# ARCHEOMAGNETIC SECULAR VARIATION

by

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# ABSTRACT

This investigation had two goals. The first was an attempt to verify a reported rapid increase in the intensity of the earth's magnetic field in the time period 800-1000 A.D., which was first noted by Bucha in 1970. The second was to measure intensity and magnetization direction on archeological samples between 4000 and 8000 years in age.

For the first objective, potsherds from Utah Highway 95 archeological digs were used. The styles of pottery were tree ring dated 750-1100 A.D. at other sites. For the second objective, baked earth samples collected from the Sudden Shelter site in southern Utah spanning 3360-7565 B.P. were used.

Paleointensities were determined using the double heating technique developed by Thellier (1935).

The paleointensities of the potsherds confirmed the anomalous increase in intensity from 800-1000 B.C. as well as the existence of relatively short period secular variation in magnetic intensity.

The directional data obtained from the Sudden Shelter samples had poor statistical precision and the mean direction was displaced from the axial dipole direction towards the present field indicating a viscous magnetization.

Paleointensity data from the Sudden Shelter site was marginal. They defined a trend differing systematically from that found by Bucha (1967) in Czechoslovakia.

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TABLE OF CONTENTS

| | |
|---|---|
| Abstract | iv |
| Acknowledgement | v |
| Figures | vi |
| Tables | vii |
| Archeomagnetism and the Secular Variation | 1 |
| Paleointensity Determination | 5 |
| Calibration and Test of the Paleointensity Apparatus | 8 |
| Data Reduction | 11 |
| Pueblo Pottery | 14 |
| Archaic Baked Earth | 16 |
| Conclusion | 25 |
| References | 26 |

FIGURES


| | | |
|---|---|---|
| Figure 1. | Apparent pole positions for archaeomagnetic data. Kawai, et al, 1965 | 2 |
| Figure 2. | Average intensity ratio $F/F_0$ for Arizona and changes of geomagnetic field during the past 2000 years. V. Bucha, 1970 | 4 |
| Figure 3. | Variation of earth's magnetic field intensity during archaeological times in Czechoslovakia. V. Bucha, 1967 | 4 |
| Figure 4. | TRM vs. NRM for sample 1-E | 12 |
| Figure 5. | Schematic composite section --Sudden Shelter (42 Sv6). University of Utah, Dept. of Anthropology, 1975 | 17 |
| Figure 6. | TRM vs. NRM for sample 211-3 | 21 |
| Figure 7. | Comparison of data in Figure 3 with Sudden Shelter data | 24 |

TABLES


| | | |
|---|---|---|
| Table 1. | Vector magnetic moments of sample 1-E | 13 |
| Table 2. | Pueblo pottery paleointensity data | 15 |
| Table 2a. | Pueblo pottery paleointensity statistics | 15 |
| Table 3. | Sudden Shelter samples with carbon dates | 18 |
| Table 4. | Sudden Shelter directional data | 19 |
| Table 5. | Sudden Shelter paleointensity data | 22 |
| Table 5a. | Sudden Shelter paleointensity statistics | 22 |
| Table 5b. | Sudden Shelter paleointensities relative to present field | 23 |

## ARCHEOMAGNETISM AND THE SECULAR VARIATION

By using ancient baked potteries and other baked artifacts which have survived to the present, one can study the secular variation of the earth's magnetic field over the period when these objects were made. These objects acquired a stable TRM which records the earth's field at the time when they were heated and subsequently cooled in the earth's field. This thesis is concerned with both the direction and magnitude of the earth's magnetic field in the past.

The virtual magnetic pole position appears to wander in a definite pattern with up to 20° deviations from the geographic pole (Fig. 1). The average position over 1000 years nearly coincides with the geographic pole of the earth. M. J. Aitken (Fig. 1a) has shown that the secular variation over the past four centuries is not representative of the historical past, which makes the previous idea of a simple cyclic secular variation unthinkable. If the main dipole of the earth were to wander, variations in apparent pole position would be identical the world over. But if the variations in apparent pole position are due only to local events, then different polar paths should be found at separate places on the earth. It is also possible that the apparent path of the pole is due to a wandering of the main dipole in a counter-clockwise sense with a superimposed local effect producing the smaller variations.

By using archeological materials, information about the apparent dipole moment of the ancient geomagnetic field can also be derived.

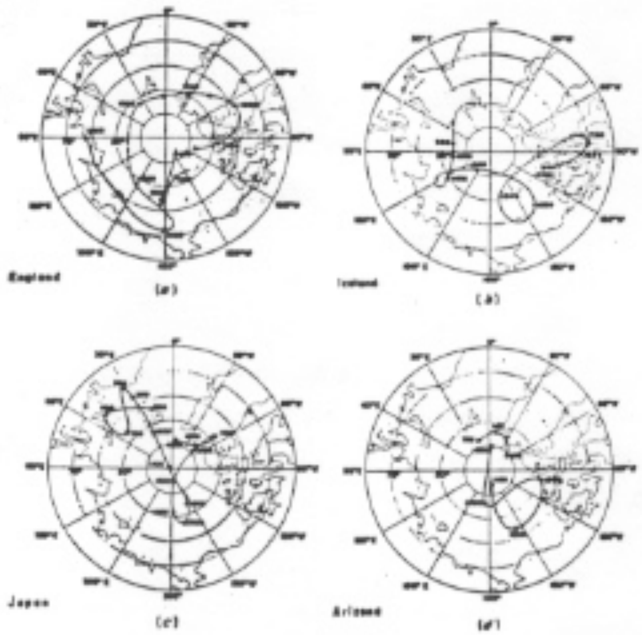

Fig. 1 Apparent pole positions for archeomagnetic data. Clockwise loops show westward drift and counter-clockwise show eastward drift. From: Kawai et al., 1965.

