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PALAEOLIMNOLOGY IN NEW ZEALAND

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What is Palaeolimnology?

The study of lakes has attracted many scientists over the years and those who specialise in attempting to understand the complex workings of the entire lake ecosystem are now known as limnologists (Wetzel 1983). Most of them deal specifically with what is happening in lakes today, but in recent years some have begun to appreciate that the present character of the lakes they study is the result of a long history. It is now realised that to fully understand the functioning of lakes and how to manage them for the future we have to understand their past.

This study of the history of lake ecosystems is known as palaeolimnology and is based on analysis of the sediments which accumulate over time on lake bottoms (Binford *et al.* 1983; Brugam 1984). These sediments are derived both from within the lake and from its catchment. From the lake come various inorganic chemical compounds such as nitrogen and phosphorus, the end products of decomposition processes such as organic compounds (e.g., lipids, pigments), and bits and pieces of plants and animals which remain in the bottom muds as microfossils (e.g., algae such as diatoms, various small crustaceans such as chydorids, and insects such as chironomids) (Fig. 1a—c). From the surrounding catchment come various inorganic minerals eroded from rock and soil materials (deposited as sand, silt, or clay particles), chemicals leached from the soil, and organic matter from both soil and vegetation (e.g., humus, leaf remains, pollen) (Fig. 1d). The sediments accumulate gradually and lock away information on the catchment and the lake. The task of the palaeolimnologist is to read this record — to open the door to the past. However, to 'open the door' is not an easy task, nor is the view through it when opened always clear. In the words of essayist Loren Eiseley,

> "The door to the past is a strange door. It swings open and things pass through it, but they pass in one direction only. No man can return across that threshold, though he can look down still and see the green light waver in the water weeds." (Eiseley 1958, p. 54)

How is palaeolimnology done? Cores through the lake sediments are taken by a variety of methods. Most commonly used is a piston corer which consists of a tube with a movable, tight-fitting plug inside attached by a line to a coring platform or boat at the lake surface. The tube is pushed or rammed into the lake sediment and the suction effect provided by the piston ensures that the sediment enters the tube without being deformed or compressed. However, this method is no good for the most recently deposited sediments which are often rather sloppy and are disturbed by the coring. For these, palaeolimnologists have begun to use a new technique, freeze coring, in which a tube containing dry ice or liquid nitrogen is carefully lowered to the bottom until it just penetrates the sediments. The sediments freeze onto the outside of the tube and can then be hauled to the surface intact. This method enables very precise studies of changes in recent lake history, sometimes on a yearly or even monthly time scale.

Once the sediment core has been obtained, the sediments are analysed by a variety of analytical methods, and usually a team of specialists is involved — geoscientists, physicists, chemists, biochemists,

