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Supporting Online Material for

High-Frequency Holocene Glacier Fluctuations in New Zealand Differ from the Northern Signature

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Materials and Methods

I. Samples, geochemistry and analyses

Samples

Large boulders are common on the Holocene moraines near Mt. Cook, and are predominantly hard, quartzo-feldspathic, fine-grained greywacke sandstone. Rock samples were taken from the most stable-looking section (typically from the center) of flat-topped, large greywacke boulders embedded in the tops of moraines (Fig. S3). We focused on sampling the top 2 cm. Target rocks were measured, described and photographed. The greywacke lithology is very resistant to erosion (e.g. (S*1*)), therefore we assume the erosion of the sampled surface to be close to zero over the relatively short time-scales discussed here. All samples were processed at the cosmogenic dating laboratory of the Lamont-Doherty Earth Observatory. At the laboratory, the rock samples were crushed to 125 μm – 710 μm.

Geochemistry

We separated and decontaminated quartz from the whole-rock samples and measured the ^{10}Be concentration from the quartz using isotope dilution techniques. In the past, fine-grained greywacke has proven very problematic to process for ^{10}Be SED, primarily because it is difficult to clean the quartz to levels required by standard processing protocols without digesting most of the quartz. In order to separate sufficient quartz material (up to 100 g) from the whole rock for the low-level ^{10}Be analysis, it was necessary to process up to 2500 g of whole rock (table S2). Accordingly, we designed an updated geochemical processing protocol based on the strategies presented by Licciardi (S*2*) and by the cosmogenic dating group at University of Washington, Seattle (http://depts.washington.edu/cosmolab/chem.html). Boiling of the crushed rock sample in Ortho-Phosphoric Acid prior to successive leaching in diluted hydrofluoric/nitric acid on the shaker table and in a heated ultrasonic bath has proven to be the key for the successful processing of greywacke samples for ^{10}Be SED (http://www.ldeo.columbia.edu/res/pi/tcn/LDEO_Cosmogenic_Nuclide_Lab/Chemistry.html).

Also fundamental to the success of this work is the low process blank at the Lamont cosmogenic nuclide laboratory. It is based on a ^{9}Be spike from a natural, deep-mine beryl crystal, that is very pure (^{10}Be/^{9}Be ratio of about 5 x 10^{-16} (table S2)). We added between 0.18-0.2 ml of the ^{9}Be spike to each sample and measured a process blank (a ^{9}Be spike processed identically to the samples) with each sample batch. The 20 process blanks range between 5-20 x 10^{-16} (table S2), corresponding to a low ^{10}Be contamination during the chemical sample processing between 6,000 to 26,000 ^{10}Be atoms/g.

AMS analysis of very low ^{10}Be/^{9}Be ratios

The ^{10}Be/^{9}Be analyses were performed at the Accelerator Mass Spectrometry (AMS) facility at the Lawrence Livermore National Laboratory (LLNL). Due to the self-designed ion source at the AMS facility at the LLNL and high purity of the samples, ^{9}Be currents for our samples were high (table S1; ^{9}Be currents range from 7 to 33 μA with a mean of 18 ± 6 μA), yielding high precision of the ^{10}Be measurement. Individual AMS sample targets were measured between 2-5 times in total, providing an internal control of the stability of the AMS. The corrections for boron -10 (^{10}B), an interfering isobar of ^{10}Be, were typically lower than 1%, but were 3% or higher for six samples out of 75) thanks to chemical suppression of the boron levels in the quartz samples and good separation of the ^{10}Be and ^{10}B peaks in the detector (Fig. S4). Overall background corrections, including boron correction, correction for process blank, and sensitivity variations of the AMS during analysis, range from a few % (for most of the samples) up to >20% for six out of 75 samples (table S2). However, the consistent ^{10}Be process blank over the various AMS runs measured with uncertainties of 10% or better for the 'high background' samples leaves us confident that even for the six samples with highest background correction, the reported ^{10}Be/^{9}Be ratio is precise within given uncertainties. Because the LLNL AMS facility allows for ^{10}Be/^{9}Be measurements in the $1x10^{-14}$ range within about 5% (1 σ), the analytical uncertainties of a single AMS analysis for samples exposed for 500 years and longer (at 700 m altitude) correspond to less than 50 years. Even for the youngest samples only 150 years in age the 1-σ uncertainty is better than 10 %, translating into an error (1σ) of 15 years. All analytical details and errors are given in table S2.

II. ^{10}Be Surface Exposure Dating of the Holocene moraines of Mueller, Hooker and Tasman glaciers

Reviews of the method of surface exposure dating (SED) using cosmogenic nuclides are given in (S*3*-*6*). In this study, we present ^{10}Be dating of very young moraines (from several thousand years in age down to 150 years, at elevations of less than 1000 m), pushing the ^{10}Be technique to new limits. ^{10}Be is the appropriate cosmogenic nuclide for SED on the short timescales discussed here due to the very low blanks and the excellent analytical precision. All input parameters needed to calculate the ^{10}Be ages discussed in this paper are given in table S2. Table S2 also presents all geochemical and analytical details. We present all the ages based on different, currently accepted scaling schemes summarized in (S*7*) (table S3). A recently completed ^{10}Be production rate calibration study by Balco et al. (S*8*) obtained production rates, for latitudes above 40º and elevations below 1000m, that are about 7% to 12% lower than the global calibration data set (S*7*). We include ages based on this revised production rate in table S3 and base our discussion on those ages (errors of moraine ages include 1σ analytical error and 5% production rate uncertainty given by (S*8*), see also Fig. S1). Note that the age differences depending on the scaling scheme are small, not affecting any of the conclusions drawn here.

The data show excellent internal consistency and agreement between chronology and stratigraphic position (Figs. 1, 2, 3, S1). As the ages were derived from three different glacier systems and 74 individual boulders of differing settings, shapes and surface lithologies, it appears that none of the geomorphic processes listed in the 'Supporting Text- Section II ' (below), which may affect individual boulders to differing degrees, contributed significantly to the exposure ages obtained. However, the presented data are precise enough to provide evidence for a small pre-exposure (inheritance) signal discernable in some of the youngest boulders, corresponding to less than 100 years, reflected in the trend towards higher χ^2 values for the ^{10}Be age distributions for the younger moraines (in particular the '400 year' and the '270 year' moraines, see Fig. S1). We discuss this issue in detail below (Section II of the 'Supporting Text').

The unprecedented consistency and the general lack of outliers of this ^{10}Be chronology warrant explanation. We consider that it reflects the rapid rate of uplift-driven erosion in the Southern Alps, providing continuous supplies of freshly exhumed rock debris (S*9*). The main source of large boulder input to these glaciers is by large rockfall events (rock avalanches) which are common in the Southern Alps (S*10*). Such rockfalls are deep-seated and of large volume (S*11*), meaning that most of the failed rock material was not exposed at the rock outcrop surface prior to the rockfall event. This implies that a large proportion of the rockfall material has no pre-exposure to cosmic radiation. We consider that this accounts for the consistency of this ^{10}Be chronology of the Holocene moraines of the Mt. Cook area.

It is likely, however, that considerable rockfall onto the large Mt. Cook valley glaciers occurs in the ablation zone, because valley walls are steep, with large extents of exposed rocks. Most of the debris falling onto the ablation zone will be transported supraglacially and exposure during transport on the glacier is likely to account for some of the multi-decade variations in boulder ages from individual moraines. Additionally, reworking of a boulder exposed on a previouly-formed moraine cannot be excluded and may account for the few instances of 'old' outliers in the data set (see Section II of the 'Supporting Text').

III. Radiocarbon dating of till stratigraphy in moraine walls

Downwasting of the Tasman Glacier has exposed the deposits within its lateral moraines, including sequences of buried soils. Each soil represents a period of reduced ice surface height, which allowed the moraine to stabilize and become vegetated, followed by a rise in the ice height which deposited till over the soil (see (S*12*)). Table S4 summarizes the data from (S*12*) (and references therein), recalculated to modern standards and calibrated using INTCAL04, including the Southern Hemisphere correction for samples younger than 1,175 ^{14}C years BP. We have normalized the AD/BC calibrated ages to years before AD 2005, when most of the ^{10}Be samples were collected for this study. In Figure S2 we show probability distributions and statistics of these individual ages obtained from the three most widely recognized ^{14}C dated soils. Calculated arithmetic means with 1σ uncertainty from these ^{14}C ages are normalized to AD 2005 to allow direct comparison with the presented ^{10}Be ages (table S4, Fig. 3).

Supporting Text

I. Setting of the Southern Alps and their glaciers

Physiography

The Southern Alps are an elongate mountain chain on the western side of the South Island of New Zealand. This 500 km long and 60 km wide belt of mountains, with peaks typically exceeding 1800 m, is deeply dissected by formerly glaciated valleys. A well-defined drainage divide, universally known as the Main Divide, lies about 20 km east of the western margin of the mountain range (i.e. 40 km west of the eastern margin). Midway along the chain are the highest peaks of the Southern Alps, with many rising to more than 3000 m, including Mt. Cook (3764 m). Temperate glaciers are widespread on the highest parts of the range near the Main Divide. More than 3000 individual glaciers cover an area of 1158 km^2 and volume of 53 km^3 (S*13*). Locally, the ice fields coalesce to form valley glaciers that drain east or west off the range.

Geology

The western margin of the Southern Alps is the Alpine Fault, the local boundary between the Australian and Pacific plates. Strike-slip displacement with a minor reverse component has been instrumental in formation of the Southern Alps. The bedrock of the Southern Alps is Mesozoic-age greywacke, but near and west of the Main Divide, this passes into increasingly metamorphosed schist. The combination of ongoing rapid uplift, high precipitation and rapid erosion has produced deep, high-sided valleys. Rockfall is the main source of sediment generation, and major earthquakes occur every 200 to 300 years on the Alpine Fault (e.g. (S*11*)). In this study area on the eastern side of the Main Divide near Mt Cook, the rock is greywacke, with subsidiary low-grade schist.

Climate

The Southern Alps forms a 500 km long barrier to the prevailing westerlies, in a temperate maritime montane climate. The mountain chain induces a strong orographic precipitation regime. Mean annual precipitation increases rapidly from 3000 mm along the narrow western coastal plains to a maximum of more than 10,000 mm on the western flank of the Southern Alps close to the Main Divide. Further eastward, there is an approximately exponential decline in precipitation to about 1,000 mm at the eastern margin of the Southern Alps (S*14*). New Zealand's temperate climate reflects the interaction of sub-tropical and sub-polar air and water masses. Contemporary annual to multi-annual variability results from the El Nino-Southern Oscillation (ENSO). El Nino conditions bring a greater frequency of southwesterly winds, increased precipitation in the Southern Alps, and generally cooler air and sea surface temperatures (S*15*). Its contrasting condition (La Nina) brings more frequent northerly winds, warmer air and sea surface temperatures and less precipitation in the Southern Alps. An Interdecadal Pacific Oscillation (IPO) (S*16*) has recently been proposed as a lower-frequency pattern within ENSO (S*17*). Positive phases of the IPO comprise more frequent and more prolonged El Nino events, while negative IPO phases are characterized by a predominance of La Nina conditions (S*15*).

Glacier behavior

Numerical modelling indicates that Southern Alps glaciers are primarily sensitive to temperature change and less responsive to changes in precipitation (S*18, 19*). Historical and climatic data from the 20th century indicate some correlation between mass-balances of glaciers in the Southern Alps and ENSO patterns. In the late 1970s the IPO switched from a negative phase, which had persisted since the 1940s, to a positive phase which continues today. During the negative phase, substantial glacier retreat occurred throughout the Southern Alps. The present positive phase has been accompanied by substantial advance of the steep, fast-flowing, Franz Josef and Fox glaciers west of the Main Divide. To the east, except for glaciers whose equilibrium has been disrupted by the formation of terminal lakes into which the glaciers calve, the glaciers have generally ceased retreating and re-advance is evident in some places (S*20*).

II. Mueller, Hooker, and Tasman glaciers and their moraine records

Setting

Mueller, Hooker and Tasman are large, valley glaciers draining the eastern slopes of the Main Divide (for details see table S1). All three glaciers receive intense precipitation in their upper reaches (largely as snow during all seasons except summer) but precipitation volumes decrease progressively eastward to around 4500 mm/yr at the glacier termini. The terminal moraines lie at relatively low altitudes (700 to 900 m). Contemporary snow cover is slight, with a 1 m snowfall being an exceptional event and melting within a few weeks. For most of the winter, the moraines are free of snow. The lowermost few kilometres of the glacier trunks have surface debris covers that, although extensive, are rarely more than 1 m thick (S*21*).

