A Bathymetrical Survey of the Fresh-Water Lochs of Scotland. Part I. The Lochs of the Trossachs and Callander District

Author(s): John Murray and Fred. P. Pullar

Source: *The Geographical Journal*, Vol. 15, No. 4 (Apr., 1900), pp. 309-352

Published by: geographicalj

Stable URL: <http://www.jstor.org/stable/1774954>

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The Geographical Journal.

No. 4.

APRIL, 1900.

VOL. XV.

A BATHYMETRICAL SURVEY OF THE FRESH-WATER LOCHS OF SCOTLAND.*

By Sir JOHN MURRAY, K.C.B., D.Sc., F.R.S., and FRED. P. PULLAR, Esq.,
F.R.G.S.

PART I.—THE LOCHS OF THE TROSSACHS AND CALLANDER DISTRICT.

INTRODUCTION.

ABOUT forty years ago excellent bathymetrical charts of Loch 'Lomond and Loch Awe were published by the Hydrographic Department of the Admiralty, based on surveys undertaken by naval officers. Some of the general charts of the Scottish coasts published by the Admiralty also show a few soundings down the centres of the fresh-water lochs forming the Caledonian Canal, viz. Loch Ness, Loch Lochy, and Loch Oich, but the charts of Lochs Lomond and Awe represent the only systematic surveys of the fresh-water lochs in Scotland that existed previous to the year 1883.

About that time many scientific men in Scotland felt that a survey of these fresh-water lochs should be undertaken, which led to the Councils of the Royal Societies of London and Edinburgh bringing this subject under the notice of Her Majesty's Government, as shown in the following correspondence:—

I. *The Secretary of the Royal Society of Edinburgh to the Secretary of H.M. Treasury.*

Royal Society of Edinburgh, July 11, 1883.

SIR,—In consequence of the investigations now being carried on with reference to the physical and biological conditions of the Scottish fresh-water lakes, and also because of the importance, in certain branches of geological inquiry, of knowing

* Maps, p. 452.

the form of the basins occupied by these lakes, it has been prominently brought under the notice of the President and Council of this Society, that no bathymetrical survey of these lakes exists.

I have, therefore, been requested by the President and Council to ascertain from H.M. Government if there is any probability of this work being soon undertaken, and, at the same time, to state that it would be a great satisfaction to the President and Council to learn that instructions had been issued by the Lords Commissioners of H.M. Treasury to the Officers of the Ordnance Survey, or of the Hydrographic Department of the Admiralty, to undertake a survey of a few of these lakes similar to the excellent ones already made of Loch Lomond and Loch Awe—say Lochs Morar, Maree, Lochy, Assynt, Shin, Tay, Ericht, Rannoch, Earn, Doon (in Ayrshire).—I am, etc.,

(signed) P. G. TAIT,
Secretary, Royal Society, Edinburgh.

II. *The Secretary of H.M. Treasury to the Secretary of the Royal Society of Edinburgh.*

Treasury Chambers, September 17, 1883.

SIR,—With reference to your letter of the 11th of July last, and the reply from this Board, dated the 10th ultimo, relating to a proposal to execute a bathymetrical survey of certain fresh-water lakes in Scotland, I am directed by the Lords Commissioners of Her Majesty's Treasury to acquaint you that my Lords are informed that the nautical surveys of Loch Lomond and Loch Awe, referred to in your letter, were undertaken by naval officers in the interests of navigation, and that the same considerations do not apply to the other lochs, of which surveys are suggested in your letter.

My Lords are also informed that the proposed bathymetrical surveys do not come within the functions of the Survey Department of the Office of Works (late Ordnance Survey).

Under these circumstances, my Lords regret that they are unable to sanction the proposed surveys. I have the honour to be, etc.,

(signed) LEONARD COURTNEY.

III. *Discussion in the House of Lords.*

In March, 1884, in reply to Lord Balfour of Burleigh in the House of Lords, Lord Sudeley said—

In reply to the noble Lord, I have to state that the operations of the Ordnance Survey have been hitherto restricted to such portions of the ground in the vicinity of fresh-water pools, and inland sheets of water generally, as are above the lowest water-levels. It is quite true, as the noble Lord has stated, that Loch Lomond and Loch Awe were surveyed, but that was undertaken by naval officers in the interests of navigation. The Government consider that a bathymetrical survey of all the lochs of Scotland would clearly be outside the function of the present Ordnance Survey of Scotland, which is already completed. Even if it were desirable, as the noble Viscount [Bury] has suggested, men would be taken off their work in England and the southern counties to carry this work out, and the general survey would be very much delayed. Such investigation would, no doubt, be most interesting from a scientific point of view in certain branches of geological inquiry to ascertain the forms of the basins occupied by the lakes. The Government will give the suggestions made by the noble Lord full consideration, and there will be no objection to lay the papers on the table.

IV. *The Secretary of the Royal Society of London to the Secretary of H.M. Treasury.*

The Royal Society, Burlington House, May 2, 1884.

SIR,—The President and Council of the Royal Society have had under consideration a communication from the Royal Society of Edinburgh, from which it would appear that the Lords Commissioners of Her Majesty's Treasury have stated that they are unable to sanction a bathymetrical survey of certain of the Scottish lochs, as proposed by the Royal Society of Edinburgh.

I am directed by the President and Council of the Royal Society to assure my Lords that they fully share the regret expressed by the Royal Society of Edinburgh that my Lords should have arrived at such a decision.

Neither from a topographical nor from a geological point of view can the survey of the United Kingdom be considered complete so long as the depths of the several inland waters remain unknown, and the absence of adequate data, concerning not only the Scottish lochs, but other large inland waters of the United Kingdom, forms, and will continue to form, a very serious obstacle to geological research.

The President and Council do not desire to urge upon my Lords any elaborate surveys entailing a large expenditure. They have reason to believe that the most important objects of the proposed surveys would be gained if series of soundings were carried across the important lakes not yet bathymetrically surveyed, at moderate intervals in each case. The exact closeness of the lines of soundings and the interval between each two soundings in each line must, in great measure, be determined at the time of observation according to the results which are from time to time obtained; but it has been suggested that lines of soundings at about a quarter of a mile interval, with soundings about 100 yards apart, would probably be found generally useful.

The President and Council venture to remind my Lords that the carrying out of such a bathymetrical survey is much facilitated by the fact that the contours of the lakes in question have all been already accurately laid down; also that the inland waters of the continent have been carefully surveyed by the several European Governments; and that, though in Scotland only Lochs Lomond and Awe have been surveyed (notwithstanding that some of the others are used for purposes of navigation) and the English lakes not at all, several of the Irish lakes were sounded by the Admiralty surveying officers in the years 1834-39 and in 1846.

The President and Council fully appreciate the difficulty which presents itself to my Lords in the facts that such bathymetrical surveys as those proposed do not fall within the province of the Survey Department of the Office of Works, and that, since the object sought is not one concerning navigation, they are foreign also to the duties of the Admiralty. The object, indeed, of the proposed survey may be most fitly spoken of as geological, but the Geological Survey has no means of carrying out such a work.

The President and Council would, however, venture to urge upon my Lords that the proposed survey, though of great scientific importance, is limited in scope and special in character, and so far not of a nature likely to establish an undesirable precedent, and they sincerely trust that my Lords may be led to reconsider their decision, and may see their way to make some arrangements by which a bathymetrical survey of the various inland waters of the United Kingdom not yet so surveyed may be speedily carried out.—I have, etc.,

(signed) M. FOSTER,
Sec. R.S.

There was no practical outcome from this correspondence; the Government declined to undertake any of the proposed surveys.

In the year 1888, Mr. J. S. Grant-Wilson published in the *Scottish Geographical Magazine* * an account of Lochs Tay, Earn, Rannoch, and Tummel in Perthshire, with special reference to the glaciation of the district, and he gives small contoured maps of these lochs, in which the positions of some of the deeper soundings are laid down. This, together with the Admiralty charts of Lochs Lomond and Awe, appears to be all the published information with respect to the depth of the Scottish fresh-water lakes. Attempts have, however, frequently been made, by neighbouring proprietors and others, to ascertain the depth of many of these lochs. About twelve years ago Mr. J. Y. Buchanan recorded the great depth of 175 fathoms in Loch Morar, and this was subsequently confirmed through numerous soundings taken by Sir John Murray, who recorded a depth of 180 fathoms near the same place. Sir John Murray and Mr. J. Y. Buchanan likewise took many soundings in the lochs of the Caledonian canal. Some of the English lakes have been surveyed within recent years by Dr. H. R. Mill, who gives an excellent account of his work in the *Geographical Journal* for 1895.†

* Vol. iv. p. 251.

† The subject of Limnology has lately excited a great deal of interest, especially on the Continent and in America. The following are some of the more important publications:—

Forel, F. A., 'Le Léman, monographie limnologique.' 2 vols. Lausanne, 1892 and 1895; and papers published in the *Arch. des Sci. phys. et nat.* Genève, 1886–1895. Forbes, S. A., "On some Lake Superior Entomostraca," *U.S. Fish Comm. Report* for 1887; also Reports of the Director of the Illinois State Laboratory of Natural History since 1894.

Belloc, E., several Papers published between 1890 and 1894, in the Reports of *Assn. franç. pour l'Avanc. des Sciences*, in the *Comptes Rendus*, in the *Annuaire du Club Alpin français*, etc.

Zacharias, O., 'Forschungsberichte aus der biologischen Station zu Plön,' Theil i.–iv. Berlin, 1893–96.

Evermann, B. W., Papers on rivers and lakes with reference to fish environment in the *Bull. U.S. Fish Comm.*, vols. xiii, xvi, and xvii, 1893–97.

Reighard, J. E., "A Biological Examination of Lake St. Clair," *Bull. Mich. Fish Comm.*, No. 4, 1894.

Thoulet, J., "Contribution à l'étude des Lacs des Vosges," *Bull. Soc. Geogr. Paris*, sér. 7, t. xv. p. 557, 1894.

Marinelli, O., "Area, profondità ed altri elementi dei principali laghi Italiani," *Rivista geogr.*, 1894–95.

Magnin, A., 'Les Lacs du Jura.' Paris, 1895.

Penck, A., and Richter, E., 'Atlas der österreichischen Alpenseen,' Lief. i. and ii. Folio. Wien, 1895–96.

Mill, H. B., "Bathymetrical Survey of the English Lakes," *Geographical Journal*, vol. vi. pp. 46 and 135, 1895.

Ward, H. B., "A Biological Examination of Lake Michigan in the Traverse Bay Region," *Bull. Mich. Fish Comm.* No. 6, 1896.

Kofoid, C. A., "Plankton Studies," *Bull. Illinois State Lab. Nat. Hist.*, vol. v. p. 1, 1897.

Marsh, C. D., "On the Limnetic Crustacea of Green Lake," *Trans. Wisconsin Acad. Sci.*, vol. xi. p. 179, 1897.

Delebecque, A., 'Les Lacs français,' text 4to, with folio atlas. Paris, 1898.

In the present paper we propose to give the results of our numerous recent observations as to the depths in Lochs Katrine, Arklet, Achray, Vennachar, Drunkie, Lubnaig, Voil, and Doine, all of which belong to the catchment-basin of the river Teith, and have a special interest from being directly or indirectly connected with the excellent water-supply to the city of Glasgow.* It is true that at the present moment Loch Arklet belongs to the catchment-basin of Loch Lomond, but the Corporation of Glasgow has power to divert its waters into the catchment-basin of Loch Katrine.

METHODS.

To undertake a survey of these fresh-water lochs with the ordinary hand-line would have occupied a very long time; in order to accelerate the work, it was essential to procure a portable wire sounding-machine that could be used in small rowing-boats. Such an instrument was exhibited by Dr. Ule at the Sixth International Geographical Congress in London in 1895. This apparatus was purchased, and with it numerous soundings were taken in Loch Morar, in Lochs Frisa, Ba, and Uisg in Mull, and also in Lochs Katrine, Lubnaig, and other lochs. After a few months' use, however, the machine—which was more or less of a toy—

* In the year 1855 the Corporation of Glasgow was empowered by Act of Parliament to raise Loch Katrine 4 feet above, and to draw it down 3 feet below the previous summer level, thus giving a total available depth of 7 feet for the supply of water to the city, the quantity of water to be drawn from the loch being restricted to fifty million gallons in twenty-four hours. For the purpose of providing compensation water to the riparian owners on the river Teith, power was also given to raise Loch Vennachar 5 feet 9 inches above its previous summer level, and to draw it down 6 feet, and also to raise Loch Drunkie 25 feet. An aqueduct was built from the southern shore of Loch Katrine to Glasgow, 8 feet wide and 8 feet high throughout, with a semicircular top, and having a fall towards Glasgow of 10 inches per mile. At first only a portion of the available fifty million gallons per day was conveyed to Glasgow, but by the end of 1881 the whole of the works necessary to complete the original design were finished. In the year 1884 it was found necessary to provide a larger quantity of water in order to keep pace with the growth of the city, and it was then found that the roughness of the rock sides of the aqueduct had a very retarding influence upon the velocity of the water, and that the aqueduct could not be made to discharge more than forty-two million gallons per day. Power was subsequently obtained from Parliament to build a second aqueduct, to raise Loch Katrine an additional 5 feet, and to convert Loch Arklet, which flows into Loch Lomond, into a reservoir by raising it 25 feet in level. These works are now in progress, and when completed are estimated to give a supply of seventy-five millions of gallons of water per day to the city of Glasgow. Should a still greater supply be necessary in the future, it is believed this can be obtained by connecting Loch Doine with Loch Katrine by a tunnel through the intervening hills, and by constructing an embankment at the bottom of Loch Doine to raise the water-level 30 feet, and another at the bottom of Loch Voil to raise the water-level of that loch 10 feet, and if still more water were wanted Loch Lubnaig could furnish it (see papers by James M. Gale, Esq., M. INST. C.E., in the *Trans. Inst. Engineers in Scotland*, vols. vii., xii., xxvi., and xxxviii., and his Report on the proposed extension of the Glasgow Corporation Water Works, dated May 17, 1884).

turned out untrustworthy, and was consequently discarded. Subsequently Mr. Pullar designed the sounding-apparatus shown in Fig. 1, which in his hands has worked admirably and accurately.

