# International Ocean Discovery Program
# Expedition 371 Scientific Prospectus

## Tasman Frontier Subduction Initiation and Paleogene Climate

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# Abstract

During International Ocean Discovery Program Expedition 371, we will core and log Paleogene and Neogene sediment sequences within the Tasman Sea. The cores will be analyzed for their sediment composition, microfossil components, mineral and water chemistry, and physical properties. The research will improve our understanding of how convergent plate boundaries form, how greenhouse climate systems work, and how and why global climate has evolved over the last 60 my. The most profound subduction initiation event and global plate-motion change since 80 Ma appears to have occurred in the early Eocene, when Tonga-Kermadec and Izu-Bonin-Mariana subduction initiation corresponded with a change in direction of the Pacific plate (Emperor-Hawaii bend) at ~50 Ma. The primary goal of Expedition 371 is to precisely date and quantify deformation and uplift/subsidence associated with Tonga-Kermadec subduction initiation in order to test predictions of alternate geodynamic models. This tectonic change may coincide with the pinnacle of Cenozoic "greenhouse" climate. However, paleoclimate proxy data from lower Eocene strata in the southwest Pacific show especially warm conditions, presenting a significant discrepancy with climate model simulations. The second goal is to determine if paleogeographic changes caused by subduction initiation may have led to anomalous regional warmth by altering ocean circulation. Late Neogene sediment cores will complement earlier drilling to investigate the third goal: tropical and polar climatic teleconnections. During Expedition 371, we will drill in a significant midlatitude transition zone influenced by both the Antarctic Circumpolar Current and the Eastern Australian Current. The accumulation of relatively thick carbonate-rich Neogene bathyal strata make this a good location for generating detailed paleoceanographic records from the Miocene through the Pleistocene that can be linked to previous ocean drilling expeditions in the region (Deep Sea Drilling Project Legs 21, 29, and 90; Ocean Drilling Program Leg 189) and elsewhere in the Pacific Ocean.


# Schedule for Expedition 371

Expedition 371 is based on International Ocean Discovery Program (IODP) drilling Proposals 832-Full2 and 832-Add (available at **http://www.iodp.org/proposals/active-proposals**). Following ranking by the IODP Scientific Advisory Structure, the expedition was scheduled for the research vessel (R/V) *JOIDES Resolution*, operating under contract with the *JOIDES Resolution* Science Operator (JRSO). At the time of publication of this *Scientific Prospectus*, the expedition is scheduled to start in Townsville, Australia, on 27 July 2017 and to end in Hobart, Australia, on 26 September 2017. A total of 51 days will be available for the drilling, coring, and downhole measurements described in this report (for the current detailed schedule, see **http://iodp.tamu.edu/scienceops/index.html**). Further details about the facilities aboard the *JOIDES Resolution* can be found at **http://www.iodp.tamu.edu/labs/ship.html**.

# Scientific background

Subduction systems are primary drivers of plate motions, mantle dynamics, and global geochemical cycles, but little is known about how subduction starts. What are the initial conditions? How do forces and kinematics evolve? What are the short-term consequences and surface signatures: uplift, subsidence, deep-water sedimentary basins, convergence, extension, and volcanism? Early Eocene onset of subduction in the western Pacific was accompanied by a profound global reorganization of tectonic plates, with known plate motions before and after the change (Billen and Gurnis, 2005; Sharp and Clague, 2006; Steinberger et al., 2004; Whittaker et al., 2007). The Izu-Bonin-Mariana and Tonga-Kermadec systems contain complementary information about subduction initiation (Figure **F1**), but the southwest Pacific has had little relevant drilling. Our primary goal is to understand Tonga-Kermadec subduction initiation through recovery of Paleogene sediment records at six new sites between Australia and New Zealand in the Tasman Frontier (Figures **F2**, **F3**).

Eocene tectonic change occurred at a turning point in Cenozoic climate. Global warming through the Paleocene–Eocene transition culminated in the Early Eocene Climatic Optimum (EECO; ~52–50 Ma), which was followed by overall cooling through the remainder of the Cenozoic (Figure **F4**) (Zachos et al., 2008). Understanding the nature and causes of this turning point will address an outstanding climate question: why does Earth oscillate between multimillion-year greenhouse and icehouse climate states? Under very high $pCO_2$ conditions or high climate sensitivity, global climate models (Huber and Caballero, 2011; Lunt et al., 2012) can reasonably simulate early Eocene warming in most regions (Douglas et al., 2014; Tripati et al., 2003), but not the extreme warmth reported in the southwest Pacific and Southern Ocean (Bijl et al., 2009; Hollis et al., 2009, 2012; Pross et al., 2012). Do southwest Pacific proxy records point to undiscovered climate phenomena that amplify high-latitude temperatures during periods of global warmth? Alternatively, did significant tectonic reconfiguration around the Tasman Sea in the Eocene (Figure **F5**) impact regional ocean circulation and climate? A secondary goal is to address these questions with new proxy records and more accurate Tasman paleobathymetry.

The Eocene–Oligocene transition and Neogene climatic variations have been subjects of past scientific drilling expeditions. Deep Sea Drilling Project (DSDP) drilling in the Tasman Sea (Legs 21, 29, and 90) was highly influential in the development of ideas that connected regional oceanography with the thermal isolation and glaciation of Antarctica and hence global climate change (Burns and Andrews, 1973; Kennett, 1977; Kennett et al., 1975; Kennett and Vonderborch, 1986). Ocean Drilling Program (ODP) Leg 189 further investigated the Eocene–Oligocene opening of the southern Tasman Sea gateway (Exon et al., 2004b). However, the significance ascribed to unconformities in the Tasman Sea did not include consideration of regional vertical tectonics or local faulting (Sutherland et al., 2010). Records in the Tasman Sea seemingly also offer key insights to understanding the late Miocene–early Pliocene biogenic bloom (Grant and Dickens, 2002). The cores and data collected during Expedition 371 will be superior (in terms of completeness, quality, and having wireline logs for correlation) to those previously collected in the Tasman Sea, and the local settings will be better surveyed and understood. Therefore, an additional secondary goal of Expedition 371 is to improve our understanding of paleoceanography since the Eocene.

## Subduction initiation and global plate tectonics

Subduction initiation and changes in plate motion are linked because the largest driving and resisting tectonic forces occur within subduction zones (Becker and O'Connell, 2001; Buffett, 2006; Lithgow-Bertelloni and Richards, 1998; Stadler et al., 2010). There are two classes of subduction initiation model: induced or spontaneous (Stern, 2004) (Figure **F6**). In the spontaneous model, oceanic lithosphere ages, cools, increases in density and gravitational instability, and sinks into the mantle under its own weight (Stern and Bloomer, 1992; Turcotte et al., 1977). In the induced model, externally applied compressive stress and convergence is necessary to overcome lithospheric strength before a convective instability can grow and subduction initiation occurs (McKenzie, 1977; Toth and Gurnis, 1998).

Half of all active subduction zones on Earth initiated during the Cenozoic (Gurnis et al., 2004), so it is possible to assemble observations to address how and why these margins evolved into self-sustaining subduction zones. Recent drilling results from International Ocean Discovery Program (IODP) Expedition 351 shed new light on this question, and new models suggest juxtaposition of a transcurrent fault and relict arc could have led to Izu-Bonin-Mariana subduction initiation just before 50 Ma (Leng and Gurnis, 2015). Subduction initiation at a passive continental margin has received considerable attention through the concept of a Wilson cycle (a class of the spontaneous model), but there are no known Cenozoic examples of passive margins evolving into subduction zones (Stern, 2004). Spontaneous and induced models predict different states of stress and vertical motions during their early stages, and this prediction underpins our drilling strategy.

The largest change in global plate motions since 83 Ma (the only period with precisely known plate kinematics) is manifest as the Emperor-Hawaii seamount chain bend. Geochronology shows that the Emperor-Hawaii bend started at ~50 Ma and may have occurred over ~8 my (Sharp and Clague, 2006). The onset of Pacific plate motion change corresponds to the timing of Pacific/Farallon plate boundary rearrangement (Caress et al., 1988) and termination of spreading in the Tasman Sea (Gaina et al., 1998), followed by a change in direction and rapid increase in rate of Australia-Antarctic spreading with consequent northward acceleration of Australia (Muller et al., 2000; Seton et al., 2012; Whittaker et al., 2007) and initiation of Australia-Pacific spreading south of New Zealand (Keller, 2003; Sutherland, 1995; Wood et al., 1996). Eocene emplacement of ophiolites and deformed flysch records the onset of convergence in New Caledonia (Aitchison et al., 1995). Reconfiguration of plate boundaries in Antarctica (Cande et al., 2000), the Indian Ocean (Cande et al., 2010), and Asia (Aitchison et al., 2007) reveals the global extent of tectonic change.

The westward swerve in Pacific plate motion occurred at about the same time as subduction zones initiated throughout the western Pacific (Gurnis et al., 2004; Hall et al., 2003; Steinberger et al., 2004). It is the only global-scale subduction initiation event for which plate motions are known before and after, and there is a clear linkage between subduction initiation and plate motion change. Solving what happened in the western Pacific is of fundamental significance for understanding subduction initiation and hence the physics of plate tectonics and mantle flow.

## Eocene greenhouse climate

Paleogene sediment records can provide new insights into Earth's climate history and underpin predictions on future greenhouse climate (Lunt et al., 2014). Available data indicate that $pCO_2$ exceeded 1000 ppmv in the early Eocene (Beerling and Royer, 2011), when global temperatures were 10°C warmer than present day and the poles were largely free of ice (Zachos et al., 2008). Climate model simulations, using either very high greenhouse gas radiative forcing or very high climate sensitivity (Figure **F7**), yield mean annual temperatures and seasonal thermal gradients consistent with most data for the early Eocene (Huber and Caballero, 2011; Lunt et al., 2012). However, at several sites in the southwest Pacific, both onshore and offshore (e.g., from Leg 189), multiple proxies yield sea-surface temperatures (SSTs) 5° to 10°C warmer than predicted by model simulations (Figure **F7**) (Hollis et al., 2012). Such SST estimates imply very low meridional temperature gradients in the early Eocene, which has long posed a climate puzzle (Barron, 1987).

Ocean circulation might account for low SST gradients in the southwest Pacific during the early Eocene. One possibility is that modeled SST predictions are too low because the region was influenced by a warm southward-flowing current system (Hollis et al., 2012). Ocean currents predicted by model simulations could be substantially wrong if paleobathymetry is not depicted accurately, for example if parts of the Tasman Frontier were much shallower than today during the early Eocene. There is evidence for large vertical movement in the Tasman Frontier during this time period (Baur et al., 2014; Sutherland et al., 2010).

The early Paleogene stratigraphic record of New Zealand has been analyzed in increasing detail over the last 15 years. In particular, the warming trend of the late Paleocene through early Eocene, the so-called hyperthermal "events" of the early Eocene, the EECO, and the subsequent cooling have been tied to sedimentary and biological responses in pelagic successions of eastern New Zealand (Hancock et al., 2003; Hollis, 2006; Hollis et al., 2005; Nicolo et al., 2007, 2010; Slotnick et al., 2012). Expedition 371 should recover intervals of lower Paleogene sediment that will enable generation of new temperature proxy data at very specific times in key locations and with minimal diagenesis or interruption of the sedimentary record.

Why did Earth's climate generally cool since about 49 Ma? Most hypotheses have invoked changes in the amount of volcanism or weathering, which would affect carbon addition to or carbon removal from the ocean and atmosphere (Brinkhuis et al., 2006; Kent and Muttoni, 2008). It has recently been suggested that Eocene tectonic change drove long-term Cenozoic climate change (Lee et al., 2013). Prior to the early Eocene, most volcanic arcs were continental, where rising magma can react with carbonate-rich crust and generate voluminous $CO_2$. Initiation of widespread island-arc subduction systems around the Pacific during the early Eocene created a network of submarine plate boundaries that likely decreased $CO_2$ fluxes to the atmosphere.

## Post-Eocene climate evolution

Initial reports for DSDP Legs 21 and 29 (Burns and Andrews, 1973; Kennett et al., 1975) laid foundations for understanding the interplay between tectonic and oceanographic events in the region, including opening of the Tasman Sea and separation of Australia and New Zealand from Antarctica (Andrews et al., 1975; Andrews and Ovenshine, 1975; Edwards, 1973, 1975; Kennett et al., 1975; Kennett and Shackleton, 1976). Stable isotope records from DSDP Leg 29 (Sites 277 and 278) reveal a general cooling trend from warm to cool temperate conditions, with evidence for a pronounced cooling step across the Eocene–Oligocene transition. A series of landmark publications from these legs proposed that ocean circulation was a primary driver of regional and global climate through the early Cenozoic, and the role of circumpolar gateways in the evolution of Antarctic ice sheets and global climate was first hypothesized (Kennett, 1977; Kennett and Shackleton, 1976; Nelson and Cooke, 2001).

ODP Leg 189 focused on the ocean gateway hypothesis and generated a wealth of data and debate (Exon et al., 2004a; Kennett and Exon, 2004). Some continue to argue for the crucial role opening the Tasmanian gateway played in southwest Pacific oceanography and climate (Kennett and Exon, 2004), whereas others link late Paleogene cooling and ice sheet growth to a tectonically driven decline in atmospheric $CO_2$ (DeConto and Pollard, 2003; Huber et al., 2004).

Drilling within the broad Indo-Pacific area has documented a phenomenon coined the late Miocene–early Pliocene biogenic bloom (Farrell et al., 1995; Dickens and Owen, 1999). Between about 9 and 4 Ma, the accumulation of biogenic components (e.g., carbonate, silica, barite) increased significantly at many sites beneath regions of modern surface water divergence (e.g., along the Equator of the eastern Pacific [Van Andel et al., 1975; Farrell et al., 1995], the far north Pacific [Rea et al., 1995], and the Oman margin [Brummer and Van Eijden, 1992]). At DSDP Site 590, which lies beneath the Tasman Front, carbonate accumulation rates doubled between the late Miocene and early Pliocene, consistent with the biogenic bloom phenomenon (Grant and Dickens, 2002). The coincidence of elevated export production at numerous locations suggests far-field oceanographic teleconnections (Figure **F8**), such as via an acceleration of Indo-Pacific upwelling and nutrient delivery to the photic zone.

Expedition 371 will collect high-quality cores and data from the key Tasman Frontier region, where the Antarctic Circumpolar Current drives abyssal bottom currents and westerly winds interacting with local physiography results in the shallow (but still significant at 1000 m depth) subtropical Eastern Australian Current (Figure **F9**). Sediment records collected during Expedition 371 will contain high-quality archives that reveal the history of evolution of these currents, and the local tectonic, oceanographic, and physiographic setting of each site will be much better understood than in previous studies. We therefore expect to collect high-resolution records at several sites that will contribute to debates about regional versus global drivers of oceanographic and climatic change.

# Geological setting

The southwestern subduction margin of the Pacific plate, the Tonga-Kermadec system, has been studied much less than the Izu-Bonin-Mariana system but is complementary and has advantages: (1) the Tonga-Kermadec system formed adjacent to thin continental crust that early back-arc spreading isolated from later complication by faulting or volcanism; (2) persistent submarine conditions and moderate water depths led to preservation of fossil-rich bathyal sediment records in many places; (3) seismic-reflection data demonstrate existence of Eocene tectonic signals of change, including compression, uplift-subsidence, and volcanism; and (4) Australia-Pacific plate-motion boundary conditions are precisely known (Cande and Stock, 2004; Sutherland, 1995).

The tectonic history of the Tasman Frontier can be divided into four phases:

- >350–100 Ma: subduction along the eastern Gondwana margin.
- 100–80 Ma: continental rifting in the Tasman Sea region.
- 80–50 Ma: oceanic rifting, passive margins, and opening of Tasman Sea.
- 50–0 Ma: Tonga-Kermadec subduction.

