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Understanding Sedimentary Systems and Processes of the Hikurangi Subduction Margin; from Trench to Back-Arc. Volume 2

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Understanding Sedimentary Systems and Processes of the Hikurangi Subduction Margin; from Trench to Back-Arc. Volume 2

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Abstract:

This is the second of a two-part *New Zealand Journal of Geology and Geophysics* Special Issue on understanding sedimentary systems in Aotearoa-New Zealand's Hikurangi Subduction Margin (HSM). This volume includes six research papers that explore sediment-tectonic interactions operating over a range of spatio-temporal scales. We take a distinctive perspective moving from the subduction deformation front in the Hikurangi Trough, upslope to the subduction wedge, and onshore to the Coastal Ranges. Temporally, papers span the onset of subduction in the Miocene, to disentangling provenance of turbidity currents triggered by the 2016 CE Kaikōura Earthquake. Collectively, the studies in the special issue reveal a complicated and continually evolving margin, where active tectonics and volcanism, coupled with vigorous climatic and oceanographic drivers, modulate erosion, transport, and depositional cycles of vast volumes of terrigenous sediment into ocean basins. Despite decades of significant research advances in our knowledge of the HSM, considerable scope remains for future work. A deeper understanding of fundamental tectonic-sediment interactions operating on active margins, along with the significant geohazards they pose, remain outstanding research needs.

Collectively, Volumes 1 and 2 highlight enduring interest in the HSM as a globally important natural laboratory for the study of subduction zone geoscience.

Keywords:

Hikurangi Subduction Margin, sedimentary basins, SW Pacific, Miocene, Quaternary, IODP, biostratigraphy, New Zealand

Introduction

This is the second and final volume of the special issue dedicated to the understanding of sedimentary systems of the Hikurangi Subduction Margin (HSM). This region, located on and offshore of eastern Aotearoa-New Zealand (Figure 1), is one of Earth's youngest and most seismically complex subduction systems (Wallace et al. 2004; Wallace et al. 2014; Wallace et al. 2016; Barnes et al. 2020; Davidson et al. 2020; Gase et al. 2022). Here the oceanic Pacific plate obliquely subducts beneath the continental Australian plate (Wallace et al. 2004). The HSM region encompasses a broad deformation zone >200 km across, stretching from the offshore Hikurangi Trough to the onshore Taupō Volcanic Zone (Ballance 1976; Lewis et al. 1993; Nicol et al. 2007; Pedley et al. 2010; Strachan et al. 2022; Figure 1). A range of sedimentary basins on the HSM, encompassing variable geometries, spatial dimensions, and depositional systems, preserve a record of subduction evolution over the last ~25 Ma (e.g. Beanland et al. 1998; Proust et al. 2005; Orpin et al. 2006; Giba et al. 2010; Paquet et al. 2011; Pouderoux et al. 2012;Bailleul et al. 2013; Burgreen and Graham 2014; Bland et al. 2015; Kuehl et al. 2016; McArthur and Tek 2021; McArthur et al. 2021; Griffin et al. 2022; McArthur et al. 2022a; Claussmann et al. 2023; Hines; et al. 2023; Bland et al. 2024; Figure 1).

The inception, propagation, and ongoing tectonic convergence associated with the dynamic HSM is arguably the most profound geodynamic process to have affected Aotearoa-New Zealand in the last 25 Ma. Rapid crustal shortening and uplift has resulted in dramatic exhumation of much of today's landmass (Litchfield et al. 2007; Mortimer et al. 2017), which continues to be influenced by frequent earthquakes (e.g. Wallace et al. 2016; Wallace 2020; Pizer et al. 2023), volcanic eruptions (e.g. Wilson et al. 1995; Hopkins et al. 2020), tsunamis (e.g. Power et al. 2016; Clark et al. 2019), vigorous climate events (e.g. Orpin et al. 2010), and associated surface processes (e.g. Fuller et al. 2016; Howarth et al. 2021). These myriad geohazards pose real risks to Aotearoa-New Zealand's inhabitants and nearest neighbours across the Tasman Sea and Pacific Ocean (Stirling et al. 2012; Gerstenberger et al. 2020; Bull et al. 2022).

This volume includes six original research papers, from a range of global researchers (Table 1). The papers explore sedimentary dynamics operating over a range of scales, from basin evolution initiated by the onset of subduction in the Miocene (Bland et al. 2022), to disentangling provenance of laterally extensive Hikurangi Channel focussed turbidity currents triggered by the 2016 CE Kaikōura Earthquake (Hayward et al. 2022).

This volume includes four chronostratigraphic studies (Crundwell and Woodhouse 2022a,b; Noda et al. 2022; Woodhouse et al. 2022) that leverage off margin histories recovered during Integrated Ocean Drilling Program (IODP) Expeditions 372 and 375 (Wallace et al. 2019). These expeditions brought together 61 scientists from around the world sailing between November 2017 CE and May 2018 CE (Wallace et al. 2019). The voyages produced a wide array of datasets (e.g. petrophysics, density, paleomagnetism, sedimentology, biostratigraphy, radiocarbon dating, tephrostratigraphy), including recovery of up to a >1 km long sediment core (IODP Site U1520, Wallace et al. 2019). The core sites spanned an upper slope to Hikurangi Trough transect, allowing researchers to address myriad questions from both incoming- and overriding-plate sedimentary successions (Figure 1). These expeditions build on several decades of marine geology research, requiring cumulative years of fieldwork, numerous voyages, and continue to drive a high level of interest, and focussed research on the HSM (Lewis et al. 1993; Lewis et al. 1998; Lewis and Barnes 1999; Barnes et al. 2010; Pouderoux et al. 2014; Mountjoy et al. 2018; Howarth et al. 2021; Schwarze et al. 2023; Maier et al. *In press*).

To that end, fundamental advances in our geological understanding of processes operating on the HSM were leveraged from a series of large international research initiatives. A key finding was the varied nature of the convergent margin along its length, and the range of geometries in the resulting structural fabric and sedimentary basins. The 1993 GeodyNZ programme provided the first detailed geomorphic map of the margin, from the Kermadec Trench to Kaikōura Canyon (Collot et al. 1996). Numerous geophysical initiatives have since provided unprecedented detail of the overriding accretionary prism tectonics and deformed backstop (e.g. Barnes et al. 2010 and references therein; Ghisetti et al. 2016), the incoming plate and basin sequence, seamount subduction (e.g. Lewis et al. 1998 and references within), gas hydrates and the interplay between imbricate fault systems and slope basins. A small selection of recent research initiatives includes: 05CM and NIGHT seismic surveys (Barker et al. 2009), MARGINS Source-to-Sink (Kuehl et al. 2016); GeoPRISMS; MANGO (Bassett et al. 2016); HOBITSS (Wallace et al. 2016); NZ3D-FWI (Davy et al. 2021); SHIRE (Gase et al. 2022; Bassett et al. 2023) and numerous NZ Ministry of Business, Innovation and Employment (MBIE) funded voyages and research programmes (Endeavour, Oceans2020, Strategic Science Investment Fund), RV *Sonne* (e.g. SO191, 192, 213, 247) surveys, *Marion Dufresne* coring campaigns (e.g. MD97, MD152), and OPD (181; Carter et al. 2004) and IODP expeditions (372 and 375; Wallace et al. 2019). Today, the HSM represents one of Earth's great geoscience laboratories, evidenced by the history of national and international science initiatives and ongoing globally significant research.

