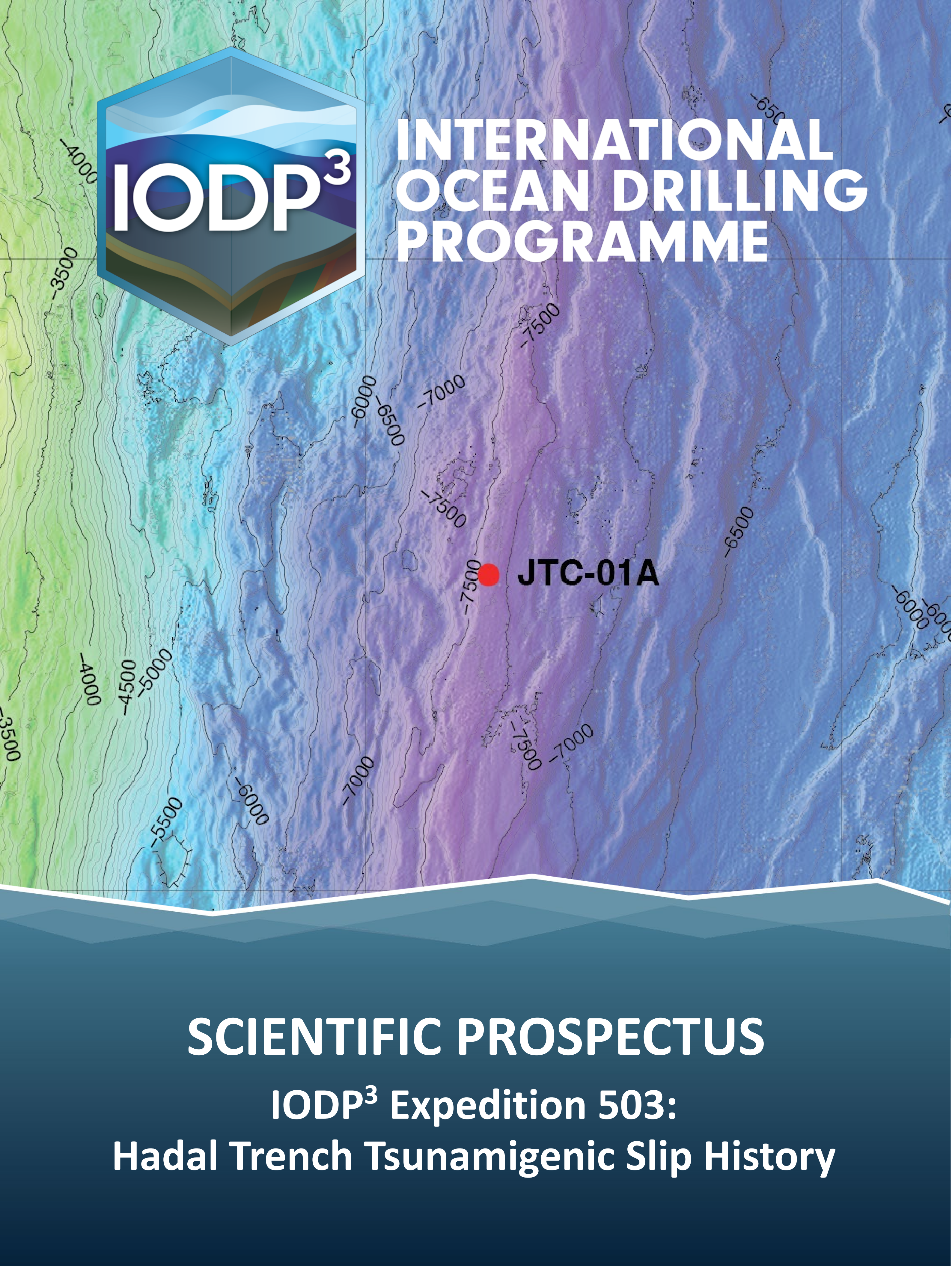
INTERNATIONAL OCEAN DRILLING PROGRAMME



SCIENTIFIC PROSPECTUS

IODP^3 Expedition 503: Hadal Trench Tsunamigenic Slip History

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IODP^3 Expedition 503 Scientific Prospectus

Hadal Trench Tsunamigenic Slip History

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Abstract

Hadal oceanic trenches are the deepest places on our planet. They form due to downward bending of subducting ocean crust along subduction zones, act as terminal sinks for sediment, particulate and dissolved organic carbon, and form high-resolution archives to unravel the history of subduction zone processes including subduction megathrust earthquakes and tsunamis. To fill the gap in long-term paleoaleoseismic records of giant (Mw9-class) subduction zone earthquakes such as the Tohoku-oki earthquake in 2011, International Ocean Discovery Program (IODP) Expedition 386 successfully collected 29 Giant Piston Cores at 15 sites along the hadal Japan Trench at more than 7500m water depth, recovering up to 37.82-meter-long, continuous successions spanning a few thousands up to ~20,000 years from 11 individual trench-fill basins. The record comprises numerous earthquake-related event deposits and has revealed new findings of earthquake-triggered carbon export to the hadal zone and dissolved carbon cycles stimulating intensive microbial activity in trench sediments. Yet, the record only covers the top 40m of the up to ~160-m-thick trench-fill sequence that is expected to comprise a much longer earthquake record and further clues on hadal zone element cycles.

Furthermore, in central JT (cJT) basins, trench-fill sediment sequences are characterised by several slightly tilted prominent seismic reflections with high amplitudes in multi-channel seismic profiles. Tilts become larger with increasing sub-bottom depths, suggesting periodic tilting events. The respective event time-horizons link to buried trench-fill deformation structures and correlative ponded depositional units hypothesised to have resulted from large coseismic slip propagation to the trench and large-scale sediment remobilisation associated with strong seafloor shaking induced by past megathrust earthquakes. The youngest slip-to-the-trench event horizon is correlative with the base of a thick turbidite bed of the 869 CE Jogan earthquake, which was a major earthquake event before the 2011 CE earthquake. However, due to so far limited coring depth, it is impossible to date the older hypothesised slip-to-trench events.

International Ocean Drilling Programme (IODP^3) Expedition 503 plans to drill a trench basin in the cJT to recover the whole trench-fill sequence for dating and establishing event-stratigraphy for paleoseismologic interpretations and further investigations of earthquake related element cycles in hadal trench environment. Combining stratigraphy and chronology of thick event deposits, interstitial-water geochemistry proxy-data for past fluid flow pulses and core-to-seismic correlation to paleo-slip-to-trench events, we would like to clarify how often the slip-to-trench events have occurred. Unravelling the complete trench-fill sedimentary record and pore water profile will significantly advance our understanding of the nature and recurrence of hadal trench tsunamigenic slip, the underlying megathrust earthquakes and related geohazards, as well as the effects on enhancing carbon accumulation in the hadal trench that may stimulate carbon transformation and eventual export into the subduction zone.

Plain Language Summary

The 2011 – Mw 9.0 – Tohoku-oki earthquake and tsunami was a catastrophic geological event with major societal consequences. Unexpected shallow and large coseismic slip contributed to the large tsunami. Short historical and even shorter instrumental records limit our perspective of earthquake maximum magnitude and recurrence, and thus are insufficient for fully characterise Earth's complex and multiscale seismic behaviour and its consequences. The geological record is a reliable tool for reconstructing the history of giant earthquakes with long recurrence intervals and to help reduce epistemic uncertainties in seismic-hazard assessment. Results of previous research based on up to ~40-m long piston cores suggested that megathrust earthquakes have been recorded as thick turbidites in the central Japan Trench. This research has also documented that the Japan Trench trench basins, which are part of the hadal ocean and thus among the deepest places on our planet, act as terminal sinks for sediment and carbon, stimulating highly active subseafloor microbial communities and potentially efficiently sequester carbon.

Therefore, the ultra deep-sea trench-fill sediments in the central Japan Trench are the best archive of past giant earthquakes to expand turbidite paleoseismology toward a much longer time and to study the hadal carbon cycle. Furthermore, the seismic profiles indicated that a deformed structure created during large coseismic slip was detected in the trench-fill sequence of central Japan Trench. Such deformation is likely another geological evidence of the extreme slip which propagated to the trench ("slip-to-the-trench") and is considered important for causing outstanding large tsunami. Establishing a chronology for such deformation horizons in seismic profiles may improve our understanding of the recurrence of tsunamigenic slip-to-the-trench vs deep megathrust rupture modes.

