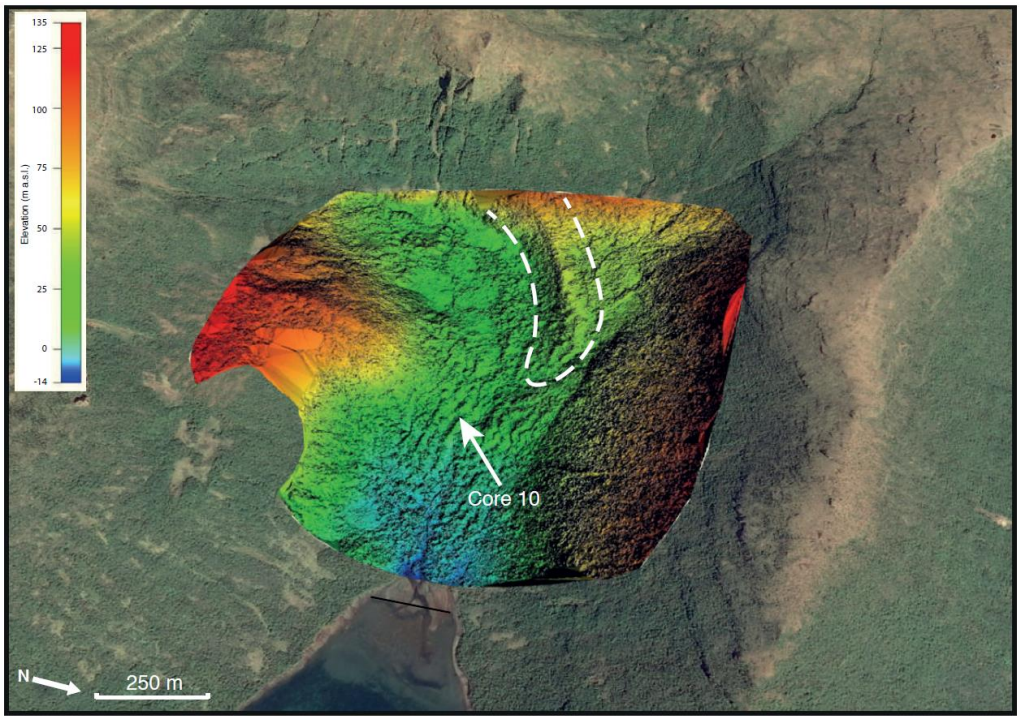
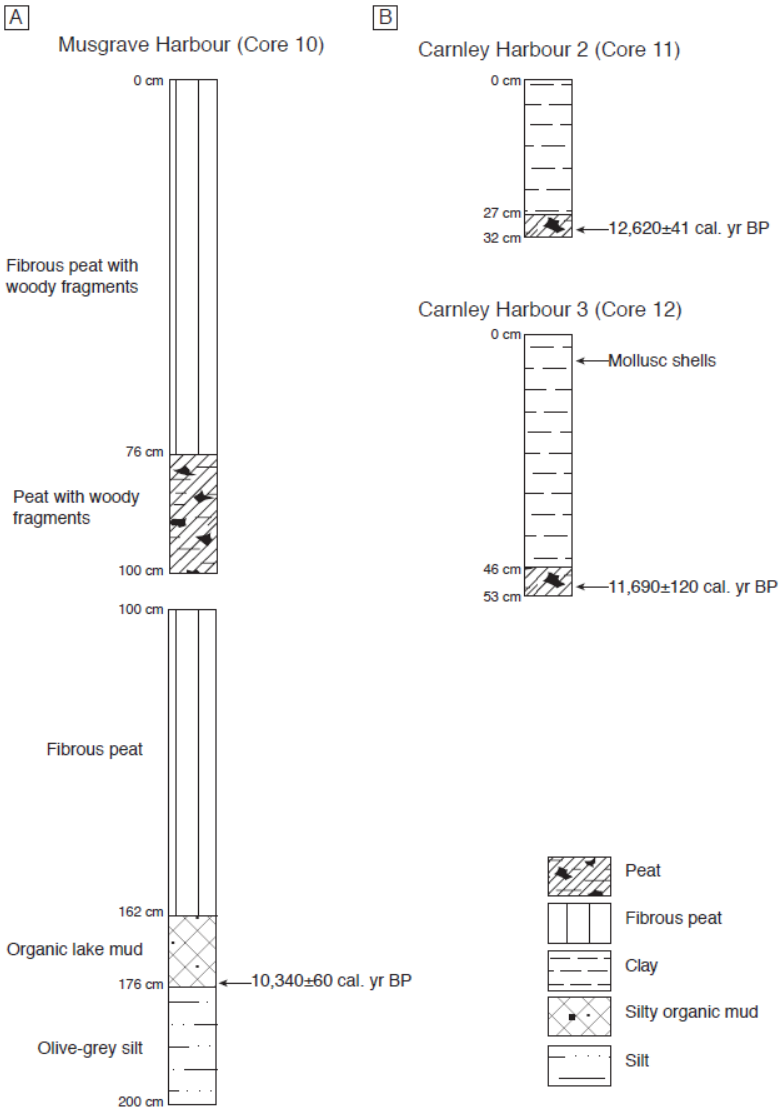
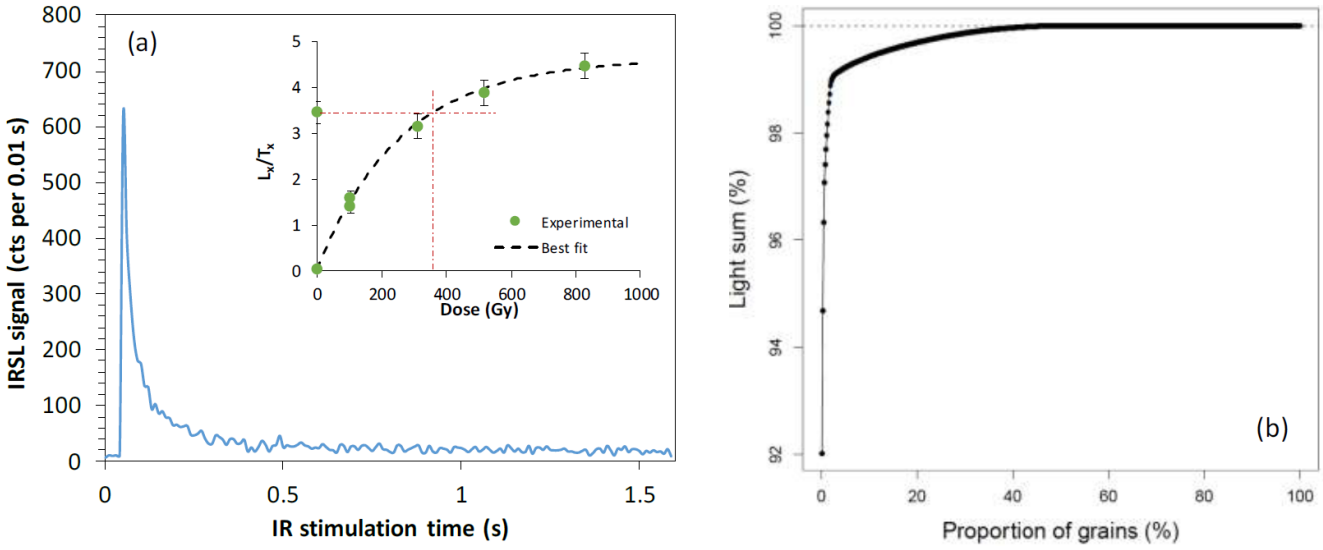
Supplementary figures



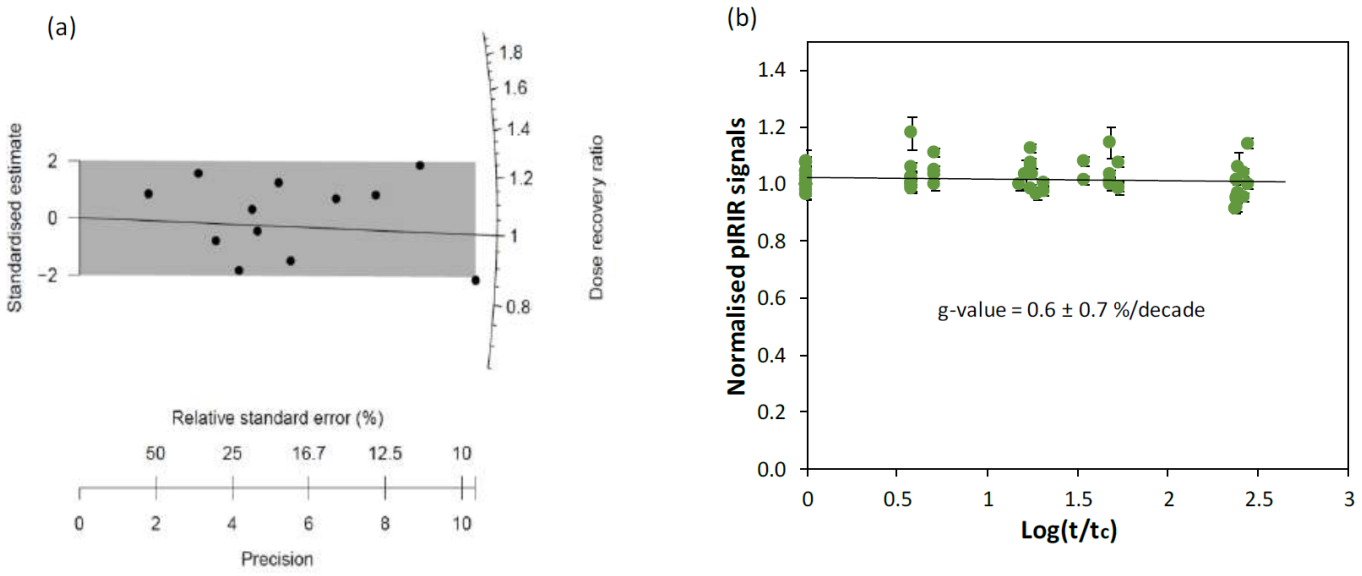
Supplementary Figure 1: Digital surface model of