If the apparent geomagnetic dipole moment varies from one location to another at the same time, this would be an indication of local secular variation. If the apparent dipole moment is similar at different locations at the same time, this would be an indication that the field itself is dipolar and the change is in the intensity of the dipole field itself. Fluctuations up to 50% can be expected in apparent dipole moment, as shown on secular variation charts. Figure 2 depicts the relative dipole moment during the last 2000 years in Arizona. Figure 3 indicates a substantial weakening of the dipole field rather than local changes in magnetic field intensity. Due to superposition of dipole and non-dipole fields, intensity measurements from a specific locality do not uniquely represent the apparent moment of the dipole itself, but data from widely separated areas show a mutually consistent weakening of the dipole over the past 2000 years.

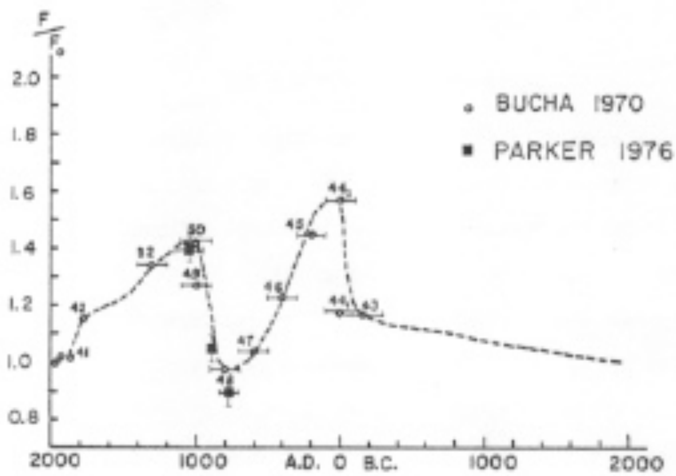


Fig. 2. Average intensity ratio $F/F_0$ for Arizona and changes of Geomagnetic field during past 2000 years. V. Bucha 1970.

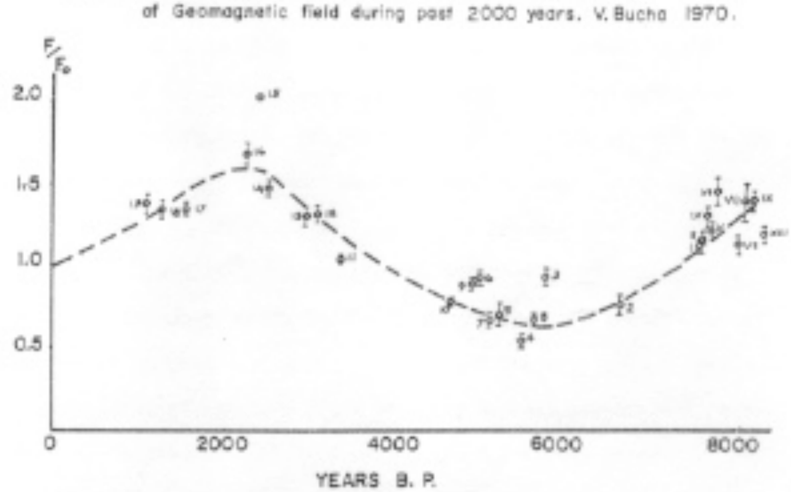


Fig. 3. Variation of Earths Magnetic Field intensity during archeological times in Czechoslovakia. V. Bucha 1967.

## PALEOINTENSITY DETERMINATION

The intensity of magnetism preserved in ancient materials is related to the intensity of the magnetic field in which it was acquired. Specific laboratory procedures (described below) allow determination of the intensity of the ancient field. TRM (thermoremanent magnetization) is the dominant cause of the remanent magnetism in the samples measured in this study, and for the weak fields in nature it is nearly proportional in intensity to and coincident with the direction of the field at the time the sample was cooled.

The classical work in paleointensity was done by Thellier and Thellier in Paris in 1935. They studied baked materials from archeological sites and with it developed the double heating method of paleointensity determination. The additive property of PTRM (partial thermoremanent magnetization) was deduced from their work. This additional law for PTRM states that the thermoremanence produced by a weak field in a specific temperature interval is independent of the magnetization produced by the field when cooling through other temperature intervals (Nagata, 1961). This property allows many determinations of the same field by using various temperature intervals. Variations of the field during the relatively short time of initial cooling are neglected. As applied in this thesis, the Thellier method requires cooling the specimen twice from any given temperature. The first cooling is in zero field and the second is in a laboratory field of controlled magnitude and direction. This double cooling is repeated from successively higher temperatures. The difference in magnetic moment after successive zero-field coolings is the NRM (natural remanent magnetism) lost in the temperature interval, while the difference in magnetic moment after successive coolings in the laboratory field is the TRM gained. The ratio of NRM lost to TRM gained is the ratio of the paleointensity to the laboratory field intensity.