FIG. 1.—F. P. PULLAR'S SOUNDING-MACHINE.

DESCRIPTION OF THE PULLAR SOUNDING-MACHINE.

The sounding-machine (see Fig. 1) is constructed of steel cycle tubes, which are held in position by means of gun-metal brackets, and is divided into two sections in order to pack into as little space as possible for transport. The first section consists of a bracket, carrying two upright tubes, with an adjustable clamp (K), by means of which the machine is fixed to the gunwale of the boat. Over the ends of the two upright tubes, at the disconnecting joint (L), is slipped the second section of the machine, consisting of two horizontal tubes, to which the drum with the sounding wire, measuring pulley, indicating dials, grease-box, etc., are all fixed. The drum (A), which carries the wire, is a small suspension wheel, with a U-shaped rim, tangent spokes, and gun-metal hub. The hub has cone bearings, which can be screwed up, so that any wear may be allowed for. The rim of the drum is capable of holding over 1000 feet of three-strand galvanized steel wire (F). On the hub of the drum is fixed

a bronze pinion wheel, in gear with another pinion wheel fitted with a crank handle (B), by means of which the wire on the rim of the drum may be wound in, and on the other side of the hub is an adjustable band-brake (E) intended to regulate the speed of the wire when running out. There is also a stop for the purpose of preventing the weight from running out when the machine is not in use. The wire, after leaving the drum, takes a complete turn round a measuring pulley (G), then through a grease-box (M), and over a guide pulley (H), to the weight (I), which takes the form of a sounding-tube constructed to procure a sample of the deposit, with flap-valve (J) at the foot, the wire being attached to the weight by means of a splice and clip-hook. The measuring pulley has a circumference of nearly 1 foot (measured through the centre of the wire it is exactly 1 foot), so that for every foot of wire which runs out the measuring pulley makes one revolution. The motion of the measuring pulley is transmitted to a series of indicating dials (1, 2, and 3), one recording feet, another tens, and a third hundreds of feet. When the weight strikes the bottom the motion ceases, and the depth may be read off the indicating dials. The dials fitted to the present machine read only to a depth of 999 feet 6 inches, but by the addition of an extra dial greater depths could be sounded.

All the soundings recorded in this paper were taken from small rowing-boats, with the exception of a few obtained from Mr. Dunsmure's steam yacht on Loch Katrine, and they were all taken with Mr. Pullar's sounding-machine. It was usual to pass from side to side of a loch along definite lines, the length of the lines and the distances between them being ascertained from the 6-inch Ordnance Survey maps, which were throughout used for plotting the positions of the soundings. Before making a section across a loch, the boatman was trained for some time to ascertain the distance covered in ten, fifteen, twenty, and fifty strokes. The position on the line of soundings was determined by reference to poles or other objects placed one behind the other on shore, and by the

FIG. 2.—METHOD OF SOUNDING.

(From a photograph by Lady Murray.)

number of strokes between each position. When necessary the position was determined by means of a pocket sextant, and frequently the position of the soundings near the shore was ascertained by measurement with tape lines, or cords several hundred feet in length, stretched from the shore. In addition to the cross-lines, soundings were usually taken in several positions between the lines. When any special feature was indicated by the soundings, a series was taken in a radial manner from a fixed point.

The level of the surfaces of the lochs was obtained by reference to the bench-marks along the shore, but as a rule no correction was made for the variations in the rise and fall of the water while the work was in

progress. Information was collected when possible from local people as to the height of the water in the various lochs in the dry and wet months of the year.

The samples of bottom-deposits were carefully collected by means of the sounding-tube furnished with a flap-valve at its lower end (see Fig. 1), the colour and general appearance being noted, and the samples carefully preserved for future examination.

Serial temperatures were taken in each of the lochs by means of Negretti and Zambra's reversing thermometers, specially adapted for use on the wire-rope of the sounding-machine; observations at the surface of the lochs, and in the streams feeding the lochs, were frequently made as opportunity offered. The pelagic fauna and flora of these lakes were examined by means of fine silk tow-nets, which were dragged through the water at different depths, and the colour and transparency of the water were frequently tested by the submergence of coloured discs.

After the completion of the survey of a particular lake, and when all the soundings had been plotted on the 6-inch Ordnance Survey maps, contour-lines of depth were drawn at definite intervals, and the areas between the consecutive contours were measured by the planimeter, from which the cubic contents and the mean depth of each loch were calculated. The drainage areas of the various lochs (as shown on Map I.) were marked off on the 1-inch Ordnance Survey maps, and the areas between the consecutive contour-lines of height were measured by the planimeter, from which the bulk and the mean height of the land above the level of the lochs were calculated.

MAPS AND ILLUSTRATIONS.

This paper is illustrated by seven coloured maps. The first three are intended to show the general physical features of the district in which the lochs, treated of in this paper, are situated, and are drawn to a scale of 2 miles to the inch.

Plate I. shows the orography of the district, the height of the land being indicated by different shades of brown, and the depth of the lochs in fathoms by different shades of blue, and the drainage areas of the various lochs are outlined by a distinctive coloured line. It will be observed that the drainage areas form together one compact area, and, indeed, it may be said that (excluding in the mean time Loch Arklet) they are in reality one united drainage system, since Lochs Doine, Voil, and Lubnaig drain into the river Leny, and Lochs Katrine, Achray, Drunkie, and Vennachar drain into the river Teith, which two rivers join above Callander, and flow onwards until they join the river Forth at Stirling, and ultimately empty themselves into the Firth of Forth.

Plate II. shows the surface geology of the district in various colours, and has been prepared from unpublished material collected during the

progress of the Geological Survey of Scotland, revised by Messrs. Peach and Horne, and now published by permission of Sir Archibald Geikie, the Director-General of the Geological Survey of the United Kingdom. A discussion of the geology and glaciation of this district, and of the relation of the depths of the lochs to the surrounding geological features of the country, will be found in the valuable and important geological notes contributed by Messrs. Peach and Horne appended to this paper.

Plate III. shows the mean annual rainfall of the district in different shades of blue, the mean rainfall at the various observing stations being given in heavy black figures. We are indebted to Dr. Alexander Buchan, F.R.S., for information which has enabled us to prepare this map.

The remaining four maps show the details regarding each of the lochs under consideration on a larger scale (3 inches to the mile, 1 : 21,120), on which the majority of the soundings taken during the survey are given in feet, the intervals between the contour-lines of depth being indicated by different shades of blue, and the intervals between the contour-lines of height of the neighbouring country by shades of brown.

Plate IV. shows Loch Katrine and Loch Arklet, the contour-lines of depth being drawn in Loch Arklet at 25 and 50 feet, and in Loch Katrine at 50, 100, 200, 300, and 400 feet.

Plate V. shows Loch Achray, Loch Vennachar, and Loch Drunkie, the contour-lines of depth being drawn in Loch Achray at 25 and 50 feet, the area deeper than 90 feet being indicated by a dotted line; in Loch Vennachar at 25, 50, and 100 feet, and in Loch Drunkie only at 50 feet.

Plate VI. shows Loch Lubnaig, the contour-lines of depth being drawn at 10, 25, 50, 75, and 100 feet.

Plate VII. shows Loch Doine and Loch Voil, the contour-lines of depth being drawn in Loch Doine at 25 and 50 feet, and in Loch Voil at 25, 50, and 75 feet, the area deeper than 90 feet being indicated by a dotted line.

We tender our thanks to J. G. Bartholomew, Esq., F.R.G.S., for the care with which he has supervised the production of these maps, and for valuable advice and suggestions during the progress of the work.

In addition to the maps, there are eleven woodcuts in the text, illustrating the character of the scenery in the vicinity of the lochs, the sounding machine, etc.

DEPTHS OF THE LOCHS.

Loch Katrine.—Loch Katrine is one of the best known and most beautiful of the Scottish lochs. The celebrated woodland scenery of the Trossachs and Ellen's isle is situated at its south-eastern end, while splendid moorland scenery prevails at the north-western end. It has a total length of about 8 miles, with a maximum width of almost exactly

1 mile between the mouths of Letter burn and Strone burn on the northern shore to a small bay on the opposite shore. The mean breadth, obtained by dividing the area of the loch by its length, is 0·6 mile, or 1056 yards, being $7\frac{1}{2}$ per cent. of the length.

The waters of the loch cover an area of 3059 acres (or $4\frac{3}{4}$ square miles), and it drains an area about eight times greater, or about 24,900 acres (nearly $37\frac{1}{2}$ square miles).* The total number of soundings taken in Loch Katrine was 775, an average of 163 per square mile, and the average depth of these was $142\frac{1}{2}$ feet, the greatest depth observed being 495 feet ($82\frac{1}{2}$ fathoms).† The positions of the majority of the soundings are shown on Map IV.

FIG. 3.—LOCH KATRINE AND ELLEN'S ISLE.

(From a photograph by J. Valentine.)

The bulk of water contained in the loch is estimated at 27,274,000,000 cubic feet, or about one-fifth of a cubic mile, and the mean depth (supposing the loch to be of uniform depth over its present area) at 199

* When the waters of Loch Arklet are diverted into Loch Katrine this drainage area will, of course, be extended.

† As long ago as September, 1812, and September, 1814, Mr. James Jardine, C.E., recorded observations on the depth and temperature of Loch Katrine (see Buchan, *Proc. Roy. Soc. Edin.*, vol. vii. p. 791, 1872). The maximum depth recorded by him is 480 feet (80 fathoms), whereas, as stated above, we found a depth of 495 feet. His temperature observations are given in the table of serial temperatures, and discussed along with the recent observations. We believe that Mr. J. Y. Buchanan took soundings and temperatures in Loch Katrine some years ago, but, as far as we are aware, they were never published, and are therefore not available for discussion (see also Art. "Lake" in *Encycl. Brit.*, 9th edit.).

feet (33 fathoms), the mean depth being over 40 per cent. of the maximum depth. The length of the loch is 85 times the maximum depth, and 211 times the mean depth.

The surface of the loch is, according to the Ordnance Survey maps, at an elevation of 364 feet above sea-level, so that our survey shows that a considerable

portion of the bottom of the loch (equal to about 645 acres, or over one square mile) lies below sea-level, the deepest part being 131 feet (or 22 fathoms) below the level of the sea. The area below the level of the sea is indicated by a red line on Map IV. In this respect Loch Katrine differs from the other lochs referred to in this paper, for in none of them is the depth sufficiently great to bring any portion of their bottoms below the level of the sea.

The soundings show that Loch Katrine practically forms a single basin, not being divided, like Loch Lomond and Loch Lubnaig, for instance, into separate basins by any important ridges or rises on the bottom. The deepest part is in the centre of the loch, a long narrow depression, with depths exceeding 400 feet, extending for over 4 miles from opposite Coilachra to opposite Ruinn Dubh-aird, with a maximum width of over a quarter of a mile; this 400-feet depression has an area of about 515 acres, or 17 per cent. of the entire superficial area of the loch. The deepest sounding (495 feet) is situated at the very eastern extremity of the 400-feet depression.

The 300-feet depression is over 5 miles in length, with a maximum breadth of one-third of a mile; it extends from off Coilachra to near Ellen's isle. The area enclosed between the 300-feet and 400-feet contour-lines is about 415 acres, or 13 per cent. of the entire area of the loch.

The 200-feet depression is $5\frac{1}{2}$ miles in length and half a mile in maximum breadth, extending from south of Ellen's isle to near Black island, where it is separated (by a sounding of 198 feet) from a small isolated area, lying between Coilachra and

FIG. 4.—LONGITUDINAL SECTION OF LOCH KATRINE, ALONG THE AXIS OF MAXIMUM DEPTH. THE BLACK PORTION SHOWS THE TRUE SLOPES; THE OUTLINE SHOWS THE SLOPES EXAGGERATED TEN TIMES.

FIG. 5.—CROSS-SECTION OF LOCH KATRINE. THE BLACK PORTION SHOWS THE TRUE SLOPES; THE OUTLINE SHOWS THE SLOPES EXAGGERATED TEN TIMES.

Black island, one-third of a mile in length by nearly one-eighth of a mile broad. The area between the 200- and 300-foot contours is about 510 acres, or 17 per cent. of the area of the loch.

There are two 100-foot depressions, the principal one (6 miles in length) stretching from close to Ellen's isle to Black island, the other extending from Black island towards the point called Rudha nam Moine, with a total length of over half a mile. The area enclosed between the 100- and 200-foot contours is about 670 acres, or 22 per cent. of the area of the loch.

The 50-foot line follows pretty closely the contour of the loch, from Rudha nam Moine into the eastern arms of the loch at the Trossachs,

FIG. 6.—LOCH ARKLET, LOOKING WEST.

(From a photograph by G. W. Wilson.)

running outside of Black island, Ellen's isle, and the small islands near the shore all round, with a small isolated patch at the junction of the Trossachs arm with the arm leading to Achray Water; it encloses a small shallow, with a beacon on it, opposite the entrance of the Glasha-hoile. The area between the 50- and 100-foot contours is about 400 acres, or 13 per cent. of the area of the loch, while the area between the coast-line and the 50-foot contour is nearly 550 acres, or 18 per cent. of the area of the loch, so that 82 per cent. of the floor of the loch is covered by over 50 feet of water.

