
A Bathymetrical Survey of the Lakes of New Zealand (Continued)

Author(s): Keith Lucas

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has quite recovered from his accident, and was invaluable to me as chief executive. He is the most energetic and indefatigable worker I have ever met.

"The *Terra Nova* kept company with us until we reached the ice-face. The two ships' companies worked together in perfect harmony, and Captain McKay gave every assistance in his power at all times. I will send you a tracing of our track to and from the Antarctic, and also copies of the photographs taken; the latter will be developed in Christchurch, and may not be ready for the first mail after our arrival. All on board are in good health, and we have had no serious cases; in fact, we might say we have had no sickness at all. With kindest regards to Lady Markham and yourself, and hoping that you are both in the best of health.

"Port Ross, Auckland Island, March 24, 1904."

A BATHYMETRICAL SURVEY OF THE LAKES OF NEW ZEALAND.*

By KEITH LUCAS.

WAIKAREMOANA.

Waikaremoana lies at the southern border of Tuhoe Land, 25 miles from the sea-coast of Hawkes bay. The land which lies between the lake and the sea-coast is intersected by irregular ranges of hills, increasing in height as the lake is approached, but nowhere reaching 2500 feet above sea-level. At a distance of about 2 miles, however, from the south-east side of the lake there begins a rapid upward slope, which culminates in a long ridge directed 25° north of east, in which the highest point, Puketapu, lies at an elevation of 3905 feet. This ridge, which is about 18 miles in length, is formed at its more western end by the Panekiri range, and at its eastern end by a similar range, which culminates at Ngamoko with a height of 3644 feet. Between these two ranges there is a break at Onepoto, where the land falls to 2015 feet, the level of the lake.

The north-west slope of the ridge, that directed towards the lake, is a very rapid one, the fall of nearly 2000 feet from Puketapu and Ngamoko to the lake's surface taking place in a horizontal distance of about $1\frac{1}{4}$ mile. In the case of the Panekiri range the fall is accomplished at first by a precipitous cliff of rock, below which a long wooded slope leads to the water's edge. The remarkable outline of this buttressed cliff forms the most striking characteristic of the scenery which the lake affords (cf. Fig. 3).

The valley occupied by the main body of the lake runs parallel to

* Continued from vol. xxiii. p. 660. Map, p. 704.

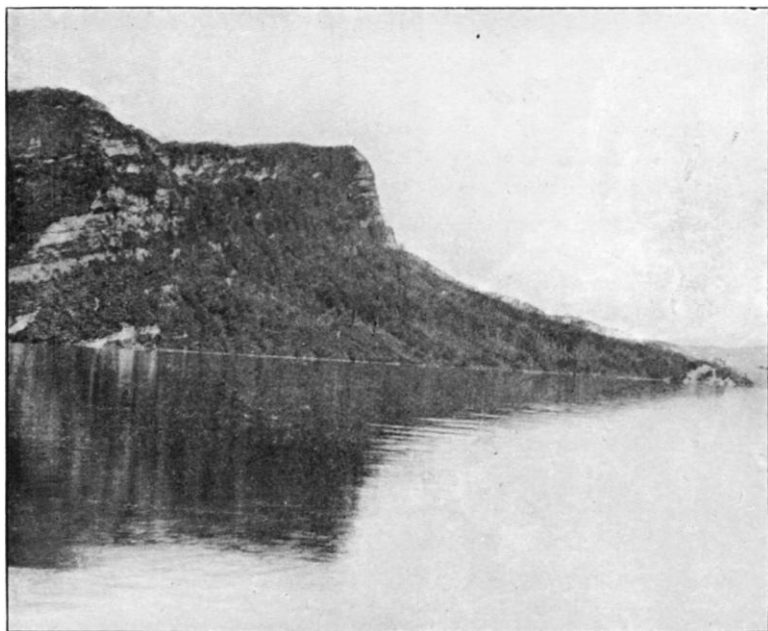


FIG. 3.—NORTH SLOPE OF THE PANEKIRI RANGE, WAIKAREMOANA. ON THE RIGHT-HAND SIDE OF THE PHOTOGRAPH A WOODED SLOPE IS SEEN LEADING DOWN TO THE WATER; ON THE LEFT, THE CLIFF DIPS STRAIGHT INTO THE WATER.

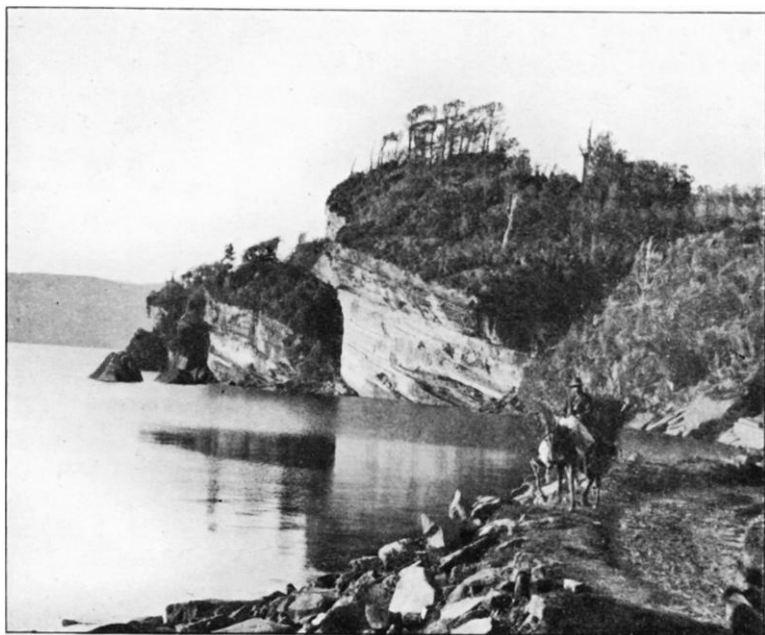


FIG. 4.—ROCKS NEAR ONEPOTO, WAIKAREMOANA. THE OUTLET OF THE LAKE IS SEEN ON THE RIGHT-HAND SIDE OF THE PHOTOGRAPH.