Continental "basement" beneath bathymetric rises is inferred to be similar to rocks found in New Zealand, New Caledonia, and eastern Australia; this inference is supported by limited dredge samples and drilling (DSDP Site 207), seismic velocities, and gravity and magnetic anomalies (Collot et al., 2012; Klingelhoefer et al., 2007; Mortimer, 2004a, 2004b; Mortimer et al., 2008; Sutherland, 1999; Tulloch et al., 1991; Wood and Woodward, 2002). The Lord Howe Rise and Challenger Plateau are probably composed of quartzose metasedimentary rocks and granitoids of Paleozoic age that represent the eastern edge of Gondwana. High-amplitude magnetic anomalies and a single dredge sample from the West Norfolk Ridge suggest that the southern New Caledonia Trough is underlain by a fossil arc of late Paleozoic and Mesozoic age that formed along the active margin of Gondwana (Mortimer et al., 1998; Sutherland, 1999). The geology of New Caledonia and northern New Zealand suggests that the Norfolk Ridge system is underlain by Mesozoic fore-arc accretionary rocks that formed at the convergent margin of Gondwana (Adams et al., 2009; Aitchison et al., 1998; Cluzel et al., 2010; Cluzel and Meffre, 2002; Mortimer, 2004b). Based on comparison with eastern New Zealand (Davy et al., 2008), the fossil Gondwana trench lay along the northeast side of the Norfolk Ridge system and the slab dipped southwest beneath the Lord Howe Rise.

The tectonic regime along the Tasman sector of the Gondwana margin changed during the Cretaceous from subduction and convergence to widespread rifting and extension. Igneous activity was widespread and of variable type and chemistry during the Cretaceous. Calc-alkaline and adakitic (high Sr/Y) activity with a subduction-related signature is characteristic of the early phase (130–110 Ma), whereas an intraplate rift setting characterizes later activity after ~105–100 Ma (Bryan et al., 1997; Cluzel et al., 2010; Higgins et al., 2011; Mortimer et al., 1999; Tulloch et al., 2009). Late Cretaceous rift basins contain coastal sandstone facies overlain by transgressive marine sandstones and mudstones in New Zealand, eastern Australia, and New Caledonia and are likely to be present in the Tasman Frontier region (Collot et al., 2009; Herzer et al., 1999; King and Thrasher, 1996; Uruski and Wood, 1991; Uruski, 2008). The end of widespread rifting in New Zealand, New Caledonia, and Australia and the subsequent transition to passive margin conditions were contemporaneous with the onset of seafloor spreading in the Tasman Sea at ~80 Ma, but local fault activity is known to have continued to ~60 Ma in Taranaki and northern South Island, New Zealand (King and Thrasher, 1996; Laird, 1993).

Late Cretaceous to early Cenozoic seafloor spreading in the Tasman Basin is inferred from magnetic anomalies (Hayes and Ringis, 1973; Weissel and Hayes, 1977). The earliest seafloor spreading may predate Chron 34y (83 Ma) east of Tasmania (Royer and Rollet, 1997), but marginal seafloor along much of the western edge of the Lord Howe Rise probably formed during Chron 33r (83–79 Ma) (Gaina et al., 1998; Sutherland, 1999). Seafloor spreading ceased in the central Tasman Sea during Chron 24 (53–52 Ma) or very shortly afterward (Gaina et al., 1998).

Deformation, exhumation, and emplacement of ultramafic, mafic, and sedimentary allochthons occurred in New Caledonia during the middle and late Eocene (Aitchison et al., 1995; Cluzel et al., 2001). The peak of high-pressure metamorphism in northern New Caledonia was at 44 Ma, and exhumation was largely complete by 34 Ma (Baldwin et al., 2007). Seismic-stratigraphic evidence shows that the New Caledonia Trough either formed or was substantially modified during this event, though Cretaceous sedimentary basins beneath the trough escaped Cenozoic convergent deformation in most places (Collot et al., 2008; Sutherland et al., 2010). Regional deformation and emplacement of allochthons in northern New Zealand occurred later than in New Caledonia or the Norfolk Ridge system, with the onset of tectonic activity during the late Oligocene and early Miocene (~30–20 Ma) (Bache et al., 2012; Herzer, 1995; Herzer et al., 1997; Rait et al., 1991; Stagpoole and Nicol, 2008).

Australia-Pacific plate motion is precisely known for the period since Chron 20 (43 Ma) because the plate boundary south of New Zealand was extensional and a plate circuit through Antarctica can be followed to provide additional constraints (Cande and Stock, 2004; Keller, 2003; Sutherland, 1995). Eocene convergence rates varied from <1 cm/y in New Zealand to 10 cm/y near New Caledonia. Late Eocene to Holocene subduction zone roll-back has produced back-arc basins (Loyalty, Norfolk, South Fiji, North Fiji, Havre, and Lau) and ridges interpreted as fossil and active arcs east of the Norfolk Ridge system (Loyalty, Three Kings, Lau-Colville, Tonga-Kermadec, and Vanuatu) (Crawford et al., 2003; Herzer et al., 2009; Herzer and Mascle, 1996; Mortimer et al., 2007; Schellart et al., 2006). The complexity of basin opening makes local determination of past plate boundary configurations and rates difficult. This back-arc region has mostly isolated the submerged continental part of the Tasman Frontier region from Cenozoic subduction-related deformation and volcanism.

A variety of tectonic models have been proposed to explain how the various Eocene-Miocene arcs and back arcs subsequently formed between the Tonga-Kermadec and Norfolk Ridges (Cluzel et al., 2006; Crawford et al., 2003; Herzer et al., 2009; Mortimer et al., 2007; Schellart et al., 2006), but there is general agreement that the modern Tonga-Kermadec system evolved from a boundary lying near to the Norfolk Ridge and New Caledonia in the middle Eocene. There is poor agreement about the exact geometry of that boundary or the nature of Cretaceous to middle Eocene plate boundaries northeast of Norfolk Ridge (Whattam et al., 2008) because the region has either been subducted or deformed and intruded and it is very sparsely sampled.

The oldest Cenozoic volcanic rocks from the southwest Pacific with clear subduction affinities were dredged from the Tonga-Kermadec fore arc and have ages between 52 and 48 Ma (Meffre et al., 2012). In New Caledonia, dikes with subduction affinities cut ophiolitic rocks and are interpreted to be approximately synchronous with felsic dikes dated at ~53 Ma (Cluzel et al., 2006). These dikes represent the earliest evidence for subduction and predate the peak of high-pressure metamorphism at 44 Ma (Baldwin et al., 2007) and nappe emplacement in New Caledonia (Aitchison et al., 1995; Maurizot, 2012). Magnetic anomaly interpretation shows that the Tasman Sea basin ceased spreading at ~52–50 Ma (Gaina et al., 1998). Therefore, there is strong evidence for Pacific-wide synchronicity: the age of the Emperor-Hawaii bend, the inception of Izu-Bonin-Mariana subduction, and a change from seafloor spreading to Tonga-Kermadec subduction initiation in the Tasman Frontier.

## Seismic studies/site survey data

During the 1960s and 1970s, a geophysical case based on bathymetric, gravity, magnetic, and seismic data was made that the Lord Howe Rise may have an underlying "continental-type" crustal structure, whereas marginal basins east of the Norfolk Ridge were related to Cenozoic evolution of Tonga-Kermadec subduction (Brodie, 1964; Karig, 1971; Packham and Falvey, 1971; Shor et al., 1971).

During the past four decades, ~100,000 line km of seismic-reflection data have been collected from the Tasman Frontier, but the region has complex sovereign boundaries (New Zealand, Australia, France, Tonga, Fiji, and Vanuatu), and most data were collected by academic or industry visitors to the region. Work over the last two decades in regard to the United Nations Convention on the Law of the Sea (UNCLOS) led to resolution of sovereign seabed boundaries, compilation of data, and collection of new data. All modern seismic-reflection data that can be released were publicly released by a collaboration between New Zealand (GNS Science), Australia (Geoscience Australia), and New Caledonia (Department of Industry, Mines and Energy [DIMENC]/New Caledonia Economic Development Agency [ADECAL]) (Sutherland et al., 2012).

Interpretation of the compiled geophysical data led to new hypotheses (Bache et al., 2012; Baur et al., 2014; Sutherland et al., 2010) and Expedition 371. Two voyages using the R/V *Tangaroa* completed detailed surveys (swath, seismic-reflection, subbottom profiles, magnetic, gravity, and dredges) at each proposed site (voyages TAN1312 and TAN1412). Two additional voyages by the R/V *L'Atalante* in 2015 collected dredge samples of the oldest Cenozoic volcanic rocks (VESPA voyage); and completed regional seismic-reflection ties between existing surveys and with boreholes (proposed and existing) (TECTA voyage).

Three scientific drilling legs have penetrated Eocene strata: DSDP 21, 29, and 90. Leg 21 was the first exploration of Cenozoic-Cretaceous stratigraphy and paleoceanography of the northern southwest Pacific (Burns and Andrews, 1973). DSDP Sites 206, 207, and 208 were drilled on this leg and are the only scientific drill holes to have penetrated our primary target interval of lower Paleogene sediments on continental crust. Leg 29 focused on paleoceanography of the southern southwest Pacific. Site 283 was drilled during this leg in the southwest Tasman Sea, west of the paleo-Tasman spreading ridge (Kennett et al., 1975). Site 283 lies on oceanic crust and represents a conjugate location to proposed Site TASS-2A (east Tasman Basin). DSDP Leg 90 focused on late Cenozoic paleoceanography (Kennett and Vonderborch, 1986; Martini and Jenkins, 1986; Nelson, 1986) and drilled four successful sites on the Lord Howe Rise (588 and 590–592) and one on Challenger Plateau (593). DSDP Sites 592 and 593 penetrated upper Eocene strata and are useful for seismic interpretation. Sites 588, 590, 591, and 593 sampled upper Cenozoic sequences using an advanced piston corer (APC) tool.

Sediment facies and discontinuities described in previous drilling studies have been correlated with sedimentary basins in New Zealand (King et al., 1999; Moore, 1988), and the first-order pattern can be summarized as a fining-upward Upper Cretaceous to Oligocene succession of siliciclastic sand and mud facies, siliceous mud and ooze, and carbonate mud and ooze, interspersed with greensands. Neogene chalk and ooze strata in distal regions (including most proposed Expedition 371 sites) provide 100–800 m thick records of evolving ocean circulation patterns. In troughs and near land, the influence of rising mountains led to progressively greater terrigenous sediment input during the Neogene (mostly clay in these distal locations).

Supporting site survey data for Expedition 371 are archived at the IODP Site Survey Data Bank (**https://ssdb.iodp.org/SSDBquery/SSDBquery.php**; select P832 for the proposal number), and additional data can be obtained from GNS Science, Geoscience Australia, or the Geological Survey of New Caledonia.

## Scientific technical objectives

Based on seismic reflection profiles, pre-Neogene sediment archives exist on four prominent bathymetric features in the Tasman Frontier region: Norfolk Ridge, New Caledonia Trough, Lord Howe Rise, and Tasman Abyssal Plain (Figure **F2**). However, only four drill sites with limited core recovery have penetrated the middle Eocene and older sequences (DSDP Sites 206, 207, 208, and 283).

1. *How and why did subduction initiation occur?*
   a. Did plate convergence precede and induce subduction initiation, or did subduction initiation happen spontaneously? Observations regarding timing, distribution, and style of deformation will be acquired to test alternative subduction initiation model predictions.
   b. What vertical stresses occurred during subduction initiation? The magnitude and timing of uplift and subsidence across a broad region will be determined through drilling targets that will enable evaluation and refinement of geodynamic models. Predictions from seismic stratigraphy of large-magnitude far-field uplift and subsidence challenge existing geodynamic theories and will be tested.

Our primary goal is to better understand the Paleogene sequence of tectonic events west of Norfolk Ridge that was associated with Tonga-Kermadec subduction initiation. Preliminary observations have been used to infer a regional pulse of Eocene minor convergent deformation (plate failure), transient regional uplift then subsidence, permanent uplift of the Norfolk Ridge, and permanent subsidence of the New Caledonia Trough (Bache et al., 2012; Collot et al., 2008; Sutherland et al., 2010). Existing stratigraphy demonstrates a broad correlation between these signals and the Eocene onset of Tonga-Kermadec subduction, but drilling is required to test these hypotheses (e.g., uplift to near sea level) and provide precise age control on events.

We will obtain new observations to test geodynamic model predictions: periods with high horizontal stresses are manifest as crustal failure and faulting, vertical stresses caused by tractions or buoyancy are balanced by surface uplift or subsidence, and thermal or chemical anomalies predicted by models may produce characteristic volcanic products.

The timing and style of faulting and volcanism can be determined from stratigraphic relationships tied to seismic reflection data. In general, three units constrain the timing of a tectonic event: faulted strata are older than the event, unfaulted strata are younger than the event, and syntectonic growth strata record progressive faulting during the event. Growth strata are typically identified from thickness changes within a sedimentary unit that drapes faulted units, and seismic reflectors within the syntectonic unit may exhibit fanning geometries close to faults.

The only practical way of measuring elevation of the crust through time is against a sea level reference frame. Flat unconformities with regional consistency on seismic reflection (and in some cases bathymetric) data are interpreted as surfaces produced by sea level–modulated erosional processes. Samples dredged from >1500 m water depth from Reinga Basin during the recent TAN1312 voyage confirm the occurrence of Eocene coarse bioclastic limestone and shallow-marine fossils and hence affirm the hypothesis that large (>1 km) vertical motions were associated with Tonga-Kermadec subduction initiation. Discovery of shallow-water (<400 m) fossils, either in place or reworked by sediment gravity flows, at our new target locations would provide direct evidence of past vertical positions at precisely dated times. Tectonic and oceanographic research objectives are aligned: fossil and geochemical proxies for ocean temperature or chemistry provide independent evidence for past vertical positions because ocean-circulation models are sensitive to paleobathymetry input conditions.

2. *Did subduction initiation influence climate?*
   a. Why was the Eocene southwest Pacific anomalously warm? New paleogeographic reconstructions and proxy data will be used to refine ocean circulation models in this climate-sensitive region.
   b. Did subduction initiation coincide with Early Eocene warmth? Can subduction initiation be linked to global changes in carbon cycling and hence the long-term cooling trend that begins at ~50 Ma? High-quality Paleogene sediment cores deposited in bathyal depths and with minimal diagenetic alteration will provide new climate proxy data from this key region.

3. *Pole-Equator climate teleconnections through the late Cenozoic*
   a. When did the modern ocean circulation system develop, and what role has it played in pole-Equator climate teleconnections through the late Cenozoic? New drilling and paleomagnetic technology will facilitate improved recovery of well-calibrated late Paleogene and Neogene sediment records.

# Drill sites

Our strategy (Figure **F10**) is to drill a transect of four sites perpendicular to and west of the southern end of Tonga-Kermadec subduction initiation, which will be combined with data from two northern sites and knowledge from New Caledonia and New Zealand to produce a proximal boundary-parallel transect (Figure **F2**). These six new primary proposed sites will be drilled in order: LHRN-3A, NCTN-8A, REIS-2A, NCTS-2A, LHRS-3A, and TASS-2A (see **Site summaries**).

The proximal ridge, the Norfolk Ridge system, which includes New Caledonia, Reinga Basin, and northwest New Zealand, is deformed and was involved in the initial phase of surface convergence. What was the timing of initial uplift, the magnitude of maximum uplift, when did faulting stop, and when did the ridge subside? What was the geometry of faults during subduction initiation? These questions are addressed at proposed Sites NCTN-8A and REIS-2A.

The proximal basin, the New Caledonia Trough, may have subsided >2 km but was only subjected to minor convergent deformation (Sutherland et al., 2010). What was the magnitude and timing of subsidence in relation to other events, and what process may have caused it? The basin contains a record of detrital products derived from ridges on either side: can we constrain and date emergence of those ridges? Subduction initiation models do not predict this trough feature, so new observations at proposed Sites NCTN-8A and NCTS-2A may require a new class of subduction initiation model.

The distal ridge, Lord Howe Rise, shows signs of minor Eocene convergent deformation and volcanism (proposed Site LHRS-3A), and significant erosion surfaces may be overlain by Eocene coral reefs (proposed Site LHRN-3A). What was the timing and magnitude of vertical motions? What was the timing of deformation and volcanism? We hypothesize that vertical motions included an initial uplift and later subsidence back to a similar depth. Multiple inferences from seismic reflection data suggest the northern Lord Howe Rise was at or near sea level during the latter part of the Eocene. The timing, magnitude, and extent of vertical motions constrain the history of dynamic topography (upper mantle flow), lithospheric buoyancy, and tractions related to shear zones. Different classes of subduction initiation model make very different predictions.

