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A BATHYMETRIC SURVEY OF THE WAIMANGU THERMAL LAKES

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ABSTRACT

Techniques and equipment used for determining the bathymetry of hot lakelets in the Waimangu thermal area are described.

INTRODUCTION

The Waimangu hydrothermal system (see Figs 1, 2) is remarkable for a number of reasons, not the least being that it currently exhibits a quasi-cyclic behaviour with a period of approximately six weeks. During a cycle the hot water lakelet in Inferno Crater fluctuates between overflow and a depth of eight to ten metres below this level (Fig. 3). The neighbouring Frying Pan Lake in Echo Crater (Fig. 4) exhibits sympathetic variations in outflow*. During the late 1960s a system to monitor this behaviour was established, mainly by E.F. Lloyd, and a summary of the data acquired is reported annually (Lloyd 1973, 1974, 1975; Scott 1975, 1976, 1977, 1978). In an attempt to develop a quantitative model of the hydrothermal mechanism responsible for such systematic behaviour it has been necessary to determine accurately the bathymetry of the two hot lakes (Keam 1976, 1977, 1978, in press a, b). Because of the unusual problems involved in obtaining data for hot lakes, it is considered appropriate to detail the methods used. Also briefly described are general methods used for sounding thermal springs.

* In 1963 Tourist and Publicity Department staff re-named Frying Pan Lake as Waimangu Cauldron, and re-named Inferno Crater (or its vent) as Ruaumoko's Throat. In this paper (and most other scientific publications) the older names are retained.

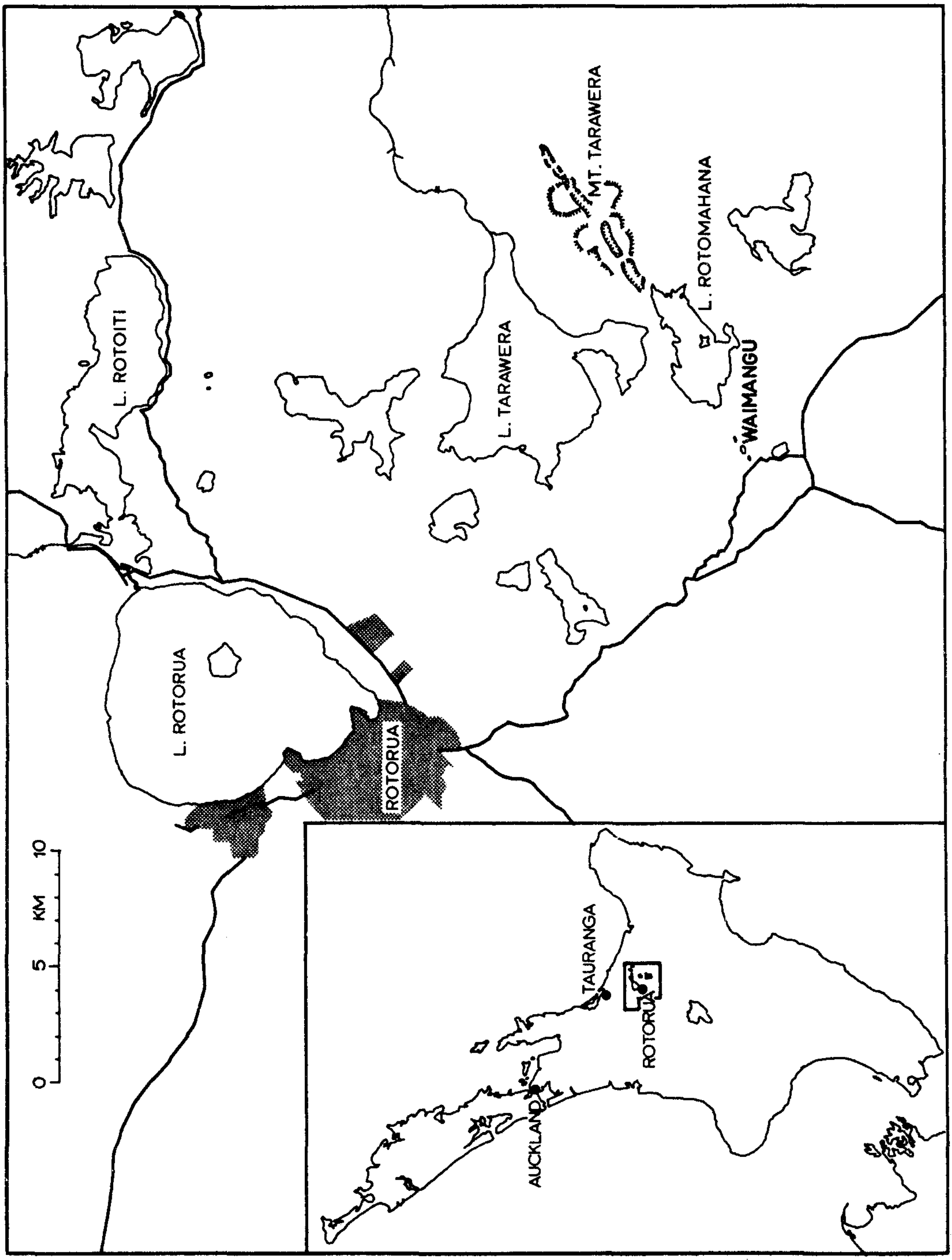

Fig. 1. Locality Map.