Loch Arklet.—At the present time Loch Arklet drains into Loch Lomond, but the corporation of the city of Glasgow have power, by the

erection of a dam at its west end, to divert the waters into the catchment-basin of Loch Katrine, in order to increase the supply of water to the city. The surface of this little moorland loch is, according to the Ordnance Survey maps, 455 feet above sea-level. It has a total length of over a mile, and a maximum width near the east end of nearly half a mile. The mean breadth is about one-third of a mile, or 587 yards, being 33 per cent. of the length. Its waters cover an area of about 210 acres (0.3 square mile), and it drains an area about sixteen times greater, or about 3400 acres ($5\frac{1}{3}$ square miles). The number of soundings taken in Loch Arklet (see Map IV.) was 135, the average depth of these being 21 feet, and the greatest depth observed being 67 feet (11 fathoms). The mass of water in the loch is estimated at 222,000,000 cubic feet, and the mean depth at 24 feet, or 36 per cent. of the maximum depth. The length of the loch is 79 times the maximum depth, and 218 times the mean depth.

The wide eastern portion of Loch Arklet is shallower than the narrower western portion. The 50-feet depression extends little more than halfway towards the eastern end of the loch, and is slightly under half a mile in length, the greatest depth (67 feet) being approximately near the centre of the depression, and nearer the western than the eastern end. The area over 50 feet in depth is estimated at about 19 acres, or 9 per cent. of the area of the loch, while the area between the 50-feet line and the shore is about 191 acres, or 91 per cent. of the entire superficial area.

Two small islands appear on the chart in the shallower part of the loch towards the north-eastern end.

Loch Achray.—This pretty little lake is situated at the entrance to the Trossachs, and immediately before the windows of the Trossachs Hotel. Loch Achray, the surface of which is, according to the Ordnance Survey maps, 276 feet above sea-level, has a total length of about $1\frac{1}{4}$ miles, with a maximum width of nearly one-third of a mile. The mean breadth is about a quarter of a mile, or 458 yards, being nearly 21 per cent. of the length. Its waters cover an area of about 205 acres (one-third of a square mile), and the area draining into it is twenty-two times greater, or about 4500 acres (7 square miles). The number of soundings taken in Loch Achray (see Map V.) was 171, and the average depth of these was $36\frac{1}{2}$ feet, the maximum depth recorded being 97 feet (16 fathoms). The bulk of water contained in the loch is estimated at 321,000,000 cubic feet, and the mean depth at 36 feet (6 fathoms), or 37 per cent. of the maximum depth. The length of the loch is 68 times the maximum depth, and 183 times the mean depth.

The 50-feet depression is over two-thirds of a mile in extreme length, with a maximum width of about one-fifth of a mile, lying uniformly near the centre of the loch, and covers an area of about 64 acres, or 31 per

cent. of the superficies of the loch. Within this area there is a depression occupying about 32 acres where the depths exceed 90 feet, the greatest registered depth (97 feet) being recorded in two places approximately in the centre of the loch. At the west end of the loch, not far from the hotel pier, a detached sounding of 50 feet is recorded; off the mouth of the Achray water there are some shallow patches, and a shallow in the centre of the loch towards the west end, on which there are 2 to 3 feet of water, is marked by a beacon. The area less than 50 feet in depth is estimated at about 141 acres, or 69 per cent. of the total area of the loch. The eastern end of the loch is relatively shallow; at one place there is a depression with 27 feet surrounded by shallower water, and at another

FIG. 7.—LOCH ACHRAY, LOOKING WEST TOWARDS BEN VENUE.

(From a photograph by J. Valentine.)

place there is what appears to be a submerged crannog covered by only 1 or 2 feet of water.

Loch Vennachar.—Loch Vennachar, the surface of which is, according to the Ordnance Survey maps, 270 feet above sea-level, has a total length of about 4 miles, with a maximum width of less than three-quarters of a mile. The mean breadth is about two-fifths of a mile, or 704 yards, being 10 per cent. of the length. Its waters cover an area of about 1030 acres (or over $1\frac{1}{2}$ square miles), and it drains an area nearly eighteen times greater, or about 18,300 acres ($28\frac{1}{2}$ square miles). The total number of soundings taken in Loch Vennachar (see Map V.) was 423, an average of 263 per square mile, the average depth of these being

41 feet, and the greatest depth observed being 111 feet ($18\frac{1}{2}$ fathoms), so that it may be regarded as a relatively shallow loch. The bulk of water contained in the loch is estimated at 1,903,000,000 cubic feet, and the mean depth at $42\frac{1}{2}$ feet (7 fathoms), being 38 per cent. of the maximum depth. The length of the loch is 190 times the maximum depth, and 498 times the mean depth.

It will be observed from an examination of the map that the loch is deeper in the eastern than in the western portion, the western end being shallow and covered with weeds, so that one must proceed nearly a mile from the west end of the loch before encountering depths of 50 feet, and this is merely a small patch separated from the principal 50-foot depression by a distance of nearly two-thirds of a mile. In August the water in the loch is at its lowest, and the weeds at the west end most abundant. The principal 50-foot depression is about 2 miles in length, with

FIG. 8.—LOCH VENNACHAR, LOOKING SOUTH-WEST.
(From a photograph by G. W. Wilson.)

a mean breadth of about one-third of a mile and a maximum breadth of nearly half a mile. It includes two 100-foot depressions: the first one is very irregular in shape, situated approximately in the centre of the loch, and contains the greatest observed length (111 feet), which lies towards the northern shore; the second one occupies the central portion of the large 50-foot depression, the greatest depth observed therein being 106 feet. Towards the eastern end of the large 50-foot depression is a small shallow patch in the centre of the loch opposite Portnellan, in which a depth of 36 feet was found.

At the extreme eastern end are situated the sluices and weir, over which the compensation water passes into the river Teith; at some distance from the sluices the depth of water flowing over a weir is recorded twice a day.

The area between the shore and the 50-foot contour is estimated at about 635 acres, or 62 per cent. of the entire superficial area of the loch, while the area between the 50- and 100-foot lines is estimated at about 324 acres, or 31 per cent., and the area with depths over 100 feet is estimated at about 71 acres, or 7 per cent. of the area of the loch.

Loch Drunkie.—This picturesque and irregular Highland loch is shut in on all sides by high hills, is difficult of access, and rarely visited. The surface of the loch, according to the Ordnance Survey maps, is 416 feet above the level of the sea, but it was raised 25 feet in connection with the water-supply to the city of Glasgow, with the view of furnishing compensation water to the river Teith. The soundings shown on the map give the depth of the loch in April, 1899.

Loch Drunkie is remarkable in many respects. It is the smallest of the five lochs in the Loch Katrine district, but deeper than the larger Loch Arklet situated at a similar high elevation, and quite as deep as the neighbouring Loch Achray situated at a lower elevation. In form it is peculiar, consisting of a quadrangular portion throwing out three arms of various sizes in different directions. The largest arm runs in a north-easterly direction, the extremity approaching within a quarter of a mile of the southern shores of Loch Vennachar; this arm contains the greatest depths observed in the loch, and near its extremity the Ordnance Survey map indicates a small island which was not seen. The second arm in point of size runs directly west, and contains a maximum depth of 80 feet. The smallest arm runs in a south-westerly direction, deepening gradually though irregularly from 6 feet at the extremity to 15 feet near the junction with the quadrangular body of the loch.

The maximum length of the loch (between the extremities of the north-eastern and south-western arms) is over one mile; from the extremity of the western arm to the opposite (eastern) shore of the loch is a little less. The maximum width of the quadrangular body of the loch is over a quarter of a mile. The mean breadth is 0.21 mile, being 21 per cent. of the length. The waters of the loch cover an area of about 138 acres (0.22 square mile), and drains an area ten times greater, or over 1400 acres (2.2 square miles). The number of soundings taken in Loch Drunkie (see Map V.) was 155, the average depth of these being $38\frac{1}{2}$ feet, the greatest depth observed (exactly the same as in the case of Loch Achray) being 97 feet (16 fathoms). The bulk of water contained in the loch is estimated at 217,000,000 cubic feet, and the mean depth at 36 feet (or 6 fathoms), being 37 per cent. of the maximum depth. The length of the loch is 54 times the maximum depth, and 147 times the mean depth.

There are two depressions with depths over 50 feet: one at the extremity of the western arm, about a quarter of a mile in length, and the other filling up the greater part of the body of the loch, and

extending some distance up the north-eastern arm, being over one-third of a mile in length and about one-quarter of a mile in maximum width. The area over 50 feet in depth is estimated at 43 acres, or 31 per cent. of the total area of the loch, while the area between the shore and the 50-foot contour is estimated at 95 acres, or 69 per cent. of the area of the loch.

Lochs Voil and Doine.—These two lochs, the surfaces of which, according to the Ordnance Survey maps, are situated at an elevation of 414 feet above sea-level, formed at no very distant date a continuous loch, which has been divided into two portions principally by the deposition of material brought down Monachyle glen by the river; this

FIG. 9.—LOCHS VOIL AND DOINE, LOOKING WEST FROM ROB ROY'S GRAVE, BALQUHIDDER.
(From a photograph by J. Valentine.)

is supported by the fact that deep water extends close up to the dividing promontory of land on both sides. The former continuous loch must have been over $4\frac{1}{2}$ miles in length. As the level of these two lochs is 50 feet higher than the level of Loch Katrine, it has been suggested by Mr. Gale that the water-supply to the city of Glasgow could, if necessary, be increased by connecting these lochs to Loch Katrine by a conduit through the intervening hills.

Loch Voil.—Loch Voil has a total length of over $3\frac{1}{2}$ miles, with a maximum width (near the western end) of about one-third of a mile. The mean breadth is about a quarter of a mile, or 422 yards, being 7 per cent. of the length. The waters of Loch Voil cover an area of

No. IV.—APRIL, 1900.]

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about 561 acres (0·88 square mile), and those of Loch Doine about 135 acres (0·21 square mile), or together over one square mile, while they drain an area thirty-five times greater, or about 24,600 acres (nearly $38\frac{1}{2}$ square miles).

The total number of soundings taken in Loch Voil (see Map VII.) is 279, the average depth of these being $39\frac{1}{2}$ feet, and the greatest depth 98 feet (or $16\frac{1}{3}$ fathoms). The bulk of water contained in the loch is estimated at 1,000,000,000 cubic feet, and the mean depth at 41 feet (or nearly 7 fathoms), being 42 per cent. of the maximum depth. The length of the loch is 189 times the maximum depth, and 451 times the mean depth.

Loch Voil becomes narrower and shallower towards the eastern end; one must proceed about a mile and a half (or over one-third of the length of the loch) from the eastern end before encountering depths of 50 feet, while deeper water is found towards the western end. The 50-foot depression extends from quite close to the western end for a distance of 2 miles towards the eastern end of the loch, with a maximum width of about a quarter of a mile. Towards the western end of the loch is a considerable area (over half a mile in length by a sixth of a mile in maximum breadth) having depths greater than 90 feet. In this all the deepest soundings are situated (the greatest depth, 98 feet, having been observed in two places). From this depression the bottom of the loch apparently rises very gradually towards the eastern end.

The area over 50 feet in depth is estimated at about 230 acres, or 41 per cent. of the entire area of the loch, while the area between the shore and the 50-foot line is estimated at about 331 acres, or 59 per cent. of the total extent of the loch.

Loch Doine.—Loch Doine has a total length of nearly one mile, with a maximum width of over a quarter of a mile; the mean breadth is about 0·21 mile, or 370 yards, being 21 per cent. of the length. The total number of soundings taken in Loch Doine (see Map VII.) was 90, the average depth of these being $34\frac{3}{4}$ feet, the greatest depth being 65 feet (11 fathoms). The bulk of water contained in the loch is estimated at 196,000,000 cubic feet, and the mean depth at 33 feet ($5\frac{1}{2}$ fathoms). The length of the loch is 81 times the maximum depth, and 160 times the mean depth.

In Loch Doine the deeper water occupies approximately the centre of the loch, the deepest soundings (65 feet) being found, however, nearer the eastern than the western end of the loch. The 50-foot depression covers over one-third of the area of the loch, being about three-quarters of a mile in length with a maximum width of over one-eighth of a mile. It seems doubtful whether this 50-foot depression is not really separated into a larger and a smaller portion, for the narrow neck shown on the map is founded upon a single sounding of exactly 50 feet. The greatest depth, 65 feet, was observed in several spots situated towards the

eastern end of the loch. The area with depths over 50 feet is estimated at 47 acres, or 35 per cent. of the entire area of the loch, while the area with depths less than 50 feet is estimated at 88 acres, or 65 per cent. of the area of the loch.

Loch Lubnaig.—The outflow from Lochs Doine and Voil passes by the river Balvag, 5 miles in length, into Loch Lubnaig, the surface of whose waters is, according to the Ordnance Survey maps, 405 feet above sea-level, or 9 feet lower than that of the other two lochs. A consideration of the intervening ground indicates that in post-glacial times these three lochs formed one single sheet of water.

FIG. 10.—LOCH LUBNAIG, LOOKING NORTH.

(From a photograph by G. W. Wilson.)

Loch Lubnaig has a total length of nearly 4 miles, following approximately a line drawn down the centre of the loch, with a maximum width of about two-fifths of a mile. The mean breadth is nearly a quarter of a mile, or 422 yards, being 6 per cent. of the length. Its waters cover an area of about 614 acres (or nearly 1 square mile), and it drains an area $36\frac{1}{2}$ times greater, or about 22,400 acres (nearly 35 square miles). The total number of soundings taken in Loch Lubnaig (see Map VI.) was 394, the average depth of these being $20\frac{1}{2}$ feet, and the greatest depth observed 146 feet ($24\frac{3}{4}$ fathoms). The bulk of water contained in the loch is estimated at 1,144,000,000 cubic feet, and the mean depth at $42\frac{3}{4}$ feet (or 7 fathoms), being 29 per cent. of the maximum depth. The length of the loch is 145 times the maximum depth, and 493 times the mean depth.