the Panekiri range for a length of $7\frac{1}{4}$ miles, measured in a straight line. Two arms run out from this valley from its opposite sides, about midway between its extreme ends. One of these, which projects towards the south, is very wide at its mouth, and leads to the outlet of the lake at Onepoto; the other, formed by the Whanganui and Mokau inlets, is far narrower, longer, and more clearly defined, and receives four of the largest rivers which enter the lake. The greater part of the lake, that part to which the name Waikaremoana is strictly applied by the Maoris, is thus seen to have the form of a cross, whose axes measure $7\frac{1}{4}$ and $6\frac{1}{2}$ miles in length. The remainder of the lake is called Wairau-moana. It is a narrow valley, nearly $5\frac{1}{2}$ miles long, directed approximately north-east and south-west, and connected to Waikaremoana by a passage half a mile in width, known as the Straits of Manaia. On the north-west side of Wairau-moana, near its middle point, there enters a small valley, forked at its upper end, known as the Marau inlet. The area of Waikaremoana is 14.7 square miles, that of Wairau-moana 6.1 square miles.

The Panekiri range and its eastward extension through Ngamoko form the south-east boundary of the lake's catchment area. The whole area has the form of a triangle, one angle of which closely embraces the southern extremity of Wairau-moana, while the two sides adjacent to that angle skirt the western shore of Wairau-moana and the southern shore of Waikaremoana. The greater part of the catchment comes from the north and north-east sides of Waikaremoana, where a large extent of country broken by irregular valleys lies between the lake and the Huiarau range. Two points of considerable height, Maungapohatu (4353 feet) and Manuaha (4603 feet), form the limit of the catchment area in this direction. There is a small lake, Waikareiti, lying to the north-east of Waikaremoana, and sending its water into the east end of the larger lake.

Though the mean gradient from the Panekiri range and from Ngamoko to the lake's surface is so rapid, yet the slope which leads immediately to the shore is in general not extremely steep. The one marked exception to this is found along the shore which lies between Onepoto and Ohiringi; here the fall is accomplished by a single cliff dipping straight into the water (cf. Fig. 3). West of Ohiringi the same cliff continues, but falls back from the water's edge, and is buttressed by the wooded slope to which reference has already been made. In other parts of the lake such cliffs as do occur are of no great height, the largest being, perhaps, that which forms the east side of the Whanganui inlet. Elsewhere the shore is bordered by slopes covered from the water's edge with dense forest.

The immediate shores of the lake are in most parts formed of irregular masses of rock, though bare earthy cliffs occur in some places, chiefly in Wairau-moana and the east side of Waikaremoana. Swamp

and vegetation fringe the shore comparatively rarely, chiefly where shallow water occurs off the mouths of small streams.

The masses of tumbled rock lying round the outlet at Onepoto present a remarkable appearance (cf. Fig. 4), giving the impression that the level of the outlet must have been at some time raised by a great slip of rock at this point. In this connection it is interesting to note that part of the outflow always passes by underground clefts directly below the surface course, and reappears through the side of the hill in several places a few hundred yards below Onepoto. During the winter these underground passages do not suffice to carry the whole of the outgoing water, and there is a strong flow over the surface course. In summer, however, the latter may become completely dry, and the water appearing from the clefts on the hillside enters a system of confluent streams, which join below to form the Waikare Taheke.

The sounding of Waikaremoana was carried out between August 14 and September 10, 1902. Through the kindness of the chief surveyor of roads at Napier, we were permitted to use a large whale-boat belonging to the Department of Roads. This boat was manned by a crew of four Maoris, and was used for all the work which was done on the lake. It was found possible to work each division of the lake from one camp, that in Waikaremoana being near Onepoto, while that on Wairauoana was on the east shore near Te Ure-o-Patae.

Soundings had been previously made in Waikaremoana on two occasions, as appears from the records kept at the District Survey Office at Napier. In the first place, there is a plan dated March 3, 1896, by Chas. Clayton, surveyor, showing 36 soundings, with a maximum depth of 840 feet in Waikaremoana, and 340 feet in Wairauoana. A second record, a report by T. H. Strauchon, road overseer, dated October, 1896, speaks of soundings having been taken every five minutes between Onepoto and Tikitiki; with this report there is a sketch showing twelve soundings, on a line almost identical with one of those made by Clayton, with a maximum depth of 836 feet.

The outline of the plan which accompanies this paper is drawn from a lithograph, on the scale of 80 chains to the inch, dated May, 1897. On it are shown only those soundings which were made in 1902. Contour-lines have been drawn within the lake at intervals of 100 feet of depth. From these it appears that the basin of Waikaremoana is an extremely regular cone. The greatest depth recorded is 846 feet, which occurs within a depression having an area of 1·3 square mile, all exceeding 800 feet in depth. This depression sends out four tongues corresponding to the four valleys in which the lake lies. The longest tongue is that which is directed west; it approaches within about half a mile of the entrance to the Straits of Manaia.

The 700-foot depression, whose area is 2·7 square miles, follows still more closely the surface form of the lake, sending one tongue northwards

well into the mouth of the northern inlet, and entering far more deeply than the 800-foot depression into the east and south arms. The 600-foot and 500-foot lines behave in the same way, and call for no special description. The area of the 400-foot depression is 7.24 square miles, approximately half the surface area of Waikaremoana; it enters deep into the Whanganui inlet, even passing the narrow part of that arm, and sends a tongue also into the Straits of Manaia, through failing to enter Wairauoana.

The remarkable regularity of the Waikaremoana basin is clearly indicated in the following table, which shows the areas included between successive contour-lines :—

| | | | |
|-----------------------------|-----|-----|--------------------|
| Area of mean depth, 50 feet | ... | ... | 2.22 square miles. |
| " " 150 " | ... | ... | 1.97 " |
| " " 250 " | ... | ... | 1.79 " |
| " " 350 " | ... | ... | 1.48 " |
| " " 450 " | ... | ... | 1.24 " |
| " " 550 " | ... | ... | 1.48 " |
| " " 650 " | ... | ... | 1.44 " |
| " " 750 " | ... | ... | 1.48 " |
| " " 820 " | ... | ... | 1.3 " |

From this table it appears that from the deepest water to the 300-foot line the areas enclosed between successive contours are almost identical, while from the 300-foot line to shore there is a gradual increase in the successive areas.

