The magnitude of the archaeomagnetic field in Egypt between 3000 and 0 BC

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Summary. Measurements of the magnitude of the archaeomagnetic field in Egypt using sun-dried adobe bricks are presented. Some results from fired materials are also presented and compared with those from the bricks. The results suggest that the magnetic field in Egypt has fluctuated quite rapidly over 3000 yr. These fluctuations are compared with those obtained by other authors and with records from observatory data. These results demonstrate the necessity of using archaeological material that can be reliably well-dated.

Introduction

Many authors in recent years (e.g. Bucha 1967; Bucha et al. 1970; Burlatskaya et al. 1970; Kitazawa & Kobayashi 1968; Rusakov & Zagniy 1973; Walton 1979; Gunn & Murray 1980; Shaw 1979) have published results obtained from archaeological materials which show fairly rapid fluctuations of the magnitude of the geomagnetic field over several hundreds of years. On the assumption that this high rate of change is a real phenomenon, it now seems clear that one of the most critical factors in archaeomagnetic studies is the accuracy of dating of the samples used. The precision of a $^{14}$C date is usually about $\pm 50$ yr, and the accuracy of the thermoluminescence method is at present 5-10 per cent. So for samples more than 2000 yr old these methods of dating are not sufficiently accurate, since such errors would not give the resolution needed to pick out the observed rapid rates of change of the geomagnetic field.

This was one of the reasons we decided to turn to Egypt for our archaeological samples, where the chronology that has been worked out is very accurate, certainly in the relative and often in the absolute sense. Most of the material used in this study was sun-dried adobe brick, which was collected from tombs and buildings which had been reliably dated. The pottery samples used were obtained either from University College, London, or from current excavations in Egypt, and again only samples which could be accurately dated were used.

Methods used to determine the magnitude of the ancient geomagnetic field

The sun-dried adobe bricks were analysed using the method described by the present author (Games 1977). Many of these results have already been presented in thesis form (Games...
1978) where they are analysed and discussed in more detail. An adobe brick becomes magnetized when it is thrown into a wooden mould or former, and we have called this magnetization a Shear Remanent Magnetization (SRM). To determine the magnitude of the ancient geomagnetic field, $B_{\text{anc}}$, the Natural Remanent Magnetization (NRM) of a 2 cm core of the adobe brick is measured and stepwise demagnetized using alternating field (af) demagnetization. An anhysteretic remanent magnetization, $\text{ARM}_1$, is given to the sample and this is also measured and af demagnetized. The sample is then crushed, mixed with water, and re-cast in a known laboratory field, $B_{\text{lab}}$, in a way which simulates the original brick-making process. When it is dry, the SRM acquired by the sample is measured and af demagnetized in the same way as the NRM. Then $\text{ARM}_2$ is given and measured and af demagnetized in the same way as $\text{ARM}_1$. Fig. 1 shows an example of a graph of NRM versus SRM for sample E10.1 using the demagnetizing alternating field as parameter. Since

**Figure 1.** The plot of NRM/SRM using the demagnetizing field as parameter for sample E10.1. The points labelled R were rejected for reasons explained in the text.

**Figure 2.** A plot of the accepted data for E10.1.
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The low coercive force region is susceptible to secondary magnetizations such as viscous remanent magnetization (VRM), the data in this region are rejected on the basis of the stability of the NRM direction. Fig. 2 shows a plot of the accepted data for sample E10.1. From this graph, the ancient geomagnetic field magnitude, $B_{anc}$, is calculated from

$$B_{anc} = \frac{\Delta \text{NRM}}{\Delta \text{SRM}}$$

where the SRM is acquired in a laboratory field, $B_{lab}$, of 50 μT. Fig. 3 shows a plot of ARM1 (given before the sample is remixed) against ARM2 (given after the resetting process) for the accepted data, which should have a gradient of 1.00 if no alteration of the magnetic properties has taken place during the process of producing the SRM. If this gradient differs from unity by more than 5 per cent, the sample is rejected. In all cases (except one, where insufficient material was available) two determinations of $B_{anc}$ were made by using two cores from each brick, and the error on the mean value of $B_{anc}$ quoted is half the difference between the two determinations. The average value of this error for all of the samples used is ±4.47 per cent.

