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THE SCIENTIFIC WORK OF THE ORDNANCE SURVEY.

PROFESSIONAL PAPERS—NEW SERIES.

No. 1.—"An Account of the Measurement of a Geodetic Base Line at Lossiemouth in 1909, together with a discussion on the theory of measurement by metal tapes and wires in catenary" [Major Johnston, R.E., and Captain E. C. Henrici, R.E.] 1912.

No. 2.—"An Investigation into the Accuracy of the Principal Triangulation of the United Kingdom," by Captain H. St. J. L. Winterbotham, R.E., with an introduction by Colonel C. F. Close, C.M.G., R.E., Director-General of the Ordnance Survey. 1912.

No. 3.—"Notes on the Geodesy of the British Isles," by Colonel C. F. Close, C.M.G., R.E., Director-General of the Ordnance Survey. 1914.

THE publication of a new series of Professional Papers of the Ordnance Survey marks an epoch in the history of this national work. It might be said without offence to the distinguished officers who had within the past thirty years directed the Survey that, being content to look upon its more refined and scientific side as complete, they devoted themselves to the administration of detail revision, and more lately to the very great improvement of the published maps consequent upon the introduction of elaborate colour printing. Since the year 1880, when Colonel Clarke retired from the Survey, scarcely any geodetic work had been attempted until quite recently. Meanwhile General Ferrero had presented to the International Geodetic Association a general report on the principal triangulations, in which he placed the British triangulation in an unfavourable light because of its considerable triangular errors. On the faith of this criticism it had become the fashion to say that the British geodetic work was not precise enough to be worthy of inclusion in the network of European triangulation, or in a discussion of the general figure of the Earth.

In England the question had been the subject of some agitation, and it had clearly become a matter of importance for the national satisfaction that the credit of our triangulation should be re-established by re-measurement or otherwise. So early as 1904 a detailed plan for the re-measurement of the British arc of meridian nad been put forward by Colonel Hills and Colonel Close. This plan would have involved the beaconing and observation of a select chain of the old stations, with perhaps the introduction of new; and it was estimated that the work would cost something like £20,000. At a somewhat later date it occurred to Colonel Close that before such a plan was seriously pressed it would be worth while to test the value of the old work by closing it upon a new base, thus providing for a test of its linear accumulation of error. For it had sometimes been forgotten by the critics that the British principal triangulation is not like a modern chain of quadrilaterals, but is a highly complex figure, of which many parts—and those probably the triangles more difficult of measurement and imbued with a larger error—do not enter with any sensible weight into the measurement of the arc of meridian. Acting on the recommendation of the Council of the British Association the Board of Agriculture and Fisheries authorized the then Director-General of the Ordnance Survey, Colonel S. C. N. Grant, to measure a base and connect it with three primary points of the old triangulation in the neighbourhood of Lossiemouth, on the southern shore of the Moray Firth. The first two papers of the new series describe various portions of this enterprise and the conclusions which have been drawn from its results.

The geodetic base was the first to be measured in Great Britain with the aid of invar wires. Those who are interested in this fascinating development of precise measurement will be familiar with the early use of these wires in the field in South

Africa under the late Sir David Gill, as well as with all the splendid work carried out at the International Bureau at Sèvres by Monsieur Guillaume—the inventor of invar and the great apostle of its use in geodesy. They will read with special interest the modifications made by Major Johnston, in command of the Ordnance Survey party which measured the Lossiemouth base in the months of September and October, 1909. The principal differences from the procedure of others may be indicated briefly as follows: The "wire" was actually a tape, on which the end scales were divided directly, thus avoiding the dangerous use of *reglettes*. The standard length was 100 feet instead of 24 metres, in order that full use might be made of the well-studied 10-foot standard bar OI_1. The use of this bar required that it should be re-determined at Sèvres in terms of the International Metre, with which the National Standard Yard had been compared in recent years. This afforded the readiest means of comparing afresh the O.S. standard with the national standard. A new 100-foot base was laid down at the Ordnance Survey Office for the standardization and study of the tape. Certain modifications were introduced into the design of tripods, straining trestles, and levelling apparatus, such as have suggested themselves to those who have used in the field the apparatus of the form designed by Mons. Guillaume. The length of the base as finally calculated has a probable error of 0·025 foot, or about 1 part in 900,000 of its length.

The account of the field work and of the elaborate standardization is completed by a thorough investigation of the theory of the tape suspended in catenary, due to the joint labours of Prof. Henrici, F.R.S., and of his son Captain E. C. Henrici. It is impossible in a brief notice to do justice to this investigation, which deserves long study and careful analysis, for it is not always easy to bear in mind at any point of the treatment just what refinements have been retained and which discarded. The student will find it advantageous as an exercise to re-write and re-arrange the various sections for himself, before he can be sure of having mastered it in all its bearings; and it will be a useful task if some one will make a tabular summary of the effects of errors of different amounts and classes, as a guide to the conduct of field work.