The distal basin, the Tasman Sea Abyssal Plain, shows signs of local convergent deformation (proposed Site TASS-2A). The force transmitted through the tectonic plate must have been large enough to stop seafloor spreading and cause failure of the lithosphere. What was the timing of this change in stress state and how does it relate to other tectonic events?

The Australia-Pacific convergence rate during the time of interest was much faster near New Caledonia than in New Zealand. Geodynamic models predict that stresses within an initiating subduction system evolve in response to the total convergence experienced (Gurnis et al., 2004), so models predict along-strike changes in timing that can be tested using biostratigraphy. The absolute timing of observables can also be compared to known plate motions. This ability to precisely track total convergence through space and time is unique to the Tonga-Kermadec system because most subduction systems have imprecisely known kinematic histories (evidence has since been subducted).

# Operations plan

## Drilling/coring/logging strategy

The operations plan and time estimates for proposed primary sites are presented in Table **T1**. Alternate sites are presented in Table **T2**. Drilling method and time estimates are based on sediment types similar to those found during DSDP Leg 21.

Expedition 371 will start in Townsville, Australia, and end in Hobart, Tasmania, requiring us to drill the sites in order: LHRN-3A, NCTN-8A, REIS-2A, NCTS-2A, LHRS-3A, and TASS-2A. Our lowest priority site is Site LHRN-3A, which we must drill first. Therefore, minimal operations are planned, with the aim of achieving our primary objective at this location: to collect the apparently (geophysical evidence) hard material (putative reef) at ~310 meters below seafloor (mbsf). A single hole will be drilled and cored with the rotary core barrel (RCB) system, and no logging program will occur. At all other sites, we will drill and core two holes: APC coring to refusal, and then extended core barrel (XCB) coring to the targeted depth. A standard logging program (with no special tools) will also occur at these five sites, including the triple-combo tool string (formation density, resistivity, magnetic susceptibility, and natural gamma radiation), the Formation MicroScanner (FMS)-sonic tool string (microresistivity imaging, sonic velocities, and natural gamma radiation), and vertical seismic profiling (check shots). Accurate correlations between seismic reflection two-way traveltimes and drilled depths are essential to the science goals.

## Risks and contingency

All six sites are likely to drill through sequences dominated by calcareous nannofossils, biogenic silica, and clay. These sequences may contain altered volcanic glass, and some biogenic material in lower intervals will be diagenetically altered to chalk and cristobalite-tridymite (CT). It is unlikely that coarse clastic facies (medium sand or greater grain size) will be encountered at any of the sites.

Proposed Site REIS-2A has adequate burial nearby for petroleum generation, according to models, but there is no direct evidence of a working petroleum system and there are no direct hydrocarbon indicators (e.g., amplitude anomalies). There is no trapping mechanism: strata dip consistently westward and would be able to drain updip if petroleum migration had occurred.

Proposed Site NCTS-2A does not have nearby evidence for burial sufficient for petroleum generation, but we consider it plausible that sufficient burial could have occurred along the axis of the New Caledonia Trough farther north. The faulted anticline of interest represents a possible pathway and trapping structure for petroleum, and seismic amplitude anomalies occur along the crestline of the structure. We positioned our sites well away from the crestline and any amplitude anomalies.

Risks associated with petroleum occurrence or other technical issues have been evaluated as negligible by an independent IODP-convened safety panel. The primary risk identified is delays caused by technical difficulties or weather.

# Sampling and data sharing strategy

Shipboard and shore-based researchers should refer to the IODP Sample, Data, and Obligations Policy and Implementation Guidelines posted on the Web at **http://www.iodp.org/policies-and-guidelines**. This document outlines the policy for distributing IODP 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 [EPM]/Staff Scientist, and IODP Curator on shore and curatorial representative on board ship) will work with the entire scientific party to formulate a formal expedition-specific sampling plan for shipboard and postexpedition sampling.

Shipboard scientists are expected to submit sample requests (at **http://iodp.tamu.edu/curation/samples.html**) ~3–6 months before the beginning of the expedition, per instructions from the EPM/Staff Scientist. Based on sample requests (shore based and shipboard) submitted by this deadline, the SAC will prepare a tentative sampling plan, which will be subject to modification depending upon the actual material recovered and collaborations that may evolve between scientists during the expedition. Modification of the sampling strategy during the expedition must be approved by the SAC.

The minimum permanent archive will be the standard archive half of each core section. All sample frequencies and sizes 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 minimizing the duplication of measurements among the shipboard party and identified shore-based collaborators will be a factor in evaluating sample requests.

For sites where a stratigraphic splice is constructed from core intervals of multiple holes and where high-resolution sampling is requested, most sampling will be deferred to a postexpedition sampling party in College Station, Texas (USA), anticipated to be scheduled for February 2018.

If critical intervals with particularly high sampling demand are recovered, special handling may be required, such as reduced sample size or continuous core sampling by a single investigator and sharing of sample and/or measurements results. A sampling plan coordinated by the SAC is typically required before critical intervals are sampled.

# Expedition scientists and scientific participants

The current list of participants for Expedition 371 can be found at **http://iodp.tamu.edu/scienceops/expeditions/tasman_frontier_subduction_climate.html**.

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Table T1. Expedition 371 proposed sites.

| Proposed site | Priority | Jurisdiction | Latitude | Longitude | Water depth (m) | Base hole planned (mbsf) | Base hole approved (mbsf) |
|---|---|---|---|---|---|---|---|
| LHRN-3A | Primary | Australia | 28.661971°S | 161.740721°E | 1494 | 320 | 320 |
| NCTN-8A | Primary | Australia | 26.488587°S | 166.528365°E | 3573 | 700 | 700 |
| NCTN-7A | Alternate | Australia | 26.293248°S | 166.549699°E | 3584 | 880 | 880 |
| NCTN-6A | Alternate | Australia | 26.375984°S | 166.557793°E | 3590 | 860 | 860 |
| REIS-2A | Primary | New Zealand | 34.4453516°S | 171.3467652°E | 1570 | 660 | 900 |
| REIS-1A | Alternate | New Zealand | 34.452753°S | 171.337573°E | 1644 | 670 | 1000 |
| NCTS-2A | Primary | New Zealand | 34.652186°S | 165.827652°E | 2913 | 610 | 610 |
| NCTS-3A | Alternate | New Zealand | 34.711508°S | 165.872625°E | 2737 | 600 | 600 |
| LHRS-3A | Primary | New Zealand | 36.328973°S | 164.558677°E | 1239 | 520 | 620 |
| LHRS-2A | Alternate | New Zealand | 36.339602°S | 164.604271°E | 1129 | 640 | 735 |
| TASS-2A | Primary | Australia | 37.561097°S | 160.31561°E | 4847 | 560 | 960 |
| TASS-5A | Alternate | Australia | 37.442183°S | 160.540186°E | 4952 | 580 | 1020 |

Table T2. Operations plan summary, Expedition 371.

| Site | Location (latitude, longitude) | Seafloor depth (mbrf) | Operations | Transit (days) | Drilling/ coring (days) | LWD/ MWD log (days) |
|---|---|---|---|---|---|---|
| Townsville | | | Begin expedition 3.0 | Port call days | | |
| | | | Transit ~1014 nmi to LHRN-3A @ 10.5 kt | 4.0 | | |
| LHRN-3A EPSP to 320 mbsf | 28.661971°S 161.740721°E | 1505 | Hole A - RCB to 320 mbsf | | 2.0 | |
| | | | Subtotal days on site: 2.0 | | | |
| | | | Transit ~286 nmi to NCTN-8A @ 10.5 kt | 1.1 | | |
| NCTN-8A EPSP to 700 mbsf | 26.488587°S 166.528365°E | 3584 | Hole A - APC/XCB to 700 mbsf | | 5.3 | |
| | | | Hole B - APC/XCB to 700 mbsf, wireline log with triple combo, FMS-sonic, and VSI | | 5.2 | 1.6 |
| | | | Subtotal days on site: 12.1 | | | |
| | | | Transit ~538 nmi to REIS-2A @ 10.5 kt | 2.1 | | |
| REIS-2A EPSP to 900 mbsf | 34.445352°S 171.346765°E | 1581 | Hole A - APC/XCB to 660 mbsf | | 3.0 | |
| | | | Hole B - APC/XCB to 660 mbsf, wireline log with triple combo, FMS-sonic, and VSI | | 3.7 | 1.4 |
| | | | Subtotal days on site: 8.1 | | | |
| | | | Transit ~273 nmi to NCTS-2A @ 10.5 kt | 1.1 | | |
| NCTS-2A EPSP to 610 mbsf | 34.652186°S 165.827652°E | 2924 | Hole A - APC/XCB to 610 mbsf | | 4.1 | |
| | | | Hole B - APC/XCB to 610 mbsf, wireline log with triple combo, FMS-sonic, and VSI | | 4.2 | 1.4 |
| | | | Subtotal days on site: 9.7 | | | |
| | | | Transit ~118 nmi to LHRS-3A @ 10.5 kt | 0.5 | | |
| LHRS-3A EPSP to 620 mbsf | 36.328973°S 164.558677°E | 1250 | Hole A - APC/XCB to 520 mbsf | | 2.3 | |
| | | | Hole B - APC/XCB to 520 mbsf, wireline log with triple combo, FMS-sonic, and VSI | | 2.9 | 1.3 |
| | | | Subtotal days on site: 6.5 | | | |
| | | | Transit ~216 nmi toTASS-2A @ 10.5 kt | 0.9 | | |
| TASS-2A EPSP to 960 mbsf | 37.561097°S 160.315610°E | 4858 | Hole A - APC/XCB to 560 mbsf, wireline log with triple combo, FMS-sonic, and VSI | | 5.5 | 1.6 |
| | | | Subtotal days on site: 7.1 | | | |
| | | | Transit ~701 nmi to Hobart @ 10.5 kt | 2.8 | | |
| Hobart | | | End expedition | 12.5 | 38.2 | 7.3 |

| | | | |
|---|---|---|---|
| Port call: | 3.0 | Total operating days: | 58.0 |
| Subtotal on site: | 45.5 | Total expedition: | 61.0 |

mbrf = meters below rig floor, mbsf = meters below seafloor; LWD = logging while drilling, MWD = measurement while drilling; EPSP = Environmental Protection and Safety Panel; nmi = nautical mile, kt = knots; RCB = rotary core barrel, APC = advanced piston corer, XCB = extended core barrel; FMS = Formation MicroScanner, VSI = Versatile Seismic Imager.

Table T3. Alternate sites, Expedition 371.

| Site | Location (latitude, longitude) | Seafloor depth (mbrf) | Operations | Drilling/ coring (days) | LWD/ MWD log (days) |
|---|---|---|---|---|---|
| LHRN-3A<br>EPSP<br>to 320 mbsf | 28.661971°S<br>161.740721°E | 1505 | Hole A - APC/XCB to 310 mbsf | 2.1 | |
| | | | Subtotal days on site: 2.1 | | |
| | | | | | |
| TASS-5A<br>EPSP<br>to 1020 mbsf | 37.442183°S<br>160.540186°E | 4963 | Hole A - APC/XCB to 580 mbsf, wireline log with triple combo, FMS-sonic, and VSI | 5.7 | 1.6 |
| | | | Subtotal days on site: 7.3 | | |
| | | | | | |
| LHRS-2A<br>EPSP<br>to 735 mbsf | 36.339602°S<br>164.604271°E | 1140 | Hole A - APC/XCB to 640 mbsf | 2.9 | |
| | | | Hole B - APC/XCB to 640 mbsf, wireline log with triple combo, FMS-sonic, and VSI | 2.8 | 1.3 |
| | | | Subtotal days on site: 7.0 | | |
| | | | | | |
| NCTN-7A<br>EPSP<br>to 880 mbsf | 26.293248°S<br>166.549699°E | 3595 | Hole A - APC/XCB to 880 mbsf | 6.7 | |
| | | | Hole B - APC/XCB to 880 mbsf, wireline log with triple combo, FMS-sonic, and VSI | 6.6 | 1.7 |
| | | | Subtotal days on site: 15 | | |
| | | | | | |
| NCTN-6A<br>EPSP<br>to 860 mbsf | 26.375984°S<br>166.557793°E | 3601 | Hole A - APC/XCB to 860 mbsf | 6.5 | |
| | | | Hole B - APC/XCB to 860 mbsf, wireline log with triple combo, FMS-sonic, and VSI | 6.5 | 1.7 |
| | | | Subtotal days on site: 14.7 | | |
| | | | | | |
| REIS-1A<br>EPSP<br>to 1000 mbsf | 34.452753°S<br>171.337573°E | 1655 | Hole A - APC/XCB to 670 mbsf | 3.1 | |
| | | | Hole B - APC/XCB to 670 mbsf, wireline log with triple combo, FMS-sonic, and VSI | 3.8 | 1.4 |
| | | | Subtotal days on site: 8.3 | | |
| | | | | | |
| REIS-1A<br>(RCB option)<br>EPSP<br>to 1000 mbsf | 34.452753°S<br>171.337573°E | 1655 | Hole A - RCB to 670 mbsf | 3.6 | |
| | | | Hole B - RCB to 670 mbsf, wireline log with triple combo, FMS-sonic, and VSI | 4.1 | 1.3 |
| | | | Subtotal days on site: 8.3 | | |
| | | | | | |
| NCTS-3A<br>EPSP<br>to 600 mbsf | 34.711508°S<br>165.872625°E | 2748 | Hole A - APC/XCB to 600 mbsf | 3.9 | |
| | | | Hole B - APC/XCB to 600 mbsf, wireline log with triple combo, FMS-sonic, and VSI | 4.0 | 1.4 |
| | | | Subtotal days on site: 9.3 | | |

mbrf = meters below rig floor, mbsf = meters below seafloor; LWD = logging while drilling, MWD = measurement while drilling; EPSP = Environmental Protection and Safety Panel; RCB = rotary core barrel, APC = advanced piston corer, XCB = extended core barrel; FMS = Formation MicroScanner, VSI = Versatile Seismic Imager.

Figure F1. Location of Tonga-Kermadec subduction in the Tasman Frontier, southwest Pacific, which hosts sediment records of Tonga-Kermadec subduction initiation.

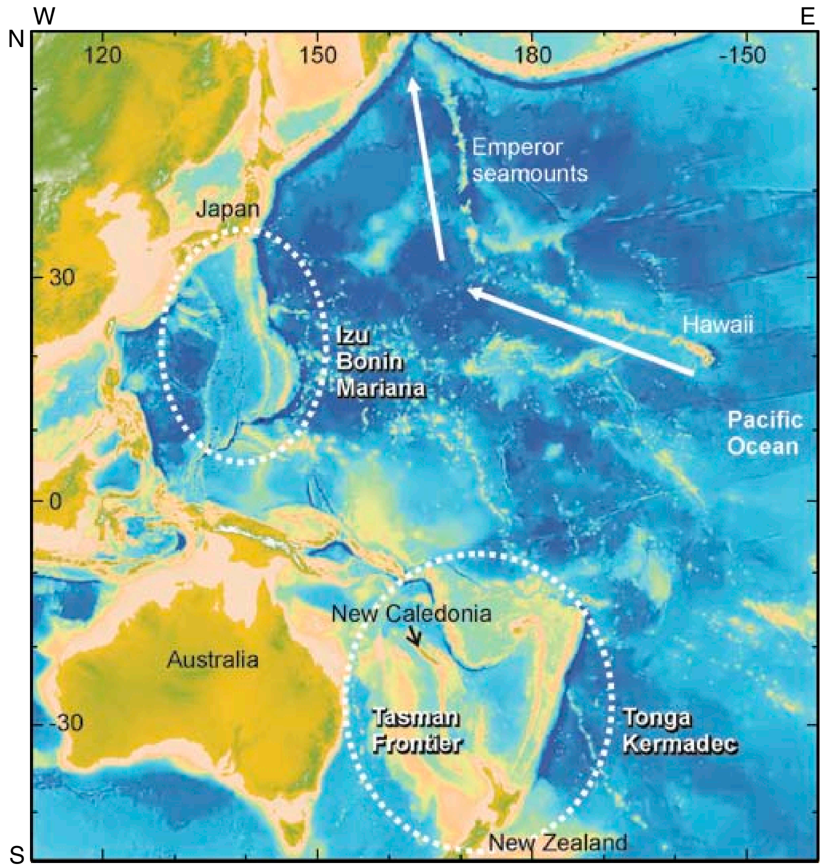


Figure F2. A. Bathymetry of the Tasman Frontier showing new drill sites (stars) and selected DSDP sites (circles). The Tasman Frontier spans 3,000,000 km[2] between Australia, New Zealand, and New Caledonia. Bathymetric rises collectively make up the continent of Zealandia. B. Cross-section through proposed Site NCTN-7A showing continental basement overlain by late Cretaceous rift basins and late Cretaceous to Holocene bathyal sediments (Exon et al., 2007).