The sherds and fired material were analysed using Shaw’s method (Shaw 1974). In all cases the thermoremanent magnetization (TRM) was given to the sample in the same direction as the NRM to within about 10°, so as to minimize the error due to fabric anisotropy as outlined by Rogers, Fox & Aitken (1979). Also the samples were cooled slowly from 700°C to room temperature in about 7 hr in order to reproduce as nearly as possible the original cooling rate of the NRM. This is to try and minimize the errors due to the effect of cooling rate on the TRM as discussed by Fox & Aitken (1979). The error quoted for these samples is the error on the slope of the best-fitting straight line through the origin. If this was less than 5 per cent, then an error of ±5 per cent is quoted (see Gunn & Murray 1979). In Fig. 4, one example of a result for a pottery sample is shown. The left-hand pair of graphs shows all of the data for the NRM versus TRM and ARM1 versus ARM2 plots. The right-hand pair of graphs shows the accepted data after rejection of the part of the coercive force spectrum which shows alteration by departing from the straight line of gradient = 1.00 drawn on the plot ARM1 versus ARM2.
Results

All of the 56 results quoted in this paper are listed in Tables 1 and 2. The value of $B_{unc}$ determined from each sample is given, and these values are also converted to Virtual Axial Dipole Moment values to enable comparison of results from differing latitudes. A brief description of each site is given along with the archaeologists' estimated age. In all cases, dates were averaged down to decades e.g. E19, Tomb of Karenen, 2133–1991 is rounded off to 2130–1990. As for the First Dynasty dates, the German School would bring the beginning of Dynasty I down to 2800 BC. The dates are based on those in Cambridge Ancient History, revised edition, vol. I, chapter 6, and on A. H. Gardiner, Egypt of the Pharaohs. An explanation of the basis of the dating is given in the Appendix by Professor Smith.
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These results are then plotted as virtual axial dipole moment values against time in Fig. 5. Values derived from fired material are shown by simple crosses and those from adobe bricks by closed circles. Fig. 6 shows a sketch map of Egypt giving the locations of most of the sites listed in Tables 1 and 2.

One of the most interesting features of these results is the fairly close agreement between the values obtained from sun-dried adobe bricks and the values obtained from fired material. Gunn & Murray (1979) have suggested that because of anisotropic effects fired materials will generally yield too great a value of the magnitude of the ancient field. The same effect would also be noticed if the cooling time for the TRM was less than that for the NRM (Fox & Aitken 1979). We have attempted to eliminate both of these sources of error, but the Egyptian fired materials do provide values of virtual dipole moments which are perhaps somewhat greater than the values derived from mud-bricks. Nevertheless, we must treat any possible difference as tentative until we have more data to reach a more definite conclusion. Despite these small differences, the fairly good agreement between the two completely different source materials gives us more confidence in the derived magnitudes of the geomagnetic field. There are a few points which disagree with the rest of the data, and we cannot with certainty explain these discrepancies. They may be simple errors, but it is also possible that in some cases the adobe bricks in a structure were actually re-used bricks from an earlier building. There are known instances of such re-use.

The graph in Fig. 5 suggests that the magnetic field in Egypt has fluctuated quite rapidly over the 3000 yr studied. During this period 3000–0 BC there are at least three maxima in the field at approximately 2600, 1350 and 200 BC, and two minima at about 1900 and 1000 BC. Near the large maximum at 1350 BC, the rate at which the field is changing reaches about 140 γ yr⁻¹ and this persists for about 300 yr either side of the maximum value. For the rest of the time, the rate of change is considerably smaller, being no greater than about 40 γ yr⁻¹. This lower rate persisted for about 500 yr at a time. The periods or ‘pulse widths’ which can be seen here are typically 400–1000 yr and their amplitudes vary by a factor of between 1.5 and 2.5.

These results are consistent with the changes in the archaeomagnetic field found by other authors. For example, Shaw (1979) has found that the field changed by just less than a factor of 2 in 150 yr and Walton (1977) reports periodicities of 100–300 yr with amplitudes varying by factors of up to 1.6. Secular variation with frequencies of between 500 and 5000 yr is suggested by the study of lake sediments (Thompson 1978). It is also interesting to find that over the last 20 or 30 yr, observatory data show that there has been a very large rate of decrease in the strength of the magnetic field centred on Paramaribo observatory (5° 49’, 304° 47’). The locality in question has shown a rate of change of the field of about 100 γ yr⁻¹ over an area of some 3000 km², and this rate has persisted from the time the observatory measurements were first recorded in 1941 up to 1971 (the date of the most recent records at our disposal). Moveover, the same feature seems to spread northwards to Dallas observatory (32° 59’, 263° 15’) and Tucson observatory (32° 15’, 249° 10’) where the rate was 40 γ yr⁻¹ for up to 30 yr, and southwards to Huancayo observatory (– 12° 27’, 284° 40’) where the rate was 56 γ yr⁻¹ for 30 yr. So it would appear that at this locality there are occurring large rates of change in the geomagnetic field today, which are comparable to those suggested by archaeomagnetic data, though of course the observations do not cover as long a time period. This is another factor which suggests that the changes shown in Fig. 5 could represent plausible features of the ancient magnetic field in Egypt.