International Ocean Drilling Programme (IODP[3]) Expedition 503 plans to drill a trench basin in the central Japan Trench to recover the whole trench-fill sequence for dating and establishing event-stratigraphy for paleoseismologic interpretations and further investigations of earthquake related element cycles in hadal trench environment. Combining stratigraphy and chronology of thick event deposits, interstitial-water geochemistry proxy-data for past fluid flow pulses and core-to-seismic correlation to paleo-slip-to-trench events, we would like to clarify how often the slip-to-trench events have occurred. Unravelling the complete trench-fill sedimentary record and pore water profile will significantly advance our understanding of the nature and recurrence of hadal trench tsunamigenic slip, the underlying megathrust earthquakes and related geohazards, as well as the effects on enhancing carbon accumulation in the hadal trench that may stimulate carbon transformation and eventual export into the subduction zone.

Schedule for Expedition 503

International Ocean Drilling Programme (IODP^3) Expedition 503 is based on IODP drilling **Proposal 1010-APL2**. Following evaluation by the IODP Scientific Advisory Structure, the expedition is scheduled for the D/V *Chikyu*, operated under contract with the Institute for Marine-Earth Exploration and Engineering (MarE3) at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). At the time of publication of this Scientific Prospectus, the expedition is scheduled in 2025, starting 22 November 2025 and ending 11 December 2025. A total of 16 (not including 3.5 contingency) days will be available for the transit, drilling, and coring, described in this report. Due to the expected high core recovery rate and short transit times, the offshore part of the Expedition is expected to be followed by several days of finalising shipboard work and personal sampling, depending on core recovery rates and the availability of D/V *Chikyu* in Shimizu, Japan. Further details on *Chikyu* can be found **here**.

Introduction

The 2011-Mw9.0-Tohoku-oki earthquake and tsunami was a catastrophic geological event with major societal consequences. Unexpectedly shallow and large coseismic slip to trench contributed to the large tsunami (Ide et al., 2011; Kodaira et al., 2021; **Figure 1**). The global average for an Mw8-class earthquake is one per year, and only four “giant” (Mw9-class) earthquakes are well documented by instrumental data, which makes our understanding of giant earthquakes limited. The long recurrence intervals of these catastrophic events result in a poor applicability of instrumental and historical records. Therefore, it is difficult to answer important questions such as what are the effects of giant earthquakes and how often should we expect them. The geological record is a promising tool for reconstructing the history of giant earthquakes with long recurrence intervals and to help reduce epistemic uncertainties in seismic-hazard assessment.

Megathrust earthquakes affect offshore environments, including deep-sea trenches along the subducting plate margins. Oceanic trenches often are >6000 m below sea level comprising the hadal zone and are among the least-explored environments on Earth (Jamieson et al., 2010). Widespread sediment remobilisation induced by shaking of giant earthquakes produces downslope gravitational sediment transport and widely distributes event-deposits in terminal trench-basins. Several submarine paleoseismic studies along subduction zones (e.g., De Batist et al., 2017; Howarth et al., 2021; Strasser et al., 2024 and references therein) have successfully obtained sedimentary event-records that can be positively correlated with modern and historical earthquakes, and/or reveal evidence for prehistorical events.

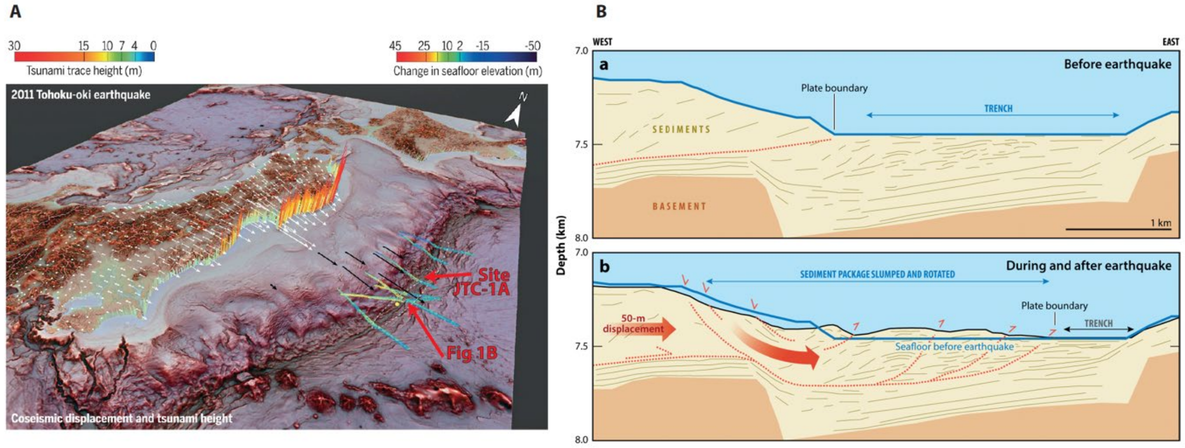


Figure 1. Coseismic displacement and tsunami height of the 2011 Tohoku-oki earthquake (A: left; Figure by Kodaira et al., 2011a) and conceptual sketch (B: right; see arrow in A for location of B) illustrating evolution (a) before (above) and movement (b) during (below) the 2011 CE Tohoku-oki earthquake resulting in trench-sediment deformation (Kodaira et al., 2013; 2021b; Strasser et al., 2013; Ueda et al., 2023); Figure adapted from Strasser et al., (2013). Note that IODP[3] Expedition 503 Proposed Site JTC-1A is located north of the area that had significant slip to the trench during the 2011 CE Tohoku-oki earthquake.

Conventional 10-m-long core (Ikehara et al., 2016; McHugh et al., 2020; Schwestermann et al., 2020; Kanamatsu et al., 2022, 2023) and sub-bottom profile studies (Kioka et al., 2019a) along the Japan Trench (JT) demonstrate the strong potential to advance our understanding of earthquake recurrence beyond timescales of the last few thousand years. Results of the International Ocean Discovery Program (IODP) Expedition 386 (Ikehara et al., 2023b; Strasser et al., 2023; Strasser et al., 2024) suggest that thick event deposits in the central Japan Trench (cJT) basins are possible records of megathrust earthquakes since the last ~20 ka (**Figure 2**). Therefore, the trench-fill sediments in the cJT are among the best archives of past giant earthquakes to expand turbidite paleoseismology toward a much longer time.

A deformed upheaval structure created during coseismic slip on the shallow plate interface and earthquake-triggered slump in the lowermost trench-slope by the 2011 CE earthquake was detected in the trench-fill sequence of cJT (Kodaira et al., 2012; Strasser et al., 2013; Ueda et al., 2023; **Figure 1**). Such deformation is probably another geological evidence of the extreme slip which propagated to the trench ("slip-to-the-trench") and is considered important for causing outstanding large tsunami (Kodaira et al., 2021) by past giant earthquakes. Several tilted reflectors with high amplitude were observed in the high-resolution multi-channel seismic (HRS) profiles in the cJT basins (**Figure 3**; Pizer et al., subm. to Geology). Tilts become larger with increasing sub-bottom depths in trench-normal profiles, suggesting periodic tilting events in the basins. The initial core-seismic correlation by IODP Expedition 386 indicates that a basal sandier layer of the third thick event deposit by the 869 CE Jogan earthquake, which was a major earthquake and tsunami event prior to the 2011 CE earthquake, is correlative to a high amplitude reflection (**Figure 4**; Pizer et al., subm.). Therefore, establishing a chronology for structural horizons in seismic data may improve our understanding of the recurrence of tsunamigenic slip-to-the-trench vs deep megathrust rupture modes.