In the examination of the behaviour of the tape apparatus Major Johnston and Captain Henrici discovered the important fact that the system of suspension—sash-cord running over 5-inch pulleys on good ball-bearings—is capable of absorbing by friction a considerable amount of the tension applied; while if steel piano-wire is substituted for sash-cord the suspension becomes so delicate that the tape cannot be held steady for reading. It is therefore of the first importance that the same suspension be used in the standardization and the field measurement—at least until some way is found of keeping the tape steady under frictionless support. The method of anchoring the tape at one end is suggested; but field experience is lacking.

The second paper, written by Captain Winterbotham, has an introduction by Colonel Close, who in 1911 succeeded to the direction of the Ordnance Survey. The account of the operations of triangulation and reduction, with the discussion of the bearing of the results upon the general problem, are highly condensed, occupying no more than twenty quarto pages; and it is possible that some advantage might have arisen from a rather more complete treatment of the theoretical questions involved. The broad result of the investigation is that the linear errors of the old network triangulation of the United Kingdom are of the same order as those found in modern chains of quadrilaterals extending over an equal distance. The discussion shows that the excellent agreement between the calculated and computed lengths of the Lough Foyle and Salisbury Plain bases was not accidental, but is confirmed by the inter-comparison of these bases with those measured at Paris and Lossiemouth. "The influence on modern Figures of the Earth of any re-measurement of the British arc

would be insignificant, and if the money for a British re-measurement were to become available it would be wise to spend it on some other geodetic operation."

The third paper of the series is based upon the Halley Lecture delivered in the University of Oxford by Colonel Close in May, 1914. Its modest title, "Notes on the Geodesy of the British Isles," hardly does justice to the great range and interest of the contents. Within a brief space we have a discussion of the relation between the British and the metric units of length; a summary of our present knowledge of the figure of the Earth, with special reference to the important part which British geodesists have played in its determination; a brief *résumé* of the above-mentioned work on the British triangulation; an important chapter upon levelling; the British determinations of the mean density of the Earth; an account of British gravity surveys; and a very useful summary of the theory of isostasy. The paper is completed by a full bibliography compiled by the Librarian to the Ordnance Survey, which does not, however, give the help which is desirable in one important matter. Clarke's figure of 1866 is probably more widely used than any other determination: the whole survey of Canada and the United States is based upon it. Yet it is not easy to find, for it was published as an appendix to the account of the comparison of standards of length of England, France, Belgium, etc. (1866), and the title-page of that volume contains no indication of the contents of the appendix, or even of its existence.

Colonel Close's Notes contain many good things. He gives a charmingly simple method of determining the radius of the Earth from the closing errors of a traverse. He finds an example of Airy's practical sagacity in his derivation of a good figure of the Earth by bad methods. He is able at last to do full justice to the merits of Colonel Clarke's masterly work on the principal triangulation. "Sir Henry James wrote the preface, but it is right to state, what could not have been stated before Colonel Clarke's death, that Sir Henry James's personal share in the work was of a limited nature, and that though he was a capable administrator, and encouraged Clarke's scientific work, he was not himself a geodesist." It is hard to estimate how great was the loss to British geodesy when Colonel Clarke retired from the service in 1880, and almost from that day abandoned his interest in the subject of which he was the greatest living master.

The history of the early levelling in England is not so well known as that of the triangulation, and here the Notes are of special interest. It is worthy of remark that in 1831 Mr. J. A. Lloyd invented the use of a mirror for reading the bubble without moving his head from the eye-end of the telescope—a device which was lost for half a century. In 1842 General Colby seems to have been the first to show experimentally that the mean height of the sea is far more consistent than that of low water at spring tides, and that mean sea-level is the proper datum for all determinations of height. We are reminded also that the datum for Irish levels is about 8 feet below the mean sea-level, and that all heights on Irish maps are therefore 8 feet too great. There is a familiar statement on the margin of British maps that "the altitudes are given in feet above the assumed mean level of the sea at Liverpool, which is 0·650 of a foot below the general mean level of the sea." But few will have been prepared for the Director-General's candid admission that "this remark need not be taken too literally, for until April, 1913, no proper steps had ever been taken to ascertain mean sea-level." It was not the primary datum only that was unsatisfactory; the old work suffers from a general defect that no care was taken to make the bench-marks stable. The familiar broad arrow is cut upon walls, kerbstones, and gateposts. No primary bench-marks were established, nor did they think to run the primary lines of levelling on solid ground and to avoid mining areas.

