Radiocarbon dating and geological assessment of sediments associated with the Clutha River delta, South Otago

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EXECUTIVE SUMMARY

Groundwater investigation drilling was undertaken in 2021 by Otago Regional Council (ORC) on the extensive low-lying plain (Clutha delta) associated with the near-coastal reach of the Clutha River / Mata-Au valley. The Clutha delta consists of poorly consolidated, geologically young, silty, sandy and gravelly sediments. Several drill holes encountered carbon-bearing fossil materials within the sediments, including plant fragments, wood, mollusc shells and microfossils. Organic fossils such as these are potentially suitable for radiocarbon dating. The ages of the fossils give information on the history of deposition of the enclosing sediments. Knowledge of the Clutha delta's recent geological history may aid the assessment of natural hazards, such as the occurrence of vertical land movement that may affect forecasts of future sea level rise. ORC engaged GNS Science to examine the drill cores, to collect and radiocarbon-date samples, and to interpret and assess the results. That work is documented in this report.

Radiocarbon dating utilises the radioactive isotope of carbon (carbon-14, symbolised as ^{14}C), which is constantly being formed in the atmosphere in trace amounts and is absorbed into living organisms. After death, ^{14}C decays radioactively at a known rate and the amount remaining is a measure of how long ago the organism died. The older limit of the ^{14}C dating method is about 50,000 years. Natural variations in the amount of ^{14}C in the environment at different times in the past means that an adjustment has to be applied to ^{14}C measurements to obtain accurate ages in calendar years before present. In addition to the ^{14}C sampling, sediment samples were collected to look for diagnostic microfossils that may indicate the environment in which the sediment was deposited (e.g. river plain, estuary or shallow sea).

Seven samples of organic material were ^{14}C-dated. One age came back at >50,000 years while the other six samples, collected from depths between ~28 m and ~4 m, yielded ages from ~9,900 to ~7,500 calendar years BP (Figure ES.1). These samples show consistent relationships between age and depth and provide a coherent picture of the recent geological evolution of the Clutha delta area. Over the ~2,400-year time span between these six samples, ~23 m of sediment accumulated on the Clutha delta. The sedimentation rate averaged across that time span was ~1 m per 100 years.

Global glacial and interglacial climate cycles have been accompanied by large natural sea level variations; the sea was as much as 120 m lower than present during maximal glacial climate. Gradient contrasts between the gentle Clutha valley and the steeper continental shelf offshore (which was land during glacial-period low sea level) have been a key long-term control on Clutha River behaviour. During glacial periods, the river cut down into its bed, forming an incised valley graded to the outer edge of the continental shelf. The most recent glacial to interglacial climate transition saw sea level rise by ~120 m between ~18,000 years ago and attainment of its present level ~6,500 years ago. The average rate of post-glacial sea rise of ~1 m per 100 years is identical to the average sedimentation rate on the Clutha delta area between ~9,900 and ~7,500 years ago. This indicates that river sediment deposition kept pace with the rising sea, a finding reinforced by the environment-of-deposition samples which indicate the sediment was deposited on a river plain, with evidence for only limited marine incursion into the lower reaches of floodplain channels. The Clutha delta evolved to its present form as an upward-building coastal river plain, and the main elements of its present form were in place by ~7,500 years ago or shortly thereafter. Wave-cut cliffs around the Clutha delta margins probably relate to a freshwater lake rather than a marine inlet, based on environmental indicators. The cliffs may date from about the culmination of sea rise ~6,500 years ago. The presence of a lake implies that a precursor to

the present coastal beach/dune barrier had already formed, otherwise seawater would have inundated the delta. The rapidity with which sediment back-filled the Clutha River's former incised channel during post-glacial sea rise suggests that any permanent lake would quickly have filled in with river sediment. It is suggested that the lake was short-lived, and after it filled in, the river and coast developed an equilibrium relationship, with virtually all the river sediment transported away to the northeast by coastal currents.

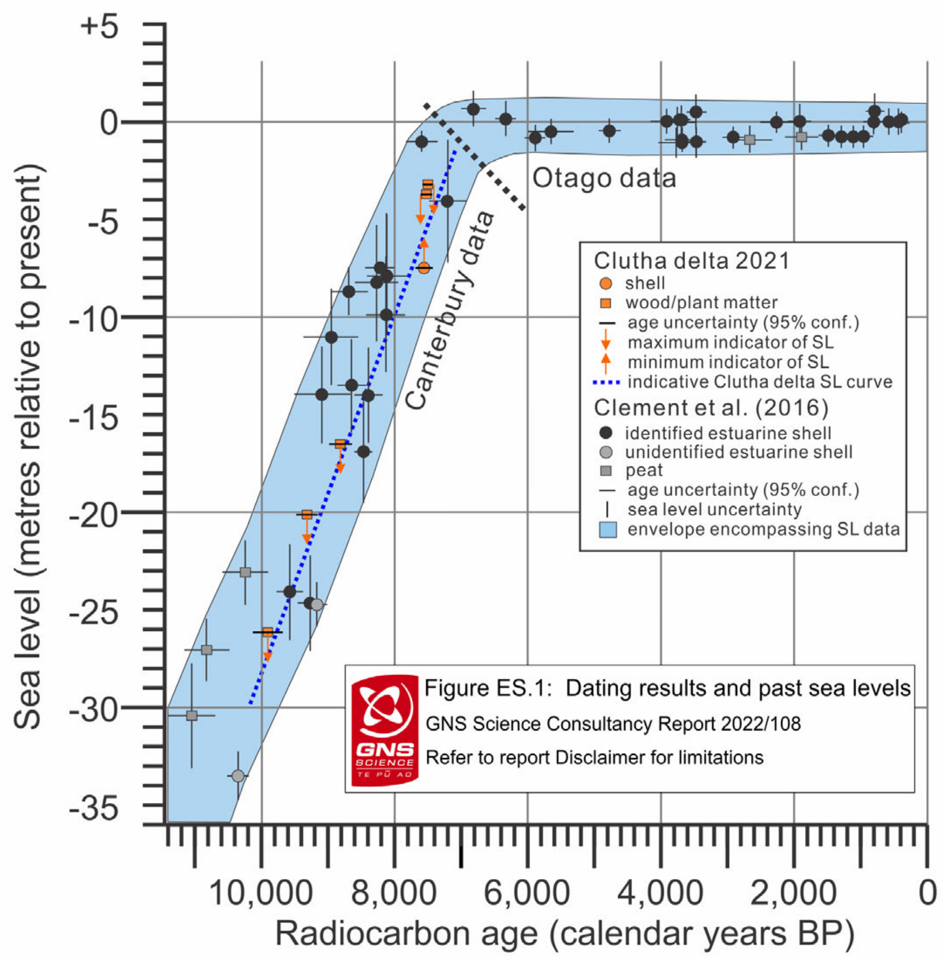

Figure ES.1 Dating results and past sea levels. The ORC 2021 Clutha delta dating results (orange) are plotted in relation to age uncertainty and the type of sea-level (SL) indication provided by the dated material. This diagram is a reproduction of Figure 4.3 of this report and more information is provided in the caption of that figure.

Geological faults near the Clutha delta have very low activity, with long recurrence intervals for large earthquakes. Poorly consolidated fine-grained sediments extensively underlie the Clutha delta. This highlights that seismic shaking amplification and earthquake-induced liquefaction (and the related phenomenon of lateral spreading) may be important potential hazards to consider in relation to infrastructure such as the flood bank network. Long-term geological evidence indicates negligible vertical land movement of the Clutha delta area over the past ~120,000 years ago, but a possibility of shorter episodes of subsidence and uplift that balanced out cannot be excluded. Based on the drilling and dating results, possibilities for overall vertical land movement over the past ~7,500 years range from slight subsidence to no change, or slight uplift. Satellite measurements indicate the Clutha delta coast is sinking slowly, at rate that by 2100 would amount to no more than 0.12 m of downward movement. The projected rise in ocean level by 2100 of between 0.2 m and 1.5 m means the effect of subsiding land would represent only a minor contribution to relative sea level rise in the Clutha delta area.

1.0 INTRODUCTION

1.1 Overview

In 2021, Otago Regional Council (ORC) undertook a project of groundwater investigation drilling on the extensive low-lying plain (referred to here as the Clutha delta) associated with the near-coastal reach of the Clutha River / Mata-Au[1] valley (Figures 1.1 and 1.2). ORC discussed the project with GNS Science (GNS) before and during the drilling, in anticipation that the drilling results may be of geoscientific interest. The holes were cored, and in several places encountered carbonaceous deposits (e.g. wood) potentially suitable for radiocarbon (^{14}C) dating. Upon further discussion, ORC engaged GNS to examine the cores, collect samples for ^{14}C dating, undertake the dating and to interpret and assess the results. This report presents the results of dating, interprets the findings within the context of the Clutha delta's geological development, and discusses the implication for natural hazards (e.g. rates of vertical land movement).

Figure 1.1 Clutha delta view. Aerial view south-southwest from near Kaitangata (see Figure 1.2 for approximate field of view). MH=Matau Hall; KP=Kaka Point township. Photo: GNS Science VML ID 3936, Lloyd Homer, dated March 1982. This photo is also published in Te Ara - the Encyclopedia of New Zealand, http://www.teara.govt.nz/en/photograph/22791/inch-clutha-and-the-river-mouth.

[1] The full name is abbreviated to Clutha River throughout this report

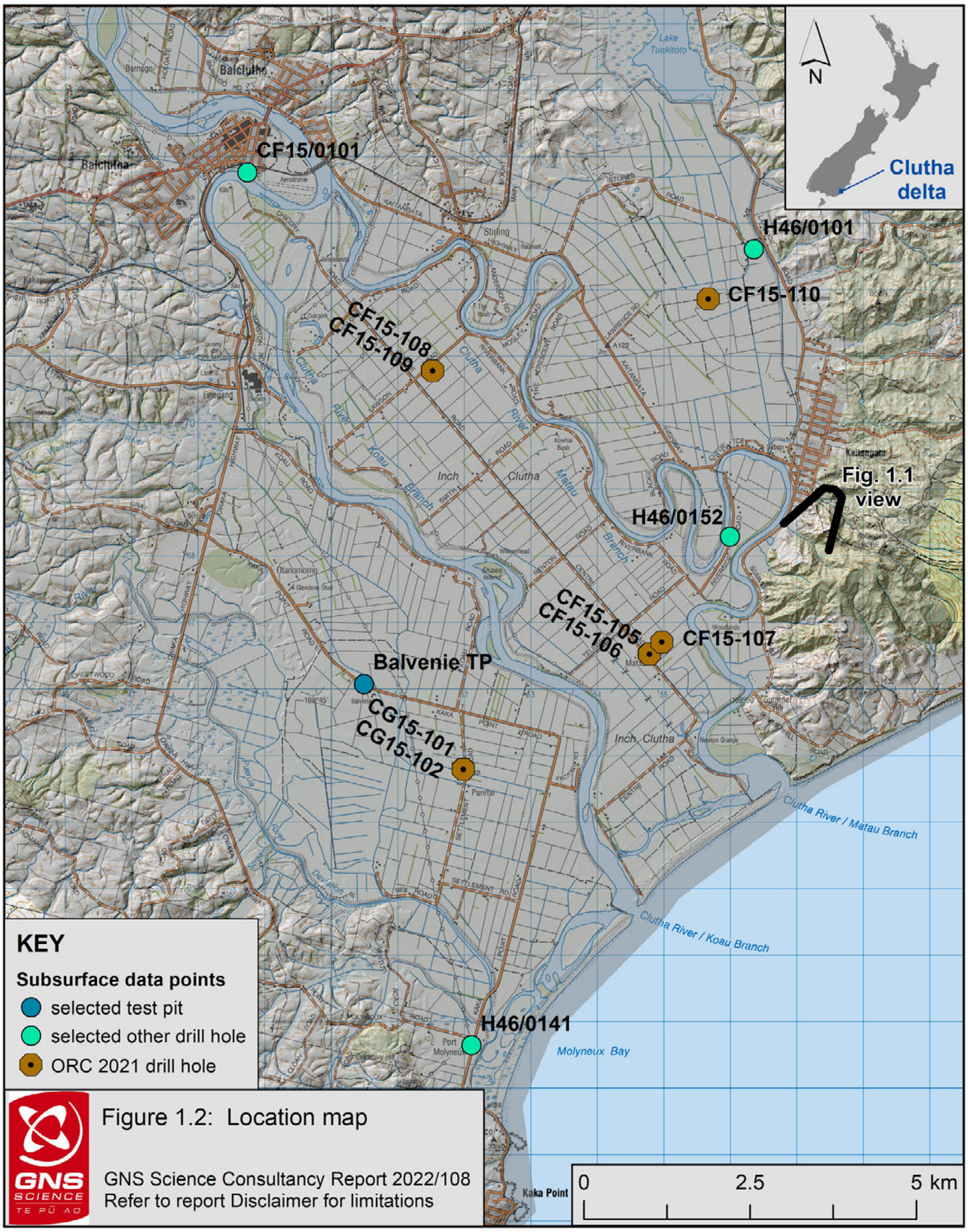

Figure 1.2 Location map. This map shows the general location of the Clutha delta area, with selected subsurface data points. The Topo 50 digital topographic map is draped transparently over a lidar-derived DEM (grey shading). The approximate field of view of Figure 1.1 is indicated. Labels presented at 45° from horizontal indicate two drill holes located side by side (i.e. within less than 10 m of one another). Refer to Appendix 1 for ORC 2021 drill hole information.

1.2 Geomorphological and Geological Setting

In the mid-1800s, the Matau Branch (Figures 1.1 and 1.3) did not have an independent mouth, but rather ran southwest along the landward margin of the beach/dune complex, to join the Koau Branch with a combined mouth at the southwest margin of the Clutha delta area near Kaka Point (Hornblow et al. 2016, MacDonald 2021). The present river configuration formed as a result of a large flood in 1878. Lake Tuakitoto in a broad northern tributary valley (Lovells Flat valley; Barrell 2019) of the Clutha delta was, at that time, much more extensive, with another small water body (Kaitangata Lake) nearby (Arthur 1883). Figure 1.3 shows their extents prior to drainage measures.

The Clutha delta area has three main geological components. From oldest to youngest, they are basement rock, cover rocks and poorly consolidated sediments (Bishop and Turnbull 1996). The basement is of Permian to Triassic age (~250 to ~200 million years old – Ma), comprising hard, predominantly sedimentary, rocks of the Maitai Group and Caples Group. The cover rocks were originally deposited over the basement rocks, but around the western and northern margins of the delta have been eroded away, exposing the basement. To the east and northeast, cover rocks are still preserved, comprising mid-Cretaceous to early Paleocene (between ~105 and ~55 Ma) conglomerates and sandstones with some coal seams.

The nature of the poorly consolidated sediments is illustrated by a geomorphological map, which emphasises the landforms developed on the sediments (Figure 1.3). The Clutha delta geomorphological map identifies four main landform types: marine terraces; river terraces; alluvial fans and the young river plain. Marine terraces represent accumulations of sediment overlying wave-cut erosion surfaces. River terraces are developed on sediments of large river valleys (in this case the Clutha River). The Clutha delta river terrace surfaces typically stand between ~2 and ~8 m higher than the young river plain. Alluvial fans are broadly fan-shaped accumulations of sediments from tributary streams built out onto the margins of the main valley floor. The fans in places may include several fan-terrace levels. An isolated remnant of an older river terrace at considerably higher elevation in the adjacent hill terrain was formed before the present configurations of river and stream valleys developed. The older river terrace is probably many hundreds of thousands of years old.

Geological dating by the thermoluminescence method, documented by Barrell et al. (1998), supports an age of Last Interglacial (between ~130,000 and ~70,000 years ago) for the river terraces at Balvenie and the marine terraces along the coast northeast of the Clutha delta (Figure 1.3). Based on its form and setting, the surface of the Clutha delta river plain is confidentially assigned a Holocene age (<11,700 years old) associated with the present episode of interglacial climate.

Geologically recent movement on the Otanomomo Fault is indicated by differences in terrace heights of several metres either side of the fault. The height difference was originally interpreted by Barrell et al. (1998) as different ages of terraces either side of the fault. However, the recent availability of high-quality lidar indicates that fault offset of formerly contiguous terraces is the most likely interpretation (Barrell 2021). For this report, a version of the geomorphology map dataset of Barrell et al. (1998) has been amended to reflect the new interpretation. The new version is used in Figure 1.3.

Over time, Titri Fault movement has uplifted the range of coastal hills extending northeast for about 70 km from the Clutha delta to the Dunedin area (Barrell et al. 2020; Barrell 2021). Differences in height between the Balvenie river terrace and marine terraces northeast of the Matau Branch may indicate between ~10 and ~15 m of movement, up to the northeast, across the Titri Fault since the terraces formed (Barrell 2021). However, due to various uncertainties, Barrell (2021) classified this section of the Titri Fault as possibly active rather than definitely active.

