International Ocean Discovery Program
Expeditions 367 and 368 Scientific Prospectus

South China Sea Rifted Margin

Testing hypotheses for lithosphere thinning during continental breakup: drilling at the South China Sea rifted margin

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Abstract

International Ocean Discovery Program (IODP) Expeditions 367 and 368 will address the mechanisms of lithosphere extension during continental breakup. State of the art deep reflection seismic data show that the northern South China Sea (SCS) margin offers excellent drilling opportunities that can address the process of plate rupture at a magma-poor rifted margin. The SCS margin shows similarities to the hyperextended Iberia-Newfoundland margins, possibly including exhumed and serpentinized mantle within the continent-ocean transition (COT). However, recent modeling studies suggest that mechanisms of plate weakening other than serpentinization of the subcontinental lithospheric mantle exist. Two competing models for plate rupture (in the absence of excessively hot asthenospheric mantle) have widely different predictions for (1) the crustal structure across the COT, (2) the time lag between breakup and formation of igneous ocean crust, (3) the rates of extension, and (4) the subsidence and thermal history. Proposed drilling will core through thick sedimentary sections and into the underlying basement to firmly discriminate between these models. We plan to occupy four sites across a 150-200 km wide zone of highly extended seaward-thinning crust with a well-imaged COT zone. Three sites will determine the nature of critical crustal entities within the COT and constrain postbreakup crustal subsidence. These three sites will also help constrain how soon after breakup igneous crust started to form. A fourth site on the continental margin landward of the COT will constrain the timing of rifting, rate of extension, and crustal subsidence. If serpentinized mantle is found within the COT, this will lend support to the notion that the Iberia-type margin is not unique, and hence that weakening of the lithosphere by introducing water into the mantle may be a common process during continental breakup. If serpentinite is not found, and alternatively, scientific drilling results for the first time are gained in support of an alternative model, this would be an equally important accomplishment. Constraints on SCS formation and stratigraphy, including industry drilling, Ocean Drilling Program Leg 184 and IODP Expedition 349 drilling, the young (Paleogene) rifting of the margin, and absence of excessively thick postrift sediment allow us to effectively address these key topics by drilling within a well-constrained setting. An initial spreading rate of ~ 2 cm/y half-rate reduces the potential complexity of magma-starved, slow-spreading crust forming after breakup. Drilling, coring, and logging to address these SCS rifted margin science objectives will be undertaken during Expeditions 367 and 368, which will be implemented as a single science program.

Schedule for Expeditions 367 and 368

Expeditions 367 and 368 are based on International Ocean Discovery Program (IODP) drilling Proposals 878-CPP, 878-Add, 878-Add2, and 878-Add3 (available at **http://iodp.tamu.edu/scienceops/expeditions/south_china _sea_II.html**). Following ranking by the IODP Scientific Advisory Structure, this scientific program was scheduled for two expeditions of the R/V *JOIDES Resolution*, operating under contract with the *JOIDES Resolution* Science Operator at Texas A&M University. At the time of publication of this Scientific Prospectus, Expedition 367 is scheduled to start in Hong Kong on 7 February 2017 and to end in Hong Kong on 9 April. Expedition 368 is scheduled to start in Hong Kong on 9 April and to end in Hong Kong on 9 June. Each expedition has a total of 61 days available for the initial port call, transit, drilling, coring, and downhole measurements described in this report (Tables **T1**, **T2**; also see **http://iodp.tamu.edu/scienceops/** for the current ship schedule). Further details about the facilities aboard the *JOIDES Resolution* can be found at **http://iodp.tamu.edu/labs/ship.html**.

Introduction

The South China Sea (SCS) margin (Figure **F1**) is an accessible and well-imaged location where drilling of synrift sediment and underlying basement will provide key constraints on the processes of rifting and eventual rupturing of the continental crust during breakup at a magma-poor rifted margin. This project includes a drilling plan spread across two 61-day expeditions. The scientific objectives and proposed drill sites are shared between the planned Expeditions 367 and 368. Two expeditions are needed in order to obtain sufficient basement penetration at key sites and to drill four primary sites in a transect across the margin, three or four of which are planned to be cased.

Although the primary focus of this proposal is to discriminate between possible models for rifting and plate rupture, the drilling will, along with results from Ocean Drilling Program (ODP) Leg 184 and IODP Expedition 349, address a secondary objective of providing much improved constraints on the Cenozoic development of the southeast Asian margin as recorded within the SCS basin. Drilling strategy, however, is entirely tailored to the primary objective.