Musgrave Harbour, captured by Unmanned Aerial Vehicle and overlain on imagery from Google Earth, showing small cirques to the south-west and north-west. Lateral moraine between two cirque glaciers highlighted by white dashed lines. Location of Core 10 given by arrow.



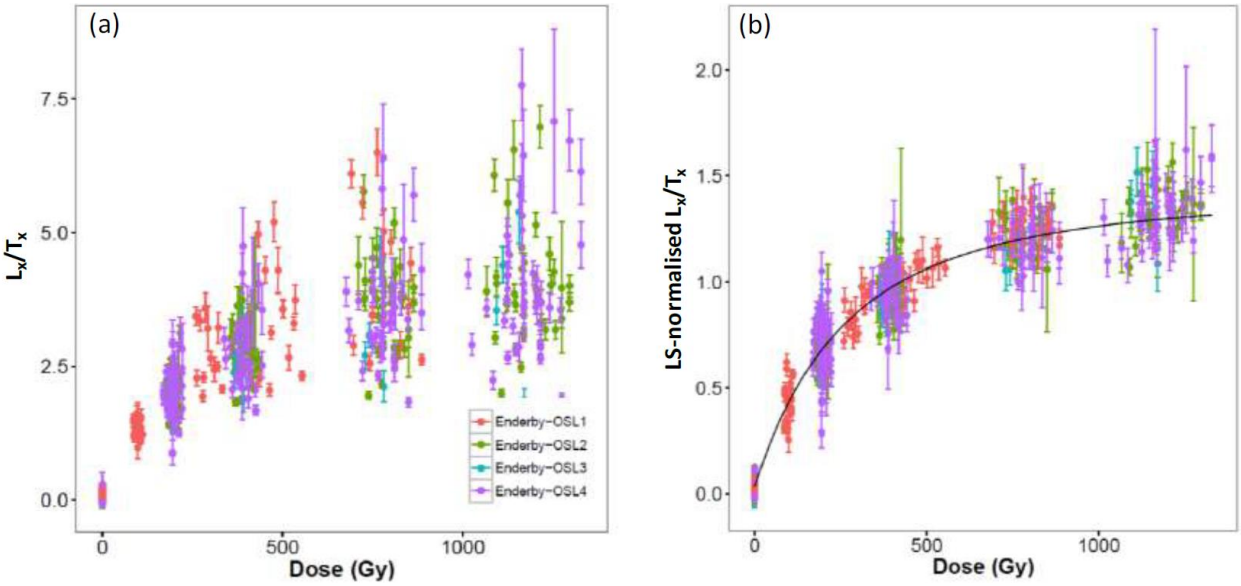
Supplementary Figure 2: Schematics of sediment cores. (A) Core taken from Musgrave Harbour (Core 10). (B) Two marine cores from Carnley Harbour (Cores 11 and 12).