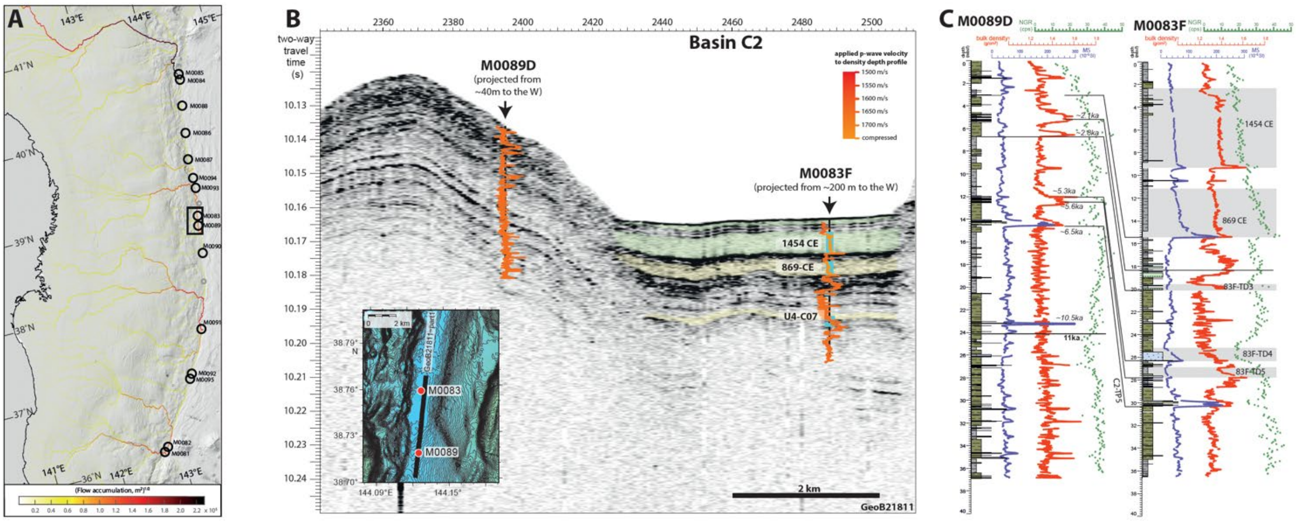


Figure 2. Location and shallow-subsurface characteristics of the study area: (A) Overview of the Japan Trench subduction margin and location of Basin C2 as the main study area of IODP^3 Expedition 503. The map shows flow accumulation (illustrated as the square root of flow accumulation (m^2)) after Kioka et al. (2019a) with IODP Expedition 386 site locations (Strasser et al., 2023). (B) Subbottom profiler (SBP) - scale event deposits imaged and sampled in Basin C2 of the Central Japan Trench. SBP profile from Kioka et al. (2019a), with depth-to-two way travel time (TWT) converted density profiles of Holes M0083F and M0089D. Different colours of the density profiles give approximated p-wave velocities applied for the depth conversion. Figure modified from Strasser et al. (2024). (C) Lithology, magnetic susceptibility (MS), density, and natural gamma-ray (NGR) logs and initial age constraints of Holes M0083F and M0089D, with SBP-scale event deposits (shaded in grey) and tie-points correlating event deposits and marker horizons between the sites. Figure modified from Strasser et al. (2024).

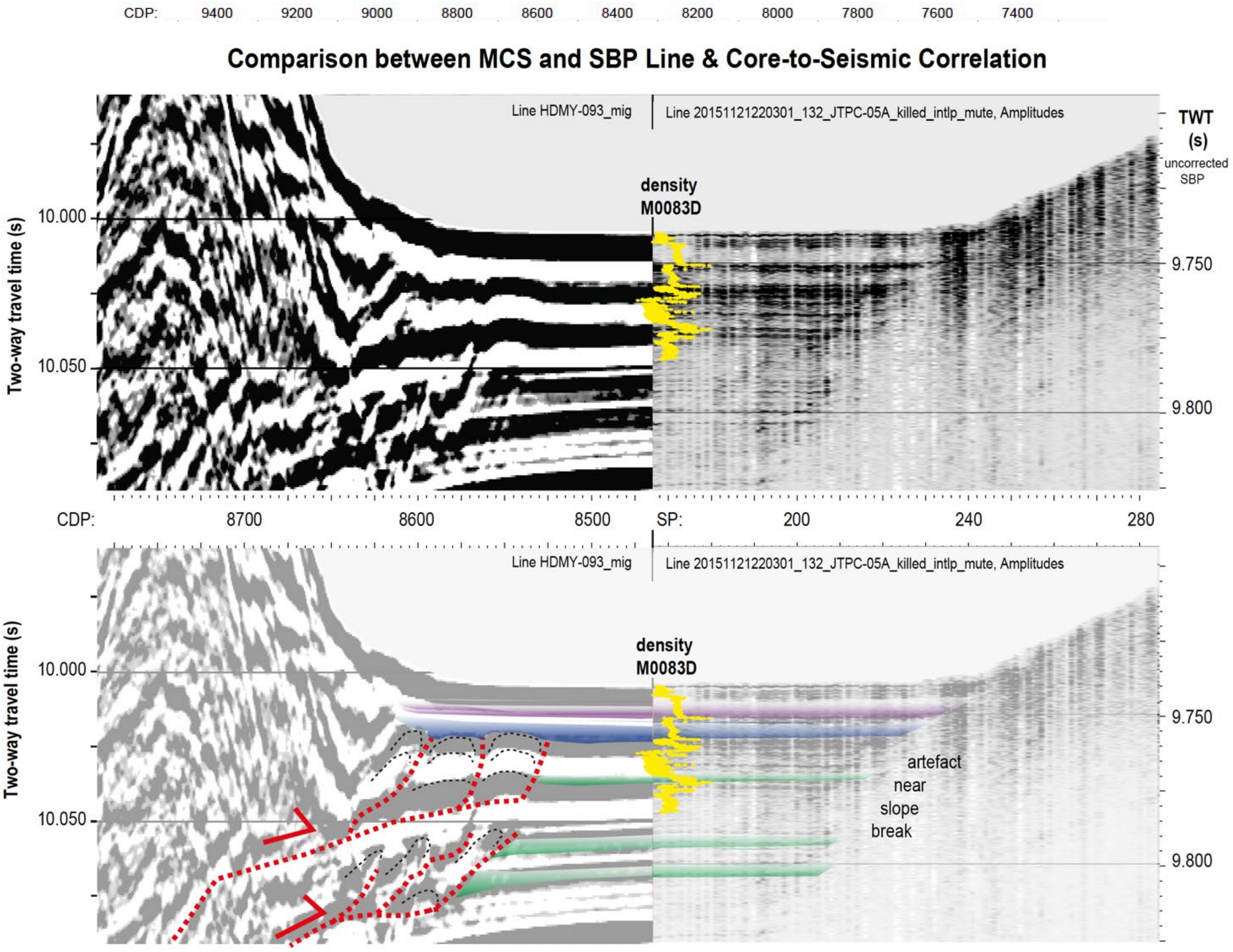


Figure 4. MCS to SBP comparison: Uninterpreted (above) and interpreted (below) MCS Line HDMY093 (right) and SBP Line 20251121220301 (left) detailing core-to-SBP-to-seismic correlation. Interpretation of coseismic-slip-propagation induced deformation of trench fill sediment is by Pizer et al. (subm.). Stratigraphic correlation suggests that the youngest slip-to-the-trench event in this basin north of the high slip area of the 2011 CE Tohoku-oki earthquake is linked to the 869 CE Jogan earthquake and tsunami. Density profile from Expedition 386 Hole M0083D is superimposed on SBP line at location of Hole M0083D, documenting good correlation of high-density basal layer of event deposits in cores with basal high amplitude reflections of 1454 CE (purple), 869 CE (blue), and interpreted pre-historical earthquake event deposits in SBP profiles (see Figure 1; Strasser et al., 2024). MCS lines do not resolve geometrical details of event deposits but indicate high-amplitude reflection to roughly correlate with major event deposits (Figure modified after Pizer et al., subm.)