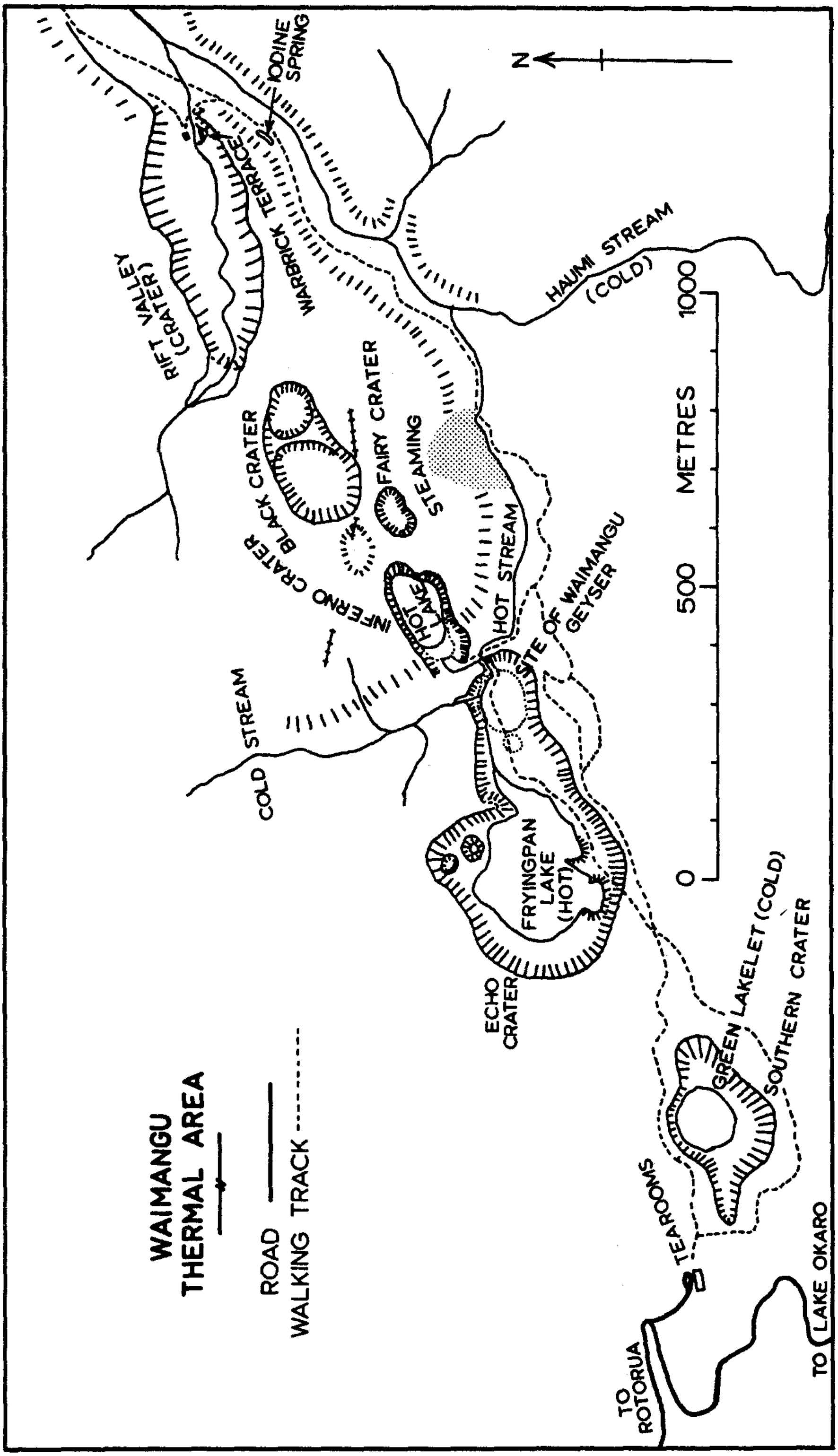

Fig. 2. Waimangu Thermal Area.