Historic behavior

Mt Cook glaciers began downwasting in the late 1800s, while elsewhere in New Zealand, a very slow retraction of glaciers began that was replaced by very rapid retreat commencing in the late 1930s (S*22-S24*). From the early 1980s, lakes began to develop at the termini of Mueller, Hooker and Tasman glaciers, and have progressively expanded up valley. The most responsive of New Zealand glaciers (Fox and Franz Josef) began to advance at that time, and remain in advanced positions today. Similarly, the retraction of glaciers east of the Main Divide has largely ceased over the last 10 years (S*17*) and some have begun to re-advance. In contrast, Swiss glaciers began to retreat rapidly about AD 1860 and, when they temporarily stabilized in the 1920s, had accomplished about half of their retreat to today's positions. Further retreat, continuing today, was punctuated by a re-expansion in the 1970s and 1980s. Although the initiation of retraction in about AD 1860 appears to have been a globally-widespread phenomenon, the detail of glacier response in both regions has been attributed to regional climatic influences (S*24, 25*).

Holocene moraine records

The most comprehensive moraine sequence is preserved around the Mueller Glacier. The Hooker Glacier has a less well preserved suite of Late Holocene moraines. The Tasman is dominated by a loop of historic moraines (mid/late 19th to late 20th

century) with remnants of older Holocene moraines in a localized area near its right-lateral terminus (Fig. 1). Individual moraine ridges are typically at least 10 m high and have several hundred meters lateral continuity. The Mueller Glacier Holocene moraine record (Fig. 1) is divided into 8 distinct age groups, at least two of which comprise more than one successive moraine ridge, and thus are of 'composite age'. Collectively, the Mueller moraine sequence reflects at least 10 distinct moraine-forming events. Fewer sets of ridges are preserved around the Hooker and Tasman glaciers (Fig. 1).

Published chronologies for the Holocene moraines of the Mt. Cook area rely to a considerable extent upon relative dating methods of surface geomorphologies, particularly lichenometry and weathering-rind dating (see review in *(6)*). Recently, Schmidt hammer techniques have been applied *(17)*. The only direct numeric calibration of the relative dating methods applied to the morainal deposits near Mt Cook is radiocarbon dating *(11)*; however it has not been possible to robustly compare the ^{14}C data of subsurface deposits at Mt Cook to the characteristics of ground surface proxies such as lichen size or rock weathering rinds. It is not our intent in this paper to re-examine the published ages derived from relative dating methods. However, the ^{10}Be ages presented here provide some direct numeric constraint that could be used elsewhere to re-evaluate and improve the local calibration of the relative dating methods.

Interpretation of moraine records

Our conceptual model is that lateral or terminal moraine ridges are constructed at times when a glacier is in, or close to, equilibrium with prevailing climate. The reaction of a glacier in equilibrium to a superimposed climate change is almost immediate. Surface sediments on a moraine ridge represent the culmination of construction of the ridge, and we assume that ridge construction ceased due to withdrawal of the glacier from that position. Thus, we regard the surface exposure age of a boulder on a moraine ridge as recording the onset of a glacier retreat. There are at least four potentially complicating 'geologic' factors:

- A boulder may have an inherited age, representing prior exposure to cosmic radiation, for example if it had been part of an exposed rock face, had been reworked from the surface of a previously formed moraine, or was transported on top of the glacier surface (boulder gives an age older than the time of its deposition on the moraine);
- Boulders on a single morphologic ridge may not necessarily be from a single depositional event; ice may have reoccupied a pre-existing moraine ridge, and deposited boulders without leaving distinctive morphologic indicators. Boulders on a moraine of composite age should show at least two age populations, if within the resolution of analytic uncertainties.
- A boulder may have been moved after retreat of the glacier, for instance due to melting of stagnant ice buried within the moraine (boulder gives an age younger than the time of its deposition on the moraine);
- A boulder may have been deposited after formation of the moraine, by non-glaciogenic processes such as rock-fall from nearby slopes.

Other surficial processes can produce exposure ages that are younger than the boulder-deposition age, such as erosion, snow-cover, and post-depositional exhumation of boulders. The exceptional consistency of ages obtained in this study, and presence of very few outlier ages provides confidence that such complications do not introduce discernable variation at this study site.

Therefore, apart from the possible small influence of pre-exposure (see below), we conclude that exposure ages of surface sediments on moraines represent the onset of glacier retreat in immediate response to a climate signal, i.e. we date 'terminations' of glacier advances.

In this study we assume that the Mueller, Hooker and Tasman glaciers have experienced similar and simultaneous responses to climate signals during the Holocene. Our justifications are that their catchments are side by side, have similar aspect and altitudes, and that the amounts and timing of their downwasting in response to the climate changes of the past century have been approximately the same.

Pre-exposure of rock surfaces

The precision of the reported ages allows for consideration of small effects of pre-exposure/inheritance. Supraglacial transport of boulders will undoubtedly result in cosmic radiation during their travel on the ice. Such boulders are likely to be reoriented continuously during transport, by processes such as ice surface deformation via pressure ridges, and dynamically-varying ice surface relief generated by differential ablation. Boulder reorientation reduces the likelihood of pre-exposure being concentrated on any particular part of a boulder surface, but also means that all parts of a supraglacial boulder are more likely to carry some degree of pre-exposure.

Prominent innermost moraines of the Mueller Glacier were assessed by previous workers as being of historic age (i.e. younger than approximately AD 1860, when the first European explorers described the area). There are differing interpretations of specific moraine ages (e.g. (S*26*) versus (S*27*)) due to equivocal evidence. Perhaps the clearest evidence comes from a photo looking across the Mueller Glacier terminus taken in AD 1895 by J. J. Kinsey, cited by (S*27*) and accessible online at National Library of New Zealand, reference number: PA1-q-137. Combining this photograph with a perspective from a similar location accessed in Google Earth, it appears unambigous that the innermost moraine dated in this study (samples Kiwi-942, -943, -944) was outboard of the glacier in AD 1895. The glacier did not re-advanced beyond this 1895 ice-front position subsequently (S*28*). Thus, from historical evidence, the age of this moraine, at the sample sites and relative to the sampling year AD 2005, is at least 110 years. The arithmetic mean age of samples Kiwi-942, -943, -944 is 160 ± 30 years. At face value, this implies a mean pre-exposure of no more than 80 years. A maximum estimate of pre-exposure of 97 years, based on this limited data set of three samples, comes from sample -943 whose older bound is 207 years.

For comparison, we derive an indicative estimate of transport time for rocks on the Mueller Glacier surface. There is no record of flow rate measurements on the Muller Glacier in the 19th century, when the glacier was in an advanced state, presumably at or close to equilibrium with climate. However, a mean cross-sectional flow rate of 30 m/yr was measured on Hooker Glacier in 1889 (S*29*). The Hooker and Mueller glaciers are of comparable length and topographic setting. We assume to a first approximation that the lower half (i.e. 6.85 km) of the 13.7 km long Mueller Glacier equates to its ablation zone. The reason for considering just the ablation zone is that a boulder falling within the accumulation zone would be buried by snow and would become incorporated within the glacier ice. Adopting the flow rate of 30 m/yr for Mueller Glacier under equilibrium conditions, the transport time down the lower half of the glacier, for a rock sitting on the ice surface, would be 228 years. For any part of such a rock to gain the full 228 years of exposure to cosmic rays would require that it be transported without any rotation, and come to rest in the moraine with the same surface facing upward. Thus, we regard such a value as being a conservative upper limit of pre-exposure that is likely to have been gained by any supraglacial boulder during transport on the Mueller Glacier. In addition, any population of boulders in a terminal moraine is likely to include some which were transported largely or entirely englacially. Thus within a moraine boulder population, the inheritance age gained during transport on Mueller Glacier would lie between 0 and a conservative upper limit of 228 years. Hence, these estimates are broadly compatible with the estimates of pre-exposure of rocks on the historic moraines, as implied by the ^{10}Be results (see above).

Summarizing these different considerations, we infer that for the Mueller moraines, the surface boulders would, on average, have less than 100 years worth of pre-exposure. Thus, the mean ages may overestimate the time since ice retreat from that moraine by not more than 100 years. We assume to a first approximation that such values are also applicable to the moraines of the Hooker Glacier and right-lateral moraines of the Tasman Glacier.

As a reality check, it is instructive to consider the c. 1,000 year old moraine, best preserved around Hooker Glacier, but with possible correlatives at Mueller and Tasman glaciers (Fig. S1(vii) – mean age 1,020 ± 70 years). There is a widely represented buried soil of about the same age (Fig. S2(iii) – mean age 1,000 ± 80 years). Conceptually, the model is that the advancing glaciers overrode and buried the soils, after which the glaciers constructed latero-terminal moraines. The surface boulders on the moraines represent the withdrawal of ice after construction of the moraines. Although not a necessary assumption given the error limits, if we were to assume that there is an average of 100 years pre-exposure in the boulder population, it would imply an age of 920 ± 70 years for ice withdrawal from the moraines. This would fit better with burial of the soils during the initial advance, prior to construction of the moraines. It would also provide a tighter match to a period of reduced summer temperatures indicated by tree ring records between about 1,000 and 900 years ago (21 – see Fig. 3).

Incompleteness of moraine records

Moraine sequences represent discontinuous records of glacier behavior. A moraine ridge formed at the culmination of a glacier advance may be overwhelmed and obliterated during subsequent, more extensive ice advance(s). Latero-terminal moraines are potentially vulnerable to erosion by meltwater streams or burial by aggrading sediment. These factors make it unlikely that any moraine sequence contains a complete record of glacier behavior. This is illustrated in this study, where the Tasman and Hooker glaciers have a less complete sequence of moraines than does the Mueller. In all cases, we regard the number of preserved moraine sets as representing a minimum estimate for Holocene glacier advances in the Mt Cook area.

III. Potential non climatic drivers of glacier events

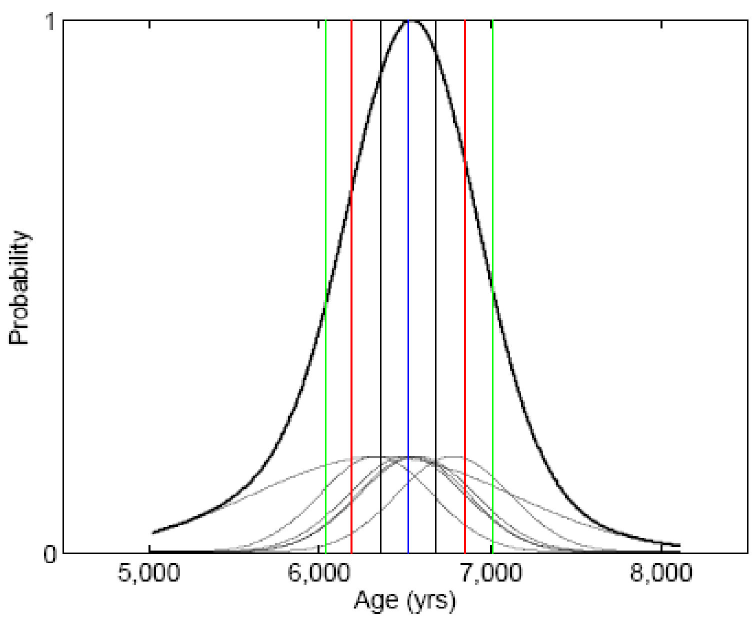
Recent hypotheses propose large rock fall events onto glaciers as an important cause of glacier advance and subsequent moraine construction in New Zealand's Southern Alps (e.g. (S*21, S30*)). Larsen et al. (S*31*) point to an apparent correlation between the timing of glacier advances and great earthquake events on the Alpine Fault, which independent evidence points to having occurred most recently at ~ AD 1717, AD 1620, AD 1425 and AD 1220 (S*32*). While rock fall is clearly an important source of sediment input to mountain glaciers, considerable reliance should be placed on the well-established empirical and observational connections between climate and glacier behavior. We assume that all of the moraines in this study represent glacier margin positions associated with climatic fluctuations. Our reasons for not favoring the hypothesis that rock falls are a primary cause of Holocene glacier fluctuations at Mt Cook, particularly in response to large earthquakes on the Alpine Fault, include:

- At least two sets of moraines are associated with glacier advances of the last ~200 years, and thus are younger than the most recent earthquake on the Alpine Fault.
- A very large rock avalanche (12 million cubic meters) onto the Tasman Glacier in 1991 has had no discernable effect on the behavior of the glacier (S*21*).
- There is no direct evidence that large earthquakes on the Alpine Fault have caused widespread rock falls throughout the catchments of the three glaciers included in this study.
- The historic observation that the Mueller, Hooker and Tasman glaciers have downwasted approximately simultaneously during the 20th century is difficult to reconcile with an earthquake-induced landslide driver.