The dominantly marine geology focussed papers in this volume (Table 1) allows us to take a distinctive perspective moving from the subduction deformation front in the Hikurangi Trough (Hayward et al. 2022; Noda et al. 2022; Woodhouse et al. 2022), up slope to the subduction wedge/lower trench slope (Crundwell and Woodhouse 2022a; b), and continuing to ancient exhumed marine strata in the onshore Coastal Ranges (Bland et al. 2022; Figures 1 and 2), corresponding roughly to the trench-slope break of the margin (McArthur et al. 2020; Strachan et al. 2022). In addition, the study by Hayward et al. (2022) provides an insight into axial Hikurangi Trough processes, whilst the studies by Crundwell and Woodhouse (2022a; b) compare subduction wedge biostratigraphic records with distal records from Ocean Drilling Program (ODP) Site 181-1123 (Carter et al. 2004), located on the deep northeastern slopes of the Chatham Rise some ~900 km ESE of the deformation front (Figures 1 and 2).

Hikurangi Trough

The study by Noda et al. (2022) uses detrital magnetic minerals to explore diagenetic processes recorded from IODP Expedition 375, Hole U1520D (Figure 3). The authors use 67 Late Pleistocene to Holocene aged samples from between 0-510 metres below seafloor (mbsf). The focus of this study is identification of magnetic "clusters" to define different types of turbidites; essentially thicker-bedded and coarser versus thinner-bedded and finer grained beds. Their analysis includes brief descriptions of the strata but omits turbidite muds from the presented statistics. A real strength of this study is that they show how magnetic properties change with depth, interpreted as a result of diagenetic processes (Figure 3). These findings are interpreted in terms of differences in sulfidization, whereby Unit 1 (0-110 mbsf) has a lack of sulfidization, which is ascribed to high sedimentation rates related to the thicker-bedded and coarser turbidites (Figure 3). This is despite the sulfate-methane transition zone occurring at 27.8 mbsf (Barnes et al. 2019). The authors develop an insightful conceptual model to explain their findings in terms of sedimentation and diagenesis (Figure 3).

The study by Woodhouse et al. (2022) offers a comprehensive, high-resolution assessment of Hikurangi Trough sedimentation from IODP Site U1520D (Figure 1). The authors focus on the upper stratigraphic unit, Unit 1 (0-110 mbsf), dated in this paper as spanning the last 45 kyrs (Figure 4). The paper focuses on understanding the response to major glacio-eustatic sea-level cyclicity, as the record spans Marine Isotope Stages 1, 2, and part of 3 (Figure 4). Central to their thesis is development of a new age model that integrates radiocarbon dates, tephrochronology, and oxygen isotope stratigraphy (Figure 4). These chronological data are supplemented with detailed lithofacies and foraminiferal analyses that allow the authors to speculate on past gravity flow processes, sediment sources, triggers, and controls through glacial-interglacial periods. To interrogate frequency-magnitude relationships, they quantify bed recurrence intervals and changing sediment accumulation rates over time. Dramatic changes in sediment flux, frequency, and depositional processes are evident between glacial and interglacial periods. Results show that turbidite recurrence varies from ~49 to ~322 years depending on the Marine Isotope Stage (Figure 4). A global comparison suggests that the HSM had one of the highest terrigenous sediment fluxes of any continental margin during the Last Glacial Maximum.

Building on the Early Miocene to Quaternary aged deep-marine gravity flow and mass-transport deposit insights of Noda et al. (2022) and Woodhouse et al. (2022), the 2016 CE Mw 7.8 Kaikōura Earthquake (Hamling et al. 2017) triggered sediment collapse and flow transformation (Fisher 1983; Strachan 2008) to turbidity currents in at least 10 submarine canyons (Mountjoy et al. 2018; Howarth et al. 2021; Maier et al. *In press*). This provided Hayward et al. (2022) the opportunity to take a novel approach to disentangling sediment provenance from the 2016 CE Kaikōura Earthquake triggered turbidity current. They analysed intra-turbidite foraminiferal faunal variability within the laterally extensive, Hikurangi Channel focussed, Kaikōura event bed to determine the sediment-source history of the deposit. Data from 17 event bed cores record a down-flow axial transect along the HSM (Figure 5). Results identify water depths of sediment-source areas along with likely geographic source regions of landslide collapse from within contributing distributary systems (Figure 5). They suggest that two regionally distinct compositions can be resolved: a Kaikōura Canyon distributary system, and a more northern Cook Strait-Opouawe canyon distributary system (Figure 5). At ~600 km from the Kaikōura Canyon head and within the Hikurangi Channel, a composite deposit sourced from the Cook Strait-Opouawe canyons is overlain by Kaikōura Canyon sourced material (Figure 5). This bed preserves evidence of temporal flow evolution and offers new insights into sedimentary processes operating within the Hikurangi Channel system (Tek et al. 2022).

Subduction wedge/lower trench slope

Crundwell and Woodhouse (2022a) present new biostratigraphic age models (Table 2) for the suite of drill holes acquired during IODP Expeditions 372 and 375 (Wallace et al. 2019). They develop a detailed biostratigraphic framework to improve the chronological dating of Middle to Late Quaternary strata in northeastern Zealandia (Table 2). In general, Zealandia is thought to have very few deep-marine Pleistocene-Holocene aged Quaternary biostratigraphic markers, resulting in insufficient biostratigraphic detail and age control to unravel the complex depositional and deformational histories. The framework presented is based on well documented and dated 0–1.2 Ma planktic foraminiferal records from Ocean Drilling Project (ODP) Site 181–1123 (Carter et al. 2004). To overcome the problem of biostratigraphic uniqueness, Crundwell and Woodhouse (2022a) employ sequences of secondary foraminiferal-based biostratigraphic markers, rather than individual biostratigraphic markers, and use them within the contextual chronological framework of traditional keystone biostratigraphic markers (Table 2). These models are likely to underpin future studies examining Middle to Late Quaternary core records from the HSM and elsewhere in the southern hemisphere, where high-resolution chronostratigraphic correlations are required.

