this correlation is opposite to the previously assumed correlation between high clay content and archaeomagnetic sample success). Second, as is apparent from the 1979 prehistoric sample group, very little of the variation in alpha 95 may be explained by variation in either clay or sand, but a slight positive correlation between sand percentages and alpha 95 values indicates an opposite relationship from that noted in the 1980 experimental group. This discrepancy between the prehistoric and experimental groups may be explained by differences in initial acquisition and maintenance of remanent magnetization. Although sandier soils initially acquire "better" remanence (i.e., they yield samples with lower alpha 95 values and higher intensity values) than clayey soils, the clay- and silt-dominated soils are more likely to maintain the magnetic moment acquired during the firing event. While this may be due to several factors, the two considered to be the most likely are mechanical disruption of magnetic grains in coarse-grained material, or the association between coarse-grained material and lower coercivity magnetic grains, which increases susceptibility to VRM. Whatever the explanation, it is apparent that the maintenance of acquired magnetic remanence by coarse-grained soils is dependent on time.

The correlation coefficient (r) and r^2 values between sand, silt, and clay percentages and the material remanent magnetization mean sample intensity are listed below (x = independent variable; y = dependent variable):

x y	r	r^2
sand/intensity	+.374	.140
silt/intensity	+.464	.215
clay/intensity	-.610	.372

Again, the expected results are not noted in these relationships. As sand and silt percentages increase, intensity values increase, and as clay percentages increase, mean sample intensity values decrease. This indicates that for similarly heated contexts, those with sandy texture will attain a more intense magnetization resulting in greater archaeomagnetic success. This correlation may be caused by an accumulation of magnetite grains, which acquire a magnetism 200 times stronger than acquired by hematite grains in sandy soils, or possibly by greater heat absorption in sandy soils than in clay-based soils.

Ferromagnetic Content Analyses

Two analyses were conducted on soil samples recovered from the 12 experimental hearths in an attempt to identify and quantify the ferric material present in the matrices. The first analysis was performed at the Colorado State University Soil Testing Laboratory and consisted of a count of the total ferric content present in the postfiring soil samples. This measurement indicates the percentage of Fe^{3+}, including magnetite, hematite, and any free iron ions, in the soils, but does not distinquish between the various ferrous materials. The ferric percentages measured for the 12 samples are listed below:

Experimental Hearth No.	Total Iron (%)
1	1.95
2	1.86
3	1.92
4	1.28
5	1.74

6	2.08
7	1.66
8	2.03
9	1.67
10	2.56
11	2.61
12	2.50

These percentages were then compared to the respective samples' remanent magnetization alpha 95 values and mean sample intensities (table 15) (figs. 12 and 13). The correlation coefficient (r) for ferric content and alpha 95 values indicated a high positive correlation (+.757), and for ferric content and mean sample intensity, a negative correlation (-.589). This comparison indicates that as ferric content increases, the alpha 95 value increases and mean sample intensity decreases, thus reducing the archaeomagnetic sample quality. This relationship does not appear compatible with current archaeomagnetic theories. The acquisition and maintenance of remanent magnetization is dependent upon the type of magnetic material present and the shape and size of such material. It seems reasonable to assume that an increase in the total iron content would also represent an increase in the magnetic minerals capable of carrying a remanence. Magnetite and hematite are two such minerals often present in archaeological soils. These two minerals have different ferromagnetic characteristics: magnetite acquires a remanence 200 times more intense than hematite, but hematite is much more stable than magnetite (Tarling 1971:31). Therefore, remanance carried in a material by hematite has an intensity value 200 times lower than remanence carried by magnetite, which might explain the inverse relationship between total ferric contents and intensity. However, over time, hematite would be expected to maintain the acquired remanence better, yielding lower alpha 95 values. Therefore the alpha 95 values of recently acquired remanence for both materials should

figure 12

figure 13

be relatively small. The identification of the different minerals was the goal of a second; however, this study was limited in scope and provided more of a qualitative analysis than a quantitative analysis.

The difference between the expected alpha 95 and intensity values and the observed alpha 95 and intensity values as compared with various iron percentages might be explained by the relationship between iron percentages and clay textural percentages. Figure 14 is a scattergram depicting this relationship. It is apparent from the correlation coefficient ($r = +.896$, $r^2 = .802$) that ferric content is highly dependent upon clay content. Therefore, the relationship noted between iron and alpha 95 and intensity values may be due more to the variation in clay than the variation in iron; it is difficult to evaluate these two variables independently. A better test of the effect of total ferric content on alpha 95 and intensity would be a situation where soil textures are kept constant while total iron content varies. It should also be noted that an analysis of variance of the four location groups indicated insignificant variation in total ferric content among all groups except between location 4 and locations 1, 2, and 3. Therefore, there may not be sufficient variation to recognize differences due to ferric content. It is also possible that the lower limits of ferric content were not tested here, and percentages less than 1 percent are insufficient to provide good archaeomagnetic sample quality.

The second analysis conducted on soil samples recovered from the experimental hearths was initiated to distinguish between the various ferromagnetic minerals present in heated soils as compared to the unheated parent material. The research objective of this study was to determine the relative amounts of magnetite and hematite present in two sets of

figure 14

samples (heated and unheated soil) and to observe any differences possibly associated with heating soil matrices. This is very important in archaeomagnetic research because magnetic remanence may be acquired in one of several ways (e.g., TRM, PTRM [partial thermoremanent magntization], CRM [chemical remanent magnetization]) (Hathaway and Eighmy 1979, Tarling 1971, McEllinny 1973) or may be the result of a combination of these sources. Although all these processes may result in a remanent magnetization parallel to the ambient field, the interpretation of the remanence carried by the different sources in an archaeological sense is quite variable. Consider a situation whereby a CRM (remanence caused by the alteration of one magnetic mineral to another or the growth of a magnetic grain to a suitably sized mineral) is acquired by a matrix upon initial firing. Provided hematite carries this remanence and subsequent firings do not attain the Curie temperature of hematite, PTRM rather than a TRM is attained. It might therefore be assumed that the CRM acquired during initial firing is the primary remanence measured subsequent to archaeomagnetic collection. Presuming continual use of a prehistoric firepit or hearth over 10-20 years, this may cause interpretive problems of the temporal association of the magnetic moment measured from the ancient firing. It is currently assumed that the remanence measured from prehistoric matrices relates to the last firing occurrence which is clearly not the case in the above hypothetical situation. It will therefore be very useful to determine a method whereby such a situation can be distinquished in the laboratory. This may resolve a lot of the current problems inconsistencies between archaeomagnetic dates and dates obtained using absolute dating methods employed by archaeologists at the present time.

The study entailed microscopic analysis of the magnetic fraction removed from soil samples of heated and unheated matrices. Observation of the magnetic fraction of unheated soils permitted the recognition of the type of magnetic minerals present in various parent materials (clays, sandy loams, and loams); observation of the magnetic fraction of heated soils allowed comparison to the parent material, thereby providing some understanding of the chemical and mineral alterations occurring as the result of heating. Integration of these results with the results from other laboratory findings (thermal and AC demagnetization of the archaeomagnetic samples) has been used to interpret the effect of heating on soils and to resolve problems relating to identification of the source of remanence in archaeological contexts.

In order to observe the magnetic minerals under the microscope, a polished section was prepared. A portion of each soil sample was placed in a water solution and ground slightly to break up any large fractions. The magnetic portion of this mixture was then removed by a powerful, plastic-covered magnet to which the magnetic particles adhered until the magnet and plastic covering separated. The selective process favors the adherence of magnetite particles due to the stronger magnetic qualities of magnetite; therefore, the removed fraction has some bias towards magnetite grains. The magnetic fraction was dried and set in epoxy. When the epoxy was fully dried the "face" was sanded and polished to expose the surfaces of the magnetic minerals. The polished section was then ready to be observed under the microscope. Polished sections were viewed under oil immersion at 400 power with reflected light and an ND 50 filter. A modal analysis was then conducted for each of the 24 polished sections (two polished sections--one from a heated sample and one from an unheated sample--for each experimental hearth matrix). This analysis consisted of a count of seven types of magnetic minerals present in each polished section: ilmenite, altered ilmenite, hematite, botryoidal hematite grains, magnetite, martite (+50 percent magnetite), and martite (+50 percent hematite). The count was continued until 300 minerals were tallied or until all the minerals in a polished section had been counted. Minerals which could not be positively identified or were not a part of this study were not included in the count.

A synopsis of the minerals under consideration in this analysis with respect to their optical microscopic properties is presented below. All seven minerals are considered opaque, which is a property whereby light rays are not permitted to penetrate through the grain (thus reflected light must be used to observe their microscopic properties). Comprehensive descriptions of opaque magnetic minerals are presented in Ramdohr (1969) and Mason and Berry (1959).

Ilmenite grains exhibit moderate reflectivity under the microscope and are generally a pinkish- to brownish-gray color. Ilmenite is often anisotropic under crossed Nicols, that is, it changes from a darker to a lighter shade when the microscope stage is rotated under crossed nicols. Crossed Nicols refers to two rays of polarized light to the stage which combine or interfere with one another, thus producing various effects on crystals depending on their structural properties. Under regular reflected light, ilmenite tends to be pleochroic, that is, it changes color hue as the stage is rotated. The main distinguishing factor between hematite and ilmenite is the brightness of the former; the main difference between magnetite and ilmenite is the anisotropism under crossed Nicols observed in the latter. Ilmenite is basically paramagnetic; it tends to parallel the ambient field at room temperature but at lower temperatures (68° ??K??) becomes antiferromagnetic. Altered ilmenite, which has been changed from ilmenite to some other mineral, possibly Leucoxine, appears as a purplish-white mottled grain. The alteration is probably not due to heating.

Hematite is very bright under reflected light and is white to light bluish-white or grayish-white (where titanium is abundant in crystal structure). It is slightly anisotropic under reflected light. Hematite often shows red internal reflections when present with silicates; the internal reflections indicate small crystals which are not opague but produce a color which is observed under the microscope. Up to its Curie temperature hematite exhibits imperfect antiferromagnetic behavior; at which Curie temperature the mineral behaves paramagnetically. The imperfect antiferromagnetic behavior of hematite results in much weaker magnetism than magnetite; however, hematite is the more stable mineral. Hematite is also sometimes found as botryoidal grains: rounded or nodular masses occurring much as a bunch of grapes (Mason and Berry 1959:179). Single botryoidal grains were counted in the modal analysis but were not considered part of the final tally, due to the abundance of these grains in magnetic fractions of heated soils.

Magnetite appears as a brownish- to pinkish-gray grain and is basically isotropic under reflected light, although when titanium-rich, it may exhibit anisotropic characteristics. Magnetite is often found together with ilmenite or hematite; the secondary mineral grows along crystallographic planes, often completely replacing the host material, magnetite. This occurrence, although most often associated with extreme temperature in an oxidizing atmosphere, may also be caused by weathering and other processes (Ramadohr 1969:906). When hematite begins to replace magnetite in this manner, the grain is referred to as martite (Ramdohr 1969:906). A distinction was made in the DAP study between martite of primarily (+50 percent) magnetite and that of primarily (+50 percent) hematite.