Fig. S1. Probability distributions of ^{10}Be boulder and moraine ages.

Individual boulder ages (table S3) are shown by thin black curves within 2σ-uncertanties, the thick black line represents the probability distribution of the respective boulder age population from the moraine (normalized to 1). Arithmetic means of all distributions are indicated by the vertical blue line, 1σ range is given by grey, 2σ range given by red, and 3σ range given by green lines. The individual sample names of each distribution from young to old are listed in the header of each plot. We give different means within respective uncertainties. For the moraine ages we use the arithmetic mean within standard deviation (1σ) of all boulder ages from one moraine and include the production rate uncertainty given by (S*8*) of 5% (numbers underlined below). We also give the reduced χ^2 statistic for each age population. This number indicates to what extent the measured scatter in the ^{10}Be ages of boulders from one moraine can be explained by the analytical 1σ uncertanties. A reduced χ^2 value below 2 is considered good, many published ^{10}Be data sets show a reduced χ^2 value around 10 or higher (S*8*).

(i) The 6,500 year moraine (n=6: Kiwi-610-2, -801B, -915, -609, -627, -626-2); Mueller and Tasman glaciers

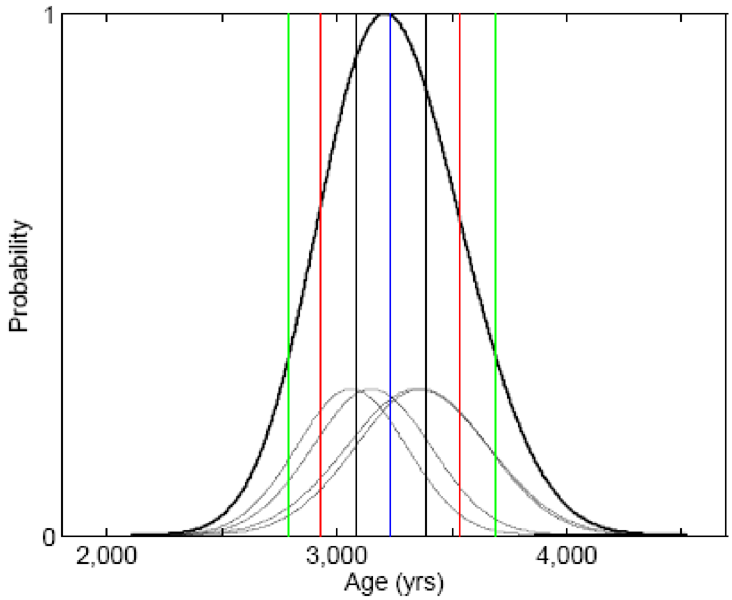


<u>Statistics:</u>

Arithmetic mean/1 sigma uncertainty: 6,520 ± 160 yrs
Including production rate uncertainty: <u>6,520 ± 360 yrs</u>

Weighted mean/weighted uncertainty: 6,540 ± 70 yrs
Peak Age: 6,530 yrs
Median/Interquartile Range: 6,530 ± 210 yrs
Reduced χ^2: 0.8

(ii) The 3,200 year moraine (n=4: Kiwi-902, -905, -938, -937); Mueller Glacier



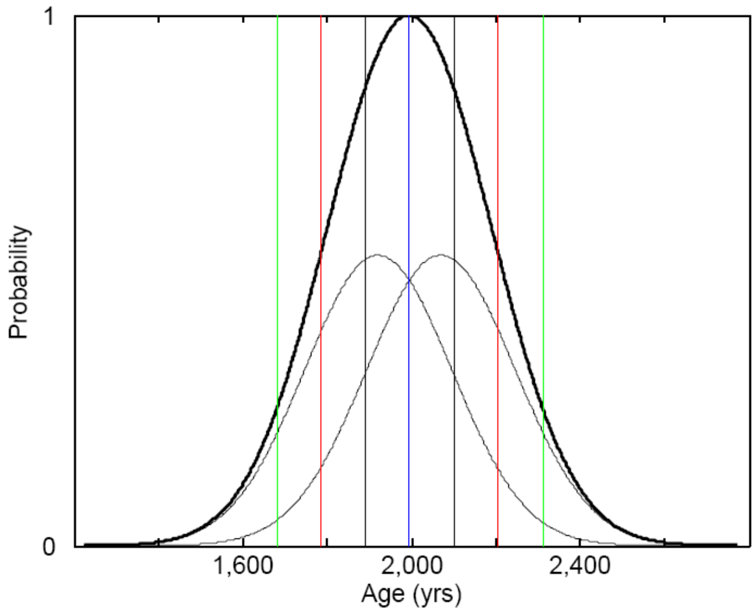
note that, in agreement with the stratigraphy, the two younger samples -902 and -905 (~ 3100 years) are from the inner part of the moraine ridge, while -938 and -937 (~ 3300 yr) are from the outer part of the moraine ridge (Figs. 1 and 2).

Statistics:

Arithmetic mean/1 sigma uncertainty: 3,230 ± 150 yrs
Including production rate uncertainty: 3,230 ± 220 yrs

Weighted mean/weighted uncertainty: 3,210 ± 70 yrs
Peak Age: 3,210 yrs
Median/Interquartile Range: 3,250 ± 250 yrs
Reduced χ^2: 1.3

(iii) The 2,000 year moraine (n=2: Kiwi-955, -956); Mueller Glacier



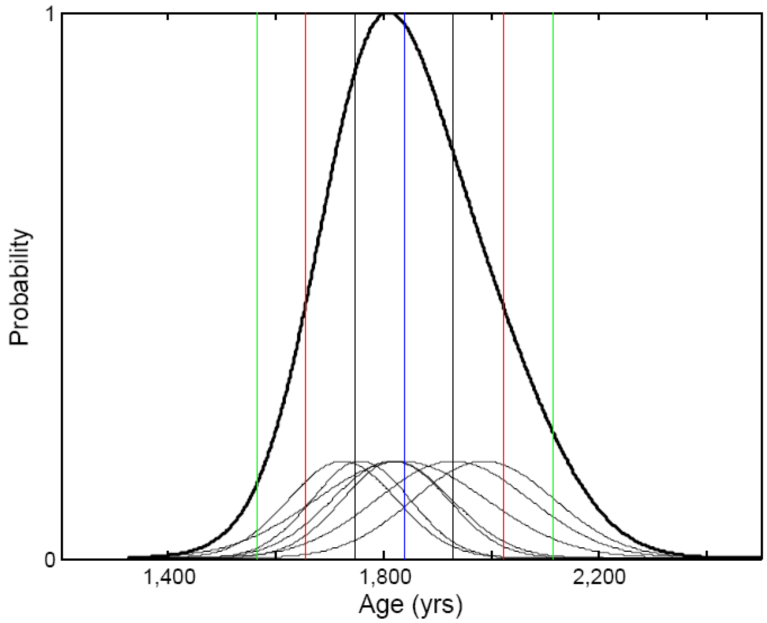
note that one sample from the right later moraine, Kiwi-X66, yielded a consistent age of 2,100 ± 100 years (see Fig. 2)..

Statistics:

Arithmetic mean/1 sigma uncertainty:	2,000 ± 110 yrs
Including production rate uncertainty:	2,000 ± 150 yrs

Weighted mean/weighted uncertainty:	2,000 ± 60 yrs
Peak Age:	1,990 yrs
Median/Interquartile Range:	2,000 ± 150 yrs
Reduced χ^2:	1.5

(iv) The 1,800 year moraines (n=7: Kiwi-X70, -X74, -X73, -X79, -957, -926, -X71); Mueller Glacier



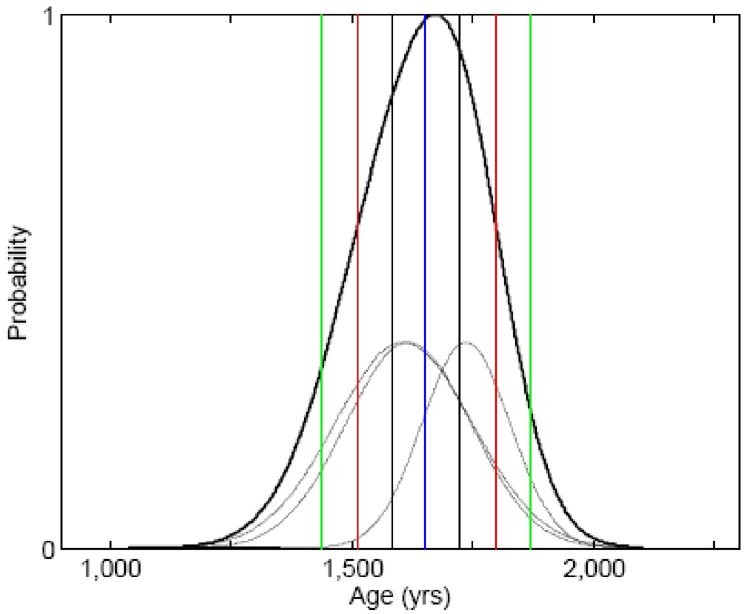
<u>Statistics:</u>

Arithmetic mean/1 sigma uncertainty: 1,840 ± 90 yrs
Including production rate uncertainty: <u>1,840 ± 130 yrs</u>

Weighted mean/weighted uncertainty: 1,820 ± 20 yrs
Peak Age: 1,800 yrs
Median/Interquartile Range: 1,820 ± 130 yrs
Reduced χ^2: 2.6

Note that these samples come from at least two distinct moraine ridges within the outermost left lateral Mueller moraine sequence (Fig. 1), but their ages are statistically indistinguishable.

(v) The 1,650 year moraine (Kiwi-628, -971, -700_1 & -700_3 (weighted mean of 700_1 and 700_3)); Tasman Glacier

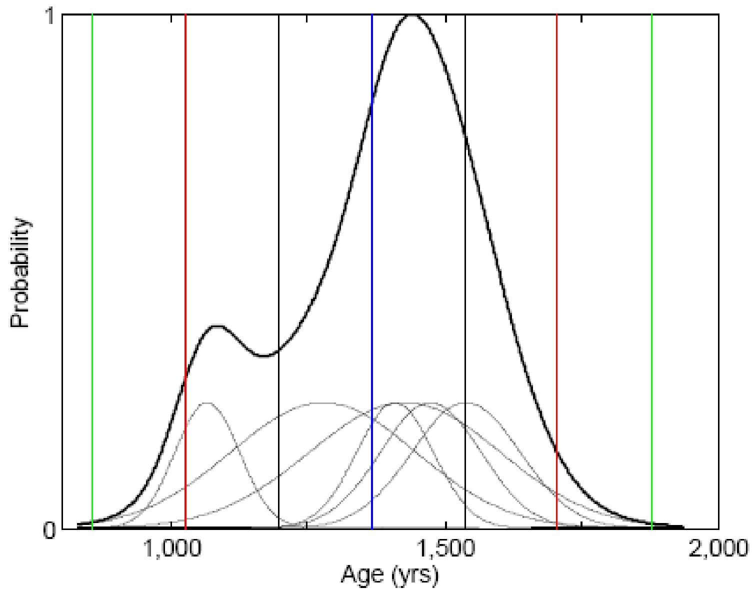


Statistics:

Arithmetic mean/1 sigma uncertainty: 1,650 ± 70 yrs
Including production rate uncertainty: 1,650 ± 110 yrs

Weighted mean/weighted uncertainty: 1,680 ± 30 yrs
Peak Age: 1,620 yrs
Median/Interquartile Range: 1,620 ± 100 yrs
Reduced χ^2: 2.0

(vi) The 1,400 year moraine (n=6: Kiwi-X51, -967, -968, -X49, -X52, -X53); Hooker Glacier



Statistics:

Arithmetic mean/1 sigma uncertainty: 1,370 ± 170 yrs
Including production rate uncertainty: 1,370 ± 180 yrs

