Rock Magnetism and the Origin of the Midland Basalts

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Summary

There has been considerable dispute about the origin of the series of Carboniferous igneous formations in the neighbourhood of the Clee Hills, Shropshire. Palaeomagnetic measurements suggest that all the formations except one are intrusive. They also indicate that the accepted geological interpretation of one formation may require revision.

1. Introduction

There has been considerable dispute amongst geologists about the origin of the series of Carboniferous igneous formations, usually called the Midland basalts, lying in the area around the Clee Hills, Shropshire (Figure 1). For a long time they were regarded as sills or dykes, but in 1931 Pocock assembled considerable evidence suggesting that they were lavas. Later Marshall (1942) argued strongly for an intrusive origin for all the formations except Little Wenlock. The most recent discussion is by Whitehead and Pocock (1947), who endorse some of Marshall's conclusions but regard the formations at Kinlet and Shatterford as probably extrusive.

For most of the formations there is very little positive evidence to support either view of the origin. The overlying sediments show little sign either of induration or of derivation from the basalts; and the basalts themselves are not obviously either chilled or weathered.

The work to be described here suggests that measurements of natural remanent magnetization may be useful in such cases. The remanent magnetization in sedimentary rocks is usually very weak with wide scatter of direction about the mean; but if the material undergoes heating to a few hundred degrees centigrade it becomes remagnetized with perhaps 50-100 times the intensity and small scatter. This increase of intensity arises primarily from the difference in process of magnetization; that is to say, the ratio of natural intensity to the saturation intensity is higher in a baked rock than in an unbaked one.

It follows that ancient sills can often be distinguished from lava flows by examining the remanent magnetism of the overlying sediments, even when there is no apparent metamorphism. Above a sill the contact sediments should be magnetized in the same direction as the igneous body, and there should be a systematic increase of scatter and decrease of intensity with distance from the contact. Above a lava the sediments should usually have a different magnetic direction from the igneous body and have uniform intensity and scatter.

Complications may arise if there are variations in the proportion of magnetic material with distance from the contact; but they should be resolved by measuring
FIG. 1.—Distribution of sites.

FIG. 2.—Results from Titterstone Clee Hill.
the ratio of the natural intensity to the intensity after saturation in a high magnetic field.

2. Origin of Midland Basalts

The overlying contacts have been examined at all the outcrops in the Midlands except Barrow Hill and Rowley Regis, where the material was unsatisfactory. Measurements were made on a Blackett magnetometer, using disks 1½ in. diameter ½ in. thick cut from oriented samples of rock. Table 1 gives the sampling details; the magnetic declinations and inclinations relative to bedding planes; the intensities of magnetization; and numerical estimates of the mean scatter of direction in each block, calculated from a formula due to Wilson (1959).

The directions for the site at Titterstone Clee Hill, which may be taken as typical, are plotted on the Schmidt projection in Figure 2. In the country sandstone 200 ft from the contact, the intensity was $0.16 \times 10^{-6}$ c.g.s. units/g and the directions were widely scattered. In the sandstone within a few inches of the top and bottom contacts, the intensities were respectively $30 \times 10^{-6}$ and $10 \times 10^{-6}$ c.g.s. units/g; while the directions were closely grouped and agreed well with the mean direction in the igneous body. At an intermediate point five feet above the top contact the intensity was $3 \times 10^{-6}$ c.g.s. units/g and the scatter lay between those of the contact and country rocks. Thus the intensity, scatter and direction of magnetization in the overlying sediments all suggest that the basalt is intrusive.

At Kinlet and Shatterford the overlying sediments again had high intensity and small scatter and agreed in direction with the igneous body. At Pouk Hill the intensity, as well as the scatter, was higher in the sample further from the contact; but this was simply due to differences in the magnetic material, for the ratio of natural to saturation intensity decreased from 0.7 per cent at 7 ft from the contact to 0.1 per cent at 15 ft. Therefore the measurements indicate an intrusive origin for each of these sites.

At Little Wenlock on the other hand the overlying sandstones were weakly magnetized with wide scatter, so the igneous body is probably a lava. The mean direction at Little Wenlock was $353^\circ$ east of true north and $7^\circ$ down as against $202^\circ$ east and $17^\circ$ down for the other sites. This also points to a difference of origin.

3. Geological aspects of the intrusions

The beds at Clee Hill and Kinlet are slightly folded and those at Shatterford extensively so. It is possible to learn something about the original geological aspects from the palaeomagnetic measurements.