The results from the modal analysis are presented in table 17. It is apparent from these results that several chemical (mineral) alterations occurred due to heating of the parent materials. There were more magnetite grains present in the parent material than in the fractions of heated soils. Magnetite grains occasionally account for one-half or one-third of the magnetite present in the parent material. These grains may be changing into hematite, although this is not apparent from the analysis results, or they may be changing into a material not included in this study. Hematite frequency appears to remain fairly constant, although there is a tendency for there to be lower frequencies in the heated soils which may be due to the inherent bias involved in obtaining the magnetic fractions. Both the hematite cement and the hematite nodule counts increase proportionally in the heated soils, although the hematite nodules appear to be much more abundant. The increase in frequency of the nodules appears to correlate with the intensity of the heating and with additional reheating of the matrices. However, it should be noted that some of the highest frequencies of these nodules are associated with the heated matrices (hearths 10 and 11) recording the lowest NRM mean sample intensities of the archaeomagnetic sample results. It is important to recognize that the magnetic properties of hematite are much weaker than the magnetic properties of magnetite. In any case, it seems likely that the remanence carried in these two hearths (10 and 11) may be due to hematite

Table 17. Results of modal analysis of polished sections

Mineral	Polished section designation* 1	2	3	4	5	6	7	8	9	10	11	12
Hematite (%)	18.6	7.7	11.9	8.0	14.6	10.6	9.3	8.0	13.3	9.3	8.7	19.6
Magnetite (%)	44.3	22.3	38.9	27.7	48.8	31.3	39.0	14.0	43.7	20.7	38.0	18.8
Martite (%) (+50% magnetite)	23.6	33.3	29.9	34.0	17.9	31.6	39.0	17.7	23.7	26.7	27.0	17.6
Martite (%) (+50% hematite)	4.1	6.7	4.8	7.3	4.3	5.9	3.7	10.3	5.3	11.7	6.7	5.4
Ilmenite (%)	2.1	1.0	1.9	1.0	1.0	1.6	1.7	0.7	0.3	0.7	0.7	0.5
Altered ilmenite (%)	0.6	1.3	1.0	1.0	0.7	2.5	1.7	9.0	0.3	2.0	0.7	4.9
Botryoidal grains (%) (hematite cement)	6.8	28.0	11.9	21.3	12.6	16.9	16.3	40.3	13.3	29.0	8.7	32.8
Single botyroidal grains (ct)	34	191	73	280	78	157	68	415	62	169	80	317
Total minerals tallied (ct)	339	300	311	300	301	320	300	300	300	300	300	204

*

Table 17. Results of modal analysis of polished sections--Continued

Mineral	Polished section designation* 13	14	15	16	17	18	19	20	21	22	23	24
Hematite (%)	10.5	13.0	10.0	10.0	14.0	10.3	9.3	6.7	9.3	7.0	7.7	10.0
Magnetite (%)	48.7	23.7	43.7	20.0	48.8	22.3	50.3	12.0	56.6	17.0	54.0	31.3
Martite (%) (+50% magnetite)	20.3	23.7	21.3	30.3	16.0	29.7	24.7	27.7	13.2	33.7	20.3	34.0
Martite (%) (+50% hematite)	2.3	5.3	6.7	8.0	3.0	4.7	5.0	5.7	8.8	6.0	5.7	6.3
Ilmenite (%)	0.7	0.3	0.3	0.0	1.0	0.3	1.3	0.3	0.6	0.0	2.7	0.7
Altered ilmenite (%)	1.6	0.3	1.0	0.7	1.0	0.7	0.7	0.7	2.2	0.0	0.3	0.0
Botryoidal grains (%) (hematite cement)	16.0	34.0	17.7	30.7	16.9	32.0	9.0	47.3	9.9	35.7	10.0	14.3
Single botyroidal grains (ct)	44	194	39	118	73	125	29	388	13	331	36	131
Total minerals tallied (ct)	306	300	300	300	301	300	300	300	182	300	300	300

* Polished section designation corresponds to the following experimental soil samples:

1 unheated soil, sample #1
2 heated soil, sample #1
3 unheated soil, sample #2
4 heated soil, sample #2
5 unheated soil, sample #3
6 heated soil, sample #3
7 unheated soil, sample #4
8 unheated soil, sample #4
9 unheated soil, sample #5
10 heated soil, sample #5
11 unheated soil, sample #6
12 heated soil, sample #6
13 unheated soil, sample #7
14 heated soil, sample #7
15 unheated soil, sample #8
16 heated soil, sample #8
17 unheated soil, sample #9
18 heated soil, sample #9
19 unheated soil, sample #10
20 heated soil, sample #10
21 unheated soil, sample #11
22 heated soil, sample #11
23 unheated soil, sample #12
24 heated soil, sample #12

produced during the heating process. The results from thermal and alternating current demagnetization presented in this report, elaborate upon these findings.

Firing Temperature Analyses

In an attempt to examine the variability of archaeomagnetic results from a variety of heating contexts and to define the lower temperature limits which will still produce reliable archaeomagnetic results, eight hearths, two from each location, were heated for a three-hour interval. Four of the hearths, one in each locality, were fired at high temperatures near or above the Curie temperature of hematite (680° C). At these temperatures, a total TRM should be acquired by the surrounding matrix. The other four hearths were fired at lower temperatures, considerably below the Curie point of hematite. At these temperatures, the source of remanence will be either a partial TRM or a CRM, rather than a total TRM. Assuming homogeneous heating, a total TRM is only acquired at the Curie temperature of the magnetic minerals carrying the remanence. The acquisition of remanence is not linear; figure 15 is an idealized curve illustrating the acquisitionof remanence for a magnetic mineral with a Curie point of 625° C. As stated by the addition law of partial TRM (Nagata 1961:160), the sum of the partial TRM acquired at the various temperature intervals is equal to the total TRM. Also, as represented in figure 15, the remanence acquired at each temperature interval is not equal; the majority of remanence is acquired within 200° C of the Curie point. Thus it was expected that the remanence acquired by the low firings would be less homogeneous (as indicated by high alpha 95 values) and less intense than the remanence acquired by the high firings. This difference should

Figure 15

be reflected in the archaeomagnetic results from the natural remanent magnetization of samples collected from the respective hearths.

Hearth Temperature Gradient Analyses

As each of the hearths was heated, temperatures were recorded by eight thermocouples located at various locations and depths (fig. 4). This data provided information on the temperature gradient throughout the hearth, from top to bottom and from exposed surfaces to inner depths. The variability noted in these recordings provided insights regarding the corresponding archaeomagnetic results.

In order to provide control of the location of temperatures recorded, the depth and height of the thermocouple wires were measured after each firing. Due to the difficulty in gauging thermocouple depth during installation, the location of the thermocouple wires varied from hearth to hearth. The locations of the thermocouples in each of the once-fired hearths and described in table 18.

Thermocouple 5 was used to monitor the highest temperatures reached by each firing. This thermocouple was always located on the north rim and was exposed to measure and control the temperature of the fire (as opposed to the matrix). When values for thermocouple 5 fell below the desired temperature, wood was added in 2-5 lb bunches depending on the amount of heat required to raise the temperature to the desired value. The frequency of refueling varied from 15 to 45 minutes depending on the type and amount of wood used and on the temperatures desired. Eighty percent of the fuel was *Pinus edulis*, with small amounts of *Artemisia tridentata*, *Quercus gambelii*, and *Juniperus osteosperma* used also.

The recorded temperatures for all eight thermocouples in each hearth are listed in tables 19-26. An average high temperature was determined

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Table 18. Location of thermocouple wires in once-fired experimental hearths

Hearth number	Thermocouple number	Thermocouple location	Depth recessed (cm)	Depth below rim (cm)
1	1	SW rim	.75	.5
	2	SE rim	1.0	1.5
	3	N rim	4.0	2.0
	4	N rim	2.0	2.0
	5	N rim	exposed	2.0
	6	N wall	2.0	6.0
	7	N wall	0.2	11.0
	8	Base-center	exposed	....
3	1	SW rim	.25	.5
	2	SE rim	.5	1.0
	3	N rim	2.0	1.5
	4	N rim	1.0	1.0
	5	N rim	exposed	1.5
	6	N wall	1.0	5.5
	7	N wall	exposed	10.5
	8	Base-center	exposed	....
4	1	SW rim	exposed	0.2
	2	SE rim	.75	1.5
	3	N rim	2.0	2.0
	4	N rim	1.0	1.5
	5	N rim	exposed	1.0
	6	N wall	0.2	11.0
	7	N wall	0.2	14.0
	8	Base-center	exposed	....
6	1	SW rim	exposed	4.0
	2	SE rim	.25	2.5
	3	N rim	2.0	1.0
	4	N rim	1.5	2.5
	5	N rim	exposed	2.5
	6	N wall	1.0	4.0
	7	N wall	0.2	12.0
	8	Base-center	exposed	....
7	1	SW rim	2.0	2.5
	2	SE rim	....	....
	3	N rim	1.0	0.5
	4	N rim	.25	.5
	5	N rim	exposed	5.0
	6	N wall	.5	14.0
	7	N wall	.5	7.5
	8	Base-center	exposed	....

NOTE: .... - Information not available.

Table 18 Location of thermocouple wires in once-fired experimental hearths--Continued

Hearth number	Thermocouple number	Thermocouple location	Depth recessed (cm)	Depth below rim (cm)
9	1	SW rim	0.5	.75
	2	SE rim	.25	2.0
	3	N rim	1.0	2.0
	4	N rim	.25	2.5
	5	N rim	exposed	5.5
	6	N wall	.25	7.5
	7	N wall	.25	15.0
	8	Base-center	exposed	....
10	1	SW rim	1.0	2.0
	2	SE rim	0.5	1.0
	3	N rim	0.5	1.0
	4	N rim	.25	1.5
	5	N rim	exposed	5.0
	6	N wall	.25	7.0
	7	N wall	.25	14.0
	8	Base-center	exposed	....
12	1	SW rim	.5	3.5
	2	SE rim	.25	1.0
	3	N rim	.25	2.0
	4	N rim	.5	3.0
	5	N rim	exposed	5.5
	6	N wall	1.0	10.0
	7	N wall	.25	13.0
	8	Base-center	exposed	....

for each set of values in the following manner. The ten highest temperatures recorded for each thermocouple were added and the average value determined. In this manner, the high spikes characteristic of a single moment were averaged out, and the effect of the lower temperatures characteristic of the early and late firing stages was minimized. This value is believed to be the best estimate of the temperatures maintained by each hearth at the various locations.

Table 19. Temperatures recorded for experimental hearth 1

Elapsed time (hrs.)	Temperatures (°C) recorded for thermocouple number 1	2	3	4	5	6	7	8
0:0	47	28	28	26	32	23	27	42
0:10	86	156	58	97	467	88	300	470
0:24	172	294	133	315	727	201	240	394
0:42	252	386	197	333	557	270	223	315
0:47*	377	340	197	341	708	261	198	295
1:03	389	347	235	371	642	261	170	256
1:13*	360	353	208	347	549	257	162	241
1:28	343	384	340	384	496	235	147	220
1:46*	382	316	355	409	687	226	136	217
2:00	269	345	353	414	397	258	144	213
2:10	418	332	341	401	549	261	147	206
2:23	303	306	298	335	586	261	147	197
2:27	420	295	273	343	625	259	146	194
2:45	371	348	286	442	574	251	143	185
2:55*	386	335	280	460	641	248	141	180
3:10	311	361	372	471	535	253	139	172
3:20	250	335	338	428	478	251	138	168
Average high temperature†	376	353	324	413	630	259	188	283

* Wood refueling.
† Average calculated on basis of 10 highest recorded temperatures.

