How ^{210}Pb dating gives information about volcanic radionuclides

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Abstract

In lake sediments from the Taupo Volcanic Zone, the 1886 Tarawera tephra is often observed. The tephra contains unsupported ^{210}Pb which corresponds to its stratigraphic age, and shows that the ^{210}Pb has been adsorbed in its passage through the air, but not from the volatiles in the volcano itself which would be expected to contain the radionuclide. It is shown that only a small portion of the available ^{210}Pb in normal air was scavenged by the tephra. Sedimentation rates derived using the tephra were similar to those from ^{210}Pb dating. Some lakes showed excess ^{210}Pb inventories, ascribed to lake-bed geothermal activity. Contrary to expectation of increased erosion following deposition of an ash layer, sedimentation rates were less.

Introduction

^{210}Pb dating (Goldberg 1963) relies on the principle that given uniform sediment deposition, the ^{210}Pb contents of leachates of lake sediment layers should decrease exponentially following the half-life of ^{210}Pb, 22.3 years. If the activities are plotted transformed to logarithms versus the depth, a straight line results. An interruption in constant deposition, for example, a sudden flux of material from an underwater slumping event of the same age, will produce a plateau in the descending line.

Surfaces near lakes in volcanic zones are subject to periodic falls of volcanic ash, or tephra, and it might also be expected that these deposits might be more subject to erosion. The lakes in the Taupo Volcanic Zone present a good opportunity to test this, since the basaltic ash eruption of Mt Tarawera in 1886 forms a thick and easily recognisable layer in many of the lakes around Rotorua.

Such an area might be a rather unusual case for study, because geothermal activity emits copious ^{222}Rn (Whitehead, 1980, 1985, Matthews, 1981, Whitehead, Barry 1994) which might give rise to ^{210}Pb and confuse the interpretation.

Some early unpublished results from the Rotorua area were recently re-analysed, found to contain some unusual features, and are presented here for the first time. I include some comments on a few other radionuclides detected. Detailed interpretation of all these early results and many others, will soon be available elsewhere (Whitehead et al. New Zealand Journal of Marine and Freshwater Research, in press)

Methods

The samples were collected between 1972 and 1978. Lakes sampled were Rotoiti (1972), Taupo (1972), Ngahewa (1973 - near Rainbow Mountain), Tikitapu (1973), Okareka (1973) and Rotorua (1978).

The chemical methods are documented here for historical interest. Direct radiochemical isolation of ^{210}Pb and other fallout radionuclides were used at that era, rather than the current determination via descendent ^{210}Po using alpha spectrometry (McCabe, Ditchburn, Whitehead, 1992).

The following radiochemical procedure is for Pb, Cs, Pm and Ce, and was simplified appropriately for subsets of that group.

Sediment cores were first cut into lengths suitable to yield dry 10 g samples and wet and dried weights recorded. These ten gram samples were leached for one hour in 50 ml hot 6M hydrochloric acid with Pb, Cs and rare earth carriers present. The residues were washed twice with 25ml 6M HCl. The supernatant solutions were treated with a few ml of nitric acid and boiled.

The Cs was extracted into an ammonium molybdophosphate column, radiochemically purified following the method of Morgan & Arkell (1963), and beta counted. Pb and rare earths were then recovered from the solution by co-precipitating Pb phosphate and rare earth hydroxides with ferric hydroxide. Several precipitations from nitric acid were required to obtain a chloride-free precipitate. On digesting with sulphuric acid, insoluble Pb sulphate formed which after separation from the solution was finally purified by dissolving in 1.5 M HCl, loading onto an anion exchange column (Dowex AG1-X8) and eluting with water. Pb was precipitated and weighed as Pb chromate. Approximately a month was allowed for the ingrowth of ^{210}Bi before beta counting in a proportional counter using a thin filter to eliminate betas from ^{210}Pb and alphas from ^{210}Po. Rare earths were radiochemically purified and separated from the iron fraction, using a cation exchange lactic acid system (Nervik 1961). After weighing as oxalate, samples were beta counted.

Results

The sedimentation rates in kg m^{-2} y^{-1} follow. If a range is given, more than one core was analysed. Rotoiti 0.18-0.49 (Tarawera 0.46-0.62), Taupo 0.18-0.30, Ngahewa 4.2±0.8 (Tarawera 4.2), Tikitapu 0.11±0.02, Okareka 0.32-0.54, Rotorua 0.74-0.84 (Tarawera 0.75). In these lakes the ^{137}Cs method often is not applicable, giving deposition rates conflicting with those derived from either Tarawera tephra or ^{210}Pb rates. ^{137}Cs diffuses to layers well before the commencement of atmospheric testing, and often does not display a subsurface maximum corresponding to the mid '60s bomb testing. Although this is frequently ascribed to surface layer mixing, the distributions of the rare earth radionuclides ^{147}Pm, ^{144}Ce, with half-lives of 2.8y and 284 days respectively, showed that the surface layers of most cores were undisturbed, hence diffusion was to blame. These rare-earth radionuclides are no longer detectable in contemporary sediment samples.