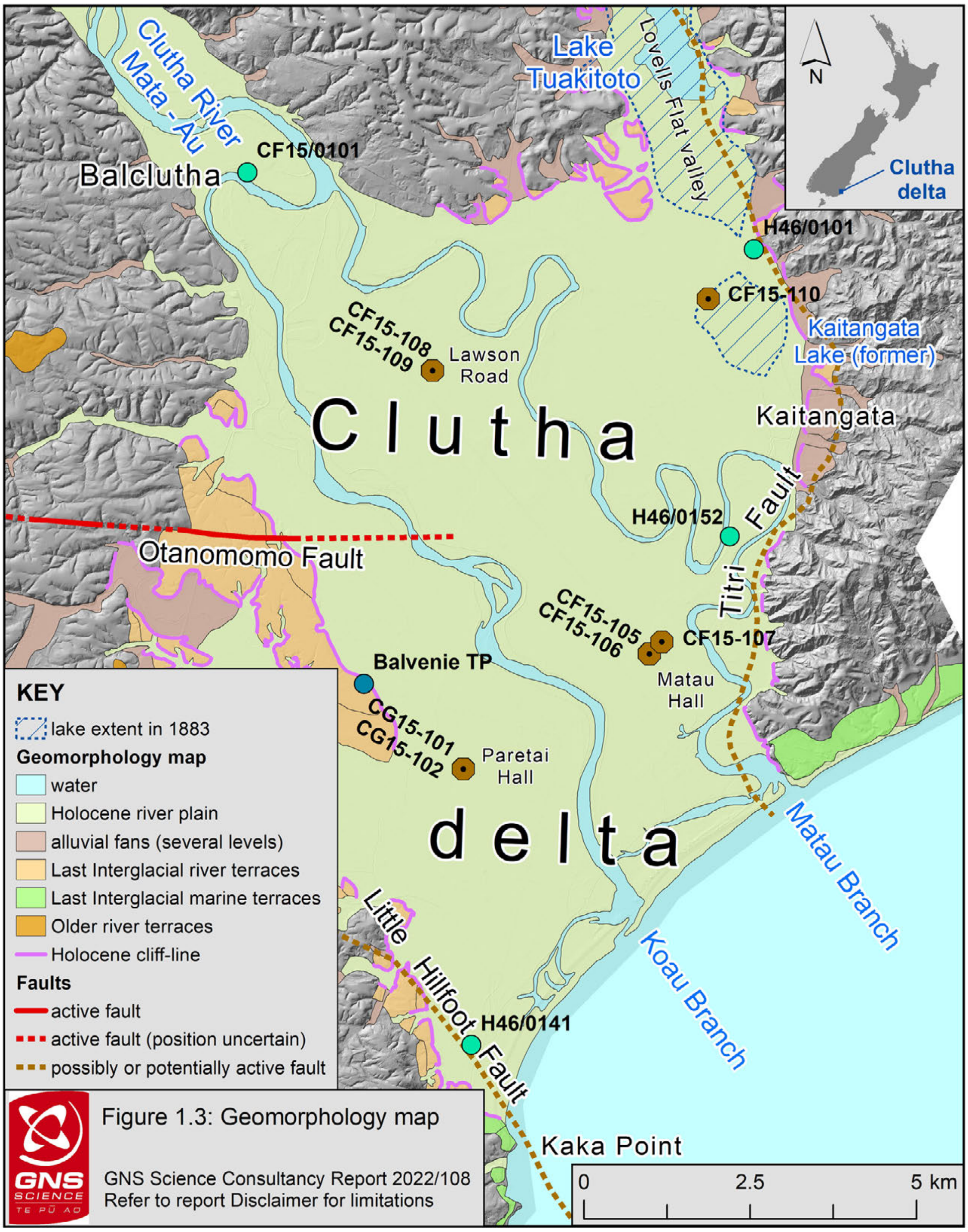

Figure 1.3 Geomorphology map. The map has the same extent as Figure 1.2, with geomorphology from the Barrell et al. (1998) dataset with minor amendments (see text). The faults are from the Barrell (2021) dataset. Refer to Figure 1.2 for key to subsurface data points. Fault names are placed on the downthrown side of each fault. The modern beach and the dune barrier along the coastline are not differentiated from other Holocene landforms. The former extents of Lake Tuakitoto and Kaitangata Lake, prior to drainage measures, are from Arthur (1883).

The Titri Fault overall is interpreted to have a relatively small long-term slip rate of ~0.15 mm/year[2], while the estimated long-term slip rate is even smaller on the Otanomomo Fault, at ~0.09 mm/year (Barrell 2021). Even so, the landform evidence is sufficient to provide stronger confidence in geologically recent movement having occurred on the Otanomomo Fault than on this (southern) section of the Titri Fault. There is no direct evidence that the Little Hillfoot Fault, identified from offset of the basement rock/cover rock contact, has experienced any geologically-recent movements, and it is classified as only possibly active with a nominal very low long-term slip rate (~0.05 mm/year) by Barrell (2021). Based on these considerations, all these faults have low rates of activity and it is highly likely that none of them have experienced significant movement during the Holocene (the past 11,700 years). These faults therefore are not regarded as having been contributors to the recent geological evolution of the Clutha delta.

[2] Slip rate represents a specified amount of fault movement averaged over a specified amount of time. Both amounts are typically estimated using various assumptions, rather than directly measured. Faults usually do not creep steadily, but instead experience metre-scale rupture events separated by long intervals without movement. Slip rate is a conceptual indicator of a fault's degree of activity; a small slip rate implies a long time (recurrence interval) between rupture events (and accompanying large earthquakes).

2.0 METHODS

2.1 Core Examination, Description and Sampling

The ORC series of eight holes was drilled in October and November 2021. Drill hole location information is in Appendix Table A1.1. Drillers logs and a series of photographs of the core of each hole were supplied electronically to GNS. The cores were stored in cardboard core boxes in a shed at the ORC Balclutha depot. The cores were examined by David Barrell, assisted by Tim van Woerden (ORC) on 6 May 2022. Generalised descriptions of the cores were made and samples were collected. Core descriptions and analytical results are collated on GNS geological log sheets, presented in Appendix 1 (Figures A1.1 to A1.8).

2.2 Environmental Assessment

Samples for environmental assessment were collected at four depths from the core of drill hole CG15-102. The samples were stored in plastic bags, prior to being transported to GNS in Lower Hutt, where the samples were washed and sub-samples examined under a stereo microscope by Martin Crundwell. Of particular interest were microscopic fossils that provide indications of the environment in which the sediment was deposited. The results are presented in Appendix Table A1.2.

2.3 Radiocarbon Dating

Radiocarbon dating involves measurement of the relative proportions of isotopes of carbon (C), the stable ^{12}C and ^{13}C isotopes and the radioactive ^{14}C isotope, within carbon-bearing material (e.g. plant or shell). ^{14}C is produced constantly in the upper atmosphere by effects of cosmic radiation, and is present in equilibrium concentrations throughout the atmosphere and hydrosphere. Carbon absorbed by a living organism has the same isotopic ratio of the air or water in which the organism lived. After the death of the organism, the ^{14}C content progressively reduces over time through radioactive decay. The decay rate is such that no ^{14}C is left after about 50,000 years, which marks the older limit of this dating method (e.g. Reimer et al. 2020 and references therein).

The laboratory measurements produce ages in 'radiocarbon years' ('conventional radiocarbon age' – CRA) via a simple calculation based on the carbon isotopic ratios and the ^{14}C radioactive decay rate. This assumes the ^{14}C content in the atmosphere and hydrosphere has been constant through time, but this is now known to have not been the case. There have been natural varations in environmental ^{14}C concentrations due to factors such as variations in the flux of cosmic radiation affecting the production of ^{14}C, and variations in the amounts of carbon stored in the ocean. Sophisticated calibrations have been developed, especially via carbon measurement of fossil tree rings, to develop records of exact carbon ratios at any particular time in the past ~50,000 years. The CRA determined in the laboratory is converted into actual solar years ('calendar age') via this calibration. Standard practice is to refer to the raw CRA as 'years (y) before present (BP), and a corrected calendar age as 'calendar years BP' (cal. y. BP). In both cases, P (present) refers to the year AD 1950. After AD 1950, environmental carbon ratios were permanently disrupted by the production of large amounts of ^{14}C by atmosphic testing of hydrogen atomic bombs, which raised environmental ^{14}C to levels far greater than natural concentrations. Radiocarbon dating is only applicable to organic materials that were formed prior to AD 1951.

A total of 12 samples of organic material were collected from the drill cores (see Appendix 1 geological logs – Appendix Figures A1.2 to A1.8). Of these, seven were selected for radiocarbon analysis. The selection took into account the nature of the samples and the anticipated value for scientific interpretation of knowing the ages of the sampled material. All samples were placed in open plastic bags and air dried at GNS in Dunedin. Those selected for dating were transported to GNS at Lower Hutt, where they were oven-dried. Samples compising sediment with desseminated organic matter were washed and, using a microscope, sufficient amounts of organic material were picked out to form sub-samples for submission for radiocarbon dating. These, together with samples comprising pieces of wood were submitted directly to the Rafter Radiocarbon Laboratory (RRL). General description of the submitted samples is provided in Table 2.1.

Table 2.1 Description of the samples on which radiocarbon dating was performed.

Sample ID	Drill Hole Name, Location and Sample Depth in Core (m)	Description
CF15-106: 9.5 m - 14C	CF15-106 (Matau Hall): 9.5 m	Shell fragments in sand. Fragments are from bivalve molluscs and barnacles.
CF15-106: 18.6 m - 14C	CF15-106 (Matau Hall): 18.6 m	Small wood fragment from silty sand.
CF15-106: 28.15 m - 14C	CF15-106 (Matau Hall): 28.15 m	Plant fragments in silt.
CF15-108: 5.8 m - 14C	CF15-108 (Lawson Rd): 5.8 m	Wood fragment in sandy silt.
CF15-109: 22.5 m - 14C	CF15-109 (Lawson Rd): 22.5 m	Large piece of wood in silt.
CG15-101: 4.2 m - 14C	CG15-101 (Paretai): 4.2 m	Wood fragment in sand.
CG15-102: 28.25 m - 14C	CG15-102 (Paretai): 28.25 m	Plant fragments in silt.

All samples were subjected to pretreatment at the RRL, as described in detail in the radiocarbon dating reports for each sample (Appendix Figures A1.9 to A1.15). Dating results are summarised in Section 3.0. Interpretations are discussed in Section 4.0, in terms of sample elevations relative to sea level, rather than depths below the present ground surface shown in Table 2.1 (see Table 4.1).

2.4 Profiling Methods

To assist in the presentation of results and illustration of geological interpretations, profiles of the land surface and seabed surface were generated using the geographic information system ArcGIS. The topographic profiles were generated from the Geographx NZ digital elevation model (DEM), with 8-metre pixel resolution, which is produced from 20-m interval elevation contours and spot heights on the Topo 50 1:50,000-scale digital topographic map, and from lidar elevation models where available. The offshore profile extension used the NIWA 1:4,000,000-scale (1:4M) bathymetric DEM (grid-cell size 250 m) to obtain the sea floor geometry. Profiles are presented and discussed in Section 4.0.

3.0 DATING RESULTS

Dating results are presented in the radiocarbon dating report for each sample (Appendix Figures A1.9 to A1.15), while age calibrations are presented in the laboratory radiocarbon calibration reports (Appendix Figures A1.16 to A1.21). Specific dating results are annotated on the drill hole geological logs (Appendix Figures A1.2 to A1.8) and the main elements of the dating results are compiled in Table 3.1.

All the ages obtained provide a consistent picture, with progressively older ages from increasing depth (compare Tables 2.1 and 3.1), and there are no anomalies in the age patterns.

Table 3.1 Radiocarbon dating results. The Lab ID is the unique formal identifier for each dating result. Conventional radiocarbon age is calculated from the radiocarbon content of the sample and is not corrected for past variations in radiocarbon content of the atmosphere. That correction is made via the calibration, which provides a correct age in calendar years, according to the SHCal20 dataset (Hogg et al. 2020), except for sample NZA 74842, which is calibrated with the Marine20 dataset (Heaton et al. 2020) which accounts for marine ^{14}C reservoir effects. The calibrated age bounds are the 95% confidence (2 sigma) age range, from which the median calibrated age and error are calculated (see Appendix 1.2). Samples are listed in order of increasing median calendar age, in contrast to the ordering by drill hole number and depth used in Table 2.1.

Sample ID	Lab ID	Conventional Radiocarbon Age (y. BP) ± error (y)	Calibrated Age - older bound (cal. y. BP)	Calibrated Age - younger bound (cal. y. BP)	Median Calibrated Age (cal. y. BP) ± error (y)
CF15-108: 5.8 m - 14C	NZA 74771	6,657 ± 27	7,570	7,430	7,500 ± 70
CG15-101: 4.2 m - 14C	NZA 74773	6,704 ± 27	7,606	7,433	7,520 ± 87
CF15-106: 9.5 m - 14C	NZA 74842	7,280 ± 25	7,680	7,430	7,555 ± 125
CF15-106: 18.6 m - 14C	NZA 74770	8,000 ± 30	8,990	8,646	8,818 ± 172
CF15-109: 22.5 m - 14C	NZA 74772	8,391 ± 32	9,478	9,155	9,317 ± 162
CF15-106: 28.15 m - 14C	NZA 74843	8,843 ± 33	10,133	9,675	9,904 ± 229
CG15-102: 28.25 m - 14C	NZA 74774	background (>50,000)	not applicable		

4.0 INTERPRETATION AND ASSESSMENT

4.1 Interpretative Framework

Important factors influencing the behaviour of the near-coastal reaches of rivers include river valley gradients, offshore gradients across the continental shelf, and effects of natural sea level changes associated with global climate cycles (e.g. Merritts et al. 1994). Tectonic factors also play a role through vertical movement of the land, but the significance of tectonics depends upon the rates of movement.

Global climatically-controlled (eustatic) sea level changes are an important factor for most river systems, because those changes have commonly been large and relatively rapid (e.g. Siddall et al. 2003; Siddall et al. 2010; Lambeck et al. 2014). Eustatic sea level changes arise mainly from the growth and decay of large ice sheets on western Europe and northern North America through glacial-interglacial climate cycles. Over the past half-million years or so, the cycles were characterised by slow decline to glacial conditions, followed by rapid return to interglacial conditions (Lisiecki and Raymo 2005; Crundwell et al. 2008), with each cycle taking about 100,000 years. Episodes of glacial climate saw the northern ice sheets grow to large size, locking up on land large amounts of water that normally resides in the oceans. When the ice sheets reached maximum size, the sea was typically about 120 to 130 m lower than present, with the shorelines lying at the outer margin of the continental shelves (Figure 4.1). The global Last Glacial Maximum (LGM) was about 20,000 years ago, with the sea ~120 m lower than now. During each shift to interglacial climate, the northern ice sheets melted almost entirely away, and the global sea rose back to about its present level. The shift to the present interglacial episode began about 18,000 years ago, when the sea began rising rapidly and attained its present level ~6,500 years ago (Lambeck et al. 2014). Although there were variations in the rate of rise, the overall average rate for that ~11,500-year period was ~1 m per 100 years. Sea level has been approximately stable for the past ~6,500 years.

These influencing factors are discussed below in relation to controls on Clutha River behaviour, evolution of the Clutha delta, and assessment of vertical land movement.

4.2 Controls on Clutha River Behaviour

A profile down the axis of the Clutha River valley and across the adjacent sea floor (P1; Figure 4.2) illustrates that the continental shelf has a gradient notably steeper than the Clutha valley floor. Subsurface investigations show a considerable thickness of river deposits underlying the Clutha valley floor, with depth to underlying bedrock at Tuapeka Mouth ~20 to 25 m below river level (GNS, unpublished data; 1980s-1990s investigations for the proposed Tuapeka dam). Pre-2021 drill hole information from the Clutha delta area (ORC, unpublished data; T. van Woerden pers. comm. 2021 – see Figures 1.1, 1.2 and 4.1 for location) show ~34 m of river sediments overlying bedrock at Balclutha (CF15/0101), close to the valley axis. Three other drill holes near the margins of the Clutha delta also reached bedrock under sediments, including north of Kaitangata (H46/0101; ~18 m of sediments and ‘timber’ overlying coloured clays and coal – probably mid-Cretaceous-Paleocene coal measures), south of Kaitangata (H46/0152; ~9 m of gravel, sand and wood overlying mudstone) and near Kaka Point (H46/0141; ~9 m of sediments overlying siltstone and grey rock).

Our interpretation is that during times of low sea levels, the Clutha River cut a deep channel out to the edge of the continental shelf, most recently at the LGM, and that the channel floor was buried by sediment during the rapid post-glacial sea level rise (Figure 4.2). Similar effects occurred elsewhere on the Otago coast. For example, at the Taieri River/Taieri Plain (Barrell et al. 1999) and the South Dunedin plain (Glassey et al. 2021), respectively 40 and 70 km northeast of the Clutha delta, incised glacial-age fluvial valleys that were drowned during post-glacial sea level rise, and became filled with sediment. Eustatic sea level change is considered to have been the main long-term influence on the Clutha River lower reaches.