Table 20. Temperatures recorded for experimental hearth 3

Elapsed time (hrs.)	Temperatures (°C) recorded for thermocouple number 1	2	3	4	5	6	7	8
0:0	36	30	34	35	37	30	37	37
0:10*	87	87	87	169	305	103	243	658
0:20	148	134	127	248	565	184	398	472
0:30	161	165	160	246	332	213	357	581
0:48	163	206	138	184	204	193	341	397
0:55*	178	198	179	293	478	234	300	528
1:09*	188	253	182	235	297	249	292	499
1:22	130	207	170	238	379	246	259	441
1:34	194	220	180	231	313	255	269	424
1:46*	195	202	169	210	273	236	259	406
1:55	236	209	177	223	301	265	325	405
2:05*	259	221	170	269	497	317	405	371
2:30	281	248	289	452	588	390	450	373
2:40*	259	238	229	296	370	257	415	382
2:52	223	257	216	260	273	322	398	387
3:00	170	179	182	201	189	259	337	320
3:10	150	161	165	181	205	234	282	363
Average high temperature†	218	226	197	277	413	290	373	481

Table 21. Temperatures recorded for experimental hearth 4

Elapsed time (hrs.)	Temperatures (°C) recorded for thermocouple number 1	2	3	4	5	6	7	8
0:0	34	25	26	28	34	24	25	33
0:15*	86	87	80	103	482	94	83	459
0:18	140	141	106	257	600	128	89	317
0:24*	249	206	131	262	430	253	91	252
0:27	284	236	148	295	456	309	96	252
0:40*	404	361	208	294	519	347	114	212
0:59*	395	394	288	431	680	308	133	211
1:06	492	450	327	433	590	290	135	205
1:18	519	462	355	470	758	272	137	199
1:27	540	490	341	425	439	255	138	194
1:37*	540	460	342	450	651	411	168	248
1:40	607	485	361	466	660	454	174	246
1:45	587	505	383	469	649	477	190	250
2:00*	553	428	311	392	659	371	202	236
2:07	685	481	464	625	710	350	197	226
2:21*	575	420	407	608	814	329	194	217
2:25	585	466	458	620	660	319	192	214
2:43*	720	448	364	386	427	375	222	256
2:47*	834	515	447	520	718	402	231	248
2:51	732	523	439	544	470	456	247	240
3:06	579	427	384	459	601	388	246	254
3:11	619	505	533	643	706	408	241	250
Average high temperature†	652	489	424	542	702	409	216	279

* Wood refueling.
† Average calculated on basis of 10 highest recorded temperatures.

Table 22. Temperatures recorded for experimental hearth 6

Elapsed time (hrs.)	Temperatures (°C) recorded for thermocouple number 1	2	3	4	5	6	7	8
0:0	55	51	58	56	50	58	49	50
0:14*	110	123	133	169	401	225	145	438
0:20	188	158	157	184	274	215	190	561
0:31*	215	237	185	230	404	295	256	498
0:38	261	283	221	271	401	332	309	574
0:49*	284	292	208	261	333	318	316	683
1:00	253	262	190	227	268	275	336	494
1:06*	253	287	203	238	403	324	342	514
1:15	364	370	261	315	316	348	363	572
1:24*	376	402	238	291	363	341	342	515
1:35	451	402	254	305	346	351	321	558
1:46	396	310	252	308	317	356	327	528
1:56*	376	293	227	281	335	335	329	459
2:07*	394	316	226	271	292	338	321	461
2:18	418	310	212	258	319	374	334	461
2:30*	315	306	221	278	388	362	319	448
2:37	357	304	254	302	385	357	304	460
2:50*	313	383	233	295	435	369	285	446
2:56	387	357	298	344	430	400	294	424
3:05	333	327	242	289	300	327	291	410
3:14	274	268	190	235	242	286	284	396
Average high temperature†	385	348	249	301	396	360	333	550

Table 23. Temperatures recorded for experimental hearth 7

Elapsed time (hrs.)	Temperatures (°C) recorded for thermocouple number 1	2	3	4	5	6	7	8
0:0	37	28	36	36	43	35	29	31
0:10*	91	88	60	80	278	98	85	404
0:17	203	168	72	98	420	147	94	433
0:23	249	264	86	138	413	292	96	407
0:28	254	278	101	225	598	333	103	331
0:35	322	374	134	226	588	363	112	291
0:50*	407	466	216	353	704	327	120	254
0:55	369	462	214	315	665	328	120	245
1:00*	346	425	268	452	756	334	121	240
1:07	404	437	359	475	671	342	122	238
1:10	406	460	333	401	595	323	121	235
1:29*	342	411	229	282	446	282	118	221
1:35	336	474	259	311	597	271	116	218
1:42	333	506	258	306	605	267	115	213
1:53*	313	466	231	295	509	266	113	420
1:56	342	515	317	439	762	290	116	475
2:05	327	473	351	403	483	319	127	482
2:10*	328	546	280	329	478	306	135	420
2:20	412	644	277	328	486	305	135	404
2:25	379	569	254	289	454	314?	137	377
2:34*	269	580	260	349	701	316?	138	357
2:40	410	618	319	415	672	319	137	346
2:47	478	578	310	377	714	318	138	336
2:55*	471	564	294	349	632	313	139	325
3:06	421	528	288	324	558	309	139	307
Average high temperature†	416	565	313	401	688	331	135	418

* Wood refueling.
† Average calculated on basis of 10 highest recorded temperatures.

Table 24. Temperatures recorded for experimental hearth 9

Elapsed time (hrs.)	Temperatures (°C) recorded for thermocouple number 1	2	3	4	5	6	7	8
0:0	29	42	37	37	41	36	32	39
0:18*	67	107	54	81	161	88	311	679
0:24*	82	117	77	119	375	159	317	569
0:30	102	135	92	144	238	215	283	512
0:46*	121	170	82	138	243	207	199	510
0:51	127	167	102	171	282	261	200	492
1:03*	144	174	132	230	315	284	191	456
1:07	172	175	145	244	430	325	193	458
1:18	131	142	122	188	242	366	188	249
1:26*	151	151	111	173	284	325	179	437
1:29	214	182	138	227	316	330	177	416
1:36	278	199	259	257	337	317	175	418
1:43	298	193	190	277	283	305	174	423
1:51	247	166	160	229	224	258	172	420
1:58*	253	189	169	249?	293	277	168	418
2:05	283	236	187	274	304	278	165	420
2:13	247	215	186	255	330	286	164	411
2:20	206	190	165	215	271	269	162	393
2:24*	203	174	169	240	327	279	160	386
2:30	246	219	198	324	427	286	158	378
2:36	251	321	230	325	279	293	155	374
2:42	233	257	209	305	364	299	153	370
2:55*	252	224	178	235	268	281	150	354
3:00	309	238	201	277	323	274	149	349
3:05	304	230	201	291	393	276	147	348
Average high temperature†	272	233	195	283	383	313	224	498

Table 25. Temperatures recorded for experimental hearth 10

Elapsed time (hrs.)	Temperatures (°C) recorded for thermocouple number 1	2	3	4	5	6	7	8
0:0	16	17	17	17	16	18	17	15
0:10*	33	60	84	167	394	135	337	552
0:22	100	159	247	358	555	286	327	406
0:30*	103	342	204	257	392	305	324	391
0:44*	159	325	244	390	562	386	235	297
0:52	212	417	286	479	597	463	232	266
1:00	217	377	267	360	764	460	207	274
1:10*	223	339	246	360	734	391	179	255
1:18	282	395	380	442	724	392	163	235
1:27	294	351	409	382	537	372	157	237
1:34*	300	367	400	456	531	344	152	226
1:43	327	421	412	476	562	314	143	211
1:53	296	484	463	497	520	302	136	203
2:04	236	354	451	402	485	292	131	200
2:12*	338	406	336	340	647	298	133	294
2:20	407	465	335	362	674	332	133	320
2:33	424	434	286	290	-	314	138	329
2:42*	405	360	355	428	617	310	137	289
2:50	415	360	376	443	630	315	133	272
3:01	361	313	348	413	526	305	131	263
3:07	333	283	311	408	504	293	129	252
3:10	300	276	312	376	440	286	129	149
Average high temperature†	361	413	393	444	651	376	234	342

* Wood refueling.
† Average calculated on basis of 10 highest recorded temperatures.

Table 26. Temperatures recorded for experimental hearth 12

Elapsed time (hrs.)	Temperatures (°C) recorded for thermocouple number 1	2	3	4	5	6	7	8
0:0	29	37	38	41	41	31	30	33
0:11*	69	70	78	104	406	68	70	518
0:20	111	135	140	199	542	105	137	580
0:28	110	137	136	174	255	237	154	548
0:34*	114	156	132	169	302	156	194	502
0:45	110	197	129	165	279	193	240	511
0:51	108	184	125	158	240	181	214	461
0:56*	128	177	133	169	278	188	193	440
1:03	140	221	142	177	301	195	184	419
1:08	157	176	139	173	424	212	188	378
1:16	148	174	158	190	230	236	208	424
1:20*	145	182	165	204	345	261	213	401
1:33	153	227	190	226	319	232	191	372
1:44*	172	174	188	227	323	215	166	393
1:52	194	165	204	243	288	230	166	420
2:02*	192	357	206	250	388	222	162	418
2:11	199	341	231	273	465	253	170	410
2:16	202	279	240	277	341	268	179	430
2:26*	191	228	228	262	312	261	182	413
2:31	185	268	213	245	320	249	180	394
2:37	174	208	207	239	320	249	180	346
2:42*	177	234	219	262	354	242	176	339
2:50	201	245	267	321	382	264	174	337
2:58	203	259	278	325	334	279	181	327
3:06	192	224	255	281	438	243	170	311
Average high temperature†	194	266	234	274	409	257	201	483

* Wood refueling.
† Average calculated on basis of 10 highest recorded temperatures.

The temperature gradient throughout each hearth was then estimated based on the average high temperature for each of the eight thermocouples. The variation of in temperature gradients among the eight hearths was also evaluated. It should be noted that some difficulty resulted from the unequal depths of corresponding thermocouples; although generalizations could be made, quantification was difficult and occasionally only trends were recognized.

Comparison of the average high temperatures of thermocouples located at similar depths at the southwest and southeast rim of each hearth (thermocouples 1 and 2) with the average high temperatures of the thermocouples located at the north rim (thermocouples 3, 4, and 5) indicates fairly uniform heating at comparable depths around the circumferences of the hearths, regardless of high firing temperature or matrix composition. There did appear to be a slight tendency for the north rim thermocouples to record slightly higher temperatures than the southwest and southeast rim thermocouples located at similar depths, apparently due to the prevailing southerly winds.

Comparison of the average high temperatures of the thermocouples located on the north rim of each hearth (thermocouples 3, 4, and 5) with the average high temperatures of thermocouples located along the north wall (thermocouples 6 and 7) indicates variable decreasing temperature values with a general trend of decreasing values from to to bottom. This trend is more noticeable in the highly-fired hearths where temperature differences are greater. For instance, thermocouple temperature differences are compared for hearths 10 (hot firing) and 12 (low firing):

Hearth	Thermocouple No*	Difference in distance from rim (cm)	Temperature difference (°c)†
10	4 & 6	5.5	68.5
	4 & 7	12.5	210.1
12	3 & 7	11.0	33.7

*All thermocouples located at recessed depth of 0.25 cm.
†Temperature differences based on average high temperature for each thermocouple.