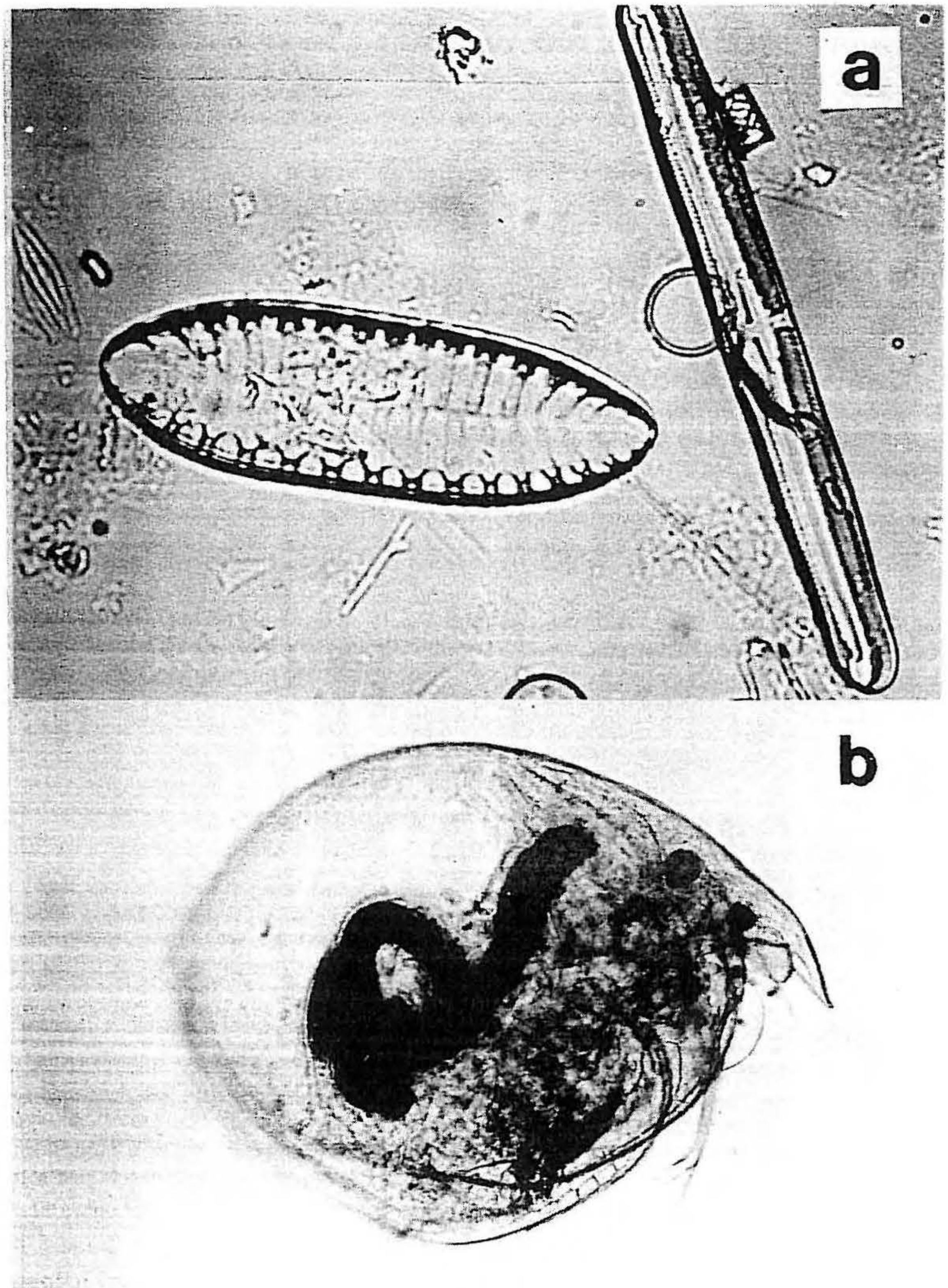
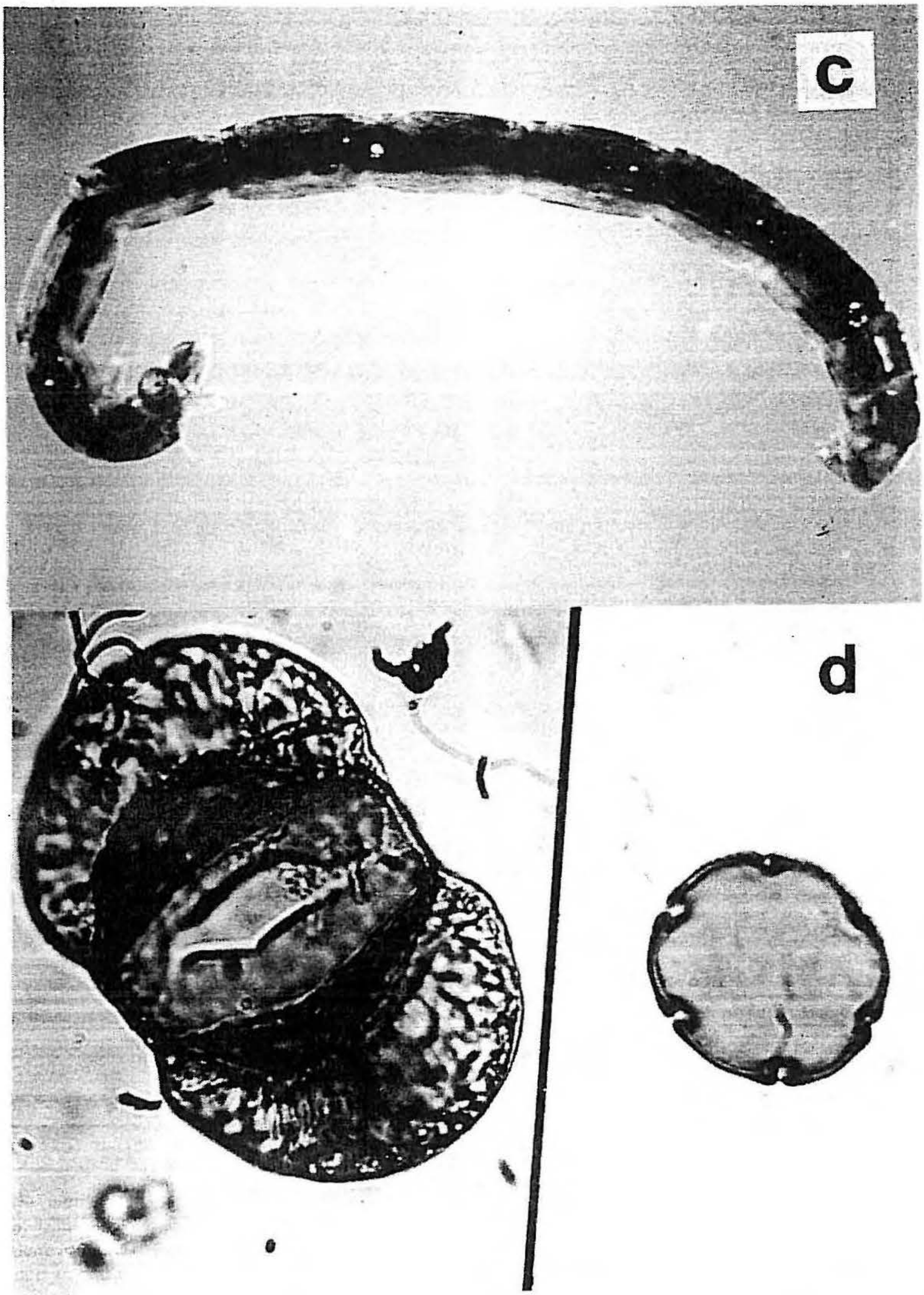


