Quaternary Geochronology 17 (2013) 68–80

Contents lists available at SciVerse ScienceDirect

Quaternary Geochronology

journal homepage: www.elsevier.com/locate/quageo

Research paper

Identifying a reliable target fraction for radiocarbon dating sedimentary records from lakes

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A R T I C L E I N F O

Article history:
Received 13 December 2012
Received in revised form
12 February 2013
Accepted 14 February 2013
Available online 26 February 2013

Keywords:
Lake sediment
Radiocarbon
Pollen
Macrofossils
Old carbon

A B S T R A C T

Lake basins that experience rapid rates of deposition act as high-resolution environmental archives because they produce sedimentary records that have centennial or even decadal resolution. However, identifying target fractions for radiocarbon dating of lake sediments remains problematic because reworked organic material from fluvial catchments can produce anomalously old radiocarbon ages. This study determines the extent to which reworked material from catchment soils impacts radiocarbon dates on pollen and other organic concentrates by comparing radiocarbon dates produced by these techniques against a chronostratigraphic marker in cores from Lake Mapourika, New Zealand. Pollen preferentially preserved and reworked from catchment soils was identified using soil palynology. A technique was then developed to remove reworked pollen types from pollen concentrates extracted from lake sediment. Identification and removal of reworked pollen from pollen concentrates produced ages that were consistently closer to the age of the chronostratigraphic horizon than other organic concentrates. However, these dates were still between 736 and 366 calendar years older than expected. The only organic fractions that reliably reproduced the age of the chronostratigraphic horizon were terrestrial leaf macrofossils, although terrestrial leaf macrofossils isolated from megaturbidite deposits, which are formed by high-energy depositional events, also provided anomalously old ages. The results indicate that leaf material extracted from hemipelagite, which accumulates gradually, is likely to be the only organic fraction to produce reliable chronology in lakes where a component of sedimentation is driven by the fluvial system. The results also demonstrate the importance of conducting a detailed investigation of physical sedimentology before selecting material for radiocarbon dating lake sediments.

1. Introduction

Lake sediments are excellent proxy records that provide continuous and high-resolution archives of environmental change (Last and Smol, 2001). The need for high-resolution paleoclimate and paleoseismic records (e.g. Moy et al., 2011; Waldmann et al., 2011) has resulted in increasing use of lake basins that have high sedimentation rates driven in part by the fluvial system (e.g. Moy et al., 2011, 2008; Schnellmann et al., 2002). High sedimentation lake basins offer a distinct advantage over smaller, closed, lake basins because the high sedimentation rate produces records that have centennial or even decadal resolution. Establishing precise chronology is an essential component of any reconstruction using such sediments because the chronology must have a comparable resolution to the events being reconstructed. Radiocarbon (^{14}C) dating of organic material within lake sediments remains the most widely used technique for establishing chronology, and the development of Bayesian statistical approaches to analysing ^{14}C datasets can produce chronologies that have near decadal precision (Blockley et al., 2007; Bronk Ramsey, 2008). Despite the development of age modelling techniques the accuracy of ^{14}C chronologies remains reliant on the ^{14}C dates providing an accurate age for sediment deposition.

The relationship between a ^{14}C date and the depositional age of sediment is particularly important for lakes where sedimentation is driven by the fluvial system. In such settings, storage, episodic

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1871-1014/$ – see front matter
http://dx.doi.org/10.1016/j.quageo.2013.02.001

fluvial re-working and deposition of organic material from catchment soils ("old" carbon) can dilute the ^{14}C content of the organic material with respect to the atmosphere at the time of deposition, causing ages to be older than the depositional event within which the carbon is embedded (Bertrand et al., 2012; Colman et al., 2004; Edwards and Whittington, 2001; McGlone and Wilmshurst, 1999). The problems associated with "old" carbon in lake sediments have driven research into identifying and excluding organic fractions containing old carbon from ^{14}C dating targets (e.g. Brown et al., 1989; Turney et al., 2000). Such research has demonstrated that leaf material from terrestrial plants is the most reliable fraction for dating lake sediments. Their terrestrial origin means that leaves have ^{14}C concentrations in equilibrium with the atmosphere and their delicate structure precludes long residence times in lake catchments before deposition in lake basins (Oldfield et al., 1997; Turney et al., 2000). Although terrestrial macrofossils are reliable targets, in many depositional settings they are rare and may not occur in sufficient abundance to allow high-precision chronology to be established.

An alternative organic fraction that has been widely used in situations where terrestrial macrofossils are scarce is pollen isolated from lake sediments (Brown et al., 1989; Chester and Prior, 2004; Long et al., 1992; Newnham et al., 2007; Moy et al., 2011; Vandergoes and Prior, 2003). Pollen is predominantly of terrestrial origin and is generally thought to be incorporated into sediment through continuous pollen rain from the atmosphere, making it relatively abundant (Brown et al., 1989; Vandergoes and Prior, 2003). A growing number of studies have argued that ^{14}C dates derived from pollen concentrates provide ages contemporaneous with sediment deposition (Brown et al., 1989; Chester and Prior, 2004; Vandergoes and Prior, 2003). However, some studies that have tested the accuracy of pollen concentrate ages against independent chronological markers have concluded that pollen concentrates may yield ages that are consistently older than the depositional age of the sediment (Kilian et al., 2002; Mensing and Southon, 1999). Fluvial reworking of pollen from catchment soils has been proposed as the most likely cause of anomalous ^{14}C ages produced from pollen concentrates (Mensing and Southon, 1999).