The second study by Crundwell and Woodhouse (2022b) applies a modified series of new biostratigraphically constrained chronologies to elucidate the sedimentary and tectonic history of Quaternary sequences on the northern HSM (Figure 6). The authors use all the core sites across the entire upper slope to deep-water trough transect of IODP Expeditions 372-375 (Wallace et al. 2019; Figure 6). The fidelity of the records varies with site, along with the impact of downslope sediment reworking, and sampling resolution. Their analysis suggests that hiatuses in the chronological records reflect tectonic deformation of the accretionary prism, and at the Hikurangi Trough core sites, the influence of proximality as a consequence of ongoing subduction convergence (Figure 6). Improvements to the biostratigraphic framework first proposed by (Crundwell and Woodhouse, 2022a) now offer an unprecedented level of biostratigraphic detail and accompanying chronological control (Figure 6; Table 2). Modifications to the biostratigraphic framework include the introduction of three new subzones: the *Tr. truncatulinoides* Marine Isotope Stage (MIS) 1 (0–11 ka), and the *Pulleniatina/Gr. tumida* MIS-21e (842–851 ka) and MIS-21g (856–867 ka) subzones.

Onshore Coastal Ranges/Trench-slope break

The study by Bland et al. (2022) investigates a fundamental period for the HSM, the onset of subduction initiation beneath the eastern North Island. They disentangle the complex sedimentary and stratigraphic records of mass-transport deposits (MTDs). Here, Bland et al. (2022) use field-based stratigraphic descriptions, mineralogy, and biostratigraphic analyses of benthic and planktic foraminifera from several outcrops, collated over ~40 years of fieldwork, to propose an amended regional lithostratigraphy. They describe the regional distribution of the highly calcareous early Waitakian (latest Oligocene) Weber Formation. Evidence of MTDs is widespread and imply critical evidence of an important episode of margin destabilization, with olistoliths of the Weber Formation preserved in the overlying Coast Road and Whakataki formations (Figure 7). They propose that these MTDs are derived directly from collapse of thrust-controlled structural highs, and the onset of subduction-related compression which the authors tie biostratigraphically to within the mid-Waitakian, ~ 23 Ma (Figure 7).

Future Research Directions

The wealth of data-rich studies presented here showcases the natural laboratory that is the HSM, one of the few subduction margins on Earth to be readily accessible to geoscientists, both on and offshore (Strachan et al. 2022). Although great advances have been made regarding understanding the effects of subduction on HSM sedimentation (Bland et al. 2022; Crundwell and Woodhouse 2022b; Woodhouse et al. 2022), it remains a fertile region for ongoing and future study.

Many research opportunities exist within the HSM to better understand, quantify, and predict interconnections between tectonics, oceanic processes, and sediment dynamics. Here we focus on four potential avenues of research: (1) landscape/seascape pre-conditioning; (2) glacio-eustatic controls; (3) the Hikurangi Channel; and (4) sedimentary influences on deformation style.

1. Landscape pre-conditioning is a well-established concept in terrestrial surface processes generally, and within the terrestrial components of the HSM (Fuller et al. 2016). The concept focuses on the interconnectivity and influence of depositional processes, deposits, and triggers points over time. The HSM is host to numerous submarine canyons, channels, and gullies (Barnes 1992; Carter and McCave 1992; Lewis 1994; Lewis et al. 1998; Lewis and Barnes 1999; Lewis and Pantin 2002; Mountjoy et al. 2018; Howarth et al. 2021), many of which could act as potential sites for real-time observatories of canyon processes (e.g. Paull et al. 2003; Xu et al. 2008; Maier et al. 2019). With a range of orientations, connectivity to littoral currents, river mouths,

ocean conditions, and varying shelf widths and canyon head indentations, the HSM's network of distributary systems could serve as ideal locations to assess active processes along an entire margin. For example, quantifying the balance of bio-physical processes in carbon burial and nourishment of deep ocean basins. Studies from other canyons globally now reveal a wider range of previously unrecognised depositional processes. Examples that collectively shape and build the seascape include the influence of incremental downslope and alongslope current processes and interactions, internal-tide and-wave processes, and catastrophically triggered (earthquakes and storm) gravity flow events (e.g. Liu et al. 2016; Azpiroz-Zabala et al. 2017; Gavey et al. 2017; Maier et al. 2019; Miramontes et al. 2021; Bailey et al. 2021; Talling et al. 2022). In addition, because the HSM hosts distal deposits of co-located volcanic eruptions, predominantly sourced from the Coromandel- (CVZ) (Shane et al. 1996; Shane et al. 1998; Carter et al. 2003) and Taupō-volcanic zones (TVZ) (Houghton et al. 1995; Wilson et al. 1995; Alloway et al. 2005; Allan et al. 2008), it is ideally located to investigate eruption histories and environmental recovery along with tephra dispersal and depositional processes (Hopkins and Seward, 2019; Hopkins et al. 2020).

2. Outcropping shallow-marine strata of Pliocene–Pleistocene age within the HSM preserve valuable records of 41 kyr and 100 kyr glacio-eustatic sea-level cyclicity. Characterisation of stratal and paleoenvironmental changes validated sequence stratigraphic concepts and approaches within an Aotearoa-New Zealand context (Vella, 1963; Beu and Edwards, 1984; Haywick et al. 1992; Bland et al. 2004; Caron et al. 2004). Continuing this work, improved depth-age models are presented within this Special Volume

(Crundwell and Woodhouse 2022a, b; Woodhouse et al. 2022) and will facilitate coupled studies of sedimentary responses to glacio-eustatic forcing. Due to the extremely high sedimentation rates of the HSM (up to ~10 m/kyr, Woodhouse et al. 2022) the sedimentary record is expanded, allowing for development of high-resolution chronologies and age models. The fidelity of the combined radiocarbon, biostratigraphic, and oxygen isotope records now allow potentially millennial-scale reconstructions of past climate and oceanographic conditions during the last 50 kyrs. Long IODP sediment cores are thought to record near continuous deposition over the last ~2 Myrs, including trench slope and Hikurangi Trough sites (Crundwell and Woodhouse 2022a). Collectively, these allow for deeper time considerations of glacio-eustatic forcing over multiple sea-level cycles, including through the mid-Pleistocene transition (Elderfield et al. 2012).

3. The Hikurangi Channel remains one of the most enigmatic sediment transport systems on Earth, with some of the longest tracking of turbidity currents ever reported (Lewis 1994; Carter et al. 1996; Maier et al. *In press*). An excellent framework exists regarding both the modern sedimentology (Lewis et al. 1998; Lewis and Pantin 2002; Mountjoy et al. 2018; Howarth et al. 2021) and ancient architecture of the channel and its levees (McArthur and Tek 2021; Tek et al. 2022; McArthur et al. 2024). Much of the existing work has focused on the proximal and mid-reaches of the channel (0–700 km from the Kaikōura Canyon), leaving scope for future work on sediment transport processes, dispersal of organic carbon and pollutants, and potential nourishment of the distal Southwest Pacific Basin, well beyond the HSM.