Loch Lubnag differs from the other lochs in the neighbourhood in that it does not constitute a single basin. The bottom is apparently very irregular; the contour-lines of depth do not follow the contour of the loch, hollows and ridges alternate with each other, and in some places comparatively deep water is found close to the shore, while in other places shallow water extends a considerable distance from shore. The loch is also, comparatively speaking, very narrow and shallow considering its size, nearly two-thirds of the area being under 50 feet in depth. The loch may be conveniently divided into two halves, defined by the central constriction in the outline of the loch at the entrance of the Ardhullarie burn, where the bottom shallows and separates the two principal deep depressions; the northern half trends in a north-west and south-east direction, while the southern half trends almost directly north and south.

There are two depressions in which the depth exceeds 100 feet, with an isolated sounding of 106 feet between them. The larger depression is contained in the southern half of the loch, and is over half a mile in length, with a maximum width of about one-sixth of a mile; the greatest depth in this depression is 118 feet. The smaller but deeper depression is situated at the base of the northern half of the loch, occupying a central position, and is over a quarter of a mile in length, with a maximum width of about one-sixth of a mile. The deepest sounding in the loch (146 feet) is centrally placed in this depression, lying north-westward of the point where the Ardhullarie burn enters the loch. The area over 100 feet in depth is estimated at about 55 acres, or 9 per cent. of the entire area of the loch.

There are three depressions in which the depth exceeds 50 feet. The largest is contained in the southern half of the loch, and is over $1\frac{1}{2}$ miles in length, with a maximum width of over a quarter of a mile. The second in point of size is centrally placed, and is over half a mile in length, with a maximum width of over a quarter of a mile. The third and smallest (and also the shallowest, the deepest sounding in it being 62 feet) is situated near the northern end of the loch, and is little more than a quarter of a mile in length and about one-eighth of a mile in greatest width. At the upper end of the loch, where the river Balvag enters, there is a long spit formed of detritus brought down by the river, and this end of the loch for a distance of three-quarters of a mile is very shallow, while at the lower end the 50-foot contour is found within 200 yards of the outlet. The area between the 50-foot and 100-foot contours is estimated at about 162 acres, or 26 per cent. of the total area of the loch, while the area with depths under 50 feet is estimated at about 397 acres, or 65 per cent. of the area of the loch.

When the loch was visited on April 6, 1899, it appeared from marks on the shore that the water had lately been 4 feet 10 inches higher than at that time, and it has been known to have been 12 or 18 inches lower,

so that the rise and fall is about 6 feet in all. On one occasion a disc was visible down to a depth of $17\frac{1}{2}$ feet, and on another down to $20\frac{1}{2}$ feet.

On the western shore, between $1\frac{1}{4}$ and $1\frac{1}{2}$ miles from the southern end of the loch, there is a remarkable sandy spit, which stretches out towards the centre of the loch, the origin of which appears to us somewhat puzzling (see the Geological Notes by Messrs. Peach and Horne).

The details regarding the different lochs have been collected together in the table on p. 330 for convenience of reference and comparison.

DEPOSITS.

As a general rule, the materials forming the deposits in these fresh-water lochs become finer grained the further from the shore and the deeper the water. Off the mouths of rivers and burns there is frequently a considerable accumulation of gravel and fine sand, extending for some distance into the lake and occasionally reaching rather deep water. Large stones, gravel, and sand are usually found all round the shores within the limits of wave-action. The height and length of the waves, and the depth to which wave-action extends, depend on the size and depth of the loch.

The central parts of the lochs are occupied by a fine impalpable mud, which is found in its most characteristic form in the greater depths far from shore; it is usually of a light or dark brown colour, and sometimes there are indications of different-coloured layers. The usual mineral species are quartz, felspars, black and white mica, amphibole, pyroxene, magnetite, garnets, etc. Chemical analysis showed that these fine muds contained no appreciable calcareous matter, but traces of sulphuretted hydrogen were always present. The loss on ignition after drying at 90° C., due to organic matter and combined water, varied from 13 to 26 per cent. Diatoms were observed in nearly all the samples, and vegetable fibre was usually present in greater or less abundance.

The samples from the deepest part of Loch Katrine were brownish, fine-grained, homogeneous muds, with glittering mica-flakes, consisting principally (50 to 70 per cent.) of angular mineral particles exceeding 0.05 mm. in diameter, the mean diameter being about 0.15 mm., with clayey and vegetable matter, and many minute mineral particles less than 0.05 mm. in diameter. A few diatoms were observed, and one sample, after drying at 90° C., gave 19.91 per cent. loss on ignition.

The mud from the deepest part of Loch Achray was of a grey-brown colour, containing much vegetable and clayey matter, the mineral particles exceeding 0.05 mm. in diameter making up probably 30 or 40 per cent. of the whole deposit. Some fine diatoms were observed, and the loss on ignition, after drying at 90° C., amounted to 12.84 per cent.

The mud from a depth of 102 feet in Loch Vennachar was yellowish-brown in colour, containing about 20 per cent. of mineral particles with

A BATHYMETRICAL SURVEY OF

Loch.	Elevation of surface above the sea.	Number of sound- ings.	Length.		Breadth, miles.		Mean breadth per cent. of length.		Depth.			Ratio of depth to length.		Volume, million cubic feet.	Area of loch.		Drainage area.	
			Miles.		Max.	Mean.			Feet.	Mean per cent. of max.	Max.	Max.	Mean.		Square miles.		Total in square miles.	Ratio to area of loch.
Katrine	...	775	8.00		1.00	0.60	7.5		495	199.189	40.4	85	211	27,274	4.78		37.42	7.83
Arklet...	...	135	1.00		0.50	0.33	33.3		67	24.190	36.1	79	218	222	0.33		5.33	16.15
Achray	...	171	1.25		0.33	0.26	20.8		97	36.009	37.1	68	183	321	0.32		7.06	22.06
Vennachar	...	423	4.00		0.75	0.40	10.0		111	42.410	38.2	190	498	1,903	1.61		28.65	17.80
Drunkie	...	155	1.00		0.25	0.21	21.0		97	36.050	37.1	54	147	217	0.22		2.20	10.00
Voil	...	279	3.50		0.33	0.24	6.9		98	40.936	41.8	189	451	1,000	0.88		38.47	35.29
Doine	...	90	1.00		0.25	0.21	21.0		65	33.130	51.0	81	160	196	0.21		34.97	36.43
Lubnaig	...	394	4.00		0.40	0.24	6.0		146	42.773	29.3	145	493	1,144	0.96		154.10	16.55
		2122												32,277	9.31			

a mean diameter of 0·1 mm., but principally made up of amorphous clayey matter with vegetable matter, and many minute mineral particles less than 0·05 mm. in diameter. There were a few diatoms; the loss on ignition, after drying at 90° C., amounted to 14 per cent.

The mud from the deeper part of Loch Drunkie was of a dirty brown colour, containing 10 to 20 per cent. of mineral particles with a mean diameter of 0·1 mm., but consisting principally of amorphous clayey matter, with many small mineral particles, and vegetable matter. A few diatoms were observed. The loss on ignition, after drying at 90° C., amounted to 26·38 per cent.

The deposit from the deeper parts of Loch Arklet was similar to that from Loch Drunkie, with even a larger quantity of vegetable matter.

The mud from the deeper parts of Lochs Doine and Voil was of a brown colour, with 30 to 40 per cent. of mineral particles, and clayey and vegetable matter, and a few diatoms. A sample from a depth of 80 feet in Loch Voil, after drying at 90° C., gave 22·74 per cent. loss on ignition.

The material from a depth of 136 feet in Loch Lubnaig was a brown impalpable mud, with 30 to 40 per cent. of mineral particles, much clayey and vegetable matter, and a few diatoms. The loss on ignition, after drying at 90° C., amounted in one sample to 16·29 per cent., and in another sample to 15·76 per cent.

TEMPERATURE OBSERVATIONS.

During the various visits to the different lochs, many observations were made on the temperature of the water, both on the surface and at intervals below the surface, down to the bottom. All the serial temperatures taken by us have been collected together in the table on p. 332,* and, in order to make the record more complete, the temperatures taken by Jardine in 1812 and 1814 in Loch Katrine are given in the first two columns.

Loch Katrine.—The surface temperatures taken in Loch Katrine during the seven days from June 5 to 11, 1897, are extremely interesting, as illustrating the effect of the wind. The range of temperature during this time was $12\frac{1}{2}^{\circ}$, from $45\cdot3^{\circ}$ to $57\cdot8^{\circ}$, the highest reading being observed at Trossachs pier on the evening of June 5, and the lowest at the same place on the evening of June 9. This was evidently the result of a strong east wind, which commenced to blow on the 6th, and continued from the same direction till the 9th, blowing the warm surface-waters before it from the east towards the west end of the loch, while colder water from below was drawn up to the surface at the east end of the loch to take its place. The gradual cooling of the water at

* Temperature observations in the surface-waters of some of the lochs under consideration have been taken by Mr. Thomas Scott, and the results published in the *Annual Reports of the Fishery Board for Scotland*.

Depth in fathoms.	Loch Katrine.						Loch Arklet.	Loch Achray.	Loch Drunkie.	Loch Venachar.		Loch Dolne.		Loch Voil.		Loch Lubnag.
	Jardine, Sept. 7, 1812.	Jardine, Sept. 3, 1814.	June 6, 1897.	June 9, 1897.	Nov. 26, 1897.	June 9, 1898.	Apr. 15, 1899.	June 12, 1897.	June 12, 1897.	June 10, 1897.	Apr. 11, 1899.	July 7, 1897.	Apr. 10, 1899.	July 7, 1897.	Apr. 10, 1899.	
Surface	57.9	56.8	55.9	—	47.4	55.0	41.2	—	57.5	—	55.8	—	54.0	—	56.0	—
1	—	—	—	—	47.4	—	41.2	—	—	—	—	—	—	—	—	—
2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	—	—	—	—	47.4	—	—	—	—	—	—	—	—	—	—	—
5	—	56.7	48.4	52.0	47.4	54.0	42.0	—	53.5	53.3	42.5	—	—	54.0	—	—
8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10	50.9	49.6	44.0	—	47.3	47.8	41.9	—	—	—	—	—	—	—	—	—
15	—	45.5	—	—	47.4	—	—	—	—	48.2	42.5	—	—	—	—	—
16	—	—	—	—	—	—	—	—	—	47.2	42.7	—	—	—	—	—
18	—	44.4	42.0	—	—	—	—	—	—	—	—	—	—	—	—	—
20	43.5	—	—	—	47.4	44.0	42.0	—	—	—	—	—	—	—	—	—
23	—	43.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
25	—	42.3	42.5	—	46.8	—	—	—	—	—	—	—	—	—	—	—
30	—	—	—	—	46.0	43.5	—	—	—	—	—	—	—	—	—	—
35	41.5	—	—	—	43.5	—	—	—	—	—	—	—	—	—	—	—
40	—	—	41.5	—	43.8	42.6	—	—	—	—	—	—	—	—	—	—
45	—	—	—	—	42.9	—	—	—	—	—	—	—	—	—	—	—
50	41.5	—	42.2	—	43.2	—	—	—	—	—	—	—	—	—	—	—
55	—	—	—	—	42.5	—	—	—	—	—	—	—	—	—	—	—
60	41.5	—	41.5	—	—	—	—	—	—	—	—	—	—	—	—	—
66	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
76	—	—	—	—	—	42.8	—	—	—	—	—	—	—	—	—	—
80	41.4	—	—	—	43.0	42.0	—	—	—	—	—	—	—	—	—	—
82½	—	41.7	—	—	43.8	—	—	—	—	—	—	—	—	—	—	—

the east end of the loch is well shown by the temperatures taken at Trossachs pier from day to day: thus at 6.30 p.m. on June 5 the temperature was 57.8° ; at 11.30 a.m. on the 6th it was 56.2° , and at 4 p.m. 55.3° ; at 7 a.m. on the 7th it was 49.2° ; at 10.30 a.m. on the 8th it was 46.3° ; and at 7.15 p.m. on the 9th it was 45.3° . By 9.30 a.m. on the 11th it had risen again to 50.1° . The effect of the wind was also shown by a series of surface-temperatures taken from the steamer on its way from Stronachlachar pier to the Trossachs pier on the evening of June 9: thus at Stronachlachar the temperature was 52.6° ; near the waterworks,

FIG. 11.—CURVES OF TEMPERATURE IN LOCH KATRINE.

52.0° ; near Letter, 49.6° ; near Brenachail, 48.8° and 48.0° ; near Ellen's isle, 47.4° and 47.0° ; and finally at Trossachs pier, 45.3° . It will thus be seen that it is very unsafe to rely on a single observation at one spot, as giving a sure indication of the temperature of the surface-waters of a loch as a whole at any given season. A year later (from June 4 to 9, 1898) the temperature of the surface-waters of Loch Katrine was not observed to fall below 50° . On November 26, 1897, the surface-temperature varied only from 46.8° to 47.4° , and on April 13 and 15, 1899, from 41.2° to 42.7° .