Various archeological materials were used by Bucha (1967) in his study of the paleointensity of the magnetic field in Czechoslovakia. The best results were obtained from burnt clays of a uniform red color. If the initial baking of the sample was in a reducing atmosphere, then it is possible that during heating in the laboratory, where the atmosphere is oxidized, magnetite will oxidize into $Fe_2O_3$ (hematite). This will result in a non-linear relationship between the demagnetization and remagnetization increments. Bucha also found that the homogeneity of the original heating throughout the sample is a very important factor. It is advantageous to use smaller samples that have baked evenly rather than larger ones that have not.

Recently, several attempts have been made to determine paleointensity by comparing the decrease of NRM in alternating-field demagnetization with the "anhysteretic" gain in remanence when the alternating field is applied with a steady laboratory field (Banerjee and Mellema, 1974; Stephenson and Collinson, 1974). This method has the potential advantage that oxidation during heating is avoided. The accuracy and reliability of "cold" paleointensity determinations has not yet been well documented and essentially all paleointensity determinations on baked clay have used a variant of the Thellier method.

CALIBRATION AND TEST OF THE PALEOINTENSITY APPARATUS

A model TSD-1 Thermal Specimen Demagnetizer was acquired from Schonstedt Instrument Company of Reston, Virginia. The first unit manufactured was delivered to the University of Utah in May of 1975. Various tests were performed on the thermal demagnetizer before actual paleointensity studies were begun.

The TSD-1 has a magnetically shielded cooling chamber. The rate of cooling in this chamber was tested by fabricating a sample rock of fine silt cemented with sodium silicate formed around a thermocouple. Cooling time was recorded as ten minutes to cool from 600°C to 40°C with the cooling fan on and the oven door closed.

In the cooling chamber, a coil is used to apply a small D.C. field to the cooling specimens. A battery in series with a resistor supplied the current. Test samples were introduced and the intensities were noted to increase upon repeated cooling in the applied field. It was suspected that the magnetic shield of the cooling chamber was becoming magnetized. The shield was then demagnetized by applying a decaying A.C. field controlled by a Variac. The A.C. voltage was increased to ten volts and allowed to decay to zero in ten seconds. The test samples were reheated and cooled in the applied D.C. field and remeasured. Results showed a definite decrease in intensity. A similar test was completed by switching the polarity of the small D.C. field rather than using an A.C. demagnetizing field.

Similar results were noted. Both methods of reducing the remanance on the shield were used in actual paleointensity studies.

When heated samples were introduced into the cooling chamber, the voltage on the current sampling resistor was noted to drop 5%, then rise back to normal as the sample cooled. This suggested that the resistivity of the coil increased significantly with temperature. A control circuit was designed using a silicon transistor for current regulation. This circuit held the current constant with changes in resistance up to 20 ohms.

The Thellier method determines the paleointensity relative to a laboratory standard field applied to the cooling samples. For the present work, the standard field was chosen to correspond to 100 ma in the coil installed by the manufacturer, Schonstedt. In telephone communication, the Schonstedt engineer reported measuring before shipment a coil sensitivity of 122.8 ma/gauss. With this value the standard field is 0.8143 gauss.

As an independent test, paleointensity determinations were run on samples of baked pottery which were heated from 600°C and allowed to cool in the laboratory. The ratio of artificial paleofield to standard field was determined by the same procedure to be used later for the actual paleofield. Two different runs were made in different locations in the lab, each with two samples. The ratios were as follows:

| | | |
|---|---|---|
| Run #1 | $0.0395 \pm 0.0135$, | $0.396 \pm 0.0126$ |
| Run #2 | $0.423 \pm 0.0125$, | $0.420 \pm 0.008$ |

The actual field intensity at each test site could not be measured directly. However, measurements of relative values of vertical field, using an Askania torsion balance showed that the fields differed by less than 0.01 gauss and were approximately 0.04 gauss less than that outside the building. At the exterior site, a Geometrics proton precession magnetometer indicated 0.5497 gauss, in close agreement with magnetic charts. By this indirect means the field intensity at either test site is estimated at 0.50 ± 0.03 gauss.

This calibration experiment is in serious disagreement with the Schonstedt factor. If the standard field is indeed 0.8143 gauss, then the artificial paleointensities are:

Run #1: 0.322 gauss

Run #2: 0.344 gauss

These values are well outside the range estimated above. One possibility is that the Schoenstedt factor is incorrect. In this case the standard field could be approximately determined from the data reported above. Run #2 is to be preferred because the site was carefully chosen in a location of low magnetic gradient. The inferred value of the standard field is

1.18 ± 0.1 gauss,

some 40% higher than the value of 0.8143 gauss calculated from the Schonstedt sensitivity factor.