The interstitial water (IW) geochemical data may also be a new methodology in submarine paleoseismology, based on our hypothesis that earthquakes trigger fluid flow events that are recorded by geochemical signals of the cored sedimentary sequences. In Expedition 386 Giant Piston Cores (GPCs), all the IW profiles are non-steady state (Strasser et al., 2023), showing they have been disturbed recently, and most likely as a result of the 2011 CE earthquake. While major ions, Na, Cl, Ca, and Mg, are like seawater, minor elements, particularly B, Li and Si, are significantly distinct from seawater. Boron isotope data from the length of the trench are comparable (between 30-35‰) and unlike seawater (39.6‰) (Rasbury et al., 2023). Dynamic compaction from earthquake shaking and subsequent migration of excess fluids is a likely mechanism to discharge fluids from depth. Sampling deeper parts of the basin fill, as well as the underlying graben floor are needed to better understand how long these signatures are preserved as well as to identify the IW source.

By combining stratigraphy and chronology of thick event deposits, IW geochemistry proxy-data for past fluid flow pulses in the cores, and core-to-seismic correlation to paleo-slip-to-trench events, we will clarify how often the slip-to-trench events have occurred in the past.

The IODP^3 is uniquely positioned to provide such paleoseismologic data by drilling and coring full sedimentary sequences that make up continuous depositional and deformational conditions and records of earthquake occurrences over longer time periods. A combination of the chronologies of thick event-deposits and major deformation horizons can provide a new perspective on the history of giant earthquakes. Beyond the current limit of earthquake histories back to maximal ~20 krys, the goal of Expedition 503 is to develop submarine paleoseismology in longer time span to detect longer-term, very rare, but extremely huge events, and to understand the recurrence patterns of large to giant earthquakes in the cJT as an example of a major subducting plate boundary on Earth.

Background

Japan Trench

The Japan Trench strikes N–S to NNE–SSW, originating at the triple junction of the Pacific, Philippine Sea and Okhotsk plates at the south and intersecting the Kuril Trench to the north. The Pacific plate is subducting beneath the Okhotsk plate at a rate of 8.0–8.6 cm/y to NW direction along the Japan Trench (DeMets et al., 2010). Water depth of the axis becomes deeper southward from ~6800 m at north to >7500 m at central and south. According to flexural bending of Pacific plate, typical horst-graben structures with N–S to NNW–SSE trend are observed on the subducting Pacific plate (e.g., Boston et al., 2014; Nakamura et al., 2023). The trench axis comprises of a series of small basins with 0.5–15 km long and 0.5–5 km wide due to relief of horst-graben structure and slightly oblique subduction of Pacific plate. Such relatively rough trench-floor morphology makes isolated basins with less along-strike connectivity. The forearc consists of a wedge made of Cretaceous and younger accreted sediments (Kodaira et al., 2017; Tsuru et al., 2000), and a seismically chaotic frontal prism, located at the seaward edge of the forearc. The prism is a wedge-shaped sedimentary package with a width of ~15–30 km that spans the margin parallel to the trench axis (Kodaira et al., 2017; Tsuru et al., 2000). The wedge appears to be composed of accreted incoming plate sediments off-scraped from the incoming Pacific plate (Nakamura et al., 2013; Schottenfels et al., 2024), modified by large slope failures (Nakamura et al., 2020). The average slope angle of the lower slope is ~50 (von Huene and Lallemand, 1990). No major canyon system connects the shelf with trench floor at the central Japan Trench near the epicenter of the 2011 CE Tohoku-oki earthquake, although a few canyon systems are observed at the northern and southernmost Japan Trench. Trench-basins are the terminal depositional sinks receiving sediments transported by sediment gravity flows through the canyon systems with and without upslope connectivity to shelf or coastal areas (Kioka et al., 2019a).

Several instrumental and historical records indicate that tsunamigenic mega-earthquakes such as 869 CE Jogan, 1454 CE Kyotoku, 1611 CE Keicho and 2011 CE Tohoku-oki earthquakes have been occurred repeatedly along this subduction margin (Goto et al., 2019; Sawai, 2020 and references therein). Geological records on large tsunamis have been reported from the past 3000–5000 years (e.g., Goto et al., 2019, 2021; Ishizawa et al., 2022). The instrumental, historical, and geological data indicate along-strike and temporal variability in rupture mode for past earthquakes and that the recurrence interval of M9-type megathrust ruptures may be as short as 570 years (Philibosian and Meltzner, 2020). From seismic moment frequency relation, return times for M9-type earthquakes off Tohoku were calculated as 260–880 years (Uchida and Matsuzawa, 2011). Based on slip deficit accumulation over time and seismo-mechanical modelling, recurrence of the earthquakes was estimated as 590–730 years (Uchida and Bürgmann, 2021), 520–800 years (Barbot, 2020) and ~600 years (Nakata et al., 2021), respectively. These are consistent with the occurrence of three giant earthquakes in the last 1500 years. A “supercycle” of giant (M9-type) earthquakes with a recurrence interval of ~600–700 years, which superimposed on the cycle of great (M7–8) earthquakes is proposed for the megathrust earthquake off Tohoku (Satake, 2015)

Japan Trench paleoseismology

Deep-sea turbidites are a potential tool for submarine paleoaleoseismology (e.g., Adams, 1990; Goldfinger et al., 2012, 2017; Howarth et al., 2021). Earthquakes are a major mechanism for the initiation of turbidity currents, although several alternative mechanisms for the initiation of turbidity currents such as large storm waves, storm surges, hyperpycnal flows (floods), rapid sediment loading, submarine groundwater discharge, volcanic eruptions, and bolide impacts have been proposed (e.g., Goldfinger et al., 2012; Pickering and Hiscott, 2015). It is well-known that earthquake-induced marine slope failures have generated turbidity currents, e.g., the 1929 CE Grand Banks earthquake, NW Atlantic (Heezen and Ewing, 1952), the 1954 CE Orleansville earthquake, Algeria (Heezen and Ewing, 1955), and the 2006 CE Pingtung earthquake, Taiwan (Hsu et al., 2008). Recent observations have demonstrated a wide range of earthquake-related sedimentary signatures linked to exceptionally large subduction zone earthquakes and their aftershocks:

- Slumps in the trench linked to co-seismic slip propagation of 2011 CE Mw 9.0 Tohoku-oki earthquake all the way to trench (Fujiwara et al., 2011; Strasser et al., 2013; Ueda et al., 2023);
- Turbidity currents released simultaneously in different canyon heads travelling downcanyon to merge below confluences during the 1700 CE Mw 9.0 Cascadia earthquake (Goldfinger et al., 2012, 2017) and the 2016 CE Mw 7.8 Kaikoura earthquake in New Zealand (Howarth et al., 2021);
- Homogeneous sediment extending for long distances across the abyssal plain of the Mediterranean linked to the 365 CE Crete earthquake (Polonia et al., 2013, 2016);
- Dense plumes of sediment remaining in suspension above seafloor for weeks to months after the 2004 CE Mw 9.2 Sumatra (Seeber et al., 2007), 2004 CE M 7.4 Kii-Hanto (Ashi et al., 2014) and 2011 CE Mw 9.0 Tohoku-oki earthquakes (Noguchi et al., 2012; Oguri et al., 2013);
- Significant volume of sediment and carbon transporting to the deep sea by canyon flushing and remobilisation of young organic carbon-rich surficial sediments over wide areas, triggered by the 2016 CE Mw 7.8 Kaikoura (Mountjoy et al., 2018) and 2011 CE Mw 9.0 Tohoku-oki (Bao et al., 2018; Kioka et al., 2019a) earthquakes.

Multimethod characterisation for detailed structural, physical, chemical, and microbiological characterisation has revealed distinct signatures and patterns for event deposit sedimentary sequences that result from (1) the remobilised material and its original provenance (as a proxy for sediment source and/or routing processes), (2) grain size distribution and structural orientation reflecting transport and depositional dynamics, and (3) consolidation and microbial organic matter degradation reflecting postdepositional processes (McHugh et al., 2011; Polonia et al., 2016; Goldfinger et al., 2017; Chu et al., 2023). Positive stratigraphic correlation of such multiproxy signatures between widely separated sites favours a common causative mechanism, especially if the respective sites are isolated from each other (Goldfinger et al., 2012; Talling, 2014; Ikehara et al., 2018; Schwestermann et al., 2020). These studies and more, many of which investigated event deposits positively correlated to historical earthquakes, proposed characteristic patterns or signals to be potentially distinctive for earthquake origin, subsequent tsunamis, and their aftershock series (Goldfinger et al., 2012; Oguri et al., 2013; Ikehara et al., 2016, 2018; Polonia et al., 2016, 2017; Kioka et al., 2019b; Schwestermann et al., 2020, 2021; Howarth et al., 2021).

