or by a set of private empirical rules which constitute his 'experience'. Whatever method is adopted, it is evident that good judgment and long practice are essentials in this difficult art. The mathematical method should be regarded as a means of indicating the most *probable* line of development. It seems that we should be unwise to expect more than this, at least for some years to come.

Ideally, any system of mathematical prediction should be based on conditions over the whole globe; but in practice, for a 24-hr. forecast in Britain, it is sufficient to restrict the calculations to the movement of air masses over a rectangle covering part of the eastern Atlantic and part of western Europe. The distribution of air pressure at the surface and at some considerable height in the troposphere is known tolerably well within this rectangle at any one time. With a conventional 'lid', say, at the tropopause, and the assumption that conditions do not change (or change according to some prescribed law) at the boundaries of the rectangle, the problem amounts to tracing the movements of the air inside the box formed by the rectangle, the vertical walls and the 'lid' in a period of, say, twenty-four hours. In other words, we set up a model atmosphere which obeys certain simplified forms of the laws of Nature, but we are not restricted to a rigid model of an anticyclone or depression in the sense used earlier.

This particular model, like many others, is a compromise. For some time to come meteorologists must be prepared to accept models which are not strictly logical, in that there is an arbitrary selection of certain features to be retained, while others are rejected, not necessarily because they are small but because their retention would make the model unworkable. As in mathematical physics generally, such models are idealizations, useful but not easily justified on strict mathematical grounds. It is important to realize that in such investigations there is no attempt to produce a forecast of weather. Attention is limited to an examination of the pressure and motion fields over a relatively small part of one hemisphere, in the middle latitudes. Even if the method were infallible (which it is not) the services of the meteorologist, as distinct from the mathematician, would still be required to 'put in the weather', a phrase which covers what may well be the most difficult part of the whole process of forecasting. It will be the responsibility of the forecaster, drawing on his experience, to accept or reject the answer provided by the mathematicians, and he must always recognize that the subjective element has not been eliminated by the mathematics but removed a stage farther back, to the initial postulates of the model.

The numerical method has been tried by the Meteorological Office, so far, on a few occasions only. The results are encouraging. The charts produced by the machine for the surface and the mid-troposphere have reproduced the main kinematical features of the real situation; they are about as good as those which were drawn by experienced forecasters on the dates in question. Thus, while it is far too early to claim that the value of the method is established, there are good grounds for continuing the research.

Conclusions

The fact that a weather forecast is essentially a statement of chances is not fully appreciated by the non-meteorologist, and some of the distrust with which the forecasts are regarded can be attributed to this misunderstanding.

The task of the meteorologist does not finish with the composition of the forecast—there is still the very important problem of conveying the results of the analysis to the public in simple and straightforward terms; and this part of the problem is almost as important as the examination of the physical processes at work.

NATURAL MAGNETIZATION OF IGNEOUS AND SEDIMENTARY ROCKS

A DISCUSSION of recent developments in Great Britain in the study of the permanent magnetization of rocks was held during January 8–9 in the Geology Department of the University of Birmingham. The chair was taken at the three sessions in turn by Prof. F. W. Shotton (University of Birmingham), Prof. O. T. Jones (University of Cambridge) and Dr. J. McG. Bruckshaw (Imperial College of Science and Technology, London).

The permanent magnetization of rocks is due to the ferromagnetism of their iron oxide minerals. Dr. G. D. Nicholls (Department of Geology, Manchester), in summarizing what is known of their mineralogy, pointed out that they are often loosely classified as 'magnetite', but it is important to know their exact composition, on which their magnetic properties are very dependent. They occur naturally as solid solutions of hæmatite (Fe_2O_3, rhombohedral), maghæmite (Fe_2O_3, cubic), magnetite (Fe_3O_4, cubic) and ilmenite ($FeTiO_3$, rhombohedral), of which the first three are ferromagnetic. The known range of solid solution is most simply expressed by the ternary FeO—Fe_2O_3—TiO_2 diagram, shown in Fig. 1.