It is apparent from these values that there is a difference between the hot and mild firings of hearths in location 4: that is, the higher the firing temperature, the greater the temperature difference from the top of the hearth to the bottom. Hearths in the other locations also exhibited this tendency; however, they could not be quantitatively compared due to differences in recessed depths of the various thermocouples. It is suspected that the differences noted between the hot and mild firings are a function of the ash buildup in the hearths during the three-hour firing. Hotter fires required much more fuel to maintain temperatures; thus, a greater amount of ash accumulated in these hearths. The ash buildup in the high-fired hearths was occasionally so excessive as to exceed the hearth rim, in which cases the ash was partially removed (to one-half the height of the hearth) to for the addition allow more fuel. Thermocouple 5 is an exposed thermocouple located on the north rim and thermocouple 8 is an exposed thermocouple located at the center of the hearth base. The average high temperatures of each of these two thermocouples for hearths 1, 3, 4, 6, 7, 9, 10, and 12 are presented below:

	High-fired hearths			Low-fired hearths		
		Average high temperature (°C)			Average high temperature (°C)	
Locality	Hearth No.	TC 5	TC 8	Hearth No.	TC 5	TC 8
1	1	629.6	282.7	3	412.8	481.1
2	4	701.6	278.6	6	395.6	549.7
3	7	688.2	417.9	9	383.1	497.5
4	10	651.1	342.4	12	408.5	482.9

*TC - thermocouple.

A comparison of thermocouple 5 and 8 average high temperatures in hearths 1, 4, 7, and 10 indicates that, in the high-fired hearths, temperatures at the top of the hearths are much greater than those at the bottom, the latter often being approximately half of the former. A comparison of the average high temperatures of the same two thermocouples in hearths 3, 6, 9, and 12 indicates that in low-fired hearths, the opposite is true; that is, the average high temperatures are higher at the bottom of the hearths.

The implications of these differences are important for archaeomagnetic purposes. If higher firing temperatures (up to curie temperature) create better archaeomagnetic conditions as stated in the additive law of partial TRM, then, based on the data presented here it appears likely that the bases of low-fired hearths yield better archaeomagnetic samples than the rims of low-fired hearths. This hypothesis was not tested in the DAP study. In a study conducted by Krause (1980), however, three heraths were constructed, control-fired, and archaeomagnetically collected in the Fort Collins area. Two samples from each hearth, one from the rim and one from the base, were collected. The archaeomagnetic results from these samples indicated that a more accurate direction and more homogeneous magnetization were obtained from the rim samples than from the base samples. However, only one of those hearths recorded higher temperatures (average high temperature) in the base than the rim.

Finally, comparison of the average high temperatures from thermocouples 3, 4, and 5 provided information regarding the heat absorption of each hearth. All three thermocouples were placed at the rim of each hearth: thermocouple 5 was exposed and extended between 0.5 and 2.0 cm out from the hearth rim; thermocouple 3 and thermocouple 4 were recessed into the hearth matrix although depths from one hearth to the next were variable. Figure 16 represents the average high temperature recorded for each of the three thermocouples plotted against the depth of the respective thermocouples. A problem exists with the data from hearth 12, where temperatures recorded at a greater depth (thermocouple 4) higher than those at a shallower depth (thermocouple 3). It was therefore assumed that these thermocouples were somehow switched and temperatures recorded for thermocouple 3 actually belong to thermocouple 4 and vice versa. A rate of temperature decrease per 0.25 cm soil depth was determined for each hearth and exhibited quite variable results among the hearths. Due to the unequal depths of thermocouples 3 and 4 among the eight hearths, these rates were determined by two methods: one from the temperature and

Figure 16

depth differences between thermocouples 3 and 5, and one from the differences between thermocouples 4 and 5. The results are listed in table 27. There appear to be similar rates of decrease among hearths 1, 3, 4, and 6, and no variation due to firing temperature is exhibited in these hearths. However, among hearths 7, 9, 10, and 12 quite variable results are noted, and rates of temperature decrease are significantly higher than decrease rates from hearths 1, 3, 4, and 6. It is apparent from all the measurements that the temperature decrease rate drops off as the distance from the rim face increases if the temperature readings for thermocouples 3 and 4 were indeed switched. This may explain some of the variation in rates between hearths 1, 3, 4, and 6 and hearths 7, 9, 10, and 12, as thermocouple placement tended to be closer to the rim in the latter group; however, thermocouple 3 from hearths 3 and 4 (located at 1 cm depth) and thermocouple 4 from hearths 7 and 9 (located at 1 cm depth) are comparable in terms of depth and a good deal of variation in average high temperatures is still noted. As some of the differentiation appears to be among location groups, soil texture was examined as a possible source. However, the main differences in textural groups among the four locations occur between location 4 and locations 1, 2, and 3. This, then, is not an acceptable explanation because the greatest rate decrease is noted in hearth 7, location 3, and the least rate decrease is noted in hearths 1, 3, 4, and 6, locations 1 and 2. There does appear to be some variation due to firing temperature in locations 3 and 4, but, as mentioned above, this is not a factor in locations 1 and 2. This problem has been discussed by Oke (1978) who has elaborated on the thermal conductivity of natural materials. If temperature, depth, and timeare held constant, and bulk averages are given, thermal conductivity is dependent upon three variables: soil porosity, conductivity of constituent particles, and water content. It is apparent from the thermal conductivity factors of wet and dry sandy soil (0.30/2.20) and wet or dry clayey soil (0.25/1.58) (Oke 1978:38) that, although soil texture is a factor in thermal conductivity, water is a much more influential factor. Therefore, it is possible that the variation in temperature rate decrease (i.e., thermal conductivity) noted among the experimental hearths may be explained by water variation; however, this factor cannot be properly tested because it was not controlled in the experiments.

Table 27. Rate of temperature decrease (°C) per 0.25 cm soil depth

Rate of temperature decrease (°C) at Experimental hearth No.	.25 cm	.5 cm	1.0 cm	1.5 cm	2.0 cm	4.0 cm
1	-	-	-	-	25.63	19.06
3	-	-	33.75	-	24.38	-
4	-	-	38.75	-	28.75	-
6	-	-	-	32.50	30.63	-
7	290.00	-	93.75	-	-	-
9	95.00	-	43.75	-	-	-
10	205.00	127.50	-	-	-	-
12*	135.00	87.50	-	-	-	-

* Rate for hearth 12 based on switched thermocouple readings (thermocouples 3 and 4).

Firing Temperature and Archaeomagnetic Sample Results

The average high temperatures attained by the high-firings and those attained by the low-firings were significantly different, while variability among the group hearths was minimal. Although temperature variability among the high-fired hearths was more pronounced, the temperatures attained were at or near the Curie temperature of hematite and all temperatures were above the Curie point of magnetite. The temperatures attained by the low-fired hearths were approximately 400° C, well below the Curie points of either magnetite or hematite. These two groups of hearths provided a good data base with which to examine the effects of temperature as they relate to the quality of archaeomagnetic samples (table 28).

Table 28. Archaeomagnetic results of selected once-fired hearths

Experimental sample No.	Average high temperature thermocouple 5 (°C)	Archaeomagnetic results NRM* alpha 95	Archaeomagnetic results NRM* mean sample intensity
1	630	1.57	1.3×10^{-3}
3	410	2.16	$.29 \times 10^{-3}$
4	700	1.32	1.3×10^{-3}
6	395	2.16	$.17 \times 10^{-3}$
7	690	2.05	$.48 \times 10^{-3}$
9	380	2.70	$.14 \times 10^{-3}$
10	650	3.08	$.16 \times 10^{-3}$
12*	410	4.09	$.039 \times 10^{-3}$

* - NRM (natural remanent magnetization) refers to untreated samples.

NOTE: Sample Nos. 1, 4, 7, and 10 were collected from high-fired hearths; the remaining samples were collected from low-fired hearths.

Figure 17 is a graph of the NRM mean sample intensity and average high firing temperatures attained by respective hearths in the four different locations. A strong positive correlation was determined($r = +.749$) between the two variables with over half of the variation in intensity explained by variation in average high firing temperature ($r^2 = .561$). The correlation is particularly notable when high and low firings are considered by location units. The correlation between NRM alpha 95 and firing temperature (fig. 18) is $r = -.624$, indicating that as average high firing temperature decreases, alpha 95 values increase, thus reducing the likelihood of archaeomagnetic success. Although only one sample (from hearth 12) produced alpha 95 values results higher than desirable for dating purposes, it is presumed that, given the above correlation coefficient, even lower firing temperatures would produce less desirable results. It should also be noted that although the low-temperature hearths attained values of only 400° C, 180° C below the

Figure 17

Figure 18

Curie temperature of magnetite and 270° C below that of hematite, the archaeomagnetic results were suitable for dating purposes in all but one sample, and all samples were observed to adequately mimic the ambient magnetic field in Dolores, Colorado.

Refiring Analyses

The effects of refiring on archaeomagnetic quality were tested in this study. It was expected that additional firings of a given matrix would increase the archaeomagnetic quality as reflected in the NRM mean sample intensity and alpha 95 value. To test this hypothesis, four hearths, one in each of the four locations, were fired at low temperatures for three-hour increments on five separate occasions. The total firing time for each hearth was approximately 15 hours. Temperatures in all hearths were monitored and recorded by two thermocouples, one on the north rim, the other on the south rim. The north rim thermocouples were always exposed; the south rim thermocouples were exposed on two hearths and recessed into the soil matrix on the other two (fig. 5). After the hearths had cooled subsequent to the last firing, archaeomagnetic samples were collected from each. The archaeomagnetic results from these samples were then compared with the results from samples collected from once-fired, low-temperature hearths in the same locality to determine if any difference exists due to repeated heating.

The recorded temperatures for each refired hearth are graphically displayed in figures 19-26. The average high temperatures were determined for each firing (table 29) and the average high temperatures for the five firings of each hearth were determined based on the 10 highest temperatures from each firing. When the average high temperatures of all firings for thermocouple 1 from the refired hearths are compared to the average

Figure 19

Figure 20

Figure 21

Figure 22

Figure 23

Figure 24

Figure 25

Figure 26

Table 29 Average high-temperatures of refired hearths

Experimental hearth No.	TC No.	TC Location	Depth Recessed (cm)	Height from rim	Average high temperature: First firing	Second firing	Third firing	Fourth firing	Fifth firing	All firing average*
2	1	N rim	exposed	1.5	385°C	360°C	350°C	320°C	410°C	365°C
	2	S rim	exposed	.75	290°C	280°C	255°C	385°C	250°C	290°C
5	1	N rim	exposed	2.5	420°C	365°C	370°C	430°C	375°C	390°C
	2	S rim	exposed	2.5	305°C	350°C	300°C	375°C	340°C	335°C
8	1	N rim	exposed	4.0	380°C	380°C	375°C	350°C	400°C	375°C
	2	S rim	1.2	1.0	260°C	325°C	230°C	265°C	250°C	265°C
11	1	N rim	exposed	3.0	420°C	355°C	360°C	425°C	360°C	385°C
	2	S rim	.25	2.0	255°C	300°C	235°C	240°C	235°C	255°C

* Average high temperature over 10 highest temperatures from each firing.

high temperatures of thermocouple 5 (similar location) from the once-fired, low-temperature hearths, the temperatures are quite similar:

Refired hearths		Once-fired, low-temperature hearth	
Hearth No.	Average high temperature (°C) Thermocouple 1*	Hearth No.	Average high temperature (°C) Thermocouple 5*
2	365	3	410
5	390	6	395
8	375	9	375
11	385	12	385

* - Thermocouple 1 in refired hearths and thermocouple 5 in once-fired, low-temperature hearths were exposed on north rim.

The archaeomagnetic results from the refired hearths (table 30) were then compared to the archaeomagnetic results from the once-fired, low-temperature hearths (see table 28) as a function of total firing hours (figs. 27 and 28). As is apparent from the graphs, with the exception of the location 3 data, the correlation between firing hours and alpha 95 values generally is inversely related (r = -.291); as firing hours increase, alpha 95 values decrease. NRM mean sample intensity and firing hours are positively correlated (r = +.415).