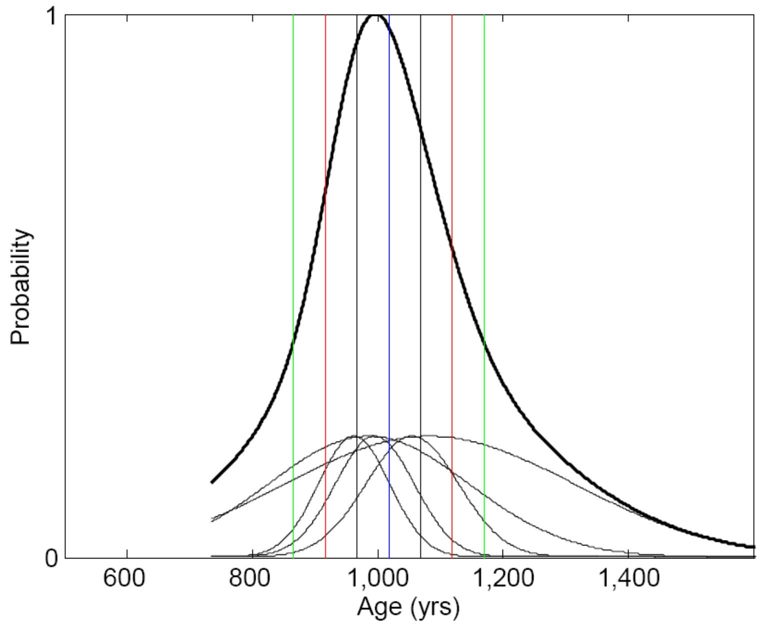
Weighted mean/weighted uncertainty: 1,310 ± 20 yrs
Peak Age: 1,430 yrs
Median/Interquartile Range: 1,420 ± 200 yrs
Reduced χ^2: 24

Statistics (based on 5 samples; Kiwi-X51, outlier defined at 1σ level, excluded):

Arithmetic mean/1 sigma uncertainty: 1,430 ± 100 yrs
Including production rate uncertainty: 1,430 ± 120 yrs

Weighted mean/weighted uncertainty: 1,440 ± 20 yrs
Peak Age: 1,430 yrs
Median/Interquartile Range: 1,430 ± 110 yrs
Reduced χ^2: 2.4

(vii) The 1,000 year moraine (n=5: Kiwi -X76, -X54, -969, -X77, -932-1); Hooker Glacier



<u>Statistics:</u>

Arithmetic mean/1 sigma uncertainty: 1,020 ± 50 yrs
Including production rate uncertainty: <u>1,020 ± 70 yrs</u>

Weighted mean/weighted uncertainty: 1,000 ± 20 yrs
Peak Age: 990 yrs
Median/Interquartile Range: 1,000 ± 80 yrs
Reduced χ^2: 1.4

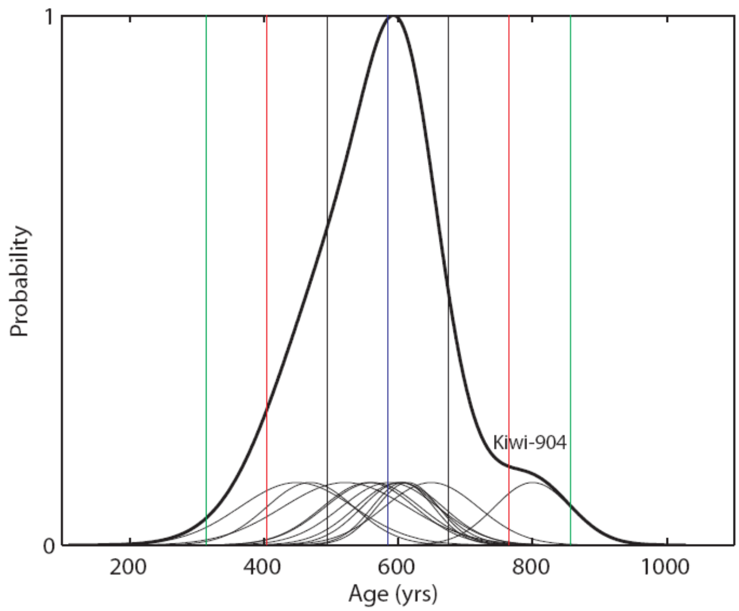
Tasman Glacier

A single sample from a Tasman Glacier moraine ridge, Kiwi-972, yielded an arithmetic mean/2 σ uncertainty of 970 ± 100 years (2 σ uncertainty is given because it is a single sample).

Hooker Glacier inner moraine ridge

A single sample from a small ridge just inside the 1000 yr moraine on the Hooker right lateral (Kiwi-927), yielded an age or 810 ± 70 years. It might date a remnant of moraine from a readvance of the glacier about 800 years ago. Soil evidence from Tasman Glacier left lateral moraines (Table S4) indicates that the Tasman Glacier readvanced after about 850 yr. It is possible that the moraine ridge sampled by Kiwi-927 formed during a coeval advance of Hooker Glacier, with this ridge providing the only morphologic remnant of this event so far found preserved.

(viii) The 570 year moraine (n=12: Kiwi-940, -912, -901, -911, -936, -909, -903, -941, -939, -X65, -900, [-904]); Mueller Glacier



Statistics:

Arithmetic mean/1 sigma uncertainty: 590 ± 90 yrs
Including production rate uncertainty: 590 ± 100 yrs

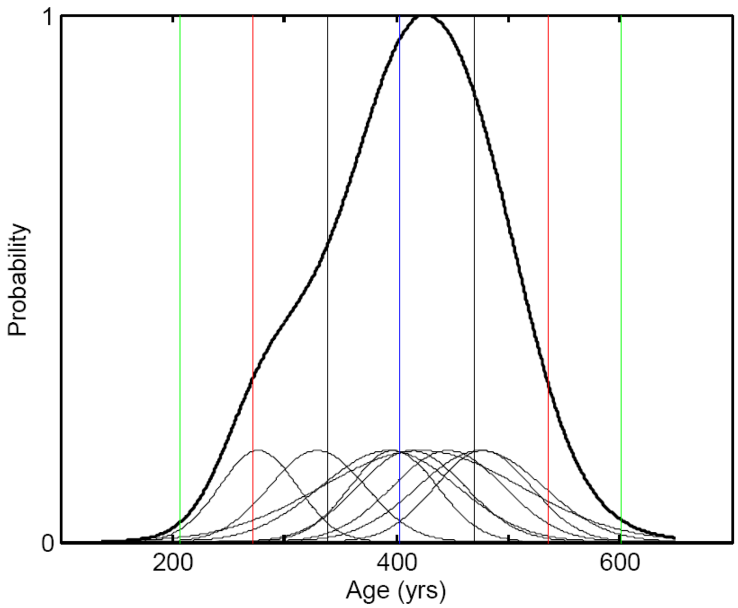
Weighted mean/weighted uncertainty: 600 ± 10 yrs
Peak Age: 600 yrs
Median/Interquartile Range: 600 ± 70 yrs
Reduced χ^2: 8.0

Statistics (based on 11 samples; Kiwi-904, outlier defined at 2σ level, excluded):

Arithmetic mean/1 sigma uncertainty: 570 ± 60 yrs
Including production rate uncertainty: 570 ± 70 yrs

Weighted mean/weighted uncertainty: 580 ± 10 yrs
Peak Age: 600 yrs
Median/Interquartile Range: 590 ± 80 yrs
Reduced χ^2: 3.4

(ix) The 400 year moraine (n=9: Kiwi-X44, -X42, -X43, -X45, -X63, -X36, -X62, -X46, -X38); Mueller Glacier



<u>Statistics:</u>

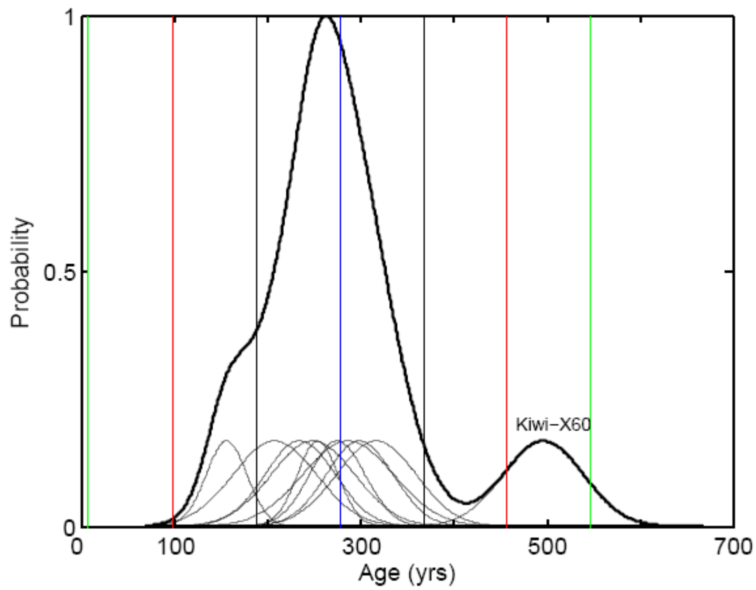
Arithmetic mean/1 sigma uncertainty: 400 ± 70 yrs
Including production rate uncertainty: <u>400 ± 70 yrs</u>

Weighted mean/weighted uncertainty: 390 ± 10 yrs
Peak Age: 410 yrs
Median/Interquartile Range: 410 ± 80 yrs
Reduced χ^2: 11

Note

These samples were collected from a moraine complex of composite morphology and age. The mean age is an average age that encompasses at least two separate glacier retreat events. This is reflected in the large reduced $\chi 2$ value.

(x) The 270 year moraine (n=10: Kiwi-X57, -908, -913, -X61, -914, -X58, -X59, -907, -906, [-X60]); Mueller Glacier



<u>Statistics (based on all 10 samples):</u>

Arithmetic mean/1 sigma uncertainty: 300 ± 100 yrs
Including production rate uncertainty: 300 ± 100 yrs

Weighted mean/weighted uncertainty: 270 ± 10 yrs
Peak Age: 280 yrs
Median/Interquartile Range: 280 ± 70 yrs
Reduced χ^2: 28

<u>Statistics (based on 9 samples; Kiwi-X60, outlier defined at 2σ level, excluded):</u>

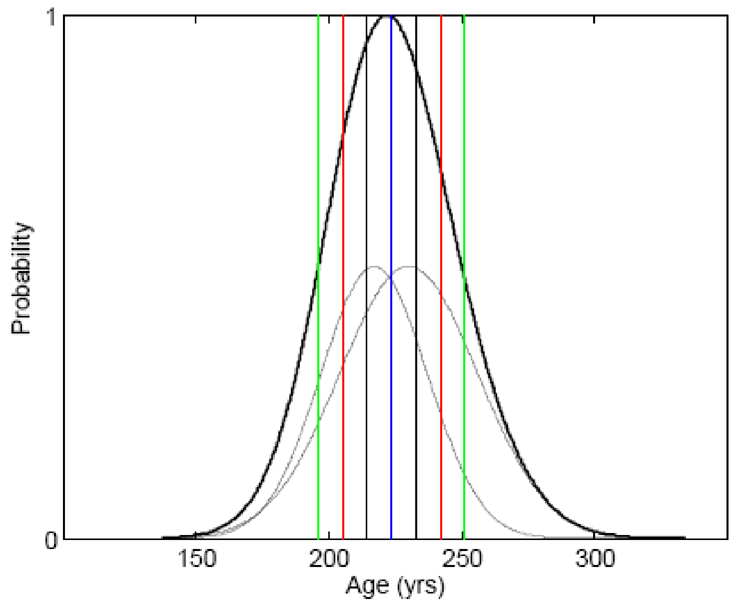
Arithmetic mean/1 sigma uncertainty: 270 ± 50 yrs
Including production rate uncertainty: <u>270 ± 50 yrs</u>

Weighted mean/weighted uncertainty: 260 ± 10 yrs
Peak Age: 280 yrs
Median/Interquartile Range: 270 ± 70 yrs
Reduced χ^2: 12

Note

These samples were collected from a moraine complex of composite morphology and age. The mean age is an average age that encompasses at least two separate glacier retreat events. This is reflected in the large reduced χ2: value.

