PALAEOLIMNOLOGICAL STUDIES ON LAKE MARATOTO, NORTH ISLAND, NEW ZEALAND.

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1. INTRODUCTION

The Middle Waikato (or Hamilton) Basin is a promising area for studies of the postglacial history of Northern New Zealand. The major geomorphological features of the basin were developed in the last 40,000 years, mainly by aggradation of the ancestral Waikato River (McCraw 1967, Hume et al 1975) and in the process a number of peat bogs and small lakes were formed which now provide suitable locations for palaeoclimatic and palaeoecological investigations. Four pollen diagrams from peats in the area have been published (Harris 1963, McGlone et al 1978) which show similar features to diagrams from elsewhere in the North Island (McGlone and Topping 1979) but there have been no comparable studies of sediments from the lakes.

Exploratory corings were made on some of the lakes in 1978 and showed that they are ideal sites for palaeolimnological studies. The lakes are shallow with soft sediments and very low sedimentation rates. Monolithic cores up to 4 m long and covering some 18,000 years were obtained easily with a simple hand corer. A particularly notable feature was the presence of a series of thin distinct volcanic ash layers throughout the sediments. The sequence and thickness of these layers was practically identical in all the lakes

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examined, and obviously of potential value as markers if they could be identified and dated.

Lake Maratoto, located near Hamilton City near the centre of the Basin, was chosen as an initial site for more detailed investigation. A 3.2 m core was taken from the lake in November 1979 and in this paper a preliminary account is given of its general features and some aspects of chemistry and sedimentary pigments. Other detailed studies are being made of the tephras (D. Lowe, Department of Earth Sciences, Waikato University), the diatoms and chydorid microfossils (J. D. Green), chironomidae (J.A.T. Boubée, Biological Sciences, Waikato University) and of the pollen (M. S. McGlone, D.S.I.R., Botany Division, Christchurch). All this work will be reported in detail elsewhere.

2. GEOMORPHOLOGY OF THE HAMILTON BASIN

The Hamilton Basin is an 80 x 40 km depression surrounded by peripheral highlands (Fig. 1). The topography consists of a series of low hills rising from an alluvial plain, with the Waikato River running in a well entrenched course from south to north (McCraw 1967).

The alluvial material is known as the Hinuera formation and consists of gravels and sands up to 90 m thick deposited in the basin by the braided river system of the ancestral Waikato River. This alluvium was derived from massive erosion in the interior of the North Island during the latter part of the last glaciation and deposited in the basin as a large low angled alluvial fan partly submerging the older hilly topography. Deposition of the Hinuera formation took place between 40,000 and 12,000 year BP in two phases, Hinuera-1 ending about 20,000 year BP and Hinuera-2 ending between 14,000 and 12,000 year BP (McGlone et al 1978).

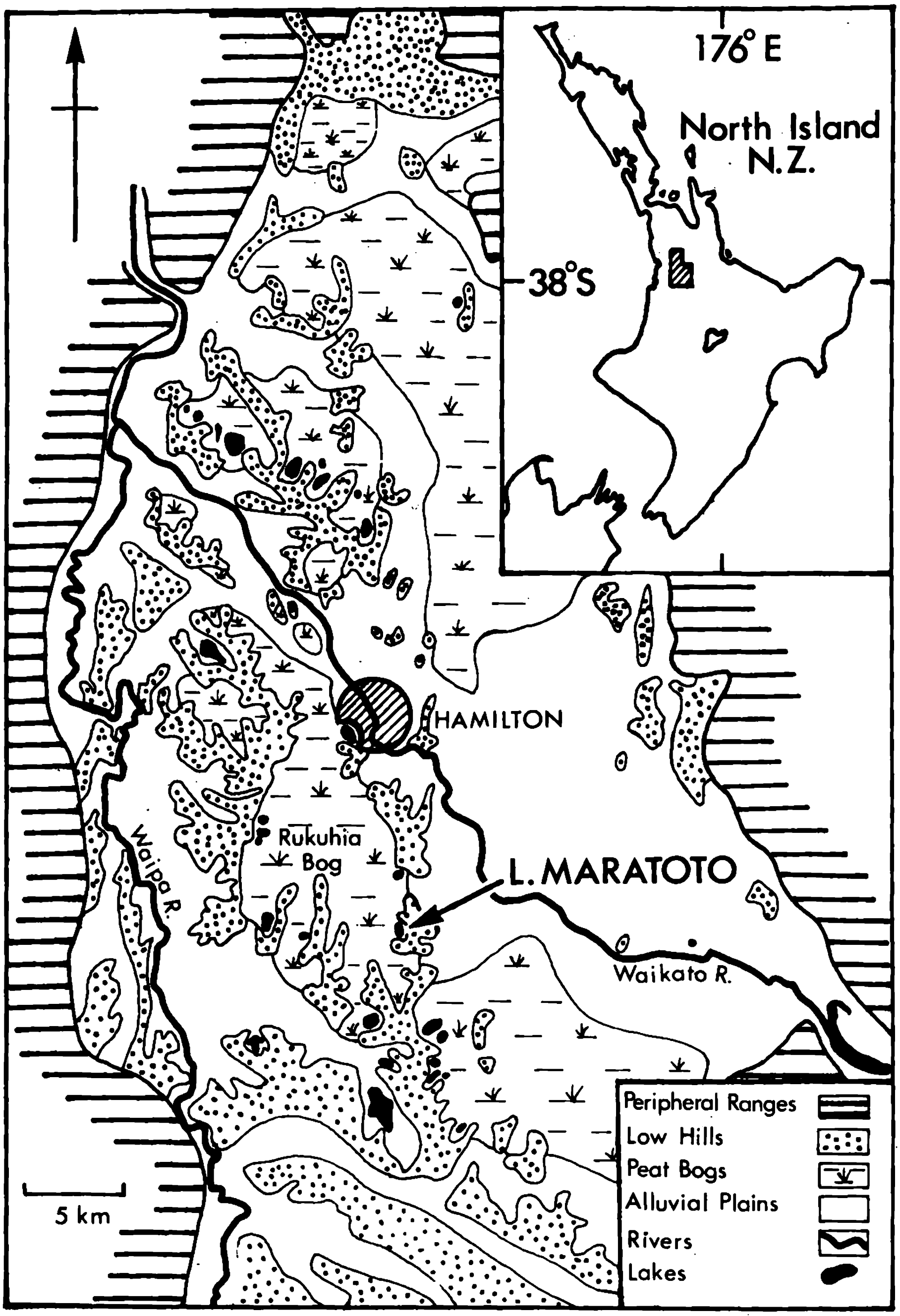

Fig. 1 - Map of the Hamilton Basin showing generlized topography and the location of Lake Maratoto.