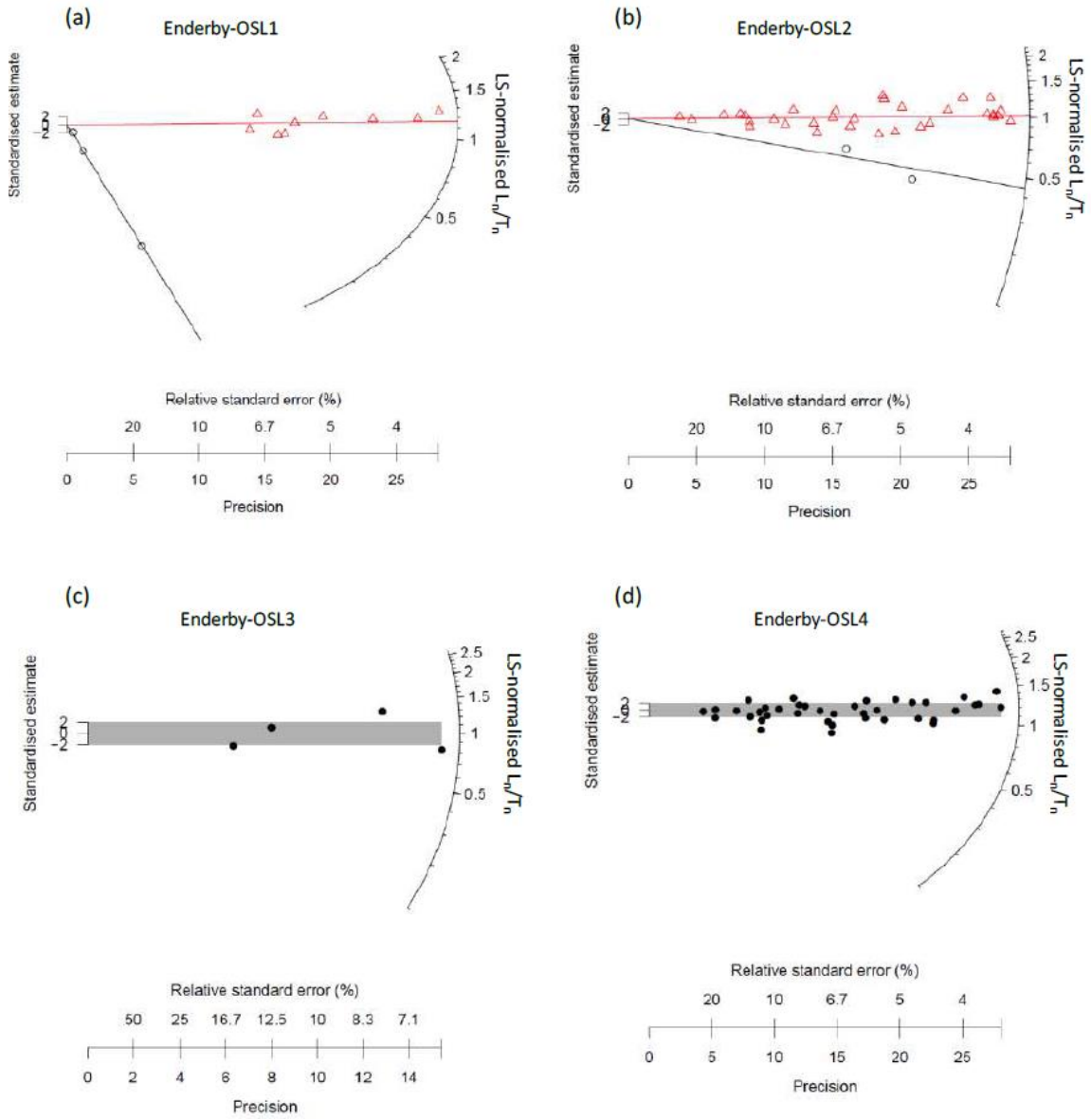
Supplementary Figure 3: (a) Natural pIRIR decay curve for a single grain of K-feldspar from Enderby-OSL1. The inset plot shows the corresponding dose response curve for the same grain. The sensitivity-corrected (L_x/T_x) dose response curve was fitted using a single saturating exponential function of the form $I = I_0(1–\exp^{-D/D}0)$, where I is the L_x/T_x value at regenerative dose D, I_0 is the saturation value of the exponential curve, and D_0 is the characteristic saturation dose. (b) pIRIR signal 'brightness' distribution for 600 individual grains of Enderby-OSL1. The cumulative light sum of the T_n signals (shown on the *y*-axis) is plotted as a function of the corresponding proportion of grains (shown on the *x*-axis) ranked according to their brightness (i.e., the brighter grains are shown on the left).