Fig. 1. Photomicrographs of plants and animals that become lake sediment microfossils. (a) Diatom frustule: diatoms are a group of algae which are abundant in lakes, and the frustule is a siliceous outer casing which remains after death. (b) A chydorid cladoceran, a microcrustacean that lives amongst weeds and on sediment surfaces in lakes. The exoskeletons of these animals remain as microfossils. (c) A chironomid larva: chironomid



larvae are the immature stages of midges and are abundant amongst plants and bottom sediments; their head capsules (right end) become microfossils. (d) Matai (*Prumnopitys taxifolia*) (left) and red beech (*Nothofagus fusca*) (right) pollen grains: such pollen often characterises late glacial transition during which patches of Nothofagus forest are replaced by full Podocarp forest. (Photos a—b, J. D. Green; c, J. A. T. Boubée; d, R. M. Newnham.)

palynologists, algologists, and various sorts of zoologists. Palaeolimnology is a perfect example of a modern multidisciplinary science (Frey 1974). Out of this collaboration can come findings that extend beyond the boundaries of the lake and its catchment. Many of the long term changes in lakes are caused by climatic variations, and so palaeolimnological studies play a large part in documenting and understanding past climates.

Obviously, for palaeolimnological studies to be of most use it is necessary to determine the age of the sediments throughout the core. There are various ways of doing this. Radiocarbon dating is widely used and covers the past 50 000 years or so. Lead-210 dating is useful for dating more recent sediments deposited in the past 100—200 years, and caesium-137, originating from atmospheric testing of atomic bombs, has been used on sediments deposited over the past few decades. A technique that has been particularly valuable in New Zealand (and other volcanic countries) is tephrochronology, the use of volcanic ash (tephra) layers as a dating tool. The eruptions from volcanoes of the North Island have resulted in the widespread deposition of many such tephra layers in lakes in New Zealand. In some lakes, there have been up to forty over the last 18000 years (Fig. 2; Lowe 1988). These provide a very detailed chronological framework for tying together lake and catchment histories in New Zealand, unsurpassed anywhere.