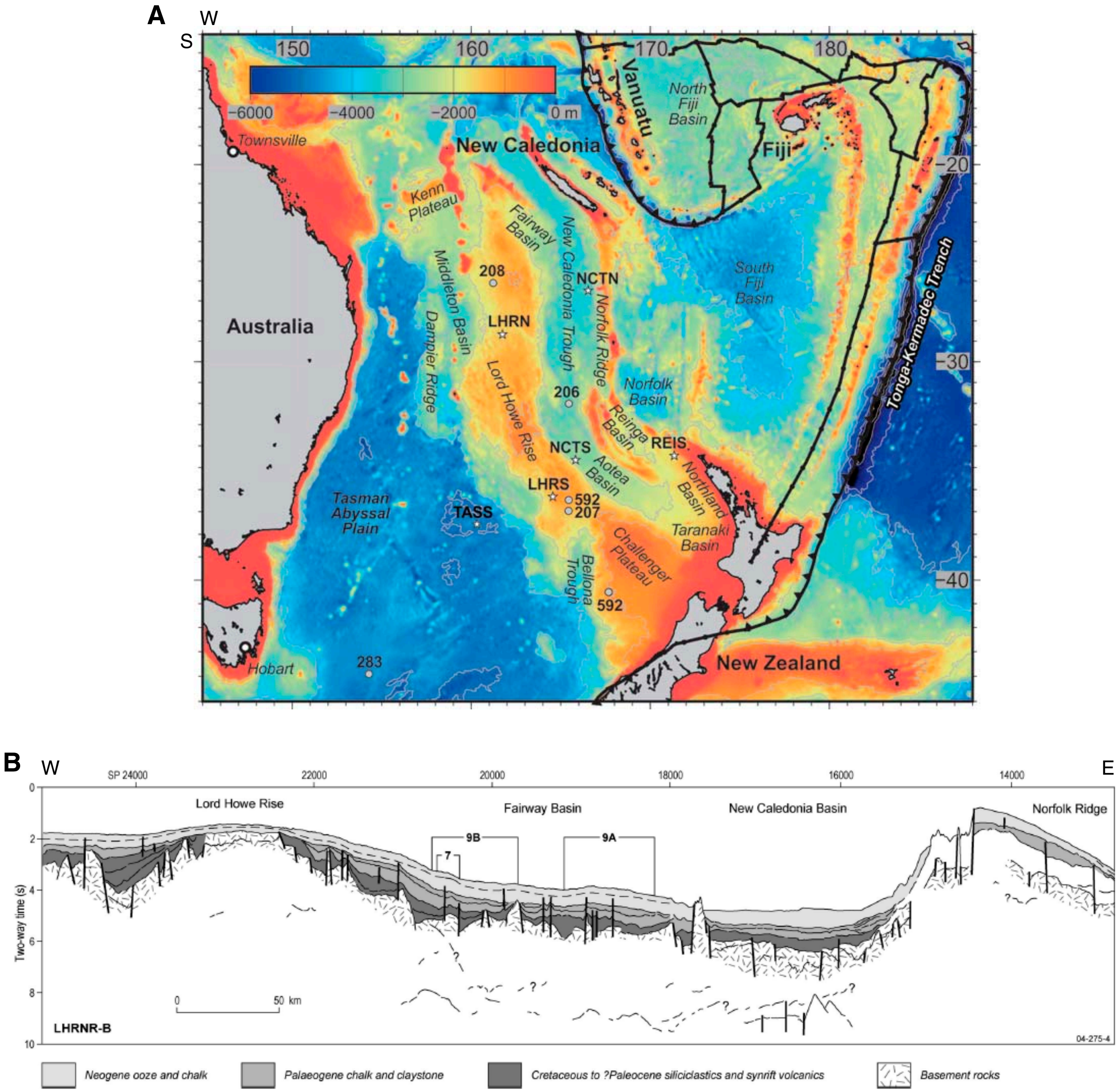


Figure F3. Location of proposed drill sites relative to political boundaries. EEZ = exclusive economic zone, ECS = Extended Continental Shelf.

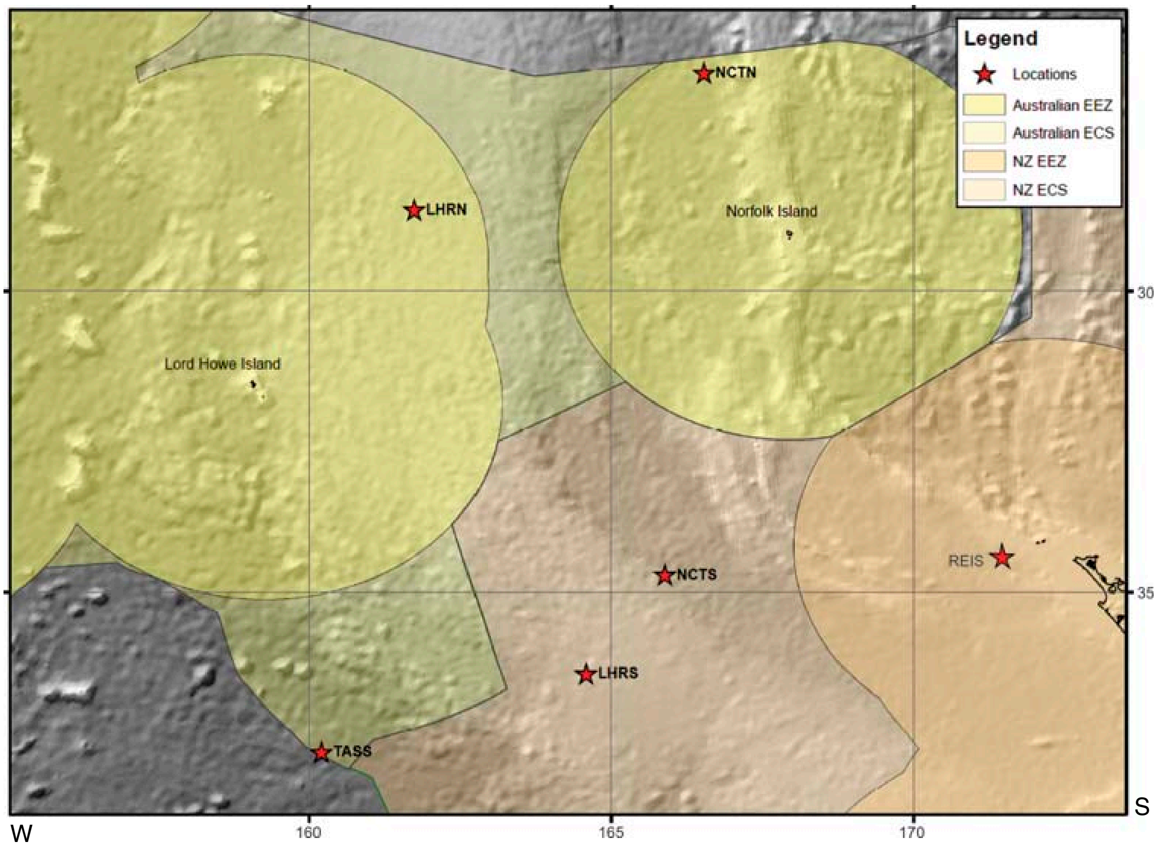


Figure F4. Carbon and oxygen isotope data of Cenozoic benthic foraminifers (Zachos et al., 2008) compared to climate/ocean and tectonic events. Note that the long-term decrease in $\delta^{18}O$, interpreted as global cooling and greater continental ice volume, begins during the EECO at ~53–50 Ma and thus coincides with significant tectonic events around the Tasman Sea. Oi1 = Oligocene isotope Event 1, MECO = Middle Eocene Climatic Optimum, PETM = Paleocene/Eocene Thermal Maximum.

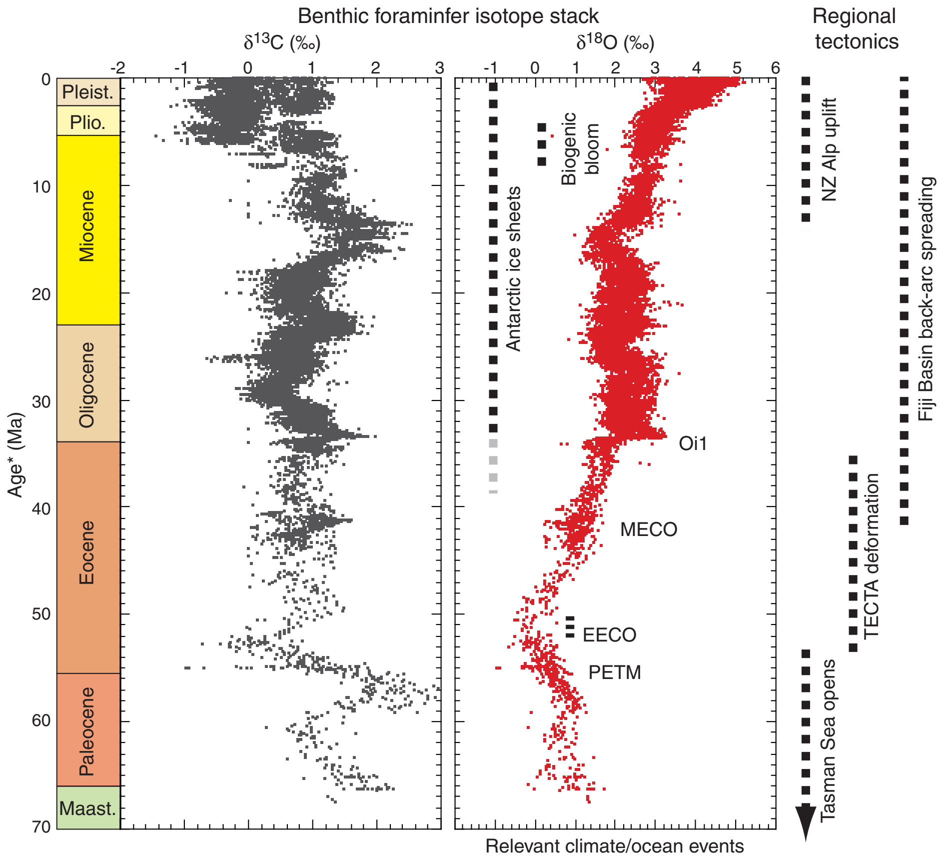


Figure F5. Before and after Tonga-Kermadec (TK) and Izu-Bonin-Mariana subduction initiation (SI). Divergent plate boundaries have white center lines. Australia and west Zealandia are pulled north and east toward new subduction zones.

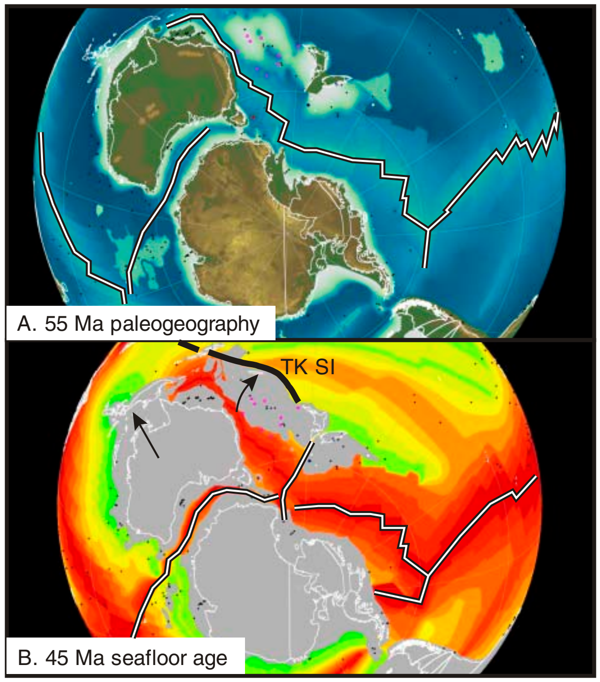



Figure F6. Two classes of subduction initiation model: induced or spontaneous (Stern, 2004). In the spontaneous model, oceanic lithosphere ages, cools, increases in density and gravitational instability, and sinks into the mantle under its own weight (Stern and Bloomer, 1992; Turcotte et al., 1977). In the induced model, externally applied compressive stress and convergence is necessary to overcome lithospheric strength before a convective instability can grow and SI occurs (McKenzie, 1977; Toth and Gurnis, 1998).

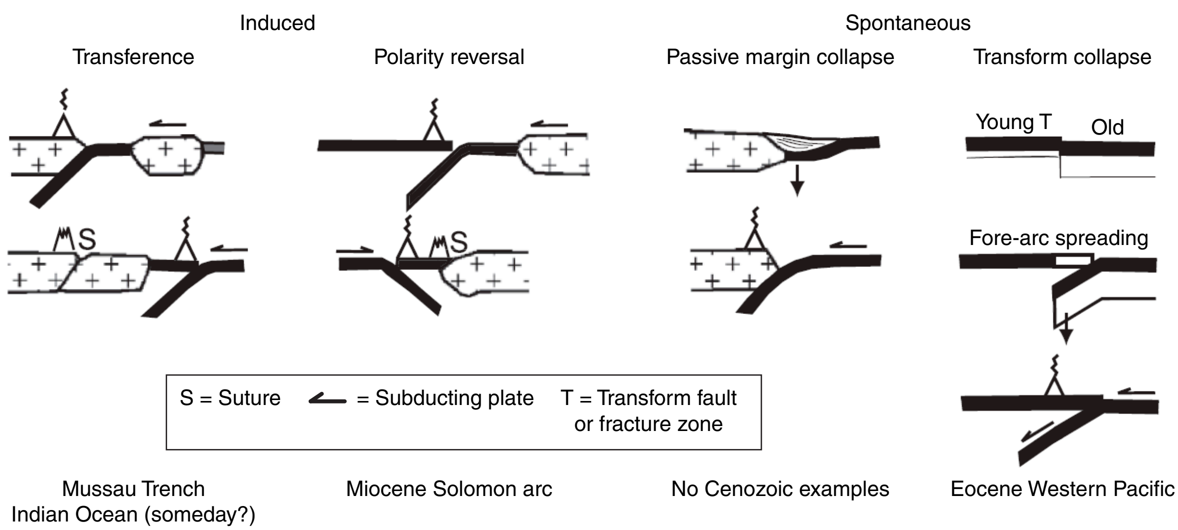


Figure F7. Modeled Eocene SSTs and surface currents assuming 16× preindustrial levels of $CO_2$–equivalent greenhouse gases (4480 ppmv) (M. Huber, pers. comm., 2016). SST estimates are derived from the geochemical proxy studies (Hollis et al., 2012). The yellow "?" highlights the absence of data from a potential source of warm-water inflow in the north Tasman Sea.