The full lines represent known solid solutions; the dotted line is conjectural but probably represents qualitatively the boundary of a region of no solid solution at magmatic temperatures. There is evidence that the size of this region increases with decreasing temperatures, leading to exsolution on cooling and the existence of two phases in the resulting mineral grains. In slowly cooled basic rocks minerals of the magnetite–ulvöspinel series seem to be most common, whereas in those which have been rapidly chilled minerals occur the compositions of which are inter-

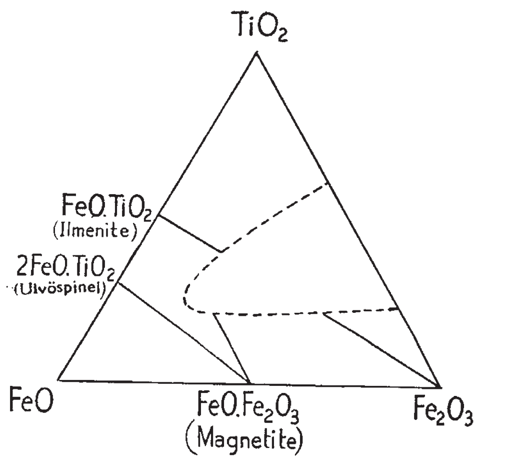

Table 1. EFFECT OF IONIC REPLACEMENT ON THE CURIE POINTS OF THE IRON OXIDES

Mineral	Ion replaced	Replacing ion	Upper limit of replacement (per cent)	Change of Curie point (°C.)
αFe_2O_3	Fe^{+++}	Al^{+++}	5	675 → 611
γFe_2O_3	Fe^{+++}	Al^{+++}	5	small
Fe_3O_4	Fe^{+++}	Al^{+++}	15	575 → 535
		Cr^{+++}	18	575 → 560
Fe_3O_4	Fe^{++}	Co^{++}	100	575 → 520
		Ni^{++}	100	575 → 595
		Mg^{++}	100	575 → 315
αFe_2O_3		Mn	about 80	675 → 140

mediate between magnetite and ilmenite. It appears that the ore minerals of basic lavas are richer in titanium than those found in acid lavas.

Dr. Nicholls then explained that partial replacement of iron by other ions in these minerals is possible and affects the Curie point. The changes he listed are shown in Table 1.

The introduction of sodium ions into magnetite has been reported to a limit of 6–7 per cent $Na_2Fe_2O_4$ in Fe_3O_4 (replacement of Fe^{++} by $2Na^{+}$?), the Curie point being lowered from 575° to 535° C. Replacements of iron ions by sodium is also possible in maghæmite, and with 5 per cent of Na_2O present the Curie point becomes 415° C. A possible replacement of Fe^{+++} Fe^{++} by $Na^{+}Si^{++++}$ in magnetite is considered to be more likely in natural ore minerals than a straight replacement of Fe^{++} by $2Na^{+}$. The reduction of Curie point which can be brought about by replacement is of interest in view of the range of Curie points which have been reported for some rocks.

Dr. Nicholls then explained that minerals exist with very abnormal magnetic properties. The ferromagnetic components of the dacite pumice from Mt. Haruna, Japan, have been separated by Nagata[1] into three fractions, *A*, *B* and *AB*. *A* is fairly pure magnetite ; *B* is similar in composition and structure to ilmenite, but is ferromagnetic and has a Curie point of about 300° C. *AB* has the remarkable property of reversing its polarity on cooling. Nagata interprets it as an intergrowth of *A* and *B* ; but examination under the ore microscope fails to reveal this so far. It is possible that the rhombohedral phase reported in *AB* originated through physical changes produced during thermomagnetic separation ; but it is not likely that the properties of the *AB* fraction can be explained solely in terms of ionic replacement in a cubic ferromagnetic phase.

Some experiments described by Dr. Bruckshaw confirm the existence in igneous rocks of minerals covering a wide range of Curie points. He has carried out a separation of the various ferromagnetic constituents of his specimens according to their Curie points, which he finds to be mainly in the range of 300–600° C., and, of eight fractions separated, four have Curie points in the 500–600° C. temperature range.

The question of the origin of the reversed magnetizations found in many rocks was continually arising in the discussion. Evidence in favour of their being due to a real reversal of the earth's magnetic field was put forward by Dr. Bruckshaw, who described careful measurements of the thermoremanence acquired by Tertiary lavas from Mull in fields from 1 gauss down to 0·02 gauss. These observations show no evidence of reverse magnetization, so that the rocks possess no property similar to that of the Haruna dacite described by Nagata[1], in which the magnetic polarization acquired near 600° C. changes sign on cooling at about 300° C. Further, it is apparent that the natural remanence of the Mull lavas could have been acquired in a reversed field comparable in intensity with that of the present field.

