# "On the Determination of the Magnetic Susceptibility of Rocks."

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In the Report of the Magnetic Survey of the United Kingdom* the question as to how far the local and regional magnetic disturbances of the earth's field may be ascribed to the influence of masses of magnetic rocks was discussed by Professors Rücker and Thorpe.†

In a previous paper‡ a method for the determination of the magnetic susceptibilities of rocks was given, together with values for the specimens then examined. It was considered desirable to add to this relatively small number of results so as to obtain a broader basis for the development of the theory. Accordingly Sir Archibald Geikie, F.R.S., Director-General of the Geological Survey, has been good enough to supply us with a typical series of specimens of the basic rocks of the country, and, after a complete overhauling of the method originally adopted, we have measured the susceptibility of sixty-eight of these new specimens of forty-five different rocks. The earlier stages of the work were carried out by Mr. F. Fisher, A.R.C.S., who would, no doubt, have taken part in the whole had he not left the college for an appointment elsewhere.

The principle of this method of determining the susceptibility of small pieces of feebly magnetic materials is to compare the susceptibility of the fragment with that of the displaced volume of liquids of known susceptibility in which it is immersed.

In more detail, the method is as follows:—

(*a*) To measure the susceptibility of the magnetic liquids a tube containing the liquid is introduced into one of two equal solenoids, the effects of which on a small magnetometer destroy each other. In these experiments a field of seven absolute units was employed. The ratio of the deflection caused by the tube of liquid to that produced by a measuring solenoid traversed by a small current, multiplied by the computed constant of the instrument, gives the absolute susceptibility of the liquid.

The apparatus was figured and described on pp. 506—509, 'Roy. Soc. Proc.,' vol. 48, 1890.

(*b*) The differences of susceptibility of rocks and liquids are measured on the calibrated sonometer scale of a Hughes' induction balance. Two tubes, filled with a liquid to the sufficient depth of 6 cm., are balanced, and the distance through which the compensator

* 'Phil. Trans.,' vol. 188, 1896.

† *Vide* pp. 637—647 and map 14.

‡ 'Roy. Soc. Proc.,' vol. 48, 1890, p. 505.

has to be moved to produce silence after the introduction of a small piece of a rock into one of the tubes is noted. This is repeated with liquids of different strengths. Then if $a$, $b$ are the differences observed between the rock of susceptibility $x$ and two liquids of susceptibility $k_1$, $k_2$ respectively, we have

$$\frac{a}{b} = \frac{K_1 - x}{K_2 - x} \qquad \therefore \; x = \frac{bK_1 - aK_2}{b - a}$$

due regard being given to the signs of the differences.

The liquid employed was pure glycerine in which finely divided magnetic oxide of iron was suspended, for no solutions of metallic salts possess a susceptibility sufficiently high for our purpose. These liquids were very carefully prepared, and in the light of the experience now gained it is desirable to add to the statements made in the earlier paper on this point. Natural magnetite cannot be ground fine enough to remain long in suspension, though experiments in which a coarsely powdered mixture of magnetite and manganese dioxide (minerals of about the same specific gravity) was shaken in water and allowed to settle rapidly into a solid mass were fairly successful.

Finally, the magnetic oxide was prepared artificially by adding ammonia to a boiling solution of sulphate of iron of which one-half had been oxidised by nitric acid. The black precipitate, dehydrated by alcohol and dried at 100°, gives a friable dark brown mass about one and a half times as magnetic as a good specimen of the powdered mineral.

By grinding with glycerine between glass plates the oxide is reduced to minute yellow scales. Glycerine mixtures made with this substance give no indications of settling for forty-eight hours.