The SCS margins provide a valuable testbed for ODP-constrained models of breakup, developed along the Iberia and Newfoundland margins, to determine if other hypothesized models not yet tested by drilling need be considered. Particularly important to this project is the exceptionally high quality seismic imaging (courtesy of the Chinese National Offshore Oil Corporation [CNOOC]) of hyperextended continental crust along the northern SCS margin. In these data we identify key targets that can be reached using the *JOIDES Resolution*. Other advantages of the SCS margin are its young age relative to North (and South) Atlantic margins and that there was a relatively fast spreading rate following breakup. The latter reduces the potential for complexity of ocean crust formed at slow to ultraslow rates.

Background

Global examples of rifted margins

The Ocean Drilling Program (1985–2003) made a major effort along the rifted margins of the North Atlantic to understand the processes of continental breakup (ODP Legs 103, 104, 149, 152, 163, 173, and 210). ODP drilling and related studies suggest that two end members of rifted margin exist:

1. Volcanic rifted margins characterized by massive igneous activity in a relatively short period of time (~1–3 million years) during breakup and initial seafloor spreading, and
2. Magma-poor rifted margins where tectonic extension and thinning of the continental lithosphere leads to exhumation and serpentinization of the subcontinental mantle lithosphere.

The classical examples of volcanic rifted margins are the conjugate margins of East Greenland and northwestern Europe (White and McKenzie, 1989). The presence of anomalously hot asthenospheric mantle in the northeast Atlantic linked to the Iceland mantle plume (Larsen and Saunders, 1998; Holbrook et al., 2001; Nielsen et al., 2002) seems to play a fundamental role in the formation of volcanic rifted margins and associated massive igneous activity. The latter is easily recognizable within both reflection seismic data (e.g., seaward-dipping reflector sequences; Larsen and Saunders, 1998) and in crustal seismic velocity data (e.g., Holbrook et al., 2001). However, the crustal structures of SCS rifted margins show none of the typical volcanic rifted margin features. On the contrary, the SCS margins show a number of similarities to the Iberia magma-poor margin (e.g., Franke, 2013; Barckhausen et al., 2014). Therefore, the drilling strategy of this proposal is tailored to acquire samples critical to further our understanding of the formation of magma-poor rifted margins: is the extremely magma-poor Iberia margin a widespread alternative to volcanic rifted margin formation, or is there a "third" way, as modeling may suggest (e.g., Huismans and Beaumont, 2011)?

The Ocean Drilling Program sampled the magma-poor Iberia-Newfoundland conjugate margins that formed between ~130 and ~110 Ma. Leg 103 at the Galicia margin discovered serpentinized mantle within the transition zone between thinned continental lithosphere and (interpreted) oceanic crust (Boillot, Winterer, et al., 1988). Legs 149 and 173 along the Iberia margin south of the Galicia margin confirmed the presence of similar structures (Whitmarsh, Sawyer, Klaus, and Masson, 1996; Beslier, Whitmarsh, Wallace, and Girardeau, 2001). Off Iberia, however, drilling also showed that the oldest ocean crust (as defined by seismic velocity structure) along the margin consists of serpentinized mantle. This "crust" is now generally accepted to have formed by ultraslow spreading. The ultraslow spreading system is prone to produce only limited amounts of igneous crust because of the effect of conductive cooling of the slow-rising asthenospheric mantle (Forsyth, 1993; Cannat et al., 2009; Dick et al., 2003, 2010). Leg 210 found that serpentinized mantle is also present at the conjugate Newfoundland margin (Tucholke, Sibuet, and Klaus, 2007), adding further drilling evidence for the existence of this type of margin.

Drilling results and associated geophysical work therefore suggest that along these magma-poor margins, profound tectonic extension of the crust ("hyperextension") dramatically thins the crust prior to breakup and at some point allows water to access the subcontinental lithospheric mantle through crust-cutting faults. Underpinning of the final and complete rupture of the continental lithosphere by profound mechanical weakening of the mantle lithosphere by serpentinization is therefore suggested (Whitmarsh et al., 2001; Pérez-Gussinyé and Reston, 2001; Pérez-Gussinyé et al., 2006; Reston, 2009; Sutra and Manatschal, 2012).

