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Research paper

Timing of the deglaciation in southern Patagonia: Testing the applicability of K-Feldspar IRSL

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ABSTRACT

The timing of the ice margin retreat of the Late Glacial Patagonian Ice Sheet (PIS) in southern Patagonia has been the object of discussion for many years. In order to resolve questions about the complex response of the PIS to past climate change, any geological interpretation and data modelling need evaluation against an absolute chronology. The aim of this project is to investigate the applicability of OSL dating to sediments from southern Patagonia; in particular, we examine the dating potential of K-feldspar IRSL signals. Samples were collected from landforms interpreted as being deposited during deglaciation of the PIS, with an expected age range of 17 and 22 ka, and from recently deposited sediment. We measure small aliquots and single grain distributions using an IR_{50} SAR protocol with IRSL stimulation at 50 °C following a preheat at 250 °C (held for 60 s). Uncertainties are assigned to our individual dose estimates based on the over-dispersion (OD) observed in laboratory gamma dose recovery experiments (22% for small aliquots and 18% for single grains). Then the possible effects of incomplete bleaching and differential fading are examined. For our natural samples we observe environmental ODs between 30 and 130% and mean residual doses between ~30 and 80 Gy. Minimum age models are used to identify the part of the dose population that is most likely to have been well-bleached and results from these models are compared. The models give ages that are consistent with each other; this may imply that they successfully identified the fully-bleached grains in the distributions, although there are some discrepancies between our small aliquot and single grain data. We observe large fading rates (on average 7.9 ± 0.6%/decade for large aliquots) but nevertheless a comparison of our fading corrected ages with the expected age range shows that 2 out of 3 ages are consistent with geological interpretation and an established radiocarbon and cosmogenic nuclide chronology. We conclude that these investigations suggest that fading corrections can be based on laboratory average small aliquot/single grain fading rates. The third age is supported by an alternative geological interpretation, and the two ages consistent with the existing chronology imply that in the Strait of the Magellan the hills of the Brunswick peninsula (>70 m.a.s.l) were deglaciated at around 22 ka.

1. Introduction

At the end of the last ice age the Patagonian Ice Sheet (PIS) was the largest body of ice in the southern hemisphere after the Antarctic Ice Sheet. During this time the Strait of Magellan, in southern Patagonia, was occupied by a large ice lobe flowing north with its ice divide located near Cordillera Darwin (Fig. 1a). Terrestrial evidence for the Magellanese Ice Lobe suggests a dynamic ice sheet sensitive to climate fluctuations (Porter et al., 1992). To answer questions about the response of the Magellan Ice Lobe to climate change; geomorphological reconstructions of its extent (e.g. McCulloch et al., 2005; Glasser et al., 2008) and numerical models of its dynamics and response to climate forcing (e.g. Hulton et al., 2002) need to be evaluated against an absolute chronology.

This study investigates the application of Optically Simulated Luminescence (OSL) dating to glaciofluvial sediment from near the Strait of Magellan in southernmost Patagonia, Chile (Fig. 1b). The

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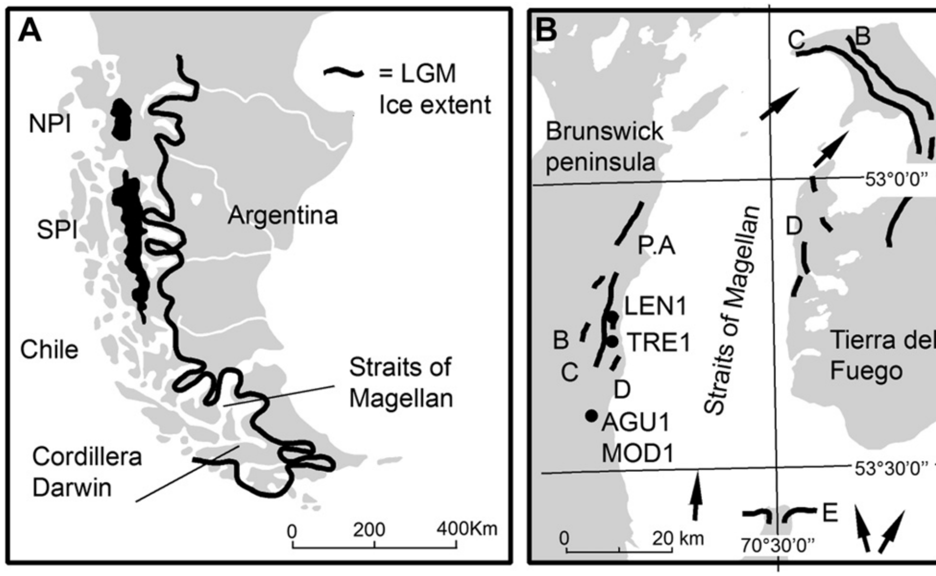