These data sets are mostly obtained by conventional gravity or piston coring. Therefore, they often only comprise few event deposits that can be linked to earthquakes for a given margin.

Conceptual depositional models of event layers are not validated against a longer temporal record. Depositional and preservation of event deposits and their stratigraphic signal vary by location and may change through time (Sumner et al., 2013; Bernhardt et al., 2015; Ikehara et al., 2018). Thus, to test the robustness of the proposed models and relations, both long temporal and spatially extensive records are needed. Coring site location is a key issue in submarine paleoseismology (Goldfinger et al., 2017; Ikehara et al., 2018; Kioka et al., 2019a). To obtain a better record of past earthquakes, detailed characterisation of the depositional history of a site is essential.

The Japan Trench is a suitable area to test and for the development of submarine paleoaleoseismology (Strasser et al., 2024). The 2011 CE Tohoku-oki earthquake is the first event of its kind worldwide for which the entire activity was recorded by offshore geophysical, seismological, and geodetic instruments. Direct observation for sediment resuspension and redeposition was documented across the entire margin by seafloor monitoring systems and/or rapid response research cruises. Submarine cable breaks were reported along the southern and central Japan Trench due to turbidity currents (Shirasaki et al., 2012; Pope et al., 2017). High bottom water turbidity (Noguchi et al., 2012) and temperature anomaly (Inazu et al., 2023) wereas considered as resulting from slope failures and sediment remobilisation related to water discharge from subsurface (Kawagucci et al., 2012; Sano et al., 2014; Inazu et al., 2023). Occurrence of tsunami-induced turbidity current was also attested by ocean-bottom instrument data (Arai et al., 2014). Submarine landslides were documented by differential bathymetry (Fujiwara et al., 2011; Strasser et al., 2013). However, the most significant volumetric contribution of earthquake-induced sediment remobilisation occurs through surface sediment remobilisation, which resuspends and redeposits the uppermost few centimetres of young, unconsolidated, and organic carbon-rich seafloor sediments over a wide area (McHugh et al., 2016; Kioka et al., 2019b; Schwestermann et al., 2020; Ikehara et al., 2020, 2021, 2023a).

Much work has been published on event deposits resulting from earthquake-induced sediment remobilisation within basins along the Japan Trench slope and trench axis. Several thick (>50 cm) event deposits are recognised within sediment cores (Ikehara et al., 2016, 2018; McHugh et al., 2020; Schwestermann et al., 2021; Usami et al., 2021; Kanamatsu et al., 2022, 2023; Strasser et al., 2024) and as acoustically transparent layers with ponding geometries in sub-bottom profile (SBP) records (Kioka et al., 2019b). Thick event deposits, which usually have thick homogeneous (structureless) mud above basal sandy bed, in the uppermost sequences of the cores from the central Japan Trench can be correlative to historical earthquakes including the 2011 CE Tohoku-oki, 1454 CE Kyotoku and 869 CE Jogan (Ikehara et al., 2016, 2018; Kanamatsu et al., 2022, 2023; Strasser et al., 2024). A thick event deposit below the 869 CE Jogan bed was dated as 2.3 ka (Kanamatsu et al., 2022, 2023). Correlative thick event deposits are also observed in slope basin cores (Usami et al., 2018). Kioka et al. (2019b) indicated that acoustically transparent layers similar to those correlative to historical earthquake events were observed in deeper positions in the trench-fill sequences of SBP records below currently reach coring depth by previous Expeditions. Therefore, the trench-fill sediments most likely include the older megathrust earthquake records as thick event deposits.

Tectonic-induced trench-fill deformation

SBP and HRS profiles indicate that trench-fill deposits in small terminal basins along the Japan Trench axis show parallelly stratified acoustic structure (Ikehara et al., 2018; Kioka et al., 2019b; Nakamura et al., 2023; **Figures 3 & 4**). At the boundary area between the central and northern Japan Trench around 39° N, where a petit-spot volcano field (Hirano et al., 2006) enters the subduction system (Fujie et al., 2020), Nakamura et al. (2020) and Schottenfels et al. (2024) indicated a large (>1 km high) escarpment, large-scale gravitational collapse and megalandslides on the lowermost landward slope. SBP records and recent coring, however, do not show young large-scale landslide deposits, suggesting the large collapse structure is older (Kioka et al., 2019b; Strasser et al., 2024). Differential bathymetry between pre- and post-earthquake observations of the 2011 CE Tohoku-oki earthquake documented a submarine landslide in the central Japan Trench basin (Fujiwara et al., 2011; Strasser et al., 2013). A deformed upheaval structure created during coseismic slip on the shallow plate interface and earthquake-triggered slump in the lowermost trench-slope by the 2011 CE Tohoku-oki earthquake was detected in the trench-fill sequence of central Japan Trench (Kodaira et al., 2012; Strasser et al., 2013; Ueda et al., 2023; **Figure 1**). Such deformation is probably another geological evidence of the extreme slip which propagated to the trench (“slip-to-the-trench”) and is considered important for causing outstanding large tsunami (Kodaira et al., 2021) by past giant earthquakes. Several tilted reflectors with high amplitude were observed in the HRS profiles in the cJT basins (**Figure 3**). Tilts become larger with increasing sub-bottom depths in trench-normal profiles, suggesting periodic tilting events in the basins. The initial core-seismic correlation by IODP Expedition 386 indicates that a basal sandier layer of the third thick event deposit by the 869 CE Jogan earthquake, which was a major earthquake and tsunami event prior to the 2011 CE Tohoku-oki earthquake, is correlative to a high amplitude reflection and correlative trench-floor deformation near the landward slope showing similar characteristics as reported for the 2011 CE Tohoku-oki slip to the trench deformation further to the south (**Figures 1, 3 and 4**; Pizer et al., subm.).

Therefore, establishing a chronology for structural horizons correlative to such trench-floor deformation and tilting events in seismic data may improve our understanding of the recurrence of tsunamigenic slip-to-the-trench vs deep megathrust rupture modes.

Earthquake-induced carbon and material cycling and fluid migration

The JT basins act as terminal sinks for sedimentary materials including carbon (Chu et al., 2023). Thus, the trench-fill sediments have a potential to form high-resolution archives to unravel the history of deep-ocean elemental cycles. Investigation of deep-ocean elemental cycles and shedding new light on sediment and carbon fluxes of earthquake-triggered sediment remobilization to a deep-sea trench and its influence on the hadal environments are important scientific targets of this Expedition. Relatively high content of total organic carbon (TOC; >~1 wt.%) both in hemipelagic and event muds coupled with high average sedimentation rate (>1 m/ky; Schwestermann et al., 2021) indicates that huge amounts of organic carbon has been buried in the JT basins. Based on results from Expedition 386 (Ikehara et al., 2023b), high TOC in the event deposits suggests that earthquake-triggered sediment remobilisation has contributed to this large mass accumulation of organic carbon (OC). Intensive remineralisation of sedimentary TOC occurs in the sediments. Inorganic geochemistry is also influenced by such organic matter degradation and remineralisation as it influences the redox conditions, which can cause precipitation of minerals such as barite, Fe-sulfides, Mn oxides and authigenic carbonates that can provide evidence of past sulphate-methane transition zones (Chu et al., 2023). Accumulation and aging of dissolved OC and dissolved inorganic carbon in the subsurface leads to enhanced production of labile dissolved carbon owing to earthquake-triggered turbidites, which supports intensive microbial methanogenesis in the trench sediments and stimulating active silicate weathering and authigenic carbonate formation (Luo et al., subm.). The residual dissolved carbon is hypothesised to accumulate in the deeper subsurface sediments and may continue to fuel the deep biosphere (**Figure 5**; Chu et al., 2023). This hypothesis and its implication for stimulating carbon transformation and eventually carbon sequestration in trench sediment and into the subduction zone will be tested by IODP3 Expedition 503 drilling.