(xi) The 220 year moraine (n=2: Kiwi-958, -959); Mueller Glacier

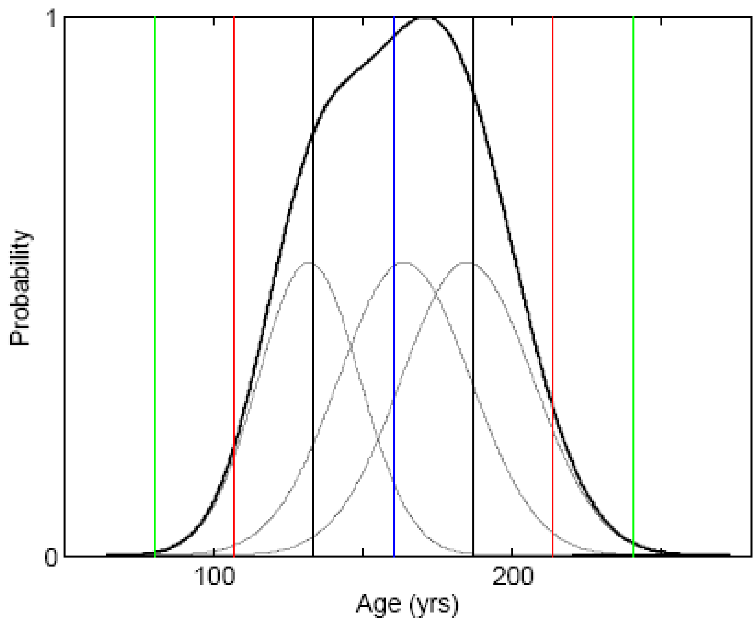


Statistics (n=2):
We give the details below although statistics based on n=2 is questionable; to stress the difference in reliability, we plot the number in italic;

Arithmetic mean/1 sigma uncertainty: *220 ± 10 yrs*
Including production rate uncertainty: *220 ± 10 yrs*

Weighted mean/weighted uncertainty: *220 ± 10 yrs*
Peak Age: *220 yrs*
Median/Interquartile Range: *220 ± 10 yrs*
Reduced χ^2*:* *0.7*

(xii) Mid/late 19th century moraine (n=3: Kiwi-942, -944, -943); Mueller Glacier



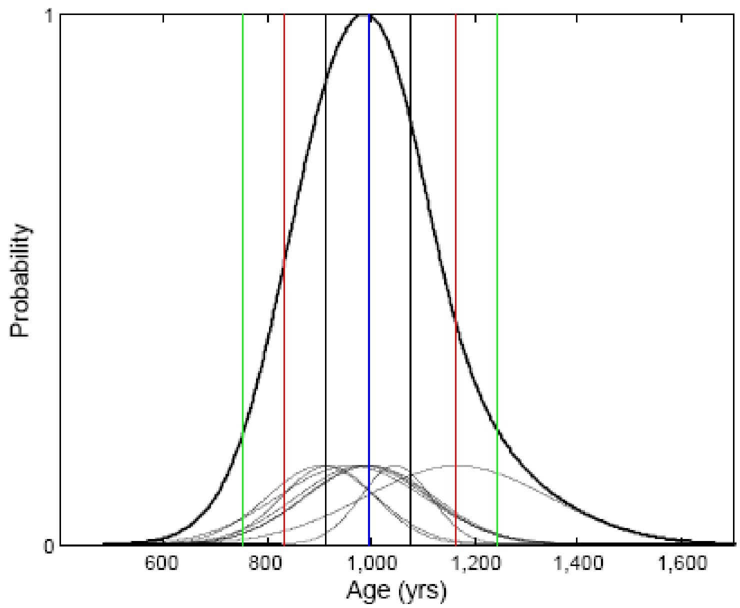
Statistics:

Arithmetic mean/1 sigma uncertainty: 160 ± 30 yrs
Including production rate uncertainty: 160 ± 30 yrs

Weighted mean/weighted uncertainty: 160 ± 10 yrs
Peak Age: 180 yrs
Median/Interquartile Range: 160 ± 40 yrs
Reduced χ^2: 7.5

Fig. S2. Probability distributions of the ^{14}C ages of the three best dated soils at Tasman Glacier from(S*12*); see also table S4. Consistent to Fig. S1, individual ^{14}C ages are given within 2σ analytical uncertainties, the arithmetic mean within standard deviation is used for the 'soil age' and plotted in Fig. 3.

(i) The 1,000 year soil (n=8: NZ- 4509, -4507, -5505, -4405, -4404, -4403, -5329, -5507); Tasman and Mueller glaciers

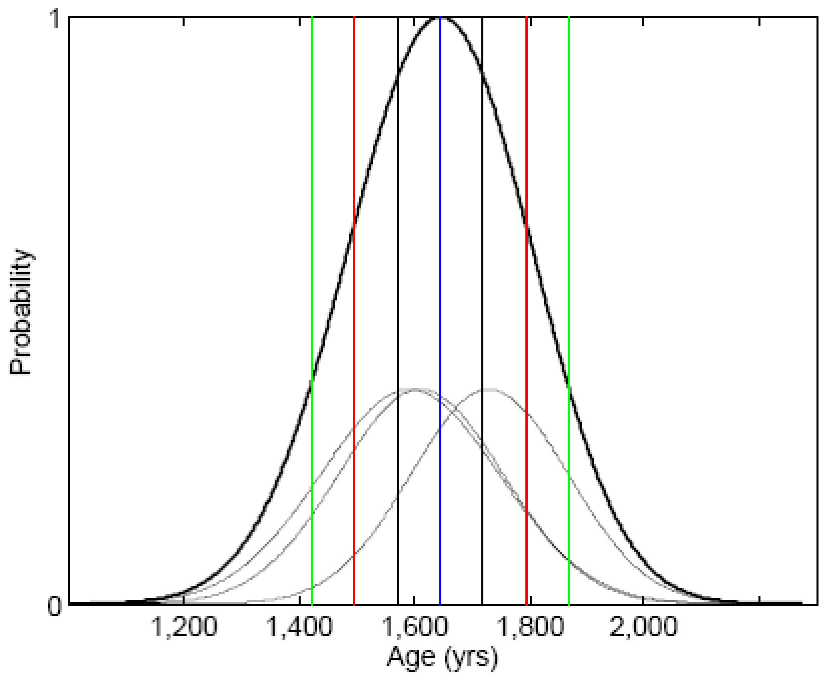


Statistics:

Arithmetic mean/1 sigma uncertainty: 1,000 ± 80 yrs

Weighted mean/weighted uncertainty: 990 ± 20 yrs
Peak Age: 960 yrs
Median/Interquartile Range: 990 ± 80 yrs
Reduced χ^2: 1.7

(ii) The 1,650 year soil (n=3: NZ- 5500, -5332, -4406); Tasman Glacier

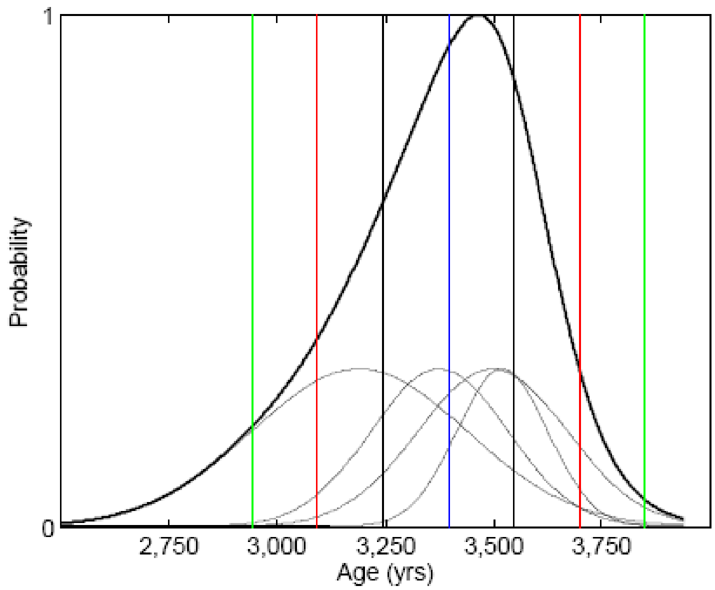


Statistics:

Arithmetic mean/1 sigma uncertainty: 1,650 ± 80 yrs

Weighted mean/weighted uncertainty: 1,650 ± 40 yrs
Peak Age: 1,620 yrs
Median/Interquartile Range: 1,610 ± 100 yrs
Reduced χ^2: 1.1

(iii) The 3,400 year soil (n=4: NZ- 5508, -5503, -5502, -5501); Tasman Glacier



Statistics:

Arithmetic mean/1 sigma uncertainty: 3,400 ± 150 yrs

Weighted mean/weighted uncertainty: 3,450 ± 40 yrs
Peak Age: 3,500 yrs
Median/Interquartile Range: 3,440 ± 230 yrs
Reduced χ^2: 3.3

Fig. S3. Example of a boulder on a Holocene moraine: Kiwi-907, embedded in the right lateral section of the '270 year moraine' of Mueller Glacier (see also Fig. 1).

Fig. S4. Detector spectrum of the CAMS facility showing the good separation of ^{10}Be (yellow dots) from ^{10}B (white dots) during a low level ^{10}Be measurement (^{10}Be/^{9}Be ≈ 4 x 10^{-16})

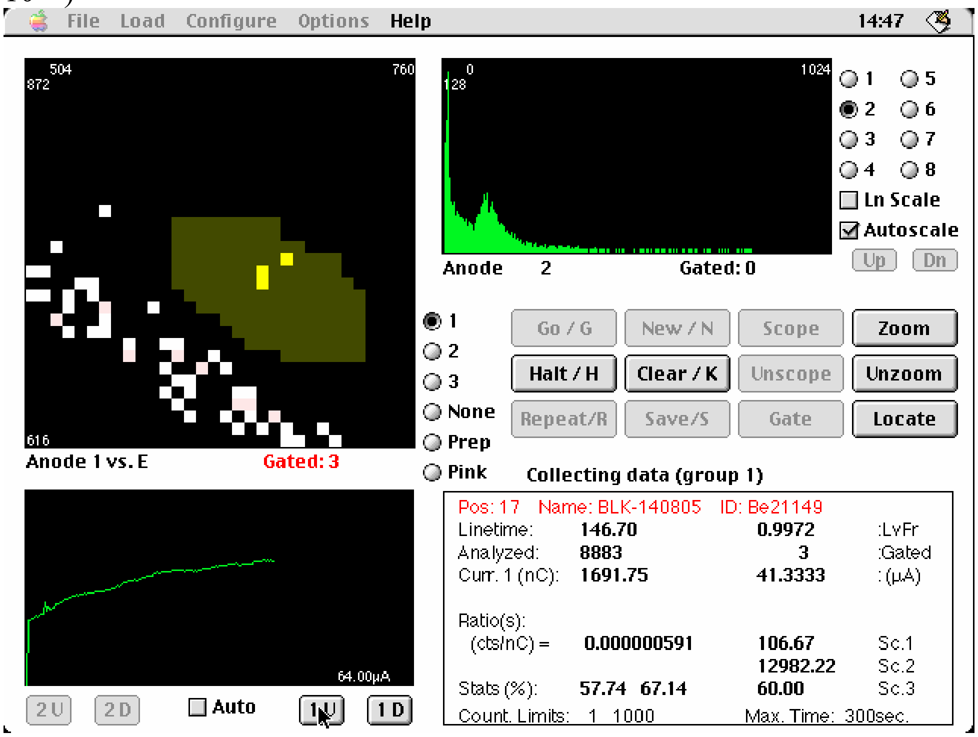


Table S1. Characteristics of the Tasman, Mueller and Hooker glaciers. Data are from a glacier inventory compiled by Trevor Chinn in 1978 (S*33*) except for ice thickness measurements of Mueller Glacier (S*34*).

	Tasman Glacier	Mueller Glacier	Hooker Glacier
Location	-43.53, 170.30	-43.74, 170.00	-43.60, 170.11
Orientation (ablation zone)	South	South East	South
Area	98.3 km^2	18.5 km^2	16.5 km^2
Elevation (maximum)	3690 m	2895 m	3754 m
Elevation (minimum)	730 m	760 m	870 m
Elevation (mean)	2210 m	1830 m	2310 m
Length (maximum)	28.5 km	13.7 km	13.1 km
Length (mean)	20 km	6.5 km	9.9 km
Width (mean)	1.9 km	0.8 km	1.1 km
Thickness (mean)	158 m	72 m	68 m
Thickness (maximum measured)	~600 m	~180 m	~200 m?

Table S2. Geographical and analytical data for the 75 samples. 20 procedural blanks, consisting of 0.18-0.20 ml ^{9}Be carrier, were processed as samples with each batch yielding ratios of ^{10}Be/^{9}Be = (5 – 20) x 10^{-16}, corresponding to blank levels of about 6,000 to 26,000 atoms ^{10}Be compared to typical levels of 70,000 to 1,000,000 atoms ^{10}Be in our samples (background correction is given for each sample). We also measured an unprocessed ^{9}Be carrier with each sample batch yielding ratios of about 5 x 10^{-16}. All ^{10}Be/^{9}Be values and ^{10}Be concentrations are normalized to the KNSTD3310 standard.