DATA REDUCTION

A Digico Spinner Magnetometer was used for measuring vector magnetic moments after each cooling. A Hewlett Packard 9100 computer was used to calculate the TRM associated with each temperature. This was accomplished by a vector subtraction of the NRM remaining after cooling in a zero field from the magnetization after cooling in the applied field. After the values of NRM and TRM were calculated for each temperature, a linear regression routine was utilized to plot TRM vs NRM, to fit the best straight line to this plot and calculate the slope, correlation coefficient and the error of the slope. The formula for the error of the slope is given as:

$$\epsilon_s = \frac{\Sigma(y_i - \bar{y})^2 \Sigma x_i^2}{(N^2 - 2N)(N\Sigma x_i^2 - (\Sigma x_i)^2)}$$

Table 1 lists vector magnetic moments for a particular example. Figure 4 shows the TRM plotted against the NRM, the best straight line fit and error statistics for this example.

For paleointensity studies the ratio needed is that of NRM relative to TRM in the standard laboratory field. However, the TRM was chosen as the independent variable y in the regression equations. (Because the TRM depends on both measurements at each temperature, it must statistically have a larger error than the NRM). Therefore, the slope given by the regression equation must be inverted and its error corrected accordingly. For the example in Figure 4.

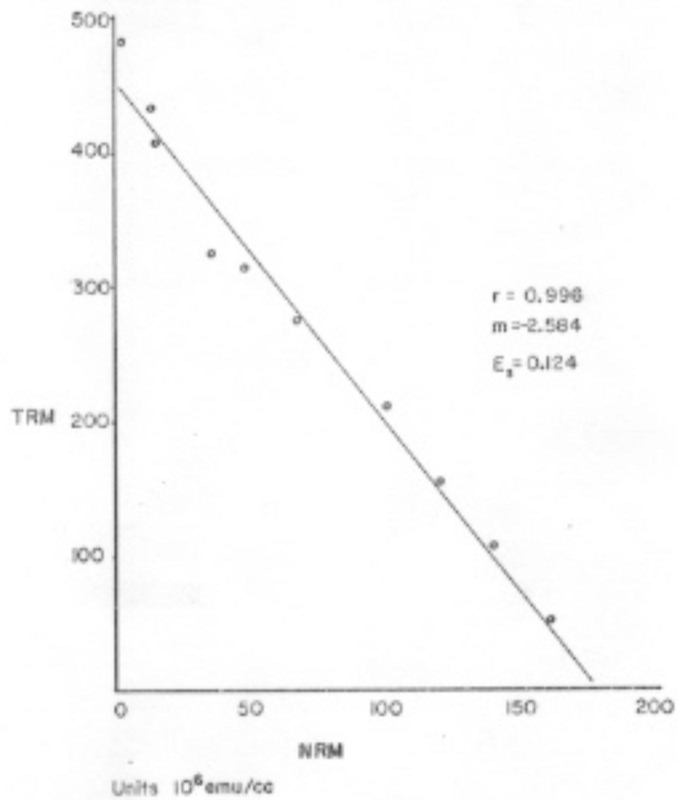


Fig. 4. TRM vs. NRM for sample I-E. 100°-580°C.

$$\text{Slope} = \text{NRM/TRM} = \frac{1}{-2.584} = -.387$$

$$\text{Slope error Es} = \frac{0.124}{(-2.584)^2} = 0.018$$

This new slope is now multiplied by the standard field to obtain paleointensity.

TABLE 1: Vector magnetic moments of sample 1-E.

| TEMP | COOLING FIELD | INTENSITY $10^{6}$EMU/CC | DEC | INC |
|---|---|---|---|---|
| 100 | applied | 163.910 | 265.5 | -32.2 |
| 100 | zero | 160.176 | 275.4 | -32.4 |
| 150 | applied | 159.646 | 264.1 | -33.4 |
| 150 | zero | 166.561 | 245.3 | -29.9 |
| 200 | applied | 139.096 | 264.8 | -32.3 |
| 200 | zero | 170.756 | 308.1 | -24.7 |
| 250 | applied | 117.354 | 264.8 | -32.7 |
| 250 | zero | 196.036 | 208.2 | -20.3 |
| 300 | applied | 99.928 | 266.8 | -32.7 |
| 300 | zero | 221.041 | 341.4 | -20.3 |
| 350 | applied | 66.318 | 267.4 | -32.7 |
| 350 | zero | 281.965 | 190.8 | -11.4 |
| 400 | applied | 46.566 | 263.9 | -34.1 |
| 400 | zero | 311.309 | 351.1 | - 6.2 |
| 450 | applied | 33.959 | 264.9 | -36.1 |
| 450 | zero | 324.511 | 181.9 | - 5.4 |
| 500 | applied | 14.602 | 258.3 | -34.8 |
| 500 | zero | 404.815 | 355.2 | - 2.0 |
| 530 | applied | 13.553 | 256.6 | -34.5 |
| 530 | zero | 451.866 | 181.5 | - .8 |
| 570 | applied | 0.968 | 208.1 | -25.0 |
| 570 | zero | 480.329 | 357.4 | - 1.6 |