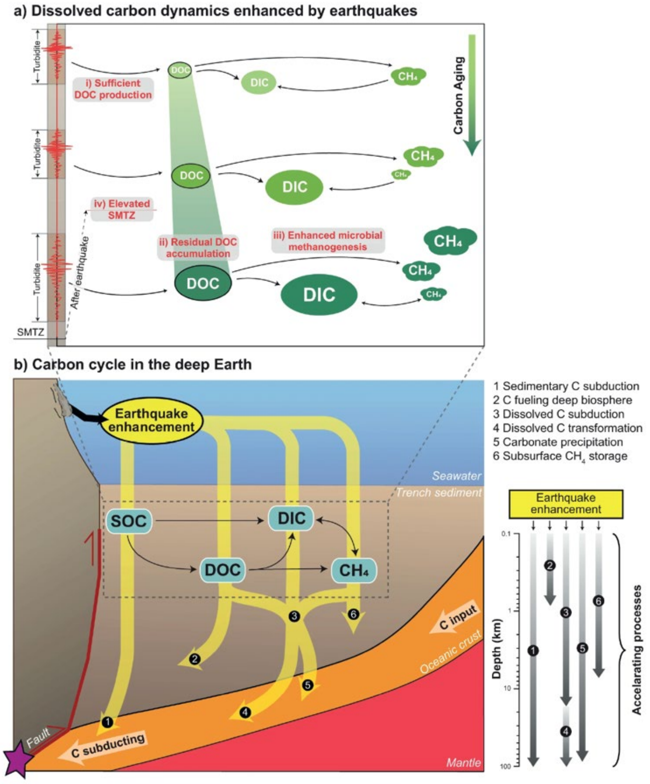


Figure 5. A) Dissolved carbon dynamics in trench sediments are enhanced by earthquakes (from Chu et al., 2023). (i) Sufficient dissolved carbon production facilitated by the combined effects of earthquake-triggered sediment deposition and compaction leads to (ii) larger dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) pools that are aging with depth, which result in (iii) enhanced microbial methanogenesis via fermentation and CO_2 reduction, and (iv) elevated sulphate methane transition zone (SMTZ) that enables methanogenesis at shallower depth. B) The impact of earthquakes on the carbon cycle in the subduction zone. The purple star indicates megathrust earthquakes along the plate boundary, which trigger seismic remobilisation of sedimentary organic carbon (SOC) to the trench. Sufficient dissolved carbon production is facilitated by the combined effects of earthquake-triggered sediment deposition and compaction leads that leads to larger DOC and DIC pools that are aging with depth, which result in enhanced microbial methanogenesis via fermentation and CO_2 reduction, and elevated SMTZ that enables methanogenesis at shallower depth. The residual dissolved carbon may continue to fuel the deep biosphere and is hypothesised to accumulate in the deeper subsurface sediments to eventually enter the subduction zone and undergoes dehydration, forming carbon reservoirs during processes in the deep Earth.

Results of IODP Expedition 386 (Ikehara et al., 2023b; Strasser et al., 2023) also suggest that minor elements in IW may lead to an improved understanding of pore water evolution. Diagenesis, including clay mineral formation or breakdown, opal transformation, and volcanic ash leaching are important mechanisms that control IW geochemistry (Luo et al., subm.). These processes have been suggested to produce distinct boron isotope ($\delta^{11}B$) signatures, particularly combined with Cl- and B concentrations in the accretionary wedge where sediments experience different degrees of burial (Saffer and Kopf, 2016). Similar IW chemistry is seen in the Japan Trench, suggesting that fluids from outside the graben sediment system itself have been introduced. Boron isotopes are isotopically lighter than seawater throughout the trench while B shows a profile to increasing concentrations up to 3 times seawater values (Rasbury et al., 2023). Trends in B, Li, and Si suggest a source where clay minerals are forming to produce an equilibrium Si concentrations of 900 micromolar, a B concentration of at least 1500 micromolar, and a Li concentration that is less than 10 micromolar. Altogether, because it would not be possible to achieve the IW chemistry in situ to the degree that we see, our results suggest a deeper origin of IW, possibly related to fluid discharge driven by dynamic compaction by strong seismic shaking (**Figure 6**), although we know little of detailed origin and processes. Finding the source of this fluid would be a major step forward in our understanding of the hydrology of this system.

Boron desorption and fractionation in Subduction Zone Fore Arcs: Implications for the sources and transport of deep fluids

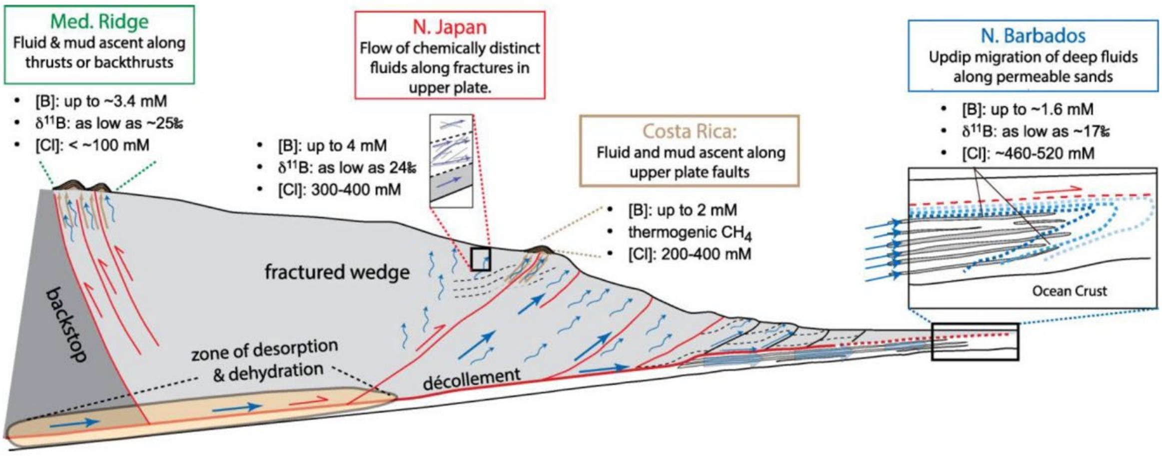


Figure 6. Model for boron concentrations and isotope ratios based on high temperature desorption and dehydration from clays from Saffer and Kopf (2016). Interstitial water (IW) geochemistry of the Japan Trench has values like that of North Barbados, with boron concentrations of 0.5–1.2 mM, $\delta^{11}B$ as low as 17‰, and chlorinity near that of seawater (Rasbury et al., 2023). While existing data are inconclusive as to the source of boron, the hypothesis that slip-to-the-trench earthquakes trigger dynamic compaction, dewatering and discharge events, will become testable by IODP[3] Expedition 503 drilling and IW-sampling.

Scientific Objectives

There is high potential of using event-stratigraphy of trench-fill sedimentary successions in the Japan Trench to reconstruct a long history of giant megathrust earthquakes for evaluating earthquake recurrence patterns. Furthermore, dating key-reflectors in seismic profiles suggesting tsunamigenic slip-to-the-trench earthquakes and testing interstitial water geochemical proxies is expected to deliver better understanding how often and when megathrust ruptures have propagated into the shallowest part to reach the trench. To address these overarching goals, the primary scientific objectives are following:

O-1: Identify and explore the temporal distribution of event-deposits and tectonic-driven deformation and tilting events to investigate time-dependent up-dip rupture variability of the megathrust fault.
O-2: Develop a long-term earthquake record for tsunamigenic giant earthquakes.
O-3: Evaluate the influence of earthquake-induced fluid migration (discharge) in trench-fill sediments.

The cores from a proposed primary site will be used for multi-method applications to characterise and date event-deposits, stratigraphically-correlative trench-fill deformation events and transient geochemical profiles. Drilling the entire trench fill will also reveal samples and data for characterising rates and states of remineralisation and transformation of OC carbon and related element cycles and deep subsurface hadal microbial activity, which is the fourth emerging objective (**O-4**) of this Expedition.