The Waikato River became entrenched in its modern course after the deposition of the Hinuera formation ceased.

It seems that the many small lakes in the Hamilton Basin were formed during the deposition of the Hinuera formation by the damming of embayments and stream valleys in the ancient landscape, and since this may have occurred at any time between 40,000 and 12,000 year BP the ages of the lakes may vary considerably. Following the final entrenchment of the river in its modern course about 12-11,000 year BP, peat began to form in swampy hollows and shallow lakes on the Hinuera surface. The peat has since expanded to form the large peat bogs characteristic of the area and which now abut against and greatly affect some of the lakes, such as Lake Maratoto.

3. FEATURES OF LAKE MARATOTO

Lake Maratoto (37°53'S 175°18'E) lies in pastureland to the south of Hamilton on the eastern border of the Rukuhia Peat Bog (Fig. 1). It has a surface area of 0.17 km^2 and a maximum depth of 8 m. Even though much of the peat surrounding it has been drained, the lake is dystrophic with characteristic dark brown acid water. Secchi transparency ranges from 0.3 to 1.0 m and pH from 4.5-6.5. Although small, Lake Maratoto is relatively deep and during the summer develops marked, fairly stable thermal stratification and resultant hypolimnetic oxygen depletion.

There is a rich plankton, but only sparse littoral vegetation (a few beds of sedges and rushes). The lake is bordered by a narrow band of manuka (*Leptospermum scoparium*) scrub and swamp vegetation, but in pre-European times was probably surrounded by larger trees as attested by the many stumps in the peat around the lake. The fauna is notable for the presence of species (the whirlygig beetle, *Gyrinus* sp. and the swamp mudfish, *Neochanna diversus*) which are very rare elsewhere in New Zealand.

4. METHODS

The core was taken in 4 m of water from the northern end of the lake (Fig. 2) using a hand operated piston corer from a small boat. The coring tube was 4 m of 60 mm I.D. PVC pipe which had been previously sawn in half longitudinally and which was held together with waterproof plastic tape. The tube was easily pushed manually into the sediment for the first 2.5 m, but thereafter a hammer had to be used to force it to the final depth of 3.3 m. A similar supplementary core was also obtained. The core was transported to the laboratory in the tube, then split longitudinally with fine wire and sampled immediately.

Both halves of the core were sampled at approximately 5 cm intervals beginning from immediately below the Taupo Pumice layer, although it was necessary to vary the interval occasionally in order to miss the volcanic ash layers. Samples were taken from a 1 cm section of the sediment either with a 1 ml tuberculin syringe in the sloppy and sticky sediment (down to about 150 cm), or in the more consolidated sediment by completely removing the 1 cm slice and sectioning it into 1 cc cubes with a razor blade. Care was taken not to include any of the smeared surface of the section. The subsamples were placed on tared aluminium or plastic boats and wet weights measured immediately where necessary. Dry weights were determined after drying to constant weight at 105°C.

Water content was determined on duplicate 1 ml samples after drying at 105°C, and one of these was then ashed at 550°C in a muffle furnace to determine loss on ignition.