It therefore can be hypothesized that weakening of the continental lithosphere to allow plate rupture may follow two distinctly different paths:

1. Convective heating (plume type) of the mantle lithosphere and associated excess magmatism during breakup and early ocean basin formation and
2. Introduction of water into the subcontinental lithospheric mantle through deep, crust-cutting faults with no or only very limited igneous activity during breakup.

Volcanic rifted margins are quite easily and firmly recognized by reflection seismic data and are found within margins of the North and South Atlantic, off Antarctica, and along the Indian Ocean (Franke et al., 2014). This strongly suggests that (excessive) thermally induced weakening of the continental lithosphere during breakup is a common process during geological history.

Application of these models to the evolution of the South China Sea

Previous studies raised the following questions:

1. Is seismic imaging of hyperextended crust along several other rifted margins sufficient to equate these with Iberia-type margin formation?
2. By implication, is serpentinization of the subcontinental mantle lithosphere another common driver of lithospheric rupture?

The pivotal feature required for concluding this is the presence at the outermost continental margin of serpentinite bodies representing (former) subcontinental mantle lithosphere. However, this critical feature is not easily identified on seismic data and is only confirmed by drilling at the conjugate Iberia-Newfoundland margins.

So key questions to answer by drilling are as follows:

1. Can exhumation of subcontinental lithosphere during breakup be verified on other margins?
2. If so, can igneous oceanic crust, unlike at the Iberia margin, form shortly after breakup provided that the initial seafloor spreading rate is high enough (>1 cm/y; half-rate) to produce significant mantle melting?
3. Alternatively, is there a third type of margin in which neither plume-type thermal weakening nor serpentinization of the subcontinental lithospheric mantle operates during breakup as suggested by modeling (Huismans and Beaumont, 2011; Brune et al., 2014)?

Other key parameters not defined by seismic data alone are the rate of extension and the subsidence during breakup. The rate of extension will constrain the mechanical model for plate rupture with a kinematic dimension. Kinematics, as well as the distribution (time and space) of margin subsidence, is important to possibly discriminate between different models of margin formation.

As we outline in more detail in the next sections, the SCS is a key location where the main framework of the global rifting models can be tested by drilling. The margins are relatively young and are not yet buried by extensive postrift sediment. There is excellent data coverage including pre-existing ODP, IODP, and industry drill holes, as well as a dense grid of high-quality multichannel seismic reflection data. Our new drill sites will test the "mantle wetting" hypothesis (Iberia-type margin) and possible alternatives for the transition from extension to seafloor spreading.

Geological setting of the eastern subbasin of the South China Sea

The SCS is a modestly sized, young ocean basin that formed along the eastern boundary of the Eurasian plate during mid- to late Cenozoic time (Figure **F1**). The SCS deep region can be divided into the East and Southwest Subbasins. Expeditions 367 and 368 will drill a transect of sites across the northwest margin of the East Subbasin. This subbasin is generally held to have formed first (~32–30 Ma) with a later expansion of spreading into the Southwest Subbasin (Briais et al., 1993; Barckhausen and Roeser, 2004; Li et al., 2012a, 2012b; Franke et al., 2014).

The continental crust that forms the margin of the SCS was accreted to the Asian margin during the Mesozoic (Zhou and Li, 2000; Zhou et al., 2008; Li et al., 2012a, 2012b). Within ~80 million years, this new continental lithosphere underwent extensive rifting during the Paleogene, most likely from the early Eocene (~45 Ma) to early Oligocene (32 Ma; Li et al., 2012a, 2012b, 2013; Barckhausen et al., 2014; unpublished industry borehole data). There are different, and as-yet unresolved, hypotheses for the origin of the extensional forces that led to breakup, such as rifting caused by subduction zone roll-back (Rangin et al., 1990), slab pull of the proto-South China Sea (Taylor and Hayes, 1983), or extrusion tectonics related to collision of the Indian subcontinent into Asia (e.g., Tapponnier et al., 1982). However, the focus of our drilling proposal is to take advantage of the SCS margins to understand the impact of extensional forces on the continental lithosphere, not the origin of the stress field. Better constraints on the timing, duration, and mechanism of lithosphere extension, however, are likely to contribute to the larger-scale tectonics as well.