	Sample	Latitude	Longitude	Elevation	Elv/pressure	Thickness	Density	Shielding	Erosion	[^{10}Be]	1 sigma	Qz	^{9}Be carrier	^{10}Be/^{9}Be	1 sigma	^{9}Be current	boron correction	background correction	^{10}Be/^{9}Be standard used
		(DD)	(DD)	(m)	flag	(cm)	(g cm^{-3})	correction	(cm yr^{-1})	(atoms g^{-1})	(atoms g^{-1})	(g)	(mg)		(%)	(uA)	(%)	(%)	in AMS analysis
mid/late 19th century moraine Mueller																			
	Kiwi-942	-43.7155	170.0995	766	std	1.67	2.7	0.981	0	1,152	80	72.69	0.1820	6.892E-15	6.9	21	1.0%	18.9%	07KNSTD3110
	Kiwi-944	-43.7155	170.0980	776	std	2.09	2.7	0.980	0	1,433	97	73.86	0.1802	8.796E-15	6.8	15	0.6%	14.8%	07KNSTD3110
	Kiwi-943	-43.7151	170.0973	781	std	1.56	2.7	0.983	0	1,644	94	71.63	0.1810	9.740E-15	5.7	20	0.6%	13.3%	07KNSTD3110
220 yr moraine Mueller																			
	Kiwi-958	-43.7085	170.0993	797	std	2.28	2.7	0.975	0	1,923	88	100.23	0.1816	1.590E-14	4.6	24	0.3%	8.2%	07KNSTD3110
	Kiwi-959	-43.7093	170.0997	799	std	10.73	2.7	0.974	0	1,900	110	63.54	0.1621	1.115E-14	5.8	22	0.5%	11.7%	07KNSTD3110
270 year moraine Mueller																			
	Kiwi-X57	-43.7110	170.0833	861	std	7.34	2.7	0.977	0	1,500	105	63.56	0.1807	7.163E-15	7.0	19	1.2%	11.6%	07KNSTD3110
	Kiwi-908	-43.7165	170.0987	782	std	1.90	2.7	0.986	0	1,978	210	30.06	0.2032	4.382E-15	10.6	15	3.0%	50.9%	KNSTD3110
	Kiwi-913	-43.7158	170.0972	789	std	3.60	2.7	0.982	0	2,205	181	40.04	0.2035	6.497E-15	8.2	13	2.8%	34.3%	KNSTD3110
	Kiwi-X61	-43.7097	170.0823	883	std	3.08	2.7	0.980	0	2,582	110	65.58	0.1814	1.268E-14	4.2	19	0.8%	6.6%	07KNSTD3110
	Kiwi-914	-43.7148	170.0966	804	std	2.00	2.7	0.977	0	2,387	217	30.07	0.2039	5.272E-15	9.1	15	2.2%	42.3%	KNSTD3110
	Kiwi-X58	-43.7111	170.0833	861	std	2.37	2.7	0.978	0	2,756	151	51.03	0.1817	1.051E-14	5.5	21	1.4%	7.9%	07KNSTD3110
	Kiwi-X59	-43.7103	170.0828	867	std	2.96	2.7	0.976	0	2,989	179	45.73	0.2008	1.019E-14	6.0	24	0.5%	13.2%	07KNSTD3110
	Kiwi-907	-43.7166	170.1000	782	std	1.50	2.7	0.984	0	2,723	229	30.02	0.1956	6.258E-15	8.4	14	1.8%	35.6%	KNSTD3110
	Kiwi-906	-43.7165	170.1004	781	std	1.20	2.7	0.981	0	3,004	201	40.10	0.1961	9.200E-15	6.7	12	2.2%	24.2%	KNSTD3110
	Kiwi-X60	-43.7100	170.0825	880	std	2.10	2.7	0.975	0	5,058	213	68.87	0.2013	2.591E-14	4.2	25	0.2%	5.2%	07KNSTD3110
400 year moraine Mueller																			
	Kiwi-X44	-43.7115	170.1022	783	std	2.92	2.7	0.967	0	2,397	149	43.04	0.2026	6.914E-15	6.2	22	1.1%	10.8%	07KNSTD3110
	Kiwi-X42	-43.7109	170.1024	788	std	2.66	2.7	0.967	0	2,867	186	34.78	0.2011	6.733E-15	6.5	20	1.5%	12.3%	07KNSTD3110
	Kiwi-X43	-43.7110	170.1024	786	std	2.62	2.7	0.976	0	3,453	263	25.09	0.1808	6.506E-15	7.6	20	2.2%	5.5%	07KNSTD3110
	Kiwi-X45	-43.7079	170.1019	815	std	1.29	2.7	0.922	0	3,416	170	40.74	0.2016	9.375E-15	5.0	21	1.3%	8.0%	07KNSTD3110
	Kiwi-X63	-43.7168	170.1016	781	std	3.18	2.7	0.988	0	3,637	213	50.79	0.1819	1.379E-14	5.9	18	1.1%	6.0%	07KNSTD3110
	Kiwi-X36	-43.7126	170.1042	784	std	1.83	2.7	0.931	0	3,554	370	18.90	0.1796	5.081E-15	10.4	20	2.5%	7.1%	07KNSTD3110
	Kiwi-X62	-43.7168	170.1016	781	std	2.92	2.7	0.987	0	3,935	222	35.09	0.1809	1.037E-14	5.6	21	1.7%	3.5%	07KNSTD3110
	Kiwi-X46	-43.7076	170.1018	819	std	1.49	2.7	0.938	0	4,168	246	30.07	0.1801	9.451E-15	5.9	18	1.2%	3.8%	07KNSTD3110
	Kiwi-X38	-43.7128	170.1043	781	std	0.97	2.7	0.936	0	4,059	188	35.25	0.2019	9.624E-15	4.6	21	1.1%	8.6%	07KNSTD3110
570 year moraine Mueller																			
	Kiwi-940	-43.7180	170.1041	761	std	2.12	2.7	0.975	0	3,861	360	45.24	0.2075	1.260E-14	9.3	10	1.8%	8.3%	07KNSTD3110
	Kiwi-912	-43.7185	170.0982	769	std	3.74	2.7	0.980	0	4,027	278	25.04	0.2017	7.487E-15	6.9	16	1.6%	29.8%	KNSTD3110
	Kiwi-901	-43.7122	170.0821	883	std	2.40	2.7	0.961	0	4,889	440	15.24	0.1983	5.627E-15	9.0	11	9.1%	7.1%	KNSTD3110
	Kiwi-911	-43.7133	170.0888	904	std	1.90	2.7	0.968	0	5,366	333	21.94	0.1461	1.207E-14	6.2	7	4.0%	3.3%	KNSTD3110
	Kiwi-936	-43.7121	170.0821	883	std	2.40	2.7	0.959	0	5,256	336	40.14	0.2037	1.551E-14	6.4	13	1.9%	7.0%	KNSTD3110
	Kiwi-909	-43.7138	170.0922	905	std	2.30	2.7	0.986	0	5,748	345	13.88	0.1518	7.873E-15	6.0	9	6.8%	5.1%	KNSTD3110
	Kiwi-903	-43.7185	170.1008	767	std	2.20	2.7	0.979	0	5,204	281	30.13	0.1961	1.197E-14	5.4	20	0.8%	18.6%	KNSTD3110
	Kiwi-941	-43.7177	170.1031	766	std	2.41	2.7	0.979	0	5,205	243	45.12	0.2063	1.705E-14	4.7	22	0.3%	6.1%	07KNSTD3110
	Kiwi-939	-43.7185	170.1037	760	std	1.70	2.7	0.979	0	5,295	201	45.10	0.1977	1.809E-14	3.8	22	0.5%	5.8%	07KNSTD3110
	Kiwi-X65	-43.7140	170.0883	884	std	4.11	2.7	0.981	0	5,709	214	42.12	0.2012	1.623E-14	3.7	21	0.4%	5.1%	07KNSTD3110
	Kiwi-900	-43.7121	170.0824	882	std	4.10	2.7	0.969	0	6,020	319	11.94	0.2046	5.262E-15	5.3	13	4.6%	7.6%	KNSTD3110
	Kiwi-904	-43.7184	170.1008	767	std	1.67	2.7	0.979	0	6,903	251	41.01	0.1872	2.265E-14	3.6	22	0.2%	4.6%	07KNSTD3110