In the Northern Hemisphere, palaeolimnological studies have been undertaken over much of this century, particularly since the 1950s. A great deal of information has been obtained and it is now possible to identify general patterns of development of lakes in many regions. In addition, the effects of human impacts on lakes have been very well documented. These include the impacts of Roman road construction on Italian lakes, the effects of palaeolithic forest clearing and farming activities on lakes in England, the enrichment (eutrophication) of many lakes in Europe and North America as a result of increased nutrient input from urban, rural, and industrial discharge, and the effects of acid rain.

Palaeolimnological Studies in New Zealand

Palaeolimnological studies in New Zealand are still in their infancy (Lowe & Green 1987) but quite a lot of progress is now being made, with small research teams active in both North and South Islands.

The earliest palaeolimnological study in New Zealand was carried out in 1955 by the American E. Deevey on lake sediments in the Pyramid Valley in Canterbury (Fig. 3). He studied animal microfossils, chiefly the chironomids (Deevey 1955). Much more recently, this work has been extended by a team, led by Dr Vida Stout of the University of Canterbury, Christchurch, which is investigating the biological history of some small lakes including Lakes Taylor and Grasmere (Schakau 1986). Barbara Schakau has described in some detail the history of the chironomid community in Lake Grasmere for the past 6000 years and showed how it varied as catchment conditions and lake productivity changed (Schakau 1990). These, and most other New Zealand palaeolimnological studies, have relied on the expertise of a small group of palynologists (who study fossil pollen), most of whom are based in the South Island. These include Drs Matt McGlone (Landcare Research, Lincoln) and Rewi Newnham (University of Otago, Dunedin). Pollen analysis provides essential information on past vegetation around a lake and in the surrounding region and is important for climate reconstruction.

Dr Dick Pickrill and Jack Irwin of the New Zealand Oceanographic Institute, National Institute of Water and Atmospheric Research (NIWAR), Wellington, have undertaken many studies of the patterns, mechanisms, and rates of sedimentation in many of the larger glacial lakes such as Wakatipu, Tekapo, Ohau, and Te Anau (Fig. 3). These and other studies have shown that these lakes are giant sediment traps for material eroded from the Southern Alps (e.g., Pickrill & Irwin 1983). As yet, however, there is little information on the chemical and biological history of these lakes, which are difficult to core primarily because of their great depths and thick sediments.

In the North Island a major focus of palaeolimnological interest has been Lake Poukawa, a small peaty lake in Hawke's Bay near Napier (Fig. 3). Dr Margaret Harper (New Zealand's leading specialist in palaeodiatoms) and her colleagues from Victoria University of Wellington have studied the Holocene history of this lake. Their detailed study found that deforestation caused by Polynesian and European settlement had marked affects on the algal communities of the lake (Harper *et al.* 1986). As well, they were able to demonstrate that the abundance of various diatoms increased following the deposition of tephra layers in the lake (because of their fertilizing effect). Another important site in Hawke's Bay is Lake Tutira, a small landslide lake in farmland which has undergone severe eutrophication and rapid sediment infilling. Drs Noel Trustrum and Mike Page (Landcare Research, Palmerston North) and others have