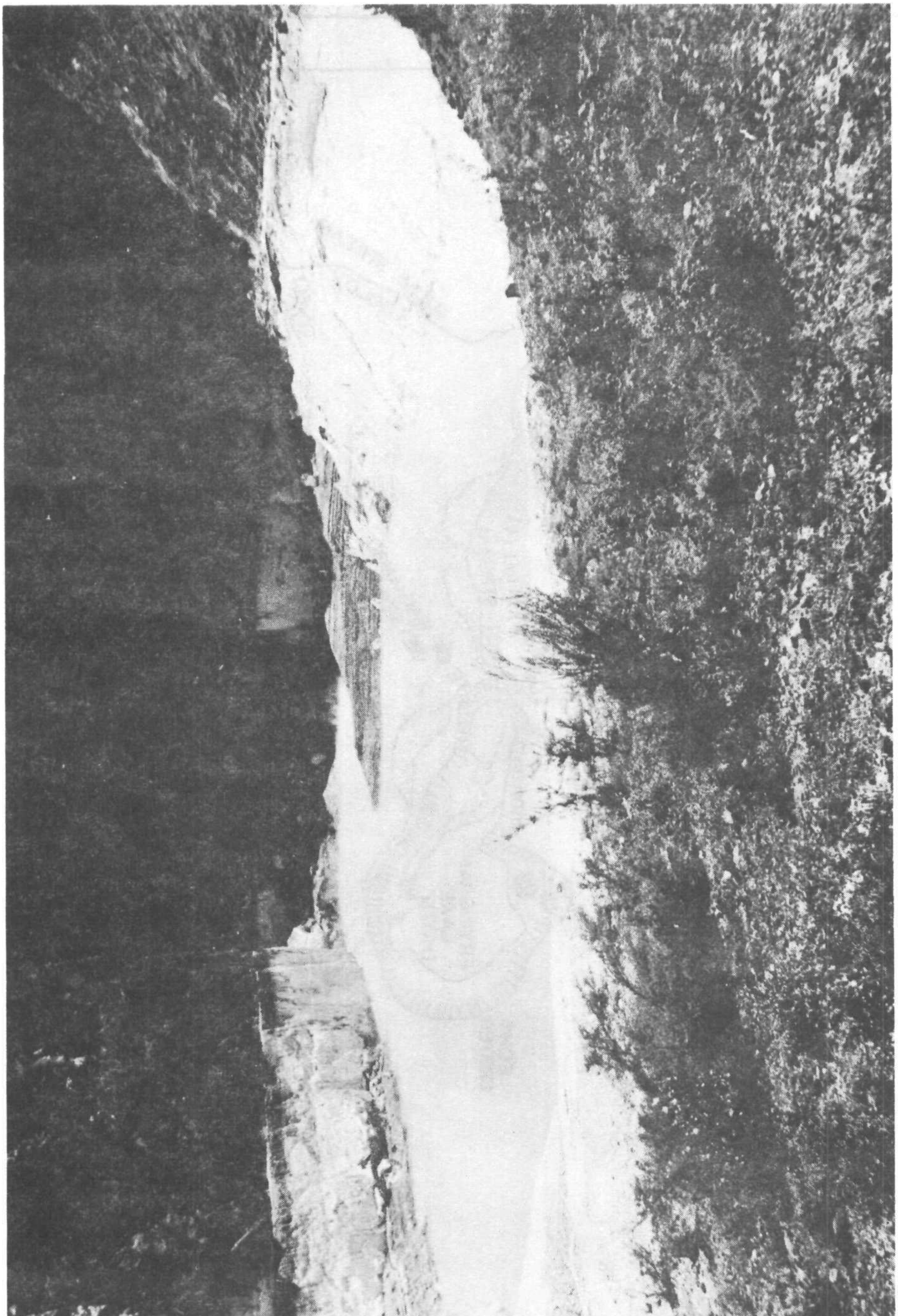

Photo : *R.F. Keam*

Fig. 3. Inferno Crater lake on 6 December 1952, showing the water surface about 8 m below outflow level.

SOUNDINGS FROM SHORE

Soundings in thermal springs of comparatively small area have been made by many investigators by lowering a weighted line to the bottom and measuring the length paid out. When pool diameters exceed 5-6 m it becomes necessary to suspend a line in some fashion over the vent. In their 1941 temperature survey of hot springs in Rotorua-Taupo thermal areas, Marshall and Rands (Rands and Wilson 1954) tautly held a second line with a ring on it across large pools, and lowered the thermometer line through the ring.

As early as 24 May 1951 E.F. Lloyd and I had made a spot sounding of the Inferno Crater lake in the following manner : a piece of wood, with cork attached to increase its buoyancy, was floated out on to the lake. Its position was controlled by a tether at either end and by the controllers walking along the lake-shore and crater edge and pulling the tethers taut. A further line with a sinker on it ran through a hole in the centre of the wooden float. The sinker was raised to touch the float and when the latter was in position the sinker was lowered until it reached the lake bed. Knots were tied by the operator controlling the sounding line at contiguous positions on the sounding line and control tether. When the system was recovered, the difference in length, between sinker and knot on the sounding line and float and knot on the control line, gave the lake's depth.

Examination, in 1972, of newly available Waimangu monitoring data led to the suggestion of a qualitative model for explaining the observed behaviour of the hydrothermal system (Keam, pers. comm. *in* Stanton 1978 : 18-23; Keam 1980). In order to develop the model further a series of spot soundings of Inferno Crater lake was made on 6 January 1973. The method was similar to that used in 1951 except that a plastic bottle replaced the wooden float. It was clear, however, that for quantitative work one needed better than sketch locations for the soundings.

E.F. Lloyd established several survey stations and began a systematic series of plane-table surveys of the edge of Inferno Crater lake at intervals of approximately 1 m from overflow to the lowest level it reached during a recession. These were then supplemented by further soundings using the float method when the lake was near a minimum level. Sounding locations on this occasion were determined by a plane-table survey of each float position. The method of measuring the fall of the sinker was simplified for each sounding by attaching a flexible metric tape to the sounding line when the sinker was at the float and noting how far this was pulled out when the sinker was lowered to the lake bed. The tape was detached between soundings while the float was repositioned.

The water in the main basin of Inferno Crater lake covers a circular area 60 m to 65 m diameter when at its minimum level. A larger lake would present considerable difficulties in sounding by the float method, mainly because the sinker would have to be inconveniently heavy in order to pull the sounding line through the float rather than allowing the portion of sounding line between float and operator to sag under its own weight to the lake-bed. For Frying Pan Lake, whose width reaches 200 m, the alternative is to take soundings from a boat.