The serial temperatures in Loch Katrine are shown graphically in the accompanying curves (Fig. 11), which exhibit the march of

temperature in the waters of the loch throughout the year. The curve for April shows that the water from top to bottom has a temperature ranging between 41° and 42° Fahr. In the two curves for June the heating effect of the sun on the surface-layers is indicated, but in depths beyond 20 fathoms the temperature has not been appreciably effected. In June, 1898, the whole body of water in the loch was apparently slightly warmer than in the previous June. The November curve shows a great accumulation of summer heat in the layers down to depths of 30 and 35 fathoms. By this time cooling has set in, and progresses slowly until the spring, when the whole of the layers assume the nearly uniform temperature indicated by the April curve. The temperature of the bottom of the loch in depths of 400 feet may vary one or two degrees from year to year, this variation being due to the strength of the winds and general character of the climate in different years.* The highest temperature recorded in Loch Katrine is 58.4° , so that the range in the central parts of the loch throughout the whole year is probably about 18° Fahr.

Loch Arklet.—Temperature observations taken in the centre of Loch Arklet on June 11, 1897, gave a temperature at the surface of 55.4° , and at 5 fathoms 54.4° ; on April 13, 1899, the surface-temperature was 42.7° . Temperatures as high as 61° have been recorded in this loch, so that the annual range probably exceeds 29° .

Loch Achray.—Observations taken in June and November, 1897, and April, 1899, showed that the temperature of the surface-waters varied from 41° in April to 59.5° in June, the temperature in November being 46° . An intermediate observation at 5 fathoms in the centre on June 12, 1897, gave 53.5° . The highest reading recorded at the surface of this loch is 64.1° , so that the annual range probably exceeds 32° .

Loch Drunkie.—Observations taken on June 12, 1897, showed that the surface-waters had a temperature of 57° , and an intermediate observation at 5 fathoms gave 52.6° . On April 14, 1899, the surface temperature was 42.4° .

Loch Vennachar.—The temperature observations taken in June, July, and November, 1897, and April, 1899, showed that the temperature of the surface-water varied from 41° in April to 56.5° in June, the temperature in November being 46° to 47° , while the water of Blairgarry stream had a temperature of 42.2° . Serial observations in the centre of the loch on June 10, 1897, showed a gradual fall in the temperature from 55.8° at the surface to 47.2° at 15 fathoms; while on April 11, 1899, the temperature was practically uniform from surface to bottom at 42.5° to 42.7° .

* See Murray, "Some Observations on the Temperature of the Water of the Scottish Fresh-water Lochs" (*Scottish Geographical Magazine*, vol. xiii. p. 1, 1897). At noon on March 10, 1900, in calm and frosty weather, the temperature of the surface-water of Loch Katrine, over the deepest part of the loch, was 40.3° , at 10 feet 40.2° ; at all other depths down to 492 feet the temperature-readings were 40.0° and 40.1° . On the same date the readings in shallow water were 39.4° .

Loch Doine.—Observations taken on July 7, 1897, and April 10, 1899, showed that the temperature varied from 42° in April to 54° in July. Serial observations in the centre of the loch in July gave a temperature at the surface of 54° , falling to 52.1° at 10 fathoms, while in April the temperature was found to be nearly uniform from surface to bottom, ranging from 41.8° to 42.6° .

Loch Voil.—Observations taken in July, 1897, and April, 1899, showed that the temperature of the surface-water varied from 41.2° in April to 56.5° in July. Serial observations taken on July 7, 1897, showed that in the centre of the loch the temperature at the surface was 55.0° , at 5 fathoms 54.0° , and at 16 fathoms 54.5° , while further down the loch the temperature appeared to be rather higher, viz. 56.0° at the surface, and 55.3° at 3 fathoms and 8 fathoms. Serials taken on April 10, 1899, showed that the whole body of water was practically uniform in temperature at about 42° .

For the sake of comparison a few surface-temperatures were taken at the head of Loch Earn on July 6, 1897, the temperature of the loch varying from 48.8° to 49.2° , while that of the streams flowing into the loch was 52.2° . On the following day (July 7, 1897) the surface of Loch Voil near the shore had a temperature of 56.4° , and a little distance from the shore 54.6° , while the water of the burn flowing into the loch had a temperature of 53.6° , and higher up the stream 53.1° . It thus appears that the waters of Loch Voil were warmer than those of Loch Earn, and in the case of Loch Voil the stream feeding the loch had a lower temperature than the loch itself, while in the case of Loch Earn the streams were warmer than the waters of the loch.

Loch Lubnaig.—Observations were taken in Loch Lubnaig only on April 6 and 8, 1899, and showed that at that time the temperature of the water was nearly uniform from surface to bottom, the range being only from 41.8° to 42.7° .

From the point of view of temperature, the Scottish fresh-water lochs may be divided into those which freeze during hard winters, and those which never freeze. Those which freeze over in winter are shallow lochs, and when frozen the water-temperature beneath the ice is at the maximum density point of fresh water (39.1°) or lower. In spring the temperature of these shallow lochs rises much more quickly through the heat of the sun, and the whole mass of water attains a higher temperature than in the case of the deeper lochs; they also lose their heat much more quickly in the autumn than the deep lochs, and consequently have a much wider range of annual temperature. In the deep lochs—those with 400 or more feet of depth—the temperature of the water never rises so high in summer, nor sinks so low in winter, as in the shallow lochs, and the range is much less. The temperature of the bottom water in some cases does not change more than 1° Fahr. from year to year, and in the deepest lochs it appears to be practically

constant at all times and seasons; 40° is the lowest temperature that has been recorded at the bottom in any of these deep Scottish lochs, so that the maximum density point is never reached. In summer, autumn, and even early winter, it is possible, by observing the temperature of the surface and sub-surface waters, to form a fairly accurate idea of the depth of a loch, the temperature being higher the shallower the loch. The waters from a deep loch—like Loch Katrine—are much the best for the water-supply to a city, for in summer the temperature is relatively low and in winter it is relatively high.

PELAGIC AND OTHER ORGANISMS.

Tow-net and other observations show that the nature and amount of the organic life in the fresh-water lochs are subject to great variation in the different lochs when compared with each other, and in the same loch at different seasons of the year. Large numbers of observations are being collected, and we may look for interesting results when these are in a state for discussion. Generally speaking, the pelagic fauna and flora are much more abundant in the warm summer months than at other times of the year, and are also more abundant in the shallow lochs than in the deep ones. In the spring months there is a great development of diatoms and other Phytoplankton, which render the water less transparent than at other times of the year.

Mr. Thomas Scott has lately been comparing the fauna in several of the Scottish lochs at different seasons of the year; some of his results for the lochs now under consideration may be noted.

In Loch Katrine the Entomostraca and other invertebrates were scarcer than in the other lochs examined. Fourteen species are recorded, *Bosmina longispina* being the only species present in all the gatherings; *Leptodora* was entirely absent from the gatherings collected during the colder months. *Cyclops strenuus* and *Polyphemus* appeared to be more frequent in the upper part of the loch, and *Bosmina* and *Leptodora* in the lower part. The sides of Loch Katrine do not generally present conditions very favourable to shore-dwellers, and an examination of the shore about Stronachlachar yielded scarcely anything that differed from the tow-net captures, while at the lower end the shore between the Trossachs pier and Ellen's isle yielded much better results. Here forty species of Crustacea were obtained, as well as one or two species of Mollusca, but they were all individually scarce. The Cladocera were more numerous in species in the warmer than in the colder months, while with the Copepoda the reverse was observed, though the difference was not so great.*

In Loch Arklet, *Holopedium gibberum*, one of the most remarkable species of the Cladocera in Britain, was moderately common in the

* Scott, *Seventeenth Annual Report of the Fishery Board for Scotland*, pt. iii. pp. 148-151, 1899.

tow-net gatherings collected in September and November, 1897, and in June, 1898, it was abundant all through the water, but when the loch was visited in March, 1898, not a trace of *Holopedium* could be seen. In June, when *Holopedium* was so abundant, other species previously observed were either very scarce or absent, as if they had been more or less crowded out by this particular cladoceran. Eleven crustacean species are recorded, *Daphnia* being the only form obtained in all the gatherings; *Bythotrephes* was observed in September and June, but not in November and March, and *Leptodora* occurred only in September. Infusoria (*Ceratium*, etc.) and micro-algæ were much less frequent in June than in the other gatherings. Forty-two species of Entomostraca were obtained by hand-net round the shores of Loch Arklet, including a few comparatively rare forms; very few molluscs were observed in any of the gatherings.*

Twelve species of Entomostraca were captured by the tow-nets in Loch Achray, *Diaptomus*, *Daphnia*, and *Bosmina* being taken in all the gatherings. *Holopedium*, though common in September and June, was not observed in November and March; *Bythotrephes* also appears to be subject to somewhat similar seasonal variation. Fifty species of Entomostraca and four species of Mollusca were obtained by the hand-net, and by dragging the tow-net for a short distance over the bottom of Loch Achray. Three rare species: *Diaptomus wierzejskii*, *Lathonura rectirostris*, and *Monospilus dispar* were obtained, and in June a green fresh-water sponge (*Spongilla fluviatilis*) appeared to be moderately common in some shallow parts of the loch.†

Loch Vennachar contains a rich crustacean fauna, as well as other invertebrates, most of which are suitable for fish food. Of forty-five species of Crustacea recorded from Lochs Katrine, Achray, and Vennachar, thirty-five species were observed in Loch Vennachar; thirteen of the species from Loch Vennachar were not observed in either Loch Katrine or Achray; fifteen of the species were common to the three lochs.‡

Twenty-five species of Crustacea and four species of Mollusca are recorded from Loch Lubnaig, including a new cladoceran (*Alona neglecta*), and one or two species new to Britain.§

RAINFALL AND OUTFLOW.

An attempt has been made to arrive at an approximation to the total amount of rain falling annually on the drainage areas of the lochs under consideration, although the available records are far from sufficient for the purpose. Dr. Alexander Buchan, F.R.S., has kindly supplied us

* Scott, *Seventeenth Report of the Fishery Board for Scotland*, pt. iii. pp. 143-146.

† *Ibid.*, pt. iii. pp. 153-156.

‡ Scott, *Fourteenth Report of the Fishery Board for Scotland*, pt. iii. p. 167, 1895.

§ Scott, *Thirteenth Report of the Fishery Board for Scotland*, pt. iii. p. 247, 1894.

with information regarding the readings of the rain-gauges at observing stations within, and in the vicinity of, the catchment-basins of these lochs. The positions of these rainfall stations, and the mean annual rainfall, are shown on one of the maps accompanying this paper (see Map III.), and further particulars will be found in the following table:—

Station.	Height of rain-gauge above sea-level.	Years observed.	Mean annual rainfall in inches.
	Fect.		
Ardlui	50	1865-70	115·10
Firkin	100	1866-79	98·38
Arrochar	15	1864-98	81·31
Head of Duchray	1800	1854-98	84·27
Glengyle	380	1854-98	92·25
Top of hill, Loch Katrine tunnel	830	1861-98	77·95
Brig o' Turk	270	1854-98	64·47
Loch Drunkie	420	1861-98	63·62
Loch Vennachar	275	1861-98	57·31
Between Ben Ledi and Glen Finlas	1800	1854-98	53·68
The Gart	230	1872-98	54·47
Leny	345	1861-98	54·23
Blaircreach	460	1893-98	82·63
Stronvar	422	1860-98	75·49
Lochearnhead	320	1866-84	65·50
Tyndrum	792	1858-61, 72-3, 76-7	90·10

Grouping these stations and their mean annual rainfall into those likely to represent the rainfall on the catchment-basin flowing out of Loch Vennachar, and those representing the rainfall on the catchment-basin flowing out of Loch Lubnaig, we arrive at an average rainfall of 76·25 inches for the Loch Lubnaig catchment, the mean height of the rain-gauges being 538 feet above the level of the sea, and an average rainfall of 75·37 inches for the Loch Vennachar catchment, the mean height of the gauges being 528 feet.

The entire catchment-basin flowing out of Loch Vennachar (*i.e.* the combined drainage-areas of Lochs Katrine, Achray, Drunkie, and Vennachar) is about 75·29 square miles, and the mean height calculated from the bulk of land above the level of the lochs is about 704·185 feet; the mean height of the surfaces of these four lochs above sea-level is 331½ feet, so that the mean height above the sea of the entire catchment is about 1035·685 feet. The entire catchment-basin flowing out of Loch Lubnaig (*i.e.* the combined drainage-areas of Lochs Voil, Doine, and Lubnaig) is about 73·39 square miles, and the mean height above the level of the lochs is about 935·129 feet; the mean height of the surfaces of these lochs above sea-level is 412 feet, so that the mean height above the sea of the entire catchment is about 1347·129 feet.

The usual practice among engineers is to add $2\frac{1}{2}$ per cent. of rainfall for each 100 feet of height above rain-gauges. Applying this rule to

the Loch Vennachar catchment-basin, where we have an observed rainfall of 75·37 inches at an average height of 528 feet, we must add 12·7 per cent. for the additional 508 feet of mean height, making an average annual rainfall over the entire catchment of 84·94 inches. This would give an annual fall of rain on the entire catchment equal to 14,857,214,000 cubic feet. Applying this rule, in like manner, to the Loch Lubnaig catchment-basin, where we have an observed rainfall of 76·25 inches at an average height of 538 feet, we must add 20 per cent. for the additional 809 feet of mean height, making an average annual rainfall over the entire catchment of 91·5 inches. This would give an annual fall of rain on the entire catchment equal to 15,600,760,000 cubic feet.