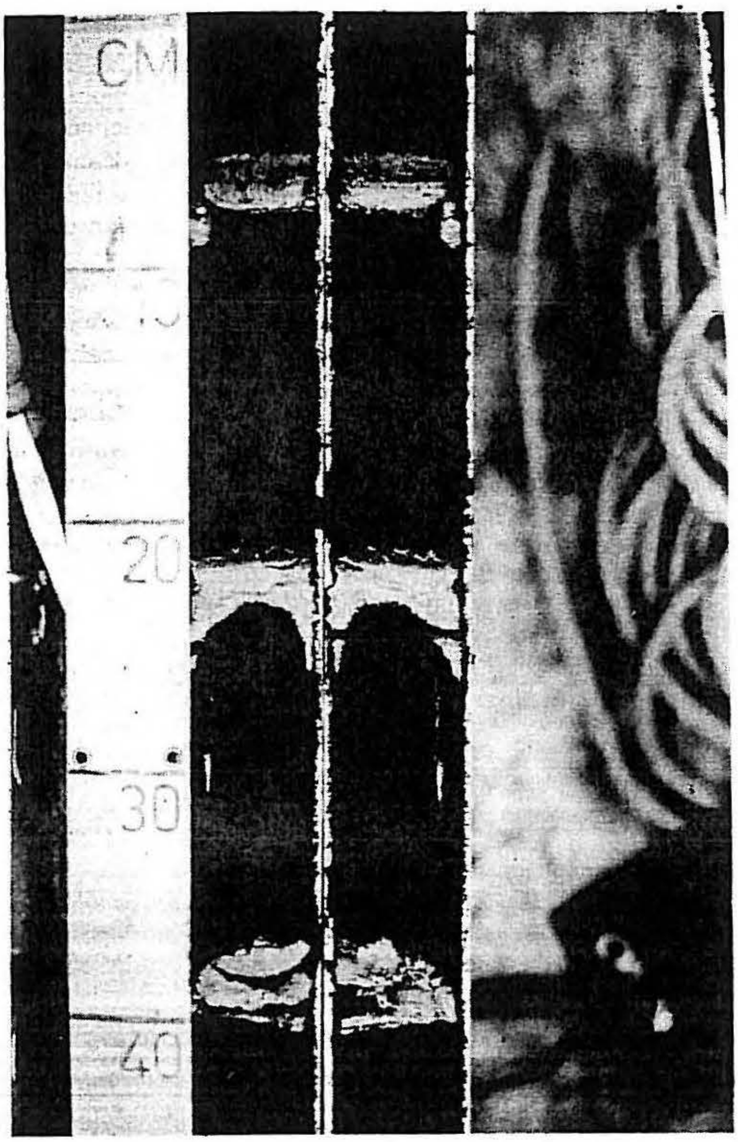


Fig. 2. Part of a sediment core from Lake Rotongata in the south Waikato region. The pale tephra layers stand out against the darker organic lake sediments. The tephras and their ages (in radiocarbon years ago) are, from the top, Tuhua (6130), Mamaku (7250), Rotoma (8530), and Opepe (9050). (Photo: D. J. Lowe.)