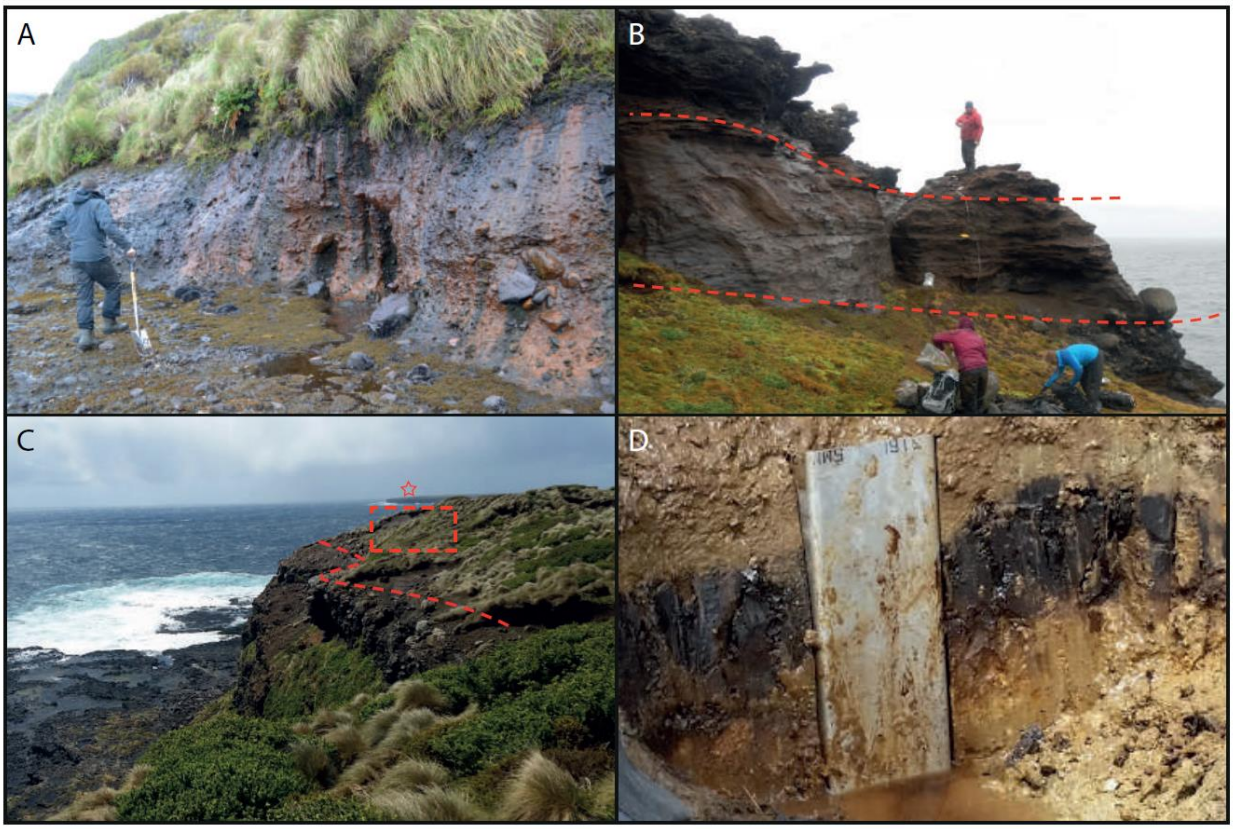
Supplementary Figure 4: (a) Radial plot (Galbraith et al., 1999; Galbraith and Roberts, 2012) of the dose recovery ratios (measured dose/given dose) for 12 accepted grains from Enderby-OSL1. The grey band is centred on the weighted mean ratio (1.06) determined using the central age model. (b) Anomalous fading test on the pIRIR signals, made using 12 aliquots of K-feldspar from Enderby-OSL1.