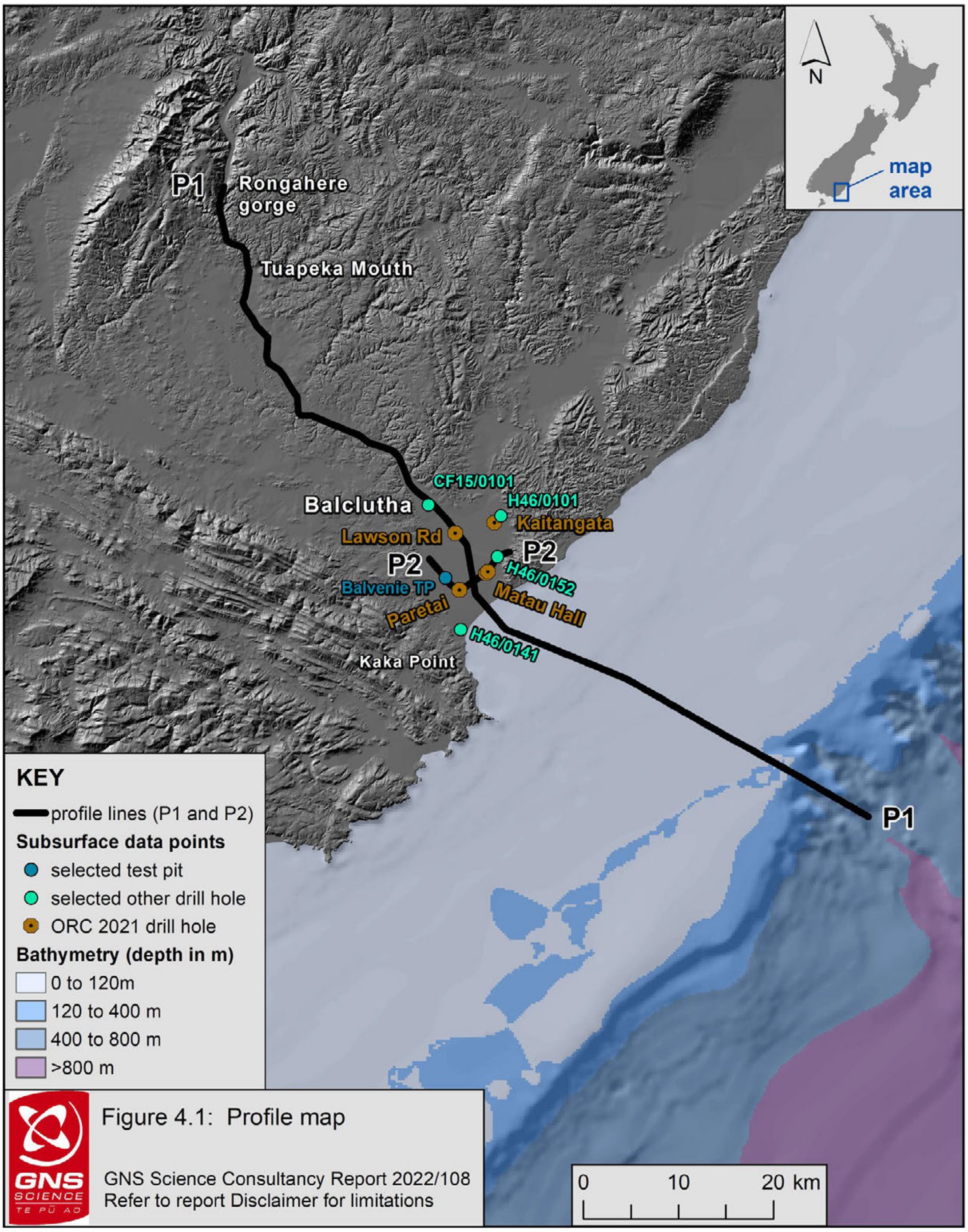

Figure 4.1 Profile map. The profiles together with subsurface geological interpretations are presented in Figure 4.2. The on-land DEM is the Geographx 8-m resolution shaded relief model. The offshore area shows the NIWA 1:4M bathymetric DEM coloured by depth and draped transparently over a shaded relief model of the 1:4M DEM. The 120 m depth boundary approximates the position of the coastline at the LGM, ~18,000 years ago.

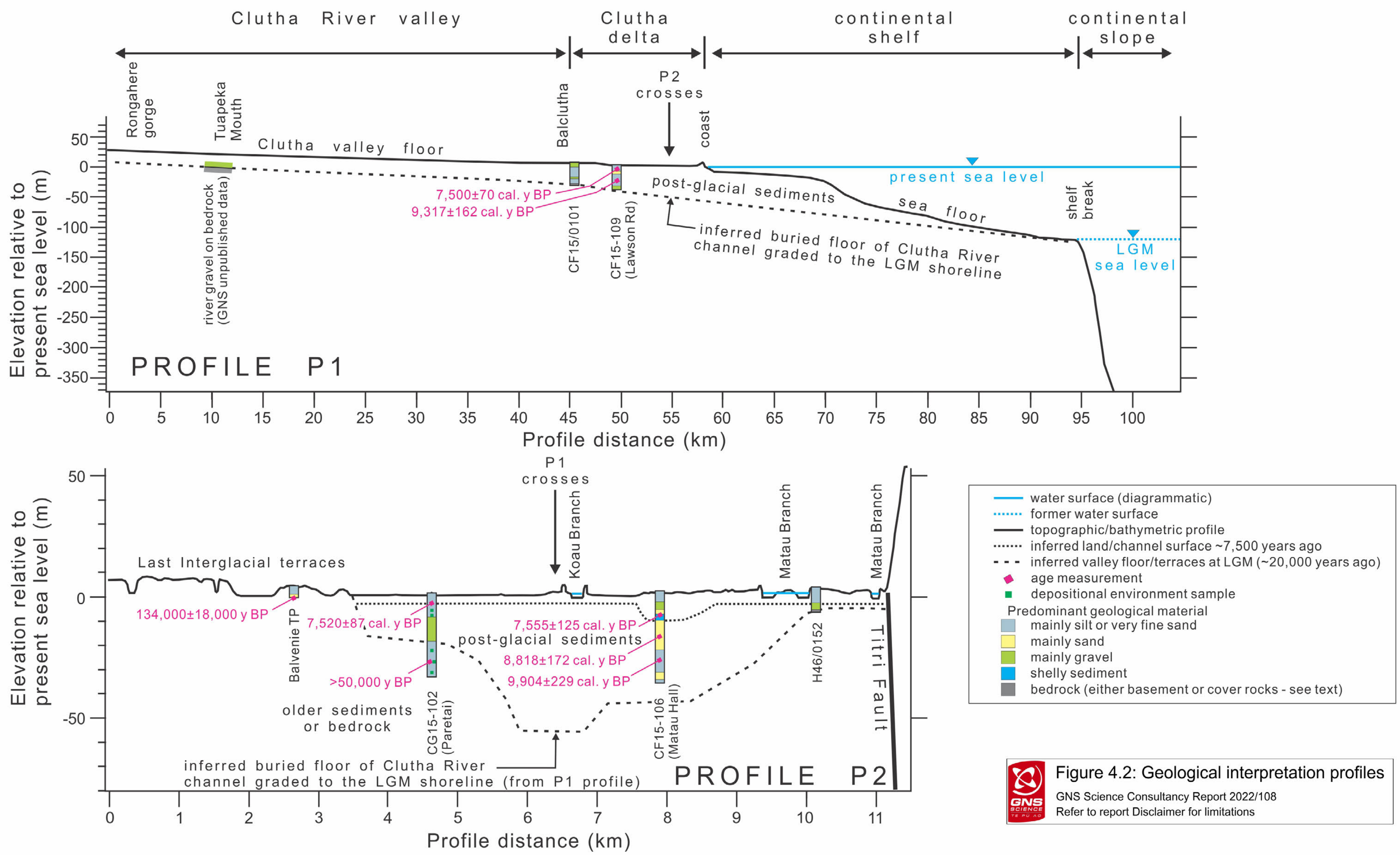

Figure 4.2 Geological interpretation profiles. Figure 4.1 shows the profile locations. The ages are from radiocarbon dating of organic materials from drill holes (this report), plus a thermoluminescence age from the Balvenie test pit, documented by Barrell et al. (1998). Note the vertical exaggeration in each profile and differences in scale between profiles P1 and P2; the ~7,500-year-old land and channel surface profile is shown only in P2. Refer to text for further explanation.

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4.3 Evolution of the Clutha Delta

Terraces around the margins of the Clutha delta area standing between ~2 and ~8 m higher than the Holocene river plain (Figure 1.3 and 4.2) were assigned a Last Interglacial age by Barrell et al. (1998), an interpretation supported by the dating at Balvenie (Section 1.2) and the presence of up to several metres of windblown silt (loess) on the terraces. Sea level at the peak of Last Interglacial (~118,000 to ~125,000 years ago) was about the same as present or a few metres higher. Later parts of the Last Interglacial period at ~100,000 and ~80,000 years ago recorded sea level maxima less than the peak interglacial (between ~5 m and ~20 m lower than present; Creveling et al. 2017). Thus, only the terraces very close to the modern river plain may be of late Last Interglacial age. Collectively, this information provides strong evidence of negligible long-term vertical land movement (VLM) having occurred in the Clutha delta area (see Section 4.4 for further discussion).

At Paretai (CG15-101/102), the ^{14}C age of >50,000 y. BP at ~28 m depth demonstrates the presence of sediments older than post-glacial at depth. A boundary between older sediments and the post-glacial sediment package at Paretai is tentatively placed at the base of fluvial gravels at ~20 m depth (Figure 4.2). Environment-of-deposition indicator samples collected from the CG15-102 core at ~24, 28 and ~33 m depth at Paretai suggest they were deposited in a fluvial rather than estuarine or marine environment (Table 4.1 and Appendix Table A1.2). It is possible that these sediments are of Last Interglacial age, perhaps representing an older equivalent of the post-glacial sediment package (see below), deposited during the rapid sea level rise that heralded the onset of the Last Interglacial (e.g. Siddall et al. 2010).

Gradient considerations and sediment thicknesses indicate that the Clutha River formed an incised valley during the Last Glaciation (~70,000 to ~18,000 years ago). This valley was progressively filled with sediment during the post-glacial sea level rise (Figures 4.2 and 4.3). The dating shows that beneath the central part of the Clutha delta, ~23 m of sediment accumulated between ~9,900 and ~7,500 calendar years ago (Table 4.1), equating to an average sedimentation rate of 9.6 mm per year (~1 m per century). This rate is about the same as the average rate of post-glacial sea level rise (Section 4.1), indicating that Clutha River post-glacial sedimentation and valley-infilling kept pace with sea level rise. This seems intuitively compatible with the Clutha River's large, natural (prior to hydro-electric dams) suspended sediment yield, estimated at 2.39 million tons per year (Mt/y) (Hicks et al. 2011). As a comparison, their estimated suspended sediment yield for the Taieri River is 0.32 Mt/y.

Fluvial conditions are indicated by environmental samples from ~7 and ~9 m depth in CG15-102 at Paretai (Appendix Table A1.2), even though Paretai is near the coast. Shells from ~9.5 m depth at Matau Hall (CF15-106) are attributed to a localised tidally-influenced channel, and are the only evidence from the ORC 2021 drill holes for marine or estuarine conditions during deposition of the Clutha delta post-glacial sediment package.

Figure 4.3 highlights the similarity between the elevation of the samples dated from the ORC 2021 drill holes, their ages, and the independently determined record of post-glacial sea level rise from eastern Canterbury compiled by Clement et al. (2016). At the Clutha delta, the rising sea is interpreted to have created accommodation space for sediment deposition. The post-glacial sediment age/depth relationships provide a close approximation of post-glacial sea level rise. The general absence of shells in the fine-grained post-glacial sediments encountered in the ORC 2021 drill holes, and indicators of a fluvial floodplain environment lead us to envisage the post-glacial evolution of the Clutha delta as a progressively upward-building coastal river plain whose present form is the surface of the Clutha delta.

While acknowledging that wood fragments can be deposited in estuarine to marine environments, we infer that the wood that was sampled and dated was deposited in a river floodplain environment (Table 4.1), compatible with the general environment of deposition indicators. Based on an assumption that the wood was deposited above the sea level of the time, and the shells at Matau Hall were deposited at or below sea level allows bounds to be placed on sea level elevation. Two samples of wood, one from Lawson Road (CF15-108) and one from Paretai (CG15-101), and the Matau Hall shell sample are all, within uncertainty bounds, of the same age (~7,500 cal. y. BP). Together, they constrain the sea level at that time to about -5 ± ~2 m, relative to present (Figure 4.3). On that basis, a land and tidal-channel surface is illustrated in profile P2 of Figure 4.2. The overall inference is that the Clutha delta at that time was close to its modern configuration, and largely all that has happened in the past ~7,500 years is that ~5 m of sediment has accumulated. This equates to an average sedimentation rate of ~7 cm per 100 years, but sedimentation was not necessarily steady. For example, most of the last ~5 m of sedimentation may have occurred shortly after ~7,500 years ago, utilising the accommodation space created by the final increment of post-glacial sea rise.

Table 4.1 Environmental interpretation of the sediments from which the radiocarbon-dated samples were collected. Ages are from Table 3.1; samples are listed by increasing median calendar age, in contrast to the listing by drill hole number and depth in Table 2.1. Former sea levels are estimated from an envelope (see Figure 4.3) encompassing the Canterbury (wider Christchurch area) and Otago sea level data presented by Clement et al. (2016). See Appendix Table A1.2 for environmental interpretation of samples from drill hole CG15-102.

Sample ID	**Median calibrated age (cal. y BP) ± error (y)**	**Sample elevation relative to modern sea level (m)**	**Estimated sea level at the time of the median age (m relative to present, rounded to nearest 5 m)**	**Interpretation**
CF15-108: 5.8 m - 14C	7,500 ± 70	-3.3	Somewhere between -10 and 0 m	Fluvial floodplain environment – above the sea level of the time
CG15-101: 4.2 m - 14C	7,520 ± 87	-3.3	Somewhere between -10 and 0 m	Fluvial floodplain environment – above the sea level of the time
CF15-106: 9.5 m - 14C	7,555 ± 125	-7.4	Somewhere between -10 and 0 m	Probably a tidal fluvial channel on the floodplain
CF15-106: 18.6 m - 14C	8,818 ± 172	-16.5	Somewhere between -20 and -10 m	Fluvial floodplain environment – above the sea level of the time
CF15-109: 22.5 m - 14C	9,317 ± 162	-20.1	Somewhere between -25 and -15 m	Fluvial floodplain environment – above the sea level of the time
CF15-106: 28.15 m - 14C	9,904 ± 229	-26.1	Somewhere between -30 and -20 m	Fluvial floodplain environment – above the sea level of the time
CG15-102: 28.25 m - 14C	background (>50,000)	-27.3	unknown	Within older fluvial sediments in a coastal plain setting

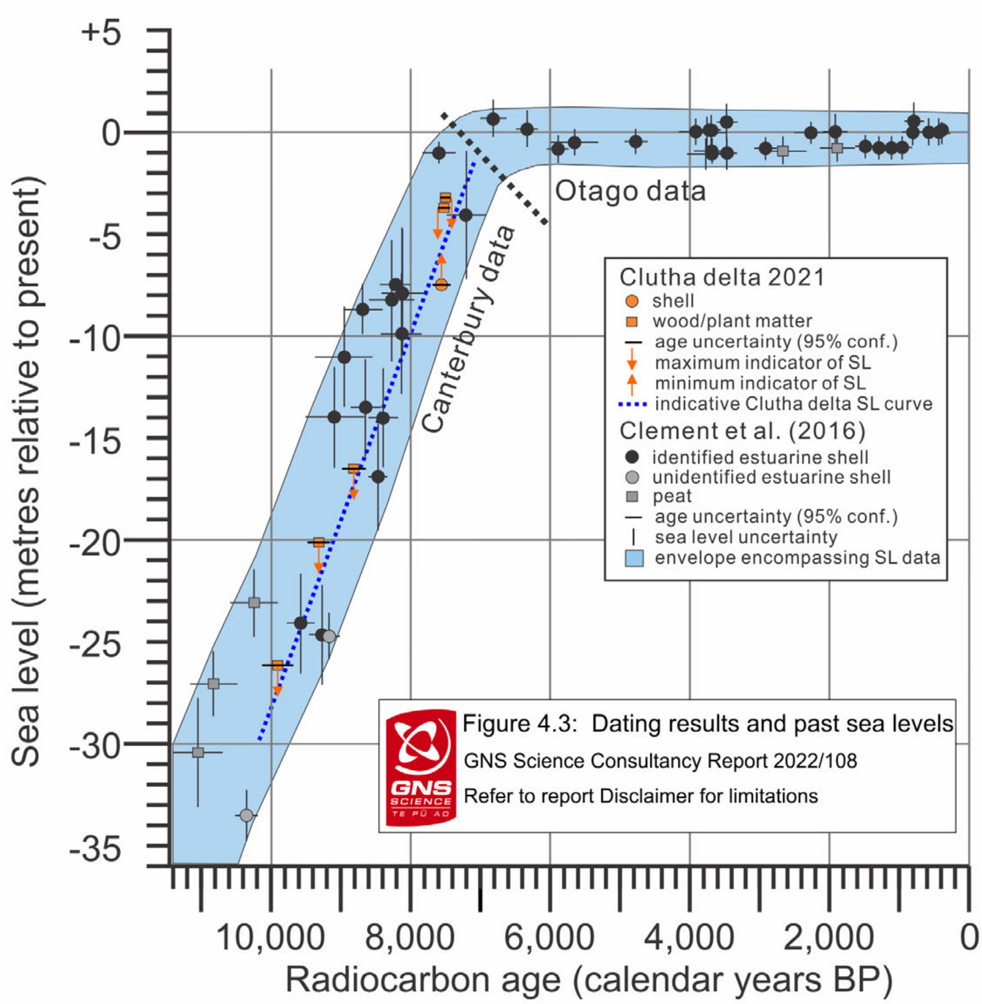

Figure 4.3 Dating results and past sea levels. The plot illustrates sea level (SL) change over the past ~11,000 years in the southeastern South Island. The Clement et al. (2016) data are reproduced from the 'Canterbury' and 'Otago' graphs in their Figure 2. Each Clement et al. (2016) data point shows uncertainty in SL elevation from the ecological character of the radiocarbon-dated material, as well as the age dating uncertainty. Several of their data points are omitted for clarity where they lie close to ORC 2021 drill hole data points. The ORC Clutha delta dating results are plotted in relation to age uncertainty and the type of SL indication provided by the dated material. Shells are an example of a minimum SL indicator (i.e. deposited at or below SL) while floodplain wood or plant material is regarded as a maximum SL indicator (i.e. deposited at or above SL). The SL indicator arrows on the ORC data are a nominal 1.5 m length. The indicative Clutha delta SL curve is positioned by visual estimate of the data points. It is most tightly constrained at ~7,500 cal. y BP by two samples of floodplain wood and one sample of bivalve and barnacle shells, implying a SL of approximately -5 ± 2 m (relative to modern) at that time.