With such a rapidly varying magnetic field, it may be possible to use these data in reverse to assign approximate dates to archaeological materials, provided that the period from which the object dates is already known to within a few hundred years.
Table 1. Adobe brick results.

<table>
<thead>
<tr>
<th>Code</th>
<th>Latitude (°)</th>
<th>Site</th>
<th>Description of site</th>
<th>Age (BC)</th>
<th>$B_{anc}(\mu T)$</th>
<th>$VADM \times 10^{27} \text{ Am}^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>E01</td>
<td>29.8</td>
<td>Saqqara</td>
<td>I Dynasty Tomb No. 3507</td>
<td>3000–2970</td>
<td>38.0 ± 1.0</td>
<td>7.45 ± 0.20</td>
</tr>
<tr>
<td>E04</td>
<td>29.8</td>
<td>Saqqara</td>
<td>I Dynasty Tomb No. 2105</td>
<td>2920–2890</td>
<td>40.5 ± 1.0</td>
<td>7.94 ± 0.20</td>
</tr>
<tr>
<td>E06</td>
<td>29.8</td>
<td>Saqqara</td>
<td>I Dynasty Tomb No. 3036</td>
<td>3000–2970</td>
<td>39.0 ± 3.0</td>
<td>7.64 ± 0.59</td>
</tr>
<tr>
<td>E10</td>
<td>29.8</td>
<td>Saqqara</td>
<td>I Dynasty Tomb No. 3357</td>
<td>3100–3070</td>
<td>35.5 ± 2.5</td>
<td>6.96 ± 0.49</td>
</tr>
<tr>
<td>E11</td>
<td>29.8</td>
<td>Saqqara</td>
<td>Tomb of Hesy (No. 2405) III Dynasty</td>
<td>2690–2620</td>
<td>44.0 ± 1.0</td>
<td>8.62 ± 0.20</td>
</tr>
<tr>
<td>E12</td>
<td>29.8</td>
<td>Saqqara</td>
<td>I Dynasty Tomb No. 2185</td>
<td>3070–3040</td>
<td>34.0 ± 1.0</td>
<td>6.66 ± 0.20</td>
</tr>
<tr>
<td>E13</td>
<td>29.8</td>
<td>Saqqara</td>
<td>I Dynasty Tomb No. 3503</td>
<td>3070–3040</td>
<td>35.0 ± 1.0</td>
<td>6.86 ± 0.20</td>
</tr>
<tr>
<td>E14</td>
<td>29.8</td>
<td>Saqqara</td>
<td>I Dynasty Tomb No. 3504</td>
<td>3040–3000</td>
<td>33.5 ± 1.0</td>
<td>6.56 ± 0.20</td>
</tr>
<tr>
<td>E15</td>
<td>29.8</td>
<td>Saqqara</td>
<td>I Dynasty Tomb No. 3505</td>
<td>2950–2920</td>
<td>40.0 ± 2.0</td>
<td>7.84 ± 0.39</td>
</tr>
<tr>
<td>E17</td>
<td>29.8</td>
<td>Saqqara</td>
<td>North Temple Town (Anubision) South Wall. Constructed not later than Ptolemy II</td>
<td>360–220</td>
<td>54.5 ± 4.5</td>
<td>10.68 ± 0.89</td>
</tr>
<tr>
<td>E18</td>
<td>29.8</td>
<td>Saqqara</td>
<td>South Temple Town (Bubastielon) North Wall. Probably contemporary with E17</td>
<td>360–220</td>
<td>49.5 ± 1.5</td>
<td>9.70 ± 0.29</td>
</tr>
<tr>
<td>E19</td>
<td>29.8</td>
<td>Saqqara</td>
<td>Tomb of Karenen. XI Dynasty</td>
<td>2130–1990</td>
<td>31.0 ± 1.0</td>
<td>6.08 ± 0.20</td>
</tr>
<tr>
<td>E20</td>
<td>29.8</td>
<td>Saqqara</td>