BOAT SOUNDINGS

Maji Moto, the boat used, was specially designed incorporating specific safety features for use on hot lakes. (See Appendix for details on construction and use.) Certain types of wooden dinghy could be modified to include these features.

During December 1974 and February 1975 staff and students of the Physics Department, University of Auckland, established a network of more than 40 survey stations at Waimangu and these have been accurately fixed with respect to the Bay of Plenty Circuit. Station elevations were determined by levelling from bench marks and by using vertical angle

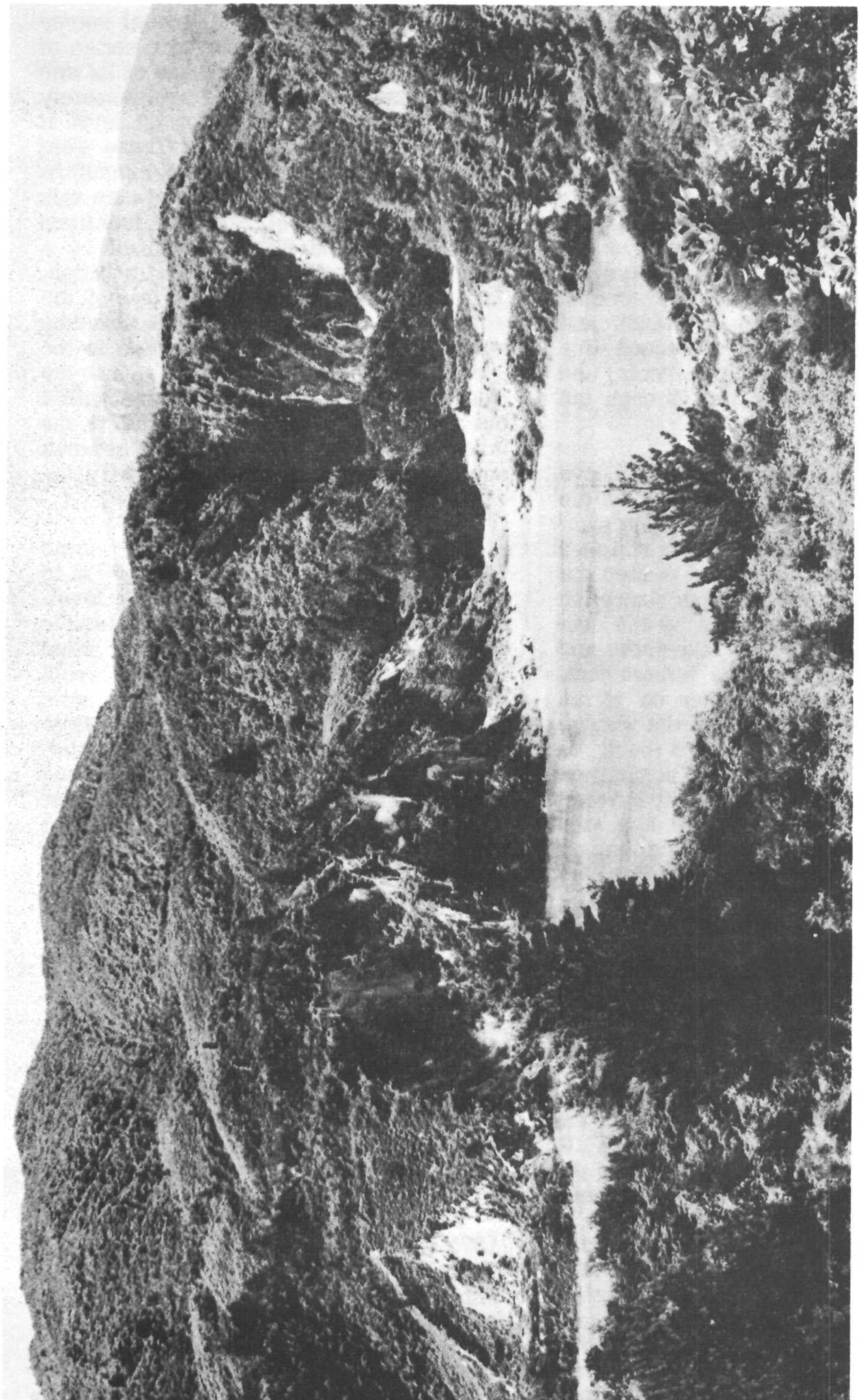

Photo : *R.F. Keam*

Fig. 4. Frying Pan Lake in Echo Crater, on 23 February 1964, viewed towards the north-east. The cliffs forming the high walls of Inferno Crater may be seen on the slopes of Mt Haszard beyond the outlet. (Mt Tarawera is in the distance.)

Photo : *A. Estie*

Fig. 5. Sounding on Frying Pan Lake from *Maji Moto*, 20 May 1975. The three-tether configuration shown was one of those tried initially. Later a two-tether transverse configuration was systematically used.