Prominent cliffs along the margins of low terraces at many locations around the Clutha delta (Figure 1.3) were mapped by Barrell et al. (1998) and interpreted from their form and position as being of post-glacial age (Barrell 2019). They are suspected to have been produced by wave erosion at the margin of a standing body of water. The Clutha delta area is as much as 10 km across, and if occupied by a water body, wave fetch would likely have been sufficient to facilitate cliff cutting. The cliffs have a subdued form, suggesting that they may have formed several thousand years ago, perhaps associated in time with the culmination of sea level rise. Shells have not been reported from the near-surface (e.g. less than 5 m depth) sediments of the Clutha delta (ORC, unpublished drill hole data), noting that the drill holes are relatively few and interpretations should be made with caution. Nevertheless, the lack of indicators of estuarine or marine conditions in the near-surface sediments suggests that any water body was more likely freshwater than sea water (i.e. coastal inlet).

The presence of a large freshwater coastal lake implies a need for co-existence of a coastal beach/dune barrier to impound the lake, with Clutha discharge through breach(es) in the barrier being sufficient to prevent large-scale incursion of sea water. However, a lake would probably not have survived for long in the central part of the Clutha delta, due to river's sediment load and efficient deposition caused by sea level rise, as discussed above. We envisage the existence of a relatively short-lived extensive shallow lake across the Clutha delta area at about the culmination of post-glacial sea level rise. If short-lived, it raises a question of how it was that the cliffs formed. A conceptual analogue for short-term cliff-cutting exists at Lake Pūkaki in inland South Canterbury. In 1979, the lake was raised ~55 m above its natural level for hydro-electric water storage (Barrell and Read 2014). The lake's operating range allows it to be lowered ~15 m below its maximum level. The maximum level is attained for brief periods seasonally following the spring snow melt, and the maximum is not reached every year (David Barrell, personal observation). Nevertheless, a prominent cliff-line has formed at the maximum lake level shoreline, during short-lived attainments of maximum lake level over the past 40 years or so.

ORC 2021 drill hole CF15-110 sited at the margin of former Kaitangata Lake (Figure 1.3 and Appendix Figure A1.6) has well-sorted sand between 2.9 and 6 m depth, tentatively interpreted as beach or dune sand. If correct, the sand must have been deposited at or above sea level and may relate to sea level sometime around ~7,500 years ago. This further indicates that Lake Tuakitoto is a remnant of what had been a persistent water body during the latter stages of formation of the post-glacial Clutha delta. Existence of a persistent lake in the Lovells Flat valley seems at odds with the inference that the Clutha River's sediment load would have been sufficient to rapidly fill any available sediment accommodation space (e.g. a lake). One possibility is that the Lovells Flat valley is peripheral to the main volumes of water and sediment travelling down the Clutha valley, placing it in a 'back-water' setting, and likely with lesser sedimentation rates than near the central part of the Clutha delta.

Overall, this investigation and assessment shows that the Clutha River lay in an incised valley during the last glaciation. Sediment built up in this valley as the river backed up during post-glacial sea level rise, and the valley was largely filled in with sediment by ~7,500 years ago (see P2, Figure 4.2), as the post-glacial sea rise was culminating. When the sea stabilised at its present level ~6,500 years ago, an equilibrium relationship likely developed between the Clutha River and the coastline, with formation of a precursory equivalent of today's coastal beach/dune barrier. We suggest that a relatively short-lived lake formed across the Clutha delta area, and was later displaced by accumulation of the final few metres of river sediment on the delta. The lake would have extended into the Lovells Flat valley where there may have been a pre-existing lake, part of which has persisted to the present day. With the sea stabilised, minimal space for accommodating new sediment on the Clutha delta makes it likely that over the past few thousand years, virtually all of the Clutha River sediment has been carried away northeast along the coast by long-shore drift (Carter 1986).

4.4 Assessment of Vertical Land Movement

Constraints on amounts of Holocene vertical land movement (VLM) can be interpreted from the shells at ~9.5 m depth (7.4 m below present sea level) at CF15-106 (Matau Hall), dated at ~7,500 cal. y. BP (Table 4.1). Taking an end-member possibility that sea level at that time was at the maximum of the envelope developed from the Canterbury data (0 m; Figure 4.3), it would imply a VLM of -7.4 m (i.e. subsidence at an overall average rate of ~-1 mm per year). The other end-member is the minimum of the envelope developed from the Canterbury data (-10 m; Figure 4.3), which would imply +2.6 m of VLM (i.e. uplift at an overall average rate of ~+0.3 mm per year). If sea level at ~7,500 cal. y. BP lay in the middle part of the Canterbury envelope (i.e. consistent with the majority of the data points), it is possible that there has been minimal VLM of the Clutha delta (at Matau Hall) since that time.

Terraces of Last Interglacial age at the Clutha delta margins offer a longer-term indication of little if any net VLM in the Clutha delta area since ~120,000 years ago. However, a possibility of there having been relatively short episodes of subsidence and uplift that balanced one-another out cannot be excluded.

The NZ Sea Rise programme (https://www.searise.nz/maps-2) has determined contemporary rates of VLM along the New Zealand coast from interpretation of short-term, satellite-based, measurements between 2003 and 2011 (Hamling et al. 2022). The coastline of the Clutha delta is interpreted to be subsiding at between ~0.3 and ~1.6 mm per year, with subsidence rates increasing from north to south. These values are potentially compatible with estimates of VLM for the past ~7,500 years from the drilling and dating results, but not consistent with negligible overall long-term VLM over the past ~120,000 years indicated by Clutha delta terraces. One possible explanation for why subsidence interpreted in the NZ Sea Rise dataset may differ from the long-term geological record is that the subsidence may reflect compaction of the post-glacial sediment sequence. Other possibilities include a significant recent change in geological processes, a transient VLM effect too short-lived to register in the geological record, or that the satellite-based measurements record some sort(s) of land-surface change (e.g. coastal erosion) that has been interpreted as subsidence.

4.5 Assessment of Natural Hazards

A comprehensive review of natural hazards on the Clutha delta is provided by Hornblow et al. (2016), and little can be added to that assessment. One point of note is that an updated review of active faults has subsequently been provided by Barrell (2021), highlighting that active or potentially active faults in the vicinity of the Clutha delta (see Figure 1.3) have slow slip rates and long recurrence intervals for large earthquakes.

The 2021 drilling has reinforced findings from earlier drilling that the Clutha delta is mostly underlain by geologically very young, poorly consolidated fine-grained sediments (Barrell 2019). This highlights that seismic shaking amplification and liquefaction (including lateral spreading) are important potential hazards to consider in the Clutha delta area.

Determining the VLM in the Clutha delta area aids in the assessment of the impacts of relative sea level rise. Applying an interpretation of negligible long-term VLM, MacDonald (2021) examined just the effects of projected sea level rise, and not vertical land movement. However, the perspectives from geoscientific data differ from the satellite-based interpretation in the NZ Sea Rise dataset of contemporary (past decade or so) downward land movement (Section 4.4). Placing this into context from now to 2100, between ~0.3 and ~1.6 mm subsidence per year amounts to downward land movement of between 0.02 m and 0.12 m. For comparison, the projected sea level for 2100 (https://www.searise.nz/maps-2) along the Clutha delta coast, setting aside the question of VLM, is between ~0.2 m and ~1.5 m higher than present. This highlights that even at the larger end-member of the NZ Sea Rise estimate of VLM on the Clutha delta coast, the additive effect due to VLM is a relatively small component of the projected relative sea level rise. This finding supports the approach taken by MacDonald (2021).

5.0 CONCLUSIONS

1. Seven samples of organic material from the cores of the 2021 ORC drill holes on the Clutha delta were ^{14}C-dated. One sample returned an age beyond the older limit of the method (>50,000 years) and the other samples yielded ages in the range of ~9,900 to ~7,500 calendar years BP.
2. The dated samples have consistent relationships between age and depth and provide a coherent picture of the recent geological evolution of the Clutha delta area.
3. Natural sea level variations during glacial and interglacial climate cycles have been a key long-term control on Clutha River behaviour. During glacial periods with the sea as much as ~120 m lower than present, the river cut down into its bed, forming an incised valley graded to the edge of the continental shelf. The most recent glacial to interglacial climate transition saw global sea level rise by ~120 m between ~18,000 years ago and attainment of its present level ~6,500 years ago.
4. The ~1 m per 100 years average rate of post-glacial sea rise was the same as average sedimentation rate in the central part of the Clutha delta area between ~9,900 and ~7,500 years ago. This implies that river sediment deposition kept pace with the rising sea. The Clutha delta evolved to its present form as an up-building coastal river plain, and the main elements of its present form were in place by ~7,500 years ago.
5. Post-glacial cliffs around the margins of the Clutha delta are interpreted to have formed at about the culmination of sea rise ~6,500 years ago, at the shores of a short-lived freshwater lake, impounded behind a precursor of the modern coastal beach/dune barrier.
6. Active and potentially active faults near the Clutha delta have low activity, with long recurrence intervals for large earthquakes. Poorly consolidated fine-grained sediments extensively underlie the Clutha delta, highlighting seismic shaking amplification and liquefaction/lateral spreading as important potential hazards to consider.
7. Geological evidence points towards negligible long-term net vertical land movement of the Clutha delta area over the past ~120,000 years ago. Results from the 2021 drilling and dating for the past ~7,500 years, together with uncertainties in sea level elevation, constrain the rate of vertical land movement over the past ~7,500 years only to somewhere between -1.0 and +0.3 mm per year (i.e. a range from slight subsidence to no change to slight uplift). Very short-term satellite-based measurements indicate the land along the Clutha delta coastline is currently sinking. If that interpretation is correct, future relative sea level change at the Clutha delta will reflect the rising ocean with an additional component due to sinking land. At most, the indicated land subsidence would amount to about 0.12 m of downward movement by the year 2100, smaller than the projected rise in ocean level of somewhere between about 0.2 m and 1.5 m.

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APPENDICES

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APPENDIX 1 SUPPLEMENTARY INFORMATION

A1.1 Drill Hole Information

This appendix presents a table of depths, elevations and coordinates for the ORC 2021 drill holes (Table A1.1), results of environmental interpretation (Table A1.2) and geological logs based on the core examination (Figures A1.1 to A1.8). Drill hole names incorporate the 1:50,000-scale Topo 50 topographic sheet corresponding to the drill hole location (e.g. sheet CF15). At three sites, a shallow hole and deep hole were drilled located side by side (see Figures 1.1 and 1.2): CF15-105/CF15-106; CF15-108/CF15-109; and CG15-101/CG15-102. A separate geological log was prepared for the companion shallow hole only if a sample was collected from its core. Thus, there is no geological log for drill hole CF15-105.

Table A1.1 2021 Drill hole depths, coordinates and collar elevations (provided by ORC). NZTM=New Zealand Transverse Mercator 2000; NZVD16=New Zealand Vertical Datum 2016, and approximates metres above sea level; WGS84=World Geodetic System 1984; dd=decimal degrees. * no geological log prepared.

Drill Hole	Total Depth (m)	Coordinates (NZTM)		Collar Elevation (m) (NZVD16)	Coordinates (WGS84)	
		Metres North	Metres East		Latitude (dd)	Longitude (dd)
CF15-105*	6.3	4866524.4	1354781.1	2.039	-46.31047507	169.8151763
CF15-106	37.9	4866528.2	1354777.9	2.071	-46.31043916	169.8151371
CF15-107	6.0	4866708.5	1354966.6	2.144	-46.30888732	169.817678
CF15-108	9.0	4870784.1	1351522.7	2.46	-46.27101332	169.7751749
CF15-109	39.4	4870787.8	1351519.5	2.447	-46.27097825	169.7751361
CF15-110	6.0	4871864.6	1355666.6	0.329	-46.26280667	169.8294315
CG15-101	6.0	4864800.5	1351985.0	0.948	-46.32494814	169.7780094
CG15-102	35.0	4864795.4	1351985.5	0.939	-46.32499479	169.778014

Table A1.2 Environment of deposition of samples from drill hole CG15-102 (Paretai Hall). Material descriptions and interpretation of the nature of the environment in which the sediments were deposited. OM=organic matter; A=abundant; C=common; D=dominant; F=few; R=rare; VR=very rare.

Sample Depth (m)	Organic Material	Description of Components	Interpreted Environment
7.2	common	Delicate fibrous OM (C), moss-like OM (F), seeds? (R), black chitinous? material (R), spores? (R); Mica (A) <212 um.	Lower coastal plain
9.3	no	Angular mostly clear quartz sand (D), sub-rounded quartz grains (R), chlorite-mica (R).	Fluvial, coastal plain
23.8	common	Delicate fibrous OM (C), fine twiggy OM (F), seeds (F), spore cases (F), moss-like OM (VR), sponge spicules (R), pyrite (VR), slender golden siliceous? rods (VR); Mica (A) <212 um.	Lower coastal plain, near coast
28.25	abundant	Twiggy coal-like material (A), seeds (F),delicate light brown fibrous OM (F), moss-like OM (VR); Mica (A) <212 um.	Lower coastal plain
33.0	common	Delicate fibrous OM (C), fine twiggy OM (F), seeds (F), spore cases (F), spores (VR), moss-like OM (VR), sponge spicules (R); Mica (A) <212 um.	Lower coastal plain, near coast

The drill hole survey vertical value refers to the collar elevation (Table A1.1). Based on lidar information, the collar elevation is within ~0.1 m of the ground elevation at each drill hole location. The collar elevation is therefore taken as an adequate approximation of ground elevation, and on the geological logs is identified as "R.L. Ground".

On the geological logs, the notation 14C means radiocarbon. Not all radiocarbon samples collected were dated; those that were are indicated by a large arrow pointing to the sample location, and the ages obtained are in large bold font. Interpreted environment of deposition of samples (only drillhole CG15-102) are similarly displayed in large bold text. In the drill hole geological log notes, the McMillan Drilling bore logs referred to are the drillers logs supplied to ORC. Any request for access to these should be directed to ORC.

A1.2 Radiocarbon Dating Results

Radiocarbon dating analytical reports for each sample are presented in Figure A1.9 to Figure A1.15. Radiocarbon age calibration reports for the samples are presented in Figure A1.16 to Figure A1.21. There is no calibration report for the sample from drill hole CG15-102 (Figure A1.15) because the sample was found to be beyond the range of radiocarbon dating.

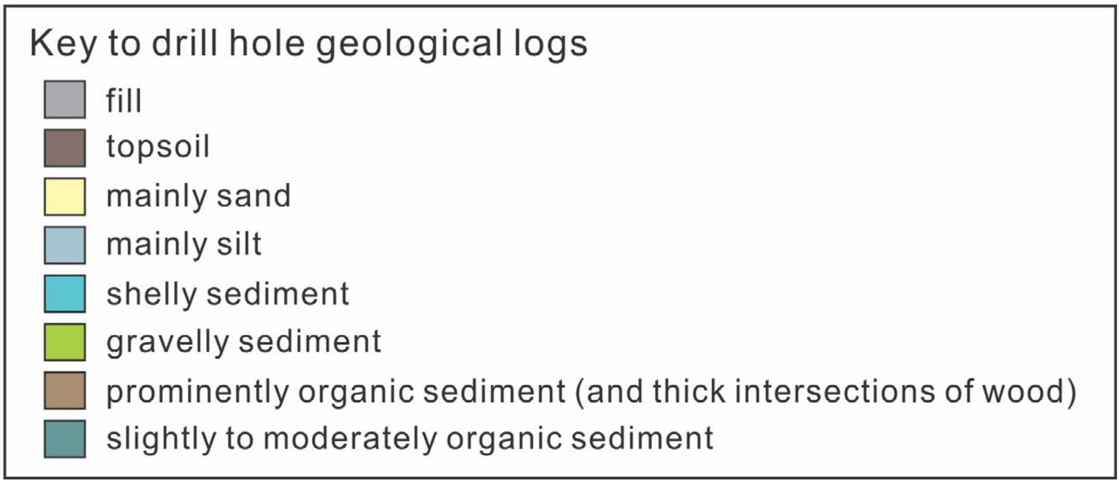


Figure A1.1 Key to drill hole geological logs.