Discussion

The ^{210}Pb activities in the sediments generally decreased with depth as expected, implying relatively uniform deposition, though there were occasional irregular points at depths which varied from core to core and therefore represented only very localised events. The deposition rates calculated from the Tarawera tephra layers usually corresponded within error with the rates calculated from ^{210}Pb analysis.

It was found recently that although the ^{210}Pb activities mostly decreased smoothly with depth, the inventories for lakes Rotoiti and Rotorua were 3-5 times those found in other local lakes. This is probably due to the known hot springs on the beds of these two lakes, which will emit ^{222}Rn, and the ^{210}Pb produced by decay will sediment together with the ^{210}Pb rained out from the atmosphere, which other work (Whitehead et al. New Zealand Journal of Marine and Freshwater Research in press) has shown accounts for almost all the ^{210}Pb in most New Zealand lakes. The continued regularity of the deposition implies that the input of these springs is very constant on a timescale of several decades.

Sub-aerial fumaroles are common in this area and may have added ^{210}Pb originating from the release of ^{222}Rn, although this is very hard to quantify. This is unlikely to have occurred in Lake Taupo (which also was largely spared the Tarawera tephra). As shown in fig 1, the ^{210}Pb

plot is quite unusual and has a constant curvature, interpreted as resulting from constantly increasing deposition of sediment, making the ^{210}Pb more dilute than when deposited in the past. The ^{222}Rn emitted from the geothermal power plant at Wairakei, 10 km north of Taupo could theoretically add to the usual ^{210}Pb deposition (Whitehead, 1985), but the core instead shows the opposite effect. The recently completed private Poihipi geothermal power plant is much nearer the lake, and may have a more measurable effect in future.

Fig 2 shows a core from one of the smaller Rotorua lakes, Lake Okareka. It is typical of those in the region, except that being near Tarawera the tephra layer is quite thick, and the plateau corresponding to it is correspondingly large. It is typical in that the ^{210}Pb from the tephra has the correct stratigraphic age. If this were not the case the plateau would be displaced up or down from the correct position. The results in the figure although unexceptional at first sight, actually require some explanation. They imply that the tephra in its passage through the air has adsorbed about the same quantity of ^{210}Pb onto its surface as non-volcanic dust of the same age, and it is not obvious this would necessarily be the case, because hot tephra is very different from other atmospheric dust.

One can also ask why the large amounts of ^{222}Rn and ^{210}Pb which must have been emitted in the eruption have apparently had no effect on this system, in spite of the fact that researchers found most of the ^{210}Pb emitted from the Mt St Helen's eruption was rained out within a few days (Olsen, Fruchter 1986). We do not observe a peak in the sediment corresponding to ^{210}Pb derived from ^{222}Rn, and it may simply be that it was diluted too fast to contribute to the content of ^{210}Pb in the air. Neither do we observe excess ^{210}Pb on the tephra surface. We must conclude, unless some unlikely coincidences have occurred, that the tephra in its passage of only a few hours through the atmosphere, has adsorbed ^{210}Pb only from the usual content in the air, which must only have happened after it had already cooled significantly. This implies that the kinetics of attachment are fast.

Some support for this idea comes from studies of coal-fired power stations, which emit ^{210}Pb in a volatile form, although most is removed through electrostatic precipitation. Studies (Wan et al. 1988) show that as much as 3% of total possible ^{210}Pb in coal is released to the atmosphere from coal burning in a power station, though the amount released through the precipitators should only be 0.5%. In the few tens of seconds of passage of the hot gases, there is not enough time for all the ^{210}Pb to attach to particles. This suggests that volatile ^{210}Pb in a rapid eruption at temperatures somewhat higher than those of coal burning, is not very likely to attach to the tephra, but attaches only at lower temperatures.

A further interpretation of the Lake Okareka data is that because the plateau is almost horizontal, only part of the inventory of ^{210}Pb in air can be scavenged. A large volume of tephra has passed through the air in a few hours, but the last portions have still been able to adsorb almost as much ^{210}Pb per unit weight as the first portions. This implies the atmospheric reservoir is large and has not been very much depleted by the passage of the tephra.