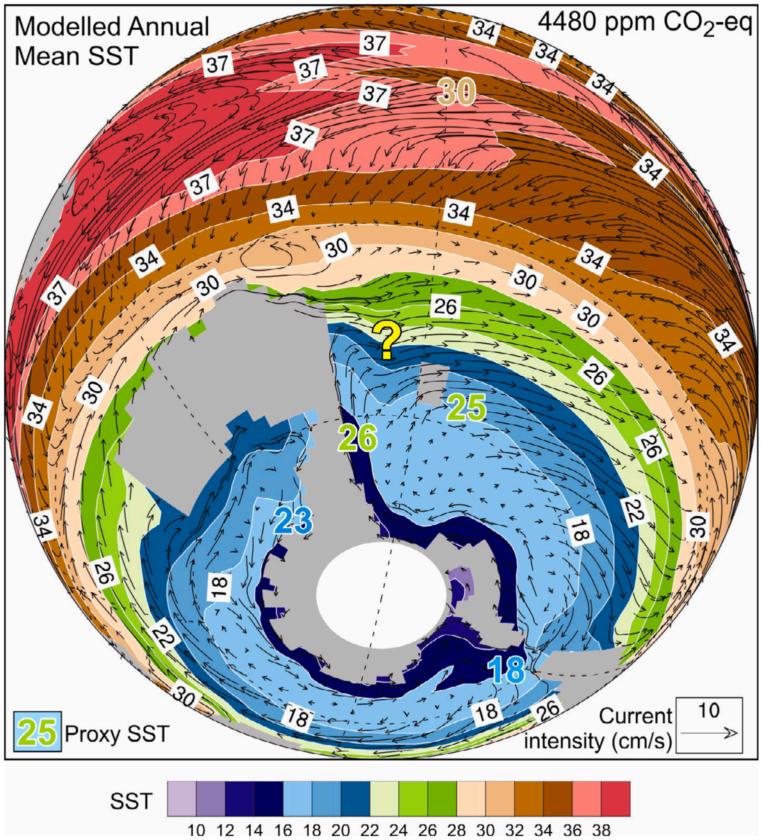


Figure F8. SSTs across the Pacific for December 1997 (strong El Niño) and December 1998 (strong La Niña) relative to long-term average SSTs for December. Note that SST anomalies extend well outside the classic Equatorial region, especially into the northern Tasman Sea. Also shown are examples of drill sites where the late Miocene–early Pliocene biogenic bloom has been documented.

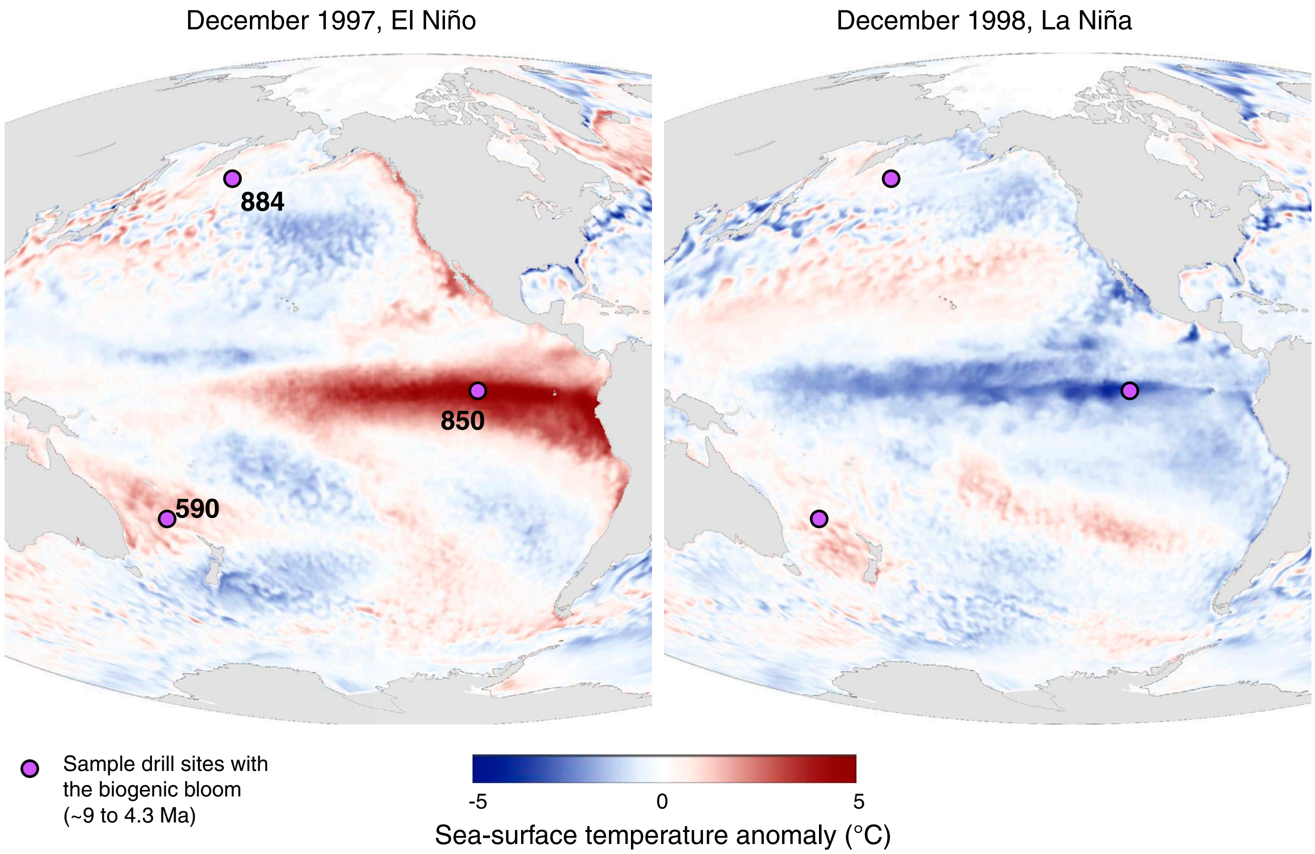


Figure F9. Primary currents (C), fronts (F), and gyres (G) of the Southern Ocean (Rintoul et al., 2001). The Tasman Sea sector is affected by the Antarctic Circumpolar Current (ACC) and Eastern Australian Current.

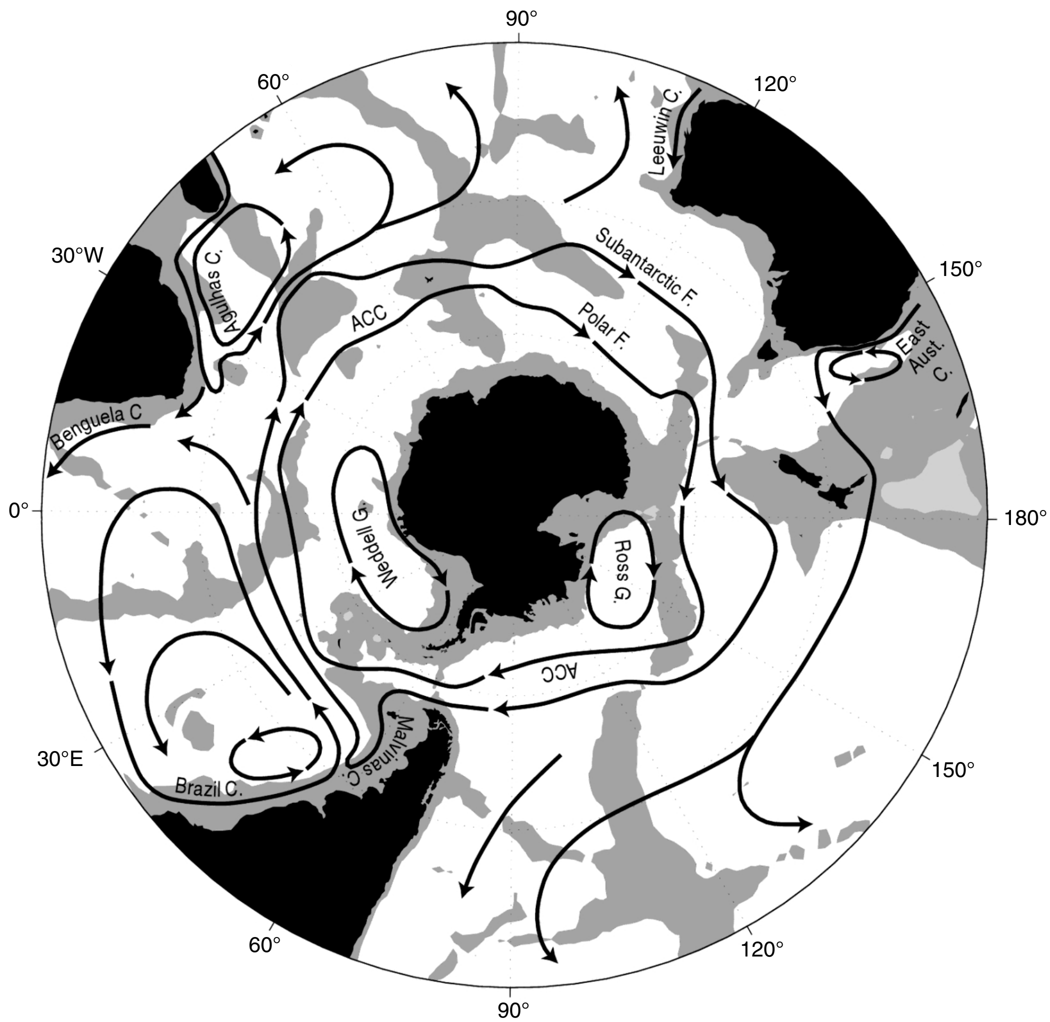
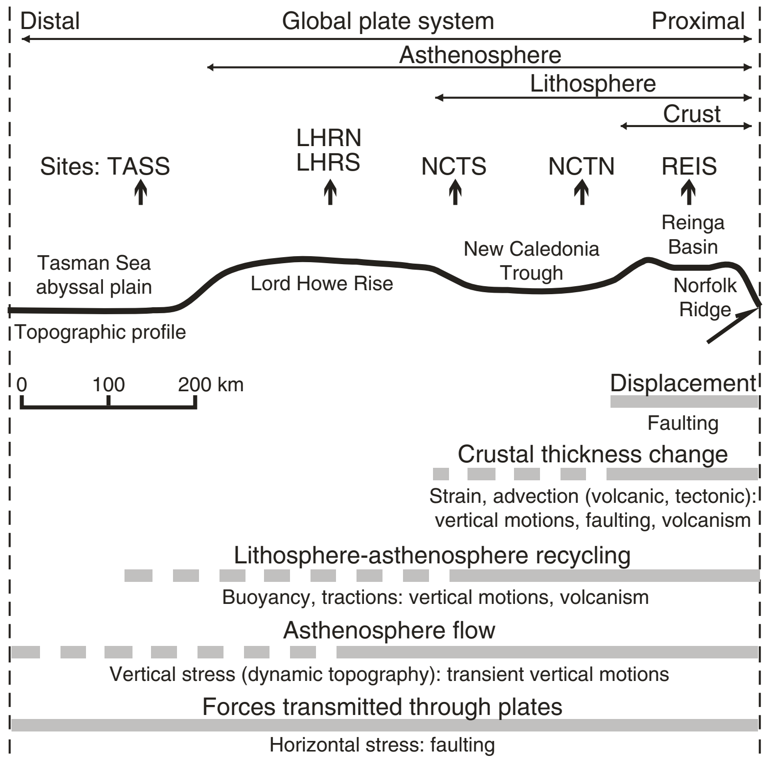


Figure 10. Scales of observation in relation to subduction initiation processes. The timing of events relative to each other, plate motion parameters, and global events is a powerful discriminator between alternate tectonic models. We chose a transect at the southern end of the plate boundary because we have the best data there, we can identify clear seismic-stratigraphic signals of Tonga-Kermadec subduction initiation, and rates of motion were lowest and resolvable with biostratigraphy.



# Site summaries

## Site LHRN-3A

| | |
|---|---|
| Priority | Primary |
| Position | 28.661971°S, 161.740721°E |
| Water depth (m) | 1494 |
| Target drilling depth (mbsf) | 320 |
| Approved maximum penetration (mbsf) | 320 |
| Survey coverage | CDP 3248 on TAN1409-LHRN_13<br>CDP 1430 on TAN1409-LHRN_06 (Figure **AF1**) |
| Objective(s) | Determine time of distal uplift and then subsidence of northern Lord Howe Rise (central subduction system). Test hypothesis of Eocene coral reef, and hence confirm uplift to sea level and magnitude of total subsidence. |
| Drilling, coring, and downhole measurements program | Hole A - RCB to 320 mbsf |
| Nature of rock anticipated | Carbonate ooze and limestone (or other lithified sediment) |

## Site NCTN-8A

| | |
|---|---|
| Priority | Primary |
| Position | 26.488587°S, 166.528365°E |
| Water depth (m) | 3573 |
| Target drilling depth (mbsf) | 700 |
| Approved maximum penetration (mbsf) | 700 |
| Survey coverage | CDP 4020 on TAN1409-NCTN_11<br>CDP 4566 on TEC08 (Figure **AF2**) |
| Objective(s) | Determine time of proximal deformation and uplift then subsidence of Norfolk Ridge and central New Caledonia Trough (central part of subduction system). |
| Drilling, coring, and downhole measurements program | Hole A - APC/XCB to 700 mbsf<br>Hole B - APC/XCB to 700 mbsf, wireline log with triple combo, FMS-sonic, and VSI |
| Nature of rock anticipated | Carbonate and siliceous ooze, chalk, chert, clay, and silt |

## Site NCTN-7A

| | |
|---|---|
| Priority | Alternate |
| Position | 26.293248°S, 166.549699°E |
| Water depth (m) | 3584 |
| Target drilling depth (mbsf) | 880 |
| Approved maximum penetration (mbsf) | 880 |
| Survey coverage | CDP 3026 on TAN1409-NCTN_07<br>CDP 1103 on TEC08 (Figure **AF3**) |
| Objective(s) | Determine time of proximal deformation and uplift then subsidence of Norfolk Ridge and central New Caledonia Trough (central part of subduction system). |
| Drilling, coring, and downhole measurements program | Hole A - APC/XCB to 880 mbsf<br>Hole B - APC/XCB to 880 mbsf, wireline log with triple combo, FMS-sonic, and VSI |
| Nature of rock anticipated | Carbonate and siliceous ooze, chalk, chert, clay, and silt |

## Site NCTN-6A

| | |
|---|---|
| Priority | Alternate |
| Position | 26.375984°S, 166.557793°E |
| Water depth (m) | 3590 |
| Target drilling depth (mbsf) | 860 |
| Approved maximum penetration (mbsf) | 860 |
| Survey coverage | CDP 3600 on TAN1409-NCTN_09 (Figure **AF4**) |
| Objective(s) | Determine time of proximal deformation and uplift then subsidence of Norfolk Ridge and central New Caledonia Trough (central part of subduction system). |
| Drilling, coring, and downhole measurements program | Hole A - APC/XCB to 860 mbsf<br>Hole B - APC/XCB to 860 mbsf, wireline log with triple combo, FMS-sonic, and VSI |
| Nature of rock anticipated | Carbonate and siliceous ooze, chalk, chert, clay, and silt |

## Site REIS-2A

| | |
|---|---|
| Priority | Primary |
| Position | 34.4453516°S, 171.3467652°E |
| Water depth (m) | 1570 |
| Target drilling depth (mbsf) | 660 |
| Approved maximum penetration (mbsf) | 900 |
| Survey coverage | CDP 8400 on REI09-012 (Figure **AF5**) |
| Objective(s) | Determine timing of proximal deformation at southern end of subduction. Date onset of subsidence from wave base. Confirm reworked shallow-marine fossils and hence magnitude of subsidence. |
| Drilling, coring, and downhole measurements program | Hole A - APC/XCB to 660 mbsf<br>Hole B - APC/XCB to 660 mbsf, wireline log with triple combo, FMS-sonic, and VSI |
| Nature of rock anticipated | Carbonate and siliceous ooze, chalk, chert, clay, and silt. Sand? |

## Site REIS-1A

| | |
|---|---|
| Priority | Alternate |
| Position | 34.452753°S, 171.337573°E |
| Water depth (m) | 1644 |
| Target drilling depth (mbsf) | 670 |
| Approved maximum penetration (mbsf) | 1000 |
| Survey coverage | CDP 8588 on REI09-012<br>CDP 47972 on REI09-011a (Figure **AF6**) |
| Objective(s) | Determine timing of proximal deformation at southern end of subduction. Date onset of subsidence from wave base. Confirm reworked shallow-marine fossils and hence magnitude of subsidence. |
| Drilling, coring, and downhole measurements program | Hole A - APC/XCB to 660 mbsf<br>Hole B - APC/XCB to 660 mbsf, wireline log with triple combo, FMS-sonic, and VSI |
| Nature of rock anticipated | Carbonate and siliceous ooze, chalk, chert, clay, silt. Sand? |