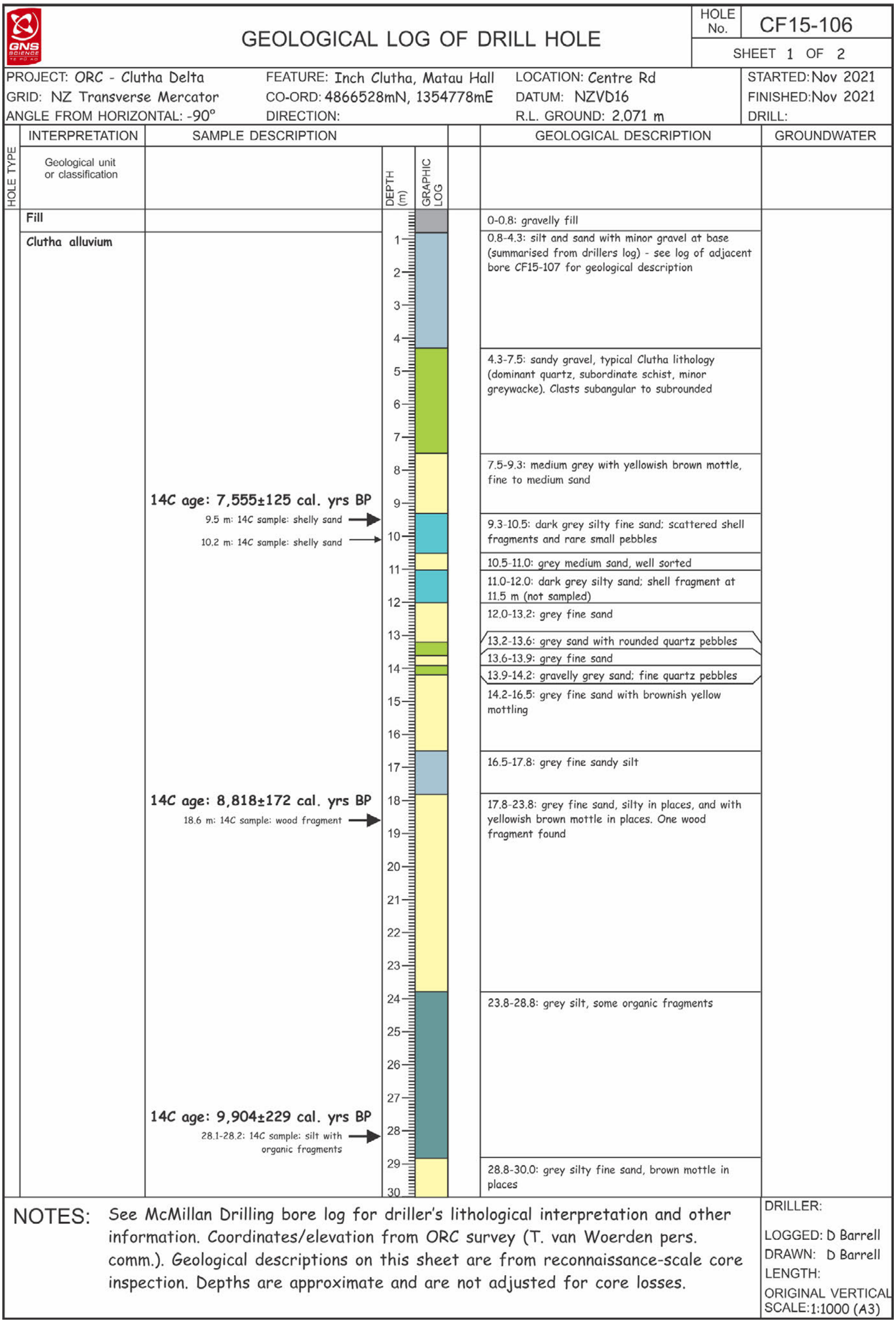
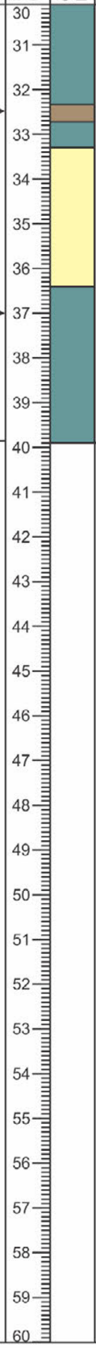


Figure A1.2 Geological log of drill hole CF15-106 (Matau Hall).

GEOLOGICAL LOG OF DRILL HOLE	HOLE No. CF15-106
	SHEET 2 OF 2

PROJECT: ORC - Clutha Delta	FEATURE: Inch Clutha, Matau Hall	LOCATION: Centre Rd	STARTED: Nov 2021
GRID: NZ Transverse Mercator	CO-ORD: 4866528mN, 1354778mE	DATUM: NZVD16	FINISHED: Nov 2021
ANGLE FROM HORIZONTAL: -90°	DIRECTION:	R.L. GROUND: 2.071 m	DRILL:

HOLE TYPE	INTERPRETATION: Geological unit or classification	SAMPLE DESCRIPTION	DEPTH (m)	GEOLOGICAL DESCRIPTION	GROUNDWATER
	Clutha alluvium		30.0–33.3	30.0-33.3: grey fine sandy silt, organic in places (notably peaty very fine sand at ~32.5 m)	
		32.5: 14C sample: peaty very fine sand	32.5		
			33.3–36.4	33.3-36.4: grey fine sand	
			36.4–37.9	36.4-37.9: grey to dark brownish grey, fine sandy silt, peaty in places	
		37.0: 14C sample: peaty silt	37.0		
		End of Hole: 37.9 m	37.9		



NOTES: See McMillan Drilling bore log for driller's lithological interpretation and other information. Coordinates/elevation from ORC survey (T. van Woerden pers. comm.). Geological descriptions on this sheet are from reconnaissance-scale core inspection. Depths are approximate and are not adjusted for core losses.

DRILLER:
LOGGED: D Barrell
DRAWN: D Barrell
LENGTH:
ORIGINAL VERTICAL SCALE: 1:1000 (A3)

Figure A1.2 Continued.

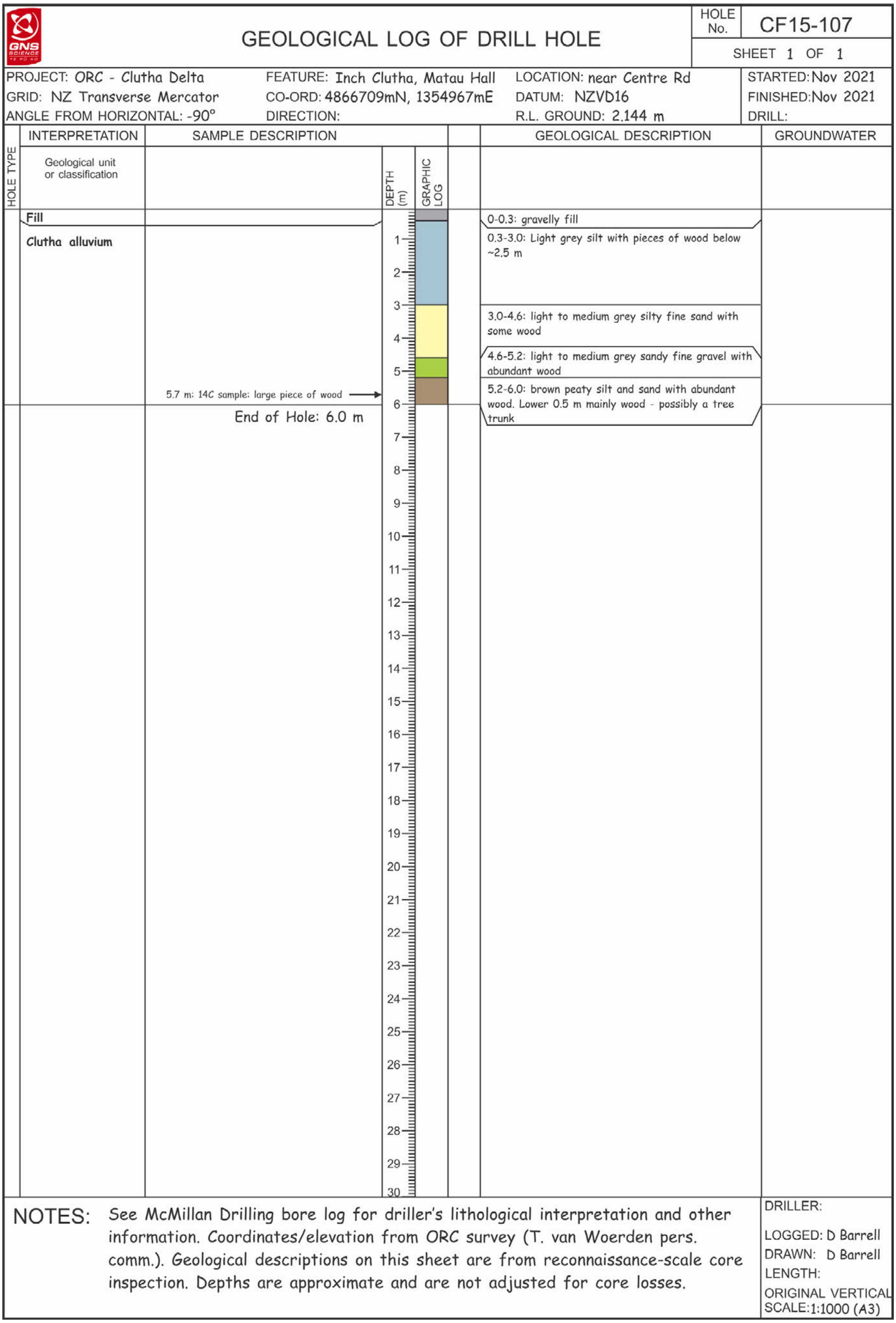


Figure A1.3 Geological log of drill hole CF15-107 (near Matau Hall).

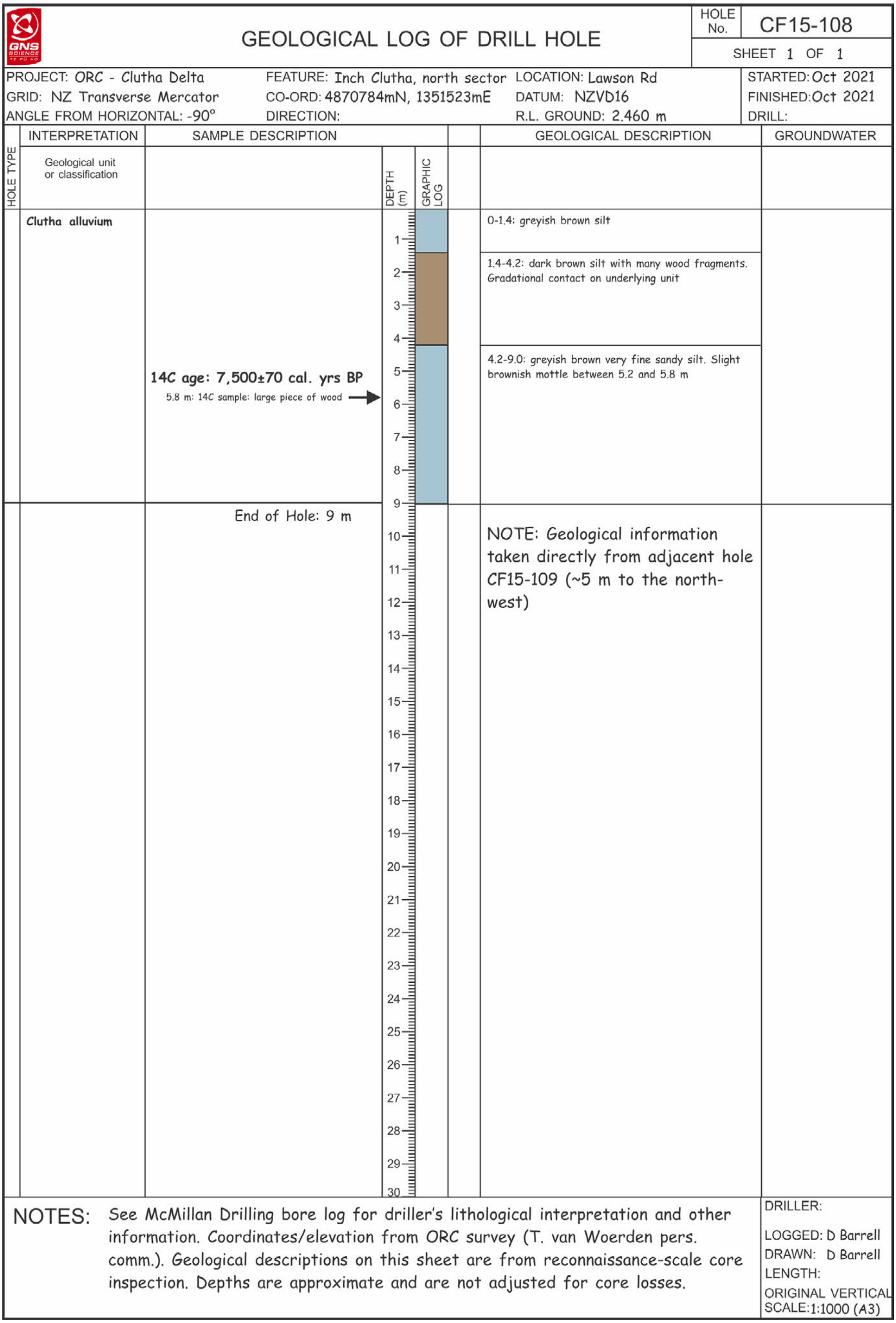


Figure A1.4 Geological log of drill hole CF15-108 (Lawson Road).

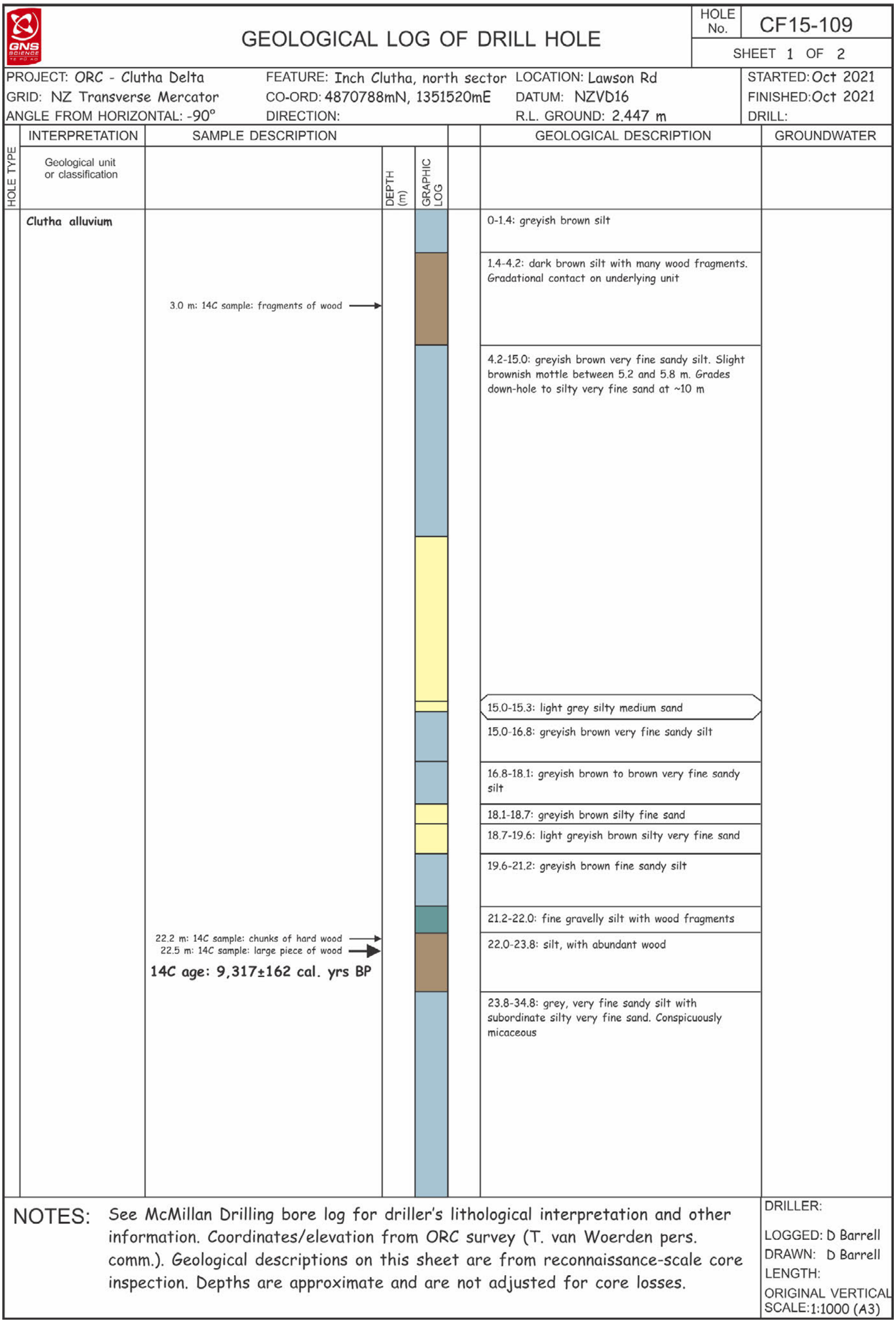


Figure A1.5 Geological log of drill hole CF15-109 (Lawson Road).

GEOLOGICAL LOG OF DRILL HOLE

HOLE No. CF15-109

SHEET 2 OF 2

PROJECT: ORC - Clutha Delta	FEATURE: Inch Clutha, north sector	LOCATION: Lawson Rd	STARTED: Oct 2021
GRID: NZ Transverse Mercator	CO-ORD: 4870788mN, 1351520mE	DATUM: NZVD16	FINISHED: Oct 2021
ANGLE FROM HORIZONTAL: -90°	DIRECTION:	R.L. GROUND: 2.447 m	DRILL:

HOLE TYPE	INTERPRETATION: Geological unit or classification	SAMPLE DESCRIPTION	DEPTH (m)	GRAPHIC LOG		GEOLOGICAL DESCRIPTION	GROUNDWATER
	Clutha alluvium					[continued] 23.8-34.8: grey, very fine sandy silt with subordinate silty very fine sand. Conspicuously micaceous	
						34.8-39.4: Grey, sandy fine gravel. Subrounded clasts, predominantly quartz with subordinate schist and minor greywacke. Clasts slightly larger below 36 m	
		End of Hole: 39.4 m					

NOTES: See McMillan Drilling bore log for driller's lithological interpretation and other information. Coordinates/elevation from ORC survey (T. van Woerden pers. comm.). Geological descriptions on this sheet are from reconnaissance-scale core inspection. Depths are approximate and are not adjusted for core losses.