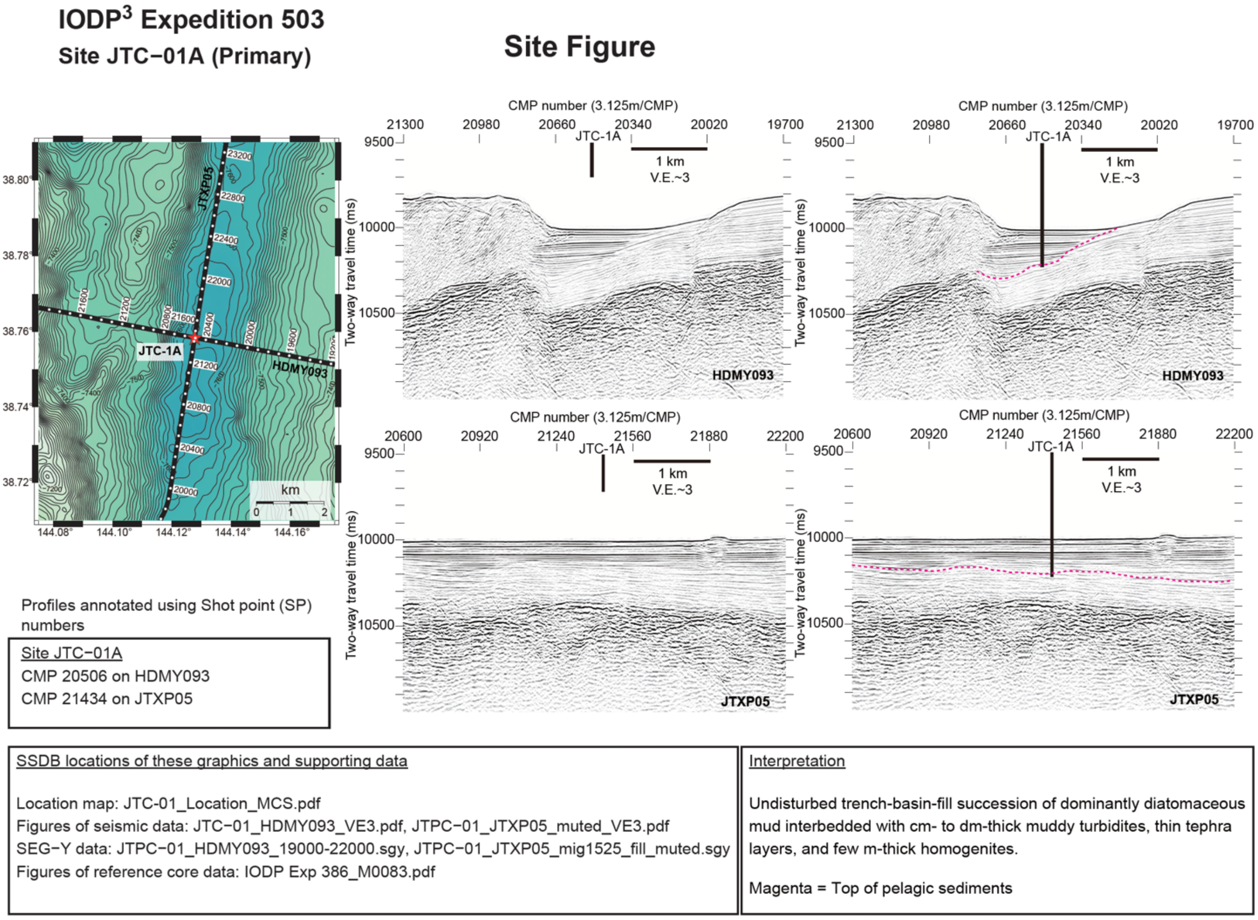
Site Characterisation

IODP^3 Expedition 503 will focus on a trench-fill basin in the cJT (Basin C2 after Strasser et al., 2023) where two GPC sites (Sites M0083 and M0089) of IODP Expedition 386 with good age-controls are located (Strasser et al., 2024; **Figure 2**). The trench-basin fill there is seismically well-stratified and includes some acoustically transparent layers and some reflectors with high amplitudes. In trench-normal profiles, tilts of reflectors increase occasionally at some high amplitude reflection horizons (**Figure 3**). Proposed Site JTC-1A is located near Site M0083 on the basin floor. Thick and well-stratified acoustic patterns with some acoustically-transparent layers in SBP record several intercalations of thick event deposits, the youngest of which related to historical megathrust earthquakes (Strasser et al, 2024; **Figure 2**). The youngest trench-fill sediment deformation at the bottom of the lowermost landward slope indicative for past earthquake slip propagation to the trench is correlates with the 869 CE Jogan earthquake event

(**Figure 4**; Pizer et al., subm.). High amplitude of the progressively tilted deeper reflectors and correlative buried trench-fill deformation structures suggests that paleo earthquake-slip-propagation-to-the-trench was recorded as event deposits with thick basal sand layers (**Figure 3**). Therefore, Proposed Site JTC-1A shows a high potential for longer-term event-stratigraphy. To avoid sediment disturbance by tectonic deformation, the primary site locates slightly offshore of the thickest trench-fill but can recover the deepest tilted reflector.

Site survey data

All site survey data for IODP^3 Expedition 503, such as bathymetric data, HRS and SBP profiles and IODP Expedition 386 core data, are archived at the IODP Site Survey Data Bank (https://ssdb.iodp.org/SSDBquery.php; select 1010 for proposal number). **Figure 7** depicts the site summary figure for Proposed Site JTC-1A.



IODP^3 Expedition 503

Site JTC−01A (Primary)

Site Figure

Profiles annotated using Shot point (SP) numbers

Site JTC−01A
CMP 20506 on HDMY093
CMP 21434 on JTXP05

SSDB locations of these graphics and supporting data

Location map: JTC-01_Location_MCS.pdf
Figures of seismic data: JTC−01_HDMY093_VE3.pdf, JTPC−01_JTXP05_muted_VE3.pdf
SEG−Y data: JTPC−01_HDMY093_19000-22000.sgy, JTPC−01_JTXP05_mig1525_fill_muted.sgy
Figures of reference core data: IODP Exp 386_M0083.pdf

Interpretation

Undisturbed trench-basin-fill succession of dominantly diatomaceous mud interbedded with cm- to dm-thick muddy turbidites, thin tephra layers, and few m-thick homogenites.

Magenta = Top of pelagic sediments

Figure 7. Site Summary Figure of Proposed Site JTC-1A.

Operation Plan / Coring Strategy

Operations will be run concurrently with IODP^3 Expedition 502; after a short portcall in Shiogama, Japan, the Expedition. 502 Science Team will disembark, and the Expedition. 503 Science Team will embark, before transiting to the first drill hole. IODP3 Expedition 503 will visit Proposed Site (JTC-1A) located in a trench-fill basin of the cJT near IODP Expedition 386 Site M0083 at 7630 m water depth (**Figure 8**). The general operations plan and time estimates are provided in **Table 1** and Site summary information is provided in **Table 2**. The operational sequence to be completed by D/V *Chikyu* during IODP^3 Expedition 503 consists of drilling and coring two adjacent 10-5/8-inch holes with the Hydraulic Piston Coring System (HPCS) to 160 meters below seafloor (mbsf) at Proposed Site JTC-1A to continuously recover the full trench-fill sequence. If HPCS refusal would occur before reaching the target depth of 160 mbsf in the first hole, extended shoe coring system and/or extended punch coring system (ESCS/EPCS) coring will continue to target depth or to refusal depth. Due to uncertainty of thickness of basin-fill, the second hole target depth will be defined based on the results of the first hole. If the base of the trench-fill sequence is not reached in the first hole, HPCS and ESCS/EPCS coring will be continued as time permits below 160 m to refusal.