## PUEBLO POTTERY

Pieces of Pueblo pottery were used for intensity studies for the period 760 to 1100 A.D. Three styles were chosen from the University of Utah collection. For intensity studies the samples should have been completely oxidized when originally fired (Bucha, 1967). This severly limits the kinds of pottery that can be used for intensity studies. The three styles chosen for this study and their dates (Breternitz, 1966) are:

Set 1 Abajo Red on Orange
760-875 A.D. best tree ring dates

Set 2 La Plata Red
850-872 A.D. best tree ring dates

Set 3 San Juan Red
900-1100 A.D. dates uncertain

The three styles were collected from two Utah Highway 95 sites excavated by the Department of Archeology of the University of Utah (University of Utah, 1974). The samples were cut to fit into an aluminum jig that could be used in the spinner magnetometer. The magnetic moment of the jig was too small to be detected. The data are tabulated in Table 2. The paleofield from each sample group with statistics is given in Table 2a.

The quality of the samples was excellent. Only two samples were not totally reddened. Upon heating, these two samples produced non-linearities in the data and, hence, are not reported in Table 2.

TABLE 2: Pueblo pottery paleointensity data.

| SAMPLE | TEMPERATURE RANGE C | # OF DATA POINTS | NRM/TRM | ERROR ON SLOPE |
|---|---|---|---|---|
| 1A | 100-500 | 9 | 0.424 | 0.078 |
| 1B | 100-500 | 9 | 0.514 | 0.055 |
| 1D | 100-500 | 9 | 0.284 | 0.012 |
| 1E | 100-570 | 11 | 0.387 | 0.018 |
| 2A | 100-500 | 9 | 0.478 | 0.071 |
| 2B | 100-500 | 9 | 0.316 | 0.021 |
| 2C | 100-500 | 10 | 0.545 | 0.031 |
| 2D | 100-570 | 11 | 0.355 | 0.032 |
| 2E | 100-570 | 11 | 0.560 | 0.037 |
| 3B | 100-530 | 10 | 0.633 | 0.043 |
| 3C | 100-530 | 10 | 0.600 | 0.041 |
| 3D | 100-570 | 11 | 0.560 | 0.028 |
| 3E | 100-570 | 11 | 0.788 | 0.036 |

TABLE 2a: Pueblo pottery paleointensity statistics.

| SAMPLE GROUP | MEAN NRM/TRM | STANDARD DEVIATION | PALEOFIELD 0.8143 STD. | PALEOFIELD 1.18 STD. | PALEOFIELD/PRESENT FIELD 0.8143 STD. | 1.18 STD. |
|---|---|---|---|---|---|---|
| 1 | 0.402 | 0.0827 | 0.327 | 0.474 | 0.605 | .877 |
| 2 | 0.451 | 0.0980 | 0.367 | 0.532 | 0.679 | .985 |
| 3 | 0.645 | 0.0883 | 0.525 | 0.761 | 0.972 | 1.41 |

The mean paleointensity from each sample group using the 1.18 gauss standard field relative to $F_0$ is plotted on Figure 2. They agree well with the curve when using the 1.18 gauss standard field calculated in the laboratory. The results confirm the anomalous increase in intensity from 800 to 1000 A.D. The quality of the data is about the same as that reported by Bucha (1970) in a study of potsherds from Arizona. These results along with those of Bucha (1970) suggest that this curve could be used to confirm the dating of objects thought to be in this age range.

## ARCHAIC BAKED EARTH

Sudden Shelter (46 sv6) is a rock shelter along the right-of-way for Interstate 70 in Salina Canyon, Utah. It was excavated in 1974 by the Utah Archeological Survey. Their work revealed a stratigraphy which included several distinct archeological levels (Fig. 5). Evidently, occasional floods deposited several inches of silt without eroding previous layers. It is thought that these sediments were deposited over a period of several milenia sometime over 2000 years ago. During these times, stone-age people who camped in the Canyon would build open fires on the earth floor of the shelter.

At the invitation of J.D. Jennings, Utah Archeological Survey, the site was visited by Dr. Ralph Shuey to assess the archeomagnetic possibilities. While the shelter contained many dozens of hearths, the enforced speed of the excavation made most of them unavailable. Only a portion of the site could be excavated and some hearths had to be cut out by the archeologists to get at deeper strata. Some of the exposed hearths appeared to be suitable for archeomagnetic measurements, in that the silt was reddened over an inch deep and appeared to have been undisturbed since the fire. However, Dr. Shuey judged that these hearths would be too sparsely distributed in time for determining a continuous directional variation curve, as in Figure 1. However, it was anticipated that radiocarbon dating of the strata would allow a comparison of paleointensity data with Figure 2.