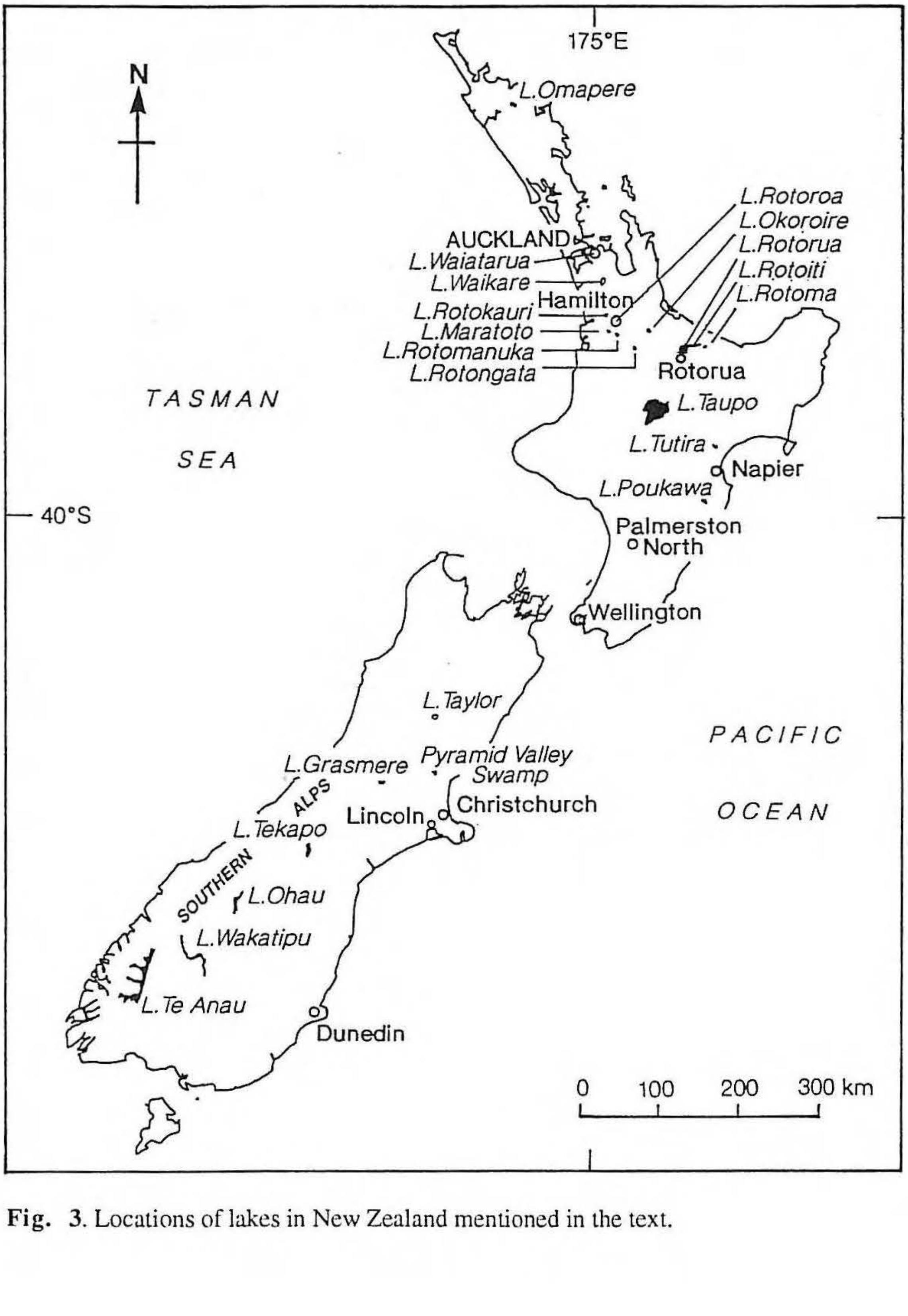


Fig. 3. Locations of lakes in New Zealand mentioned in the text.

been studying the history and rates of change of these processes. One aim of the project is to model rates and processes of catchment erosion in eastern North Island to help land use management planning (Trustrum & Page 1992), and freeze coring has been carried out to obtain detailed information on variations in erosional rates in the catchment over the past 100 years or so (Ryan 1992).

The lakes in the central volcanic region have also attracted some palaeolimnological attention. In Lake Taupo, Professor Cam Nelson, of the University of Waikato, Hamilton, and others, have made some progress in understanding the patterns of sedimentation in the lake. There has been relatively little biological work as yet, but diatom variability in relation to nutrient levels has been studied in short cores by Dr D. Rawlence and co-workers (Rawlence & Reay 1976; Rawlence 1986). In the Rotorua area (Fig. 3), there have been detailed studies on Lakes Rotoiti and Rotoma lead by Cam Nelson and Dick Pickrill (Nelson 1983; Pickrill *et al.* 1992). These have looked at variations in sedimentation patterns and composition over time, and also some environmental changes of the last 1000 years or so, especially the effects of tephra falls. In Lake Rotorua, D. Rawlence has studied diatoms and pigment stratigraphy for the period since the AD 1886 Tarawera eruption (Rawlence 1984), and, for the same period, Dr Geoff Fish investigated sediment nutrient levels in an attempt to determine if these showed any changes in association with eutrophication of the lake (Fish 1979). A detailed history of lake level changes in Lake Rotorua over the past 140 000 years has been worked out by Neil Kennedy and associates using evidence provided by ancient shorelines dated by tephrachronology (Kennedy *et al.* 1978). Matt McGlone has added to this story by pollen analysis of lake sediments deposited over the past 10 000 years (McGlone 1983).

In the Waikato region, Dr John Clayton and others of the Aquatic Plants section, NIWAR, Hamilton, have recently begun analysing the distribution of a range of heavy metals in surficial sediments and short cores from Lake Rotoroa (Hamilton Lake). The aim is to assess the persistence and fate of arsenic used in the past for controlling aquatic macrophytes, and the effect of stormwater inflows into the lake.