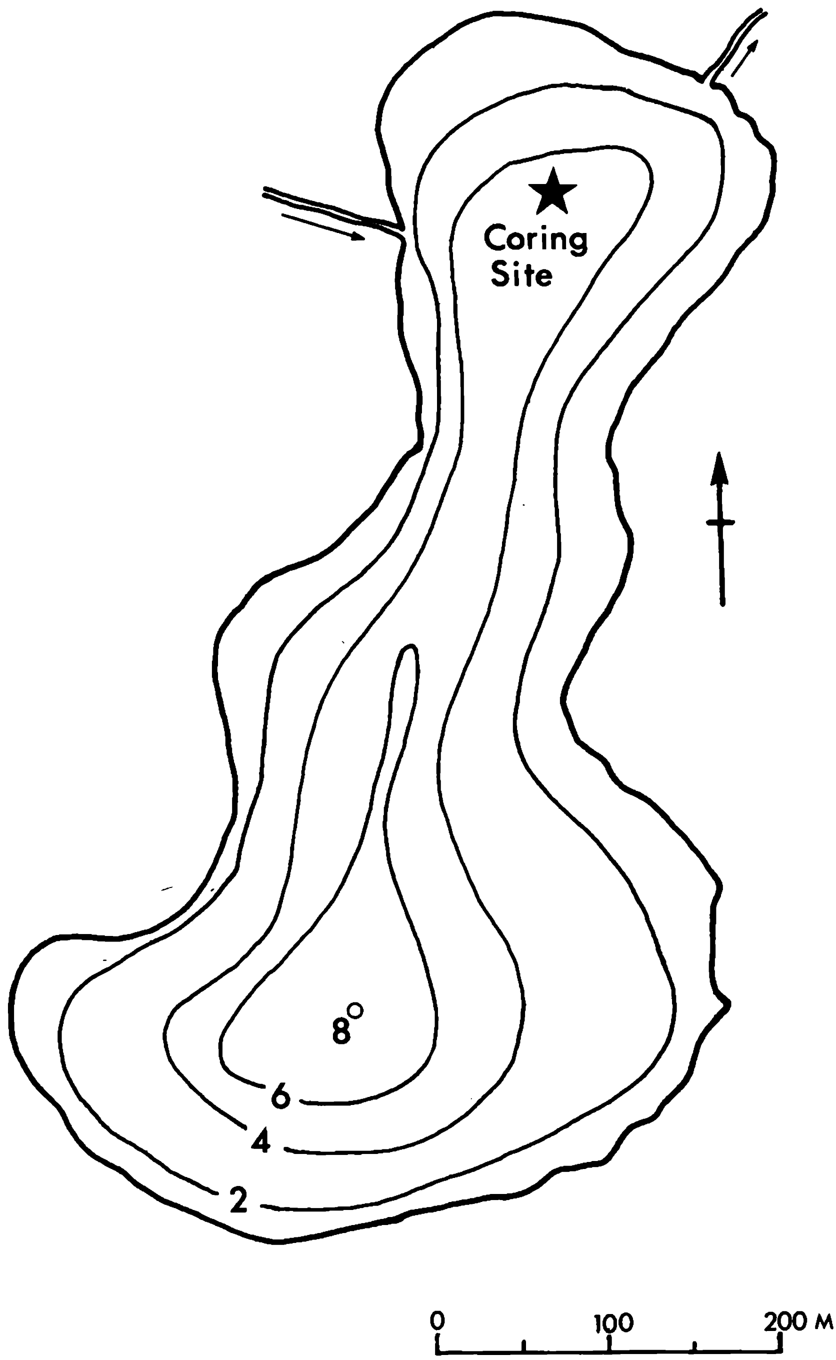

Fig. 2 - Bathymetric map of Lake Maratoto showing the coring site.

For determination of total Fe and Mn, weighed portions of dried sediment were digested in nitric acid and analysed by atomic absorption spectrometry.

Conductivity was determined on 1 ml of wet weighed sediment after mixing with 50 ml of milli-Q deionized water and allowing the sediment to settle. The conductivity of the supernatant was measured with a Triac conductivity cell and values corrected to 25°C and back calculated as µS per gram of interstitial water.

Sedimentary pigments were analysed using methods described by Sanger and Gorham (1972). 2 ml of sediment of known wet weight was mixed with 90% acetone and left to extract overnight in the dark at 4°C. The extract was filtered through a sintered glass filter, 10 ml removed for analysis of chlorophyll degradation products and the remaining 10 ml used for determination of carotenoids. The carotenoid sample was added to an equal volume of 20% (W/V) methanolic KOH and saponified on a shaker in the dark for 2 hours. The carotenoids were then extracted into 10 ml of petroleum ether in a separatory funnel, and epiphasic and hypophasic carotenoids further separted by partition against 90% methanol.

Pigments were measured with a Shimadzu spectrophotometer using a slit band of 1 nm at 667 nm for chlorophyll derivatives and 645 nm for carotenoids. Pigment concentrations have been expressed in the conventional manner as units per gram organic matter, one unit being equivalent to an absorbance of 1.0 in a 10 cm cell when dissolved in 10 ml of solvent.

5. CORE DESCRIPTION

The core suffered no apparent compression during sampling and consisted of approximately 2.5 m of dy-gyttya deposits, intercalated with at least twelve thin (2-40 mm) distinct volcanic ash layers, overlying a series of basal muds and clays (Fig. 3). The surface of the sediment was very sloppy, and because of this all measurements have been made from the uppermost ash layer (Taupo Pumice).

The ash layers are the most visually striking feature of the core, since they are exceptionally well preserved and clearly distinguished from the gyttya by their contrasting texture and lighter colour. Most are pumiceous and highly vitric, occasionally finely bedded, and texturally range from fine ash to very fine lapilli. Since they are unweathered and unmixed they are considered to be primary airfall tephra deposits. Lowe et al (1980) have identified most of the tephras from their mineralogy and relative stratigraphic position, and these identifications are shown in Fig. 3. Some of the tephras, particularly the ?Rotoma Ash contain many light brown fibres which appear to be charophyte rhizomes.

The gyttya deposits extend down to 244 cm below the Taupo Pumice, are fine grained and lack any large vegetation remains. The sediment is black to 150 cm, but below this gradually lightens in colour to very dark greyish-brown at 240 cm.

At 244 cm the gyttya grades abruptly into a layer of greenish-grey homogenous mud containing small carbonaceous fragments extending to 293 cm. This mud layer is interpreted to be fine overbank river deposits laid down when the lake was formed, and presumably deposited rapidly. The junction between the gyttya and the mud layer at 244 cm is thus thought to mark the origin of the lake.