4. Distinct from the record of deformation that sediments provide (Bailleul et al. 2007; Bland et al. 2022; Claussmann et al. 2022), studies are now revealing the role that sedimentation may have on modulating structural deformation (de Sagazan and Olive 2021; McArthur et al. 2021; McArthur et al. 2022b). Fundamentally, the type of sediment, hence its density, strain thresholds etc., present in a deforming sequence may dictate the nature and timing of deformation (Butler 2020). Recent work has documented the role of sediment type and thickness in effecting the type of deformation seen along the HSM, with areas of slow-slip partly dictated by sediments and fluid escape in the subducting plate (Gase et al. 2022; Bangs et al. 2023). Developing an integrated understanding of how subduction margins evolve should be a critical point of future research, on the HSM and other subduction margins.

The HSM also affords the opportunity for more applied research, specifically in relation to the current energy transition and geohazards. Both represent some of the most pressing issues of our time. As Aotearoa-New Zealand continues to transition its electricity generation network towards increasingly renewable and low-emission sources, porous rocks within the HSM may provide potential for 'Earth-battery' storage opportunities, e.g., sub-surface temporary storage of compressed air, hydrogen, or the long-term geological sequestration of atmospheric CO_2 (Funnell et al. 2009).

The HSM is a nexus for multiple natural geohazards including earthquakes (Wallace et al. 2004; Stirling et al. 2012; Wallace et al. 2014; Gerstenberger et al. 2020; Wallace, 2020), tsunami (Bell et al. 2014; Power et al. 2016; Clark et al. 2019), and both terrestrial and submarine landslides (Mountjoy et al. 2014; Watson et al.

2020; Cook et al. 2023; McArthur et al. 2024). Given the southwest Pacific’s dominant weather patterns and storm tracks, the region is also prone to cyclones, associated large-scale surface flooding (Tunnicliffe et al. 2018), and following explosive CVZ and TVZ volcanism, inundation of volcanic ash via atmospheric plume and surface processes (Hopkins and Seward 2019; Hopkins et al. 2020).

Current national seismic hazard modelling (Stirling et al. 2012; Gerstenberger et al. 2020) suggests that the HSM is thought to have the potential to generate a Mw 9.1 EQ in the next 25 years, that could result in tens of thousands of deaths, hundreds of thousands displaced, and the cost of building and infrastructure damage could exceed $100 billion. The basis for such models relates to ongoing seismic monitoring, historical earthquake and tsunami records, and paleoseismic records that use preserved co-seismic deposits to predict likely future earthquake magnitude and likely recurrence. The historic records are relatively short in Aotearoa-New Zealand, at best extending back 180 years, and current paleoseismic records mainly form preserved onshore records that extend the records back several thousands of years (Litchfield et al. 2007; Clark et al. 2019; Ninis et al. 2023; Pizer et al. 2023). There is much potential for linked onshore to offshore records of paleoseismic, paleotsunami, and paleotempestite deposits on the margin at a range of timescales to help improve national hazard and risk modelling and planning into the future.

Conclusions

This data-rich special issue comprises of two volumes showcasing 15 original research papers by a total of 67 authors and co-authors from around the globe. The overarching theme of both volumes is subduction and its indelible impact on the spatio-temporal evolution of sedimentary systems along and across the HSM (Figure

1). The papers within Volumes 1 and 2 fall into two distinct themes: Miocene, and Quaternary sedimentary systems, allowing for easy comparison between ancient reconstructions and modern active processes and controls. The work in the special issue builds on many decades of focussed research and reveals a vastly complex evolving margin where active tectonics and volcanism, coupled with vigorous climatic and oceanographic stressors are driving erosion, transport, deposition and reworking of vast volumes of sediment into offshore basins. The impact of IODP Expeditions 372 and 375 has been hugely important for the special issue, with 6 papers across Volumes 1 and 2 using the depositional histories retrieved. There is scope for much future work focussed on understanding both fundamental processes on active margins, and potential future applications. Collectively, the papers within Volumes 1 and 2 highlight the enduring international interest in the HSM as a natural laboratory for the study of earth science of subduction zones, which provides ample scope for future research on the sedimentation of active margins.

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Disclosure Statement

No potential conflict of interest was reported by the authors.

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Figures

Figure 1. Bathymetric and topographic map of the North Island of Aotearoa-New Zealand, showing the main morpho-structural and -sedimentary elements of the HSM, together with the location of the study areas in this paper, and the location of the regional cross-section in Figure 2. Mapping data from the 250 m 2016 NIWA grid.

Figure 2. Schematic cross-section of the HSM showing the distribution of the study sites within this volume. Modified from Bailleul et al. (2007). Subdivisions of the

subduction wedge follow McArthur et al. (2019). C.R. – coastal ranges; A.P – accretionary prism.

Figure 3. This figure, from Noda et al. (2022) shows their conceptual model for sulfidization under fast deposition (A) and slow deposition (image provided courtesy of Noda et al. (2022) and with permission from the Royal Society of New Zealand. https://www.tandfonline.com/doi/full/10.1080/00288306.2022.2099910).

Figure 4. This figure, from Woodhouse et al. (2022) shows their integrated age model for the upper 110 m of IODP Site U1520 (image provided courtesy of Woodhouse et al. (2022) and with permission from the Royal Society of New Zealand. https://www.tandfonline.com/doi/full/10.1080/00288306.2022.2099432).

Figure 5. This figure, from Hayward et al. (2022) shows their summary model showing the sediment cores and inferred sources and sequences of turbidity currents based on foraminiferal analyses (image provided courtesy of Hayward et al. (2022) and with permission from the Royal Society of New Zealand. https://doi.org/10.1080/00288306.2022.2103157).

Figure 6. This figure, from Crundwell and Woodhouse (2022b) shows their combined chronostratigraphy for IODP Expeditions 372 and 375, correlated with the Global Geochronological Scale (image provided courtesy of Crundwell and Woodhouse (2022) and with permission from the Royal Society of New Zealand. https://doi.org/10.1080/00288306.2022.2101481).

Figure 7. This figure, from Bland et al. (2022) shows their summary schematic interpretations of the evolving Miocene depositional setting (image provided courtesy of Bland et al. (2022) and with permission from the Royal Society of New Zealand. https://doi.org/10.1080/00288306.2022.2108069).

Table

Table 1. Summary of the main themes covered by the scientific contributions to the *New Zealand Journal of Geology and Geophysics* Special Issue: Understanding Sedimentary Systems and Processes of the Hikurangi Subduction Margin; from Trench to Back-Arc. Volume 2.