Table 30. Archaeomagnetic results of refired hearths

	Archaeomagnetic results	
Experimental sample No.	NRM* alpha 95	Mean sample intensity
2	1.38	$.65 \times 10^{-3}$
5	1.95	$.26 \times 10^{-3}$
8	2.88	$.25 \times 10^{-3}$
11	3.09	$.084 \times 10^{-3}$

* - NRM (natural remanent magnetization) refers to untreated samples.

When archaeomagnetic results and firing time are regarded by location units (i.e., soil textural units), similarities are observed between locations 1 and 4 and locations 2 and 3. The results from locations 1 and 4 indicate a greater variation in sample results between the refired and

Figure 27

Figure 28

once-fired hearths than do the refired and once-fired hearths of locations 2 and 3. There is a very slight difference in archaeomagnetic results between hearths 5 and 6 (location 2) and alpha 95 values for hearths 8 and 9 (location 3) exhibit a reversed (positive) correlation related to firing time.

A comparison of the high-temperature once-fired hearths with the low-temperature refired hearths suggests that archaeomagnetic quality improves with repeated low-temperature firings of a hearth matrix. Alpha 95 and mean sample intensity for low-temperature refired and high-temperature once-fired hearths were plotted over firing time (figs. 29 and 30) and correlation coefficients were determined (x = independent variable; y = dependent variable):

Firing time (x)/Alpha 95
$r = +.228 \quad r^2 = .052$

Firing time (x)/Mean Sample Intensity (y)
$r = -.534 \quad r^2 = .285$

Very little difference is observed in alpha 95 values due to higher firing temperatures between hearths 1 and 3 (location 1) and between hearths 10 and 12 (location 4). However, the alpha 95 values between hearths 4 and 6 (location 2) and between hearths 7 and 9 (location 3) (i.e., between hot once-fired and refired hearths) were more differentiated, the high-temperature matrices correlating to the lower (better) alpha 95 values. The correlation between high-temperature matrices and refired matrices and mean sample intensity values is more pronounced: samples from hearths in all locations exhibited higher intensities in the high-temperature matrices. Thus it is noted from these experiments that additional reheating at low temperatures of hearth matrices does improve the archaeomagnetic quality of a matrix; however, the effects beyond the limitations

Figure 29

Figure 30

of these experiments are unknown. For instance, what archaeomagnetic results could be expected from a matrix fired periodically over a years time? Certainly the noted correlation does not continue, or eventually alpha 95 values would decrease to zero, which is not observed in the archaeological collections.

In addition, although reheated low-temperature matrices approach alpha 95 values of high-temperature, single-fired matrices, the intensity values measured from high-temperature hearths is greater than that measured from refired hearths.

Sun Compass and Brunton Compass Cube Orientation Methods

Several analyses were performed on the measurements obtained by Sun and Brunton compass methods. First, the difference between the two observed recordings of each specimen orientation was determined; this difference corresponds to the magnetic declination of the Dolores valley. It is important in archaeomagnetic research that the present ambient field direction be precisely determined because consistent error in the data can produce biased results and cause problems in temporal interpretation of archaeomagnetic samples. The mean sample declination differences were also examined to determine if any consistent differences are apparent between the high-fired (i.e., highly magnetic) and the low-fired hearths due to magnetic interference of the hearths on the Brunton compass.

In a second analysis the mean remanent direction of each sample was calculated using the values obtained by the two different methods. These directions were compared with the ambient field direction to establish any differences and to ascertain any patterns inherent in these differences.

In a third analysis, the alpha 95 values from the archaeomagnetic results for the two methods were compared to determine if measurement errors of the two methods are similar. If the magnetic field strength of a burned hearth affects the surrounding magnetic field lines (i.e., magnetic declination) enough to influence a magnetic compass, then this effect might be noted in one of two ways: by a consistent measurement bias either east or west or a random effect due to specimen locations in a hearth which would produce a somewhat larger error in Brunton compass measurements.

The individual specimen orientation measurements of the two methods and the difference between the two values are presented in table 31. The differences noted for each specimen were then averaged over each sample, and a standard deviation calculated (table 32). These values indicate the best estimate of the magnetic influences (including main field direction) in the sampling areas. The mean value averaged over all 148 measurement differences is 11.4° E. This value was used in all subsequent Sun and Brunton compass analyses as the reference direction to which archaeomagnetic sample results were compared. An analysis of variance calculated for the mean differences noted for samples in experimental localities indicated no difference among the locality groups at a 95 percent confidence level.

Table 32. Mean experimental sample direction differences between sun compass values and Brunton compass values

Locality	Sample	Mean direction difference*	Standard Deviation
1	1	12.6	1.26
	2	13.2	0.83
	3	11.5	0.97
2	1	11.8	0.89
	2	11.8	0.85
	3	11.1	0.62
3	1	11.4	1.6
	2	10.6	1.1
	3	9.3	3.31
4	1	11.0	0.97
	2	11.6	1.23
	3	11.0	1.5

* Mean direction difference represents average value of all specimens in sample unit.

Table 31. Measurements obtained by Brunton compass and sun compass orientation methods

Specimen No.	1 B.C*	1 S.C†	1 Diff§	2 B.C*	2 S.C†	2 Diff§	3 B.C*	3 S.C†	3 Diff§	4 B.C*	4 S.C†	4 Diff§	5 B.C*	5 S.C†	5 Diff§	6 B.C*	6 S.C†	6 Diff§
	Experimental sample No.																	
1	355.0	6.9	11.9	348.5	1.4	12.9	18.0	28.5	10.5	57.0	70.3	13.3	339.0	350.9	11.9	13.0	24.6	11.6
2	4.0	16.4	12.4	38.5	52.8	14.3	11.0	22.3	11.3	45.0	56.6	11.6	42.5	52.7	10.2	17.0	28.6	11.6
3	28.5	39.4	10.9	39.5	53.1	13.6	30.5	42.9	12.4	338.5	348.9	10.4	16.0	26.5	10.5	41.5	52.4	10.9
4	339.0	351.1	12.1	348.5	2.0	13.5	11.0	23.5	12.5	29.0	39.8	10.8	335.5	347.8	12.3	2.0	13.5	11.5
5	34.5	47.3	12.8	321.0	333.9	12.9	0.5	11.8	11.3	334.0	345.3	11.3	47.5	60.3	12.8	8.5	19.1?	10.6
6	2.0	13.8	11.8	313.5	325.5	12.0	354.0	5.3	11.3	24.0	35.4	11.4	38.4	50.6	12.6	10.5	21.6	11.1
7	334.5	347.3	12.8	15.0	29.2	14.2	5.0	15.6	10.6	35.0	46.9	11.9	19.5	31.1	11.6	314.5	324.5	10.0
8	34.5	46.6	12.1	339.0	351.3	12.3	36.5	48.5	12.0	51.0	63.8	12.8	41.5	54.4	12.9	321.0	331.4	10.4
9	326.0	338.5	12.5	18.5	33.2	14.6	331.0	334.4	13.4	318.5?	331.4	12.9	347.0	358.2	11.2	6.5	17.5	11.0
10	354.0	10.0	16.0	359.0	11.5	12.5	11.5	23.7	12.2	26.0	37.7	11.7	9.5	21.9	12.4	344.0	355.1	11.1
11	341.0	352.8	11.8	341.0	353.4	12.4	45.0	54.8	9.8	13.5	25.0?	11.5	326.0	337.5	11.5	22.5	35.1	12.6
12	10.0	24.1	14.1	28.0	41.7	13.7	44.5	55.4	10.9	335.5	346.5	11.0	329.0	341.2	12.2	24.5	35.6	11.1

Specimen No.	7 B.C*	7 S.C†	7 Diff§	8 B.C*	8 S.C†	8 Diff§	9 B.C*	9 S.C†	9 Diff§	10 B.C*	10 S.C†	10 Diff§	11 B.C*	11 S.C†	11 Diff§	12 B.C*	12 S.C†	12 Diff§
	Experimental sample No.																	
1	299.5	313.3	13.8	333.5	342.5	9.0	18.0	28.1	10.1	342.5	352.0	9.5	53.0	65.6	12.6	14.5	27.3	12.8
2	292.0	305.8	13.8	15.0	23.6	8.6	316.0	325.9	9.9	31.0	41.4	10.4	6.5	18.7	12.2	333.5	346.6	13.1
3	35.0	46.1	11.1	311.0	322.5	11.5	30.5	29.7	-.8	352.0	1.6	9.6	18.0	26.0	8.0	1.0	13.0?	12.0
4	22.5	35.5	13.0	334.0	345.4	11.4	337.0	347.9	10.9	327.5	337.5	10.0	46.5	58.3	11.8	16.0	27.4	11.4
5	4.0	14.0	10.0	355.0	3.9	8.9	29.5	40.3	10.8	2.0	12.5	10.5	8.5	19.7	11.2	345.5	357.8	12.3
6	342.0	357.0	15.0	294.0	305.1	11.1	335.5	334.7	9.2	339.5	351.1	11.6	37.0	49.0	12.0	13.5	25.7	12.2
7	323.5	334.9	11.4	325.0	336.1	11.1	47.5	58.4	10.9	353.0	4.9	11.9	311.5	324.5	13.0	339.5	350.0	10.5
8	308.0	319.5	11.5	345.5	356.9	11.4	343.5	353.3	9.8	32.0	42.5	10.5	0.5	12.8	12.3	359.0	10.0	11.0
9	304.0	313.8	9.8	15.0	26.2	11.2	13.0	23.5	10.5	323.0	334.4	11.4	35.0	47.2	12.2	320.0	328.4	8.4
10	15.0	25.6	10.6	323.5	334.6	11.1	18.5	29.9	11.4	356.5	8.7	12.2	358.0	9.8	11.8	354.5	4.2	9.7
11	358.0	7.9	9.9	336.5	347.7	11.2	34.0	40.5	6.5	308.5	321.1	12.6	323.0	334.1	11.1	342.0	350.9	8.9
12	336.0	346.2	10.2	354.5	5.6	11.1	51.5	63.5	12.0	323.0	334.2	11.2	10.5	21.7	11.2	25.0	35.0	10.0
13	16.0	25.0	9.0															
14	2.5	13.9	11.4															
15	32.0	42.4	10.4															
16	358.5	9.5	11.0															

* Brunton compass value.
† Sun compass value.
§ Difference between Brunton compass value and sun compass value.

The values given in table 31 for sun compass and Brunton compass measurements were then used to determine archaeomagnetic sample parameters, that is, remanent magnetic directions (declination only) and alpha 95 values (table 33). The NRM alpha 95 values obtained from the sun compass and Brunton compass values could then be compared to determine any inherent variation due to use of one instrument or the other. This was possible because the measured remanent direction for each specimen was identical, only the cube orientations varied. A paired-comparison t-test was conducted for the alpha 95 values of both methods, and the means of the two methods were unequal at the 95 percent confidence level. However, contradictory to the experimental hypothesis, the Brunton compass values yielded lower (better) alpha 95 values. This indicates that the sun compass method is a less accurate method of cube orientation, that is, more variation is noted between the sun compass orientation values of in situ archaeomagnetic cubes than Brunton compass values. However, the difference between the two alpha 95 values, which was never more than 0.2°, was probably primarily due to instrument inaccuracies in obtaining the orientation values.