Numerous experiments with various suspensions of natural magnetite called attention to the fact that in a magnetic field the particles rotated slowly to set their axes along the lines of force, thus giving a fictitious susceptibility largely dependent on the permanent magnetisation of the grains of magnetite. With the artificial oxide this effect is extremely small, but, to avoid it altogether, we prepared gelatinised glycerine mixtures which at ordinary temperatures become solid. In this state we repeatedly determined, firstly, their absolute susceptibility with the magnetometer apparatus, and, secondly, the value in sonometer scale divisions of each balance tube filled with the jelly. With these particular tubes one division = susceptibility 0·0001075. The balance tubes being thus standardised, the absolute magnetic value of a liquid is determined by the induction balance under exactly the same conditions that hold during the tests of rocks.

*Sensitiveness and Accuracy.*

The errors arising from various sources have been carefully considered. They naturally fall into two groups—

First. Errors in the determination of the primary standard of susceptibility, and affecting all results equally.

Second. Errors affecting individual specimens.

1. Under the first heading come the probable errors in the magnetometer constant and readings.

In the value of the constant there is an estimated probable error of $\pm$ 1 per cent. Combining with this several smaller errors due to temperature, variation of resistances, imperfect adjustment, external magnetic disturbances, &c., we conclude that the susceptibility of each standard jelly is subject to a probable error $\pm$ 2 per cent. The two jellies actually gave factors 0·000109 and 0·000106 (the error of constant being the same in each case). *Presumably the mean factor* 0·0001075 *is within* $\pm$ 2 *per cent. of the truth.*

2. Errors in the values of individual rocks arise from the limited sensitiveness of induction balance, telephone, and ear. The values of the magnetic liquids are not appreciably affected by this, but it becomes important in the case of rock specimens of small size and feeble susceptibility.

In the earlier paper already referred to it was stated 0·00013 was the lower limit to the range of measurement by the methods adopted and experiments made since with magnetic and non-magnetic substances indicate about the same degree of accuracy. For moderate susceptibilities, however, the accuracy now attained has been greater than in the earlier work, and the errors cannot in most cases be much greater than 1 per cent. The difference between two specimens taken from the same rock is of course greater than this, as the composition of the rocks is not uniform.

It is not necessary to give a detailed example of an experiment. Suffice it to say that in a particular case the susceptibility of the rock (No. 2) was determined by comparison (1) with liquids H and D of susceptibilities 0·00074 and 0·00357, and (2) with liquids H and C of susceptibilities 0·00074 and 0·00250. The results obtained were 0·00164 and 0·00179, the mean being 0·00172.

The agreement of these two values is not particularly good, though not exceeding the probable error given above.

For some unrecorded reason this specimen was tested again, and gave—

From D and H′, $x$ = 0·00174
„ C and H′, $x$ = 0·00170
Mean value = 0·00172

The susceptibility was not in this case computed from mixtures D

and C taken together, for that would introduce extrapolation, which we avoid as much as possible.

In the case of the three specimens of susceptibilities greater than 0·01 we are compelled to extrapolate beyond our strongest mixture, and with the eighteen specimens below 0·001 we make our weakest mixture a factor in the extrapolations.

In some instances (*e.g.*, No. 45) there is a very distinct difference in the strength of two pieces broken off the same hand specimen.

A few of the specimens used in the earlier investigations were re-examined, and gave considerably larger susceptibilities than those previously measured. This is probably due to an error in the determinations of the absolute value of the susceptibilities of the liquids employed, but in the case of any individual rock this error would not exceed the difference often observed between two different fragments of the same specimen. The fact also that the mean value now obtained is almost exactly the same as that formerly given (viz., 0·00255 as against 0·00245) justifies the conclusions based upon the use of this or the smaller number (0·00160) which was used in many of the calculations on the magnetic effects of basaltic rocks. The accuracy of the absolute values now given has been tested by experiments on ferric chloride. Although the susceptibility of this substance is much smaller than that of most of the rocks, the result of our measurements was in close accord with the means of values deduced from the experiments of Quincke and Townsend.