There is another method of estimating the rainfall, without taking the mean height of the drainage-area into consideration. Supposing the usually accepted increase of $2\frac{1}{2}$ per cent. per 100 feet of height, and also the mean annual rainfall at the average height of the rain-gauges, to be approximately correct, it is possible to calculate the rainfall at any given height. For the Loch Vennachar catchment the probable rainfall at the same heights and intervals as the contour-lines on the Ordnance Survey maps has been calculated from the starting-point of the mean of the observing stations 75·37 inches at 528 feet. Thus at the surface of Loch Vennachar the rainfall would be about 70·5 inches; at 500 feet above the sea, 75·2; at 750 feet, 79·9; at 1000 feet, 84·6 inches; and so on, adding $6\frac{1}{4}$ per cent. for each succeeding interval of 250 feet. Multiplying the area between any two consecutive contour-lines by the mean of the two figures calculated for the same two lines should give an approximation to the amount of rain falling on that area. The result as obtained by this method for the entire catchment-basin flowing out of Loch Vennachar is given in the following table :—

					Cubic feet.
Level of lochs to	500 feet,	16·53 square miles	×	72·8 inches	= 2,795,710,000
500 „ 750 „	10·67	„	×	77·5 „	= 1,921,117,000
750 „ 1000 „	10·35	„	×	82·2 „	= 1,976,514,000
1000 „ 1250 „	9·46	„	×	86·9 „	= 1,909,847,000
1250 „ 1500 „	10·22	„	×	91·6 „	= 2,174,874,000
1500 „ 1750 „	7·86	„	×	96·3 „	= 1,758,476,000
1750 „ 2000 „	5·94	„	×	101·0 „	= 1,393,784,000
2000 „ 2250 „	3·06	„	×	105·7 „	= 751,422,000
2250 „ 2500 „	0·99	„	×	110·4 „	= 253,917,000
over 2500 „	0·21	„	×	115·1 „	= 56,154,000
Total					14,991,815,000

This result comes very near to that obtained from the calculation based upon the mean height, which gave a total annual rainfall of 14,857,124,000 cubic feet.

Applying the same method to the entire catchment-basin flowing out of Loch Lubnaig, we arrive at the following result :—

						Cubic feet.
Levels of lochs to	500 feet,	6.82 square miles	×	74.6 inches	=	1,181,982,000
500 "	750 "	7.15 "	×	77.9 "	=	1,293,991,000
750 "	1000 "	9.05 "	×	82.7 "	=	1,738,769,000
1000 "	1250 "	9.70 "	×	87.4 "	=	1,969,568,000
1250 "	1500 "	9.89 "	×	92.2 "	=	2,118,434,000
1500 "	1750 "	9.43 "	×	97.0 "	=	2,125,060,000
1750 "	2000 "	8.06 "	×	101.7 "	=	1,904,337,000
2000 "	2250 "	6.64 "	×	106.5 "	=	1,642,879,000
2250 "	2500 "	3.30 "	×	111.3 "	=	879,148,000
2500 "	2750 "	1.88 "	×	116.1 "	=	507,081,000
2750 "	3000 "	1.02 "	×	120.8 "	=	286,256,000
over 3000 "	0.35 "	"	×	126.6 "	=	102,941,000
Total						15,750,446,000

Here, again, there is a close agreement between the result obtained by this method and that calculated from the mean height, which gave a total annual rainfall of 15,600,760,000 cubic feet.

A third method of estimating the amount of rain falling on any particular region is afforded by drawing lines of equal rainfall, measuring the areas between the lines, and multiplying by the mean annual rainfall. Where the lines are based upon sufficiently numerous records of the rainfall at various heights, this method should give excellent results; but in the cases under discussion the number of observing stations is small, and the majority of the rain-gauges are situated on the low-lying grounds, only two being placed at heights exceeding 1000 feet, both at 1800 feet: therefore the figures obtained in these cases are most probably below the truth. Nevertheless, we have attempted to lay down the lines of equal rainfall from the available records, as shown on the rainfall map accompanying this paper (see Map III.). The areas enclosed by the lines of rainfall have been measured with the planimeter, and the rainfall calculated for the Loch Vennachar catchment-basin, with the following results:—

With the following results:

					Cubic feet.
50 to 60 inches,	12.35 square miles	×	55 inches	=	1,578,040,000
60 " 70 "	28.97 "	×	65 "	=	4,374,714,000
70 " 80 "	18.93 "	×	75 "	=	3,298,372,000
80 " 90 "	8.55 "	×	85 "	=	1,688,400,000
90 " 100 "	4.21 "	×	95 "	=	929,166,000
100 " 110 "	2.28 "	×	105 "	=	556,175,000
Total					12,424,867,000

In like manner, the rainfall has been calculated for the Loch Lubnaig catchment-basin, with the following results:—

					Cubic feet.
50 to 60 inches,	3.79 square miles	×	55 inches	=	484,272,000
60 " 70 "	23.89 "	×	65 "	=	3,607,591,000
70 " 80 "	21.79 "	×	75 "	=	3,796,700,000
80 " 90 "	19.02 "	×	85 "	=	3,755,928,000
90 " 100 "	4.41 "	×	95 "	=	973,307,000
100 " 110 "	0.49 "	×	105 "	=	119,530,000
Total					12,737,328,000

The results obtained by these three methods may be summarized thus :

	Vennachar catchment.	Lubnaig catchment.
First method ...	14,857,214,000	15,600,760,000
Second „ ...	14,991,815,000	15,750,446,000
Third „ ...	12,424,867,000	12,737,328,000
Mean ...	14,091,299,000 c. ft.	14,696,178,000 c. ft.

Since Loch Katrine has been made use of by the Glasgow Corporation as the source of the water-supply to that city, a record has been kept of the amount of water flowing out of Lake Vennachar—or rather, a record has been taken twice a day of the depth of water flowing over a weir at Coilantogle, from which the quantity of water discharged may be calculated. When the height of the water on the weir exceeded 5 inches, the weir became a drowned weir, so that it was difficult to estimate the outflow, as there was a considerable velocity of approach, especially during floods.

Mr. Gale has kindly supplied us with the readings, taken twice a day during the year 1869, of the depth of the outflowing water at Coilantogle, and from these figures the outflow has been estimated for that year at 9,572,000,000 cubic feet. The year 1869 was the driest year during a period of twenty-four years, and we are not satisfied that this computation can be accepted as a very correct estimate of the outflow from this catchment-basin even for that year. It would have been interesting to have calculated the outflow for twenty-five years in the same way as we have done for the year 1869, and to have taken the mean. However, accepting the above estimate for the year 1869, and adding to it the quantity of water supplied to Glasgow for that year, which, from Mr. Gale's table showing the average amount of water supplied per day during the first six months of the years 1866 and 1871, may be taken at about 1,659,300,000 cubic feet, we find that the mean rainfall exceeds the outflow in this year by

According to the first method ...	...	...	3,625,914,000 cubic feet.
„ „ second „ ...	...	...	3,760,515,000 „
„ „ third „ ...	...	...	1,193,567,000 „
or a mean of ...	...	...	2,859,999,000 „

Leslie * made experiments for twenty consecutive years on the allowance to be made for absorption by vegetation and for loss by evaporation, and he calculated that the average annual amount of water absorbed and evaporated is equal to about 13 inches of rainfall. On this basis, and assuming for the present that the evaporation from the surface of the water is equal to absorption and evaporation from the land, the total amount of water lost through absorption and evaporation over the entire catchment-basin of Loch Vennachar would be about

* See *Jour. Scot. Met. Soc.*, vol. v. p. 108, 1878.

2,273,885,000 cubic feet per annum.* Comparing this figure with the figures given above showing the excess of rainfall over outflow, we observe that, according to the mean of the three methods, the difference between the rainfall and outflow is greater than would be accounted for by absorption and evaporation as estimated by Leslie, there being an excess according to the first two methods, and a deficiency according to the third method.

The foregoing figures, calculated for the year 1869, show that the rainfall unaccounted for by outflow at Coilantogle, and supply of water to Glasgow, is according to the first method 26 per cent., according to the second method 27 per cent., and according to the third method 8 per cent.: this percentage must be referred to loss by absorption, evaporation, and the loss of water through underground channels.

NOTES ON THE GEOLOGY OF THE LOCH KATRINE DISTRICT.†

By Messrs. BEN. N. PEACH, F.R.S., and JOHN HORNE, F.G.S., from unpublished observations made during the course of the Geological Survey of Scotland.

All the lochs referred to in this paper, with the exception of Loch Arklet, lie within the catchment-basin of the river Teith above Callander. Though situated about a mile to the west of Loch Katrine, the small lake, Loch Arklet, drains into Loch Lomond.

1. *Geological Structure of the area embracing these Lochs.*

All the lochs, save the lower part of Loch Vennachar, lie within the territory of the crystalline schists of the Highlands, which are bounded along the Highland border by a powerful fault stretching from Stonehaven to the Firth of Clyde. As shown on the geological sketch-map accompanying this paper, this dislocation extends from Aberfoil north-east by Leny to Luirgeann on the Kelty water. On the south-east side of this fault the strata belong to the lower Old Red Sandstone formation, comprising, next the fault, andesitic lavas and agglomerates well seen in the Kelty water. Further to the south-east there is a broad belt of conglomerate arranged in beds, which are inverted or vertical near the fault, and as the observer approaches the plain they dip towards the south-east and pass underneath the overlying red sandstones.

On the north-west side of this great boundary fault of the Highlands there is a narrow strip of sedimentary rocks about half a mile in breadth, referred provisionally to the Arenig division of the Silurian

* The evaporation from the surface of the lakes will, of course, exceed Leslie's figures for loss through absorption and evaporation.

† Published by permission of Sir Archibald Geikie, D.C.L., F.R.S., Director-General of the Geological Survey of the United Kingdom.

system, and consisting of red and black shales, radiolarian cherts, limestones and grits.

To the north of this belt of doubtful strata, the whole of the area included in the geological map accompanying this paper is occupied by rocks grouped under the general term of the crystalline schists of the Highlands. The latter are arranged in a definite order, but as yet it is uncertain whether it indicates the original sequence of deposition. The groups are here given in apparent descending order—

7. Garnetiferous mica-schists.
6. Loch Tay limestone with sills of epidiorite.
5. Mica-schists with sills of epidiorite.
4. Schistose epidiotic grits ("Green Beds").
3. Ben Ledi grits, massive and sometimes schistose.
2. Aberfoil slates with subordinate bands of grit.
1. Leny and Aberfoil grit.

For a distance of about 5 miles northwards from the great boundary fault, the members of groups 1 to 4 are arranged in more or less parallel belts or strips running south-west and north-east, the strata dipping at high angles to the north-west. The groups appear in consecutive order, the Leny and Aberfoil grit being exposed immediately to the north of the doubtful Arenig rocks, while the Aberfoil slates and Ben Ledi grits appear successively to the north. The schistose epidiotic grits (group 4), which lie apparently at the top of the Ben Ledi grits, are developed still further to the north, being traceable from a point not far to the south of Ben Lomond, north-east by Loch Chon and the lower part of Loch Katrine, thence across the hills to Strathyre and Loch Voil. From the Braes of Balquhider they can be followed northwards to Glen Dochart, and they reappear in Glen Falloch in the extreme north-west part of the map. At the head of Loch Lubnaig and in the Braes of Balquhider sills or intrusive sheets of epidiorite occur at no great distance from the "Green Beds."

In the belt between Loch Chon and Loch Lubnaig the "Green Beds," together with the Ben Ledi grits, form a series of compound synclinal folds, the strata being inclined at high angles. To the north and west of the "Green Beds" the representatives of the Ben Ledi grits reappear and cover a wide area, extending from Ben Lomond north-east by Loch Katrine and the heights surrounding the head of Loch Voil, northwards by Ben More and westwards to Glen Falloch. Throughout this extensive area the strata are inclined at gentle angles: in marked contrast with the structure along the Highland border already indicated. There is here a change, over part of the area at least, in the lithological characters of the Ben Ledi grit group. The strata become more schistose and micaceous, merging in places into mica-schists. The accompanying geological map shows generally where these grits still retain their massive character and where they merge into mica-schists.

The outcrop of the Loch Tay limestone is indicated on the geological map, from which it will be seen that this limestone, together with the sills of epidiorite, is traceable from the upper part of Strathgryre, by the Kirkton glen, to Luib, in Glen Dochart.

In addition to the great boundary fault already referred to, separating the lower Old Red Sandstone from the crystalline schists, various faults trending N.N.E. and S.S.W. traverse the south-east part of the area under consideration. These are, in the main, branches of the great dislocation which has been traced across the Highlands for a distance of 60 miles, from Loch Vennachar by Loch Lubnaig and Loch Tay to Glen Tilt. In common with the dislocation referred to, the branch faults have a down-throw to the west or north-west, and they shift for some distance the outcrops of the strata which they traverse. They are truncated by the great boundary fault of the Highlands, and may be of pre-Old-Red-Sandstone age.

The existing valley-system of the basin of the Teith has been carved out of a tableland of crystalline schists of varying hardness. Though there is conclusive evidence of great erosion during the successive glaciations of the region, yet it is clear that the present valley-system must have been developed in pre-glacial time. There is one point connected with the geological structure of this region which has had an important bearing on the evolution of the valley-system. Along the Highland border, as already indicated, there is a great development of conglomerates, coarse pebbly grits, and greywackes, belonging partly to the crystalline schists and partly to the Old Red Sandstone. These strata, being vertical or nearly so, would be much less easily eroded than the gently inclined schistose rocks lying to the north-west. Such an arrangement would naturally lead to the formation of narrow and comparatively flat-bottomed valleys behind rocky gorges, the latter being cut through the vertical beds of hard grit and conglomerate along the Highland border. That this remarkable structure must have likewise contributed to the erosion of rock-basins during the glacial period will become apparent on a closer examination of the geological structure of the area traversed by the larger lakes.