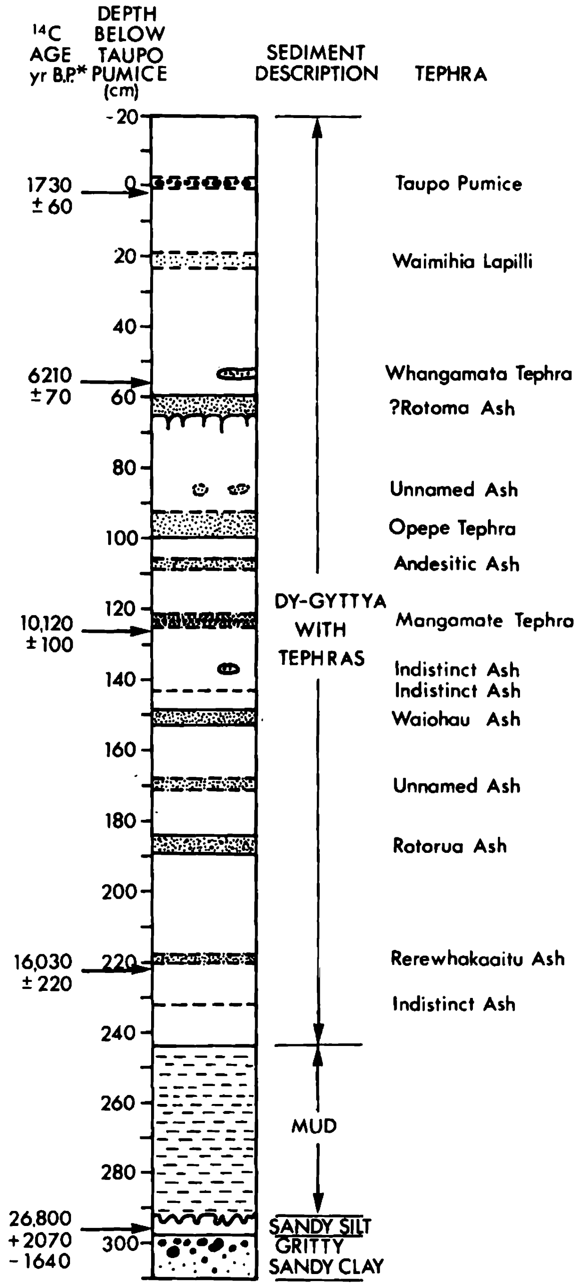

Fig. 3 - Stratigraphy of the core from Lake Maratoto. Tephra layers are stippled and ^{14}C dates shown.

An irregular but marked discontinuity occurs at 293 cm between the mud layer and a dark olive grey sandy silt, containing black organic zones, extending to 297 cm. This zone may be an old pond deposit or a swampy palaeosol. At 297 cm a junction occurs between this layer and the lowermost part of the core which comprises dark greyish brown gritty sandy clay, the upper area containing a number of fine to coarse pumiceous lapilli. The bottom of the core is at 311 cm below the Taupo Pumice.

6. CHRONOLOGY AND SEDIMENTATION RATES

^{14}Carbon dates, which have been determined from other cores from the lake, for four of the tephras (Lowe et al 1980) and the basal sandy silt layer are shown in Fig. 2. The tephra dates have been plotted against tephra-free sediment depth (Fig. 4) and the relationship used to interpolate ages of sediment between the dated sections of the core (and to extrapolate ages below the Rerewhakaaitu tephra), and also to calculate average sedimentation rates.

Sedimentation rates have been very low during the history of the lake, the mean figure between the Taupo (1,730 year BP) and Rerewhakaaitu (16,030 year BP) ashes being 0.127 $mm.yr^{-1}$. Sedimentation rates remained essentially constant between 16,000 years BP and 6,000 year BP and then decreased between 6,000 year BP and 1,700 year BP. The lower rates since 1,700 year BP may be underestimated since the position of the sediment surface could not be determined accurately.

The date (Wk 211) of 27,600 $\pm^{2,070}_{1,640}$ year BP has not been published previously and provides a maximum age for the existence of the lake, and possibly also of Hinuera-2 sedimentation in the area. The deposit was apparently laid down between the Hinuera-1 and Hinuera-2 phases of the Hinuera sedimentation which are usually

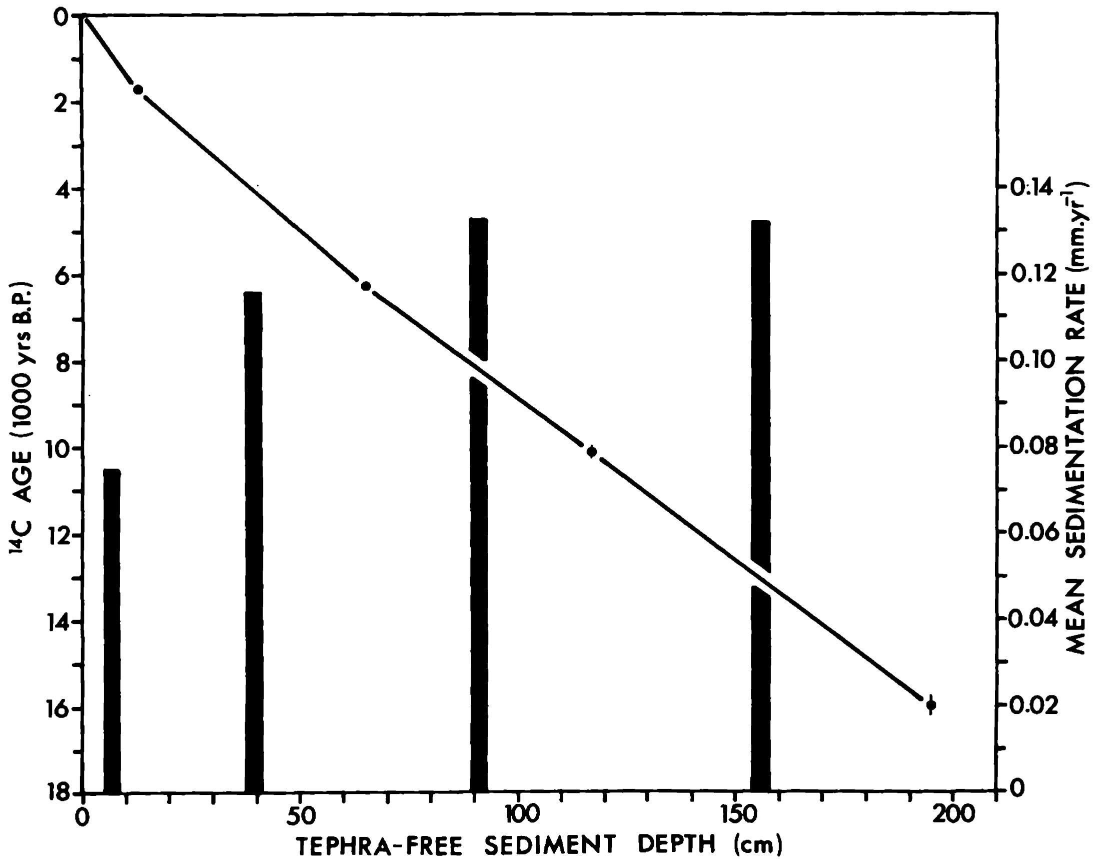

Fig. 4 - Age-depth curve for the Lake Maratoto core. Tephra-free sediment depth is calculated from the sediment surface. Average rates of deposition between dated points are shown by vertical bars.

ascribed time limits of 40,000 - 20,000 year BP and 20,000 - 12,000 year BP respectively (McGlone et al 1978).