## Site NCTS-2A

| | |
|---|---|
| Priority | Primary |
| Position | 34.652186°S, 165.827652°E |
| Water depth (m) | 2913 |
| Target drilling depth (mbsf) | 610 |
| Approved maximum penetration (mbsf) | 610 |
| Survey coverage | CDP 1239 on TAN1409-NCTS_02<br>CDP 2421 on TAN1409-NCTS_07 (Figure **AF7**) |
| Objective(s) | Determine timing of convergent deformation and subsidence of southern New Caledonia Trough (southern end of subduction system). |
| Drilling, coring, and downhole measurements program | Hole A - APC/XCB to 610 mbsf<br>Hole B - APC/XCB to 610 mbsf, wireline log with triple combo, FMS-sonic, and VSI |
| Nature of rock anticipated | Carbonate and siliceous ooze, chalk, chert, clay, and silt |

## Site NCTS-3A

| | |
|---|---|
| Priority | Alternate |
| Position | 34.711508°S, 165.872625°E |
| Water depth (m) | 2737 |
| Target drilling depth (mbsf) | 600 |
| Approved maximum penetration (mbsf) | 600 |
| Survey coverage | CDP 3051 on TAN1409-NCTS_03<br>CDP 1172 on TAN1409-NCTS_07 (Figure **AF8**) |
| Objective(s) | Determine timing of convergent deformation and subsidence of southern New Caledonia Trough (southern end of subduction system). |
| Drilling, coring, and downhole measurements program | Hole A - APC/XCB to 600 mbsf<br>Hole B - APC/XCB to 600 mbsf, wireline log with triple combo, FMS-sonic, and VSI |
| Nature of rock anticipated | Carbonate and siliceous ooze, chalk, chert, clay, and silt |

## Site LHRS-3A

| | |
|---|---|
| Priority | Primary |
| Position | 36.328973°S, 164.558677°E |
| Water depth (m) | 1239 |
| Target drilling depth (mbsf) | 520 |
| Approved maximum penetration (mbsf) | 620 |
| Survey coverage | CDP 10652 on TAN1409-LHRS_02<br>CDP 874 on TAN1409-LHRS_06 (Figure **AF9**) |
| Objective(s) | Determine age of distal deformation at southern end of subduction system. Test hypothesis of uplift to shelf depths. Date uplift and subsidence. |
| Drilling, coring, and downhole measurements program | Hole A - APC/XCB to 520 mbsf<br>Hole B - APC/XCB to 520 mbsf, wireline log with triple combo, FMS-sonic, and VSI |
| Nature of rock anticipated | Carbonate and siliceous ooze, chalk, chert, clay, and silt |

## Site LHRS-2A

| | |
|---|---|
| Priority | Alternate |
| Position | 36.339602°S, 164.604271°E |
| Water depth (m) | 1129 |
| Target drilling depth (mbsf) | 640 |
| Approved maximum penetration (mbsf) | 735 |
| Survey coverage | CDP 1848 on TAN1409-LHRS_09<br>CDP 1594 on TAN1409-LHRS_05 (Figure **AF10**) |
| Objective(s) | Determine age of distal deformation at southern end of subduction system. Test hypothesis of uplift to shelf depths. Date uplift and subsidence. |
| Drilling, coring, and downhole measurements program | Hole A - APC/XCB to 640 mbsf<br>Hole B - APC/XCB to 640 mbsf, wireline log with triple combo, FMS-sonic, and VSI |
| Nature of rock anticipated | Carbonate and siliceous ooze, chalk, chert, clay, and silt |

## Site TASS-2A

| | |
|---|---|
| Priority | Primary |
| Position | 37.561097°S, 160.31561°E |
| Water depth (m) | 4847 |
| Target drilling depth (mbsf) | 560 |
| Approved maximum penetration (mbsf) | 960 |
| Survey coverage | CDP 5168 on TAN1409-TASS_01<br>CDP 1538 on TAN1409-TASS_08 (Figure **AF11**) |
| Objective(s) | Determine time of deformation of Tasman Sea oceanic crust to constrain the time of maximum horizontal force through the plate (far-field). Constrain early Paleogene depth of the carbonate compensation depth. |
| Drilling, coring, and downhole measurements program | Hole A - APC/XCB to 560 mbsf, wireline log with triple combo, FMS-sonic, and VSI |
| Nature of rock anticipated | Carbonate and siliceous ooze, chalk, chert, and clay |

## Site TASS-5A

| | |
|---|---|
| Priority | Alternate |
| Position | 37.442183°S, 160.540186°E |
| Water depth (m) | 4952 |
| Target drilling depth (mbsf) | 580 |
| Approved maximum penetration (mbsf) | 1020 |
| Survey coverage | CDP 1296 on TAN1409-TASS_01<br>CDP 1356 on TAN1409-TASS_12 (Figure **AF12**) |
| Objective(s) | Determine time of deformation of Tasman Sea oceanic crust to constrain the time of maximum horizontal force through the plate (far-field). Constrain early Paleogene depth of the carbonate compensation depth. |
| Drilling, coring, and downhole measurements program | Hole A - APC/XCB to 580 mbsf, wireline log with triple combo, FMS-sonic, and VSI |
| Nature of rock anticipated | Carbonate and siliceous ooze, chalk, chert, and clay |

Figure AF1. Background data, proposed Site LHRN-3A.

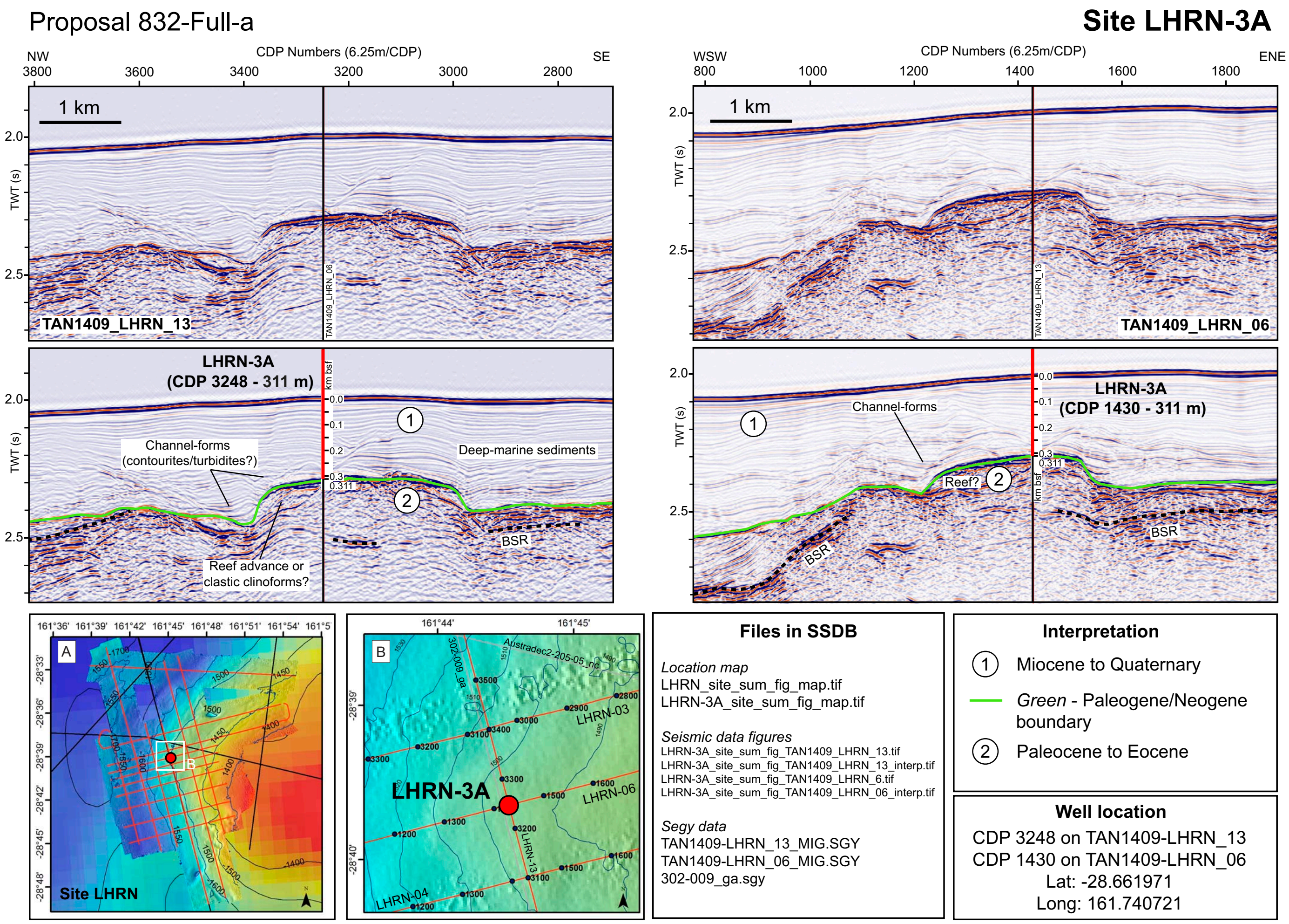


Figure AF2. Background data, proposed Site NCTN-8A.

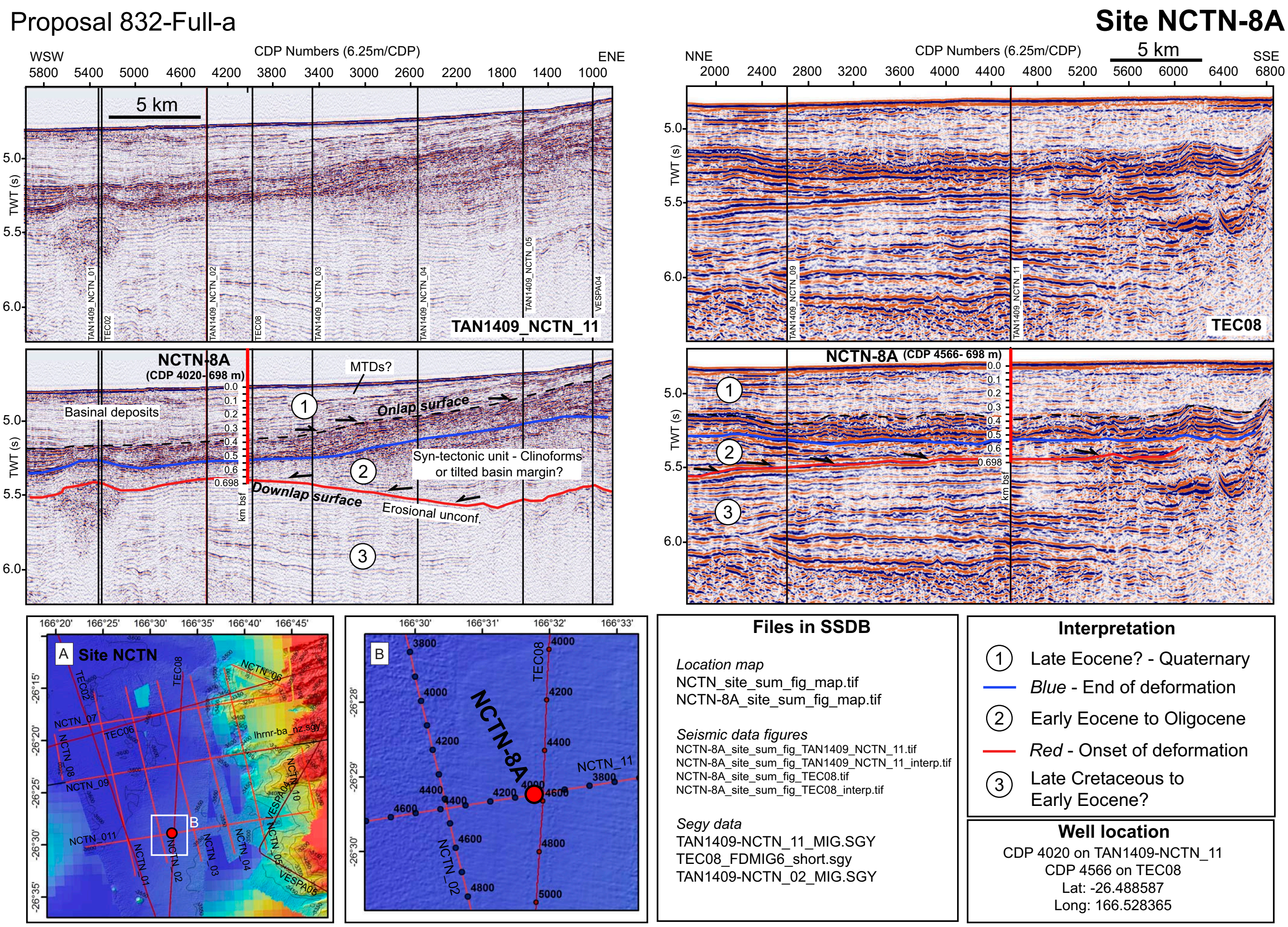


Figure AF3. Background data, proposed Site NCTN-7A.

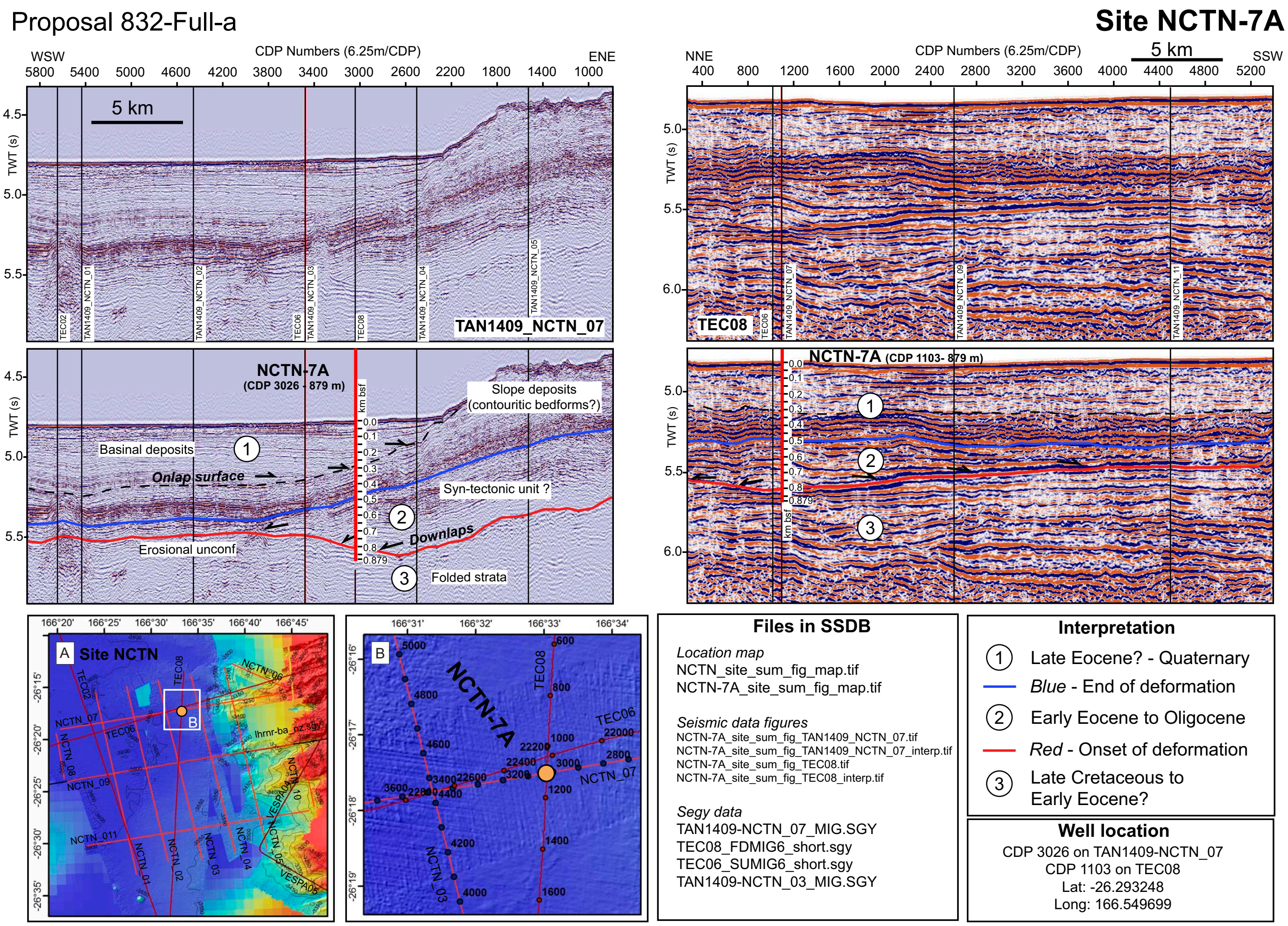


Figure AF4. Background data, proposed Site NCTN-6A.