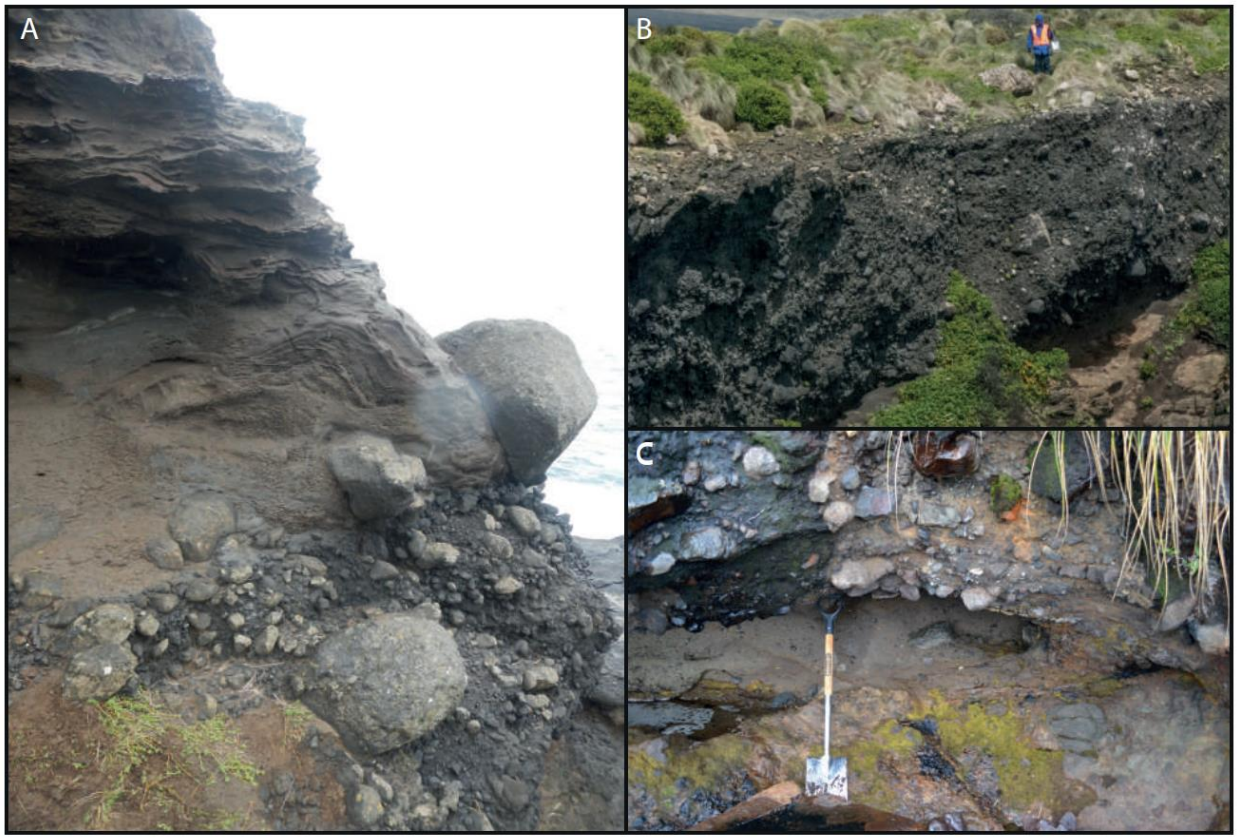
Supplementary Figure 5: (a) Sensitivity-corrected signals (L_x/T_x) for different grains of each of the Enderby samples. (b) LS-renormalised L_x/T_x ratios, using the same data as shown in (a). LS-normalisation was achieved using the built-in function provided in the R-package 'numOSL' (Peng et al., 2013; Peng and Li, 2017). The black line is the best-fit curve obtained using the general-order kinetic model (Guralnik et al., 2015).