The basin of Wairauoana continues that of Waikaremoana without interruption. The general slope in the former is downward from all sides towards the Straits of Manaia, near which the deepest sounding, 375 feet, occurs. The 300-foot depression reaches from the Straits of Manaia to a point about halfway down Wairauoana, where it appears to end bluntly at the foot of a curious shoal, on which a depth of only 72 feet was found. Excepting the interruption caused by this shoal, the contour-lines conform fairly closely to the surface outline of the lake. The areas which successive contours in Wairauoana enclose are tabulated below; they show an increase as the shallow water is approached.

| | | | |
|-----------------------------|-----|-----|--------------------|
| Area of mean depth, 50 feet | ... | ... | 1.87 square miles. |
| " " 150 " | ... | ... | 1.66 " |
| " " 250 " | ... | ... | 1.54 " |
| " " 340 " | ... | ... | 1.04 " |

There are no islands of considerable size in Waikaremoana; in Wairauoana there are four, having an aggregate area of one-tenth of a square mile. All the islands are in close connection with the shore, none lying outside the 100-foot contour.

The mean depth of Waikaremoana, calculated from the contour-lines, is 397 feet, that of Wairauoana 175 feet; or, expressed as percentages of the maximum depth in each case, that of Waikaremoana is 47 per cent., that of Wairauoana 49 per cent.

LAKES OF THE MIDDLE WAIKATO: WAIKARE AND WHANGAPE.

At some 45 miles from its mouth, and shortly after its junction with the Waipa, the river Waikato breaks through a chain of low hills and enters a broad plain. In its course through this plain the river is flanked on either side by a series of shallow lakes. The more important of these are Waikare and Kimihia on the east side of the river, and Whangape, Roto Ngaro, and Wahi on the west.

Lake Waikare lies close against a range of hills which forms the eastern limit of the plain (cf. Fig. 5), and it is separated from the Waikato river by a strip of low land $1\frac{1}{4}$ mile in width at its narrowest part.

The lake has an area of 10.7 square miles. In shape it is a rough parallelogram, with diagonals measuring $6\frac{1}{2}$ and $4\frac{3}{4}$ miles, the longer of these being directed north-west and south-east. From the west side of the lake there projects a peninsula, which divides the water into a larger north and a smaller south basin, leaving a channel a mile in width between them.

The form of the lake-basin is extremely simple. Over the greater part of its area the bottom is almost level, the water varying in depth only between 8 and 9 feet. From this level the slope is very gentle, until a depth of 6 feet is reached, and more rapid from that point to the shore. The gradients are throughout more gradual to the west, where the land is low, than to the east, where the hills rise immediately from the water's edge.

In the northern basin there are two islands, lying together on an extension of shallow water which deflects the 6-feet contour outwards from the southern shore. The larger of these, Motu Nuia, rises some 30 feet above the level of the lake, the smaller not more than 5 feet. There are also two small islands in the channel between the two basins, and yet another in the south basin, all of these lying between the 6- and the 8-feet contours. In the north basin, between the same contours, there occurs an area of shallow water where the least depth is 2 feet 6 inches.

The western shores of the lake are low throughout, often swampy and ill-defined. Swamp extends, for example, for three-quarters of a mile inland between the two creeks, Te Onetia and Rangiriri. Marshy land also divides the peninsula practically into two islands, between which the land is so low that a canoe can pass over it in flood-time. To the east, and in less degree to the north and south, the rise of the land is more abrupt. At some points along these shores there are precipitous earthy cliffs. The cutting away of these cliffs by wave-action goes on with considerable rapidity, to some extent by the formation of caves at the water-level, followed by subsidence of the overlying earth. One such cave which existed on the north shore in 1902



FIG. 5.—THE MIDDLE WAIKATO. LAKE WAIKARE LIES ON THE LEFT, BETWEEN THE RIVER WAIKATO, WHICH IS SEEN IN THE FOREGROUND, AND THE HILLS WHICH FORM THE BOUNDARY OF THE PLAIN.



FIG. 6.—TE ONETEA, THE STREAM WHICH CONNECTS LAKE WAIKARE WITH THE WAIKATO RIVER.

measured 4 feet in diameter at the mouth, and extended 18 feet into the cliff.

The catchment area of Waikare is extremely small. The Matahuru, the one stream which it receives, drains only a single valley of insignificant size. The outlet is by the two streams Te Onetea (cf. Fig. 6) and Rangiriri. When the Waikato is low, these two streams actually serve as outlets for the lake, but a slight rise in the level of the river is sufficient to reverse the current in them. In this way the Waikato serves as the chief source of water for the lake at certain seasons. During rainy weather the changes of direction in Te Onetea may occur with considerable frequency. I have, for example, observed three successive changes of direction in the current of Te Onetea within three weeks.

Of the two creeks, Te Onetea and Rangiriri, the latter is of less importance, being small and much choked by willows, Owing, however, to its joining the river at a lower level, it sometimes serves as an outlet to the lake at a time when Te Onetea is serving as an inlet. Since the current in Te Onetea runs into the lake only during times of heavy rain, the water which enters by this way is always heavily charged with suspended matter. There is, consequently, a considerable deltaic formation in the lake at the mouth of the stream, marshy land covered with low bushes extending for several hundred yards from the general shore-line at this point.

In most parts of the lake weeds reaching from the bottom to the surface of the water extend from shore to a depth of a little more than 6 feet. They are, however, absent where the shores are steep. In such places rushes and low vegetation, reaching only a few inches from the bottom, bridge the gap between the shore and the commencement of the larger weeds.

Close to the two islands which lie in the channel connecting the north and south basins of the lake there is a small depression a few feet across, reaching a maximum depth of 12 feet. In this depression there is a hot spring. The highest temperature recorded here was 95° Fahr. It appears, however, that the flow of water from the spring must be extremely small, for at a distance of a foot from the bottom the temperature was only 72° Fahr., the general temperature of the lake at the time being 60° Fahr. This spring can, therefore, have no sensible effect on the general temperature of the lake. The water in the neighbourhood of the spring gives off a strong smell of sulphuretted hydrogen.

