Available online at www.sciencedirect.com

SCIENCE DIRECT®

Science of the Total Environment 366 (2006) 837–850

Science of the Total Environment
An International Journal for Scientific Research into the Environment and its Relationship with Humankind

www.elsevier.com/locate/scitotenv

Radionuclide dating (^{210}Pb, ^{137}Cs, ^{241}Am) of recent lake sediments in a highly active geodynamic setting (Lakes Puyehue and Icalma—Chilean Lake District)

F. Arnaud [a,b,1], O. Magand [c,*], E. Chapron [d,2], S. Bertrand [e], X. Boës [e], F. Charlet [d], M.-A. Mélières [c]

[a] *Processus et Bilan en Domaine Sédimentaire, UMR CNRS 8110, Bât. SN5, UST Lille 1, F-59655 Villeneuve d'Ascq, France*
[b] *Géodynamique des Chaînes Alpines, UMR CNRS 5025, Bât. Belledonne, Université de Savoie, F-73373 Le Bourget du Lac, France*
[c] *Laboratoire de Glaciologie et Géophysique de l'Environnement, UMR CNRS 5183, 54 rue Molière, F-38402 Saint Martin d'Hères Cedex, France*
[d] *Renard Centre of Marine Geology, University of Gent, Department of Geology and Soil Science, Krijgslaan 281 S8, B-9000 Gent, Belgium*
[e] *U.R. Argiles et Paléoclimats, University of Liege, Allée du 6 Aôut, B18, ULG-Sart-Tilman, B-4000 Liège, Belgium*

Received 5 August 2005; accepted 10 August 2005
Available online 22 September 2005

Abstract

This study presents an attempt to use radionuclide profiles to date four short sediment cores taken from two Chilean lakes located in a highly active geodynamic setting. In such settings, sediment series commonly contain earthquake-triggered reworked layers and/or volcanic ash layers. All of these layers affect the vertical distribution of radionuclides. The drawing up of accurate chronologies is made even more problematic by the low fallout rates of both natural (^{210}Pb) and artificial (^{137}Cs, ^{241}Am) radionuclides. However, radionuclide profiles can be "corrected" by subtracting the influence of instantaneous deposits that have been identified from detailed sedimentological studies. Thus, radionuclides can be used to provide approximate dates for sediment. Independent confirmation of these dates can be provided by varve counting and/or the recognition of historical events. For Lake Puyehue, this approach has allowed particular sediment features to be related to the effects of the 1960 Chilean earthquake (Mw 9.5) on the lake basin and its catchment area. For Lake Icalma, there is a good agreement between radionuclide dates and the dates of the three tephra layers formed during large eruptions of the Llaima volcano in 1946, 1917 and 1883. For

* Corresponding author. Tel.: +33 4 76 82 42 59; fax: +33 4 76 82 42 01.
E-mail address: magand@lgge.obs.ujf-grenoble.fr (O. Magand).

[1] Present address: Environnement Dynamique et Territoires de Montagnes, UMR CNRS 5204, Bât. Belledonne, Université de Savoie, F-73373 Le Bourget du Lac, France.

[2] Present address: Geological Institute, ETH Zürich, CH-8092 Zürich, Switzerland. Address to which the proofs should be sent: Olivier Magand, LGGE, UMR CNRS 5183, 54 rue Molière, F-38402 Saint Martin d'Hères Cedex, France.

0048-9697/$ - see front matter
doi:10.1016/j.scitotenv.2005.08.013

both lakes, artificial radionuclide fallout, which culminated in 1965, provides more robust chronological information than ^{210}Pb dating.

Keywords: ^{210}Pb; ^{137}Cs and ^{241}Am dating; Earthquake; Volcanic eruption; Catastrophic flood; South America; Chile

1. Introduction

Radiometric dating methods have proved their reliability in a large number of studies of lacustrine environments, whether sediment accumulation rates are uniform or non-uniform. When ^{210}Pb and sediment supply mechanisms can be assessed, it is a standard practice to apply one of the three commonly used models: CFCS (Constant Flux, Constant Sedimentation, Goldberg, 1963; Krishnaswami et al., 1971), CRS (Constant Rate of Supply, Appleby and Oldfield, 1983) and CIC (Constant Initial Concentration, Pennington et al., 1976). Whatever the model or procedure used, ^{210}Pb-based chronologies must always be confirmed by independent methods (Smith, 2001). Generally, ^{210}Pb dates are confirmed using ^{137}Cs profiles, when the ^{137}Cs profiles are sufficiently intact (Appleby and Oldfield, 1983). The only source of ^{137}Cs in southern South America is the atmospheric testing of nuclear weapons during the 1950s and 1960s (essentially between 1952 and 1963) (Schuller et al., 1993, 2002). Hence, in the southern hemisphere, ^{137}Cs sediment records can be used to identify sediment layers deposited in 1965 (shortly after most atmospheric testing had ceased) when ^{137}Cs deposition rates were at their peak (Pennington et al., 1973; Cambray et al., 1989; Appleby et al., 1991; UNSCEAR, 2000).

The radionuclide ^{241}Am can be used to corroborate ^{137}Cs dates when the profile has been disturbed. There is a growing evidence that ^{241}Am is less mobile in lake sediments than ^{137}Cs (Appleby et al., 1991) and it is more strongly particle-associated than caesium, especially under low pH conditions (Oldfield et al., 1995). Between 1952 and 1965, direct ^{241}Am fallout was negligible (Krey et al., 1976) and the ^{241}Am found in present-day archives is a decay product of ^{241}Pu from weapons test fallout. Although ^{241}Am activities are much lower than ^{137}Cs activities, Appleby et al. (1991) showed that its distribution in cores is a more accurate marker of maximum fallout (i.e. 1965 in the southern hemisphere) than ^{137}Cs.

In active geodynamic settings, disturbances to radionuclide profiles may preclude the direct use of any ^{210}Pb dating models. Such disturbances can be caused by earthquakes, which rework old ^{210}Pb-depleted material (Arnaud et al., 2002), or by volcanic activity, which leads to the sporadic deposition of variable amounts of volcanoclastic material (e.g. tephra layers). In such cases, artificial radionuclides (^{137}Cs and ^{241}Am) provide indispensable chronostratigraphic markers, but they do not cover the entire 100–150 year span provided by the ^{210}Pb method. When the fingerprints of disturbed sediment layers are well constrained, such sedimentary events may be considered instantaneous deposits that have to be subtracted from the total accumulation in order to assess the mean continuous sedimentation rate (Arnaud et al., 2002; Nomade et al., 2005). Despite these difficulties, the recognition of historical earthquake- or volcanic-triggered deposits in lake sediments may provide additional chronological information that can be used to support data derived from radiometric measurements (Chapron et al., 1999; Ribeiro-Guevara et al., 1999; Arnaud et al., 2002; Nomade et al., 2005).

In this paper, we present the radiometric profiles of four short sediment cores from two lakes in the Chilean Lake District: an area strongly affected by major earthquakes and volcanic eruptions. Our study combined radiometric and sedimentological investigations in order to assess sedimentation rates and the chronological succession of specific layers that may be related to well-documented historical events.

2. Setting

The Chilean Lake District (37° to 42° S, Fig. 1) contains a number of large lakes of glacial origin