Dr. S. K. Runcorn (Department of Geodesy and Geophysics, Cambridge) described measurements he has made, in co-operation with Dr. C. D. Campbell, of the State College of Washington, Pullman, on the Miocene lavas of the Columbia River of the northwestern United States. In series of flows at different localities are found groups of normally and reversely magnetized lavas (cf. those of similar age found by Hospers[2] in Iceland). Dr. Runcorn agreed with Hospers's interpretation that these series of reversed and normal flows indicate that the earth's field has been constant in direction for periods of hundreds of thousands of years, but has suffered reversals which took place in a few thousand years. This would be consistent with the probable relaxation time of the current systems postulated in present theories of the geomagnetic field. In reply to exponents of the various mechanisms of self-reversal put forward by Néel[3], Nagata[1] and Graham[4] to account for reversed magnetizations, Dr. Runcorn objected that some modern lavas should possess reversed magnetization if such mechanisms were not exceptional. Further, only three rocks[1,5] and one synthetic spinel[6] show self-reversal in the laboratory, in contrast to the large number of reversed magnetizations found in the field.

Both in these measurements on igneous rocks, and in those on sediments which were described later, the scatter in the direction of magnetization is usually very wide. In these circumstances the assumption that the components of declination and inclination are separately distributed in a Gaussian manner is invalid. Sir Ronald Fisher (Cambridge) described how he had developed the statistics of dispersion of points over the surface of a sphere[7], based on the function $\exp(\varkappa \cos \theta)$, where θ is the angular error, and $\varkappa$ is a measure of precision. He described how to derive from this distribution function the radius of a 'circle of confidence' within which the mean direction would be expected to lie with any desired probability.

Dr. J. Hospers (Bataafsche Petroleum Maatschappij, The Hague ; formerly of the Department of Geodesy and Geophysics, Cambridge) described an application of this statistical treatment to a set of measurements made by several different workers on Tertiary igneous rocks. He has found the probable position of the magnetic pole at various geological periods and the radius of the circle of confidence for each result. He concluded that there is no evidence for the large 'polar wandering' suggested by Wegener and others for comparatively recent geological times, but that there is some indication of a 5° movement of the pole since Eocene times[8].

Information on the direction of magnetization of sediments was presented, which covered the whole range of the geological column. Mr. E. Irving (Department of Geodesy and Geophysics, Cambridge) described measurements on silt and fine sandstone specimens collected from sixty-three localities in a 9,000-ft. thick stratigraphical succession in the Torridonian of north-west Scotland. Of these, thirty-seven have a magnetization directed towards the south-east with a downward inclination, sixteen have north-west directions with an upward inclination, and ten localities show oblique directions. The mean directions of magnetizations of the first two groups are :

	Declination (east of True North)	Inclination
South-east localities	122°	+ 49
North-west localities	292°	− 33

The localities are grouped into sixteen zones with alternating south-east and north-west magnetization, these varying from 100 ft. to 2,000 ft. in thickness. With one exception the localities with directions oblique to the general axis of magnetization occur between zones of opposed magnetization and are probably in some way transitional. (A study of the magnetization of Torridonian pebbles in conglomerates of New Red Sandstone age, and of beds folded during the Caledonian orogeny, shows that these directions have remained unaltered for at least 10^8 years.) Mr. Irving's work on the Torridonian included an interesting study of the directions of magnetization of these siltstones in both small- and large-scale slumps. In the former, the directions he measured are practically random, as though the magnetization took place at deposition and the directions were randomized by the slumping. Specimens from the large-scale slumps, on the other hand, show uniform magnetization, implying that the beds were magnetized or remagnetized after the slumping had taken place.

Mr. K. M. Creer (Department of Geodesy and Geophysics, Cambridge) produced data for sediments from the Devonian, Triassic and Eocene periods, and from the lava traps of the Exeter Volcanic Series of Permian age. Rocks from both the Lower and Upper Old Red Sandstone all show reversed polarizations, the declination on the whole being just west of south and the inclinations extremely shallow. The Exeter Traps are also reversely magnetized along the same horizontal axis but with slightly greater (although still small) inclinations. Samples taken from a 110-ft. cliff of Keuper Marl (Triassic) at Sidmouth, Devon, are only partially stable, but even so there is strong evidence for magnetization along a north-east – south-west axis. The upper and lower portions of the cliff are normally polarized, but the middle 34 ft. is reversed. The Bagshot Sands (Tertiary) give directions not very different from the present earth's field.