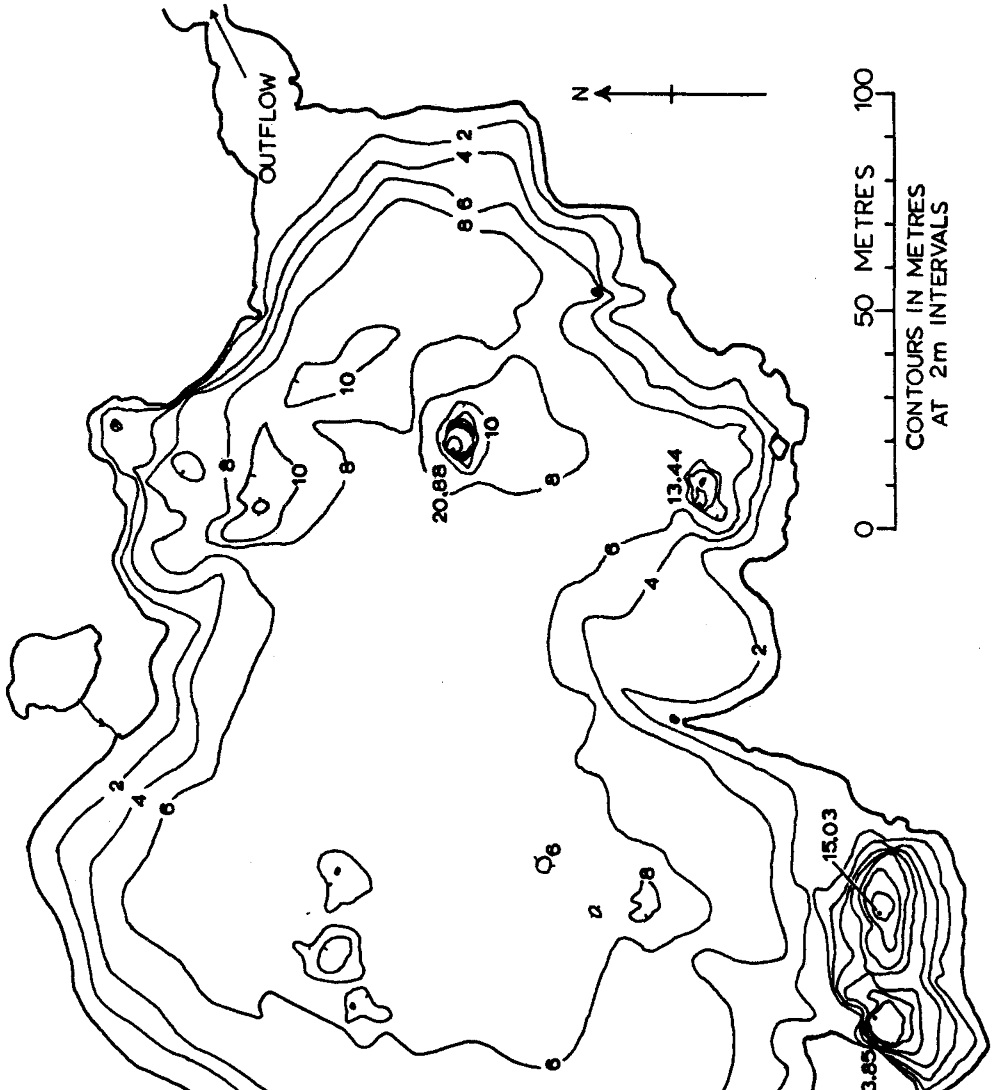

Fig. 6. Outline bathymetry of Frying Pan Lake.

theodolite observations and a least squares fitting procedure. A level datum has been established for each lake.

Sounding locations were determined from theodolite observations with the instruments being set up on stations of the established network (Fig. 5). The theodolite target was a small sphere on top of an aluminium tube directly above the sounding reel. Soundings were made by hand-lowering a lead weight at the end of a stainless steel or fibre-glass tape wound on the reel.

Communication between the boat crew, tether controllers and theodolite operators was predominantly by whistle signals but was also by direct voice and radio-telephone. Various configurations and numbers of tethers were used. The most efficient method utilised two tethers, one attached to each side, with the drawback that the boat was still able to move relatively freely normal to the line of the tethers. Wind gusts tended to produce movement, so soundings were made when movement was judged to be least, a whistle sighting-signal being given for the theodolite operators (who were following movement of the target sphere with their telescopes) to freeze movement of their instruments simultaneously at the instant when the weight made contact with the lake-bed. A third tether, tied to some shore object and operated from the boat, was used if persistent wind made it otherwise difficult to stay on station. A recent modification was the provision of a wide board able to be lowered into the water through slots parallel to and hard against the stem. Its drag in the water when lowered reduced the effect of wind gusts. It was disadvantageous to use it, however, when there were significant currents.

During two separate week-long expeditions in May 1975 and November-December 1976, and on 17 March 1977, 28-29 October 1977 and 16-17 March 1978 1173 soundings were made in Frying Pan Lake at well determined positions and the bathymetry was defined (Fig. 6).

Maji Moto was also used for soundings below low water level in Inferno Crater lake during the periods 16-17 December 1976, 15-17 March, 30-31 October 1977 and 14-16 March 1978. A total of 786 soundings were recorded from the boat together with 78 earlier ones using the float method (Fig. 7).

THEODOLITE TECHNIQUES

The earlier plane-table determinations of the location of the lake-edge over its range of levels in Inferno Crater were superseded by a method which uses a single theodolite ("Angle of Depression" technique). The geometry is such that from a suitable elevated position, and provided the instrument's height above lake-level is known, observations of vertical and horizontal angles to points on the lake edge by a single theodolite are sufficient to define the co-ordinates of each point so observed. Both with this method and when sounding it was necessary to monitor carefully the movements of lake-level which typically are around 20-25 mm/hour.