### Table of Results.

| Number. | Numerical description on list sent by Sir A. Geikie. | Nature. | Locality. | Susceptibility of 1st specimen. | Susceptibility of 2nd specimen. | Mean susceptibility. |
|---|---|---|---|---|---|---|
| | | | *1 to 12.—Rocks from Northumberland, Cumberland, and Durham.* | | | |
| 1 | E 1348 108 | Basalt-dyke | ½ mile E. of Otterburn Church, Northumberland | .. | .. | 0·00835 |
| 2 | E 1349 — | Basalt-dyke | Near coal working, 1¼ miles N.E. Folstone Church, North Tyne, Northumberland | .. | .. | 0·00172 |
| 3 | E 1352 — | Basalt-dyke | 300 yards E. of Middle Riding, and 1¼ miles N.E. of Elsdon, Northumberland | 0·01008 | 0·01009 | 0·01009 |
| 4 | 102 | Diabase or dolerite | Cunsfell, 2⅜ miles S.E. Melmerby Church, Cumberland | .. | .. | 0·00020 |
| 5 | .. .. | Olivine dolerite | ⅞ mile N.E. Melmerby Church, Cumberland | .. | .. | 0·00058 |
| 6 | 108 | Basalt | Westerly continuation of Acklington Dyke, S. of Hindhope, Cheviots | 0·00447 | 0·00333 (readings rather discordant) | 0·00390 |
| 7 | E 1369 109 N.W. | Basalt | Whin Sill, Rugley, near Alnwick, Northumberland | 0·00455 | 0·00447 | 0·00451 |
| 8 | 110 S.W. | Basalt | Whin Sill, Belford Quarry, Northumberland | 0·00289 | 0·00268 | 0·00280 |
| 9 | E 896 *a* 102 S.E. | Dolerite | Whin Sill, Sleight Edge, W. of Wemmergill Lunedale, (?) Teesdale, Durham | 0·00359 | 0·00331 | 0·00345 |
| 10 | E 690 — | Dolerite | Whin Sill, Middleton, Teesdale, Durham.. | .. | .. | 0·00265 |
| 11 | (?) 103 | Basalt-dyke | Bowleis Beck, Durham ................ | 0·00230 | 0·00221 | 0·00225 |
| 12 | 101 | Gabbro | (Boss), White Crags, Carrock Fell, Cumberland | (a very small piece) | | 0·00023 |

*13 to 20.—Rocks from Wales, Stafford, and Salop.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 13 | | 78 | Dolerite | The Skerries, Anglesey | .. | .. | 0·00680 |
| 14 | E 618 | 78 N.W. | Basalt | Llanfechell, Anglesey | .. | .. | 0·00213 |
| 15 | E 887 | 56 | Gabbro | Hanter Hill, near Kington, Radnor | 0·00007 (a very small piece) | 0·00007 | 0·00007 |
| 16 | E 1916 | 40 | Gabbro | St. David's Head | | | 0 |
| 17 | | 62 | Olivine-dolerite | Rowley Regis, Staffs. | .. | .. | 0·00454 |
| 18 | | 55 | Olivine-dolerite | Clee Hills, near Ludlow, Salop | .. | .. | 0·00445 |
| 19 | E 2006 | — | Olivine-dolerite | Butterton Hall Park, Staffs. (Post-Triassic) | 0·00229 | 0·00244 | 0·00236 |
| 20 | E 2168 | 19 | Olivine-dolerite | Stoke Lane quarry, Mendip Hills | .. | .. | 0·00111 |

*21 to 25.—Rocks from Devon and Cornwall.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 21 | | 21 or 26 | Olivine-basalt | Radden Court quarry, N. Devon | 0·00021 | 0·00022 | 0·00022 |
| 22 | 1039 | 22 | Dolerite | N. of railway cutting, N. of Ashton St., Devon | 0·00027 | 0·00034 | 0·00031 |
| 23 | | 22 | Dolerite | Crocombe, Thrusham Station, Devon | .. | .. | 0·00027 |
| 24 | | 32 | Gabbro | Kildown Cove, Cadgwith, Cornwall (a very coarse-grained specimen) | 0·00113 (mainly felspar) | 0·00029 (mainly diallage, (?)) | 0·00071 |
| 25 | .. | .. | Hornblende-schist | Quarry near Church Cove, Lizard | .. | .. | 0·00028 |