7. RESULTS AND DISCUSSION

Interpretation of Data:

The data and derived ratios in Figs 5 and 6 can be used to infer past conditions in and around the lake, although such inferences must be regarded as tentative because of the complex interactions affecting each of the factors measured.

In enclosed lakes such as Lake Maratoto, Fe and Mn enter predominantly via the groundwater in a reduced state (Digerfeldt 1972). In oxidized lake waters of neutral pH they are immediately precipitated and immobilized in the lake sediment, although in acid waters much of the iron may remain in solution. An absolute increase in concentrations of Fe and Mn in lake sediments thus implies increased ground water supply to the lake, possibly due to increased precipitation and/or a higher ground water table, or increasingly reduced soil condition (e.g. due to changing vegetation cover). In the latter case, Mn would be mobilized first and increase in the lake sediments before Fe.

During hypolimnetic deoxygenation Mn is mobilized from the sediment before Fe and sediments later during reoxygenation, so is more likely to be lost via any outlet. The ratio Fe/Mn can thus provide information on the intensity of reducing conditions in the hypolimnion (Mackereth 1966). An increase in the ratio indicating greater deoxygenation results perhaps from effects such as increasing lake productivity, decreasing hypolimnetic volume or increasing length of stratification. In unstratified lakes and those with an oxidizing hypolimnion, Fe/Mn ratios will approach those of the surrounding soils and bedrock.

Levels of sedimentary chlorophyll degradation products (CD) and total carotenoids (TC) are a measure of primary productivity, oligotrophic lakes falling within the ranges 1-5 CD units.gm OM^{-1} and 1-10 TC units.gm OM^{-1}, and eutrophic lakes 10-16 CD units.gm OM^{-1} and 25-60 TC units.gm OM^{-1} (Sanger and Crowl 1979). Since carotenoids are more subject to diagenesis than chlorophyll under oxidizing conditions (as in soil humus layers or oxidized hypolimnetic waters) the ratio CD/TC can indicate the trophic status of a lake and/or the relative proportions of allochthonous and autochthonous material entering the sediments. A high CD/TC ratio indicates either greater allochthonous input or greater oxidation of pigments in the hypolimnion or at the sediment surface. Eutrophic lakes usually have lower ratios than oligotrophic lakes because of relatively lower allochthonous input, more intense reducing conditions in the hypolimnion and greater sedimentation (and thus burial) rates. The ratio epiphasic carotenoids (EC)/hypophasic carotenoids (HC) gives similar information although generally more difficult to interpret (Gorham and Sanger 1976). Since terrestrial plants generally have a lower EC/HC ratio than aquatic plants (Gorham and Sanger 1975) a decrease in the ratio may indicate greater terrestrial input.

% loss on ignition is taken to be equivalent to % organic matter of the sediment, while conductivity of the interstitial water probably measures mainly Na^{+} and Cl^{-}, the two dominant ions of New Zealand lake waters (Green 1975).

Seven phases in the history of the lake have been tentatively identified:

Phase 1 (18,000-15,000 year BP):

Fe and Mn, and conductivity of the interstitial water gradually increase to high levels, perhaps indicating the development of reducing soils, a higher water table and possibly relatively high lake levels. Organic content of the sediment, CD and TC show an early increase, which may be due to an initial flush of macrophytes and allochthonous input (fragments of aquatic macrophyte leaves are present in the upper mud layer between 260 and 240 cm and CD/TC is relatively high). Following a decline these factors, and thus production rates, increased during the remainder of the phase. The values of sedimentary pigments and the CD/TC ratio indicate that the lake was oligotrophic (cf Sanger and Crowl 1979), and EC/HC suggests progressively greater organic matter contributions from aquatic sources. Since Fe/Mn is high the lake was thermally stratified and the hypolimnion deoxygenated.

This is interpreted to be a phase of increasing nutrient supply from the watershed and increasing productivity. Lake levels were probably relatively high and autochthonous sources of organic matter predominant.

Phase 2 (15,000-12,000 year BP):

Levels of Fe and Mn abruptly decline at 15,000 year BP and continue at low levels throughout this phase, suggesting low lake levels. Production (CD and TC) is generally relatively high apart from a short period of lower productivity at 13,000 year BP, when EC/HC is also low suggesting terrestrial input. Fe/Mn shows that conditions were more oxidizing than in phase 1, and thus may explain the generally higher CD/TC ratios and lower sedimentary organic matter content. Since production rates were relatively high, these effects may have been due to less persistent stratification than in phase 1.

This phase is interpreted to be drier than phase 1 resulting in shallower lake depths and less stable stratification. Productivity was relatively high but allochthonous sources of organic matter may have become more important as the lake became shallower and relatively swampy conditions could have prevailed for a short period about 13,000 year BP. Conditions improved slightly towards the end of the phase and the hypolimnion became gradually more reducing.

Phase 3 (12,000 - ca 10,300 year BP):

During this phase productivity declined to low levels although the high values of EC/HC indicate that there was still a considerable proportion of autochthonous input. The pronounced peaks of Fe and Mn indicate a marked increase and then decline in water levels. Hypolimnetic waters were reducing in the early period (Fe/Mn), becoming oxidizing later, perhaps as a result of the effects of shallowing depths combined with low productivity. The build up of sedimentary organic matter is presumably due to allochthonous input, which is also suggested by the increase in CD/TC.

It is suggested that the climate became much wetter during this phase, grading into drier conditions towards the end. The pronounced decline of productivity may have been due to wetter weather with perhaps lower temperatures, although one can speculate that at this time the lake may have been surrounded by large trees causing increases in allochthonous organic matter inputs, stabilizing stratification and reducing productivity by shading and nutrient entrappment.