Steam severely restricted visibility during periods of high lake-temperature and it was found impractical to use either sounding or angle-of-depression methods for some littoral portions of the Inferno Crater lake basin. Such regions of the basin which were accessible in safety were surveyed by establishing a sequence of temporary stations (by laying a coloured golf-ball on the surface) and observing these with two theodolites on network stations. Regions not so accessible were comparatively economically surveyed by a single operator observing identifiable physical features alternately through two theodolites set up on adjacent network stations.

ACCURACY

Precision in determining the positions of sounding locations has varied, depending on environmental conditions (wind

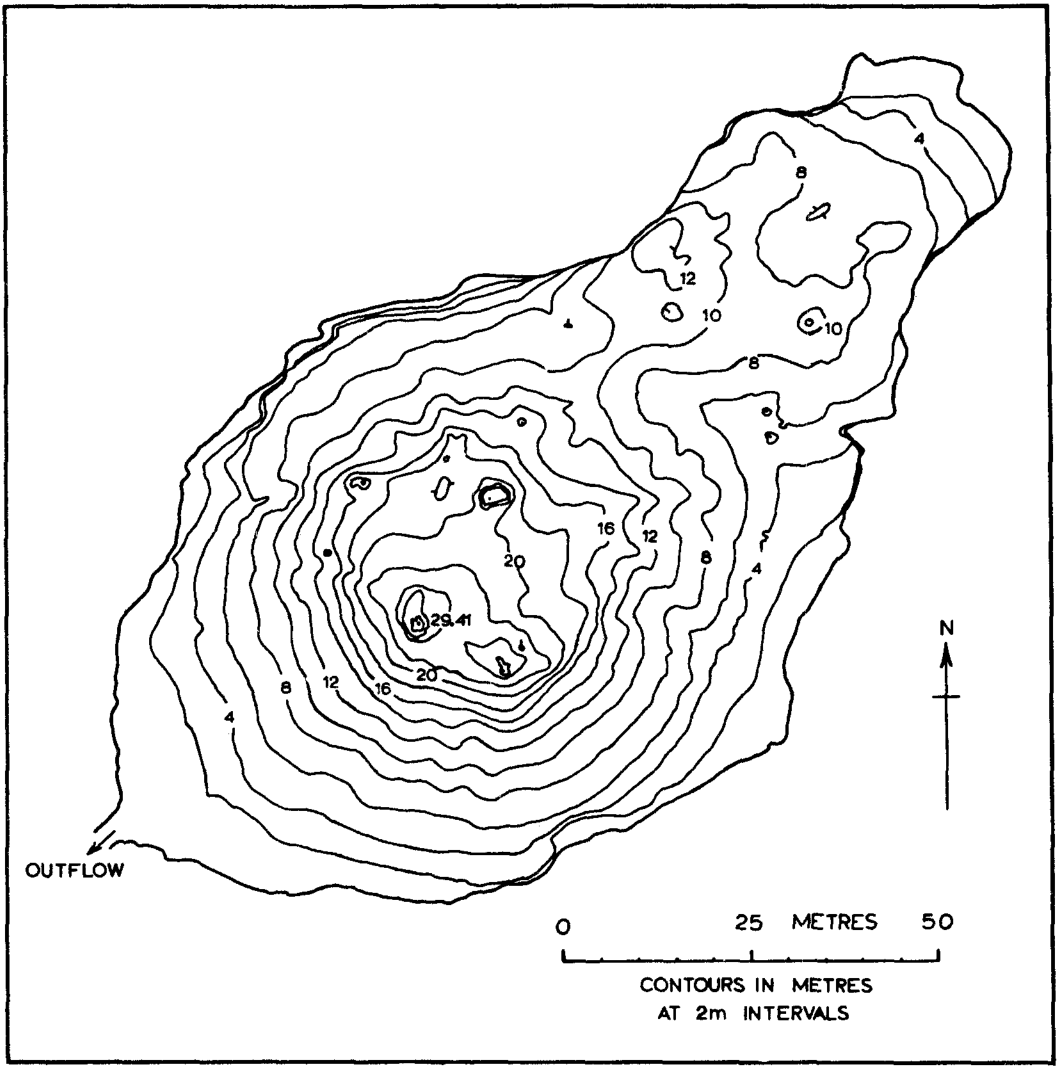

Fig. 7. Outline bathymetry of Inferno Crater Lake. [In February 1978 a hydrothermal disturbance formed a new vent ENE of the deepest existing vent. The bathymetry shown here is that which existed before this event.]

causing boat movement, steam obscuring sighting sphere) and increasing with experience with any given set of environmental conditions. At times three theodolites were used simultaneously. The in-circle radius of the horizontal triangle formed by intersection of vertical planes through their axes seldom exceeded 10 cm. Further checks were available through the theodolite vertical angle readings, which were also systematically recorded. The position of the sighting sphere can therefore, in most cases, be regarded as having been determined to within ca. 10 cm.

Whether the sphere, in these circumstances, was directly over the sinker depended on inclination of the tape in the water. This in turn depended on whether significant drift had occurred during the time the tape was being lowered and between lake-bed contact and the sighting signal and on the effects of any currents. The top metre or so of the tape was observed through the centre-board casing, and when there was any noticeable departure from the vertical, or too much boat movement, the sinker was raised and lowered again. A departure from the vertical of > 5° would probably have been noticed. Maintained over the length of the tape, this would give a maximum positional error of 8% of the water depth - for Frying Pan Lake with an average depth of approximately 6 m this would be about 0.5 m. The error region for location can therefore be regarded as an ellipse with semi-minor axis around 10 cm, semi-major axis < 8% of water depth and oriented with the minor axis along the line of tethers. (Two sets of soundings in Inferno Crater were achieved in completely calm conditions with expected location errors of no more than a few centimetres.)