In the case of Loch Katrine, which is the largest and deepest of the lochs under consideration, there is a great rocky barrier at its outlet due to the Ben Ledi grits. Here they form a belt over a mile in breadth, and give rise to the rugged scenery so characteristic of that region. They appear on the crags of the Trossachs at the mouth of the loch, on the crest and slopes of Ben Venue (2393 feet), on Ben Bhreac (2295 feet), and on the heights round Ben An (1326 feet). The strike of these hard and durable strata is E.N.E. and W.S.W.—that is, at right angles to the outlet of the loch, and the beds are vertical or highly inclined.

The potency of the Ben Ledi grits as a rocky barrier must have been considerably increased by the development of epidotic grits or "Green

Beds" lying immediately to the north. The latter, though not so massive as the Ben Ledi grits, are hard and durable; they are repeated by a series of compound folds for nearly a mile across the strike, their northern limit being near Brenachoil Lodge. Their trend is likewise north-east and south-west, and the beds are vertical or highly inclined.

On both sides of Loch Katrine above Brenachoil Lodge the geological structure is widely different, for in this area the Ben Ledi grits, greywackes, and slates reappear in a highly schistose form, the strata dipping generally at low angles to the south-east. Over much of this region, as already indicated, the altered sediments merge into mica-schists owing to the development of mica. It is obvious that these materials would yield more readily to the agents of denudation than the massive pebbly grits of Ben Venue and the Trossachs.

Loch Achray, which lies about a mile to the east of the outlet of Loch Katrine, is only about 88 feet below the level of the latter loch. A powerful fault or dislocation, trending north-east and south-west, crosses the head of the loch near the Trossachs Hotel, which brings the massive Ben Ledi grits to the west in contact with slates to the east. It is a true rock basin which has been excavated mainly in the group of less durable slates.

Loch Vennachar is crossed by the great boundary fault, already referred to, along the Highland border, the floor of the eastern portion being composed of Old Red Sandstone conglomerate, while that of the western part is formed of grits and slates belonging to the crystalline schists. Though there is a covering of drift on both sides of the lower part of the loch, still this sheet of water forms a true rock basin, for the Old Red conglomerate is exposed in the river about 1200 yards below the outlet.

Loch Drunkie presents several interesting geological features. On referring to the map it will be seen that an arm of this loch runs nearly east and west for upwards of half a mile; the northern margin is composed of massive grits, while the southern margin and probably the floor of this branch of the loch is formed of less durable slates. Another arm of this lake runs N.N.E., in the direction of Loch Vennachar, the eastern margin of which nearly coincides with the course of a fault that crosses Loch Vennachar to the east of Lanrick.

The three lakes, Loch Doine, Loch Voil, and Loch Lubnaig, must have formed one continuous sheet of water in post-glacial time. Loch Doine is now separated from Loch Voil by two cones of alluvium, to be referred to presently. Loch Voil is separated from Loch Lubnaig by a narrow plain of alluvium 5 miles in length, the surface of Loch Lubnaig being 9 feet lower than that of Loch Voil. These lochs form isolated parts of a true rock basin. Below the outlet of Loch Lubnaig there is a prominent rocky barrier composed of the massive grit of Leny and Aberfoil, from a half to three-quarters of a mile in breadth. The strike

of this pebbly grit is north-east and south-west, and the beds are inclined to the north-west at high angles.

Loch Lubnaig is traversed by several faults, to which special reference will be made in the sequel. The lower part of the loch coincides with the trend of two faults, which, in all likelihood, determined for some distance the course of the river in remote geological time.

2. *Glaciation.*

The glacial phenomena in the lake district of the basin of the Teith prove beyond doubt that, during the climax of the ice-age, the ice-shed lay to the north of the area now under consideration; that the ice-movement was more or less independent of the existing valley-system; and that even the highest mountains were overridden by the ice. This great development was followed by a period of local glaciation, when the glaciers were confined mainly to the existing valleys, and when the boulder-clay or ground-moraine of the earlier period was largely removed. The upper limit of the valley glaciation is frequently defined by prominent lines of moraines strewn with boulders, which rise to a considerable height on the mountain-slopes. The evidence pointing to these conclusions may now be briefly summarized.

On the watershed to the north of Lochs Doine and Voil, the trend of the ice-movement during the great glaciation, as proved by the striæ, was S.S.E. Again, on the lofty watershed east of Loch Lubnaig and south of Loch Earn, between Ben Each (2660 feet) and Ben Vorlich (3224 feet), there is conclusive evidence that the highest mountains in that part of the lake district were overridden by the ice. There the mountains are composed of grits, and the striæ are well preserved. On Ben Each the striæ point S.E.; on the col between that hill and Stuc a Chroin, S. 40° E.; on the latter mountain about S.E., and on the slopes of Ben Vorlich, at a height of 2500 feet, the trend of the ice-markings is E. 40° S. In the tract between Loch Lubnaig and Loch Katrine similar evidence is obtained of a south-easterly movement at great elevations. For example, on Ben Vane (2685 feet), at a height of 2642 feet, the striæ point S. 15° to 20° E.; on the north and west slopes of Ben Ledi, S. 35° E., and on the crest of that mountain, at a height of 2875 feet, the direction is S.E. In like manner the mountains guarding the outlet of Loch Katrine are glaciated to the summit. Striæ occur on the top of Ben Venue at a height of 2386 feet, pointing S. 40° E.; on Ben An, at an elevation of 1750 feet, E. 30° S.; and on Ben Bhreac, to the west of Ben Venue, the direction of the ice-markings is S. 30° to 40° E. Again, on the watershed between Loch Voil and Loch Katrine, the evidence indicates a south-easterly movement during the great extension of the ice. For instance, at various points on Taobh na Coille, at elevations between 2000 feet and 2250 feet, the striæ point S. 30° E., and on Meall Gaothach, S. 30° E. In the tract immediately to the south-west

Loch Katrine the trend of the ice-markings varies from S.S.E. to E.S.E. For example, on Maol Mor (2249 feet) about the 2000-feet contour-line, to the north of Loch Arklet, the direction is about S. 15° E.; and on the crest of Ben Uaimhe, to the south of that loch, S. 10° to 15° E. Eastwards, throughout the tract between Loch Chon and the Trossachs, the trend is E.S.E. To the south of the lofty heights stretching from Ben Venue towards Ben Ledi, the direction of the striæ is more easterly, thus showing that the ice, after crossing the high ground, was deflected more towards the east (see glacial striæ on Map II.).

The general south-easterly movement of the ice during the great glaciation, throughout the lake district of the basin of the Teith, is confirmed by the dispersal of stones in the boulder-clay, and by the transport of erratics. Many of the boulders have been carried far from their source, and are now found on the tops of the highest mountains of the district, some even at greater elevations than the parent rock.

To the east of Loch Lubnaig, on Ben Vorlich, at a height of 3000 feet, boulders of garnetiferous mica-schist are found resting on glaciated surfaces of pebbly grit. Again, on the same mountain, at a similar elevation, there are erratics of epidiorite and hornblende-schist—rocks which are associated with the Loch Tay limestone, and which must have been transported from lower ground to the north. Similar boulders are met with on Stuc a Chroin and on Ben Each. Again, in the boulder-clay on the slopes of Ben Ledi, blocks of hornblende-schist occur, which must have been transported for some distance. On the south side of Loch Katrine, between Stronachlachar and the aqueduct of the Glasgow waterworks, boulders of quartzite and garnetiferous mica-schist, which are foreign to the basin of Loch Katrine, are found in the boulder-clay. Eastwards near Brenachoil Lodge, on the north side of Loch Katrine, there are blocks of black schist, like that which accompanies the quartzite of central Perthshire, and which has not been detected within the catchment-basin of Loch Katrine. These examples are sufficient to prove that, during the climax of the glacial period, the ice-movement was independent of the existing valley-system. Indeed, from the evidence furnished by the striæ and the transport of boulders, it may be inferred that the minimum thickness of the ice-sheet during this period must have been not less than 3000 feet in the lake district of Perthshire.

The boulder-clay or ground-moraine, which was laid down during the great glaciation, must have been extensive, for it is found at great elevations, and it sometimes attains a great thickness. For instance, in the lee of the ridge of Ben Vane, to the west of Loch Lubnaig, it reaches a height of 2290 feet, and in places it is over 100 feet thick. But a large part of this deposit was removed during the later glaciation by the valley glaciers, for the relics occur above the limits of the valley-moraines, the latter resting frequently on the solid rock.

Only a brief allusion is necessary to show the development of the later glaciers. The striae produced by this later movement coincide generally with the trend of the existing valleys. But though this is true, there is evidence to prove that even the larger valley-glaciers were thick enough to overflow minor watersheds. For instance, the glacier which descended the basin of Loch Katrine was thick enough to override the low col between that loch and Loch Chon, while another branch passed westwards by Loch Arklet towards Loch Lomond. Another example of the same phenomenon might be quoted. The glacier which descended the basin of Loch Voil towards Loch Lubnaig was thick enough to overflow the col between Strathyre and Loch Earn, while another branch ascended Glen Buckie and joined the Loch Lubnaig glacier at Laggan.

Moraines are well developed in most of the valleys, and are frequently arranged in concentric lines, as in Glen Finglas, north of Brig o' Turk. On the south side of Loch Katrine, between the jetty and Glasahoile, the moraines are distributed in parallel lines along the shore of the lake. As already indicated, the upper margins of the valley-glaciers are defined by the moraines.

3. *The Soundings viewed in Relation to the Geological History of the Area, and with Reference to the Origin of the Lakes.*

Loch Doine, Loch Voil, and Loch Lubnaig.—Reference has already been made to the fact that, in post-glacial time, Loch Doine, Loch Voil, and Loch Lubnaig must have formed one continuous sheet of water, and that their subsequent isolation has been due to the deposition of sediment.

Loch Doine has been separated from Loch Voil by alluvial cones laid down by two streams, one from the north at Monachylemore, and another from the south at Monachyle Tuarach. The 50-foot subaqueous line has been traced round the Loch Doine basin, and the deepest sounding is 65 feet. At the head of this loch there is an alluvial flat that stretches westwards for $1\frac{1}{2}$ miles, formed by the Lochlarig river and its tributaries. The gradual silting up, which is in constant progress at the head of Loch Doine at the mouths of the Lochlarig river and Allt Carnaig, is well shown by the resultant curve in the 50-foot contour-line.

That Loch Voil is merely a continuation of the Loch Doine basin is further proved by the soundings, for immediately to the east of the cones just referred to, the 50-foot contour-line is met with, and has been traced round both sides of the loch eastwards to about Ledereich—a distance of about 2 miles. From this point eastwards the lake gradually shallows towards the alluvial flat at Balquhiddier, where moraines occur within 400 yards of Kirkton and Stronvar Bridge. The deepest part of the lake is enclosed by the 90-foot contour-line at the head of the loch near Monachylebeg, and the deepest sounding within this line is 98 feet.

The trend of Lochs Doine and Voil roughly coincides with the strike of the crystalline schists in that district. It is oblique—indeed, nearly at right angles—to the movement of the great ice-sheet during the climax of glacial conditions, and it harmonizes with the course of the later valley-glacier. Several small faults occur on the Braes of Balquhiddier, north of Loch Voil, and on the hill-slope south of Loch Doine, but these are of little structural importance.

The long stretch of alluvium that separates Loch Voil from Loch Lubnaig has been laid down by the Calair burn in Glen Buckie, by the Kirkton burn at Balquhiddier, and by various streams on both sides of Strathyre. The silting up now in progress at the head of Loch Lubnaig is well shown by the tongues of alluvium, on both sides of the Balvag river, that project for some distance into the loch and isolate small basins of fresh water. About half a mile north of Loch Lubnaig a moraine rises out of the alluvium, probably a fragment of the adjacent moraine on both sides of the valley. As the top of this moraine probably rose above the level of the ancient united lake, the depth of the latter near this locality could not have been very great.

A glance at the chart of Loch Lubnaig will show that its floor is much more irregular than that of Loch Voil. This may be accounted for partly by the presence of alluvial cones formed by various streams, and by features connected with the geological structure of the basin.

The deepest parts of this lake form two basins enclosed by the 100-foot contour-line, one to the north and the other to the south of Ardchullarie More. The upper one, about 500 yards long, is 146 feet deep, and the lower one, about 900 yards long, is 108 feet in depth. Though now separated by alluvial detritus brought down by the Ardchullarie burn from the north-east, and by the Dubh Shruith burn from the south-west, these basins were probably originally continuous. The powerful Loch Tay fault with a N.N.E. and S.S.W. course, and with a downthrow to the west, crosses Loch Lubnaig immediately to the south of Ardchullarie More, and strikes the west margin of the lake near the spit of sand to be referred to presently (see Map II.). The steep gradient on the west side of the lake to the north and south of this spit of sand coincides with the course of the Loch Tay fault. About a quarter of a mile to the west of the Loch Tay fault a minor dislocation, with a similar trend and downthrow, crosses the lake and follows the channel of the Dubh Shruith burn. Now the lower deep basin lies to the east or upthrow side of the Loch Tay fault, and the upper deep basin is on the west or downthrow side of the Dubh Shruith fault. These dislocations doubtless produced brecciation of the strata along the lines of movement, which led to more rapid disintegration of the materials.

Close to the north-west limit of the upper basin enclosed by the 100-foot contour-line the loch shallows to 20 feet, and from thence north-westwards to a point opposite Bienacreag the depth increases to

62 feet. Here there is a small basin enclosed by the 50-foot contour-line.