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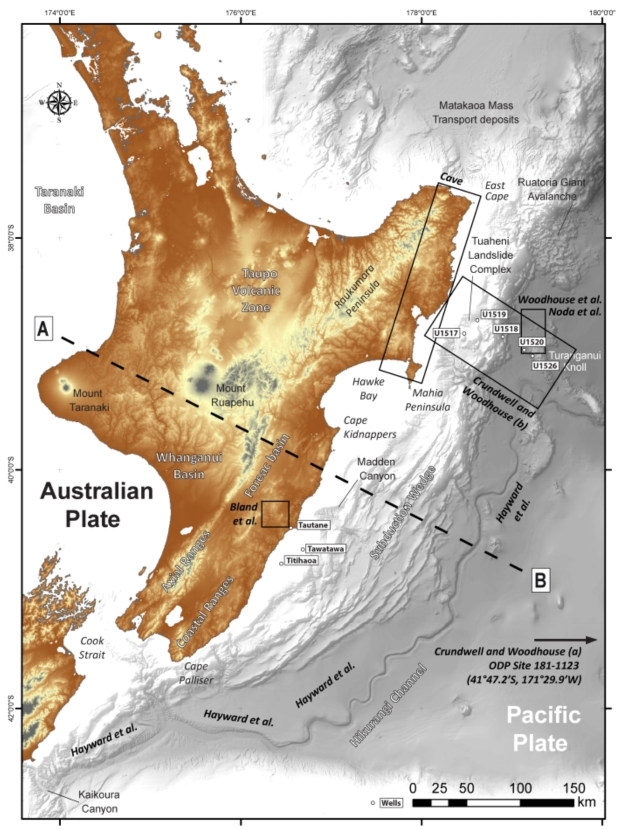


Figure 1. Bathymetric and topographic map of the North Island of Aotearoa-New Zealand, showing the main morpho-structural and -sedimentary elements of the HSM, together with the location of the study areas in this paper, and the location of the regional cross-section in Figure 2. Mapping data from the 250 m 2016 NIWA grid.

300x347mm (300 x 300 DPI)

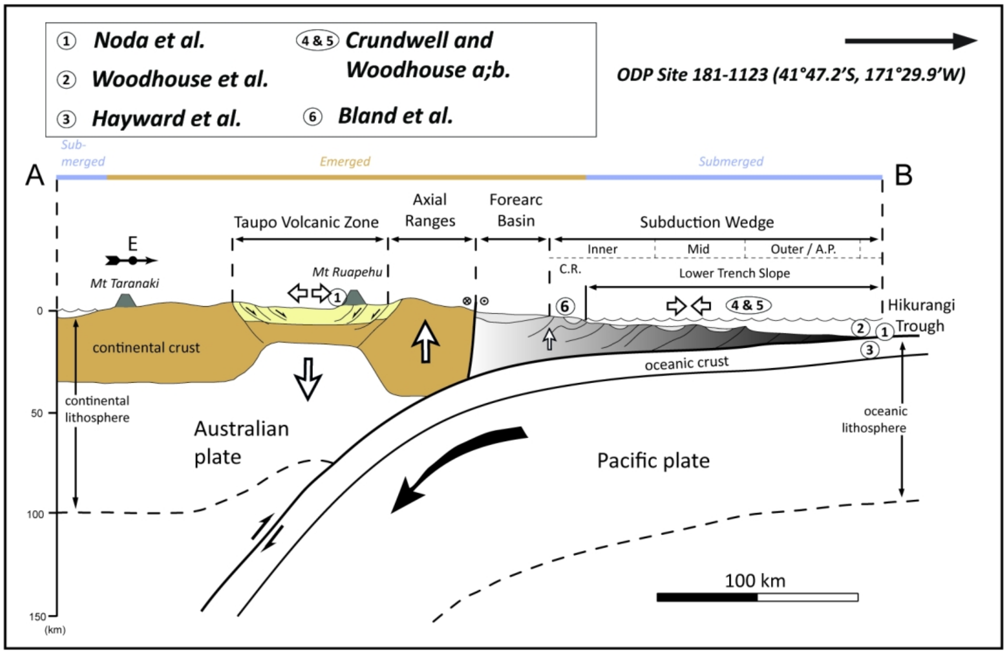


Figure 2. Schematic cross-section of the HSM showing the distribution of the study sites within this volume. Modified from Bailleul et al. (2007). Subdivisions of the subduction wedge follow McArthur et al. (2019). C.R. – coastal ranges; A.P – accretionary prism.

143x92mm (300 x 300 DPI)

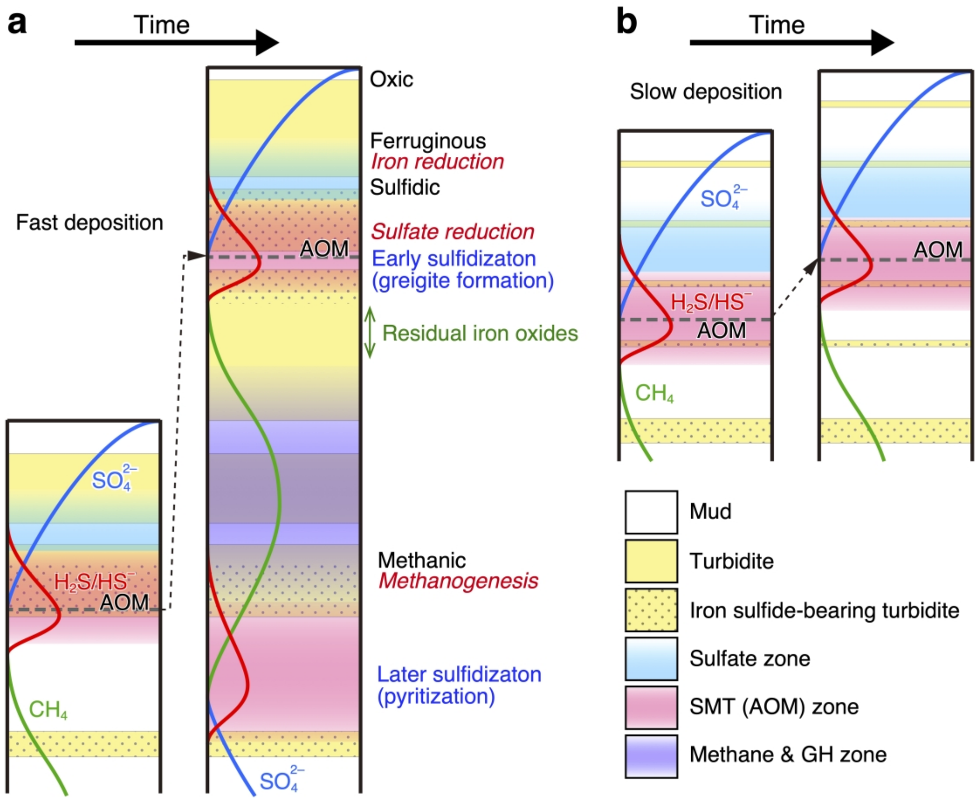


Figure 3. This figure, from Noda et al. (2022) shows their conceptual model for sulfidization under fast deposition (A) and slow deposition (image provided courtesy of Noda et al. (2022) and with permission from the Royal Society of New Zealand. https://www.tandfonline.com/doi/full/10.1080/00288306.2022.2099910).