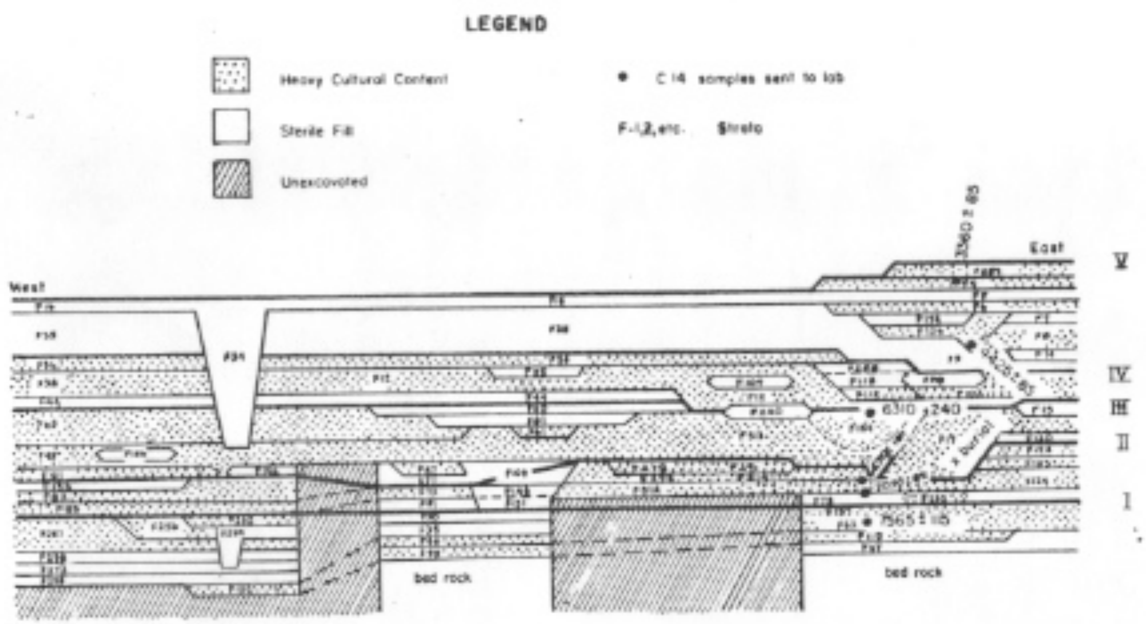


Fig. 5. Schematic composite section — Sudden Shelter (42 Sv 6). University of Utah, Dept. of Anthropology (1975).

The decision was made to sample all available hearths which seemed potentially useful for archeomagnetism. The samples were encased in oriented plaster cubes. No more than six cubes were taken from any hearth, to reduce the time needed for sampling. It was judged that six cubes would suffice to give a good estimate of directional scatter (Fisher precision index k). Only those hearths with low scatter of magnetization direction would be considered for paleointensity measurements. Six samples would not suffice to give a highly accurate estimate of the mean direction even if the sample scatter were low. However, as mentioned earlier, it was expected that a precise paleofield direction would be of little value because radiocarbon dating of any given hearth would be uncertain by several hundred years. Sample quality ranged from poor to excellent with 20% being completely reddened by the ancient fires. The stratigraphic section with respective horizons is shown by Figure 5.

The sample sets, their respective horizons in the stratigraphic section and radiocarbon dates for each horizon are listed in Table 3.

TABLE 3: Sudden Shelter samples with carbon dates.

| SAMPLE SETS | HORIZON # | RADIO CARBON DATE B.P. |
|---|---|---|
| 232, 207 | I | 7565 ± 115 |
| 205, 206, 212<br>213, 214, 217 | II | 7090 ± 85 |
| 204, 210, 211<br>231 | III | 6310 ± 240 |
| 203, 215, 216<br>209 | IV | none available |
| 208, 233, 234 | V | 4425 ± 85 |

Magnetization directions were determined with an astatic magnetometer. About one tenth of the samples were A.C. demagnetized at 50 gauss to remove secondary viscous magnetization and remeasured. In each case the directional data moved toward the mean for the set (Refer to Table 4). A magnetic variation of 15 degrees east was used in correcting magnetic north to geographic north. The results are tabulated in Table 4.

TABLE 4: Sudden Shelter directional data.

| SAMPLE SET # | N | INC | DEC | K | ALPHA 95 |
|---|---|---|---|---|---|
| 203 | 5 | 59.4 | 14.3 | 430 | 3.7 |
| 204 | 6 | 63.4 | 8.1 | 70 | 8.0 |
| 205 | 5 | 66.4 | 16.7 | 31 | 13.9 |
| 206 | 6 | 65.4 | - 4.9 | 31 | 12.2 |
| 208 | 4 | 57.3 | - 2.5 | 63 | 11.7 |
| 209 | 6 | 60.6 | 7.2 | 140 | 5.7 |
| 210 | 6 | 63.0 | 20.2 | 69 | 8.2 |
| 211 | 6 | 66.3 | 3.7 | 370 | 4.0 |
| 212 | 5 | 68.3 | 13.7 | 290 | 4.5 |
| 213 | 6 | 55.1 | 5.6 | 83 | 7.4 |
| 214 | 6 | 59.2 | - 0.8 | 150 | 5.6 |
| 215 | 3 | 56.7 | 16.1 | 19 | 29.4 |
| 216 | 4 | 69.8 | 5.7 | 470 | 4.3 |
| 217 | 5 | 66.6 | 6.5 | 210 | 5.3 |
| 231 | 5 | 65.1 | 13.3 | 210 | 5.3 |
| 232 | 6 | 62.1 | - 6.2 | 120 | 6.1 |
| 233 | 6 | 59.3 | - 2.8 | 2.3 | 58.4 |
| 234 | 6 | 63.9 | 1.4 | 83 | 7.4 |

Mean of inclination = 62.7
Mean of declination = 6.4

The mean direction is displaced from the axial dipole direction towards the present field. This may be attributed to viscous magnetization. The overall statistical precision is poor. The Fisher precision index k is never greater than 470. Sixty-five percent of the sets have k less than 200.