Table 33. Comparison of sun compass and Brunton-compass archaeomagnetic results, experimental

Sample	Archaeomagnetic results based on Brunton compass values		Archaeomagnetic results based on sun compass values	
	NRM* alpha 95	Remanent declination	NRM* alpha 95	Remanent declination
1	1.57	12.6	1.75	13.6
2	1.38	10.1	1.36	11.7
3	2.16	8.8	2.27	9.1
4	1.32	12.0	1.32	12.4
5	1.95	9.9	1.97	10.1
6	2.16	12.9	2.14	12.5
7†	2.05	10.1	2.23	9.5
8	2.88	11.9	3.00	11.0
9	2.70	11.1	2.86	8.7
10	3.08	13.3	3.26	11.6
11	3.09	15.2	3.19	15.2
12	4.09	7.8	4.11	7.2

* NRM (natural remanent magnetization) refers to untreated samples
† 12 of 16 speciments were used in analysis.

The mean sample NRM remanent declinations of both Brunton compass and sun compass values, are similarly dispersed about the reference location (11.4° E). Moreover, there does not appear to be any tendency of high-fired hearths (1, 4, 7, and 10) to be associated with more variable results than the low-fired hearths.

Laboratory Cleaning Techniques

AC demagnetization. AC demagnetization is a laboratory technique for removing the unwanted secondary magnetizations acquired subsequent to acquisition of original TRM or CRM. Secondary magnetizations from a number of sources can be imposed on the burned context prior to archaeomagnetic collection or on archaeomagnetic samples during laboratory storage. Of these sources only IRM and VRM are of concern to archaeomagnetists. IRM is produced by the presence of a large magnetic field or magnetically oriented contexts. Lightening strikes are a good example of this source; however, other strong magnetic fields, such as synthetically produced magnets, may also affect samples. VRM is produced when magnetically "soft" grains relax over time to the ambient field, that is, they do not maintain their remanent directions. Very soft grains (low-coercivity grains) will aline to the ambient field fairly quickly; hence a small VRM factor may be acquired by stored archaeomagnetic samples. IRM and VRM components differ from the TRM or CRM components by requiring lower field strengths for removal. VRM components can often be removed by field strengths of 100 oertseds of AC demagnetization (Tarling 1971:43). The AC technique applies an alternating magnetic field to a tri-axial tumbling specimen. The field is slowly allowed to degenerate to zero, causing the grains of lower and lower coercivities to aline with the induced magnetic field. The effect is a random ordering of magnetic alinements of those grains, thus removing effects of secondary components caused by grains of coercive-forces effected by that field strength. Different field strengths are necessary to remove effects of the various components, hence increasing levels of demagnetization are imposed on samples to obtain the optimum level. The magnetic remanence remaining at each demagnetization step is measured by either an astatic, spinner, or cryogenic magnetometer. The treatment levels are accomplished in 25 or 50 Oe steps, up to an optimum level as defined by alpha 95 values, mean sample intensity values, and the relative mean sample direction movement. For the experimental samples, the optimum level could be defined as the directions (declination and inclination) nearest the reference directions determined for the Dolores valley. Although a declination value of 11.55° E was used to date the DAP sites, the previously reported declination of 13.5° E was used for the experimental studies because the "new" declination was not calculated until part way through the analysis. This descrepancy shold not affect the validity of the study because the conclusions drawn are based on relative measures rather than absolute figures. An inclination of 64.1° (dip) was used in the experimental studies.

It was hypothesized that the optimum demagnetization level of similar textural contexts would be similar. It was thought that there would be a tendency for lower-coercivity grains ("soft" magnetic particles) to be associated with the larger-grained textural contexts and vice versa and thus similar textures would tend to exhibit similar secondary components. For this analysis, 6 of the 12 samples (samples 4, 5, 6, 10, 11, 12) chosen as pilot samples for the experimental group were AC demagnetized in 25 Oe steps from NRM (0 Oe) to 200 Oe. The remaining six samples (samples 1, 2, 3, 7, 8, 9) were demagnetized at 50 Oe levels including the optimum level determined from similar-textured pilot samples. The archaeomagnetic results are presented in table 34. The optimum demagnetization level for each sample was then determined (table 35) based on the above criteria, and samples were compared to determine if any pattern of demagnetization for like-textured or like-fired samples exists. Comparisons of optimum demagnetization levels for samples within the same location (and therefore with similar textures) and between samples from locations with similarly-textured soil (locations 1 and 4 and locations 2 and 3) indicate no pattern inherent in samples of similar textures. Comparison of the high-temperature once fired samples (Nos. 1, 4, 7, and 10), the high- and low-temperature refired samples (Nos. 2, 5, 8, and 11), and the low-temperature once-fired samples (Nos. 3, 6, 9, and 12) does not indicate a pattern either. It appears that the optimum level of demagnetization for each sample is independent of the factors examined. Although the optimum level of demagnetization chosen for these samples is the level which yielded results <u>closest</u> to the direction to the reference location (13.5° E), it should be noted that the remanent directions at each demagnetization level are mostly within the alpha 95 range of the reference location. Other indicators used in archaeomagnetic research, such as alpha 95 and mean sample intensity, to obtain the optimum demagnetization level also do not pertain to the experimental samples. If alpha 95 values are used to select the optimum level, these levels do not coincide with the best remanent direction. Intensity values tend to drop at regular intervals with approximately 20 percent of the remanence remaining after 200 Oe demagnetization. There does appear to be some correlation, however, between high intensity values and accuracy of the remanent direction repeated firings may also be a factor here. Again, it should be pointed

Table 34. Archaeomagnetic results at different demagnetization treatment levels, experimental samples

Experimental sample No.	Archaeo-magnetic results	NRM* (0 Oe)	25	50	75	100	125	150	175	200
		Treatment level (Oe)								
1	alpha 95	1.57		1.47		1.62		1.61		1.68
	inclination	64.5		64.1		64.3		64.1		64.5
	declination	14.5		14.6		14.6		15.0		14.9
	mean sample intensity	$.13x10^{-2}$		$.13x10^{-2}$		$.88x10^{-3}$		$.67x10^{-3}$		$.42x10^{-3}$
2	alpha 95	1.38		0.8		1.10		1.03		1.23
	inclination	65.5		65.1		64.5		64.2		64.3
	declination	12.0		13.7		13.7		13.3		14.3
	mean sample intensity	$.65x10^{-3}$		$.58x10^{-3}$		$.32x10^{-3}$		$.24x10^{-3}$		$.12x10^{-3}$
3	alpha 95	2.16		1.61	3.48	1.49		1.36		2.95
	inclination	64.5		64.1	64.2	63.3		63.7		64.0
	declination	10.7		11.6	11.3	11.4		11.7		15.4
	mean sample intensity	$.29x10^{-3}$		$.23x10^{-3}$	$.18x10^{-3}$	$.13x10^{-3}$		$.11x10^{-3}$		$.54x10^{-4}$
4	alpha 95	1.32	1.31	1.64	1.55	1.79	1.87	1.93	2.53	2.13
	inclination	64.3	63.7	62.6	63.5	63.6	63.5	64.1	63.3	63.4
	declination	13.9	14.5	14.3	14.0	13.1	14.0	14.0	14.6	14.1
	mean sample intensity	$.13x10^{-2}$	$.13x10^{-2}$	$.11x10^{-2}$	$.87x10^{-3}$	$.66x10^{-3}$	$.53x10^{-3}$	$.50x10^{-3}$	$.39x10^{-3}$	$.28x10^{-3}$
5	alpha 95	1.95	1.56	1.37	1.72	1.71	1.79	2.04	1.97	3.01
	inclination	66.1	65.3	64.8	64.0	64.4	63.6	63.6	63.0	64.1
	declination	11.8	11.7	12.8	12.3	13.6	11.2	9.4	11.2	9.1
	mean sample intensity	$.26x10^{-3}$	$.25x10^{-3}$	$.21x10^{-3}$	$.17x10^{-3}$	$.11x10^{-3}$	$.85x10^{-4}$	$.79x10^{-4}$	$.60x10^{-4}$	$.45x10^{-4}$

Table 34. Archaeomagnetic results at different demagnetization treatment levels, experimental samples--Continued

Experimental sample No.	Archaeomagnetic results	Treatment level (Oe) NRM* (0 Oe)	25	50	75	100	125	150	175	200
6	alpha 95	2.16	1.89	2.30	2.09	2.01	2.06	1.72	2.11	1.83
	inclination	64.5	64.0	63.9	63.5	63.2	63.9	63.4	63.0	62.6
	declination	14.9	15.9	15.2	13.8	13.6	12.7	14.8	14.0	14.5
	mean sample intensity	$.17x10^{-3}$	$.17x10^{-3}$	$.14x10^{-3}$	$.11x10^{-3}$	$.75x10^{-4}$	$.61x10^{-4}$	$.5x10^{-4}$	$.38x10^{-4}$	$.29x10^{-4}$
7	alpha 95	2.05		1.73		1.37		1.54		1.80
	inclination	62.4		62.8		62.6		63.1		61.6
	declination	12.1		12.0		11.7		13.3		12.2
	mean sample intensity	$.48x10^{-3}$		$.44x10^{-3}$		$.21x10^{-3}$		$.21x10^{-3}$		$.91x10^{-4}$
8	alpha 95	2.88		2.29		2.03		2.04		2.42
	inclination	64.9		64.0		64.1		63.8		64.4
	declination	13.9		15.8		14.6		15.3		13.3
	mean sample intensity	$.25x10^{-3}$		$.23x10^{-3}$		$.14x10^{-3}$		$.11x10^{-3}$		$.51x10^{-4}$
9	alpha 95	2.70		2.47	2.39	2.30		2.60		3.37
	inclination	63.7		63.5	63.3	64.2		62.6		61.4
	declination	13.1		14.3	14.0	14.8		14.6		14.6
	mean sample intensity	$.14x10^{-3}$		$.12x10^{-3}$	$.90x10^{-4}$	$.64x10^{-4}$		$.55x10^{-4}$		$.27x10^{-4}$
10	alpha 95	3.08	2.39	1.72	1.49	1.59	1.63	1.75	1.64	2.05
	inclination	65.2	64.6	63.2	63.0	63.2	63.4	63.5	62.6	63.2
	declination	15.2	16.8	16.7	17.0	16.2	15.7	16.0	15.2	14.2
	mean sample intensity	$.16x10^{-3}$	$.17x10^{-3}$	$.13x10^{-3}$	$.89x10^{-4}$	$.76x10^{-4}$	$.68x10^{-4}$	$.61x10^{-4}$	$.38x10^{-4}$	$.28x10^{-4}$

Table 34. Archaeomagnetic results at different demagnetization treatment levels, experimental samples--Continued

Experimental sample No.	Archaeo-magnetic results	Treatment level (Oe) NRM* (0 Oe)	25	50	75	100	125	150	175	200
11	alpha 95	3.09	2.21	1.94	2.19	1.99	2.24	2.93	3.28	3.45
	inclination	65.9	66.4	65.3	65.1	64.7	65.8	65.3	65.0	64.3
	declination	17.2	17.5	16.2	15.7	15.7	13.3	14.0	16.5	13.0
	mean sample intensity	$.84 \times 10^{-4}$	$.83 \times 10^{-4}$	$.64 \times 10^{-4}$	$.48 \times 10^{-4}$	$.31 \times 10^{-4}$	$.26 \times 10^{-4}$	$.24 \times 10^{-4}$	$.20 \times 10^{-4}$	$.14 \times 10^{-4}$
12	alpha 95	4.09	4.57	3.59	4.88	5.42	5.53	6.09	4.47	8.40
	inclination	65.0	66.3	62.9	63.2	62.3	61.8	62.4	61.2	63.5
	declination	9.7	11.1	11.4	15.8	9.5	9.0	9.6	12.4	4.2
	mean sample intensity	$.39 \times 10^{-4}$	$.38 \times 10^{-4}$	$.27 \times 10^{-4}$	$.18 \times 10^{-4}$	$.14 \times 10^{-4}$	$.15 \times 10^{-4}$	$.11 \times 10^{-4}$	$.93 \times 10^{-5}$	$.76 \times 10^{-5}$

* NRM (natural remanent magnetization) refers to untreated samples.

out that the relative directional changes of the remanent direction which may be the best method of determining the optimum demagnetization level, were not more than 2°-4° for most experimental samples.