DRILLER:
LOGGED: D Barrell
DRAWN: D Barrell
LENGTH:
ORIGINAL VERTICAL SCALE: 1:1000 (A3)

Figure A1.5 Continued.

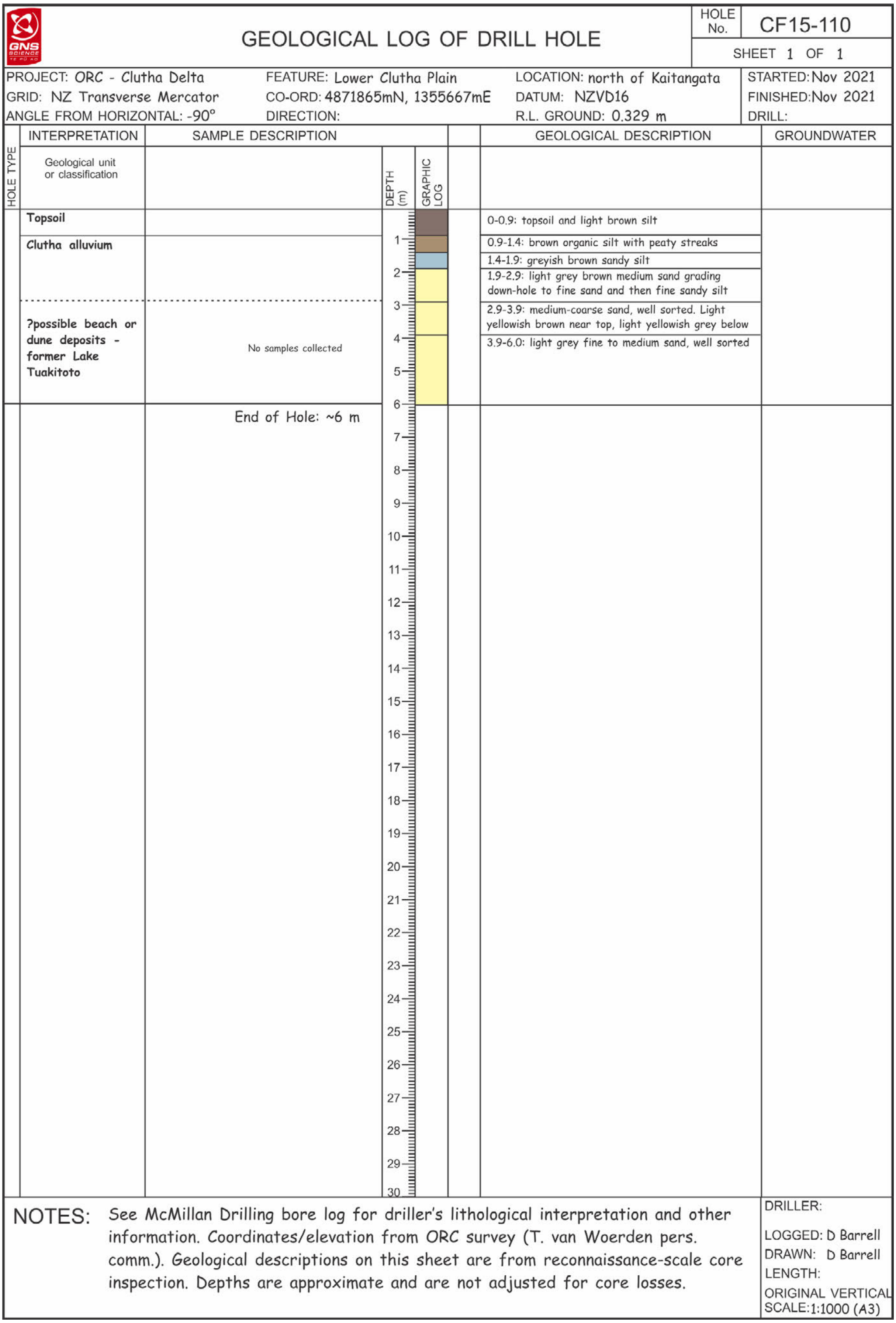


Figure A1.6 Geological log of drill hole CF15-110 (north of Kaitangata).

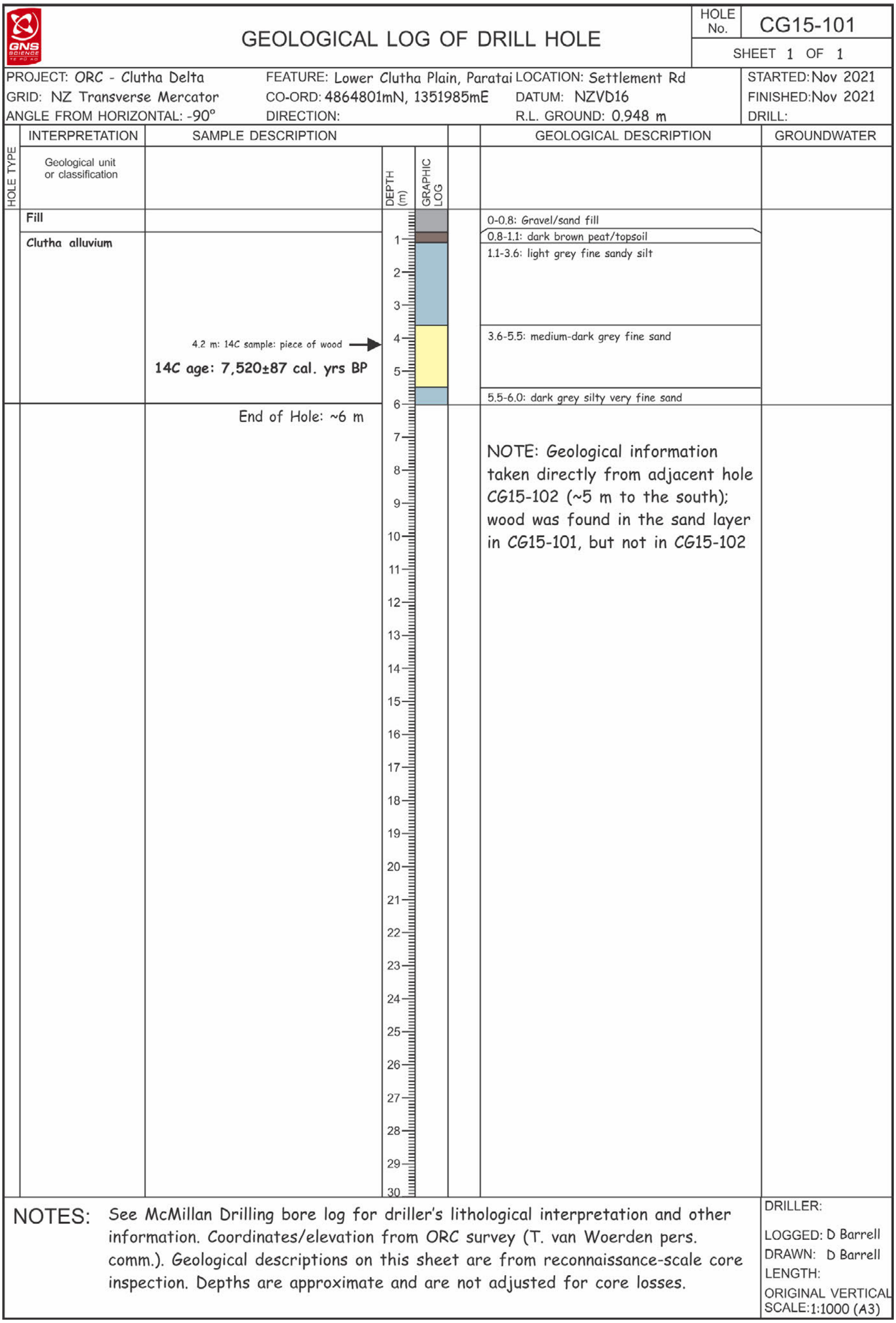


Figure A1.7 Geological log of drill hole CG15-101 (Paretai Hall).

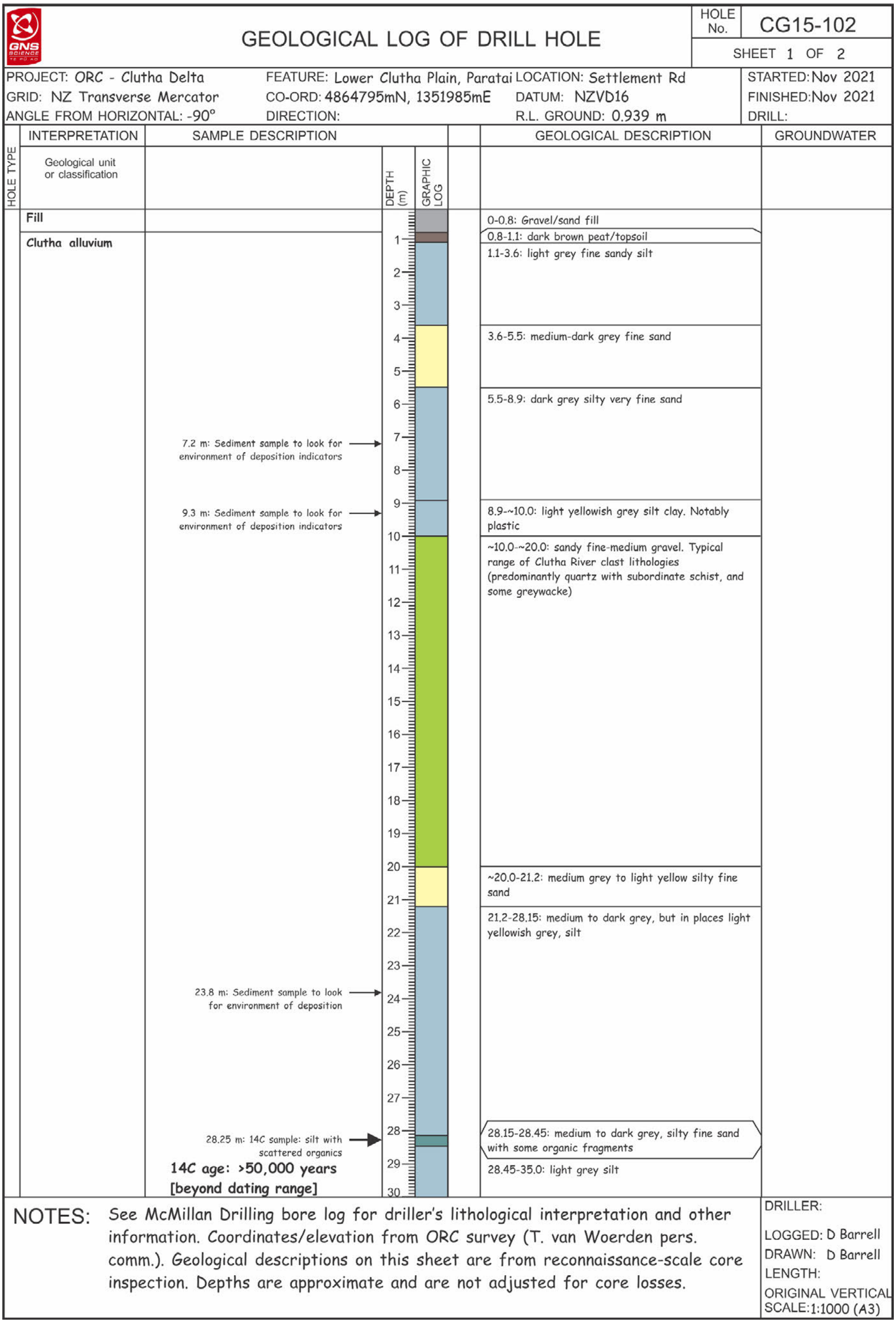


Figure A1.8 Geological log of drill hole CG15-102 (Paretai Hall).

GEOLOGICAL LOG OF DRILL HOLE

HOLE No. CG15-102

SHEET 2 OF 2

PROJECT: ORC - Clutha Delta
GRID: NZ Transverse Mercator
ANGLE FROM HORIZONTAL: -90°

FEATURE: Lower Clutha Plain, Paratai
CO-ORD: 4864795mN, 1351985mE
DIRECTION:

LOCATION: Settlement Rd
DATUM: NZVD16
R.L. GROUND: 0.939 m

STARTED: Nov 2021
FINISHED: Nov 2021
DRILL:

HOLE TYPE	INTERPRETATION (Geological unit or classification)	SAMPLE DESCRIPTION	DEPTH (m)	GRAPHIC LOG		GEOLOGICAL DESCRIPTION	GROUNDWATER
	Clutha alluvium	33.0 m: Sediment sample to look for environment of deposition →				[continued] 28.45-35.0: light grey silt	
		End of Hole: 35 m					

NOTES: See McMillan Drilling bore log for driller's lithological interpretation and other information. Coordinates/elevation from ORC survey (T. van Woerden pers. comm.). Geological descriptions on this sheet are from reconnaissance-scale core inspection. Depths are approximate and are not adjusted for core losses.

DRILLER:
LOGGED: D Barrell
DRAWN: D Barrell
LENGTH:
ORIGINAL VERTICAL SCALE: 1:1000 (A3)

Figure A1.8 Continued.

Rafter Radiocarbon

Accelerator Mass Spectrometry Result

This result for the sample submitted is for the exclusive use of the submitter. All liability whatsoever to any third party is excluded.

NZA 74842
R 41741/1
Job No: 221447
Report issued: 28 Jul 2022

Sample ID	CF15-106: 9.5 m - 14C
Description	Shell fragments in sand
Fraction dated	Shell
Submitter	David Barrell
	GNS Science Dunedin

Conventional Radiocarbon Age	**7280**	±	**25**	(years BP)
$\delta^{13}C$ (‰)	0.9	±	0.2	from IRMS
Fraction modern	0.4040	±	0.0013	
$\Delta^{14}C$ (‰) and collection date	-599.5	±	1.3	6 May 2022
Measurement Comment				

Sample Treatment Details

800 mg of raw sample was received. Description of sample when received: Sample was submitted in a microcentrifuge tube and consisted of a collection of small shell fragments. The largest and more robust pieces were selected for treatment. 220 mg was subsampled and prepared by: Surface Etch. Pretreatment description: Under the microscope shells were clean but had a light blue sheen. Shells were acid etched in 0.5M HCl for two minutes, then rinsed, and dried. Blue sheen was removed by acid etching. Shells were crushed in a mortar and pestle. Carbon dioxide was generated by carbonate CO2 evolution and 1.2 mgC was obtained. Sample carbon dioxide was converted to graphite by reduction with hydrogen over iron catalyst.

Conventional Radiocarbon Age and $\Delta^{14}C$ are reported as defined by Stuiver and Polach (*Radiocarbon 19*:355-363, 1977). $\Delta^{14}C$ is reported only if collection date was supplied and is decay corrected to that date. Fraction modern (F) is the blank corrected fraction modern normalized to $\delta^{13}C$ of -25‰, defined by Donahue et al. (*Radiocarbon*, *32*(2):135-142, 1990). $\delta^{13}C$ normalization is always performed using $\delta^{13}C$ measured by AMS, thus accounting for AMS fractionation. Although not used in the ^{14}C calculations, the environmental $\delta^{13}C$ measured offline by IRMS is reported if sufficient sample material was available. The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error based on the analysis of an ongoing series of measurements of standard materials. Further details of pretreatment and analysis are available on request.

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Figure A1.9 Radiocarbon dating report for sample from 9.5 m depth in CF15-106 (Matau Hall) (NZA 74842).

Rafter Radiocarbon

Accelerator Mass Spectrometry Result

This result for the sample submitted is for the exclusive use of the submitter. All liability whatsoever to any third party is excluded.

NZA 74770
R 41741/2
Job No: 221448
Report issued: 28 Jul 2022

Sample ID	CF15-106: 18.6 m - 14C
Description	Wood fragment from silty sand
Fraction dated	Wood
Submitter	David Barrell GNS Science Dunedin

Conventional Radiocarbon Age	**8000**	±	**30**	(years BP)
$\delta^{13}C$ (‰)	-25.7	±	0.2	from IRMS
Fraction modern	0.3694	±	0.0014	
$\Delta^{14}C$ (‰) and collection date	-633.8	±	1.4	6 May 2022
Measurement Comment				

Sample Treatment Details

501.12 mg of raw sample was received. Description of sample when received: Sample was submitted in a plastic bag and consisted of a ~2.5 cm long piece of wood with a light coating of sediment. The wood piece was flat on one side and had a split down the length on the other side. The wood piece was split fully along this side and a subsample was taken from this area, remainder stored. 278 mg was subsampled and prepared by: Cut/Scrape. Pretreatment description: The wood was scrapped with a scalpel to remove the sediment, then chopped into slithers for cellulose treatment. Chemical pretreatment was by cellulose extraction. Weight obtained after chemical pretreatment was 25.2 mg. Carbon dioxide was generated by sealed tube combustion and 0.9 mgC was obtained. Sample carbon dioxide was converted to graphite by reduction with hydrogen over iron catalyst.