Phase 4 (10,000-5,000 year BP):

This phase is characterised by a marked increase in the level of sedimentary organic matter, and the very pronounced increases in CD/TC suggest that this is mainly due to a greater input of allochthonous organic material. CD concentrations indicate that productivity also shows an increase, but this does not seem great enough to explain the higher sedimentary organic matter concentrations. The hypolimnion becomes progressively more oxidizing and this must indicate more transient stratification and possibly decreasing lake depth, since the supply of organic matter to the bottom waters had clearly not decreased. Fe and Mn levels show a gradual decline indicating a decrease in the input of groundwater.

These smooth trends were broken by sharp increases in Fe (but not Mn) Fe/Mn, CD and CD/TC between 80 and 90 cm (ca 8,000 year BP). These changes immediately followed the deposition of the Opepe tephra, and it may be that this ash shower resulted in destruction and perhaps burning of surrounding vegetation, resulting in a large input of allochthonous organic material to the lake, in quantities sufficient to markedly increase the degree of hypolimnetic deoxygenation. The peak of Fe presumably also originates from decaying vegetation, rather than higher groundwater inflows, since Mn did not show a similar increase.

It is thought that during Phase 4 Lake Maratoto became progressively dystrophic and possibly shallower as a result of the development of peat around the lake margins and growth of the neighbouring Rukuhia Peat Bog. Greater inflows of nutrient poor acidic bog water may account for the decreasing levels of Fe and Mn. Lower pHs would also inhibit bacterial action at the sediment surface and may partly account for the build up of organic matter.

If this interpretation is correct this period must have been relatively moist to enable peat development to occur.

Phases 5 (5,000-3,700 year BP), 6 (3,700-1,800 year BP) and 7 (1,800-0 year BP):

These phases are defined mainly on the basis of changes in sedimentary pigments. During phase 5 there was a marked decrease in allochthonous organic input (CD/TC) and an increase in the autochthonous component (EC/HC). This may indicate a recession in peat development and suggests that this phase was drier, and perhaps cooler since productivity (CD) declined. In phase 6 these trends were reversed, implying a return of warmer and wetter conditions, which continued into phase 7. Phases 6 and 7 are thus very similar and separated only on the basis of declines in the pigment curves at 1,800 year BP, presumably resulting from the deposition of the Taupo Pumice.

Summary: Lake Maratoto has been relatively unproductive throughout its history, although there have been considerable variations. It has probably always been thermally stratified, however variations in depth have occurred affecting the extent of hypolimnetic deoxygenation and the balance between autochthonous and allochthonous sources of organic matter. The lake has apparently been more or less dystrophic for the last 10,000 years.

Comparison with other data:

The various phases in the history of Lake Maratoto are compared in Fig. 7 with the North Island pollen zones identified from peat bogs near Hamilton and on the Hauraki Plains to the north east

(Harris 1963, McGlone et al 1978) and from the Mount Tongariro region in the centre of the North Island (McGlone and Topping 1977). Palaeotemperatures for Waitomo 40 km south of Hamilton determined from $^{18}O/^{16}O$ analysis of speleothems (Hendy and Wilson 1968) are also shown.

The palaeolimnological history of Lake Maratoto generally supports what is known from these studies about New Zealand's post-glacial (Aranuian) climate. There is considerable resemblance between the zones identified in the various studies, in particular between those from Maratoto and Tongariro. Phase 3 in Lake Maratoto was not identified specifically from Tongariro, but corresponds with Harris' zone 2 and coincides with a recognised cold phase in the Southern Hemisphere (Burrows 1979).

In the Hamilton peat Harris identified a burnt zone at 5.25 - 5.5 m depth, halfway through zone 3, showing that the vegetation had been affected by a fire. This seems to have occurred about 8,000 - 9,000 year BP and may correspond with the disturbances in Lake Maratoto, following the deposition of the Opepe tephra c.8,700 year BP, which also seemed to indicate destruction of vegetation.

Evidence for the influence of peat on Lake Maratoto is not obvious until after 10,000 year BP and thus corresponds with what is known of the ages of peat bogs in the Waikato region. Radiocarbon ages from the bases of the Rukuhia and nearby Moanatuatua peat bogs are 11,100 ± 100 year BP and 12,170 ± 120 year BP respectively (McGlone et al 1978). Throughout the North Island in general peat accumulation did not begin until about 10,000 year BP (McGlone and Topping 1979) when the climate was warmer and wetter than at present.