A curious feature of the Lake Okareka data is the differing slopes above and below the plateau. They suggest that the more recent deposition rate was actually slower than before the eruption, although one might expect the opposite.

Conclusions

The tephra from the eruption does not radiologically reflect its volcanic origin, but instead reflects the ^{210}Pb content of the air through which it has passed on its way to the lake sediments. This is rather similar to other New Zealand experience in which it was not possible to find obvious environmental effects of the large quantities of ^{222}Rn emitted from the Wairakei and Ohaaki geothermal power stations (Matthews, 1981, Whitehead, 1985). The radiological emissions from Tarawera are not apparent in the present study, but might be found on exami-

nation of other sediment, perhaps in the nearest lake, Lake Tarawera.

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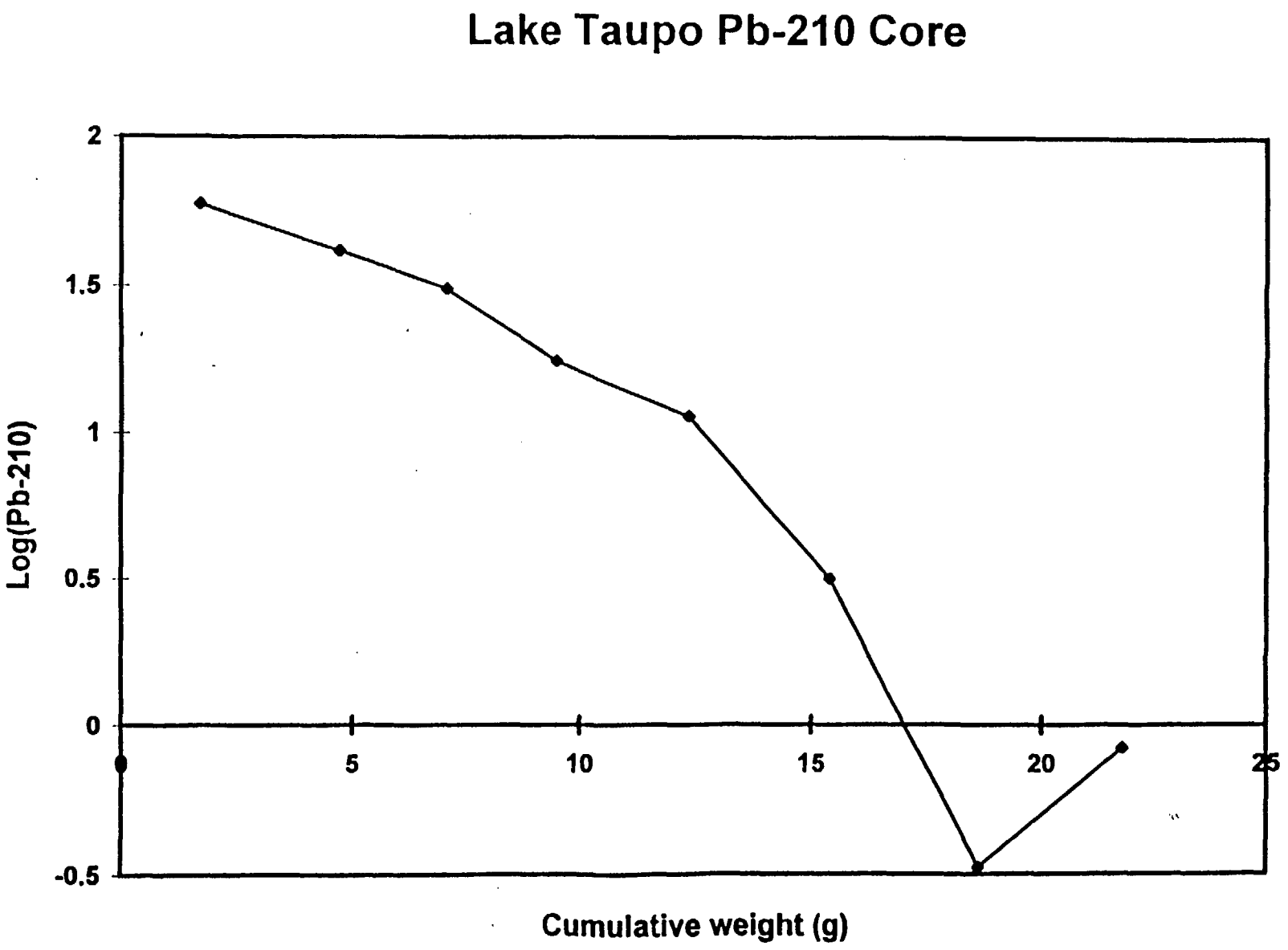
Lake Taupo Pb-210 Core
Log(Pb-210)
2
1.5
1
0.5
0
-0.5
5
10
15
20
25
Cumulative weight (g)