Reworked pollen from catchment soils has considerable implications for studies using pollen concentrates to establish high-precision chronology in lakes where fluvial sedimentation is a significant component of deposition. Despite this, there has not been a systematic analysis of the impact of reworked pollen and other organic material on ^{14}C ages from lake sediments. In this paper we determine whether reworked material from soils make ^{14}C dates on pollen and other organic concentrates substantially older than expected. The study focuses on Lake Mapourika, New Zealand (Fig. 1). Lake Mapourika is located adjacent to the Alpine Fault and its catchment drains the range front topography of the Southern Alps. The sedimentary record from the lake contains deposits formed by large earthquakes on the Alpine Fault, which have been precisely dated using terrestrial leaf macrofossil datasets from multiple lakes (Howarth et al., 2012; Howarth, 2012). The coseismic deposits provide chronostratigraphic horizons in both basins of the lake, which provide an independent test for the accuracy of the pollen and organic concentrate dates. We use the results of the test to develop a dating strategy for lakes where fluvial sediment flux dominates deposition.

2. Study setting

Lake Mapourika is situated 3.5 km from the surface trace of the Alpine Fault where it strikes along the base of the range front of the Southern Alps (Fig. 1). The lake is 8.3 km^2 and is composed of two basins separated by a 5 m high sill. The southern basin has a maximum depth of ~75 m, while the northern basin has a maximum depth of ~77.8 m (Irwin, 1979). Both basins are characterised by relatively flat basin floors and steep sides that are continuous with the subaerial slopes of a latero-terminal moraine complex bounding the lake. The 66.3 km^2 fluvial catchment of the lake drains predominantly into the southern basin and has 1820 m of relief between the highest peaks and lake level. There are also a number of subsidiary streams that drain into Lake Mapourika's northern basin from the low relief moraine complex west of the Alpine Fault. The catchment is covered with native podocarp/hardwood temperate rainforest below the treeline at 1000 m a.s.l (Wardle, 1991).

The sediments of Lake Mapourika are characterised by a repeating sequence of three deposits (Howarth, 2012). The depositional sequence starts with megaturbidite deposits characterised by a normally graded, sandy silt base, overlain by relatively thick, homogeneous, very fine sandy silt that is capped with a thin layer of medium silt (Fig. 2 A). Megaturbidites are the thickest deposits in the centre of both lake basins, they can be traced across the lake

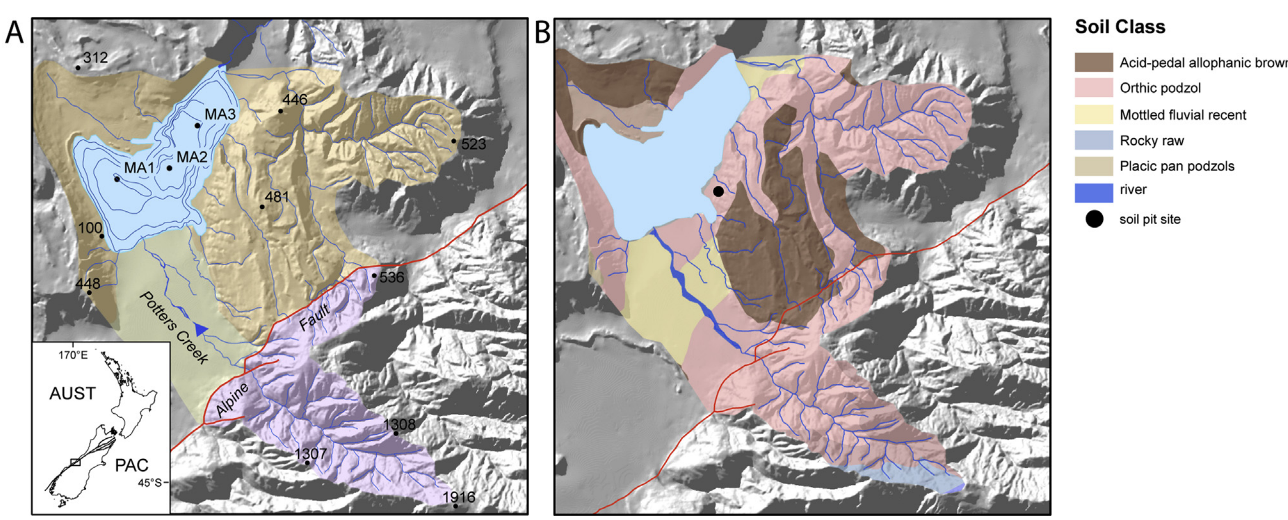

Fig. 1. Map of the Lake Mapourika study site. A) The lithology (orange – Quaternary moraines, purple - schist and yellow – Quaternary gravels), the configuration of the catchment, and sediment core sites within the basins. B) The soil types that occur within the lake catchment and the location of the soil pit. The inset shows the study area in the wider context of New Zealand. Pac. – Pacific plate, Aust. – Australian plate and red line – Alpine Fault.