Table 35. Optimum demagnetization level, experimental samples

Location N .	Experimental Sample No.	Optimum demagnetization level (Oe)	Remanent Directions Inclination	Declination
1	1	50	64.1	14.6
1	2	150	64.2	13.3
1	3	200	64.0	15.4
2	4	150	64.1	14.0
2	5	100	64.4	13.6
2	6	75	63.5	13.8
3	7	150	63.1	13.3
3	8	200	64.4	13.3
3	9	NRM*	63.7	13.1
4	10	200	63.2	14.2
4	11	200	64.3	13.0
4	12	50	62.9	11.4

* NRM (natural remanent magnetization) refers to untreated samples (0 Oe)

The results from these analyses indicate that the optimum demagnetization level for each sample is different and cannot be forecasted by textural or firing conditions or by archaeomagnetic parameters. As suggested by Tarling (1971:41), changes in a sample's remanence over several months can indicate only gross instabilities in acquired remanence, and longer periods are necessary to properly observe the instability of a remanence held by a given matrix. It is apparent from these results that very few secondary components were present in the experimental samples, and that perhaps the samples used in these experiments were not representative of the prehistoric samples due to their relatively recent nature. Demagnetization results of selected 1981 archaeological samples are presented in table 36. Relative directional changes and alpha 95 values were used to determine the optimum demagnetization level. It is apparent in several instances that alpha 95 values are reduced from NRM (0 Oe) to demagnetized levels, often below critical values used in archaeomagnetic dating. The archaeomagnetic samples tend to reach a critical point of demagnetization, above which the alpha 95 values increase (as illustrated by prehistoric sample 1 (5MT4613-1) and experimental samples 1, 2, 5, 7, 8, 9, 10, 11, and 12), although remanent directions are not displaced by more than a few degrees. Therefore, it seems advantageous from a dating standpoint to consider the optimum level, the level at which the smallest alpha 95 values coincide with the least amount of directional change.

Thermal demagnetization. Thermal demagnetization is a 'cleaning' procedure used by paleomagnetists and archaeomagnetists to observe magnetic properties of a rock or clay sample and to distinguish certain components inherent in those samples. Two methods of thermal demagnetization, progressive and continuous, are currently employed. The progressive method requires that a sample be heated thoroughly to a specific temperature and then cooled in a zero field (mer-metal shields are commonly used). When the sample is at room temperature, it is measured for the remaining magnetic remanence. This procedure is continued in a stepwise fashion, typically at 50° C intervals, up to temperatures exceeding the various magnetic minerals' Curie temperatures or until all remanence is removed. The continuous method measures a sample's magnetism continuously throughout the heating procedure; remanence is measured and observed up to the Curie point and during the cooling process. This procedure requires a more complicated set of equipment which was not available for these studies; therefore the progressive method was used.

Following AC demagnetization of the experimental samples at 200 Oe, thermal demagnetization was conducted on selected specimens from samples 4, 5, 6, 10, 11, and 12. This cleaning technique was employed after AC demagnetization for several reasons. First, the results from the modal analysis of the magnetic minerals in heated and unheated soils indicated

Table 36. Demagnetization results of selected 1981 Archaeomagnetic samples from prehistoric sites

Experimental sample No.	Archaeo-magnetic results	NRM* (0 Oe)	Demagnetization level (Oe) 50	75	100	125	150	200
1 5MT4613-1	alpha 95	3.53	4.37	3.55	3.55	3.23	5.18	4.58
	declination	340.3	341.9	341.7	340.8	341.4	346.0	345.7
	inclination	59.9	59.0	59.8	59.4	59.6	59.3	58.8
2 5MT5106-2	alpha 95	2.11	1.50	1.55				
	declination	345.5	347.2	347.4				
	inclination	63.0	62.8	63.3				
3 5MT5106-3	alpha 95	2.96	1.77	1.98				
	declination	359.8	2.9	2.67				
	inclination	55.3	53.4	52.9				
4 5MT5106-5	alpha 95	3.44	2.49	2.10				
	declination	2.2	5.4	3.42				
	inclination	52.6	52.7	52.8				
5 5MT5106-6	alpha 95	3.26	3.06	3.00				
	declination	359.3	2.4	2.1				
	inclination	55.1	54.6	54.8				
6 5MT5106-7	alpha 95	4.29	2.79	2.64				
	declination	5.1	2.3	2.0				
	inclination	57.7	57.9	58.1				
7 5MT5107-3	alpha 95	5.21	2.85	2.47				
	declination	9.2	7.5	6.0				
	inclination	49.3	48.5	49.0				

Table 36. Demagnetization results of selected 1981 Archaeomagnetic samples from prehistoric sites--Continued

Experimental sample No.	Archaeo-magnetic results	NRM* (0 Oe)	Demagnetization level (Oe) 50	75	100	125	150	200
8 5MT5107-4	alpha 95	3.69	3.02	2.93				
	declination	360.0	2.53	2.9				
	inclination	52.6	51.3	51.9				
9 5MT5107-8	alpha 95	3.57	2.53	2.38†				
	declination	7.6	9.9	7.1				
	inclination	53.9	53.7	53.2				
10 5MT5108-1	alpha 95	3.19	2.72	2.60†				
	declination	1.70	2.5	2.7				
	inclination	49.7	49.2	49.4				
11 5MT5108-3	alpha 95	2.85	3.14	1.86†				
	declination	3.6	5.0	7.3				
	inclination	57.1	56.2	56.0				
12 5MT5108-4	alpha 95	7.08	2.44†	3.50				
	declination	358.3	3.8	2.5				
	inclination	52.2	53.0	52.9				
13 5LP242-1	alpha 95	3.02	3.69	3.51	3.25	2.65†		
	declination	359.2	2.5	359.8	359.4	0.80?		
	inclination	50.8	50.2	49.7	50.4	49.5		

* NRM (natural remanent magnetization) refers to untreated samples.
† Optimum demagnetization level.

production of new hematite grains in heated soils, and thermal demagnetization was recognized as a means of verifying that a CRM had occurred in heated soils. Although CRM can be acquired at temperatures below the Curie points of magnetite and hematite (Strangeway 1970:46), the remanence acquired can be stable up to the Curie temperature of the remanence-holding mineral, and the resultant magnetization behaves much as TRM (McEllenny 1973:60). Therefore, if CRM is the source of remanence, hearths which did not attain firing temperatures near the Curie points of magnetite or hematite should maintain a remanent direction up to the Curie point of hematite as it is suspected that hematite is being produced. Second, as stated by the law of partial TRM (Nagena 1961:158, Irving 1964:26), the magnetization acquired during any one temperature interval is independent of the remanence acquired during other temperature intervals, and the total TRM is equal to the magnetization acquired at various temperature intervals. Therefore, thermal demagnetization was viewed as a method for distinguishing the various temperature intervals at which the majority of remanence is carried in each sample. For instance, in the low-fired hearths the measured remanence should dissipate after the temperature reached during firing is obtained in demagnetization procedures. However, in the high-fired hearths the measured remanence should follow more of a normalized TRM curve for either magnetite or hematite (the major carriers of remanence in clay samples) because the firing temperatures achieved the Curie points of magnetite and hematite. This situation is somewhat complicated by two facts: the matrix temperatures during firing were characterized by a gradient, and material closest to the fire was subjected to much higher temperatures than material at greater distances from the fire. Hence, within each 1- by 1- by 1-cm clay pedestal, a gradient of partial TRMs is inherent. Consider the firing temperatures from hearth 9: at the rim face (thermocouple 5) the average high temperature was 380° C, yet at a depth of 1 cm (thermocouple 3), the average high temperatures was at 195° C.

Finally, thermal demagnetization was viewed as a method for identifying the magnetic mineral responsible for carrying the primary remanence. The Curie temperature of magnetite is 580° C, of hematite 675° C; therefore, if the majority of remanence is removed at 580° C thermal heating, it might be deduced that magnetite was the primary carrier of remanence.

The thermal demagnetization method was employed, therefore, as a device to distinguish the source of remanence acquired by hearths heated to different temperatures. The direction and intensity values are both indicators of the magnetic remanence present in each specimen. Twenty-two specimens were step-demagnetized by progressive thermal methods. Although ideally the specimens should have been demagnetized at 50° C intervals, a problem with specimens cracking apart necessitated fewer heating steps. All specimens were heated at 150° C and 300° C, and then, depending on the physical condition of the individual specimen, at 400° C, 475° C, 500° C, and/or 580° C. At least two specimens from each sample were demagnetized at 580° C. Figures 31-33 display the intensity curves for each specimen throughout the thermal demagnetization process. Figures 34-40 plot the directional changes for each specimen.

The results from sample 4 are problematic because the firing temperatures of the matrix were sufficient to produce a total TRM, yet the directions of specimens 6 and 7 are displaced before the Curie temperature of either magnetite or hematite is reached. However, specimens 2 and 7

Figure 31

Figure 32

Figure 33

Figure 34

Figure 35

Figure 36

Figure 37

Figure 38

Figure 39

Figure 40

display a "typical" TRM relationship, with nearly all remanence removed by 580° C. The evidence from the direction of magnetization indicates the possibility of chemical change during the thermal demagnetization process and although the remanence is removed by 580° C, it is difficult to determine if the remanence was carried by magnetite or hematite. The results from sample 10 are more typical of a total TRM, with the majority of remanence removed at 580° C thermal demagnetizaion. However, the directions at 580° C of specimens 6 and 12 still adequately mimic the ambient field at the firing location. This evidence indicates that, although the majority of remanence was carried by magnetite, hematite was also carrying a remanent direction. Consider the magnetic properties of magnetite and hematite; although hematite is a much more stable substance, magnetite acquires a more intense magnetization.

Hearths 5, 6, 11, and 12 were all heated to temperatures below the Curie points of magnetite, hence, a total TRM should not have been acquired by any of these hearths. The intensity curves of these hearths, however, indicate that even after average high firing temperatures were achieved during thermal demagnetization, much of the remanence was still present. The specimen directions indicate the ambient field direction is replicated up to 500° C; at 580° C the remanent directions have fallen well away from the ambient field direction. Although thermal demagnetization temperatures of only 400° C were reached before stepping to 580° C, the remanent directions from sample 6 indicate identical results. The three specimens selected from hearth 11 were thermally demagnetized at 150° C, 300° C, 475° C, and 580° C. The remanent directions fall near the ambient field direction up to 475° C, but at 580° C no longer replicate this field direction, with the exception of specimen 4. The remanent directions for sample 12 specimens demagnetized at 400° C are spurious at this temperature, and it is apparent that the remanent directions have been removed at the temperature to which the matrix was heated in the ambient field direction.

The results from these analysis are confusing. The results from hearths 5, 6, and 11 indicate a strong remanence even after firing temperatures were achieved in demagnetization, yet most of the remanence is at 580° C. Assuming a CRM, the remanence carried should have been carried by hematite due to oxidation processes; however, the primary remanence is eliminated by 580° C, indicating that magnetite was the primary source of remanence.