Conventional Radiocarbon Age and $\Delta^{14}C$ are reported as defined by Stuiver and Polach (*Radiocarbon 19*:355-363, 1977). $\Delta^{14}C$ is reported only if collection date was supplied and is decay corrected to that date. Fraction modern (F) is the blank corrected fraction modern normalized to $\delta^{13}C$ of -25‰, defined by Donahue et al. (*Radiocarbon*, *32*(2):135-142, 1990). $\delta^{13}C$ normalization is always performed using $\delta^{13}C$ measured by AMS, thus accounting for AMS fractionation. Although not used in the ^{14}C calculations, the environmental $\delta^{13}C$ measured offline by IRMS is reported if sufficient sample material was available. The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error based on the analysis of an ongoing series of measurements of standard materials. Further details of pretreatment and analysis are available on request.

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Figure A1.10 Radiocarbon dating report for sample from 18.6 m depth in CF15-106 (Matau Hall) (NZA 74770).

Rafter Radiocarbon

NZA 74843
R 41741/3
Job No: 221449
Report issued: 28 Jul 2022

Accelerator Mass Spectrometry Result
This result for the sample submitted is for the exclusive use of the submitter. All liability whatsoever to any third party is excluded.

Sample ID	CF15-106: 28.15 m - 14C
Description	Plant fragments in silt
Fraction dated	Plant material
Submitter	David Barrell
	GNS Science Dunedin

Conventional Radiocarbon Age	**8843**	±	**33**	(years BP)
$\delta^{13}C$ (‰)	-27.3	±	0.2	from IRMS
Fraction modern	0.3326	±	0.0014	
$\Delta^{14}C$ (‰) and collection date	-670.3	±	1.4	6 May 2022
Measurement Comment				

Sample Treatment Details

700 mg of raw sample was received. Description of sample when received: Sample was submitted in two microcentrifuge tubes. Sample consisted of a collection of carbonaceous leafy material. One of the tubes was selected for treatment and the other stored. 350 mg was subsampled and prepared by: Picking. Pretreatment description: leafy material was black, shiny, thin flakes that easily broke apart. Silty pieces were removed and several white fibres were picked out with tweezers. otherwise sample appeared clean. Chemical pretreatment was by acid, alkali, (which was repeated three times), acid. Weight obtained after chemical pretreatment was 144.1 mg. Carbon dioxide was generated by sealed tube combustion and 1.1 mgC was obtained. Sample carbon dioxide was converted to graphite by reduction with hydrogen over iron catalyst.

Conventional Radiocarbon Age and $\Delta^{14}C$ are reported as defined by Stuiver and Polach (*Radiocarbon 19*:355-363, 1977). $\Delta^{14}C$ is reported only if collection date was supplied and is decay corrected to that date. Fraction modern (F) is the blank corrected fraction modern normalized to $\delta^{13}C$ of -25‰, defined by Donahue et al. (*Radiocarbon*, *32*(2):135-142, 1990). $\delta^{13}C$ normalization is always performed using $\delta^{13}C$ measured by AMS, thus accounting for AMS fractionation. Although not used in the ^{14}C calculations, the environmental $\delta^{13}C$ measured offline by IRMS is reported if sufficient sample material was available. The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error based on the analysis of an ongoing series of measurements of standard materials. Further details of pretreatment and analysis are available on request.

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Figure A1.11 Radiocarbon dating report for sample from 28.15 m depth in CF15-106 (Matau Hall) (NZA 74843).

Rafter Radiocarbon

Accelerator Mass Spectrometry Result

This result for the sample submitted is for the exclusive use of the submitter. All liability whatsoever to any third party is excluded.

NZA 74771
R 41741/4
Job No: 221450
Report issued: 28 Jul 2022

Sample ID	CF15-108: 5.8 m - 14C
Description	Wood fragment in sandy silt
Fraction dated	Wood
Submitter	David Barrell
	GNS Science Dunedin

Conventional Radiocarbon Age	**6657**	±	**27**	(years BP)
$\delta^{13}C$ (‰)	-24.3	±	0.2	from IRMS
Fraction modern	0.4366	±	0.0015	
$\Delta^{14}C$ (‰) and collection date	-567.2	±	1.5	6 May 2022
Measurement Comment				

Sample Treatment Details

251400 mg of raw sample was received. Description of sample when received: Initial weight was wet weight. Sample was submitted in a plastic bag and consisted of a 5 x 3 x 3 cm solid piece of wood. One end of the wood was intensely frayed, the subsample was cut from the other end. A ~3 cm piece with a mass of 1000 mg was subsampled and prepared by: Cut/Scrape. Pretreatment description: A small portion of bark and silt on the surface of the wood was removed. Otherwise sample appeared clean. Wood was cut into slivers for cellulose treatment, then dried. Chemical pretreatment was by cellulose extraction. Weight obtained after chemical pretreatment was 52.1 mg. Carbon dioxide was generated by sealed tube combustion and 1 mgC was obtained. Sample carbon dioxide was converted to graphite by reduction with hydrogen over iron catalyst.

Conventional Radiocarbon Age and $\Delta^{14}C$ are reported as defined by Stuiver and Polach (*Radiocarbon 19*:355-363, 1977). $\Delta^{14}C$ is reported only if collection date was supplied and is decay corrected to that date. Fraction modern (F) is the blank corrected fraction modern normalized to $\delta^{13}C$ of -25‰, defined by Donahue et al. (*Radiocarbon*, *32*(2):135-142, 1990). $\delta^{13}C$ normalization is always performed using $\delta^{13}C$ measured by AMS, thus accounting for AMS fractionation. Although not used in the ^{14}C calculations, the environmental $\delta^{13}C$ measured offline by IRMS is reported if sufficient sample material was available. The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error based on the analysis of an ongoing series of measurements of standard materials. Further details of pretreatment and analysis are available on request.

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Figure A1.12 Radiocarbon dating report for sample from 5.8 m depth in CF15-108 (Lawson Rd) (NZA 74771).

Rafter Radiocarbon

Accelerator Mass Spectrometry Result

This result for the sample submitted is for the exclusive use of the submitter. All liability whatsoever to any third party is excluded.

NZA 74772

R 41741/5

Job No: 221451

Report issued: 28 Jul 2022

Sample ID	CF15-109: 22.5 m - 14C
Description	Large piece of wood in silt
Fraction dated	Wood
Submitter	David Barrell
	GNS Science Dunedin

Conventional Radiocarbon Age	**8391**	±	**32**	(years BP)
$\delta^{13}C$ (‰)	-25.7	±	0.2	from IRMS
Fraction modern	0.3518	±	0.0014	
$\Delta^{14}C$ (‰) and collection date	-651.3	±	1.4	6 May 2022
Measurement Comment				

Sample Treatment Details

44000 mg of raw sample was received. Description of sample when received: Initial weight was wet weight. Sample was submitted in a plastic bag and consisted of a large cross-section piece of wood with a thick layer of mud around the edges. One edge of the wood was sliced off and subsampled. 1000 mg was subsampled and prepared by: Cut/Scrape. Pretreatment description: Silt was scraped off with a scalpel, and then wood was sliced into slivers for cellulose treatment. Subsample dried to obtain starting mass. Chemical pretreatment was by cellulose extraction. Weight obtained after chemical pretreatment was 34.8 mg. Carbon dioxide was generated by sealed tube combustion and 0.9 mgC was obtained. Sample carbon dioxide was converted to graphite by reduction with hydrogen over iron catalyst.

Conventional Radiocarbon Age and $\Delta^{14}C$ are reported as defined by Stuiver and Polach (*Radiocarbon 19*:355-363, 1977). $\Delta^{14}C$ is reported only if collection date was supplied and is decay corrected to that date. Fraction modern (F) is the blank corrected fraction modern normalized to $\delta^{13}C$ of -25‰, defined by Donahue et al. (*Radiocarbon*, *32*(2):135-142, 1990). $\delta^{13}C$ normalization is always performed using $\delta^{13}C$ measured by AMS, thus accounting for AMS fractionation. Although not used in the ^{14}C calculations, the environmental $\delta^{13}C$ measured offline by IRMS is reported if sufficient sample material was available. The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error based on the analysis of an ongoing series of measurements of standard materials. Further details of pretreatment and analysis are available on request.

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Figure A1.13 Radiocarbon dating report for sample from 22.5 m depth in CF15-109 (Lawson Rd) (NZA 74772).

Rafter Radiocarbon

Accelerator Mass Spectrometry Result

This result for the sample submitted is for the exclusive use of the submitter. All liability whatsoever to any third party is excluded.

NZA 74773
R 41741/6
Job No: 221452
Report issued: 28 Jul 2022

Sample ID	CG15-101: 4.2 m - 14C
Description	Wood fragment in sand
Fraction dated	Wood
Submitter	David Barrell
	GNS Science Dunedin

Conventional Radiocarbon Age	**6704**	±	**27**	(years BP)
$\delta^{13}C$ (‰)	-24.0	±	0.2	from IRMS
Fraction modern	0.4340	±	0.0015	
$\Delta^{14}C$ (‰) and collection date	-569.8	±	1.5	6 May 2022
Measurement Comment				

Sample Treatment Details

6300 mg of raw sample was received. Description of sample when received: Initial weight was wet weight. Sample was submitted in a plastic bag and consisted of a 4 x 1 cm wood fragment. No observable rings, so one edge was sliced off with a scalpel for treatment. 850 mg was subsampled and prepared by: Cut/Scrape. Pretreatment description: Subsample had a light coating of sandy silt that was removed with a scalpel. otherwise sample was clean of contaminants. Wood was then sliced into slivers for cellulose treatment and dried to obtain starting mass. Chemical pretreatment was by cellulose extraction. Weight obtained after chemical pretreatment was 157.5 mg. Carbon dioxide was generated by sealed tube combustion and 0.5 mgC was obtained. Sample carbon dioxide was converted to graphite by reduction with hydrogen over iron catalyst.

Conventional Radiocarbon Age and $\Delta^{14}C$ are reported as defined by Stuiver and Polach (*Radiocarbon 19*:355-363, 1977). $\Delta^{14}C$ is reported only if collection date was supplied and is decay corrected to that date. Fraction modern (F) is the blank corrected fraction modern normalized to $\delta^{13}C$ of -25‰, defined by Donahue et al. (*Radiocarbon*, *32*(2):135-142, 1990). $\delta^{13}C$ normalization is always performed using $\delta^{13}C$ measured by AMS, thus accounting for AMS fractionation. Although not used in the ^{14}C calculations, the environmental $\delta^{13}C$ measured offline by IRMS is reported if sufficient sample material was available. The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error based on the analysis of an ongoing series of measurements of standard materials. Further details of pretreatment and analysis are available on request.

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Figure A1.14 Radiocarbon dating report for sample from 4.2 m depth in CG15-101 (Paretai Hall) (NZA 74773).

Rafter Radiocarbon

NZA 74774
R 41741/7
Job No: 221453
Report issued: 28 Jul 2022

Accelerator Mass Spectrometry Result

Sample ID	CG15-102: 28.25 m - 14C
Description	Plant fragments in silt
Fraction dated	Plant material
Submitter	David Barrell
	GNS Science Dunedin

Conventional Radiocarbon Age	**Background**	±		(years BP)
$\delta^{13}C$ (‰)	-25.6	±	0.2	from IRMS
Fraction modern	-0.0004	±	0.0012	
$\Delta^{14}C$ (‰) and collection date	-1000.4	±	1.2	6 May 2022

Measurement Comment

This result is indistinguishable from 14C-free background materials prepared and measured concurrently with this sample. Therefore the reported fraction modern is a limiting age, not absolute.

Sample Treatment Details

344.4 mg of raw sample was received. Description of sample when received: Sample was submitted in a microcentrifuge tube and consisted of a collection of carbonised leaf fragments. The sample appeared mostly homogenous. Roughly half of the sample was selected for treatment and the rest stored. Pretreatment description: A few stones and clear fibres were removed with tweezers. The leaves had a light coating of silt. Chemical pretreatment was by acid, alkali, (which was repeated three times), acid. Weight obtained after chemical pretreatment was 103.5 mg. Carbon dioxide was generated by sealed tube combustion and 1.1 mgC was obtained. Sample carbon dioxide was converted to graphite by reduction with hydrogen over iron catalyst.

Conventional Radiocarbon Age and $\Delta^{14}C$ are reported as defined by Stuiver and Polach (*Radiocarbon 19*:355-363, 1977). $\Delta^{14}C$ is reported only if collection date was supplied and is decay corrected to that date. Fraction modern (F) is the blank corrected fraction modern normalized to $\delta^{13}C$ of -25‰, defined by Donahue et al. (*Radiocarbon*, *32*(2):135-142, 1990). $\delta^{13}C$ normalization is always performed using $\delta^{13}C$ measured by AMS, thus accounting for AMS fractionation. Although not used in the ^{14}C calculations, the environmental $\delta^{13}C$ measured offline by IRMS is reported if sufficient sample material was available. The reported errors comprise statistical errors in sample and standard determinations, combined in quadrature with a system error based on the analysis of an ongoing series of measurements of standard materials. Further details of pretreatment and analysis are available on request.

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Figure A1.15 Radiocarbon dating report for sample from 28.25 m depth in CG15-102 (Paretai Hall) (NZA 74774).

Rafter Radiocarbon
Calibration Report

NZA 74842

R 41741/1

Report issued: 28 Jul 2022

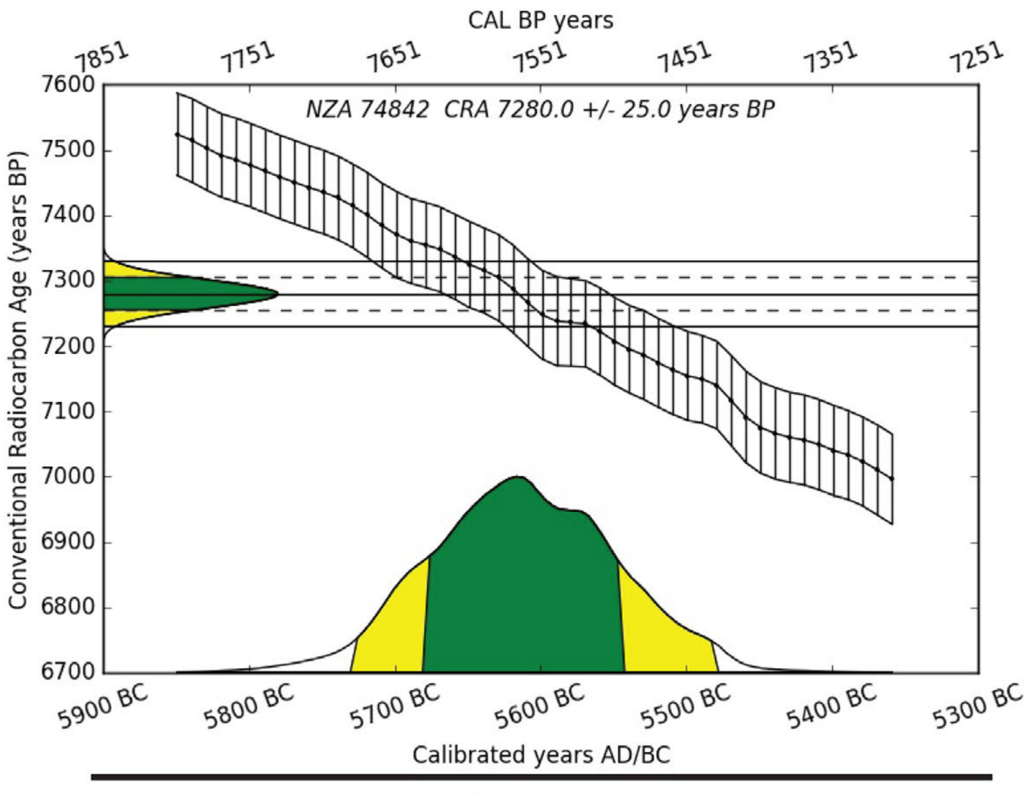
CONVENTIONAL RADIOCARBON AGE 7280 ± 25 years BP

Calibrated with Marine20 (Marine data from Heaton et al (2020) Radiocarbon 62. doi: 10.1017/RDC.2020.68.).

CALIBRATED AGE in terms of confidence intervals

1 sigma interval is 5677 BC to 5547 BC 7628.0 BP to 7498.0 BP (100.0% of area)

2 sigma interval is 5729 BC to 5479 BC 7680.0 BP to 7430.0 BP (100.0% of area)



Calibration performed using Winscal v. 6.0 adapted from: Stuiver and Reimer (*Radiocarbon 35*(1): 215-230, 1993).

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Figure A1.16 Radiocarbon calibration report for NZA 74842 from 9.5 m depth in CF15-106 (Matau Hall).