At the time the Sudden Shelter samples were collected they were encased in plaster for safety and ease of handling. This plaster had to be removed from the samples for paleointensity studies. During the process of removing the plaster forty-four percent of the samples were lost. The remaining fifty-six percent were cemented together with sodium silicate diluted in water. Sodium silicate cements the samples together without adding any magnetism and has a melting point well above the temperatures used in thermal demagnetzation. Sample sets 203, 211 and 216 were completely reddened. The remaining samples ranged from red at the top of the sample decreasing towards the bottom to very slight reddening. Table 5 lists the preliminary paleointensity data. Figure 6 shows the quality of the data and the best fit line for sample 211-3. Sample set 207 was unavailable for directional studies but was utilized for paleointensity work.

In the analysis of the paleointensity data, samples 211-5, 213-3, 231-1 and 231-6 were discarded because of anomalous NRM/TRM ratios. The mean and standard deviation from the mean were calculated for each sample set and samples whose NRM/TRM ratio was more than one standard deviation unit from the mean were discarded. A new mean was calculated and the sample sets grouped into their respective time levels. A weighted mean NRM/TRM was calculated for each time level from these sets and used to calculate the paleofield, Table 5a. The ratio of the paleofields to the present field is given in Table 5b.

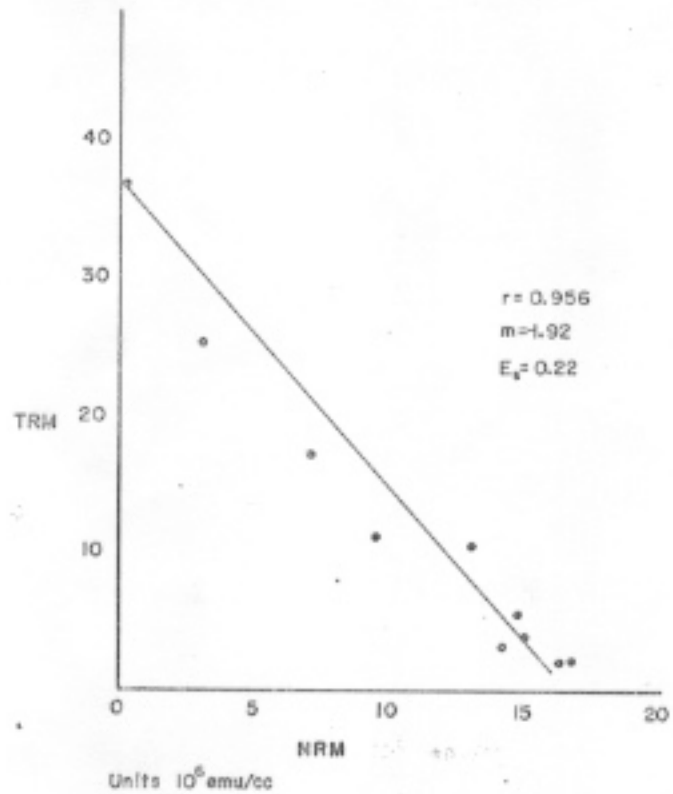


Fig. 6. TRM vs. NRM for sample 211-3. 100°-550° C.

TABLE 5: Sudden Shelter paleointensity data.