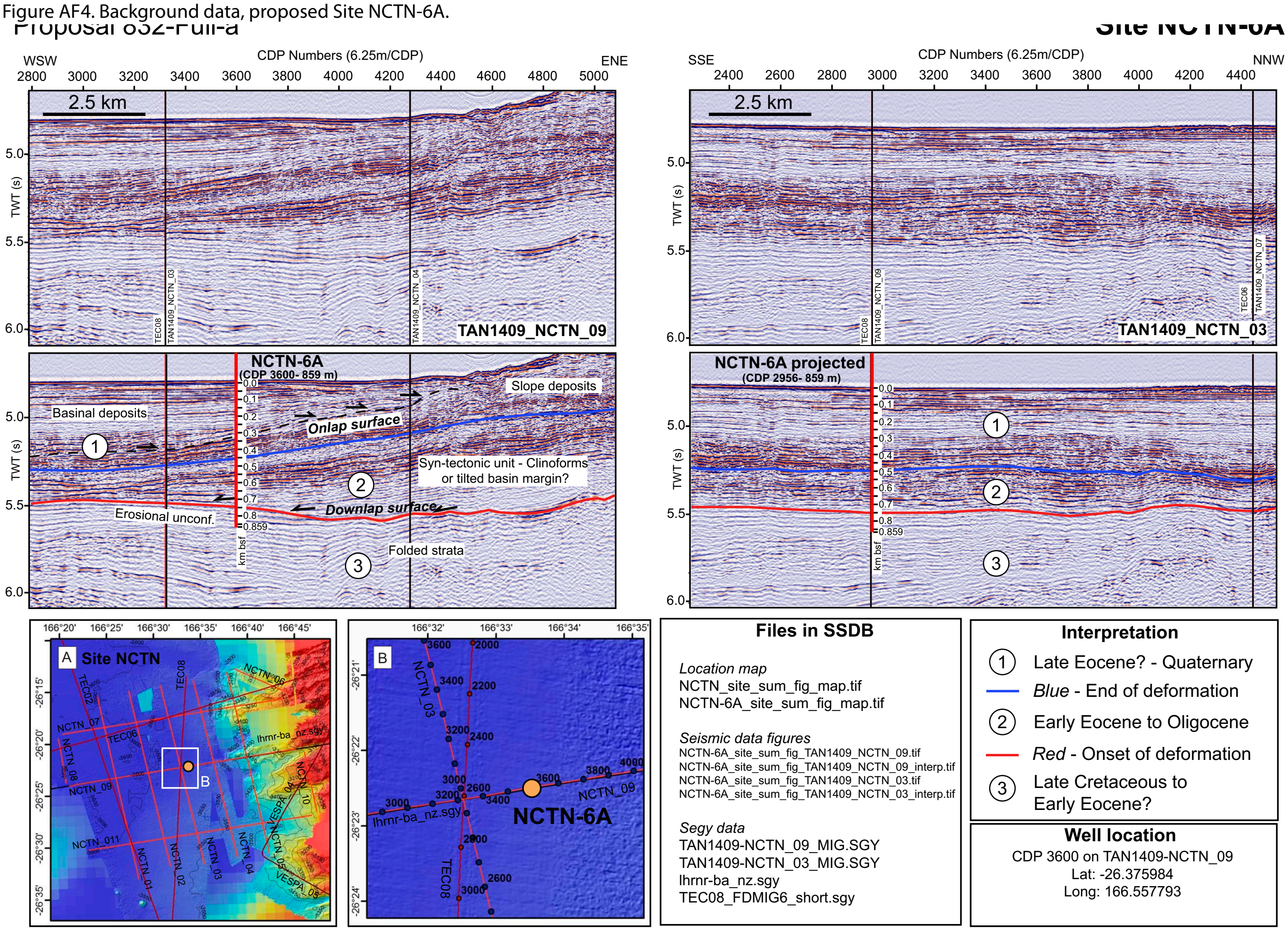


Figure AF5. Background data, proposed Site REIS-2A.

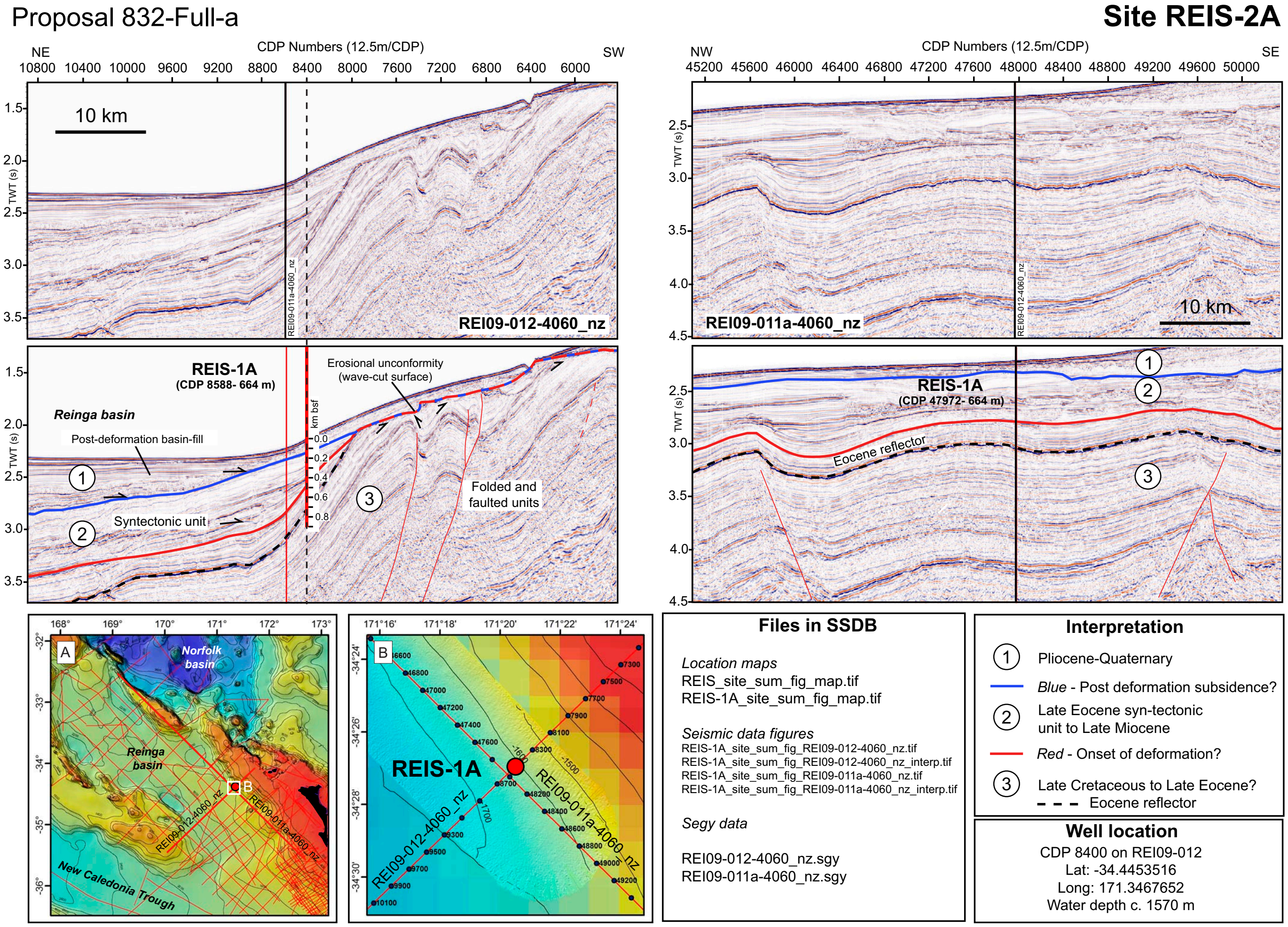


Figure AF6. Background data, proposed Site REIS-1A.

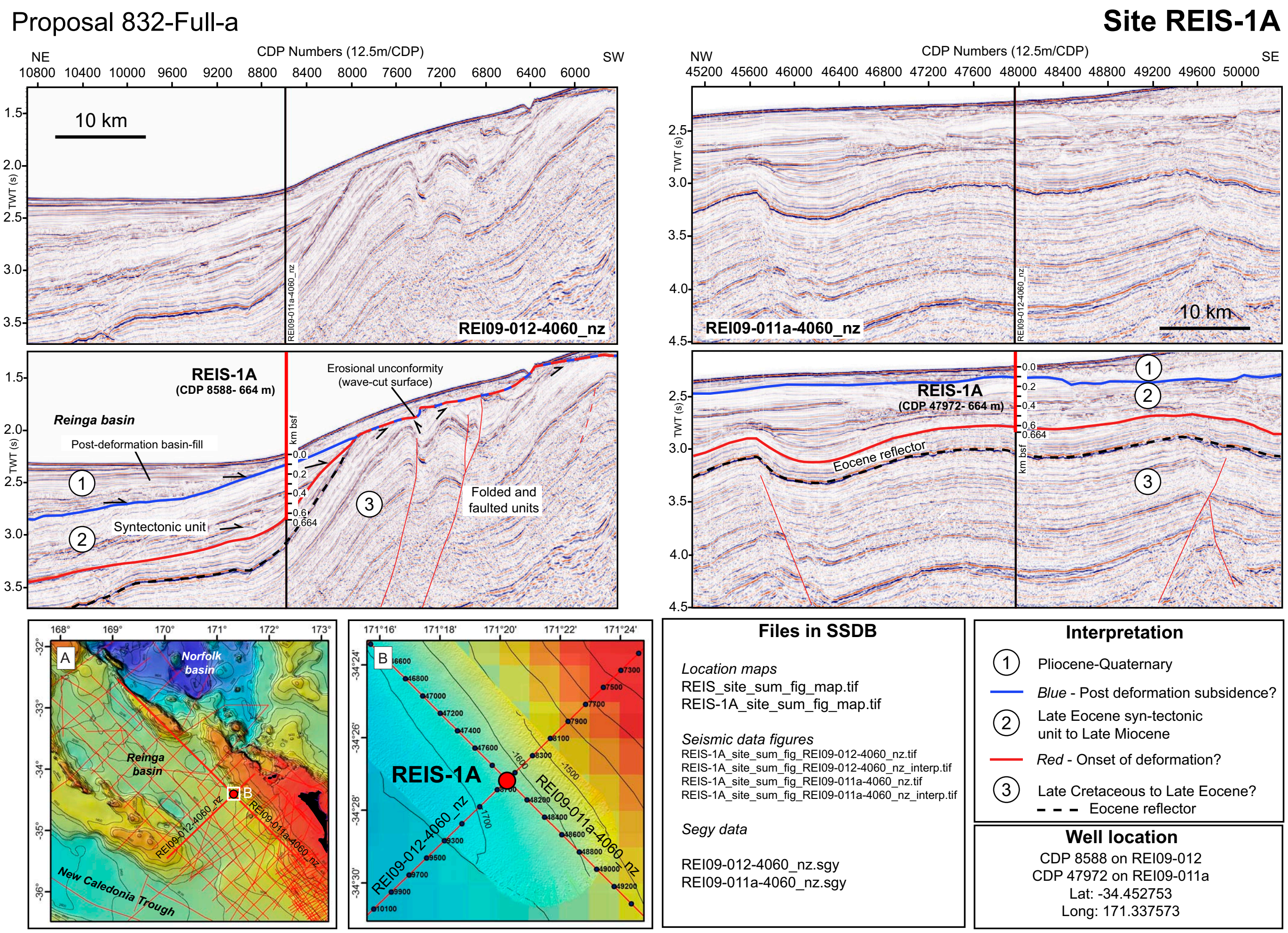


Figure AF7. Background data, proposed Site NCTS-2A.

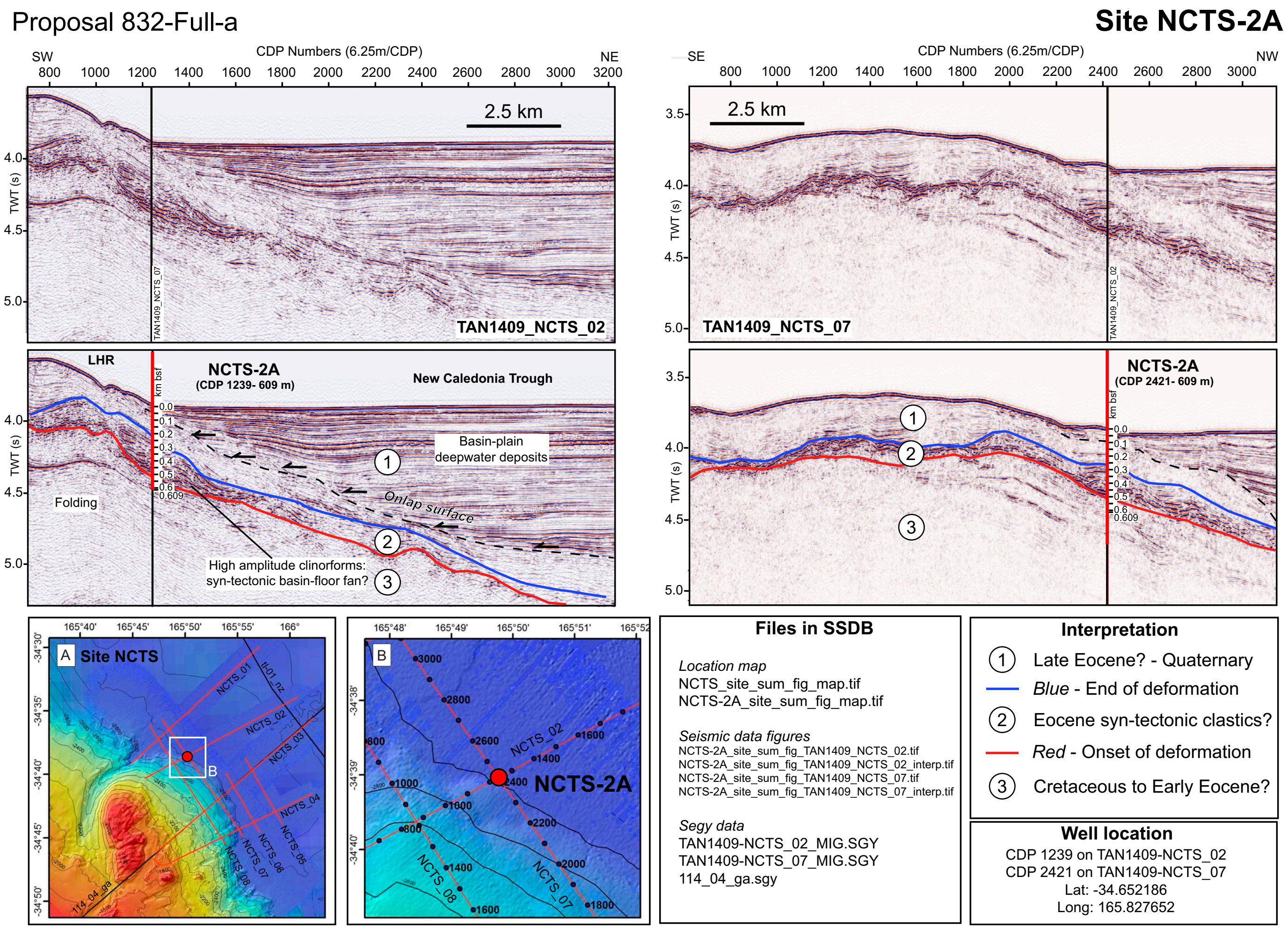


Figure AF8. Background data, proposed Site NCTS-3A.