The sounding tape was a 30 m carbon steel measuring tape graduated in millimetres but replaced by a fibre-glass tape for the March 1978 soundings. Depths were read to the nearest centimetre. With a hard bottom and no-drift conditions this was found to be completely repeatable. With a soft bottom one had to define the depth and I took it to be the level at which the sinker stopped sinking at a noticeable rate. The main depth error would probably have arisen from non-verticality of the tape, as above, with a five degree slant contributing a 0.3% excess depth error. Allowing for soft bottom uncertainty and some curvature (catenary effect) a 10.00 m measured depth would almost certainly imply a real depth within the range 9.95 m to 10.02 m. Corrections where appropriate have been made for thermal expansion of the steel sounding tape. At most these amount to 1 cm.

Soundings by the float method were less accurate than boat soundings, with an expected error of ± 0.1 m. Those using plane-table locations of the float have been disregarded and only soundings using theodolite determinations of position have been used in defining the bathymetric maps. Location accuracy can therefore be regarded as comparable with that for the boat soundings.

ACKNOWLEDGMENTS

I am grateful to D.A. Jones, Senior Technical Officer, Physics Department, University of Auckland for designing the *Maji Moto* and for incorporating the special safety features. The boat was supplied by the Plywood Association of New Zealand and constructed by R.L. Fink of Tamahere.

I should also like to record my gratitude to the following people and organisations : E.F. Lloyd, now of Geological Survey, for help in our early investigations and later survey work and the initial contouring within Inferno Crater lake basin; B.J. Scott, W. Crafar, P. van der Werff, also of N.Z. Geological Survey; the Tourist and Publicity Department for freedom of access into the Waimangu Scenic Reserve and the willing personal help of its employees, particularly A.S. Marx, P. Scott, S. Hitchens, H. McNickle; the Lands and Survey Department for convenient accommodation; and other staff and students of the University of Auckland for many hours of both rewarded and unrewarded labour often in trying weather conditions. This work was also supported in part by a research grant from the University of Auckland.

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APPENDIX

Details of Boat Construction, Safety Features and Usage

(Construction details have been provided by D.A. Jones, Physics Department, University of Auckland)

see Fig. 8

1. The bottom skin of the boat was cut from a single sheet of 2.44 m x 1.22 m x 10 mm marine ply to B.S.S. 1088.

2. All joints were glued/screwed/nailed using boil-proof resorcinol glue.

3. Two foam buoyancy "tanks" were each cut from a single slab of high density polyurethane foam. To fit the side of the boat small saw cuts were made at intervals vertically across the mating face to allow the foam to take up the curve of the hull. It was first glued to the hull using P.V.A. glue and then clamped to the sides with battens and 'G' clamps. After the