1210x1005mm (96 x 96 DPI)

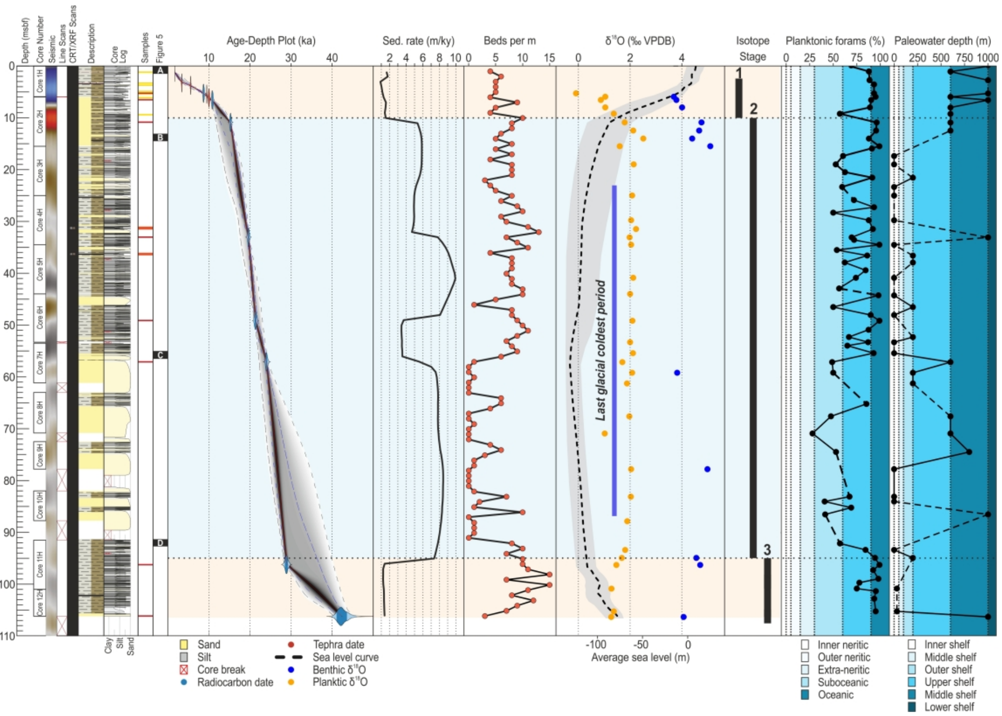


Figure 4. This figure, from Woodhouse et al. (2022) shows their integrated age model for the upper 110 m of IODP Site U1520 (image provided courtesy of Woodhouse et al. (2022) and with permission from the Royal Society of New Zealand. https://www.tandfonline.com/doi/full/10.1080/00288306.2022.2099432).

287x203mm (300 x 300 DPI)

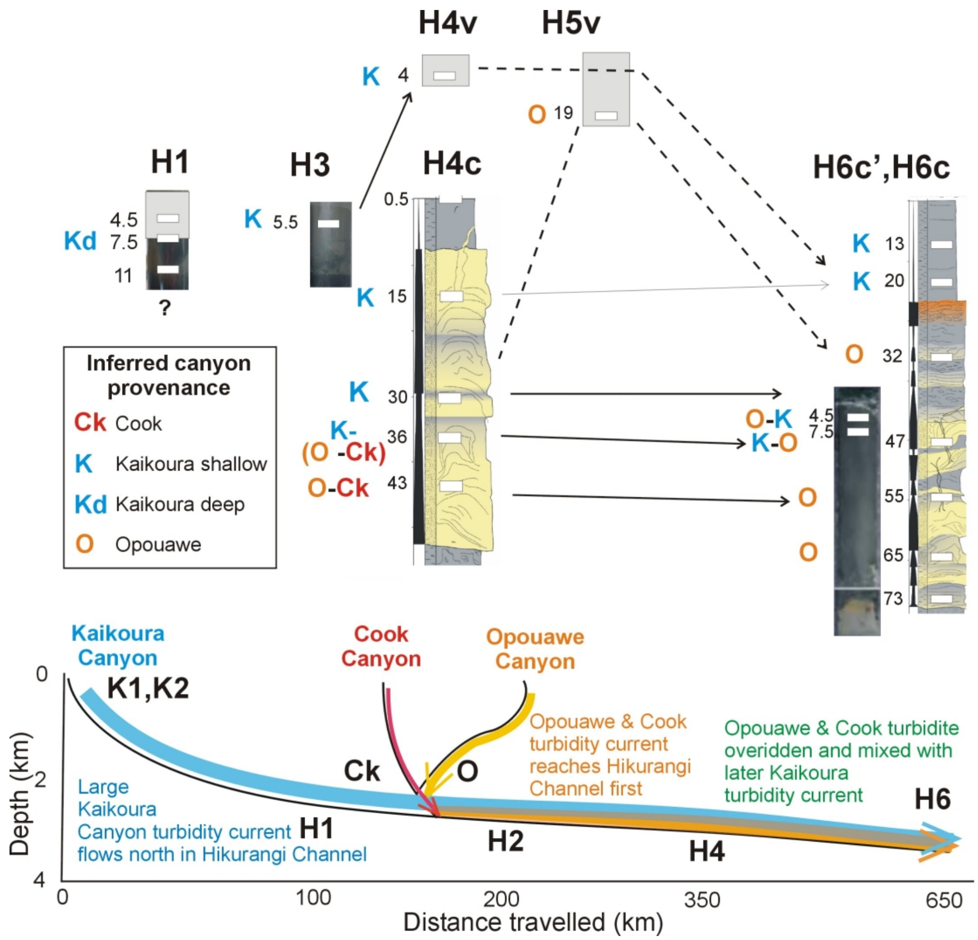


Figure 5. This figure, from Hayward et al. (2022) shows their summary model showing the sediment cores and inferred sources and sequences of turbidity currents based on foraminiferal analyses (image provided courtesy of Hayward et al. (2022) and with permission from the Royal Society of New Zealand. https://doi.org/10.1080/00288306.2022.2103157)

193x178mm (300 x 300 DPI)