| SAMPLE # | TEMPERATURE RANGE C | # DATA POINTS | NRM/TRM | ERROR ON SLOPE |
|---|---|---|---|---|
| 203-1 | 100-500 | 7 | 0.321 | 0.04 |
| 203-2 | 100-400 | 5 | 0.260 | 0.05 |
| 203-0 | 100-400 | 5 | 0.410 | 0.03 |
| 203-4 | 100-400 | 5 | 0.645 | 0.06 |
| 203-5 | 100-400 | 5 | 1.01 | 0.20 |
| 203-6 | 100-500 | 7 | 0.390 | 0.04 |
| 206-1 | 100-400 | 5 | 1.04 | 0.09 |
| 207-1 | 100-400 | 5 | 2.13 | 0.35 |
| 207-2 | 100-400 | 5 | 2.56 | 0.33 |
| 209-4 | 100-400 | 5 | 0.704 | 0.07 |
| 209-5 | 100-400 | 5 | 0.550 | 0.08 |
| 209-6 | 100-400 | 5 | 0.662 | 0.06 |
| 211-2 | 100-500 | 8 | 0.470 | 0.08 |
| 211-3 | 100-550 | 10 | 0.520 | 0.06 |
| 211-4 | 100-400 | 5 | 0.750 | 0.03 |
| 211-5 | 100-400 | 5 | scattered | |
| 212-2 | 100-400 | 5 | 0.520 | 0.01 |
| 213-2 | 100-400 | 5 | 0.719 | 0.05 |
| 213-3 | 100-400 | 5 | 0.30 | 0.03 |
| 213-4 | 100-400 | 5 | 0.826 | 0.09 |
| 213-5 | 100-400 | 5 | 0.680 | 0.05 |
| 213-6 | 100-400 | 5 | 0.780 | 0.09 |
| 214-1 | 100-400 | 5 | 0.752 | 0.10 |
| 214-2 | 100-400 | 5 | 0.714 | 0.06 |
| 216-4 | 100-400 | 5 | 0.560 | 0.07 |
| 216-5 | 100-400 | 5 | 0.470 | 0.04 |
| 217-1 | 100-400 | 5 | 0.520 | 0.01 |
| 217-2 | 100-400 | 5 | 0.585 | 0.05 |
| 217-4 | 100-400 | 5 | 0.685 | 0.11 |
| 217-5 | 100-400 | 5 | 0.675 | 0.04 |
| 231-1 | 100-400 | 5 | 1.15 | 0.07 |
| 231-5 | 100-400 | 5 | 0.625 | 0.03 |
| 231-6 | 100-400 | 5 | scattered | |

TABLE 5a: Sudden Shelter paleointensity statistics.

| LEVEL | SAMPLE SETS | N | WEIGHTED MEAN NRM/TRM | STD. DEV. FROM WEIGHTED MEAN | PALEOFIELD 0.8143 STD. | 1.18 STD. |
|---|---|---|---|---|---|---|
| I | 207 | 2 | 2.35 | --- | 1.914 | 2.773 |
| II | 212,213 214,217 | 12 | .686 | .069 | 0.559 | 0.809 |
| III | 211,231 | 4 | .59 | .025 | 0.480 | 0.696 |
| IV | 203,209 216 | 11 | .506 | .113 | 0.412 | 0.597 |

TABLE 5b: Sudden Shelter paleointensities relative to present field.

| LEVEL | AGE B.P. | PALEOFIELD/PRESENT FIELD 0.8143 STD | 1.18 STD |
|---|---|---|---|
| I | 7565±115 | 3.54 | 5.14 |
| II | 7090± 85 | 1.04 | 1.49 |
| III | 6310±240 | 0.89 | 1.29 |
| IV | none available | 0.76 | 1.11 |

The quality of the samples seems to be as good as in Bucha's 1967 study of the paleointensity of Czechoslovakia. The number of samples was considerably less. Figure 7 is a comparison of the data from Figure 3 with the Sudden Shelter paleointensities using the 1.18 standard field verified by the Pueblo pottery study. The values are well within the limits of possibility generated by Bucha's data and could be true paleointensities if short period fluctuations in intensity are realized as in Figure 2.

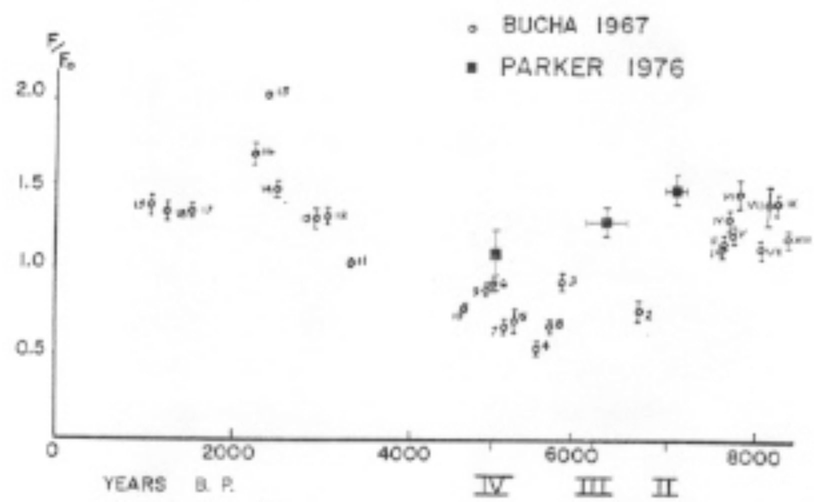


Fig.7 Comparison of data in Fig.3 with Sudden Shelter data.

# CONCLUSION

The Pueblo Pottery paleointensity study confirmed a rapid increase in the intensity of the earth's magnetic field in the southwest United States from 800-1000 A.D. as well as verifying the existence of relatively short period fluctuations in intensity. This could be of use in studies dealing with the nature of magnetic field generation within the Earth.

The Sudden Shelter paleointensities seem to differ systematically from Bucha's Czechoslovakian data (Fig. 7). A systematic error in laboratory procedure would seem to be precluded by the agreement found with Pueblo pottery (Fig. 2). The departure from Bucha's curve may be brought about by short period fluctuations as in Fig. 2. On the other hand, the departure of points from Bucha's curve may be due to a real difference in paleointensity between two widely separated geographical areas, Utah and Czechoslovakia.

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