The sounding of Lake Whangape was undertaken in order to ascertain whether it presented sufficient difference from Lake Waikare to justify a separate biological examination. Though the lakes differ greatly in outline, in almost all other features they are in close agreement.

Whangape lies to the north-west side of the plain through which

the Waikato runs. It has an area of 4 square miles. Its extreme length, measured on a straight line running roughly north-east and south-west, is $5\frac{1}{4}$ miles. Its greatest breadth, measured at right angles to the long axis, is a little more than 2 miles. A narrow channel, a quarter of a mile broad, divides a larger north from a smaller south basin.

The form of the lake-floor agrees closely with that of Waikare, the greater part of the area being included within the 8-feet contour. The maximum depth is the same as that of Waikare, namely, 9 feet. The deeper water of the north and south basins is separated by a stretch of shallower water at a point where the lake is narrowest. There are three islands in Whangape, two lying in extensions of shallow water running out from the shore, while the third is surrounded by water 8 feet deep.

The shores of Whangape are, in general, steeper than those of Waikare, since the former lies in more undulating land than the latter. In places, however, the shores of Whangape also are marshy and ill defined.

The number of soundings made in Waikare was 212, or 19·8 to the square mile; in Whangape 380, or 95 to the square mile. The work on the two lakes occupied from April 5 to 28, 1902. The sounding on Waikare was done from a small boat rowed by a Maori, that on Whangape from a stern-wheel steamer.

The outline, on which the soundings were plotted, was taken from a lithograph on the scale of 1 mile to the inch.

ROTO AIRA.

One small lake was sounded of which it is impossible to give any chart, since there is no existing plan of it in which the outline is shown with sufficient accuracy to be of any value. This is Roto Aira, a small lake of about 5 miles in area, situated 8 miles to the south of Lake Taupo, in the saddle between Tongariro and Pihanga. The water which leaves it enters Lake Taupo by the Waikato river.

Eighty-three soundings were made in the lake, the deepest water found being 48 feet, which occurred about the middle of the north-east side of the lake, rather less than half a mile from shore. The eleven lines of soundings which were made showed in almost every case a very rapid fall of the bottom from shore to a depth of between 30 and 40 feet, and after this depth was reached an almost level bottom. Shallower water was only found in the extreme north and south ends of the lake, in the neighbourhood of marshy shores.

LAKE WAKATIPU.

In a paper on the "Reconnaissance Survey of the Lake Districts of Otago and Southland,"* James McKerrow, district surveyor of the province of Otago, speaks in 1864 of some soundings having been made in Lake Wakatipu, near Queenstown, a depth of 200 fathoms being found. In the same year a map of the north-west district of Otago, showing six soundings in Lake Wakatipu, was made by Dr. Hector, and placed in the Otago museum. To these soundings Dr. Hector refers in a paper on "Mining in New Zealand,"† published in 1869. Speaking of the lake, he says, "It has been found by soundings to vary from 1170 to 1296 feet, the bottom being nearly level from side to side and from end to end." In 1870, in a paper on the "Physical Geography of the Lake Districts of Otago,"‡ McKerrow speaks in detail of Dr. Hector's soundings, and also mentions others having "been taken by several persons independently," the greatest depth given being "1400 feet about the middle of the lake off Collins bay, and 16 miles from the south end of the lake." Hutton also quotes the maximum depth as 1400 feet in a paper "On the Formation of Lake Wakatipu,"§ giving McKerrow as his authority; and, again, he quotes the same depth in his 'Geology of Otago.'||

The measurements of Lake Wakatipu given in this paper are taken from a plan, on the scale of 1 mile to the inch, compiled by the Department of Lands and Survey at Dunedin, and supplied for the purpose of plotting the soundings taken. On this plan the positions of all trigonometrical stations close to the lake were shown; and, owing to the want of natural headlands or other marks on the shore, these stations were used in fixing the positions of soundings. The method employed was to place flags on the trigonometrical stations, and to run lines of soundings between pairs of flags on opposite shores of the lake.

The work done on Lake Wakatipu in 1902 occupied from October 1 to November 7. During this time 194 soundings were made, and these are shown in the plan which accompanies this paper. All sounding and dredging was carried out from the steamboats *Antrim* and *Ben Lomond*, which were formerly owned by the Lake Wakatipu Shipping Company, but were transferred, while the work was in progress, to the New Zealand Government Railways.

Lake Wakatipu extends from $44^{\circ} 50'$ to $45^{\circ} 20'$ S. lat., and from $168^{\circ} 20'$ to $168^{\circ} 43'$ E. long. The two ends of the lake lie in a direction almost north and south; the middle part is, however, deflected, so as to run nearly east and west. The extreme length, measured along a line running from end to end of the lake, and roughly midway between the two shores, is 49 miles. Throughout this length

* *Journ. R.G.S.*, vol. xxxiv. p. 56.

† *Trans. N.Z. Inst.*, vol. ii., 1869.

‡ *Ibid.*, vol. iii. p. 254.

§ *Ibid.*, vol. v. p. 394.

|| Dunedin, 1875.

the breadth is uniform, and the outline regular, except where the Frankton arm, a narrow extension of the lake $3\frac{3}{4}$ miles in length, projects in an easterly direction. Otherwise the extreme regularity of the breadth is indicated by the fact that, while the mean breadth is 2·3 miles, the greatest breadth is no more than 3·3 miles. The few bays which occur in various parts of the lake, such, for example, as Bob's cove, Beach bay, and Wilson's bay in the middle arm, and Collins bay, Drift bay, and Halfway bay in the Kingston arm, are of no great size; none of them project so much as a mile beyond the general coast-line.

The lake covers an area of 112·3 square miles, exclusive of islands, a small group of which, lying near the north end or head of the lake, has a total area of 1·25 square mile.

The surface of the water lies at a height of 1016 feet above sea-level,* the mountains which immediately border the lake having their highest points between 5000 and 8000 feet above the sea. The slope from the shores to the mountain peaks is abrupt, a height of 5000 or 6000 feet above the lake being often reached in a horizontal distance of 2 or 3 miles.