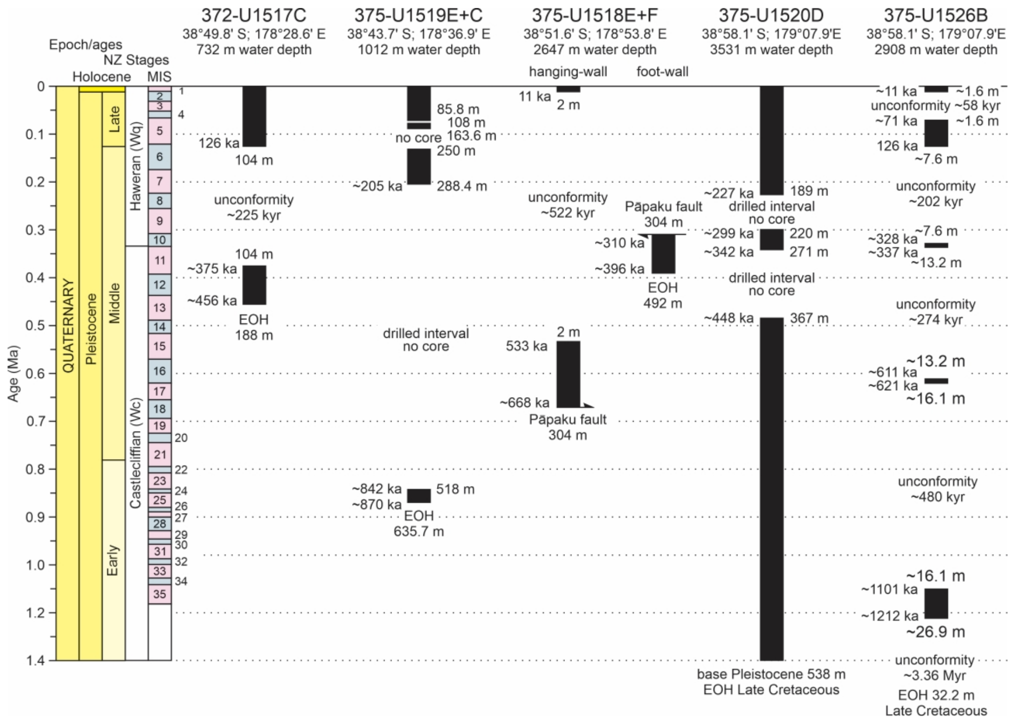
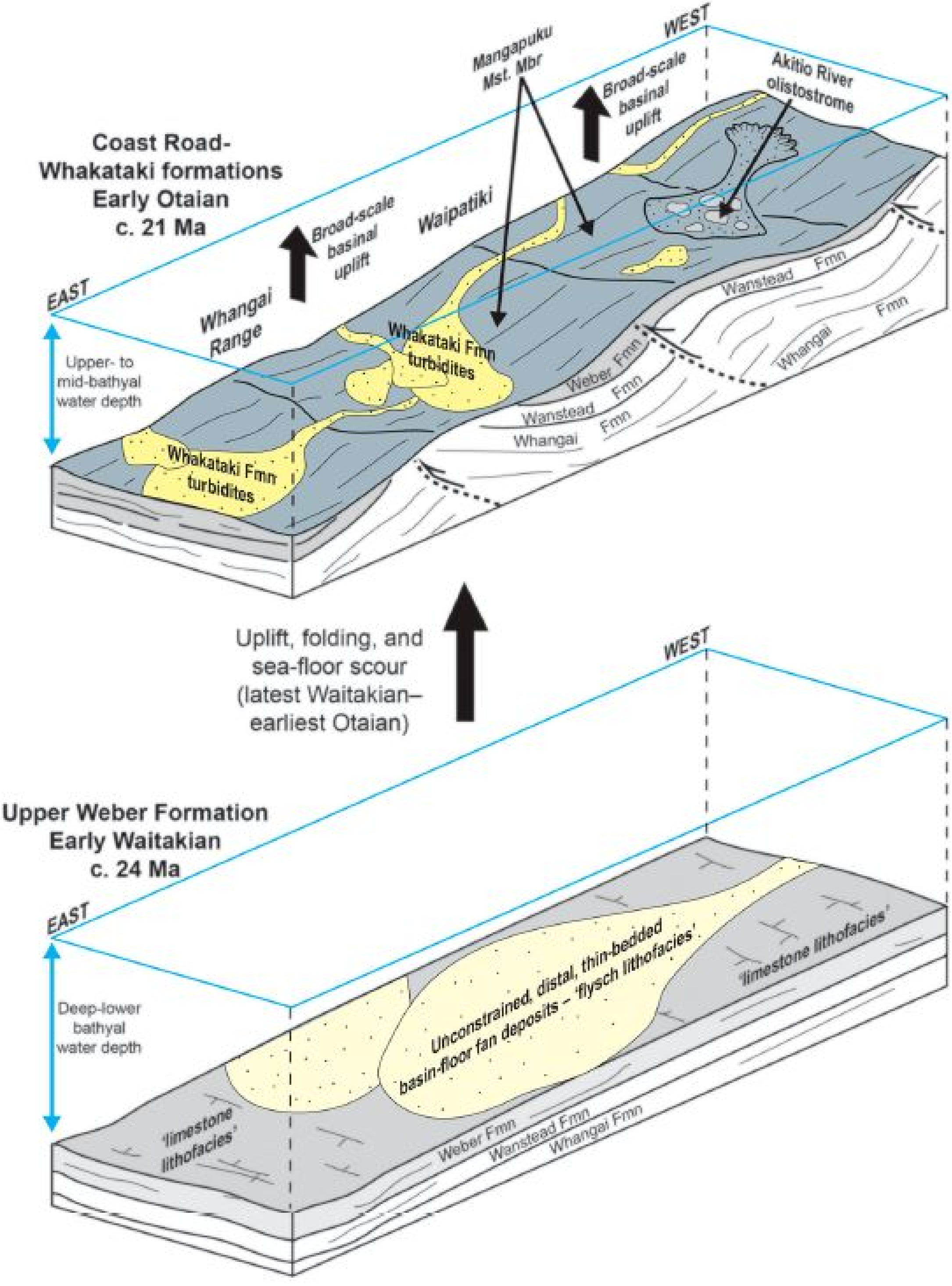


Figure 6. This figure, from Crundwell and Woodhouse (2022b) shows their combined chronostratigraphy for IODP Expeditions 372 and 375, correlated with the Global Geochronological Scale (image provided courtesy of Crundwell and Woodhouse (2022) and with permission from the Royal Society of New Zealand. https://doi.org/10.1080/00288306.2022.2101481).

303x215mm (300 x 300 DPI)



Coast Road-
Whakataki formations
Early Otaian
c. 21 Ma
WEST
EAST
Mangapuku
Mst. Mbr
Broad-scale
basinal
uplift
Akitio River
olistostrome
Waipatiki
Whangai
Range
Whakataki Fmn
turbidites
Upper- to
mid-bathyal
water depth
Wanstead Fmn
Weber Fmn
Whangai Fmn
Uplift, folding, and
sea-floor scour
(latest Waitakian–
earliest Otaian)
Upper Weber Formation
Early Waitakian
c. 24 Ma
Deep-lower
bathyal
water depth
Unconstrained, distal, thin-bedded
basin-floor fan deposits – 'flysch lithofacies'
'limestone lithofacies'
'limestone
lithofacies'

HIKURANGI SUBDUCTION MARGIN	Sedimentation rates / Glacio-eustatism	Dynamics of gravity-driven sedimentary Systems	Biostratigraphy / Dating	Interplays between Tectonics and Sedimentation / Fluid circulations	Diagenesis/Magnetics	IODP Expeditions 372A and 375	IODP Expedition 181
Onshore		Bland et al	Bland et al.	Bland et al.			
Offshore	Woodhouse et al. Crundwell and Woodhouse (a;b)	Noda et al. Woodhouse et al. Hayward et al.	Woodhouse et al. Crundwell and Woodhouse (a;b)	Woodhouse et al. Hayward et al.	Noda et al.	Noda et al. Woodhouse et al. Crundwell and Woodhouse (a;b)	Crundwell and Woodhouse (a;b)

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268x50mm (96 x 96 DPI)

Table 5. Quaternary biostratigraphic markers identified during the preliminary investigation of Hikurangi margin sites drilled during IODP Expeditions 372 and 375 – after Wallace et al. (2020).