Table S2 continued

	Sample	Latitude (DD)	Longitude (DD)	Elevation (m)	Elv/pressure flag	Thickness (cm)	Density (g cm^{-3})	Shielding correction	Erosion (cm yr^{-1})	[^{10}Be] (atoms g^{-1})	1 sigma (atoms g^{-1})	Qz (g)	^{9}Be carrier (mg)	^{10}Be/^{9}Be	1 sigma (%)	^{9}Be current (uA)	boron correction (%)	background correction (%)	^{10}Be/^{9}Be standard used in AMS analysis
1,000 year moraine Hooker&Tasman(-972)																			
	Kiwi-927	*-43.6904*	*170.0967*	*880*	*std*	*2.69*	*2.7*	*0.970*	*0*	*7,432*	*322*	*25.65*	*0.1826*	*1.576E-14*	*4.3*	*18*	*0.6%*	*2.7%*	*07KNSTD3110*
	Kiwi-X76	-43.6896	170.1084	968	std	2.28	2.7	0.953	0	9,506	280	51.30	0.2016	3.633E-14	2.9	21	0.2%	2.9%	07KNSTD3110
	Kiwi-X54	-43.6888	170.1092	976	std	1.26	2.7	0.947	0	9,917	311	35.54	0.1794	2.951E-14	3.1	20	0.4%	1.4%	07KNSTD3110
	Kiwi-969	-43.6927	170.1054	933	std	3.60	2.7	0.965	0	9,470	767	15.07	0.1915	1.116E-14	8.1	15	1.9%	9.7%	KNSTD3110
	Kiwi-X77	-43.6923	170.1056	930	std	3.07	2.7	0.956	0	10,052	350	31.27	0.1735	2.721E-14	3.5	20	1.1%	1.5%	07KNSTD3110
	Kiwi-932_1	-43.6937	170.0945	868	std	2.04	2.7	0.975	0	10,058	2,142	8.55	0.1522	8.457E-15	21.3	16	12.2%	26.4%	KNSTD3110
Tasman	Kiwi-972	-43.6942	170.1645	767	std	2.54	2.7	0.976	0	8,805	435	20.06	0.2015	1.313E-14	4.9	18	0.8%	4.8%	07KNSTD3110
1,400 year moraine Hooker																			
	Kiwi-X51	-43.6931	170.1057	942	std	1.57	2.7	0.956	0	10,372	284	40.75	0.1800	3.527E-14	2.7	22	0.6%	2.6%	07KNSTD3110
	Kiwi-967	-43.6925	170.1063	960	std	1.90	2.7	0.970	0	12,735	841	15.05	0.2045	1.404E-14	6.6	13	1.9%	7.7%	KNSTD3110
	Kiwi-968	-43.6925	170.1063	961	std	3.10	2.7	0.943	0	13,684	835	15.11	0.2042	1.516E-14	6.1	15	1.3%	7.1%	KNSTD3110
	Kiwi-X49	-43.6929	170.1059	944	std	2.20	2.7	0.952	0	13,540	342	52.00	0.2006	5.272E-14	2.5	22	0.2%	1.6%	07KNSTD3110
	Kiwi-X52	-43.6891	170.1096	993	std	2.86	2.7	0.951	0	14,647	464	36.75	0.1720	4.701E-14	3.2	21	0.2%	2.0%	07KNSTD3110
	Kiwi-X53	-43.6889	170.1098	997	std	1.69	2.7	0.947	0	15,411	492	38.37	0.1804	4.923E-14	3.2	20	0.2%	1.9%	07KNSTD3110
1,650 year moraine Tasman																			
	KIWI-628	-43.6943	170.1637	781	std	5.00	2.7	0.990	0	13,624	598	40.28	0.2014	4.076E-14	4.4	30	0.5%	5.2%	KNSTD3110
	KIWI-971	-43.6924	170.1633	763	std	1.43	2.7	0.979	0	13,749	549	20.18	0.2036	2.041E-14	4.0	21	0.4%	7.6%	07KNSTD3110
	Kiwi-700-1	-43.6953	170.1644	782	std	6.80	2.7	0.991	0	15,620	637	16.50	0.2030	1.900E-14	4.1	17	0.9%	2.6%	KNSTD3110
	Kiwi-700-3	-43.6953	170.1644	782	std	1.60	2.7	0.991	0	14,828	501	32.19	0.2032	3.515E-14	3.4	15	0.4%	1.4%	KNSTD3110
	Kiwi-700_wm	-43.6953	170.1644	782	std	1.60	2.7	0.991	0	15,130	394								
1,800 year moraines Mueller																			
	Kiwi-X70	-43.6999	170.0958	860	std	2.63	2.7	0.984	0	15,816	461	41.58	0.2031	4.397E-14	2.9	21	0.2%	1.9%	07KNSTD3110
	Kiwi-X74	-43.6985	170.0942	865	std	2.91	2.7	0.985	0	16,166	421	35.17	0.2009	3.843E-14	2.6	23	0.2%	2.2%	07KNSTD3110
	Kiwi-X73	-43.6985	170.0942	865	std	3.32	2.7	0.985	0	16,625	506	30.07	0.1961	3.463E-14	3.0	23	0.2%	2.4%	07KNSTD3110
	Kiwi-X79	-43.6977	170.0944	861	std	3.54	2.7	0.989	0	16,662	449	35.24	0.2042	3.905E-14	2.7	21	0.2%	2.1%	07KNSTD3110
	Kiwi-957	-43.6991	170.0959	856	std	2.72	2.7	0.977	0	16,607	710	16.47	0.2033	2.015E-14	4.3	19	0.3%	2.4%	07KNSTD3110
	Kiwi-926	-43.6975	170.0940	861	std	2.22	2.7	0.979	0	17,648	647	20.14	0.2027	2.625E-14	3.7	17	0.4%	7.0%	KNSTD3110
	Kiwi-X71	-43.6999	170.0956	861	std	5.50	2.7	0.985	0	17,780	587	35.51	0.2012	4.261E-14	3.3	21	0.2%	2.0%	07KNSTD3110
2,000 year moraine Mueller																			
	Kiwi-955	-43.6976	170.0959	849	std	2.00	2.7	0.976	0	17,360	781	25.09	0.2039	3.196E-14	4.5	20	0.2%	2.3%	07KNSTD3110
	Kiwi-956	-43.6982	170.0969	842	std	4.03	2.7	0.973	0	18,212	778	20.57	0.2030	2.763E-14	4.3	19	0.4%	3.1%	07KNSTD3110
	Kiwi-X66	-43.7146	170.0896	878	std	2.31	2.7	0.986	0	19,526	476	60.91	0.2017	8.857E-14	2.4	22	0.4%	0.9%	07KNSTD3110
3,200 year moraine Mueller																			
	Kiwi-902	-43.7167	170.0940	806	std	1.10	2.7	0.985	0	26,983	1,052	11.59	0.2058	2.275E-14	3.9	8	3.7%	1.8%	KNSTD3110
	Kiwi-905	-43.7173	170.0945	790	std	1.70	2.7	0.983	0	27,187	1,115	9.50	0.1484	2.606E-14	4.1	11	2.0%	1.5%	KNSTD3110
	Kiwi-938	-43.7171	170.0911	786	std	3.70	2.7	0.973	0	28,220	1,213	15.12	0.1992	3.207E-14	4.3	17	0.5%	3.4%	KNSTD3110
	Kiwi-937	-43.7165	170.0900	807	std	3.10	2.7	0.981	0	28,950	1,332	11.14	0.2031	2.378E-14	4.6	16	0.7%	4.5%	KNSTD3110
6,500 year moraine Mueller&Tasman																			
	Kiwi-610-2	-43.7007	170.1603	693	std	3.10	2.7	0.979	0	50,048	1,301	12.27	0.1968	4.673E-14	2.6	12	0.9%	0.9%	KNSTD3110
	KIWI-801B	-43.7207	170.0920	760	std	3.20	2.7	0.980	0	53,327	3,154	2.07	0.1467	1.125E-14	5.9	16	1.4%	9.5%	KNSTD3110
	Kiwi-915	-43.7007	170.1603	693	std	1.80	2.7	0.979	0	52,085	1,354	12.20	0.1962	4.851E-14	2.6	10	1.5%	0.8%	KNSTD3110
	KIWI-609	-43.7005	170.1601	691	std	4.00	2.7	0.979	0	51,364	1,272	17.61	0.2017	6.716E-14	2.5	33	0.2%	3.2%	KNSTD3110
	KIWI-627	-43.7008	170.1604	693	std	10.00	2.7	0.981	0	49,322	1,267	20.08	0.2012	7.371E-14	2.6	29	0.2%	2.9%	KNSTD3110
	KIWI-626-2	-43.7005	170.1601	691	std	4.30	2.7	0.982	0	53,333	1,297	20.14	0.2007	8.016E-14	2.4	32	0.2%	2.6%	KNSTD3110
"Outliers" Hooker																			
	Kiwi-931	-43.6926	170.0942	877	std	2.15	2.7	0.976	0	4,249	306	25.00	0.2034	7.822E-15	7.2	21	1.1%	28.5%	KNSTD3110
	Kiwi-930	-43.6921	170.0940	880	std	1.60	2.7	0.971	0	6,780	692	9.07	0.1531	6.014E-15	10.2	18	1.8%	37.1%	KNSTD3110

Table S3. ^{10}Be ages in years of all 75 samples based on six different scaling protocols documented in(S*7*): ‘St/Lal ntd’ based on (S*35*), giving an update to (S*6*), scaling parameters assumed constant with time; ‘St/Lal td’ being the time dependent version of ‘St/Lal ntd’; ‘Du’: scaling according to (S*36*); ‘Li’: scaling according to (S*37*); ‘De’: scaling given by (S*38*); and ‘De updated PR: scaling according to (S*38*), updated by a new production rate calibration experiment relevant for latitudes higher 40º and altitudes below 1000m, yielding about 7-10% lower production rate values in this case (S*8*).

		St/Lal ntd	2 sigma	ext error	St/Lal td	2 sigma	Du	2 sigma	Li	2 sigma	De	2 sigma	De, updated PR	1 sigma	2 sigma
mid/late 19th century moraine Mueller															
	Kiwi-942	122	16	13	124	16	121	16	119	16	123	16	**132**	**9**	**17**
	Kiwi-944	151	20	17	153	20	150	20	147	19	153	20	**164**	**11**	**22**
	Kiwi-943	171	20	18	174	20	170	20	167	20	173	20	**185**	**11**	**22**
220 year moraine Mueller															
	Kiwi-958	200	18	20	204	18	199	18	195	18	203	18	**217**	**10**	**20**
	Kiwi-959	211	24	22	215	24	210	24	206	23	215	24	**230**	**13**	**26**
270 year moraine Mueller															
	Kiwi-X57	154	22	17	157	22	152	22	150	21	156	22	**167**	**12**	**24**
	Kiwi-908	205	44	28	209	45	204	44	201	43	208	45	**223**	**24**	**48**
	Kiwi-913	232	38	28	236	39	230	38	226	37	235	38	**251**	**21**	**41**
	Kiwi-X61	251	22	24	256	22	248	22	244	21	254	22	**272**	**12**	**24**
	Kiwi-914	246	44	31	250	45	244	44	240	43	249	45	**266**	**24**	**48**
	Kiwi-X58	272	30	28	277	31	269	30	264	29	275	30	**294**	**16**	**32**
	Kiwi-X59	295	36	31	301	37	292	36	287	35	299	36	**320**	**20**	**39**
	Kiwi-907	282	48	34	288	49	281	48	276	47	287	49	**307**	**26**	**52**
	Kiwi-906	312	42	34	318	43	310	42	305	41	317	43	**339**	**23**	**46**
	Kiwi-X60	491	42	47	500	43	486	42	477	41	497	43	**532**	**23**	**45**
400 year moraine Mueller															
	Kiwi-X44	255	32	27	260	33	254	32	249	31	259	33	**277**	**17**	**35**
	Kiwi-X42	304	40	33	309	41	302	40	296	39	308	41	**330**	**22**	**43**
	Kiwi-X43	363	56	42	370	57	361	56	354	55	368	57	**394**	**30**	**61**
	Kiwi-X45	367	36	37	374	37	364	36	357	35	372	36	**398**	**20**	**39**
	Kiwi-X63	381	44	40	388	45	379	44	372	43	387	45	**414**	**24**	**48**
	Kiwi-X36	389	82	53	397	84	387	82	380	80	395	83	**423**	**45**	**89**
	Kiwi-X62	412	46	43	420	47	409	46	402	45	418	47	**447**	**25**	**50**
	Kiwi-X46	439	52	46	448	53	436	52	428	51	445	53	**476**	**28**	**56**
	Kiwi-X38	440	40	43	449	41	438	40	430	39	447	41	**478**	**22**	**43**
570 year moraine Mueller															
	Kiwi-940	413	78	53	421	80	411	78	404	76	420	79	**449**	**42**	**85**
	Kiwi-912	431	60	48	440	61	429	60	422	59	438	61	**469**	**33**	**65**
	Kiwi-901	482	86	60	491	88	476	85	468	84	487	87	**521**	**46**	**93**
	Kiwi-911	514	64	55	524	65	508	63	499	62	520	65	**556**	**35**	**69**
	Kiwi-936	519	66	56	529	67	513	65	504	64	525	67	**562**	**36**	**71**
	Kiwi-909	542	66	57	553	67	536	65	527	64	549	67	**587**	**36**	**72**
	Kiwi-903	552	60	56	563	61	550	60	541	59	563	61	**602**	**33**	**65**
	Kiwi-941	554	52	54	565	53	552	52	542	51	564	53	**603**	**28**	**57**
	Kiwi-939	563	42	53	574	43	562	42	552	41	574	43	**614**	**23**	**46**
	Kiwi-X65	559	42	53	570	43	554	42	544	41	567	43	**607**	**23**	**46**
	Kiwi-900	597	64	61	610	65	593	64	583	62	607	65	**649**	**35**	**70**
	Kiwi-904	729	52	69	746	53	732	52	720	51	748	53	**800**	**29**	**57**

Table S3 continued

		St/Lal ntd	2 sigma	ext error	St/Lal td	2 sigma	Du	2 sigma	Li	2 sigma	De	2 sigma	De, updated PR	1 sigma	2 sigma
1,000 year moraine Hooker&Tasman(-972)															
	Kiwi-927	*736*	*64*	*71*	*753*	*65*	*735*	*64*	*723*	*63*	*752*	*65*	***805***	***35***	***70***
	Kiwi-X76	881	52	81	903	53	879	52	865	51	900	53	**963**	**28**	**57**
	Kiwi-X54	912	58	84	934	59	909	58	894	57	931	59	**996**	**32**	**63**
	Kiwi-969	902	146	107	924	150	901	146	886	143	922	149	**987**	**80**	**160**
	Kiwi-X77	964	68	90	988	70	964	68	949	67	987	70	**1056**	**37**	**74**
	Kiwi-932_1	986	420	227	1011	431	990	422	974	415	1013	432	**1084**	**231**	**462**
Tasman	Kiwi-972	940	92	94	963	94	947	93	933	91	968	95	**1036**	**51**	**101**
1,400 year moraine Hooker															
	Kiwi-X51	973	54	88	998	55	973	54	958	53	996	55	**1066**	**30**	**59**
	Kiwi-967	1164	154	127	1194	158	1173	155	1150	152	1195	158	**1279**	**85**	**169**
	Kiwi-968	1298	158	138	1331	162	1314	160	1285	156	1335	163	**1428**	**87**	**174**
	Kiwi-X49	1280	64	116	1313	66	1296	65	1269	63	1317	66	**1409**	**35**	**70**
	Kiwi-X52	1341	84	124	1375	86	1357	85	1327	83	1378	86	**1474**	**46**	**92**
	Kiwi-X53	1398	90	129	1434	92	1417	91	1385	89	1438	93	**1539**	**50**	**99**
1,650 year moraine Tasman															
	KIWI-628	1447	128	141	1483	131	1484	131	1450	128	1502	133	**1607**	**71**	**142**
	KIWI-971	1455	116	139	1491	119	1493	119	1459	116	1511	120	**1617**	**64**	**129**
	Kiwi-700-1	1680	138	161	1722	141	1735	143	1692	139	1751	144	**1874**	**77**	**154**
	Kiwi-700-3	1529	104	142	1567	107	1572	107	1534	104	1589	108	**1700**	**58**	**116**
	Kiwi-700_wm	1560	82	141	1599	84	1605	84	1566	82	1622	85	**1736**	**46**	**91**
1,800 year moraines Mueller															
	Kiwi-X70	1554	90	142	1593	92	1594	92	1554	90	1611	93	**1724**	**50**	**100**
	Kiwi-X74	1585	82	143	1624	84	1626	84	1585	82	1643	85	**1758**	**45**	**91**
	Kiwi-X73	1635	100	150	1676	103	1680	103	1638	100	1697	104	**1816**	**56**	**111**
	Kiwi-X79	1640	88	149	1681	90	1686	90	1644	88	1703	91	**1822**	**49**	**98**
	Kiwi-957	1650	142	160	1691	146	1697	146	1654	142	1713	147	**1833**	**79**	**158**
	Kiwi-926	1736	128	163	1779	131	1789	132	1743	129	1804	133	**1930**	**71**	**142**
	Kiwi-X71	1786	118	166	1830	121	1843	122	1795	119	1857	123	**1987**	**66**	**131**
2,000 year moraine Mueller															
	Kiwi-955	1726	156	169	1769	160	1780	161	1734	157	1795	162	**1921**	**87**	**174**
	Kiwi-956	1857	158	180	1903	162	1921	163	1871	159	1935	165	**2070**	**88**	**176**
	Kiwi-X66	1882	92	170	1928	94	1945	95	1893	93	1959	96	**2096**	**51**	**102**
3,200 year moraine Mueller															
	Kiwi-902	2733	214	260	2792	219	2850	223	2781	218	2864	224	**3064**	**120**	**240**
	Kiwi-905	2809	230	270	2870	235	2931	240	2862	234	2946	241	**3152**	**129**	**258**
	Kiwi-938	3004	258	291	3068	263	3130	269	3061	263	3149	270	**3369**	**145**	**289**
	Kiwi-937	2990	276	294	3054	282	3114	287	3045	281	3133	289	**3352**	**155**	**309**
6,500 year moraine Mueller (-801)&Tasman															
	KIWI-801	5737	680	603	5783	685	5903	700	5809	689	5951	705	**6368**	**377**	**755**
	Kiwi-610-2	5690	296	516	5741	299	5872	305	5781	301	5919	308	**6333**	**165**	**329**
	Kiwi-915	5860	306	531	5903	308	6040	315	5943	310	6086	318	**6512**	**170**	**340**
	KIWI-609	5893	292	532	5935	294	6074	301	5975	296	6120	303	**6548**	**162**	**324**
	KIWI-627	5918	304	536	5959	306	6098	313	5998	308	6144	316	**6574**	**169**	**338**
	KIWI-626-2	6116	298	551	6150	300	6296	307	6188	302	6341	309	**6785**	**165**	**331**
													6333	**165**	
"Outliers" Hooker															
	Kiwi-931	414	60	47	421	61	409	59	402	58	418	61	**447**	**32**	**65**
	Kiwi-930	659	134	88	673	137	656	133	645	131	671	136	**718**	**73**	**146**