8. ACKNOWLEDGEMENTS

I particularly wish to thank M. Brockelsby for invaluable

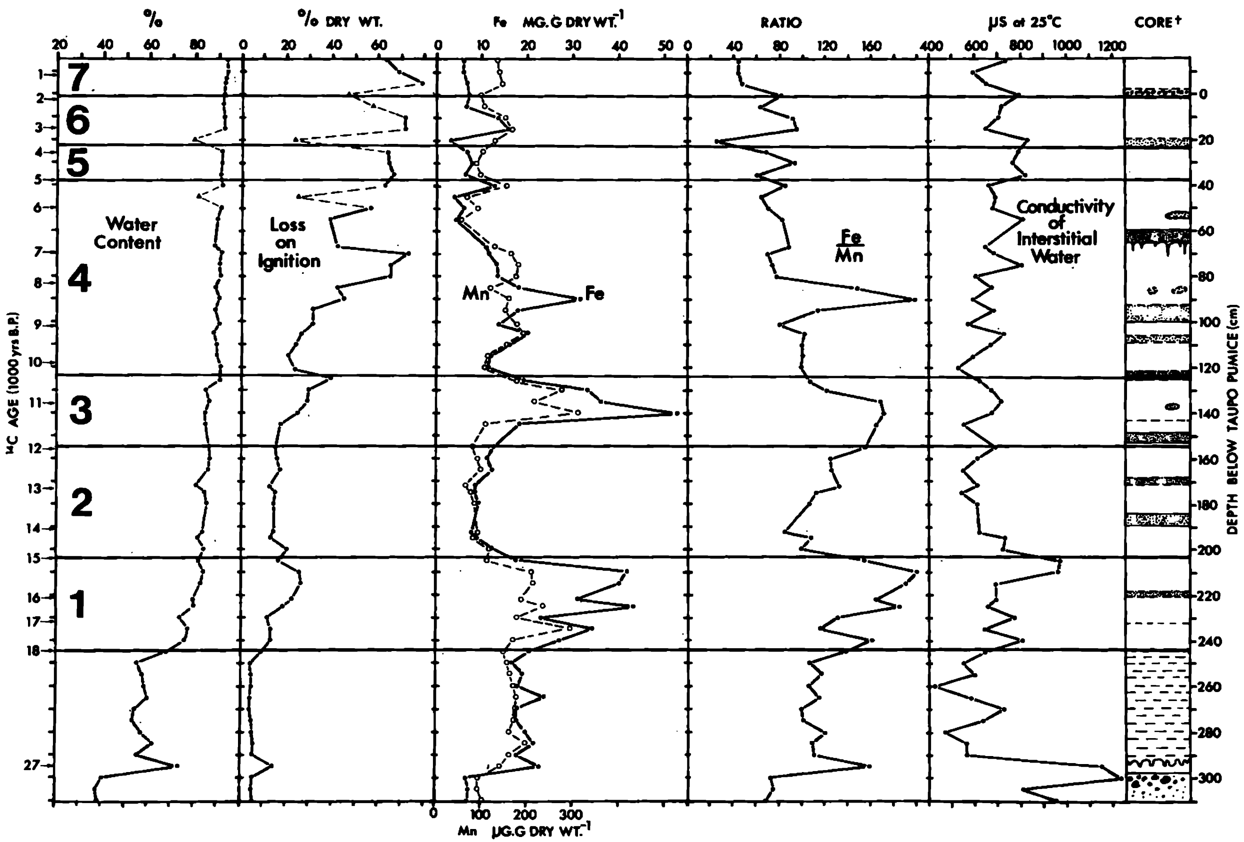

Fig. 5 - Profile of some chemical features of the Lake Maratoto core. ^{14}C dates are interpolated from the curve in Fig. 4. The various phases identified in the history of the lake are indicated by large numerals (1-7). †Core zones are as in Fig. 3.

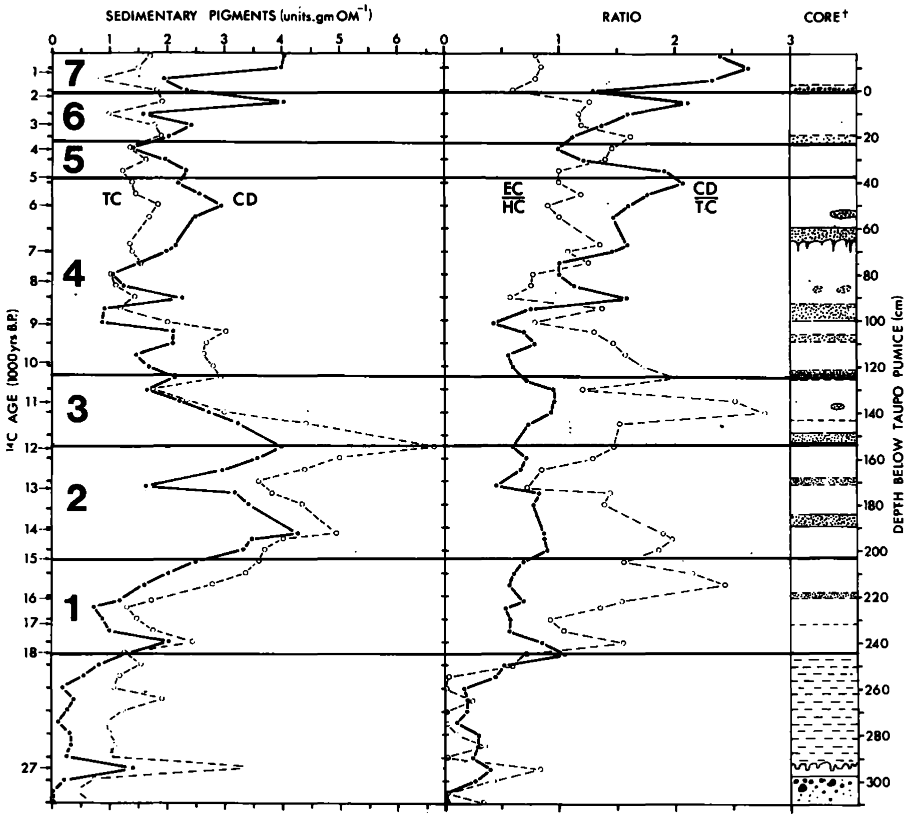

Fig. 6 - Profile of sedimentary pigment concentrations and pigment ratios in the Lake Maratoto core. The various phases identified in the history of the lake are indicated by large numerals (1-7). †Core zones are as in Fig. 3. (CD = chlorophyll derivatives, TC = total carotenoids, EC = epiphasic carotenoids, HC = hypophasic carotenoids).