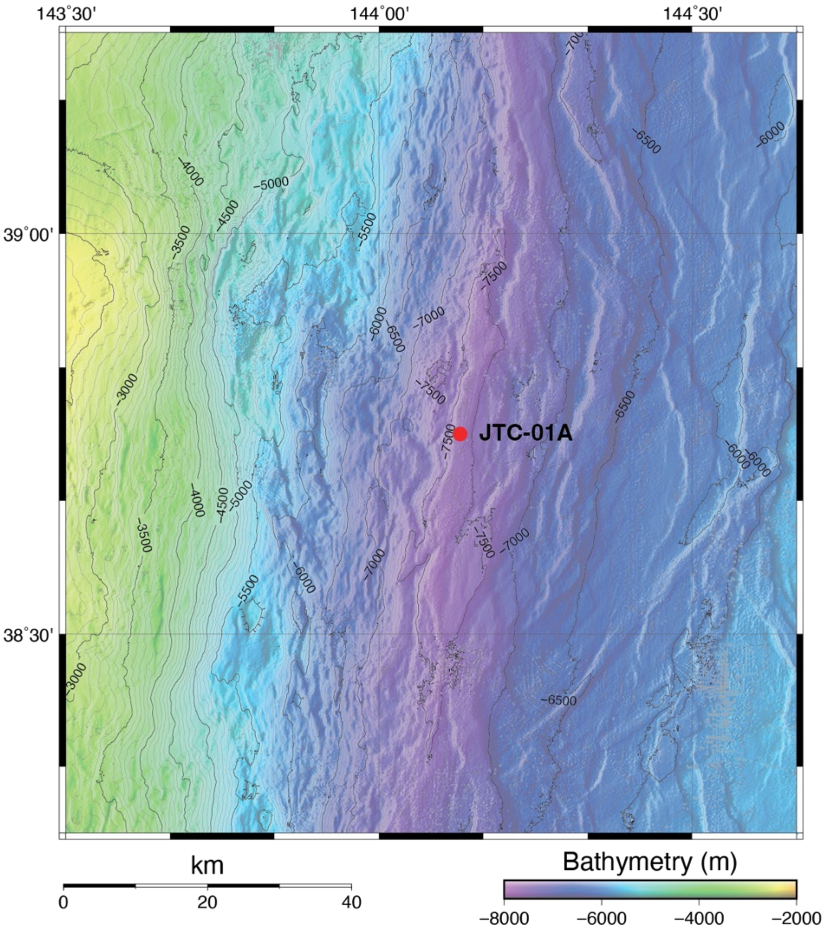


Figure 8. Proposed IODP^3 drilling Site JTC-1A.

Table 1. Operations schedule for IODP^3 Expedition 503.

Operation	Hole Size (inch)	Depth (m)	Day(s)	Subtotal (days)	Total (days)
Portcall			1	1	1
Site JTC-1A: HPCS	10-5/8	160	6	6	
Site JTC-1A: HPCS	10-5/8	160	6	12	
Transit			3	15	16
Offload in Shimizu			2	2	18
Contingency Time			3.5	3.5	21.5

Table 2. Site Summary.

Site Priority:	Proposed Site JTC-A1 Primary
Position:	38.7583 N, 144.1277 E
Water depth (m):	7630
Target drilling depth (mbsf): Approved maximum penetration (mbsf):	160 160
Survey coverage:	Extensive survey data from 3-D seismic data: • CMP 20506 on HDMY093 • CMP 21434 on JTXP05
Objective:	HPCS coring • Drill out hole to TD Anticipated lithology: Silicious ooze, clayey silt, ash, silty clay

Downhole Logging

There will be no downhole logging programme for Expedition 503.

Science Operations

A Sampling and Measurements Plan (SMP) for IODP^3 Expedition 503 will be prepared by MarE3 and the Co-Chief Scientists to meet the scientific objectives of the expedition. Science activities on the D/V *Chikyu* during the Expedition will guaranty standard IODP^3 shipboard curation, measurements, and reporting. Details of the facilities that will be available can be found on the *Chikyu* wiki pages. The Measurements Plan will take account of *Chikyu* specifications for QA/QC. The following briefly summarizes the scientific activities:

- Lithology: Visual core description and smear slide observation, high-resolution digital imaging, X-ray computed tomography (CT) scans, colour reflectance spectrophotometry, bulk mineralogy with X-ray diffraction (XRD);

- Micropaleontology: Biostratigraphic analyses of siliceous microfossils (e.g., radiolaria), benthic foraminifers and redeposited calcareous pelagic micro- and nannofossils;
- Physical properties: Multi-sensor core logging for gamma density, P-wave velocity, electrical resistivity, magnetic susceptibility and natural gamma radiation, thermal conductivity measurement, P-wave velocity and moisture and density (MAD) on discrete samples, undrained shear strength and unconfined compressive strength;
- Paleoaleomagnetic measurements;
- Geochemistry: Taking samples for headspace (HS) shipboard gas analyses of concentrations and relative abundance of light hydrocarbon gases (C1 to C4), pore fluid chemistry (by Rhizon and squeezed samples), whole-rock geochemistry, X-ray fluorescence (XRF) spectroscopy; and carbon-hydrogen-nitrogen-sulfur (CHNS) elemental analysis;
- Taking and proper storage (+4° and −80°C) of samples for microbiological post-expedition research and for ephemeral properties.

In principle, report preparation will take place on board as required; the reports to be compiled include:

- Daily and weekly operational reports compiled by MarE3 and provided to the management and panels of IODP^3, and any other relevant parties;
- Expedition Summary compiled by the Science Team (submission to IODP^3 publication services at the end of expedition);
- The Site Reports compiled by the Science Team (submission to IODP^3 publication services as soon as practically possible after the expedition).

Research Planning: Sampling and Data sharing strategy

All researchers requesting samples should refer to the **IODP^3 Sample, Data, and Obligations Policy**. This document outlines the policy for distributing IODP3 samples and data to research scientists, curators, and educators. The document also defines the obligations that sample and data recipients incur. The Sample Allocation Committee (SAC; composed of Co-Chief Scientists, Expedition Project Manager, and IODP^3 Curator) will work with the entire Science Team to formulate an expedition-specific sampling plan for “shipboard” (expedition) and post-cruise (personal post-expedition research) sampling.

Members of the Science Team are expected to carry out scientific research for the expedition and publish it. Before the expedition, all members of the Science Team are required to submit research plans and associated sample/data requests via the IODP^3 Sample, Data and Research Request Manager (SDRM; https://web.iodp.tamu.edu/SDRM/#/) system ~6 months before the beginning of the expedition (Deadline will be announced by IODP^3). Based on sample/data requests submitted by this deadline, the SAC will prepare a tentative sampling plan, which can be revised on the ship and once cores are split as dictated by recovery and cruise objectives. All post-cruise research projects should provide scientific justification for desired sample size, numbers, and frequency. The sampling plan will be subject to modification depending upon the material recovered and collaborations that may evolve between scientists during the expedition. This planning process is necessary to coordinate the research to be conducted and to ensure that the scientific objectives are achieved. Modifications to the sampling plan and access to samples and data during the expedition and the 1-year post-expedition moratorium period require the approval of the SAC.

The permanent archive halves are officially designated by the IODP^3 curator. Should there be a copy of an interval from parallel holes, they may be classified as temporary archives. All sample frequencies and volumes must be justified on a scientific basis and will depend on core recovery, the full spectrum of other requests, and the expedition objectives. Some redundancy of measurement is unavoidable, but minimising the duplication of measurements among the shipboard team and identified shore-based collaborators will be a factor in evaluating sample requests.

If critical intervals are recovered, there may be considerable demand for samples from a limited amount of cored material. A sampling plan coordinated by the SAC will be required before critical intervals are sampled. The SAC strongly encourages, and may require, collaboration and/or sharing among the shipboard and shore-based scientists so that the best use is made of the recovered core. Coordination of post-cruise analytical programmes is anticipated to ensure that the full range of geochemical, isotopic, and physical property studies are undertaken on a representative sample suite.

Core and Data Management

The data management plan follows the standard *Chikyu* and IODP^3 measurement policies:

- Core sections will be registered in J-CORES, the *Chikyu* Lab Management System, along with all personal samples, subsamples, data, images, and standard shipboard measurements.
- Core sections (archive and working halves) will be stored at the Kochi University/JAMSTEC Kochi Core Center (Japan).

- Shipboard data will be available in the JAMSTEC Scientific Ocean Drilling Data (J-SODD).

Outreach

JAMSTEC/MarE3, PMO offices, and IODP^3 will collaborate on outreach activities before, during, and post expedition.

Staffing

Scientific staffing is determined on the basis of task requirements and nominations from the IODP^3 Programme Member Offices. Staffing is based on the need to carry out the drilling and scientific operations safely and efficiently. A list of participants for Expedition 503 will be added to the JAMSTEC *Chikyu* **Expedition 503 website** when available.

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