The catchment area of the lake amounts to a total of 1130 square miles. This area is bounded by well-defined ranges of hills, which are so disposed that the lake receives the bulk of its water from the north and west sides. The Richardson mountains (7432 feet), the Remarkables (7688 feet) (cf. Fig. 7), and the Hector mountains (7650 feet) lie indeed so close to the east shore that they contribute only small mountain streams. From the north, on the other hand, there come the two rivers, Rees and Dart, draining the more distant Forbes mountains (8159 feet), the Barrier range (7750 feet), and Mount Earnslaw (9200 feet). Similarly, on the west side the Ailsa mountains (8102 feet), the Thomson mountains (6306 feet), and the Eyre range (6530 feet) lie at a considerable distance from the lake-shores, and contribute respectively the Greenstone, the Von, and the Lochy rivers. At the south end of the lake the hills fall back and give way to a plain, which slopes away towards the south, and sends no streams into the lake. The outlet of the lake is by the Kawarau river, which flows out by the Frankton arm, and ultimately joins the Clutha river.

The shores of Lake Wakatipu are either steep slopes of broken rock, or beaches formed of coarse sand and pebbles. In the former case the slope of the shore is continued unbroken below the water-line, whereas in the latter case a shallow terrace usually runs out for a chain or more into the lake; beyond this terrace the bottom falls suddenly away into deep water. Such shores as these afford no foothold for vegetation, so that reeds or rushes nowhere fringe the shore. All vegetation which

* The height above sea-level is given in many maps as 1069 feet. This cannot be so, since one of the trigonometrical stations on the shore lies at 1042 feet. On the authority of the chief surveyor of Dunedin, I take the approximate height as 1016 feet.

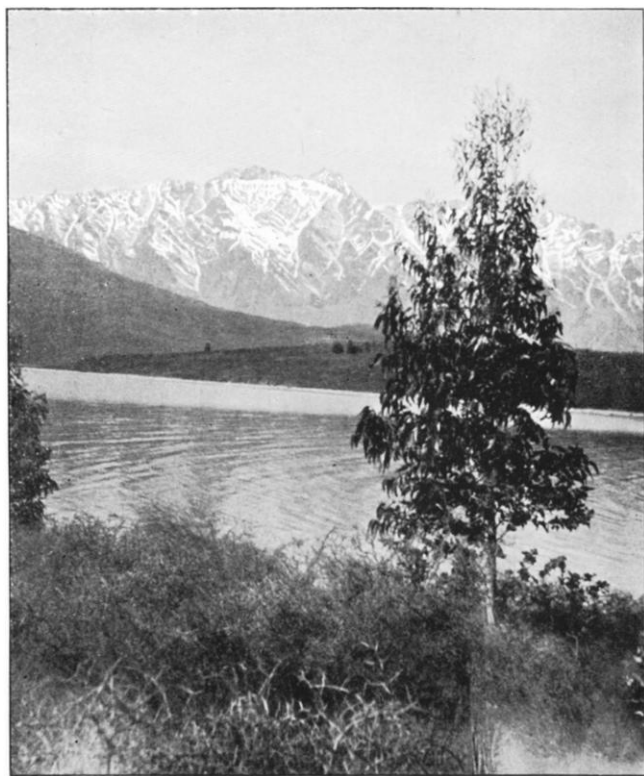


FIG. 7.—THE REMARKABLES, LAKE WAKATIPU, IN THE FOREGROUND IS SEEN THE FRANKTON ARM.

does occur is found entirely submerged, and for the most part at a depth beyond the reach of violent wave-action. On the shallow terraces, however, there is often a growth of short submerged weed, which neither reaches to the extreme margin of the water nor extends more than about a fathom below the surface.

The basin of Lake Wakatipu agrees with other features of the lake in showing a remarkable regularity. From the north end or head of the lake, the bottom shows an unbroken fall, rapid at first, but constantly decreasing, for a distance of 32 miles. For the next 9 miles beyond there is a level floor, forming the lowest depression in the basin : thirteen soundings were taken within this depression, and the extreme variation of level recorded was 6 feet. The greatest depth found was 1242 feet. From the southern end of the level depression the upward slope of the floor commences, and a fairly uniform rise over a distance of 8 miles leads up to the shore at Kingston, the southern end of the lake.

The maximum depth of 1242 feet, which was obtained in 1902, does not agree with those depths which have been previously obtained. As has been stated above, in the account of previous soundings taken in the lake, depths of 1296 feet and 1400 feet are recorded. The latter depth, in particular, is said to have been found about the middle of the lake off Collins bay, and 16 miles from the south end of the lake. At the time when soundings were being made in 1902, the general belief among the inhabitants of Queenstown was that the deepest water was to be found off Collins bay, and for this reason a line of soundings was taken at that point, one sounding being placed midway across the lake, at a distance of between 15 and 16 miles from the south end of the lake; but no evidence was found of water of a greater depth there than elsewhere.

Contour-lines have been drawn in the plan, which accompanies this paper, at intervals of 200 feet of depth within the lake-basin. An examination of these contours will serve to illustrate the gradients of the lake-floor from end to end, and for this purpose the distances between successive contours, from the head of the lake to the south end, are given below in tabular form :—

| | | | | | |
|------------------|---------------------|------------------|-----|-----|------------|
| | Shore to | 200-feet contour | ... | ... | 0.3 miles. |
| North slope | 200-feet contour to | 400 | " | ... | 0.5 " |
| | 400 " | 600 | " | ... | 2.7 " |
| | 600 " | 800 | " | ... | 5.3 " |
| | 800 " | 1000 | " | ... | 6.3 " |
| | 1000 " | 1200 | " | ... | 9.7 " |
| Level depression | 1200 " | 1200 | " | ... | 17.4 " |
| South slope | 1200 " | 1000 | " | ... | 1.3 " |
| | 1000 " | 800 | " | ... | 1.0 " |
| | 800 " | 600 | " | ... | 1.7 " |
| | 600 " | 400 | " | ... | 1.3 " |
| | 400 " | 200 | " | ... | 1.0 " |
| | 200 " | shore | " | ... | 0.5 " |

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From this table the regularly decreasing gradient of the north slope, the long level depression, and the fairly constant gradient of the rapid south slope can be clearly seen.