Rafter Radiocarbon Calibration Report

NZA 74770

R 41741/2

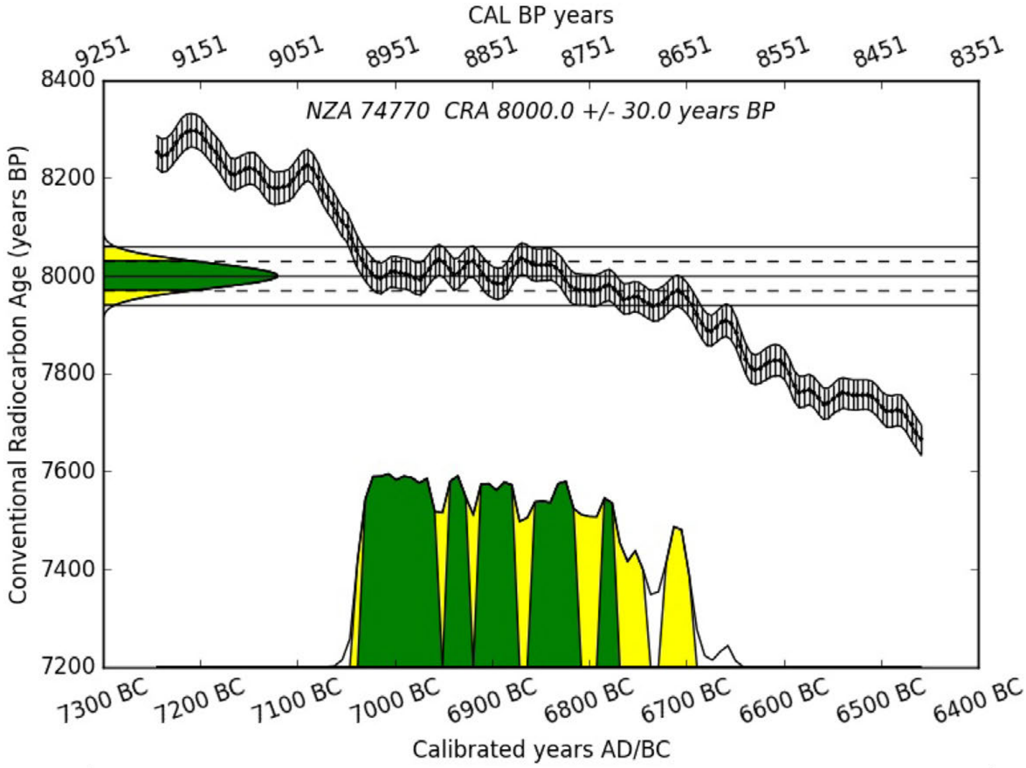
Report issued: 28 Jul 2022

CONVENTIONAL RADIOCARBON AGE 8000 ± 30 years BP

Calibrated with SHCal20 (Hogg et al. 2020 Radiocarbon 62. doi: 10.1017/RDC.2020.59).

CALIBRATED AGE in terms of confidence intervals

1 sigma interval is	7032 BC to 6957 BC	8983.0 BP to 8908.0 BP (36.6% of area)
	6950 BC to 6920 BC	8901.0 BP to 8871.0 BP (13.9% of area)
	6918 BC to 6873 BC	8869.0 BP to 8824.0 BP (21.1% of area)
	6861 BC to 6813 BC	8812.0 BP to 8764.0 BP (21.4% of area)
	6789 BC to 6773 BC	8740.0 BP to 8724.0 BP (6.9% of area)
2 sigma interval is	7039 BC to 6741 BC	8990.0 BP to 8692.0 BP (93.2% of area)
	6725 BC to 6695 BC	8676.0 BP to 8646.0 BP (6.8% of area)



Calibration performed using Winscal v. 6.0 adapted from: Stuiver and Reimer (*Radiocarbon 35*(1): 215-230, 1993).

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Figure A1.17 Radiocarbon calibration report for NZA 74770 from 18.6 m depth in CF15-106 (Matau Hall).

Rafter Radiocarbon
Calibration Report

NZA 74843

R 41741/3

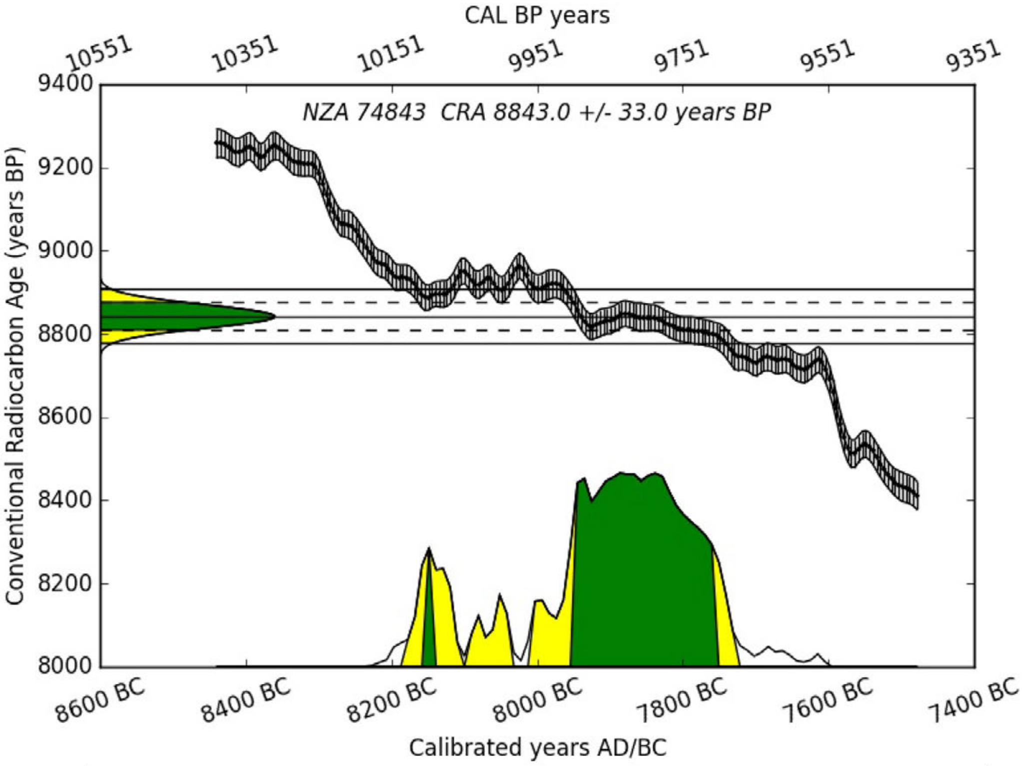
Report issued: 28 Jul 2022

CONVENTIONAL RADIOCARBON AGE 8843 ± 33 years BP

Calibrated with SHCal20 (Hogg et al. 2020 Radiocarbon 62. doi: 10.1017/RDC.2020.59).

CALIBRATED AGE in terms of confidence intervals

1 sigma interval is	8154 BC to 8147 BC	10105.0 BP to 10098.0 BP (2.4% of area)
	7954 BC to 7757 BC	9905.0 BP to 9708.0 BP (97.6% of area)
2 sigma interval is	8182 BC to 8108 BC	10133.0 BP to 10059.0 BP (11.8% of area)
	8092 BC to 8034 BC	10043.0 BP to 9985.0 BP (5.5% of area)
	8012 BC to 7724 BC	9963.0 BP to 9675.0 BP (82.7% of area)



Calibration performed using Winscal v. 6.0 adapted from: Stuiver and Reimer (*Radiocarbon 35*(1): 215-230, 1993).

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Figure A1.18 Radiocarbon calibration report for NZA 74843 from 28.15 m depth in CF15-106 (Matau Hall).

Rafter Radiocarbon
Calibration Report

NZA 74771

R 41741/4

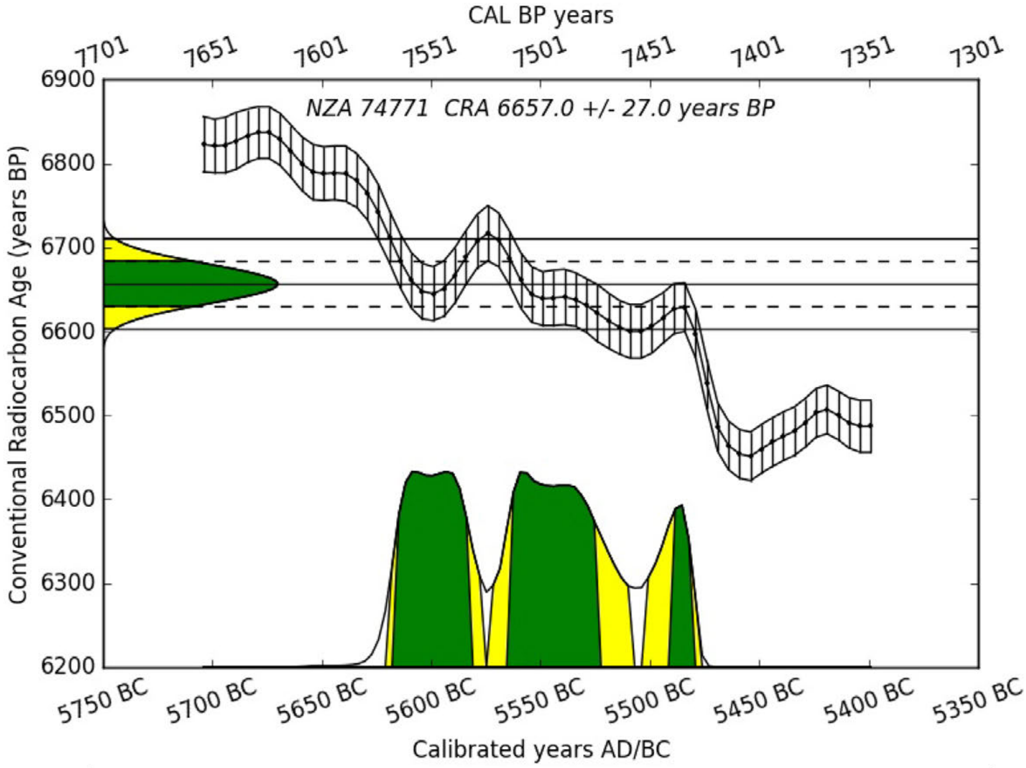
Report issued: 28 Jul 2022

CONVENTIONAL RADIOCARBON AGE 6657 ± 27 years BP

Calibrated with SHCal20 (Hogg et al. 2020 Radiocarbon 62. doi: 10.1017/RDC.2020.59).

CALIBRATED AGE in terms of confidence intervals

1 sigma interval is	5615 BC to 5583 BC	7566.0 BP to 7534.0 BP (41.9% of area)
	5564 BC to 5525 BC	7515.0 BP to 7476.0 BP (49.2% of area)
	5490 BC to 5482 BC	7441.0 BP to 7433.0 BP (8.9% of area)
2 sigma interval is	5619 BC to 5575 BC	7570.0 BP to 7526.0 BP (36.5% of area)
	5572 BC to 5509 BC	7523.0 BP to 7460.0 BP (48.4% of area)
	5503 BC to 5479 BC	7454.0 BP to 7430.0 BP (15.1% of area)



Calibration performed using Winscal v. 6.0 adapted from: Stuiver and Reimer (*Radiocarbon 35*(1): 215-230, 1993).

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Figure A1.19 Radiocarbon calibration report for NZA 74771 from 18.6 m depth in CF15-106 (Matau Hall).

Rafter Radiocarbon
Calibration Report

NZA 74772

R 41741/5

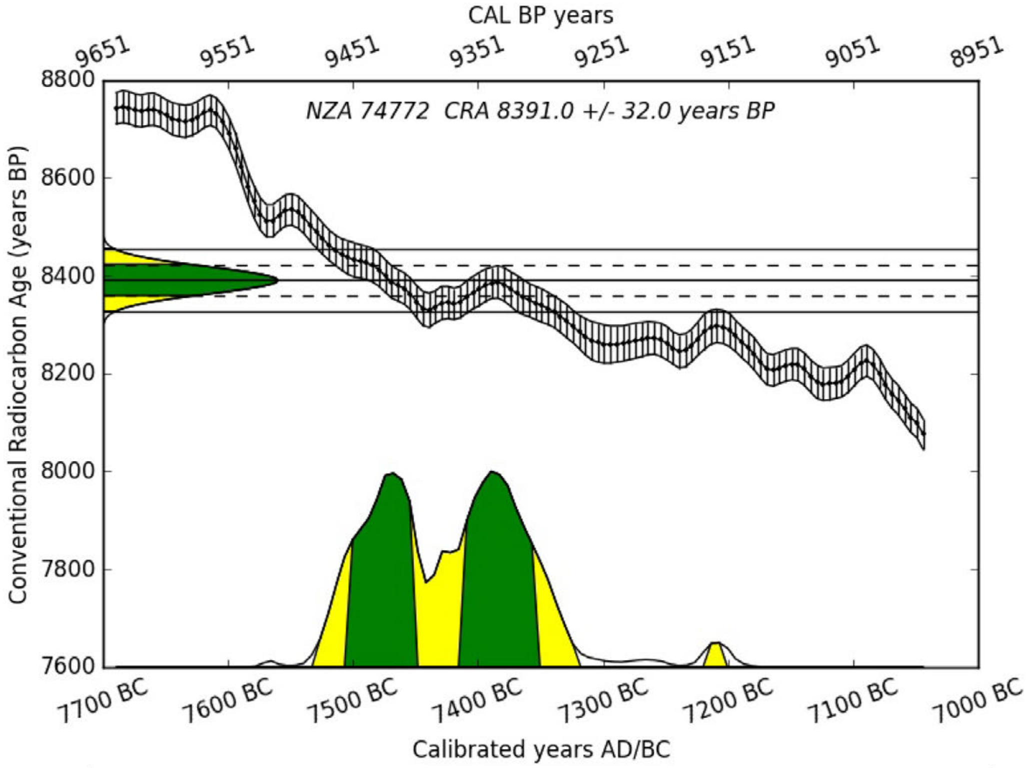
Report issued: 28 Jul 2022

CONVENTIONAL RADIOCARBON AGE 8391 ± 32 years BP

Calibrated with SHCal20 (Hogg et al. 2020 Radiocarbon 62. doi: 10.1017/RDC.2020.59).

CALIBRATED AGE in terms of confidence intervals

1 sigma interval is	7503 BC to 7448 BC	9454.0 BP to 9399.0 BP (47.2% of area)
	7415 BC to 7354 BC	9366.0 BP to 9305.0 BP (52.8% of area)
2 sigma interval is	7527 BC to 7324 BC	9478.0 BP to 9275.0 BP (99.1% of area)
	7214 BC to 7204 BC	9165.0 BP to 9155.0 BP (0.9% of area)



Calibration performed using Winscal v. 6.0 adapted from: Stuiver and Reimer (*Radiocarbon 35*(1): 215-230, 1993).

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Figure A1.20 Radiocarbon calibration report for NZA 74772 from 5.8 m depth in CF15-108 (Lawson Rd).

Rafter Radiocarbon Calibration Report

NZA 74773

R 41741/6

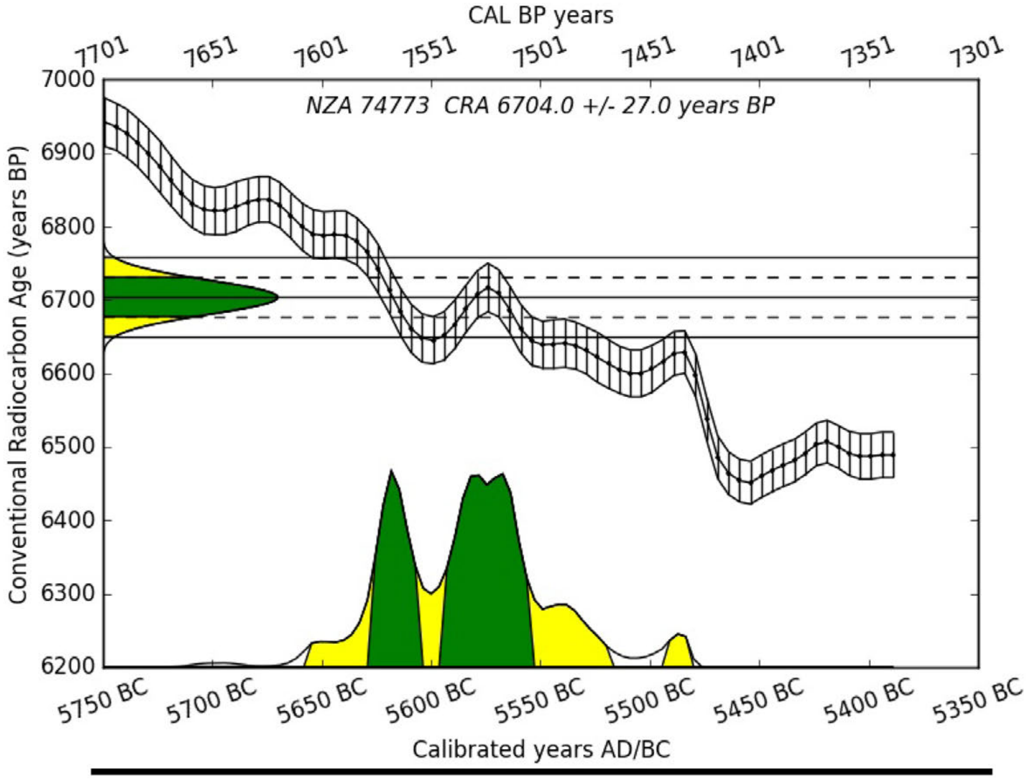
Report issued: 28 Jul 2022

CONVENTIONAL RADIOCARBON AGE 6704 ± 27 years BP

Calibrated with SHCal20 (Hogg et al. 2020 Radiocarbon 62. doi: 10.1017/RDC.2020.59).

CALIBRATED AGE in terms of confidence intervals

1 sigma interval is	5627 BC to 5604 BC	7578.0 BP to 7555.0 BP (34.7% of area)
	5594 BC to 5555 BC	7545.0 BP to 7506.0 BP (65.3% of area)
2 sigma interval is	5655 BC to 5519 BC	7606.0 BP to 7470.0 BP (97.7% of area)
	5492 BC to 5482 BC	7443.0 BP to 7433.0 BP (2.3% of area)



Calibration performed using Winscal v. 6.0 adapted from: Stuiver and Reimer (*Radiocarbon 35*(1): 215-230, 1993).

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Figure A1.21 Radiocarbon calibration report for NZA 74773 from 4.2 m depth in CG15-101 (Paretai Hall).

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