The Clee Hill formation is shaped like a saucer. The magnetic directions from opposite points on the rim agree closely relative to the bedding planes but diverge by about $10^\circ$ relative to the present horizontal. Since the directions seem to be very reliable, I am inclined to regard the difference as significant and conclude that the saucer was formed after intrusion. At Kinlet also, the directions agree more closely relative to the bedding planes, so again folding probably occurred after intrusion.

At Shatterford the problem is more complicated. At first sight the igneous body appears to be a dyke, a few feet wide and about two miles long. However since it lies parallel to the surrounding beds, which are steeply tilted, it may really...
<table>
<thead>
<tr>
<th>Site</th>
<th>Type of rock</th>
<th>Distance from contact</th>
<th>Magnetic declination (deg. East of true North)</th>
<th>Magnetic inclination</th>
<th>Dispersion</th>
<th>Natural intensity ( \times 10^{-6} ) c.g.s. units/g</th>
<th>Sampling details</th>
</tr>
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<tbody>
<tr>
<td><strong>Titterstone</strong></td>
<td>Igneous</td>
<td>—</td>
<td>222°</td>
<td>26° down</td>
<td>24°</td>
<td>700</td>
<td>Clee Hill Southern Quarry</td>
</tr>
<tr>
<td>Clee Hill</td>
<td></td>
<td>2 ft</td>
<td>203°</td>
<td>22° down</td>
<td>1° 5</td>
<td>10</td>
<td>Titterstone Clee Hill Quarry</td>
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<tr>
<td></td>
<td></td>
<td>6 in.</td>
<td>197°</td>
<td>20° down</td>
<td>3°</td>
<td>30</td>
<td>Magpie Quarry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 ft</td>
<td>197°</td>
<td>25° down</td>
<td>10°</td>
<td>3</td>
<td>Magpie Quarry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>200 ft</td>
<td>240°</td>
<td>64° down</td>
<td>26°</td>
<td>0·16</td>
<td>Benson's Brook</td>
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<tr>
<td><strong>Kinlet</strong></td>
<td>Igneous</td>
<td>—</td>
<td>182°</td>
<td>18° down</td>
<td>—</td>
<td>1400</td>
<td>Mass House Quarry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 ft</td>
<td>202°</td>
<td>17° down</td>
<td>4°</td>
<td>27</td>
<td>Raggits Quarry</td>
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<tr>
<td></td>
<td></td>
<td>6 in.</td>
<td>210°</td>
<td>7° down</td>
<td>2°</td>
<td>36</td>
<td>Mass House Quarry</td>
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<tr>
<td></td>
<td></td>
<td>30 ft ?</td>
<td>187°</td>
<td>0°</td>
<td>26°</td>
<td>0·8</td>
<td>North-west Quarry</td>
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<td><strong>Shatterford</strong></td>
<td>Igneous</td>
<td>—</td>
<td>30°</td>
<td>5° down</td>
<td>—</td>
<td>1000</td>
<td>Witnells End Stream section</td>
</tr>
<tr>
<td></td>
<td></td>
<td>—</td>
<td>215°(^{(1)})</td>
<td>1° down(^{(1)})</td>
<td>9°</td>
<td>15</td>
<td>Stream section</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 in.</td>
<td>196°(^{(1)})</td>
<td>15° down(^{(1)})</td>
<td>5°</td>
<td>5·5</td>
<td>Stream section</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 in.</td>
<td>204°(^{(1)})</td>
<td>17° down(^{(1)})</td>
<td>2° 5</td>
<td>14</td>
<td>Stream section</td>
</tr>
<tr>
<td></td>
<td></td>
<td>not sampled</td>
<td>—</td>
<td>—</td>
<td>—</td>
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\footnotesize{\textsuperscript{(1)}See Table 2.}
<table>
<thead>
<tr>
<th>Location</th>
<th>Igneous</th>
<th>Underlying material</th>
<th>Overlying material</th>
<th>Country material</th>
</tr>
</thead>
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<tr>
<td><strong>Barrow Hill</strong></td>
<td>—</td>
<td>208° 12° down</td>
<td>—</td>
<td>Quarry Ic(3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>not sampled</td>
<td></td>
<td>SO 915 817</td>
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<tr>
<td><strong>Pouk Hill</strong></td>
<td>—</td>
<td>7 ft 194° 13° down</td>
<td>3° 0.5</td>
<td>Bentley’s Quarry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15 ft 205° 1° down</td>
<td>24° 1-100</td>
<td>Bentley’s Quarry</td>
</tr>
<tr>
<td><strong>Rowley Regis</strong></td>
<td>—</td>
<td>168° 15° down</td>
<td>20° 1400</td>
<td>Element’s Quarry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>not sampled</td>
<td></td>
<td>SO 969 884</td>
</tr>
<tr>
<td><strong>Little Wenlock</strong></td>
<td>—</td>
<td>356° 15° down</td>
<td>—</td>
<td>270</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 in. 10° 13° up</td>
<td>2° 1.2</td>
<td>Doseley Quarry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 ft 349° 1° up</td>
<td>14° 0.4</td>
<td>Doseley Quarry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 in. 200° 70° down</td>
<td>45° 0.7</td>
<td>Lydebrook Dingle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.2</td>
<td></td>
<td>Lydebrook Farm</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>The Hatch</td>
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<td></td>
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<td></td>
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<td>SJ 645 083</td>
</tr>
</tbody>
</table>