The consequence of all this was that when the Royal Commission on Coast Erosion was happily inspired to inquire of the Director-General of the Ordnance Survey whether the British Isles as a whole were rising, or sinking, or tilting, he was able to reply with confidence that there was no information upon the subject; and he was perhaps not surprised to read the Commission's recommendation that steps should be taken to obtain such information for the benefit of posterity.

No time was lost in putting into execution a well-considered scheme for the establishment of tide gauges and of a series of primary bench-marks covering the British Islands. Every care was taken to obtain the best possible advice as to the situation of the gauges and the lines of greatest solidity in the crust of the country. The tide gauge at Dunbar has been at work since April, 1913, and that at Newlyn since April, 1915; a third at Felixstowe is in contemplation. Already a very considerable part of the primary levelling has been completed. The principal instrumental improvements are the adoption of the parallel plate object glass micrometer, and of levelling staves divided on invar. The probable error in the early stages of the work was of the order of a quarter of an inch in 100 miles of levelling; and it is expected that this will be reduced by improvements in the instruments and methods.

Thus for the first time we are given a sure foundation for future inquiry as to movements of our country in reference to the mean level of the sea on our shores; and it is hardly necessary to point out how urgent in the future may be a knowledge of the data which will repose upon this foundation. The tectonic school of geodesists believe that considerable movements of the Earth's crust are still in progress, and that rising or falling are comparable in their effects with coast erosion and building up. It must be a matter of supreme importance to our future to know whether we should be prepared to deal with gradual shallowing or deepening of our ports and estuaries. In the hard times which are coming pure science will have to economize, with the rest of the world; but we most earnestly hope that no forced retrenchment after the war will put a stop to this inquiry of real utility.

When we turn to the subject of gravity surveys in England we are reminded of a phrase in a Cambridge Guide Book that "the history of a certain College is concerned mainly with its foundation." In the experiments at Schiehallion Maskelyne was the first to make a successful determination of mountain attraction and the mean density of the Earth. Captain Kater's determination of gravity with his invariable pendulum made an advance in method which is the foundation of modern work. Since his time much has been done by the British in other parts of the world, and notably in India and the Antarctic; but no serious extension of gravity survey has been made in this country. The gravimetric history of the country ends with Kater and Sabine.

Nor has anything yet been done to put the computation of topographical deflections upon a modern basis. The inter-comparison of the astronomical and geodetic latitudes of the principal triangulation showed that local discordances, though not excessive, are considerable. But these comparisons were made long before the theory of isostasy was heard of. Colonel Close remarks that "all the calculations for plumb-line deflection in the United Kingdom existing up to the present time are probably valueless, and if we are to examine effectively the question of the deviation of the plumb-line in this country we must follow the example of the United States and India. . . . The work has its practical side, but more important than this is the need of satisfying our legitimate desire to learn what is possible of the structure of the Earth on which we live."

We welcome this avowal that a spirit which slept for a generation has now inspired afresh the practice of the Ordnance Survey. Since the outbreak of the war Colonel Close has been occupied with other and more pressing needs of the time; but may we here express the hope that after peace is concluded he may remain in a position to ensure that the scientific work of our National Survey becomes once more thoroughly established as a normal and essential part of its duty to the State.

A. R. H.

Ellis Martin drawing, from Ordnance Survey Christmas card, 1923

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THE ORDNANCE SURVEY AND THE WAR

The Ordnance Survey and the War 1914–1919.— Printed at the Ordnance Survey Office, Southampton, 1919.

NO branch of the Government service has been put to a severer test by the war than the Ordnance Survey; and certainly none has better risen to the emergency, acquitted itself more creditably, or done work of greater importance than that department. The demand made upon it for the production of maps for the use of the armies in France and elsewhere abroad was tremendous and ever increasing, but this demand was fully met, thanks to the able superintendence of the Director-General, and the hearty and energetic support of the officers and staff working under him. Not only was there this large demand for trench and other maps for the various fronts, but a great many maps and charts were prepared and printed for the Admiralty, and for military use at home, besides the keeping up, as far as circumstances would admit, of a certain amount of the ordinary work of the Survey.

A good idea of the work carried out can be obtained from a small volume just issued by the Office at Southampton, a copy of which has been forwarded to the Society, entitled 'The Ordnance Survey and the War 1914–1919.' This consists of the report of the Survey as affected by the war, 4 August 1914 to 21 June 1915; the annual reports for the financial years April 1 to March 31 following for each subsequent year; an account of the Overseas Branch of the