At the University of Waikato, palaeolimnological studies have developed rapidly in the past ten years or so, favoured by the multidisciplinary approach fostered by its School of Science and Technology. These developments have been facilitated by the University's Radiocarbon Dating Laboratory, directed by Dr Alan Hogg, and an active Geochronology Research Unit directed by Cam Nelson. Studies by the Waikato group, to which the writers belong, have initially focussed on a number of the small peaty riverine lakes in the Waikato region that have turned out to be palaeolimnological gold mines. This is because many of them are as old as 18 000 years or so, a period spanning the major climatic changes between the end of the last glaciation and the warmer climates of the last 10 000 years, and because the sediments contain many tephra layers (Fig. 2) that enable changes from lake to lake to be matched in time (Lowe 1988). Dozens of cores have been taken from 14 lakes, and a very detailed study of the origins and development of one of them, Lake Maratoto (Fig. 4), has been made (Green 1979; Green & Lowe 1985). This study made use of ground radar techniques for the first time in New Zealand (Lowe 1985). Studies of pollen records by Rewi Newnham and Matt McGlone from some of the lakes, including Rotokauri, Rotomanuka, and Okoroire (Fig. 3), have enabled changes in the vegetation and climate across the region to be reconstructed (Newnham *et al.* 1989). These, together with various chemical and microfossil studies by Drs Jacques Boubée, Bruce McCabe, Chris Hendy, Margaret Harper, and the writers, have allowed a synthesis of both catchment and lake level changes in relationship to climate change. A summary of a palaeoenvironmental reconstruction from work on Lake Maratoto is shown in Fig. 5.

In addition to these studies dealing with relatively long time spans, it is planned to use freeze coring techniques to make detailed studies of the impact that Polynesian and European colonisation has had on lake ecosystems in the northern North Island. Previous results indicate that Polynesian settlers had a dramatic effect on the vegetation in the Waikato region from about 800 years ago (Newnham *et al.* 1989). Other lines of enquiry include the study of palaeomagnetism by Dr Gillian Turner of Victoria University of Wellington which enable positions in the magnetic pole and the strength and direction of the Earth's magnetic field over time to be determined.

The Waikato team is also involved in studies of lakes in Auckland, Northland, Antarctica, and British Columbia, Canada. In Lake Waiatarua (Lake St. Johns) in Auckland, studies of pollen and tephrachronology have elucidated the history of volcanism and vegetation changes in the area for the past 10 000 years (Newnham & Lowe 1991). A project involving international cooperation between New Zealand and Japan is underway at Lake Omapere near Kaikohe, Northland (Fig. 3), and is providing tantalising glimpses of past environments

Fig. 4. A view of Lake Maratoto near Hamilton. This lake was formed about 17 000 years ago and has been the subject of detailed palaeolimnological investigations. (Photo: D. J. Lowe.)