(1) Assuming beds not inverted, see Section 3 and Figure 4.
(2) This material, being very fissile, had to be measured in lumps about the size of a fist.
be a sill that has undergone extensive folding after formation. Most of the samples were collected either at Witnell's End or at the stream-section 300 yards south of Witnell's End (see Figure 3). Between these two sites the tilt direction changes by about 90°, implying that the sill has undergone helical folding into the form of a propeller-blade. The fold cannot be traced in detail, since the intervening material, although marked by a prominent ridge of land, is not actually exposed.

The magnetic directions at the two exposures are plotted relative to the present horizontal in Figure 4(a). They are almost opposite. Since the exposures appear definitely to form part of the same intrusion, this indicates that some of the material has probably undergone self-reversal. However no proof of a self-reversing mechanism has yet been found in laboratory experiments.

There is a discrepancy of about 40° between the mean axis in Figure 4(a) (205° E, 20° up) and the direction for the other Midland basalts (202° E, 17° down). It is interesting to examine the directions relative to the bedding planes. These are given in Figure 4(b), which contains two groups of results for the stream sections, depending on whether the beds are assumed to be inverted (the accepted geological interpretation) or not. On the assumption that the beds are inverted the results are unsatisfactory; but on the other assumption the axes coincide at 200° E and 10° down, in excellent agreement with the results from the other Midland sites.

There are thus two possible explanations of the results. Either intrusion took place after the folding of the sediments, at a different time from the other
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Fig. 4(a).—Results from Shatterford.
Group A: Igneous material at Witnell's End.
Group B: Baked and igneous material from stream section.
• Downward dip; × upward dip; plotted relative to present horizontal.

Fig. 4(b).—Results from Shatterford.
Group A: Material at Witnell's End.
Group B: Material from stream section, assuming beds inverted.
Group B¹: As Group B but assuming beds not inverted.
Plotted relative to bedding planes.
formations; or intrusion took place before folding and at the same time as the other formations, but the beds of the stream section are not in fact inverted. A re-examination of the geology may be worthwhile to see whether the second interpretation is possible.

4. Conclusion

The conclusions from the present work may be summarized as follows. The formations at Clee Hill, Kinlet, Shatterford and Pouk Hill appear to be intrusive, whereas Little Wenlock appears to be extrusive. Therefore since Little Wenlock lies in the Carboniferous Limestone, it must be older than the intrusions, which occur in the Millstone Grit. The magnetic directions are consistent with the existence of a difference in age: the mean for Little Wenlock being 355°E and 7° down and for the other sites 202°E and 17° down.

The sites at Barrow Hill and Rowley Regis have not been studied in detail. The geological evidence for their intrusive origin is strong (Marshall 1946). The magnetic directions of the igneous material from these sites agreed well with the directions in the other intrusions, suggesting that they were formed at the same time. The overall mean direction for the intrusions of 200°E and 17° down agrees well with other palaeomagnetic results for the Carboniferous period (Everitt & Belshé, to be published), and thus endorses the conclusions of Pocock & Marshall that the formations were of Carboniferous age.

The measurements from different parts of the formations at Clee Hill and Kinlet suggest that intrusion occurred before the country beds were folded. At Shatterford they indicate that the accepted geological interpretation may require re-examination. Some of the igneous rocks at Shatterford have probably undergone self-reversal.

Acknowledgments

I wish to record my thanks to Dr J. A. Clegg who supervised this work and to Professor P. M. S. Blackett for his continued and stimulating interest in it.

Figure 3 is based on a Crown Copyright Geological Survey map by permission of the Controller of H.M. Stationery Office.

I am indebted to the D.S.I.R. for the award of a research studentship.