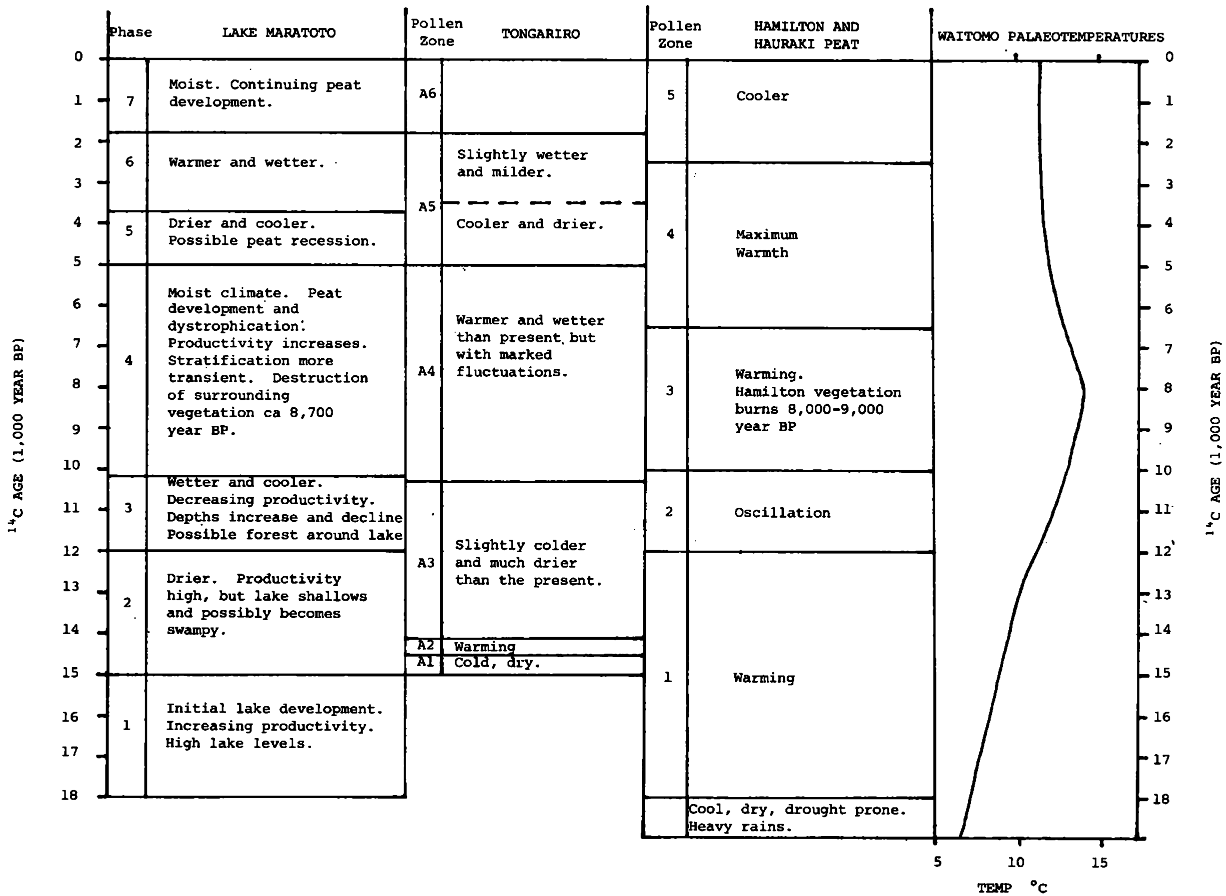

Fig. 7 - A comparison of phases in the history of Lake Maratoto with postglacial pollen zones from some sites in the North Island, New Zealand. Speleothem palaeotemperatures from the Waitomo Caves are also shown. (Tongariro zones from McGlone and Topping 1977; Hamilton and Hauraki zones since 18,000 year BP from Harris 1963; Hamilton weather 20,000 - 18,000 year BP from McGlone et al 1978; speleothem palaeotemperatures from Hendy and Wilson 1968).

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REFERENCES

BURROWS, C. J. 1979 : A chronology for cool-climate episodes in the southern hemisphere 12,000-1,000 year BP. *Palaeogeography, Palaeoclimatology, Palaeoecology 27* : 287-347.

DIGERFELDT, G. 1972 : The postglacial development of Lake Trummen. Regional vegetation history, water level changes and palaeolimnology. *Folia Limnologica Scandanavica 16* : 1-104.

GORHAM, E. and SANGER, J. E. 1975 : Fossil pigments in Minnesota lake sediments and their bearing upon the balance between terrestrial and aquatic inputs to sedimentary organic matter. *Verhandlungen Internationale vereinigung für Limnologie 19* : 2267-2273.

GORHAM, E. and SANGER J. E. 1976 : Fossil pigments as stratigraphic indicators of cultural eutrophication in Shagawa Lake, northeastern Minnesota. *Geological Society of America Bulletin 87* : 1638-1642.

GREEN, J. D. 1975 : Physicochemical features of Lake Ototoa, a sand-dune lake in northern New Zealand. *New Zealand Journal of Marine and Freshwater Research 9* : 199-222.

HARRIS, W. F. 1963 : Paleo-ecological evidence from pollen and spores. *Proceedings of the New Zealand Ecological Society 10* : 38-44.

HENDY, C. H. and WILSON, A. T. 1968 : Palaeoclimatic data from speleothems. *Nature 219* : 48-51.

HUME, T. M., SHERWOOD, A. M. and NELSON, C. S. 1975 : Alluvial sedimentology of the Upper Pleistocene Hinuera Formation, Hamilton Basin, New Zealand. *Journal of the Royal Society of New Zealand 5* : 421-462.

LOWE, D. J., HOGG, A. G., GREEN, J. D. and BOUBEE, J.A.T. 1980 : Stratigraphy and chronology of Late Quaternary tephras in Lake Maratoto, Hamilton, New Zealand. *New Zealand Journal of Geology and Geophysics* (in press).

MACKERETH, F.J.H. 1966 : Some chemical observations on post-glacial lake sediments. *Philosophical Transactions of the Royal Society (London) B 250* : 165-213.

McCRAW, J. D. 1967 : The surface features and soil pattern of the Hamilton Basin. *Earth Sciences Journal 1* : 59-74.

McGLONE, M. S., NELSON, C. S. and HUME, T. M. 1978 : Palynology, age and environmental significance of some peat beds in the Upper Pleistocene Hinuera Formation, South Auckland, New Zealand. *Journal of the Royal Society of New Zealand 8* : 385-393.

McGLONE, M. S. and TOPPING, W. W. 1977 : Aranuian (post-glacial) pollen diagrams from the Tongariro region, North Island, New Zealand. *New Zealand Journal of Botany 15* : 749-760.

SANGER, J. E. and GORHAM, E. 1972 : Stratigraphy of fossil pigments as a guide to the postglacial history of Kirchner Marsh, Minnesota. *Limnology and Oceanography 17* : 840-854.

SANGER, J, E, and CROWL, G. H. 1979 : Fossil pigments as a guide to the Paleolimnology of Brown Lake, Ohio. *Quaternary Research 11* : 342-352.