IODP Hole	Age (ka)	Sample (maker)	Depth (CSF-B m)	Sample (constraining)	Depth (CSF-B m)	Mid-Point (CSF-B m)
372-U1517C (38°49.7822S 178°28.5632′E; 720.2 m) cores 1H–36F (0–187.58 mbsf)						
Base *Hr. hirtsuta* MIS-1 subzone	11	1H-3, 70–74 cm	3.70–3.74	1H-4, 42–47 cm	4.92–4.97	4.33
Top *Hr. hirsuta* MIS-5b/c subzone	89	17H-2, 64–68 cm	92.65–92.69	17H-1, 65–69 cm	91.24–91.28	91.97
Base *Hr. hirsuta* MIS-5b/c subzone	100	17H-2, 64–68 cm	92.65–92.69	17H-3, 64–68 cm	93.78–93.82	93.24
Top *Hr. hirsuta* MIS-5d/e subzone	106	17H-7, 46–50 cm	97.96–98.00	17H-6, 45–49 cm	97.00–97.04	97.50
Base *Hr. hirsuta* MIS-5d/e subzone	126	18H-3, 83–87 cm	102.39–102.43	18H-4, 81–85 cm	103.78–103.82	103.11
375-U1518E (38°51.5669′S, 178°53.7618′E; 2626.1 m) cores 1H–32X (0–174.67 mbsf)						
Base *Hr. hirtsuta* MIS-1 subzone	11	1H-2, 47–52 cm	1.97–2.02	1H-2, 83–88 cm	2.33–2.38	2.18
Top of DTZ	533	1H-2, 83–88 cm	2.33–2.38	1H-2, 47–52 cm	1.97–2.02	2.18
Top *Hr. praehirsuta* MIS-14a/b subzone	539	3H-5, 97–107 cm	24.81–24.90	3H-4, 72–80 cm	23.16–23.23	24.03
Base *Hr. praehirsuta* MIS-14a/b subzone	541	3H-5, 97–107 cm	24.81–24.90	3H-CC, 22–27 cm	27.65–27.70	26.27
Top *Hr. praehirsuta* MIS-16a subzone	621	23F-3, 25–33 cm	113.95–114.02	22F-CC, 13–23 cm	108.90–109.00	111.47
Base *Hr. praehirsuta* MIS-16a subzone	633	27X-5, 73–80 cm	139.96–140.03	27X-6, 92–100 cm	141.45–141.53	140.74
375-U1518F (38°51.5694′S, 178°53.7619′E; 2626.1 m) cores 2R–32R (199.80–492.38 mbsf)						
Top *Hr. praehirsuta* MIS-16b subzone	650	7R-2, 6–10 cm	247.15–247.19	6R-CC, 0–13 cm	239.08–239.21	243.16
Base *Hr. praehirsuta* MIS-16b subzone	659	10R-2, 24–28 cm	275.78–275.82	10R-3, 13–16 cm	276.88–276.91	276.35
Top STZ (below DTZ; age reversal)	<533	13-CC, 9–12 cm	306.95–307.06	11R-CC, 0–10 cm	296.90–297.00	301.98
375-U1519E (38°43.6572′S, 178°36.8949′E; 1000.3 m) cores 1H–13F (0–85.78 mbsf)						
Base *Hr. hirtsuta* MIS-1 subzone	11	2H-1, 50–58 cm	5.08–5.16	2H-1, 92–100 cm	5.48–5.56	5.32
375-U1519C (38°43.6483′S, 178°36.8773′E; 1000.3 m) cores 2R–12R (108.08–284.80 mbsf)						
Top DTZ	533	14R-1, 25–33 cm	518.65–518.73	12R-CC, 6–16 cm	284.70–284.80	401.72
375-U1520D (38°58.1475′S, 179°7.8991′E; 3520.3 m) cores 1H–52X (0–525.54 mbsf)						
Base *Hr. hirtsuta* MIS-1 subzone	11	1H-CC, 15–20 cm	5.88–5.93	2H-1, 50–58 cm	6.49–6.56	6.22
Top *Hr. hirsuta* MIS-5d/e subzone	106	18H-4, 81–85 cm	103.78–103.82	18H-3, 83–87 cm	102.39–102.43	103.11
Base *Hr. hirsuta* MIS-5d/e subzone	126	14H-3, 48–56 cm	123.02–123.09	14H-4, 38–47 cm	124.28–124.36	123.69
Top DTZ	533	37X-4, 67–70 cm	390.57–390.60	37X-3, 64–67 cm	389.32–389.35	389.96
HCO *Tr. crassacarina*	1101	47X-1, 59–62 cm	472.49–472.52	46X-CC, 27–33 cm	464.95–465.05	468.75
375-U1526B (39°1.3146′S, 179°14.7481′E; 2888.4 m) cores 1H–4H (0–26.13 mbsf)	a					b
Base *Hr. hirtsuta* MIS-1 subzone	11	1H-1, 6–8 cm	0.06–0.08	1H-1, 75–83 cm	0.75–0.83	0.07
Top *Hr. hirsuta* MIS-5d/e subzone	106	1H-4, 70–72 cm	5.20–5.22	1H-3, 75–77 cm	3.75–3.77	4.49
Base *Hr. hirsuta* MIS-5d/e subzone	126	2H-1, 102–104 cm	6.82–6.84	2H-2, 103–105 cm	8.32–8.34	7.58
Top DTZ	533	2H-6, 29–31 cm	13.58–13.60	2H-5, 91–93 cm	12.70–12.72	13.15
Top *Hr. praehirsuta* MIS-16a subzone	621	2H-CC, 0–7 cm	14.23–14.30	2H-6, 29–31 cm	13.58–13.60	13.93
Base *Hr. praehirsuta* MIS-16a subzone	633	2H-CC, 0–7 cm	14.23–14.30	3H-2, 105–107 cm	17.86–17.88	16.07
HCO *Tr. crassacarina*	1101	3H-2, 105–107 cm	17.86–17.88	2H-CC, 0–7 cm	14.23–14.30	16.07

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198x156mm (96 x 96 DPI)