*26 to 44.—Tertiary Rocks from Antrim. 45 from Down.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 26 | | 7 | Dolerite | New quarry, back of railway station, Portrush | 0·00229 | 0·00207 | 0·00218 |
| 27 | J.R. 232 | — | Basalt | (Upper sheets), Giant's Causeway | 0·00157 | 0·00160 | 0·00159 |
| 28 | 222 | — | Basalt | (Upper sheets), Brocky Set quarry, Ballintoy | 0·00295 | 0·00284 | 0·00290 |
| 29 | 212 | — | Basalt | (Upper), Carrick-a-Raidhe | .. | .. | 0·00137 |
| 30 | 234 | — | Basalt | (Lower sheets), Giant's Causeway | 0·00122 | 0·00124 | 0·00123 |
| 31 | 208 | 8 | Dolerite | Intrusive, resting on headland, Murlough Bay, S.E. of Fairhead | 0·00276 | 0·00254 | 0·00265 |
| 32 | | — | Dolerite | Segregation vein in the preceding | .. | .. | 0·00420 |
| 33 | 197 | — | Basalt | Intrusive in carboniferous, in stream $1\frac{1}{2}$ miles E. of Ballycastle | 0·0154 (?) | 0·0124 (?) | 0·01390(?) |

Table of Results—*continued.*

| Number. | Numerical description on list sent by Sir A. Geikie. | Nature. | Locality. | Susceptibility of | | Mean susceptibility. |
|---|---|---|---|---|---|---|
| | | | | 1st specimen. | 2nd specimen. | |
| 34 | 167 14 | Basalt | (Lower sheets), Garron Point .......... | 0·00026(?) | 0·00036 | 0·00031(?) |
| 35 | 20 | Basalt | Scawt Hill, 4 miles S.S.E. of Glenarm | .. | .. | 0·00302 |
| 36 | 92 | Basalt | (Lower sheets), immediately above trachyte, N. slope of Brown Dod Hill | 0·00115 | 0·00067 | 0·00091 |
| 37 | 243 | Basalt | (Upper), ½ mile N.W. of Slemish Mountain | 0·00034 | 0·00031 | 0·00033 |
| 38 | 118 21 | Basalt | (Lower tabular trap), near Aularp Head, 1½ miles S.E. of Glenarm | .. | .. | 0·00051 |
| 39 | 122 | Basalt | (Upper sheets), quarry by road, 1 mile S. of Glenarm | .. | .. | 0·00085 |
| 40 | 22 28 | Basalt | (Neck), quarry S. side of Carnmoney Hill | .. | .. | 0·00308 |
| 41 | 29 — | Basalt | (Plateau, flow), quarry, Carnmoney Hill.. | .. | .. | 0·00019 |
| 42 | 64 — | Basalt-dyke | Near Tardree ........................ | 0·00188 | 0·00177 | 0·00183 |
| 43 | 98 — | Basalt | (Lower trap), E. side of Dongon Hill, 1 mile N. of Park Gate | 0·00051 | 0·00075 | 0·00063 |
| 44 | 33 — | Basalt | (Overlying ash bed), quarry by railway, Ballypalidy, 2 miles N.E. of Temple Patrick | .. | .. | 0·00082 |
| 45 | 294 71 | Diorite-dyke, epidiorite, or protobase | Rostrevor, co. Down (post-silurian) ..... | 0·00659 | 0·01026 | 0·00843 |

The mean susceptibility of 1 to 12 (Northern Counties) is ...................... 0·00340
" " 13 " 20 (Welsh, &c.) .............................. 0·00268
" " 21 " 25 (Devon and Cornwall) ...................... 0·00036
" " 26 " 45 (Antrim) .................................. 0·00255
∴ Mean of 25 English rocks ......................... 0·002559
" 20 Irish rocks.............................. 0·002546
Mean of all .......................... 0·002553