Figure 1

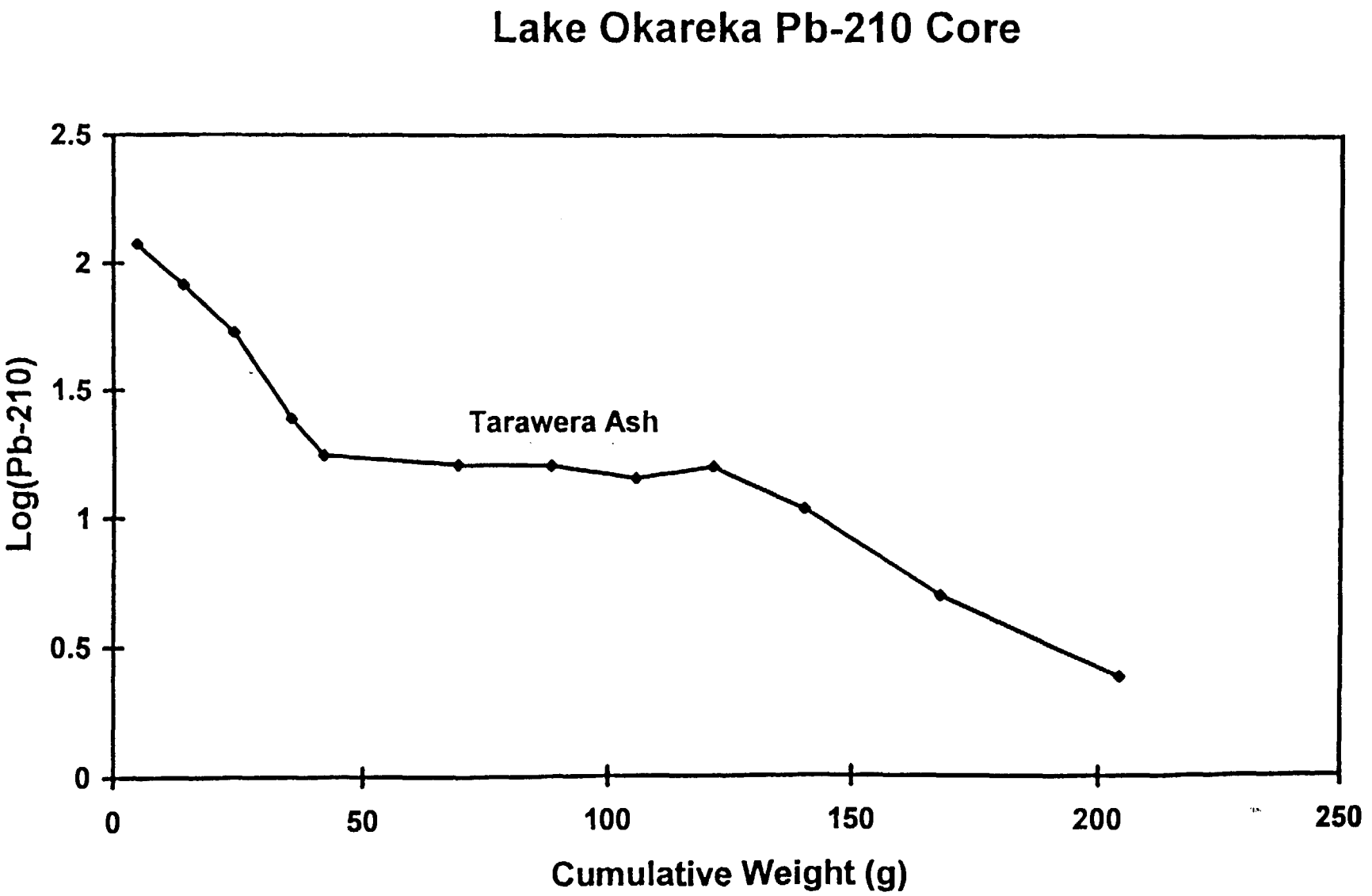
Lake Okareka Pb-210 Core
Log(Pb-210)
2.5
2
1.5
1
0.5
0
Tarawera Ash
0
50
100
150
200
250
Cumulative Weight (g)

Figure 2