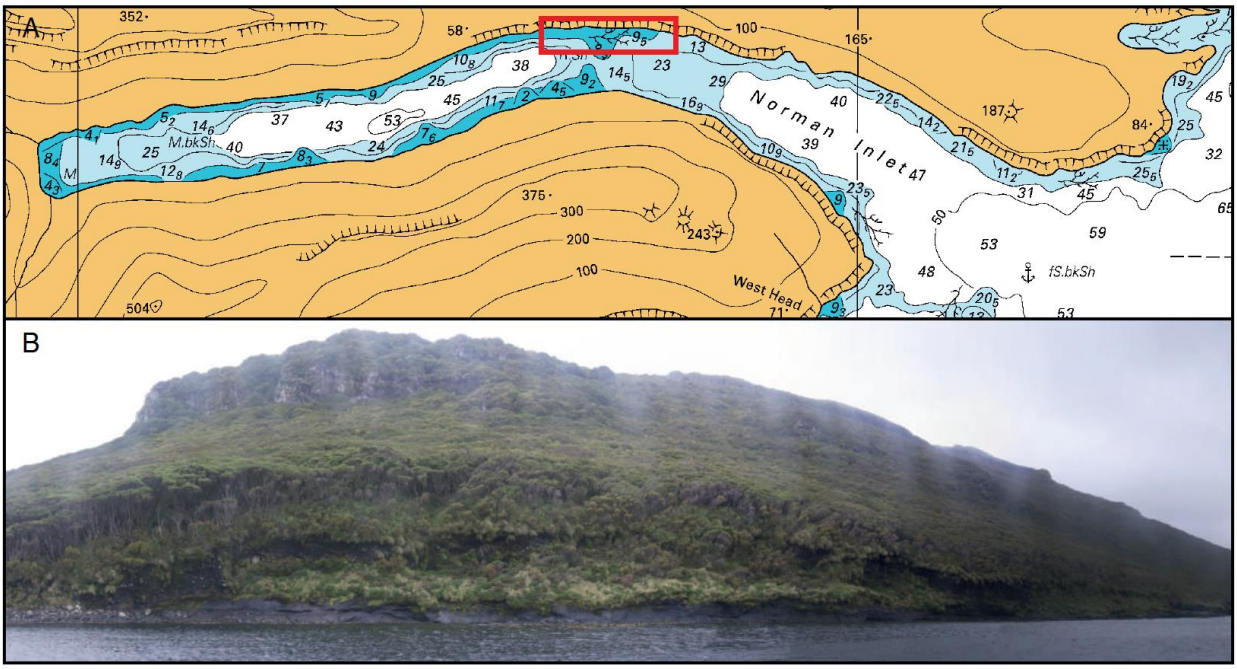
Supplementary Figure 6: Radial plots showing the LS-normalised L_n/T_n ratios for individual grains of each sample: (a) Enderby-OSL1, (b) Enderby-OSL2, (c) Enderby-OSL3 and (d) Enderby-OSL4. The red triangles and black circles in (a) and (b) distinguish the two components identified using the finite mixture model (FMM). The red and black lines are centred on the weighted mean values for each of these components, calculated using the FMM. The grey bands in (c) and (d) are centred on the weighted mean values estimated using the central age model (CAM). The FMM and CAM were fitted to these data using the build-in functions in the R-package 'Luminescence' (Kreutzer et al., 2012).



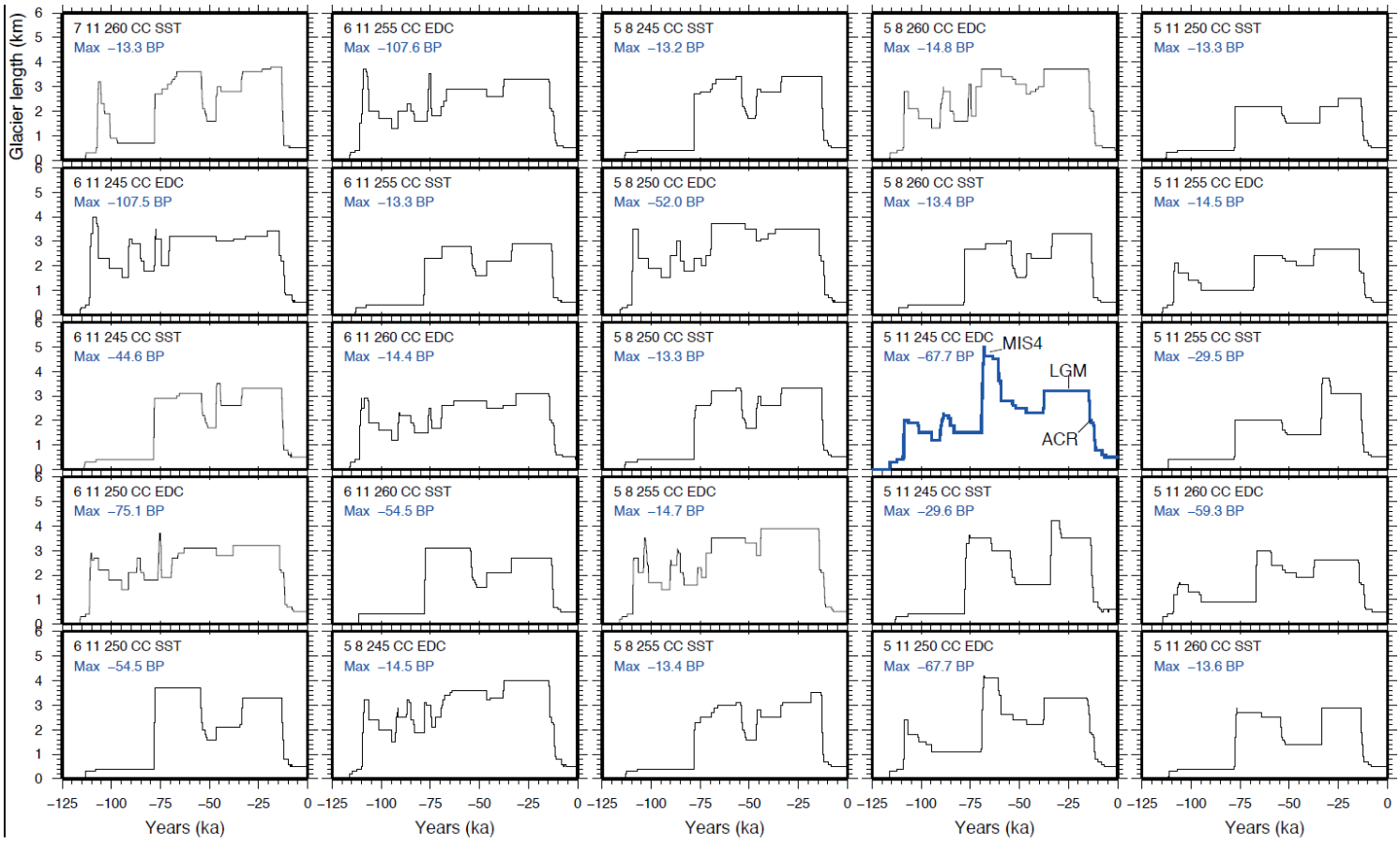
Supplementary Figure 7: Photos showing sediment deposits at (A) Emergency Bay (photo: Verity Flett), (B) Enderby Island (photo: Greg de Wet) and (C) Pillar Rock (photo: Chris Turney). Red dashed lines in (B) show delineation of upper and lower tills, with laminated lake sediments in between. (D) shows organic silts from 237-250 cm in the Pillar Rock sediment sequence (photo: Chris Turney).



Supplementary Figure 8: Photos showing details of glacial 'Enderby Till' at (A) Enderby Formation, (B) Pillar Rock, (C) Emergency Bay.