Mr. Creer found that the magnetization of his Keuper Marls was partially unstable, the measured directions being affected only slightly by the horizontal component of the earth's field but appreciably by its vertical component after only a few weeks in the laboratory. All these rocks contain a red-staining mineral, probably hæmatite, and the presence of this mineral leads to a high coercivity of several thousand gauss. Bleached specimens of the same marl have coercivities an order of magnitude less than this. The instability is not, however, associated with low coercive force or with absence of the red component. It was found, rather, that stable and unstable specimens contained about the same amount of the red mineral, but that, in general, the unstable rocks were less strongly magnetized than the stable ones. It might be, then, that the magnetization due to the red mineral is essentially unstable, and that the more stable specimens contain a greater proportion of a magnetically stable material, which would account also for their greater intensity. In the weakly magnetized specimens, on the other hand, there would be insufficient stable material to mask the instability of the red mineral. Mr. Creer explained this paradoxical association of high coercivity and instability in terms of Néel's theory of the magnetic properties of particles small enough to be single ferromagnetic domains. Néel has shown[9] that such particles can have long relaxation times and therefore be magnetically stable, if their volume is greater than a lower limit set by the demagnetizing effect of thermal fluctuations. On the other hand, extremely small particles will be unstable because of their short relaxation times, even though their coercive force is very high. Mr. Creer has estimated that the particles of his red mineral were of this size and, in support of his explanation, has extended to the case of ferric oxide Néel's calculation of the relaxation time for iron particles. He has found that, to have a relaxation time of the order of thousands of years, the ferric oxide particles would have to be too large to be single domains. This implies that for ferric oxide there may be no 'stable range' of particle size limited at the lower end by the effect of thermal fluctuations and at the upper by the appearance of domain boundaries in the particle.

Commenting on these palæomagnetic directions, which span much of geological time, Dr. Runcorn said that reversed polarizations seem not to be confined to Tertiary strata or to igneous rocks, in which they were first studied. The processes generating the main field are now sufficiently understood to make reversals of its polarity scarcely surprising. In addition to the external field, there is reason for believing in the existence within the core of much stronger toroidal fields[10] to which the former owes its origin. Reversals of the dipole field may not involve reversals of this toroidal field. The coincidence of the magnetic and rotational axes through Tertiary times, covering many reversals, is explained by the dominance of the Coriolis force on motions within the earth's core and is thus likely to be true in other eras. Thus an additional hypothesis is necessary to explain the palæomagnetic directions in pre-Tertiary times. Dr. Runcorn considers that movement of the earth's surface relative to the axis of rotation in space is the simplest suggestion. The 'polar wandering' inferred from the measurements in Britain for each geological epoch should be tested by measurements on similar formations in other continents.

Dr. J. A. Clegg (Imperial College of Science and Technology, London) gave an account of measurements on rocks from ten sites in the Keuper Marl Series, covering the lateral extent of this Series in England from Carlisle and Yorkshire down to Devonshire. In five of these sites the rocks are polarized approximately 40° east of north and with downward dips of 30–40°. In four sites the polarization is almost exactly reversed, being to the south-west and with upward dips of similar magnitude. In the tenth site at Sidmouth, Devon, the magnetization of the rocks is found to be unstable in the earth's field. Further measurements on Lower Old Red Sandstone rocks from Gloucestershire and Upper Coal Measure rocks from Bristol show that these have the same axis of polarization.

Demagnetization tests on specimens in alternating and steady fields at various temperatures varying from 0 to 600° C. show that there are two magnetic constituents present in the rocks. The first or 'soft' component is easily magnetizable by d.c. fields of the order of a few gauss at room temperature and by the earth's field at temperatures greater than 80° C. It can be demagnetized by relatively small a.c. fields. The second or 'hard' component is stable in fields of the order of hundreds of gauss and at temperatures as high as 500° C.

This uniformity of magnetization combined with high magnetic stability of rocks ranging over such a wide geographical area and geological age evidently has some physical significance. Dr. Clegg considered a number of possible reasons for this preferential direction of the magnetic polarization and concluded tentatively that it might be due to a movement of Britain relative to the earth's geographical axis.