In McKerrow's paper,* the data of which are taken from Dr. Hector's soundings, with the depth of 1400 feet interpolated from another source, the sudden fall to 1400 feet is made to cause a break in the regular decrease of gradient in the northern slope, which break does not occur, as far as appears from the soundings made in 1902. To make this point clear, a parallel table is given below showing the gradients as determined from the two sources :—

| | | | | As given by McKerrow. | | As determined in 1902. | |
|-----------------------|--------|---|-----|--------------------------|-----|---------------------------|-------|
| Fall in first 2 miles | | | | 180 feet per mile | ... | 250 feet per mile. | |
| " | next 4 | " | ... | 70 | " | ... | 50 |
| " | " 5 | " | ... | 50 | " | ... | 32 |
| " | " 7 | " | ... | 40 | " | ... | 31 |
| " | " 6 | " | ... | 6 | " | ... | 18 |
| " | " 6 | " | ... | 14 | " | ... | 6 |
| " | " 3 | " | ... | 30 | " | ... | 5 |
| Rise | " 7 | " | ... | 6 | " | ... | level |
| " | " 9 | " | ... | 96 | " | ... | 136 |

From this table it appears that, according to the figures given by McKerrow, the north gradient, which has been steadily decreasing to a distance of 24 miles from the head of the lake, begins to increase at this point, and continues to increase for the next 9 miles, when the deepest water is reached; whereas the more recent figures show no break in the decrease of gradient until the level depression is reached.

Transverse sections taken at almost any part of the lake resemble one another to a remarkable degree. They show steep slopes leading down from opposite shores to a wide level floor, of a width equal to or rather greater than half the width of the lake at surface level. This characteristic trough-like formation is most marked where the depth is considerable. Within the 800-feet, the 1000-feet, and the 1200-feet contours, for example, the level floor at some points occupies as much as 50 per cent., 60 per cent., and 70 per cent. of the surface width. And even in shallower water a similar formation is evident, though to a less extreme degree.

There is but little special description needed to modify the general scheme of the lake-basin which has been already laid down, for the regularity of the basin is disturbed in but few places. The two larger islands, Pigeon island and Pig island, which lie in the north arm, are connected by a shallow bank, while the smaller Tree island, which lies to the west of them, is separated from them by water of greater depth, probably exceeding 200 feet. The whole group lies within a projecting arm of the 400-feet contour, which runs in a southward

* *Trans. N.Z. Inst.*, vol. iii. p. 254.

direction from the eastern shore. The channel between the eastern shore and the islands exceeds 400 feet in depth, except in its most northern part, while between the islands and the western shore there is a continuous channel over 600 feet in depth.

The Frankton arm barely passes a depth of 100 feet at any point, and is separated from the body of the lake by a barrier over which there is little more than 60 feet of water. Queenstown bay is also shallow, and its mouth is also crossed by a barrier. The other more open bays which the lake contains showed, as far as special soundings were made in them, a regular deflection of the contours, which calls for no special mention.

The volume of water in Lake Wakatipu, as calculated from the areas included between successive isobathic contours, is 15 cubic miles, and the mean depth is 707 feet.

LAKE MANAPOURI.

The work carried out on Lake Manapouri occupied from November 10 to December 13, 1902. Much of this time was spent in throwing a triangulation over the main body of the lake, with a view to the more accurate fixing of the soundings. There had been previously only two trigonometrical stations placed on the immediate shore of Lake Manapouri, namely, those on Leaning peak and View hill, at the west and east ends of the lake respectively. It appears from a paper by McKerrow, "On the Reconnaissance Survey of the Lake Districts of Otago and Southland,"* that other points had undoubtedly been observed. McKerrow speaks in that paper of the inaccessible nature of the mountains, and the fact that the shore-line was shaded over with foliage, having rendered a vertical triangulation with magnetic bearings necessary. But these early observations had, of course, left no traces on the ground; nor was it possible to distinguish from the plan provided by the Department of Lands and Survey at Invercargill whether any particular point on the shore had been sketched or observed. Under these circumstances it was possible that the soundings might be fixed by relation to points which did not pretend to accuracy, and so might prove useless.

Accordingly a triangulation was thrown over the main body of the lake, based upon the trigonometrical stations† which lay nearest to the east shore. A plan showing the bearings of these stations was provided by the Survey Office of Invercargill. The triangulation included forty-one points on the lake-shore, and almost all of these were used as the extreme points of lines of soundings.

It will be seen from the plan which accompanies this paper, that the triangulation was not carried beyond the mouths of the various

* *Journal R.G.S.*, vol. xxxiv. p. 81. † View hill, Freestone hill, and "a."

arms or fiords which project from the body of the lake. Within these arms the broad features of the shore-line have been taken from the plans provided, while the details have been altered in such a way as to show clearly any minor features which may serve to identify the points between which lines of soundings were taken. The justification of such alterations, made without fresh trigonometrical data, lies in the greater certainty with which the lines of soundings may be re-plotted, if at any time the lake shall be more accurately mapped.

All angular measurements were made with a 5-inch transit theodolite. The points observed are shown in the plan as single circles; no cairn or other permanent record of these stations was left on the ground. The thick clothing of bush, which covers the country to the very water's edge, made it necessary to complicate the triangulation to some extent in order to avoid making large clearings near the water-line. In many cases this difficulty was overcome by using as observing stations small outlying rocks and islands too small to carry a dense covering of bush.

During the whole survey, including both the sounding and the triangulation, the steam-launch *Titiroa*, owned by Mr. Dore, of Manapouri, was used. A great debt of gratitude is owing to Mr. Dore for the constant active assistance which he gave to the work.

Lake Manapouri extends from $45^{\circ} 27'$ to $45^{\circ} 35'$ S. lat., and from $167^{\circ} 28'$ to $167^{\circ} 40'$ E. long. The main body of the lake runs in a direction almost east and west for a length of about 12 miles, divided by the large island of Pomona into an eastern and a western part. The latter gives off three arms or fiords, the north arm, the west arm, and the south arm, all narrow, and recalling in shape the sounds of the west coast, from which they are separated at the nearest point by barely 7 miles of land. To the east of Pomona the form of the lake is widely different. Three arms—namely, Shallow bay, Manapouri arm, and Hope arm—project from this part of the lake, but their outline is more rounded and less regular than that of the western arms. Moreover, the eastern end is closely studded with islands, one group of which, the Channel islands, forms a barrier extending across the lake from north to south.