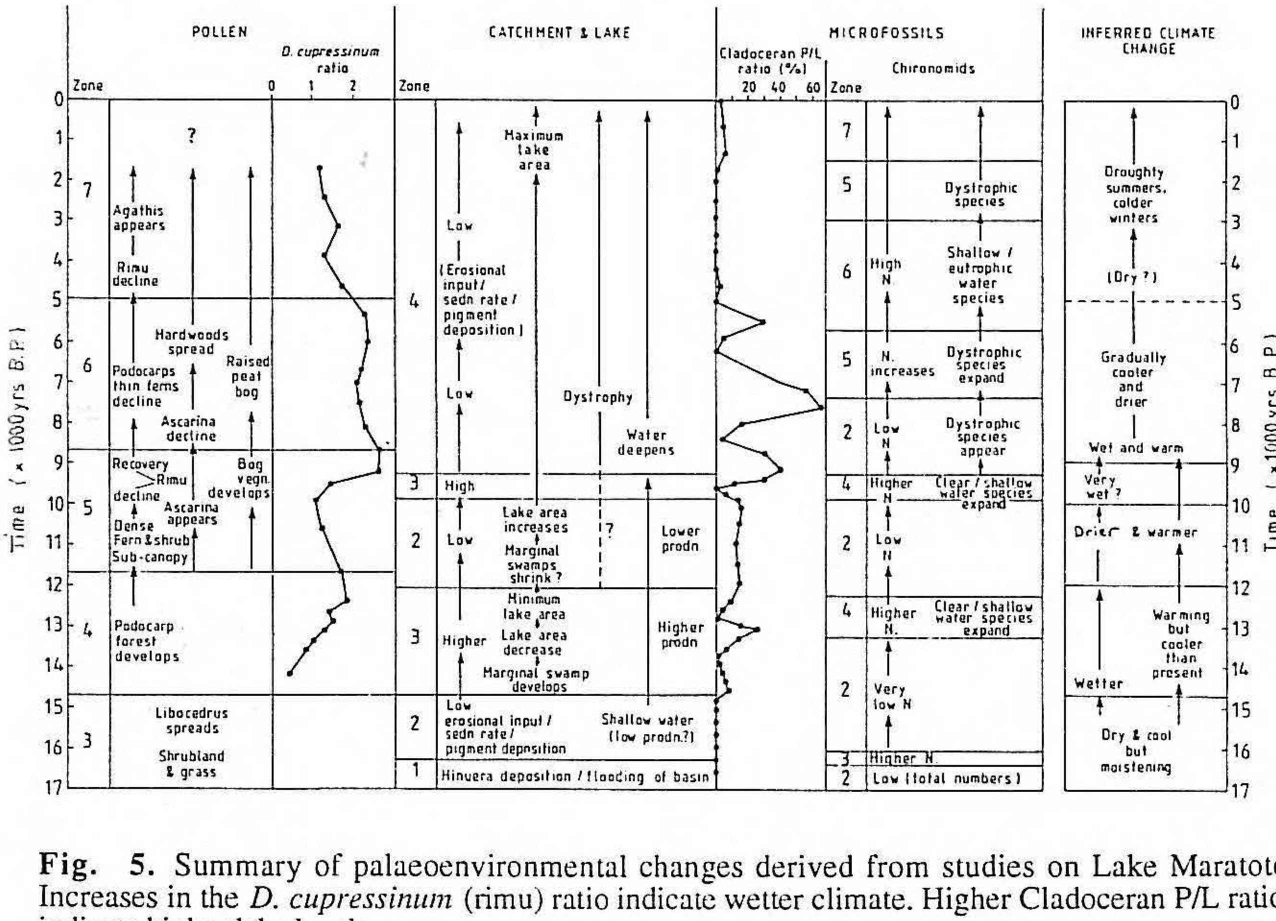


Fig. 5. Summary of palaeoenvironmental changes derived from studies on Lake Maratoto. Increases in the *D. cupressinum* (rimu) ratio indicate wetter climate. Higher Cladoceran P/L ratios indicate higher lake levels.

in the area extending back to perhaps 100 000 years. The lake has appeared and disappeared a number of times during this period and has probably always been rather shallow and weedy as it is today. Similar collaborative work is also underway on a core from Lake Waikare in the Waikato region.

Chris Hendy and others of the University's Antarctic Research Unit have been involved in palaeolimnological studies of permanently ice-covered lakes in the Ross Dependency of Antarctica for many years. This work is partly directed towards the history of Antarctic glaciations and has utilised pioneering work on the technique of uranium-thorium dating.

Another international effort is between the University of Waikato and a team at the University of British Columbia, Vancouver, led by Professor Tom Northcote and Dr Ken Hall. The project concerns the past history of an unusual saline lake, Mahoney Lake, in the dry interior of southern British Columbia. Early indications are that this lake has the potential to provide the most detailed record of palaeoenvironmental change known for the area (Lowe *et al.* in press).

Conclusion

Palaeolimnology is an exciting and rapidly growing discipline and studies on New Zealand lakes have the potential to make a real contribution to its development. An increasing number of scientists have been attracted to the field in the last ten years and this growth is evidenced by the recent appearance of a specialist journal, the *Journal of Paleolimnology*, for the publication of results of palaeolimnological studies. As well, there are now regular specialist international conferences for palaeolimnologists. The next of these, the 6th International Conference on Palaeolimnology, is to be held in Canberra, Australia, in April 1993, and an associated field trip to visit North Island sites has been proposed. We hope that this conference, being held for the first time in the Southern Hemisphere, will help to stimulate further the development of palaeolimnology in New Zealand.

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