Fig. 1. (a) Southern South America and Patagonia. NPI and SPI = North and South Patagonian Ice fields. LGM ice extent is adapted after Caldenius (1932) (b). Sample locations in the Magellan Strait. Black lines represent moraine limits for glacial events B – E according to McCulloch et al. (2005), P.A = Punta Arenas, arrows mark general ice flow directions inferred from the geographical distribution of glacial lineations and the black circles represent sample positions for MOD1, AGU1, TRE1 and LEN1.

samples examined here are associated with sediments and landforms created during the last deglaciation of the PIS. As previously pointed out by Duller (2008) the application of luminescence dating to glacial sediment is one of the greatest challenges for the luminescence community. Problems associated with dating of glacial sediment include low sensitivity quartz and incomplete bleaching (Fuchs and Owen, 2008). Past studies in Patagonia have reported poor quartz luminescence characteristics (e.g. Duller, 2006; Glasser et al., 2006; Harrison et al., 2008) and this is consistent with existing reports from our study area (pers. comm. H. Rodnight 2011). Therefore, we turned our attention to K-rich feldspar extracts. We applied K-feldspar Infrared Stimulated Luminescence (KF-IRSL) using the IR signal stimulated at 50 °C; although this signal is unstable, it is known to bleach more readily than the more stable pIRIR signals (e.g. Buylaert et al., 2011a, 2012). We then used established methods to correct for anomalous fading (Huntley and Lamothe, 2001).

The possible effects of incomplete bleaching and differential fading were examined by measuring small aliquot equivalent dose (D_e) distributions for one modern analogue sample and three glaciofluvial samples and single grain D_e distributions for two of these samples. To assign uncertainties to individual dose estimates we quantified the laboratory over-dispersion (OD) in laboratory-bleached and gamma (γ) irradiated samples for both small aliquots ($\sim$5 grains) and single grain measurements using the Central Age Model (CAM, Galbraith et al., 1999). Statistical models (Minimum Age Model – MAM, Galbraith et al., 1999: Internal External Uncertainty – IEU – approach; Thomsen et al., 2003, 2007) were thereafter applied to identify the part of the dose population that was most likely to have been well-bleached and to calculate the average weighted equivalent dose (D_w). The resulting ages are compared and evaluated against an established radiocarbon and cosmogenic nuclide chronology for the ice retreat (e.g. McCulloch et al., 2005; Kaplan et al., 2008).

2. Geological context and sampling locations

The study area is located in southern Chilean Patagonia and includes the shores of the Magellan Strait (Fig. 1b). Geomorphological mapping describes a complex ice marginal and proglacial environment including several recessional post-LGM end moraines, lateral glaciofluvial channels and glacial lineations (e.g. drumlins and fluting) on both sides of the Strait (Bentley et al., 2005; Glasser and Jansson, 2008; Blomdin, 2011). Three samples (LEN1, TRE1 and AGU1) were retrieved from exposed sections of fossil glacial lake deltas and glaciofluvial terraces in tributary valleys, perpendicular to the general ice flow direction of the Magellan Ice Lobe (Fig. 1b). These tributary valleys are often in-filled with glaciofluvial sediments that are deposited close to the former ice margin (Glasser et al., 2006). The deltas/terraces are therefore contemporaneous with the existence of ice in the straits and accurate and precise dating of these features would provide insight into the timing of the retreating ice margin. A modern analogue sample (MOD1) was also collected from a hand-dug pit on a river bank; from the morphology of this deposit, this sample is assumed to be <100 years old.

3. Expected age range

The expected age range of the sediments can be estimated by comparing the geographical and geomorphological position of the sampled landforms with published AMS ^{14}C and ^{10}B chronologies (McCulloch et al., 2005; Kaplan et al., 2008). It is thought that the Magellan Ice Lobe is sensitive to climate change (Porter et al., 1992) and so one can expect deglaciation sediment to have been deposited within a relative short time frame after ice retreat. It is unlikely that our samples are older than $\sim$25 ka, the age of the LGM moraine limit (Fig. 1b, glacial event B). We interpret our sediments to be associated with glacial stages C or D (McCulloch et al., 2005) based on the position of the sampled landforms between two moraine limits and the absence of sedimentological evidence for an overriding glacier, i.e. no thick till sequence and no deformation of sediment. According to these constraints, our samples should have a maximum age of $\sim$22 ka and a minimum age of $\sim$17 ka.

4. Sample preparation and instrument facilities

Samples were retrieved by hammering opaque plastic tubes into distinct homogenous layers, glaciofluvial in origin and dominated by medium sand. The samples were prepared and processed under