Supplementary Figure 9: (A) Hydrographic chart showing sill and over-deepening of Norman Inlet, east coast of Auckland Island. Red box shows location of a potential moraine, shown in (B), taken on north shore of Norman Inlet (photo: Chris Turney).



Supplementary Figure 10: Subset of the 25 simulations that have a MAAT of 5-7°C, constrained by realistic palaeo temperature reconstructions of the islands and which use a temperature-coupled precipitation regime. Plots show glacier length in km against time in ka. The simulation highlighted in blue is that which best fits all available field data (Figure 7A). MIS4, LGM and ACR are labelled.

Step	Treatment	Observed
1	Give regenerative dose, D_i [a]	
2	Preheat at 320 °C for 60 s	
3	IR diode stimulation at 200 °C for 200 s	$L_{n(200)}$, $L_{x(200)}$
4	Single-grain IR laser stimulation at 275 °C for 1.5 s	$L_{n(275)}$, $L_{x(275)}$
5	Give test dose, D_t	
6	Preheat at 320 °C for 60 s	
7	IR diode stimulation at 200 °C for 200 s	$T_{n(200)}$, $T_{x(200)}$
8	Single-grain IR laser stimulation at 275 °C for 1.5 s	$T_{n(275)}$, $T_{x(275)}$
9	IR bleaching at 325 °C for 100 s	
10	Return to step 1	

Table S1: The single-grain pIRIR regenerative-dose procedure for K-feldspar. [a] For the 'natural' sample, i = 0, $D_0 = 0$ and the observed pIRIR signals are denoted L_n and T_n. The entire sequence is repeated for several regenerative doses (with the observed signals denoted L_x and T_x), including a zero dose and a repeated dose.