The surface of the lake covers an area of 56 square miles inclusive of islands, which amount to $1\frac{1}{2}$ square mile. The extreme length, measured on a curved axis running between the township of Manapouri and the head of the west arm, is 36 miles. The whole outline of the lake is so complicated that any attempt to convey an idea of its form by measurement must prove futile.*

The surface of the water lies at approximately 597 feet above sea-level, and the surrounding mountains rise on three sides to heights of

* Cf. 'Forel Handbuch der Seenkunde,' p. 39.



FIG. 8.—WALTER PEAK, AND PART OF CECIL PEAK (ON THE EXTREME LEFT), SEEN FROM QUEENSTOWN BAY, LAKE WAKATIPU.

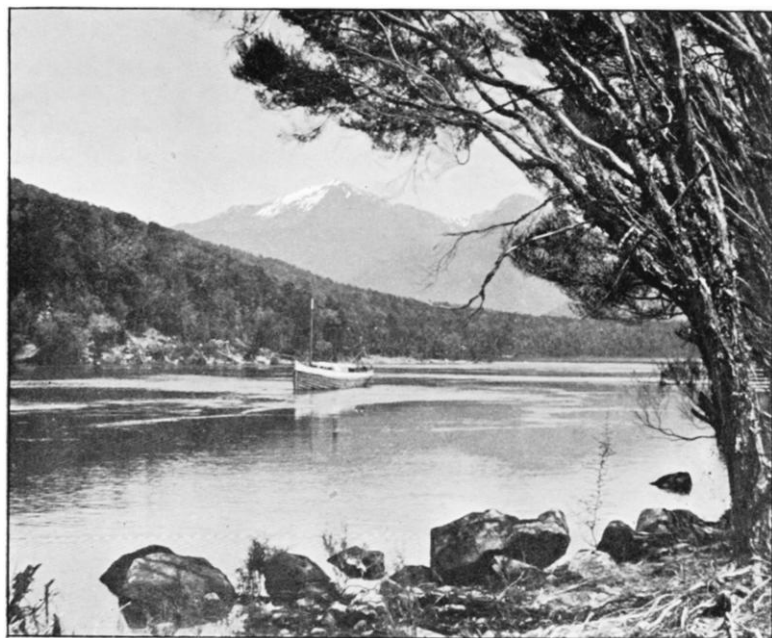


FIG. 9.—RIVER WAIATU, AT THE OUTLET OF LAKE MANAPOURI. THE HUNTER MOUNTAINS ARE SEEN IN THE BACKGROUND.

4000 and 5000 feet. These heights are, indeed, less than those of the mountains which rise from the shores of Lake Wakatipu, but the gradient from the water's edge to the mountain summits is more abrupt in the case of Manapouri, where heights of 4000 and 4500 feet above the level of the lake are reached in horizontal distances as small as a mile and $1\frac{3}{4}$ mile respectively from the shore.

On the north side of Lake Manapouri the catchment area is limited by the Kepler mountains, which contribute three considerable streams, the Iris burn, the Freeman burn, and the Awe burn. The west end receives the Spey river, draining the Matterhorn mountains which divide the lake from the west coast sounds. From the south comes a larger river than these, the Grebe river, which drains the Heath and Hunter mountains (cf. Fig. 9). The area drained by these rivers, which come directly into Manapouri, amounts to 460 square miles.

On the east side of the lake there lies a stretch of flat land extending for several miles from the lake-shore at an elevation of about 100 feet above the surface of the water. No streams of any size drain from this plain into the lake, but through it there passes the Waiau river, bringing into Manapouri the whole of the outflow from Lake Te Anau. With the addition of the area of 1340 square miles drained in this way by the Waiau river, the total catchment area of Manapouri amounts to 1800 square miles. The outflow from the lake is by a continuation of the Waiau river, which leaves in a south-easterly direction at a point close to the township of Manapouri.

The shores at the western end of Lake Manapouri resemble those of Lake Wakatipu in the alternation of almost perpendicular slopes with beaches of coarse sand and stones. Towards the east end, however, the beaches become far more prevalent, and in some places, where there is a considerable extent of shallow water, the shore is fringed with grass and reeds. In every part of the shores, excepting a small part near the township, dense bush extends from the hills to the water-line, and in many places even overhangs the water. In this point Manapouri offers a remarkable contrast to Wakatipu, from whose shores bush is absent, excepting some small remnants which survive in the more sheltered valleys.

The greatest depth found in Manapouri was 1458 feet. This depth occurs within a large depression, 2·7 square miles in area, all of which exceeds 1400 feet in depth. It is well to note that the deepest depression in this lake is surrounded by the highest and the steepest slopes which the shores afford. The mean gradient from the shore to the nearest summit is on the north side approximately 1 in 2 until a height of 4531 feet above the lake is reached, and on the south side 1 in 1·5 up to a height of 4272 feet above the lake. The 1400-foot depression sends out two considerable tongues, one into the south arm, and the other eastward between Pomona island and Cone peak. The depression

included within the 1200-foot contour follows a similar though far more extensive course. Failing to enter the passage which reaches westwards towards the west and north arm, it sends a tongue fully halfway up the south arm, and another eastwards beyond the more northern of the Channel islands. There is a remarkable widening of this depression where it passes to the south-east of Pomona; having been narrowed to a bare quarter of a mile in the straits between Pomona and Cone peak, it expands until it reaches a width of almost a mile at its widest part. Finally, it narrows again to pass between the Channel islands.

The 1000-foot depression is interesting, because, unlike those which lie below it, it runs deep into the north arm, and closely skirts the entrance of the west arm. Elsewhere it follows the deeper depressions, running southwards within 2 miles of the head of the south arm, and eastwards between the Channel islands to the mouth of the Manapouri arm. It includes an area of 10 square miles.