<td>North Temple Town. Eastern Wall of Bes Chambers. Late Ptolemaic–Roman</td>
<td>100 BC–AD 50</td>
<td>49.5 ± 3.5</td>
<td>9.70 ± 0.69</td>
</tr>
<tr>
<td>E21</td>
<td>29.8</td>
<td>Saqqara</td>
<td>Pepi I Temple. Early VI Dynasty</td>
<td>2340–2300</td>
<td>40.5 ± 2.0</td>
<td>7.94 ± 0.39</td>
</tr>
<tr>
<td>E22</td>
<td>29.8</td>
<td>Saqqara</td>
<td>Mastabat-el-Faraun. End of IV Dynasty</td>
<td>2500–2490</td>
<td>52.0 ± 3.0</td>
<td>10.19 ± 0.59</td>
</tr>
<tr>
<td>E23</td>
<td>29.8</td>
<td>Saqqara</td>
<td>Tomb of Desi. VI Dynasty</td>
<td>2360–2300</td>
<td>37.5 ± 1.0</td>
<td>7.35 ± 0.20</td>
</tr>
<tr>
<td>E24</td>
<td>29.8</td>
<td>Saqqara</td>
<td>Tomb of Khui. VI Dynasty</td>
<td>2360–2300</td>
<td>43.0 ± 2.0</td>
<td>8.43 ± 0.40</td>
</tr>
<tr>
<td>E25</td>
<td>29.8</td>
<td>Abusir</td>
<td>Mortuary Temple of Neferirkere. 3rd King of V Dynasty</td>
<td>2450–2430</td>
<td>41.0 ± 1.0</td>
<td>8.04 ± 0.19</td>
</tr>
</tbody>
</table>
Thebes  
E27  29.8  Abu Ghurab  Solar Temple of Userkaf. 1st King of V Dynasty  
E28  29.8  Saqqara  Sacred Animal Necropolis. N. Saqqara. North Ibis Galleries. Date uncertain  
E30  29.8  Saqqara  Sacred Animal Necropolis. N. Saqqara. Precinct D in Mother of Apis Complex. inf. Late XXVI–XXVII Dynasty  
E33  29.8  Saqqara  Sacred Animal Necropolis. N. Saqqara. South enclosure wall of Temple precinct. inf. XXVIII–XXX Dynasty  
E38  25.4  Thebes  Ramses III Temple, inner girdle wall, Medinet Habu. XX Dynasty  
E39  25.4  Thebes  Ramses III Temple, great girdle wall, Medinet Habu. XX Dynasty  
E40  25.4  Thebes  House of Butehamun Medinet Habu. XX Dynasty  
E44  25.4  Thebes  Cliff tomb of Deir-el-Bahri. XI Dynasty  
E45  25.4  Thebes  Ramesseum Store House. XIX Dynasty  
E46  25.4  Thebes  Temple of Tuthmosis IV. XVIII Dynasty  
E51  25.4  Thebes  Pylon: Temple of Montuemhat. XXV Dynasty  
E52  25.4  Thebes  Pylon: Temple of Ptes. XXV Dynasty  
E54  25.4  Thebes  Palace of Amenophis III. Malqata. XVIII Dynasty  
E57  25.4  Dahshur  Temp. Amenemhat III. XII Dynasty  
E61  29.8  Saqqara  Late Old Kingdom–Middle Kingdom tombs  
E64  29.8  Saqqara  Tomb of Unas-Hai. XII Dynasty  
E76  29.8  Saqqara  Aov Anubieion Kihn – unfired brick from base  
E77  29.8  Saqqara  Grain bin – contemporary with E75P  
E78  25.4  Karnak  XVII Dynasty. Karnak  
E79  25.4  Karnak  Middle Kingdom. Sesosiris III  
E90  25.4  Thebes  Tomb of Sheshonk. XXII Dynasty  
ER9  25.4  Thebes  XVIII Dynasty – exact origin unknown  