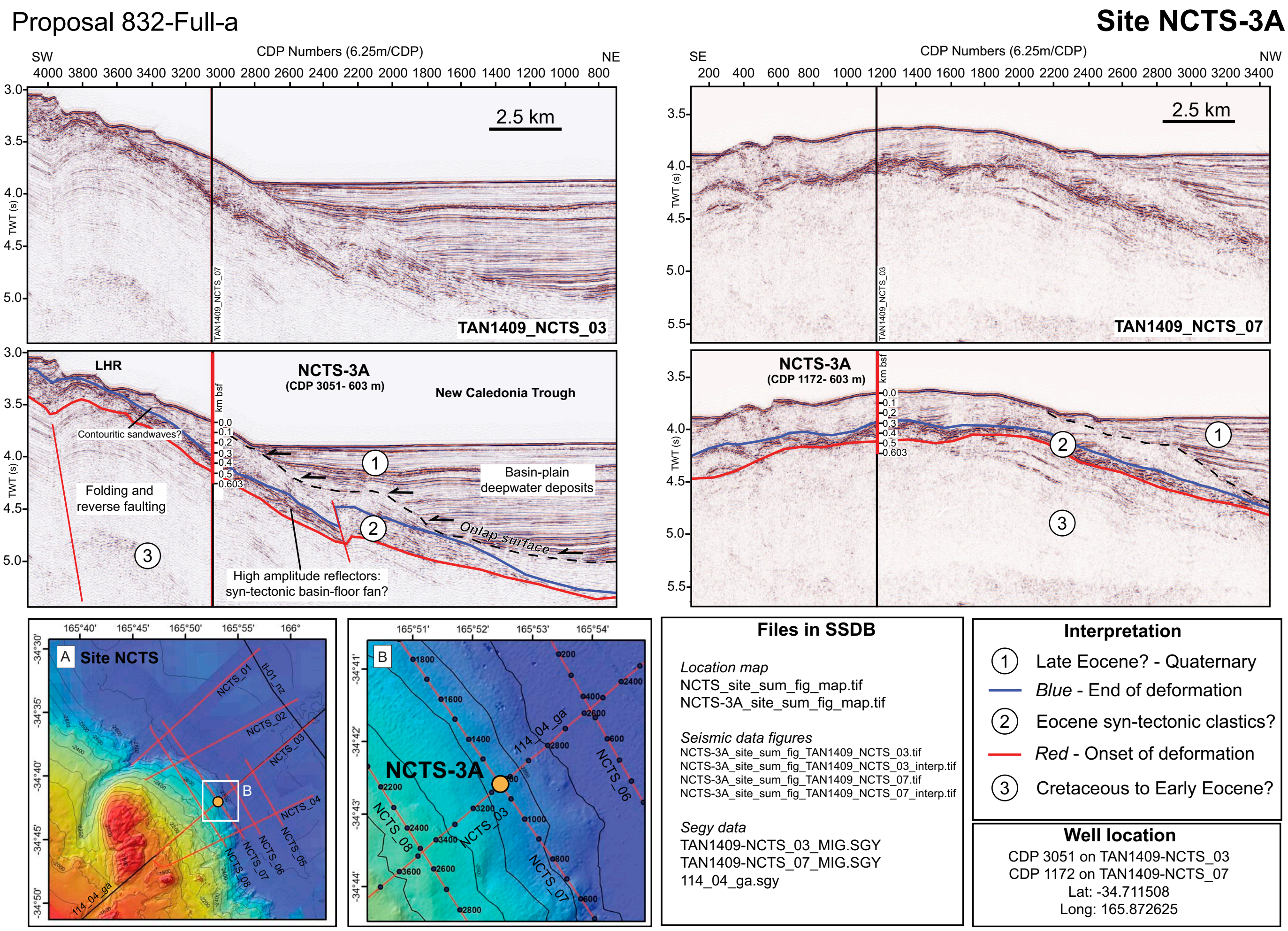


Figure AF9. Background data, proposed Site LHRS-3A.

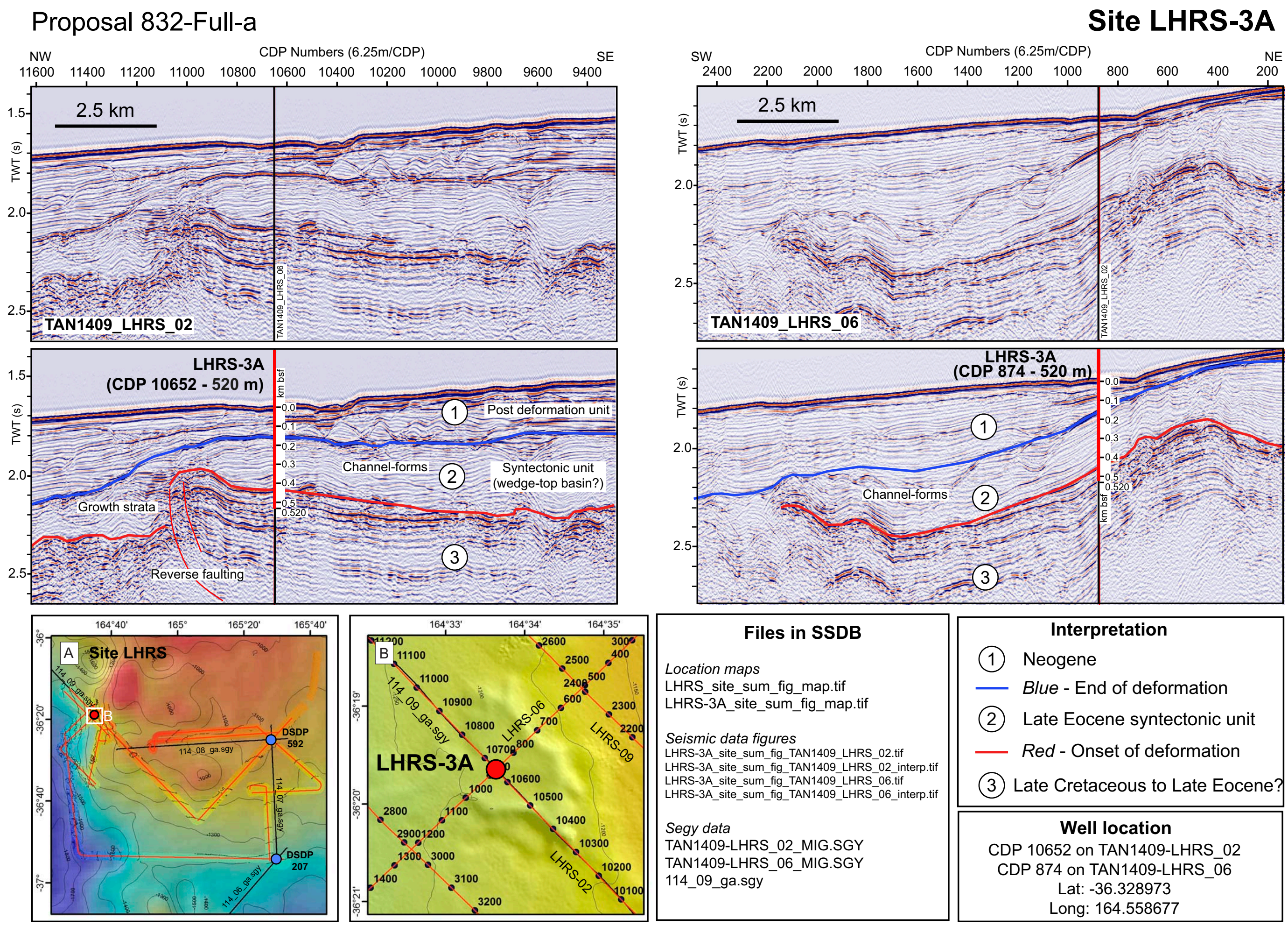


Figure AF10. Background data, proposed Site LHRS-2A.

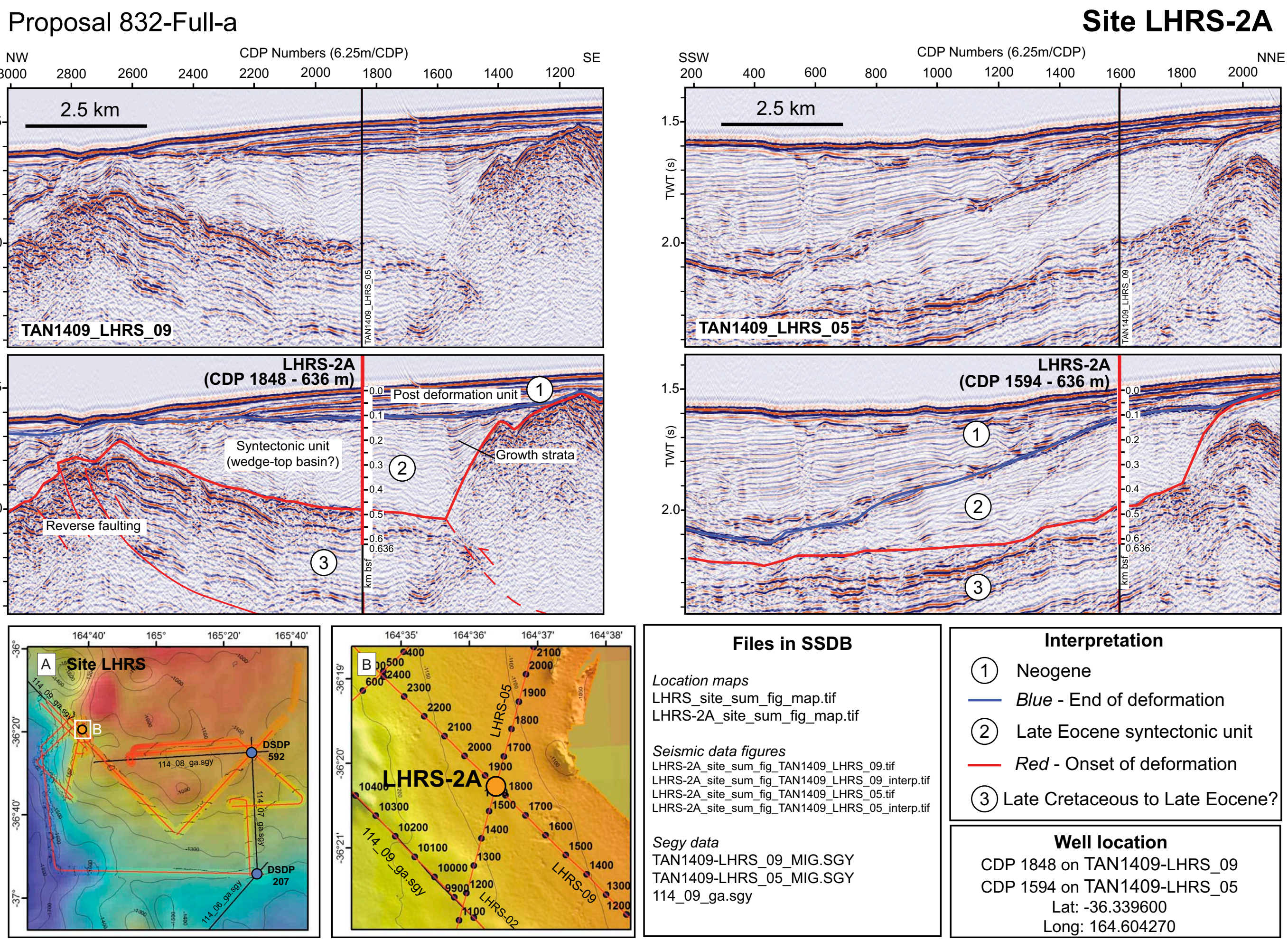


Figure AF11. Background data, proposed Site TASS-2A.

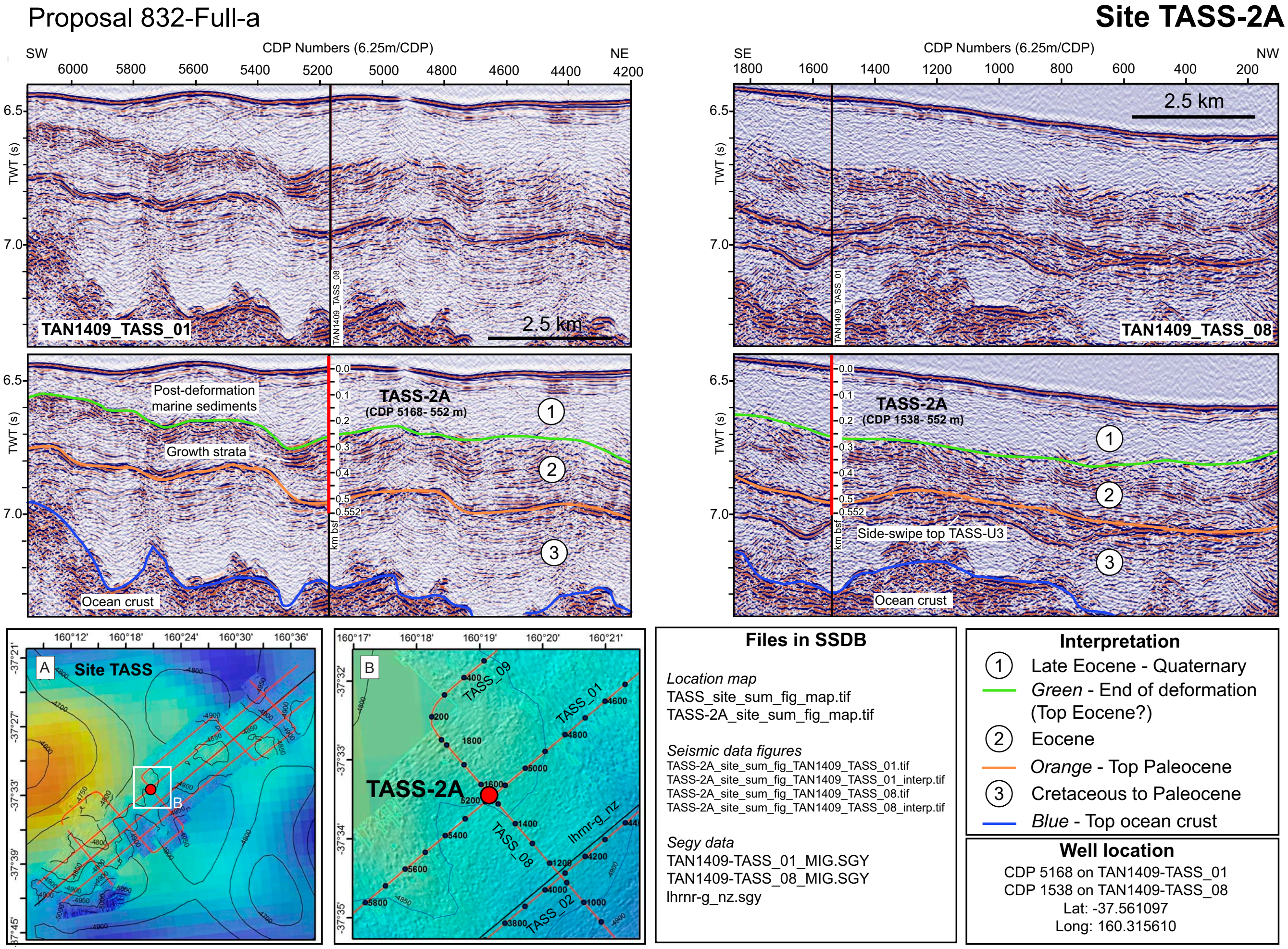


Figure AF12. Background data, proposed Site TASS-5A.