The remaining contours take for the most part an even course between the 1000-foot depression and the shore, except where they are deflected by the many islands which the lake contains. Thirty-three of these islands are shown in the accompanying plan, and there are many more of smaller size. To these islands the lake owes much of the character of its scenery (cf. Fig. 10), as well as the configuration of its basin. None of the islands are surrounded by water of a depth exceeding 600 feet. Pomona (cf. Fig. 11), the largest, whose area is a little more than a square mile, is connected to the north shore by a bank covered by 200 feet of water at its narrowest part, so that all the contours, excepting the 200-foot line, are deflected to the south of the island. Rona island, the next in size, lies between the 200-foot and 400-foot lines, causing considerable outward deflection of the latter.

The Channel islands appear on the surface to form a continuous chain stretching right across the lake. In reality they are divided into three groups, a north, a south, and an intermediate. The north group, consisting of two islands, or rather of an island and a rock, is connected to the Beehive by a channel only 150 feet in depth. The south group, in which eleven islands are included, also lies within the 200-foot contour, being connected to a headland of the south shore by a channel 170 feet in depth. The intermediate group contains six islands. It is separated from the south group by a channel about 500 feet deep, while between it and the north group there lies water of a depth exceeding 1200 feet. This group of islands deflects all the contours on its west side in a remarkable way. It appears to have a long western slope, extending for three-quarters of a mile under water before a depth of 400 feet is attained.

All the islands which have not been already mentioned lie between the 200-foot contour and the shore.

Of the three large arms which the west end of the lake gives off,



FIG. 10.—LAKE MANAPOURI, LOOKING WEST BETWEEN THE CHANNEL ISLANDS.



FIG. 11.—LAKE MANAPOURI, LOOKING NORTH-WEST FROM THE MOUTH OF HOPE ARM. POMONA ISLAND IS SEEN ON THE LEFT, AND BEYOND IT LIE THE CATHEDRAL PEAKS.

the larger south arm contains the deepest water. Next in depth is the north arm, sloping quite as rapidly as the south arm, and only lagging behind in depth because its length is less. The west arm is the shallowest of the three, and its gradient is the least steep.

The arms of the eastern end are far shallower than those of the west end. Hope arm and Manapouri arm closely resemble one another in depth, each admitting the 600-foot depression. Shallow bay admits the 400-foot depression, but a depth of 600 feet does not occur near its mouth. The smaller bays of the eastern end, such as Circle cove and Calm bay, are shallow, not reaching a depth of 200 feet.

CONCLUSION.

It is difficult to make general statements which will sum up any points in the morphology of the lakes which have been described. This difficulty arises in the main from the strange heterogeneity of the lake-basins. It would be hard, for example, to find any points of resemblance between two lakes such as Taupo and Wakatipu. In the latter the lake-basin seems to be an integral part of the surrounding country; its slopes continue the slopes of the mountain-sides. It is a mountain valley filled with water, and if it were drained dry it would scarcely appear in any way remarkable. Contrast with this the basin of Taupo. It is a trough abruptly sunk in a country which seems wholly unprepared to receive it. The perpendicular cliffs which form its western shore drop suddenly down from among hills whose slopes are comparatively gentle; in one place the cliff even forms a clean section through a large hill, cutting it from base to summit with a perpendicular face over 1000 feet in height.

In their relations to the surrounding country, Manapouri may be classed with Wakatipu, and Rotoiti with Taupo. In the former group there is a correspondence between the position of the deepest water and the gradient of the land in the immediate neighbourhood; in the latter group no such relation can be traced. In Wakatipu the greatest heights combined with the steepest gradients are those of the Remarkables (cf. Fig. 7) and Cecil peak, and between these the deepest water lies. In Manapouri the same conditions are fulfilled by the Cathedral peaks (cf. Fig. 11) and Cone peak. The existence of this relation indicates a rough correspondence in type between these two southern lakes and such familiar types as the lakes of the English Lake District.

A further point of similarity between Wakatipu and Manapouri is the presence in each of a large flat area where the water is deepest. This peculiarity of form is not to be confused with the tank-like form of Taupo. In the former, sloping sides lead down to a level floor, which marks the limit of depth; in the latter, perpendicular sides lead to a level floor, beyond which there is a further slope to the deepest point.

In Lake Taupo, the steepest gradient leading to the highest point is found at Karangahape, on the western shore, but the deepest water lies in the north-east part of the lake. In Rotoiti there is a similar lack of correspondence between Matawhaura, at the east end of the lake, and the deep water which lies some distance to the west of it.

The two lakes Taupo and Rotoiti have in common a tank-like form of basin. It is also possible that a relation between the two may be indicated by the presence in each of isolated banks or shoals. Examples of such shoals are found in the west end of Rotoiti, and in Taupo between Karangahape and the island Motutaiko.

The remaining lakes form a very heterogeneous lot. Rotorua is a saucer-like depression, a mere continuation of the whole catchment basin in which it lies, regular in its outline and in its subaqueous slopes. It cannot be compared to the more abrupt and tank-like lakes among which it lies, though it may possibly have with them a common origin in subsidence, similar but less violent.

Waikaremoana presents features which connect it with the valley lakes. It may be considered as a system of radiating valleys, having its deepest depression at the point where all the valleys meet. It differs, however, from the southern lakes in the more blunt and open form of its valleys, and in the fact that sections of its basin show an outline resembling rather the letter V than the letter U.

Waikare and Whangape are so shallow as to rank rather with swamps than with lakes, in spite of their considerable area. The interest of the former lies chiefly in its peculiar relation to the Waikato river, a relation which enables it to reduce the harmful effects of floods, though not lying on the river's actual course.

THE WALDSEEMÜLLER FACSIMILES.*

By EDWARD HEAWOOD, M.A.

THE promised facsimiles of the Waldseemüller maps, discovered in 1901 by Prof. Fischer at the castle at Wolfegg, have at last been published, and in a style which is fully worthy of the importance of the subject; both the actual reproduction of the maps and the general get-up of the volume being a credit to all concerned. The excellence of the result is due, in part, to a grant from the Imperial Academy of Sciences at Vienna, which has made it possible to do justice to the subject without unduly increasing the cost. The matter supplied by

* 'The oldest map with the name America of the year 1507, and the Carta Marina of the year 1516, by M. Waldseemüller (Ilacomylus).' Edited by Prof. Jos. Fischer and Prof. Fr. v. Wieser. Innsbruck: Wagner. London: Henry Stevens, Son and Styles. 1903.