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Thebes  
E27  29.8  Abu Ghurab  Solar Temple of Userkaf. 1st King of V Dynasty  
E28  29.8  Saqqara  Sacred Animal Necropolis. N. Saqqara. North Ibis Galleries. Date uncertain  
E30  29.8  Saqqara  Sacred Animal Necropolis. N. Saqqara. Precinct D in Mother of Apis Complex. inf. Late XXVI–XXVII Dynasty  
E33  29.8  Saqqara  Sacred Animal Necropolis. N. Saqqara. South enclosure wall of Temple precinct. inf. XXVIII–XXX Dynasty  
E38  25.4  Thebes  Ramses III Temple, inner girdle wall, Medinet Habu. XX Dynasty  
E39  25.4  Thebes  Ramses III Temple, great girdle wall, Medinet Habu. XX Dynasty  
E40  25.4  Thebes  House of Butehamun Medinet Habu. XX Dynasty  
E44  25.4  Thebes  Cliff tomb of Deir-el-Bahri. XI Dynasty  
E45  25.4  Thebes  Ramesseum Store House. XIX Dynasty  
E46  25.4  Thebes  Temple of Tuthmosis IV. XVIII Dynasty  
E51  25.4  Thebes  Pylon: Temple of Montuemhat. XXV Dynasty  
E52  25.4  Thebes  Pylon: Temple of Ptes. XXV Dynasty  
E54  25.4  Thebes  Palace of Amenophis III. Malqata. XVIII Dynasty  
E57  25.4  Dahshur  Temp. Amenemhat III. XII Dynasty  
E61  29.8  Saqqara  Late Old Kingdom–Middle Kingdom tombs  
E64  29.8  Saqqara  Tomb of Unas-Hai. XII Dynasty  
E76  29.8  Saqqara  Aov Anubieion Kihn – unfired brick from base  
E77  29.8  Saqqara  Grain bin – contemporary with E75P  
E78  25.4  Karnak  XVII Dynasty. Karnak  
E79  25.4  Karnak  Middle Kingdom. Sesosiris III  
E90  25.4  Thebes  Tomb of Sheshonk. XXII Dynasty  
ER9  25.4  Thebes  XVIII Dynasty – exact origin unknown  

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Table 2. Pottery and fired brick results.

<table>
<thead>
<tr>
<th>Code</th>
<th>Latitude</th>
<th>Site</th>
<th>Description of site</th>
<th>Age (BC)</th>
<th>$B_{anc} (\mu T)$</th>
<th>VADM x $10^{22} A m^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>E04P</td>
<td>29.8</td>
<td>Saqqara</td>
<td>Sherd found in first Dynasty, brick E04. Inf. 1st Dynasty</td>
<td>3100–2900</td>
<td>42.0 ± 2.0</td>
<td>8.23 ± 0.39</td>
</tr>
<tr>
<td>E75P</td>
<td>29.8</td>
<td>Saqqara</td>
<td>Pot from floor AUM (water jar) Ptolemaic</td>
<td>300–200</td>
<td>49.0 ± 2.5</td>
<td>9.60 ± 0.49</td>
</tr>
<tr>
<td>E76P</td>
<td>29.8</td>
<td>Saqqara</td>
<td>AOV Kiln. Fired brick. Ptolemaic</td>
<td>100 BC–100 AD</td>
<td>51.0 ± 2.6</td>
<td>10.00 ± 0.51</td>
</tr>
<tr>
<td>E83P</td>
<td>25.4</td>
<td>Karnak</td>
<td>Sherd from foundation deposit, Tuthmosis I. XVIII Dynasty</td>
<td>1520–1500</td>
<td>55.0 ± 5.0</td>
<td>11.42 ± 1.0</td>
</tr>
<tr>
<td>E85P</td>
<td>25.4</td>
<td>Thebes</td>
<td>Kiln brick. Menkare. XXI Dynasty</td>
<td>1080–940</td>
<td>22.0 ± 1.0</td>
<td>4.57 ± 0.20</td>
</tr>
<tr>
<td>E86P</td>
<td>29.8</td>
<td>Dahshur</td>
<td>Sherd – temp. Sneferu. IV Dynasty</td>
<td>2620–2600</td>
<td>56.0 ± 3.0</td>
<td>10.97 ± 0.62</td>
</tr>
<tr>
<td>E94P</td>
<td>29.8</td>
<td>Dahshur</td>
<td>Sherd. XII Dynasty</td>
<td>1840–1790</td>
<td>33.0 ± 4.0</td>
<td>6.46 ± 0.79</td>
</tr>
<tr>
<td>E95P</td>
<td>29.8</td>
<td>Dahshur</td>
<td>Sherd. XIII Dynasty</td>
<td>1750–1650</td>
<td>37.0 ± 1.9</td>
<td>7.25 ± 0.37</td>
</tr>
<tr>
<td>E102P</td>
<td>29.5</td>
<td>Gerzeh</td>
<td>Gerzean sherd. Hemamieh G: 261c, 2' 6&quot; Predynastic</td>
<td>19678</td>
<td>31.0 ± 1.6</td>
<td>6.10 ± 0.32</td>
</tr>
<tr>
<td>E103P</td>
<td>26.2</td>
<td>Abydos</td>
<td>Sherd from Royal Tomb of Djer. I Dynasty</td>
<td>17347</td>
<td>34.0 ± 1.7</td>
<td>6.98 ± 0.35</td>
</tr>
<tr>
<td>E105P</td>
<td>29.5</td>
<td>Kahun</td>
<td>Workmen's village. XII Dynasty</td>
<td>18585</td>
<td>31.0 ± 2.0</td>
<td>6.10 ± 0.39</td>
</tr>
<tr>
<td>E106P</td>
<td>27.4</td>
<td>Amarna</td>
<td>Sherd with potmark. Akhenaten. XVIII Dynasty</td>
<td>24348</td>
<td>79.0 ± 4.0</td>
<td>15.98 ± 0.81</td>
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<tr>
<td>E107P</td>
<td>27.4</td>
<td>Amarna</td>
<td>Pink ware sherd, collected by Mrs V. Hankey, Akhenaten. XVIII Dynasty</td>
<td>25045</td>
<td>64.0 ± 6.2</td>
<td>12.95 ± 1.24</td>
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<tr>
<td>E121P</td>
<td>26.8</td>
<td>Qua el Kebir</td>
<td>Nubian sherd. XVI Dynasty</td>
<td>1680–1570</td>
<td>39.0 ± 2.0</td>
<td>7.95 ± 0.39</td>
</tr>
</tbody>
</table>
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Figure 5. A plot of Virtual Axial Dipole Moment values against time. Values derived from fired material are shown by simple crosses, and those from adobe bricks by closed circles.