The most recent sediments measured are some post-glacial varved clays from Sweden. Dr. D. H. Griffiths (Geology Department, Birmingham) described measurements on two contemporaneous series of these clays from localities several miles apart on the Ångerman River. The directions of magnetization show a regular variation suggestive of secular variation, and, over the 500-year period of overlap between the two series, good correlation of the directions is obtained, provided that corrections for the geological dip of the series are applied, amounting in one instance to 13°. Unfortunately, there is no supporting geological evidence for the validity of this correction. Dr. Griffiths also described measurements on recent varved-clay core samples obtained from the Ångerman River delta with a non-magnetic Kullenberg core-sampler carrying a device for recording sample orientation. More than a hundred samples were measured covering the period A.D. 1400–1900, and it was therefore possible to compare magnetization directions with observatory records of the earth's field for this period. There was a rather large scatter in the measurements and average values of sets of samples had to be taken. The directions of the horizontal components of magnetization of the samples showed good agreement with the earth's field for corresponding periods, but inclinations were very variable and inconsistent. Correction for the small geological dip of the beds tended to improve correlation. These results were not altogether in agreement with measurements on the older varves, which were from the same general area, for in the older varves the evidence suggested that both declinations and inclinations were reliable.

A laboratory experiment showing how magnetization of sediments was acquired on deposition was described by Dr. R. F. King (Department of Geology, Birmingham). He had redispersed some of the Swedish varved clay on which Dr. Griffiths's measurements were made, and had allowed it to settle slowly in the field of the earth. The direction of magnetization of this artificial sediment was not appreciably altered by the later application of a field in a different direction, although this was done while the clay was still under water and completely unconsolidated. Dr. King also described other experiments on re-sedimentation of clay, discussing in particular the discrepancy between the inclination of the remanence of the sediment and that of the applied field. This discrepancy has been noticed by other workers both in the laboratory and in the field, and is generally thought to be due to elongated or flattened magnetic particles tending to settle with their long axis or axes horizontal. Dr. Clegg, who had also noticed the effect, suggested that it could be due to rotation of the particles during the early stages of compaction. He described also an experiment in which a post-depositional field was applied to artificially deposited Keuper Marl. In contrast to the result of Dr. King's experiment, the direction of magnetization was found to rotate into that of the new field. The water content of his deposit was, however, considerably greater than that of the freshly deposited Swedish clay.

The various contributions to the meeting showed that over the past year or two our knowledge of rock magnetism has greatly increased. Yet, despite the large number of observations that have been collected, it is obvious that many important problems will have to be solved before any general criteria of reliability can be established for rock magnetism measurements. For example, there is still some conflict of opinion on the question of reversed magnetization. There is also, as yet, no direct way of testing the stability of rock magnetization, though there is sometimes good indirect evidence of this. Finally, as model experiments are beginning to show, there is still much to be learned about the method by which the magnetic moment is acquired.

D. H. GRIFFITHS
R. F. KING

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NEW LABORATORY OF THE MOTOR INDUSTRY RESEARCH ASSOCIATION

By DR. J. R. BRISTOW

THE Motor Industry Research Association's new Laboratory, together with the Proving Ground, was officially opened on May 21 by the Minister of Transport, the Right Hon. Alan Lennox Boyd, in the presence of distinguished guests, representing the motor industry, universities and Government departments, and some twelve hundred visitors.

The Laboratory stands on an 11-acre site in the angle formed by the Watling Street (*A*5), and a private road leading to the Association's Proving Ground, at Lindley, near Nuneaton. The Laboratory, which has a floor area of about 30,000 sq. ft., together with other buildings (canteen, garages and workshop) having a total floor area of about 10,000 sq. ft., occupies about half the site, thus providing room for considerable future expansion.

The lay-out of the main building is based on a wide *L*-shaped corridor with offices, conference room, drawing office, entrance hall, etc., on the 'outside' of the corridor forming a main frontage, about 300 ft. long, parallel to the Watling Street, and a subsidiary frontage, about 125 ft., parallel to the private road to the Proving Ground. The separate research laboratories—electronics, metallurgical, general engineering, engine, machine shop and stores—consist of open wings (with windows along both sides and roof lights) leading off at right angles from the longest corridor. There are no small separate rooms for research purposes, a small number of large open floor spaces being more suited to the Association's needs than a large number of small restricted floor