Magnetometer Survey

In order to more fully understand the magnetism produced by different firing temperatures in (0.5 m diameter) features, a magnetometer survey was conducted at 0.5 m intervals with quarter gamma sensitivity. At such intervals, small burned features, such as the experimental hearths, should be detectable by a magnetometer survey (Burns et al. 1981:160). The magnetic field of a 10- by 10-m area was magnetically surveyed after construction of the hearths, but prior to hearth firing. The survey was then repeated after all three hearths in each of the locations were fired. The results from the magnetometer survey were then compared with the results from the archaeomagnetic samples collected from each hearth. It was hypothesized that the intensity of the anomalies from the magnetometer survey would be proportional to the intensity of the archaeomagnetic samples from each hearth. Since intensity tends to relate directly with archaeomagnetic success, this would provide an indicator of probable archaeomagnetic success prior to collection (or even excavation).

The magnetometer survey of experimental hearths 1-6 in locations 1 and 2 before and after firing experiments produced no useful information; no magnetic anomalies were distinguished in the magnetic profile (figs. , , , and). TIM I NEED TO ADD HERE THE MAPS OF THE HEARTH LOCATIONS IN LOCALITIES 1 AND 2, THESE ARE IN THE 1980 MAGNETOMETER NOTEBOOK IN THE FRONT SECTION. LEE CAN DRAFT FROM THESE COPIES AND I NEED TO HAVE THE HEARTH COORDINATES MENTIONED IN THE TEXT. SORRY, BUT I DO NOT HAVE A COPY OF THESE.

Although the original goal of correlating anomaly intensity with that measured in the NRM of archaeomagnetic sample results, was not accomplished due to the lack of a magnetic anomaly around the hearthsit is clear that small, burned features may be sufficiently magnetized by archaeomagnetic standards without necessarily producing magnetic field-like deflections of adequate strength to be noticed in a magnetometer survey such as the one tested. This does not, however, mean that magnetometer survey can be of no assistance in locating features of archaeomagnetic interest. It is suggested that a similar study might be initiated using known features which were detected during magnetometer reconnaissance and which were archaeomagnetically sampled. The anomaly intensity could then be compared to the archaeomagnetically determined sample intensity.

SUMMARY

The 1980 archaeomagnetic program produced 42 new dates for the prehistoric sites excavated by the DAP. The 1980 archaeomagnetic sampling program was more successful than the programs of previous years; 75 percent of the 1980 samples yielded remanent directions adequate for dating purposes. The Colorado State University research group also provided new temporal estimates for the 1978-1980 archaeomagnetic collections based on the DAP refined curve (Hathaway et al. 1979).

The intensive analyses conducted during the 1980 season contributed to ongoing archaeomagnetic research. Although the priority system was shown to be ineffective at the highest priority level, lower priority levels followed expected patterns of success. On the basis of these findings, it is suggested, that a stricter evaluation of burned features include a priority system for each of the five criteria listed in the 1979 archaeomagnetic report (Hathaway and Eighmy 1979:). In this manner the problems discovered in the 1980 (and 1979) analyses may be properly addressed and eventually solved.

The two orientation methods used for the experimental and prehistoric samples yielded contradictory results (the prehistoric collection indicated no difference between the sample alpha 95 means of Brunton and sun compass values, whereas the results from the experimental sample indicated a small difference). The differences cannot be a function of instrument measurement error as identical instruments were used to gather the data. These differences, however, are seen to be very small, and for all practical purposes the two measurement methods produce very similar archaeomagnetic results. Because the sun compass requires slightly more

effort and the presence of the sun and an accurate watch, the Brunton compass is regarded as the most reliable and quickest method for recording a specimen's in situ position. However, the sun compass is very useful when used in tandem with the Brunton compass to establish the true value of the local magnetic declination. The value published in several documents would never have been questioned if the differences between the sun and Brunton compases had not been discovered.

The experimental hearth data coupled with the results of analyses of the prehistoric collection set led to several important conclusions regarding archaeomagnetic sampling. First, as is apparent from the modal analysis and the thermal demagnetization treatments, CRM is an important aspect of low-fired as well as high-fired hearths. However, it is also apparent that the growth of the small hematite nodules does not contribute a great deal to the remanence. Magnetite appears to be a more likely candidate for the primary remanent carrier. It also is apparent that partial TRM may be a more important source of remanence than total TRM, and an understanding of the effects of partial TRM components over long time periods is crucial if the temporal associations of such features are to be adequately assessed. Based on the refiring experiments, it seems likely that each low-temperature fire contributes somewhat to the remanent direction; thus, it would be more appropriate to assume the remanence from multiple-use features, such as central hearths in pitstructures, is more accurately described by some midpoint of occupational use. It should be interjected here that any <u>one</u> high temperature (670° C) will 'erase' previous remanence and a <u>total</u> TRM will ensue; however, it is quite unlikely that the hearths inside pitstructures ever attained such temperatures.

Second, it appears from soil analyses and archaeomagnetic analyses of the prehistoric and experimental groups that although aquisition of TRM is a function of sand percentages, this relationship breaks down over time, and clay and silt percentages are more important for ancient archaeomagnetic media. This implies that a well-burned, sandy matrix, although originally acquiring a very intense remanence, will lose this remanence much quicker than will a poorly magnetized clay matrix. This might explain the relatively poor archaeomagnetic results from the Site 5MT2151 and Site 5MT2161. The samples fom both sites were comprised primarily of sand, and although the features appeared to be very burned, the archaeomagnetic results were very poor and for the most part did not yield datable results.

The temperature gradient noted in the hearths may be another factor in the aquisition of remanence. The experimental hearths associated with the greatest heat absorption are also correlated with the most intense archaeomagnetic results, and vice versa. Also, the temperature gradient was found to drop off rather radically with greater soil depth. This only reinforces the importance of collection procedures which ensure that the outermost portion of a features matrix (the portion nearest the fire) be recovered as the acquired remanence is severely reduced at greater soil depths.

Finally, AC demagnetization procedures were apparently not a necessary treatment for experimental samples but greatly improved the results from the prehistoric collection, primarily by reducing alpha 95 values to an archaeomagnetically appropriate level. It is important in demagnetization procedures to note any changes in directions from one step to the next. To ensure that primary remanence is not reduced so severly as to hinder dating of the sample, it is very important not to use an extreme level before first measuring intermittent levels.

In conclusion, the DAP archaeomagnetic program is providing empirical information which has improved the results obtained for samples collected from prehistoric sites excavated by the DAP. The Dolores refined curve (A.D. 700-900) has provided a better reference curve with which to evaluate archaeomagnetic samples. Advancements in collection and laboratory techniques have resulted in a higher success rate over previous years. It is hoped that further archaeomagnetic research will continue to reduce the inconsistencies and provide a more comprehensive set of data which archaeologists may use for dating prehistoric sites.

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GLOSSARY

Alpha 95 - Represents the radius of a circle around the mean sample direction within which the true mean is expected to fall 95 percent of the time. Smaller values indicate tighter clustering around the mean direction and, thus, better archaeomagnetic quality. Alpha 95 values greater than 3.5° are not used for archaeomagnetic dating.

Alternating current demagnetization (C) - A laboratory treatment applied to archaeomagnetic samples which is though to reduce the effects of secondary components (especially VRM) by application of an alternating field of varying intensities to an archaeomagnetic specimen; the field is brought to the desired level and then slowly reduced to zero. Generally conducted in a stepped-fashion from 25 oersteds up to +200 oersteds.

Archaeomagnetic sample - In situ pedestals of burned earth encompassed in a 1" clay cube. Each cube recovered represents one specimen, 12 of which are usually collected for a complete sample.

Chemical remanent magnetization (CRM) - Magnetic remanence acquired as a magnetic mineral grows past a critical diameter (blocking volume) or as one magnetic mineral adheres to another (ferromagnetic mineral).

Coercivity - The field required to reduce a saturated magnetic substance to 0. Coercivity is a measure of the magnetic stability of remanence--the larger the coercive force, the more stable a substance's remanence.

Curie temperature - The point at which a substance's previous magnetic orientation is completly "erased" and it's orientation alines parallel to the applied field (i.e., the Earth's field) occurs. This point varies depending upon the magnetic mineral affected.

Error perpendicular to the great circle (EM) and error along the great circle (EP) - Derived from the polar projection of the alpha 95 cone of confícence and centered on the mean paleopole direction (paleolatitude and paleolongitude). EP runs along the great circle described by a line drawn from the site latitude and longitude to the mean paleopole direction. EM is perpendicular to EP; both are centered on the mean paleopole position.

Ferromagnetic minerals - Those magnetic minerals present in a soil matrix (up to 5 percent) which are capable of acquiring and retaining a magnetic remanence over long periods of time. These minerals are commonly hematite and magnetite.

Isothermal remanent magnetizaion (IRM) - Magnetic remanence acquired as a result of a large magnetic field or electrical charge (such as lightning) being applied near a substance, thus erasing any previously acquired magnetic orientation.

Magnetic declination - The apparent magnetic field direction of a given area; the difference, measured in degrees east or west, between true north, and magnetic north.

Magnetic inclination - The degree to which the Earth's magnetic field is deflected from the center of the axis of rotation (dip).

Magnetic remanence - Magnetism acquired and retained by a substance in one of several manners (TRM, PTRM, CRM, IRM). The magnetic direction acquired parallels the ambient magnetic field present (i.e., the Earth's field) and may by retained for millenia.

Natural remanent magnetization (NRM) - The magnetism of a pristine, untreated archaeomagnetic sample; NRM may be a result of both primary and secondary magnetization.

Oersted (Oe) - Unit of measurement designating magnetic field strength.

Outlier - A specimen's remanent direction which is not representative of the rest of the sample. An outlier is any specimen direction which falls over two angular standard deviations from the sample mean direction. Once defined as such, the specimen in excluded from the sample set and a new mean and alpha 95 are determined.

Paleolatitude and paleolongitude - The ancient magnetic direction as recorded by archaeomagnetic samples. Paleolatitude and paleolongitude represent the projection of the remanent declination and inclination from the site latitude and longitude to the north polar region.

Partial thermoremanent magnetization (PTRM) - The magnetism acquired when a matrix is heated below the Curie temperature of the magnetic mineral present.

Primary remanence - The component of archaeomagnetic remanence acquired during the firing episode; may be caused by TRM, PTRM, CRM, or a combination of these.

Remanent directions - The magnetic orientation measured from a single archaeomagnetic specimen, or may refer to the mean sample direction.

Saturation magnetization - The point at which a substance can not acquire additional magnetism.

Secondary remanence - That component of archaeomagnetic remanence which has been acquired subsequent to the firing episode; generally caused by either VRM or IRM.

Southwest archaeomagnetic curve - A series of VGP locations recorded over an extended period of time (A.D. 700-1500) for the southwest region of North America.

Thermal demagnetization - Demagnetization of an archaeomagnetic sample by heating each specimen to a specific temperature and then cooling it in a zero magnetic field. This technique is accomplished in temperature steps, generally from 150° C - 680° C

Thermoremanent magnetization (TRM) - Magnetic orientation acquired as a substance is heated above a critical point, the Curie temperature; TRM becomes "frozen" upon cooling to room temperature.

Virtual geomagnetic pole (VGP) - The projected north polar position of the apparent magnetic field at a given place and time recorded in archaeomagnetic material.

Viscous remanent magnetization (VRM) - Magnetic remanence which results from the influence of the Earth's magnetic field over long periods of time. Some of the "soft" magnetic grains in a substance tend to lose their orientation and aline towards the ambient field (i.e., the present Earth's field which changes through time). This component may be substantial and thus mask primary remanence (TRM, PTRM, and/or CRM).

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