At the lower end of the loch, on the east side, there is a steep gradient which coincides with a line of fault, having a downthrow to the west (see Map II.). As already indicated, this dislocation together with the Loch Tay fault may have determined in part the course of the river in remote geological time. But an impartial consideration of the evidence furnished by the soundings shows that the faults cannot account for the erosion of the lake basin. The striking fact that the lower deep basin of Loch Lubnaig coincides with the upthrow side of the Loch Tay fault—the most powerful dislocation traversing the crystalline schists of this area—shows that this rock-basin must be ascribed to an erosive agent acting independently of the lines of fault. It has further been shown that Lochs Voil and Doine must have been originally continuous with Loch Lubnaig. The deepest sounding in Loch Voil is 98 feet, and in Loch Lubnaig 146 feet, and it is obvious that their erosion must be ascribed to a common cause. The upper part of Loch Lubnaig coincides roughly with the trend of the ice-sheet during the great glaciation, which, from the evidence adduced in the foregoing pages, must have attained a minimum thickness of 3000 feet. But the basin must have undergone further erosion by the large valley-glacier.

About half a mile to the south of Ardochullarie More, on the west margin of Loch Lubnaig, there is a prominent spit of sand extending into the lake for about 100 yards. It occurs not far to the south of the bend in the lake, at the meeting-point of the waves produced by the prevalent westerly winds. By the action of the waves the sand is steadily borne outwards on both sides of the spit, and from the soundings it is clear that this feature projects far into the lake. Further, it must have been in process of formation when the loch stood at a higher level, for a section appears in the adjacent railway cutting, which shows the sloping layers of sand coinciding with the form of the spit.

Loch Lubnaig originally extended to a point below Coireachrombie, about three-quarters of a mile below its present outlet. This point has been silted up by the detritus laid down by the Stank and Anie burns. The original southern termination of the lake touched the rocky barrier formed by the Leny grit. It is worthy of note, also, that the level of Loch Lubnaig has been lowered about 20 feet by the denuding action of the river Leny.

Loch Katrine.—For a distance of 4 miles west from Brenachoil Lodge to Stronachlachar—about the half of the total length of the loch—this lake has a comparatively flat bottom, enclosed by the 400-foot contour-line. The deepest sounding in Loch Katrine, 495 feet, is at the eastern limit of this basin, nearly due south of Brenachoil. The chart shows that the soundings throughout this basin gradually increase in depth eastwards to Brenachoil Lodge. The position of the deepest sounding

is of interest, seeing that the strata which form the floor of the lake at this point consist of schistose micaceous grits, to the north-west of the epidotic grits ("Green Beds") and the Ben Ledi grits, the two latter groups having formed the great rocky barrier at and above the outlet of the lake.

Near the upper end of the loch a rocky barrier crosses the lake from Portuellan by the Black island to Rudha Maoil Mhir an-t Salainn. The deepest sounding along this barrier is 90 feet, and the shallowest is 48 feet. On its lower side the 100-feet contour-line well-nigh crosses the lake. Above it there is another basin over half a mile in length, the greatest depth of which is 128 feet, immediately in front of the rocky ridge just referred to. Westwards the lake shallows, and at its head it has been silted up for a distance of half a mile by the alluvium laid down by the Gyle river.

Below Brenachail Lodge the soundings show an uneven floor, due probably to ridges of rock rather than to morainic deposits, if we may judge from the geological features on both sides of the lake. Ellen's isle is composed of epidotic grits ("Green Beds"), and the promontories of Am Priosan partly of "Green Beds" and partly of Ben Ledi grits. The promontory between the pier and the sluice is formed of Ben Ledi grits.

During the geological survey of that region several small faults were found to cross Loch Katrine, but these are of minor importance, and have produced locally a slight brecciation of the strata. It is a typical example of a rock basin. The deepest sounding occurs in the front of the great rocky barrier in the lower part of the lake, in accordance with what we might naturally expect on the theory of glacial erosion. Though the soundings prove the deepest part of the lake to be 131 feet below sea-level, yet this depth is in proportion to the vast thickness of the ice during the successive glaciations of the basin.

Loch Achray.—This lake forms one basin, the deepest part being enclosed by the 90-feet contour-line, and the deepest sounding being 97 feet. A fault, with a downthrow to the west, crosses the head of the loch at the Trossachs Hotel, which has produced considerable brecciation of the strata, a feature probably continued along the floor of the loch between the hotel and Achray. The greater part of this lake is on the upthrow side of the fault just referred to, and the basin, as already indicated, has been excavated mainly in slates.

Loch Vennachar.—Between Loch Achray and Loch Vennachar there is a strip of alluvium, the difference in level between the two lakes being 6 feet. The successive terraces show that these two lakes originally formed one sheet of water, which stood at a somewhat higher level. Loch Vennachar contains one prominent basin, about 2 miles in length, enclosed by the 50-feet contour-line. Within this limit there are two smaller basins, which fall below the level of the

100-feet contour-line (see Map V.). The deepest sounding is 111 feet, which occurs to the north-east of Invertrossachs, on the line of the great boundary fault along the Highland border, which has a downthrow to the south-east. West of this dislocation the floor of the lake rises sharply to a level of 20 feet below the surface. Westwards, however, near Lanrick, the depth increases to 50 feet, a feature which coincides with the course of two faults crossing the loch—branches of the Loch Tay fault, and each having a similar downthrow to the west. Doubtless where the deep soundings coincide with lines of fault, the strata have been much shattered and crushed, which has led to the more rapid disintegration of the materials. But though these faults may have led to local modifications of the floor of the lake, they obviously do not account for the excavation of the basin. The long, narrow hollow, crossing obliquely these lines of dislocation, points to glacial erosion.

Loch Drunkie.—Reference has already been made to the geological features of this basin (see p. 345). In the western portion of the west branch, where the hollow has been scooped out of slates, a small part of the floor is enclosed within the 50-feet contour-line. The deepest sounding, 97 feet, occurs in the north branch of the lake in front of a ridge to the east, which rises to a height of about 150 feet above the loch. The direction of the striæ at Loch Drunkie is E. 20° S., and the deepest sounding is found where the erosion must have been greatest.

Loch Arklet.—This lake lies across the path of the great ice-sheet, and coincides with the trend of the later movement (see pp. 347 and 348). Both the north and south shores of this loch are surrounded by moraines, but though such is the case, the stream flows over solid rock, where it leaves the alluvial flat $1\frac{1}{2}$ miles west of the outlet, and continues to flow for half a mile over solid rock. Originally the lake must have extended westwards to this barrier, for the intervening strip of alluvium has been laid down by the burns joining the Arklet water not far from the outlet. On this flat there are moraines rising up in the midst of the alluvium. The greatest depth of the loch is 67 feet. At the upper or east end, where the loch is shallow, two islets appear, one formed of solid rock and the other of moraine matter.

The soundings of the various lakes in the basin of the Teith above Callander, when viewed in connection with the geological structure and glacial phenomena of that area, furnish strong evidence in support of the theory of their excavation by ice-action. It is probable that, though the lakes lie, as a rule, across the path of the great *mer de glace*, they may have been partially eroded by that ice-sheet; at the same time there can be little doubt that their final modification must have been produced by the large valley-glaciers.

BATHYMETRICAL SURVEY OF

PLATE I

BY SIR JOHN MURRAY, K.C.B., LL.D., F.R.S.

OROGRAPHY AND DRAINAGE AREAS

Scale 2 Miles to an Inch

0 1 2 3

SCALE OF COLOURS

ABOVE

3750

TO

3750

TO

3500

TO

3250

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3000

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2750

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2500

TO

2250

TO

2000

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1750

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1250

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OROGRAPHICAL COLOURING

Contours are drawn at intervals of 250 feet and tinted according to Height

BATHYGRAPHICAL COLOURING

Contours showing Depth in Fathoms

K.C.B., LL.D., F.R.S., AND FRED. P. PULLAR, F.R.G.S.

THE GEOGRAPHICAL JOURNAL 1900

OROGRAPHY AND DRAINAGE AREAS

Scale 2 Miles to an Inch

SCALE OF COLOURS

ABOVE

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3750

3500

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OROGRAPHICAL COLOURING

Contours are drawn at intervals of 250 feet and tinted according to Height

BATHYGRAPHICAL COLOURING

Contours showing Depth in Fathoms

The Edinburgh Geographical Institute

Published by the Royal Geog

SURFACE GEOLOGY

Scale 2 Miles to an Inch

0 1 2 3

SCALE OF GEOLOGICAL COLOURING

Alluvium

Peat

Drift—Clay, Sand & Gravel

c¹ Lower Old Red SandstoneARENIG
AGE?b¹ Greywacke, Limestone, Black
Shale, Radiolarian Chert

METAMORPHIC ROCKS

Limestone

g Mica Schists

l Clay Slate

x Schistose Grit & Greywacke

B^e Epidiorite & Hornblende
Schist

IGNEOUS ROCKS

Pc¹ Porphyrite in
Lower Old Red Sandstone

B Basalt in Dykes

F Felstone

Di Diorite

--- Faults

→ Direction of Ice-flow
during great glaciation↗ Direction of Ice-flow
during valley glaciation

BATHYMETRICAL SURVEY OF THE SCOTTISH

BY SIR JOHN MURRAY, K.C.B., LL.D., F.R.S., AND FRED. P. PULLAR, F.R.G.

FACE GEOLOGY

Scale 2 Miles to an Inch

SURVEY OF THE SCOTTISH LOCHS.

K.C.B., LL.D., F.R.S., AND FRED. P. PULLAR, F.R.G.S.

THE GEOGRAPHICAL JOURNAL 1900

SURFACE GEOLOGY

Scale 2 Miles to an Inch
0 1 2 3

SCALE OF GEOLOGICAL COLOURING

- Alluvium
- Peat
- Drift—Clay, Sand & Gravel
- Lower Old Red Sandstone
- Greywacke, Limestone, Black Shale, Radiolarian Chert

ARENIG AGE?

METAMORPHIC ROCKS

- Limestone
- Mica Schists
- Clay Slate
- Schistose Grit & Greywacke

IGNEOUS ROCKS

- Epidiorite & Hornblende Schist
- Porphyrite in Lower Old Red Sandstone
- Basalt in Dykes
- Felstone
- Diorite

--- Faults

→ Direction of Ice-flow during great glaciation

→ Direction of Ice-flow during valley glaciation

The Edinburgh Geographical Institute

FACE GEOLOGY

Scale 2 Miles to an Inch

MEAN ANNUAL RAINFALL

Scale 2 Miles to an Inch

0 1 2 3

INCHES		M. M.
under 50		under 1270
50 to 60		1270 to 1524
60 to 70		1524 to 1778
70 to 80		1778 to 2032
80 to 90		2032 to 2286
90 to 100		2286 to 2540
100 to 110		2540 to 2794
over 110		over 2794

BATHYMETRICAL SURVEY OF THE SCOTTISH I

BY SIR JOHN MURRAY, K.C.B., LL.D., F.R.S., AND FRED. P. PULLAR, F.R.G.S.

ANNUAL
FALL

to an Inch

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LL.D., F.R.S., AND FRED. P. PULLAR, F.R.G.S.

THE GEOGRAPHICAL JOURNAL 1900

Scale 2 Miles to an Inch

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BATHYMETRICAL SURVEY OF

By SIR JOHN MURRAY, K.C.B., LL.D., F.R.S.

L.D., F.R.S., AND FRED. P. PULLAR, F.R.G.S.

4° 28'

4° 27'

4° 26'

LOCHS KATRINE & ARKLET

SURVEYED IN 1899

Scale 1 : 21,120 = 3 INCHES TO 1 MILE
 0 1 0.31 KILOMETRE = 1 CENTIMETRE
 1 Mile
 1.61 Kilometres

Height of Surface of Water above Sea Level [L. Katrine 364]
 [L. Arklet 455] Feet

The Land contours are from the Ordnance Survey

56°
16'

56°
15'

56°
14'

The Edinburgh Geographical Institute

J. G. Bartholomew.

PLATE V

BATHYMETRICAL SURVEY OF THE

BY SIR JOHN MURRAY, K.C.B., LL.D., F.R.S., AND FRED

4° 23'

4° 22'

4° 21'

4° 20'

K.C.B., LL.D., F.R.S., AND FRED. P. PULLAR, F.R.G.S.

 $4^{\circ}20'$

4° 19'

 $4^{\circ}18'$

LOCHS ACHRAY, VENNACHAR, AND DRUNKIE.

SURVEYED IN 1899

Scale 1 : 21,120 = 3 INCHES TO 1 MILE

0 1 2
0 1 2
0.31 KILOMETRE = 1 CENTIMETRE 1 Mile 1.61 Kilometres

Height of Surface of Water above Sea Level (L. Achray 276)
(L. Vennachar 270)
(L. Drunkie 216)

The Land contours are from the Ordnance Survey

J. G. Bartholomew.

BATHYMETRICAL SURVEY OF THE SCOTT

PLATE VI

By SIR JOHN MURRAY, K.C.B., LL.D., F.R.S., AND FRED. P. PULLA

PHYSICAL SURVEY OF THE SCOTTISH LOCHS.

N MURRAY, K.C.B., LL.D., F.R.S., AND FRED. P. PULLAR, F.R.G.S.

THE GEOGRAPHICAL JOURNAL

4° 19'

4° 18'

4° 17'

LOCH LUBNAIG

SURVEYED IN 1899

Scale 1: 21,120 = 3 INCHES TO 1 MILE
0 1 2 Kilometres 1-61
0 0.31 KILOMETRE = 1 CENTIMETRE

Height of Surface of Water above Sea Level 405 Feet

The Land contours are from the Ordnance Survey

The Edinburgh Geographical Institute

Published by the Royal Geographical Society.

PLATE VII

The Edinburgh Geographical Institute

BATHYMETRICAL SURVEY OF THE SCOTTISH LOCHS.

By SIR JOHN MURRAY, K.C.B., LL.D., F.R.S., AND FRED. P. PULLAR, F.R.G.S.

Published by the Royal Geographical Society.

LOCHS.

S.

THE GEOGRAPHICAL JOURNAL 1900

J. G. Bartholomew.