Figure 6. A sketch map of Egypt showing the location of most of the sites listed in Tables 1 and 2.
Conclusions

These results show that values of the magnitude of the archaeomagnetic field can be obtained from sun-dried adobe bricks and fired material which are in fairly good agreement with each other. This fact, together with the accuracy of the dating of Egyptian material, suggests that the fluctuations observed in the magnitude of the archaeomagnetic field in Egypt are real. The results also demonstrate the necessity of using such well-dated material in archaeomagnetic studies of geomagnetic field strength. There are still some gaps in the curve (Fig. 5) where there exists little or no data, or where more data is needed to define the curve more precisely. Until this is done, it is a little too soon to try to 'date' archaeological samples using this curve, but in the near future application of the curve may be of some assistance to archaeologists.

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Finally, I wish to thank Mrs B. Bridges for measuring the fired material and the staff of the Geophysics Department for their help and support.

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The archaeomagnetic field in Egypt 3000–0 BC


Appendix

Apart from their geophysical interest, Dr Games's results, if confirmed, will clearly have important archaeological applications. Valuable as radiocarbon dating has been, from the point of view of 'historical archaeology' it suffers from three disadvantages: (i) it can rarely be certain how long a period elapsed between the cutting of ancient timber and its use in a particular structure or its deposition as charcoal in a particular stratum; (ii) the standard errors given in determinations of radiocarbon dates are often too great to make them particularly useful in historical archaeological contexts: (iii) the necessity, originally demonstrated by the comparison of a long sequence of radiocarbon determinations of carbon specimens from sites in Egypt with their 'historical' dates, to use the Suess Bristlecone-pine calibration for dates later than 5000 BP has introduced an extra uncertainty. Thermoluminescent and magnetic data of potsherds likewise suffer from the disadvantage that an unknown time interval must in most cases have elapsed between the firing of the pottery vessel and the deposition of the sherd in the stratum in which it is found. Mud-brick, however, is a material which is virtually always freshly made and sun-dried for the building of individual structures; and even in those cases where mud-bricks have been re-used from earlier structures, this should normally be observable by the archaeologist from the condition of such bricks, their sizes, and the manner in which they have been employed. Mud-brick, in areas where it was or is a basic building material, is almost ubiquitous and almost indestructible. Nothing could be simpler to provide and be less subject to erratic documentation than the requirement of a single half-brick hewn from the interior of a wall.