Table S4. Radiocarbon data of wood buried in soil, covered by till ((S*12*)and references therein). To be able to directly compare given ^{14}C and ^{10}Be ages, we have nomalized the AD/BC calibrated ^{14}C ages to years before AD 2005, when most of the ^{10}Be samples were collected for this study.

Location	Lab No. (1)	Latitude (2)	Longitude (2)	CRA (1)	Calendric younger bound (AD/-BC) (3)	Years before AD 2005 - younger bound (4)	Calendric older bound (AD/-BC) (3)	Years before AD 2005 - older bound (4)	Mid-point of age range (years before AD 2005) (5)	2-sigma uncertainty of age range (years) (5)	Stratigraphic context (6)	Interpretation (6)	Reference (6)
Tasman Glacier, Ball Hut	NZ-5504	-43.6167	170.1933	-189+/-79							Twigs and organic soil buried by till, 2 m below moraine crest	Either post-1950, or contaminated with post-1950 carbon	b
<325 yr soil providing maximum age for an advance of Tasman Glacier													
Tasman Glacier, Ball Hut	NZ-5506	-43.6167	170.1933	88+/-54	1956	49	1679	326	188	139	Branches from surface of soil, buried by 2.5 m thick flow till	Dates a period of glacier expansion	b
< 550 yr soil providing maximum age for an advance of Tasman Glacier													
Tasman Glacier, Novara	NZ-5330	-43.6154	170.2156	343+/-55	1793	212	1455	550	381	169	Branches from surface of buried soil, 10.5 m below moraine crest	Records glacier expansion following a period of soil and vegetation development	b
~ 650 yr soil providing maximum age for an advance of Tasman Glacier													
Tasman Glacier, Ball Hut	NZ-5535 (NZ-711)	-43.6167	170.1933	663+/-61	1420	585	1280	725	655	70	5 cm of soil with branches, on till, buried by till	Records glacier expansion following a period of soil and vegetation development	a, b
~ 650 yr soil providing minimum age for formation of a Hooker Glacier moraine ridge													
Hooker Glacier, Hooker Hut	NZ-5253	-43.6624	170.1117	685+/-35	1393	612	1290	715	664	52	Leaves and soil on sand deposited against moraine ridge. Soil buried by colluvium	Minimum age for moraine formation	b
arithmetic mean/1 sigma									659	6			
~850 yr soils providing maximum age for advance of Tasman Glacier													
Tasman Glacier, Novara	NZ-5331	-43.6154	170.2156	864+/-57	1291	714	1046	959	837	123	Branches from surface of buried soil, 17 m below moraine crest	Records a soil buried by glacier expansion. Assumed to be part of the same sloping soils surface as dated by NZ-5254	b
Tasman Glacier, Novara	NZ-5254	-43.6154	170.2156	933+/-57	1263	742	1028	977	860	118	Soil on till, buried by till, 14 m below moraine crest	Records a soil buried by glacier expansion. Assumed to be part of the same sloping soils surface as dated by NZ-5331	b
arithmetic mean/1 sigma									848	16			
~900 to ~1100 yr soils providing maximum age for advances of Tasman and Mueller glaciers													
Tasman Glacier, Ball Hut	NZ-4509	-43.6167	170.1933	996+/-58	1204	801	994	1011	906	105	Small branches in a soil on till, buried by till	Records glacier expansion following a period of soil and vegetation development	a
Mueller Glacier, left lateral	NZ-4507	-43.6987	170.0876	1007+/-45	1177	828	995	1010	919	91	Twigs & roots in a soil on till buried by till, 14 m below moraine crest	Prominent soil 1 m lower than NZ-5329 soil. Records glacier expansion following a period of soil and vegetation development	a
Tasman Glacier, Ball Hut	NZ-5505	-43.6167	170.1933	1033+/-57	1184	821	903	1102	962	141	Branches from surface of a soil on till, buried by till, 12-20 m below moraine crest	Records glacier expansion following a period of soil and vegetation development. Assumed to part of a single sloping soil surface, also sampled by NZ-5507	b
Tasman Glacier, Ball Hut	NZ-4405	-43.6167	170.1933	1077+/-47	1148	857	895	1110	984	127	Small branches in a soil on till, buried by till	Lowest of 3 buried soils at one site. May approximate fluctuating level of glacier surface	a
Tasman Glacier, Ball Hut	NZ-4404	-43.6167	170.1933	1100+/-47	1133	872	890	1115	994	122	Small branches in a soil on till, buried by till	Middle of 3 buried soils at one site. May approximate fluctuating level of glacier surface	a
Tasman Glacier, Ball Hut	NZ-4403	-43.6167	170.1933	1112+/-47	1130	875	883	1122	999	124	Organic material in soil on till, buried by till, about 30 m below moraine crest	Highest of 3 buried soils at one site. May approximate fluctuating level of glacier surface	a
Mueller Glacier, left lateral	NZ-5329	-43.6987	170.0876	1129+/-40	1025	980	889	1116	1048	68	Soil on till buried by till, 14 m below moraine crest	Thin soil 1 m higher than NZ-4507 soil. Records glacier expansion following a period of soil and vegetation development	b
Tasman Glacier, Ball Hut	NZ-5507	-43.6167	170.1933	1193+/-100	1016	989	661	1344	1167	178	Branches from surface of soil on till, buried by till, 3-5 m below local moraine crest	Records glacier expansion following a period of soil and vegetation development. Assumed to part of a single sloping soil surface, also sampled by NZ-5505	b
arithmetic mean/1 sigma									1000	80			
~1600 to ~1700 yr soils providing maximum age for an advance of Tasman Glacier													
Tasman Glacier, Novara	NZ-5500	-43.6154	170.2156	1662+/-59	536	1469	251	1754	1612	143	Twigs from above soil on till, buried by till, 21.5 m below moraine crest	Records glacier expansion following a period of soil and vegetation development. Inferred by Burrows to be part of same sloping burried soil surface as at NZ-5332	b
Tasman Glacier, Novara	NZ-5332	-43.6154	170.2156	1622+/-60	567	1438	258	1747	1593	155	Branches from surface of a soil on till, buried by till, 26 m below moraine crest	Records glacier expansion following a period of soil and vegetation development. Inferred by Burrows to be part of same sloping burried soil surface as at NZ-5500	b
Tasman Glacier, Ball Hut	NZ-4406	-43.6167	170.1933	1742+/-48	410	1595	139	1866	1731	136	Small branches in a soil on till, buried by till, about 40 m below moraine crest	Records glacier expansion following a period of soil and vegetation development	a
arithmetic mean/1 sigma									1650	80			
~2300 yr soil providing maximum age for an advance of Tasman Glacier													
Tasman Glacier, Ball Hut	NZ-5335	-43.6167	170.1933	2284+/-41	-207	2212	-405	2410	2311	99	Wood in soil on till, buried by till, 50 m below moraine crest	Records glacier expansion following a period of soil and vegetation development	b
~3200 to ~3500 yr soils providing ages for progressive expansion of Tasman Glacier													b
Tasman Glacier, Ball Bluff	NZ-5508	-43.6230	170.1930	2988+/-96	-938	2943	-1434	3439	3191	248	Soil, peat & twigs on till, buried by till, 12 m below AD1880 moraine crest	Records glacier expansion following a period of soil and vegetation development. Burrows infers to represent a slow glacier expansion that progressively buried a soil	b
Tasman Glacier, Ball Bluff	NZ-5503	-43.6230	170.1930	3125+/-66	-1212	3217	-1528	3533	3375	158	Branches from surface of soil on till, buried by till, 15 m below AD1880 moraine crest	Records glacier expansion following a period of soil and vegetation development. Burrows infers to represent a slow glacier expansion that progressively buried a soil	b
Tasman Glacier, Ball Bluff	NZ-5502	-43.6230	170.1930	3216+/-66	-1321	3326	-1664	3669	3498	172	Branches from surface of soil on till, buried by till, 18 m below AD1880 moraine crest	Records glacier expansion following a period of soil and vegetation development. Burrows infers to represent a slow glacier expansion that progressively buried a soil	b
Tasman Glacier, Ball Bluff	NZ-5501	-43.6230	170.1930	3224+/-52	-1410	3415	-1619	3624	3520	105	Branches from surface of soil on till, buried by till, 38 m below AD1880 moraine crest	Records glacier expansion following a period of soil and vegetation development. Burrows infers to represent a slow glacier expansion that progressively buried a soil	b
arithmetic mean/1 sigma									3400	150			
~3650 to ~3750 yr soils providing maximum ages for advance(s) of Tasman Glacier													
Tasman Glacier, Novara	NZ-5333	-43.6154	170.2156	3361+/-95	-1447	3452	-1886	3891	3672	220	Enigmatic soil-like water-laid deposit, 43 m below moraine crest	Presumably coeval with or post-dating an advance	b
Tasman Glacier, Novara	NZ-5334	-43.6154	170.2156	3446+/-68	-1540	3545	-1940	3945	3745	200	Branches from surface of a soil on till, buried by till, 70 m below moraine crest	Records glacier expansion following a period of soil and vegetation development	b
arithmetic mean/1 sigma									3708	52			

NOTES
(1) All analyses performed at Rafter Radiocarbon Laboratory, GNS Science, New Zealand (and its precessors). Laboratory numbers and Conventional Radiocarbon Age (CRA), recalculated to modern standards, from the Rafter 14C database, accessed 2004.
(2) Locations are digital degrees in terms of WGS84 datum based on information in References (note 6).
(3) Calendar ages (2 sigma uncertainty) derived from INTCAL04, using CALIB 5.0.1, with Southern Hemisphere correction for samples with median CRA < 1175 years, and otherwise using Northern Hemisphere atmosphere curve. Negative values denote BC.
(4) Time elapsed between the calendric date and AD 2005.
(5) Mid-point of time elapsed between AD 2005 and older/younger calendric bounds, with associated uncertainty
(6) Stratigraphic context and interpretations as presented in the references; a) C. J. Burrows, New Zealand Journal of Geology and Geophysics 23, 239 (1980); b) C. J. Burrows, New Zealand Journal of Geology and Geophysics 32, 205 (1989)

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