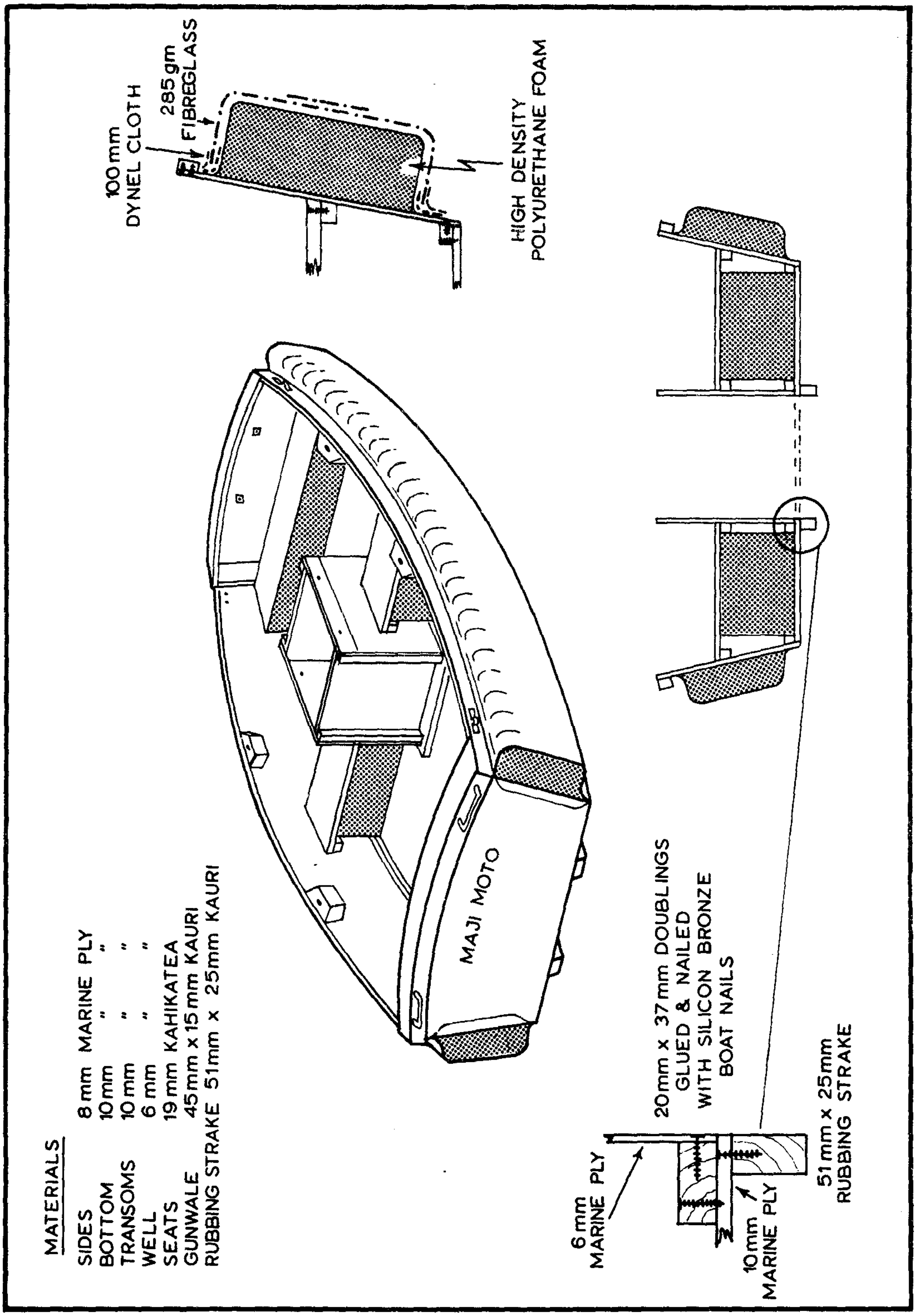

Fig. 8. Construction details of *Maji Moto*.

P.V.A. glue had cured the foam was covered with epoxy resin and fibre-glass cloth. First a small 10 cm wide fillet of dynel cloth was "epoxied" to the hull and to the surface of the foam at both the top and bottom of the foam slab (dynel cloth had been chosen for its ability to mould to sharp angles). When the resin had cured, 285 g fibre-glass cloth was spread over the foam slab and overlapped on to the dynel cloth. A small stiff brush was helpful in forcing the glass and epoxy into place. A second fillet of dynel cloth 10 cm wide was then epoxied over the top edge of the 285 g cloth and laid up the sides of the hull thus locking firmly the 285 g cloth to the hull structure. Finally a 15 cm strip of fibre-glass cloth was epoxied to the sides of the foam forming a protective belting to the buoyancy tank.

4. Additional buoyancy was provided by foam slabs locked in position under the seats so that in the event of the boat filling the occupants could sit on the bow and stem decking and place their feet on the seats clear of the water.

5. On completion of the fibre-glassing the boat was painted with Everdure (a clear epoxy preservative), primer reaction lacquer undercoat and sprayed with several coats of reaction lacquer. All nails were punched down and the nail holes filled with epoxy filler.

6. Dimensions :

Sides 0.41 m high
Well 0.30 m x 0.30 m
Foam Slab Section 0.25 m x 0.10 m
Overall Length 2.49 m

7. Carrying handles were fixed to the transoms. They also served, together with metal loops on the gunwales, as securing points for the rope tethers.

Safety features comprised the following :

1. The wide shallow floor combined with low sides ensured maximum stability against tipping of the boat.

2. All soundings and samplings were done through the centre-board casing, precluding the necessity for any crew member to lean over an end or side. A gantry, with the sounding and theodolite-target gear, was fitted over the casing, i.e., in the most stable location.

3. "Tanks" of high-density polyurethane foam along the sides and beneath the seats provided sufficient buoyancy to support two crew members above water-level in the event of a catastrophic floor or casing failure.

4. Nylon tethers, attached to handles on the ends and loops on the sides, provided means of propulsion, positioning and holding the boat on-station, and also of enabling rapid rescue from the shore. (A test on a cold lake showed that the boat could be hauled 100 metres in about 45 secs.)

5. Gumboots were provided for the crew. These found normal use in launching the boat or wading in the hot lake for any other purpose, but also would have enabled the crew to move around in the boat had a serious leak occurred.

6. Gas-masks were provided. (In the event these were later usually dispensed with as no significant problem with fumes was encountered.)

7. Oars were provided as an alternative method of propulsion.

So far *Maji Moto* has been afloat on Frying Pan Lake (whose measured surface temperature ranged between 49.3°C and 61.8°C) for approximately 93 hours. It has also been on Inferno Crater lake at comparable or lower temperatures for 142 hours - including five times being moored there overnight - and on other occasions at temperatures of around 74°C for a total of 4 hours. No significant structural response has occurred and there appears to be no reason to prevent the boat's use on even hotter bodies of water.

It is perhaps interesting to recall (Warbrick 1934) that another hot lakelet once existed at Waimangu which was sounded from a boat. This was the Waimangu Geyser whose site in Echo Crater is now a sediment-filled basin lying between Inferno Crater and Frying Pan Lake. On 10 August 1903 A.P. Warbrick and H.E. Buckeridge rowed a dinghy across and around the pool for 12 minutes during a quiescent stage between eruptions. A maximum depth of 48 feet was found. Water temperature was not recorded but Warbrick notes that when hauling up the lines between soundings Buckeridge "hurriedly dropped the rope in the boat to avoid scalding his hands". Safety precautions were non-existent and perhaps superfluous since the main danger undoubtedly lay in the possible occurrence of an untimely eruption.

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