The choice of Egypt as a field from which to obtain a sequence of test samples had two obvious advantages. First, mud-brick has been in use in Egypt from the fourth millennium BC to the present day. Egypt should be capable with the advance in modern scientific excavation of supplying carbon, pottery and mud-brick samples from a series of controlled contexts with 'historical' dating evidence, spread evenly both in point of location and time sequence, which would allow thorough testing and correlation, magnetic and radiocarbon systems of dating. That the series which the Egypt Exploration Society and other archaeological missions in Egypt have, with the generous permission and cooperation of the Egyptian Antiquities Service, helped Dr Games to collect is chronologically incomplete and not at present evenly spaced through history has been due to the fact that excavation is uneven in its incidence and progress, and that sites quickly become sanded up in Egypt. Time and careful planning would be required to produce the perfect trial sequence; but the potential value of this method to archaeologists is certainly such as to justify the most rigorous testing.

Secondly, the chronology of ancient Egyptian history is reasonably well established back to the beginning of the third millennium BC. All reigns back to 715 BC (beginning of Dynasty XXV) are fixed by synchronisms with other cultures or by exact information within a
maximum limit of error of 2 yr, and in general precisely. Between 1100 and 715 BC the exact dating of individual reigns and even in certain cases the order of rulers is much less certain, and for this reason no samples of this period (Dynasties XXI—XXIV) have been used in this initial study: but, even in this period, at no point is an error of more than ±25 yr at all probable. The dates of accessions of the Ramesside Kings of Dynasties XIX—XX though uncertain in detail, can be fixed reasonably closely by monumental and documentary evidence from the accession date of Ramesses II, c. 1290 BC, down to that of Ramesses III in 1182 BC, which are well-fixed by Near Eastern synchronisms. Within the preceding XVIIIth Dynasty, two ancient observations of the heliacal rising of Sirius (Sothis) allow astronomically calculated fixed dates for the second king, Amenophis I (9th year = 1541 BC ± 6 yr) and (partially) for the sixth, the conqueror Tuthmosis III, though arguments about whether the observations were made in the latitude of Thebes or that of Memphis cause a possible 25 yr shift in the calculation. Nevertheless, the succession and length of reigns of the XVIIIth Dynasty is well fixed within this limit of error. For the preceding Second Intermediate Period (Dynasties XIII—XVII), dates and sequence of royal reigns are often very uncertain, and no dates of this period have been used in this initial survey. But an ancient observation of the heliacal rising of Sirius in the reign of Sesostris III of the XIIth Dynasty (9th year = 1872 BC ± 6 yr) fixes the preceding XIIth Dynasty, for which the lengths of all reigns are known, to the period 1991—1786 BC ± 6 yr. Thus the uncertainties of the Second Intermediate Period are confined within the period 1786—1670 BC, without effect on earlier periods. Previous to 1991 BC, the chronology is much less certain. However, a summary in the Turin papyrus, our most reliable ancient document, gives a total of 955 yr for the period from the beginning of Egyptian Dynastic history (Dynasty I) to the end of the Memphite Old Kingdom (Dynasty VIII). This leaves an uncertainty concerning the duration of the First Intermediate Period (Dynasties IX—XI), but a combination of monumental, archaeological and stylistic evidence suggests strongly that they can hardly have exceeded a period of more than 150 yr. This would give a date of c. 2150 BC for the end of Dynasty VIII, and thence of c. 3100 for the beginning of Dynasty I. These dates have been challenged (a) by scholars wishing to reduce the length of the First Intermediate Period; (b) by those wishing to lower the Turin Papyrus figure on the grounds that the papyrus, a XIXth Dynasty document, may have duplicated or extended reigns. They would advocate a date of 2900 BC for the beginning of Dynasty I: but even if these arguments are allowed 3000 BC ± 100 yr is a reasonably soundly attested date for the beginning of Dynasty I. Within the third millennium, the succession of individual rulers is fairly well established, and in many cases lengths of reigns can be estimated on a combination of king lists and monumental sources. An error of ±25 yr in Dynasty VI mounting cumulatively to ±100 yr in Dynasty I should be allowed, but the relation of individual reigns is better established than this figure would suggest. The Egyptian Dynastic sequence provides a very sound test of Dr Games's thesis, even though not scientifically demonstrable in the strictest sense.

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