Creation of oceanic crust in the SCS started in the early Oligocene, with the oldest interpreted magnetic anomaly being C12n (~32 Ma) within the eastern-most part of the East Subbasin (Briais et al., 1993; Li et al., 2013; Franke et al., 2014). Seafloor spreading ceased within the middle Miocene (Taylor and Hayes, 1980, 1983; Briais et al., 1993; Barckhausen and Roeser, 2004; Barckhausen et al., 2014). The SCS is a slow to intermediate spreading-rate system with initial seafloor spreading rates of ~2 cm/y that increase to ~2.5 cm/y (half-rate; Li et al., 2014). Subduction of the eastern part of the SCS basin along the Manila Trench started at or before ~15 Ma (Li et al., 2013). However, this post-spreading tectonism did not affect the margin where the drill sites of Expeditions 367 and 368 are located. For a more complete review of the regional setting and tectonic development see Shi and Li (2012), Li et al. (2013), and Franke et al. (2014).

Previous drilling

The first deep-sea drilling expedition to the SCS was ODP Leg 184 in 1999. Its primary scientific objective was investigating the late Cenozoic East Asian monsoon and its global climate impact. Leg 184 recovered 5463 m of Oligocene to Quaternary sediment from Sites 1143–1148 in the SCS. All of these sites provided hemipelagic deposits rich in calcareous microfossils that enabled the application of stable isotopes and faunal analyses for addressing Leg 184 scientific goals. The suite of sites yields an almost continuous record of the environmental history of the SCS during the last 32 million years. Site 1143 is located in the Nansha or Spratly Islands area of the southern SCS and recovered a composite section recording the depositional history of the last ~12 million years. On the northeast continental slope of the SCS Site 1144 provided a composite section from a sediment drift spanning the last 1.5 million years. At Site 1145 a composite section representing the last 3 million years was recovered, and Site 1146 recovered a composite section representing a 19 million year stratigraphic record. Site 1147 recovered the top several meters of sediment missing at Site 1148, while Site 1148 recovered a composite section spanning the last ~32 million years. The Oligocene/Miocene boundary in the northern SCS (Site 1148) is marked by sedimentary deformation, abrupt lithologic changes, and a stratigraphic hiatus (23–28 Ma). These related features will help resolve the nature and timing of one of the most significant Cenozoic tectonic and climatic changes of this region. The high accumulation rates of Oligocene sediment on the lower continental slope near the continent crust margin probably reflect active downslope transport of terrigenous sediment during the early stage of seafloor spreading of the SCS basin. The recently completed Expedition 349 to the SCS basin (Li et al., 2015a) targeted the spreading history of the SCS and successfully recovered samples from near the extinct axes of both the East (Site U1431) and Southwest Subbasins (Sites U1433 and U1434) as well as from a marginal high (Site U1435) close to the continent–ocean transition (COT) at the northern margin of the East Subbasin (Figures **F1**, **F2**).

Ocean floor–type (mid-ocean-ridge basalt [MORB]) basalt was recovered from the center of both the East and Southwest Subbasins. Shipboard data (see expedition reports of Sites U1431, U1433, and U1434; Li, Lin, Kulhanek, and the Expedition 349 Scientists, 2015) indicate that cessation of spreading in the SCS took place around 13–17 Ma, providing an important calibration point for modeling seafloor spreading magnetic anomalies across the basin.

Site U1435 drilled during Expedition 349 is located on a highly elevated, narrow, and isolated seamount-like structure just landward of the interpreted magnetic Chron C11n (~30 Ma; Figure **F2**). Close to 300 m of sediment was recovered at Site U1435. An upper, deep-marine sequence of Pleistocene to early Oligocene age is underlain by shallow-water (possibly lacustrine) sedimentary rocks of inferred late Eocene to early Oligocene age (lower sequence barren of microfossils). This lowermost succession shows increasing dip with depth and is interpreted as synrift deposits reflecting (waning) tectonic tilting as rifting progresses toward final breakup. Lacustrine sediment of Eocene age has also been recovered by industry drilling further inland on the northern SCS margin; however, this facies was not expected to be present at Site U1435, located at the outermost margin. By implication of the age and nature of the oldest overlying sedimentary rocks, basement in this location is interpreted to be of continental origin. This may suggest that the continent/ocean boundary is located between Site U1435 and the nearby (interpreted) seafloor-spreading Anomaly C11.

Site 1148 is quite close to Site U1435 (Figure **F2**). The oldest sedimentary rocks recovered at Site 1148 are deep marine and also of early Oligocene age (~33 Ma; Wang, Prell, Blum, et al., 2000), but they could be underlain by older, shallow-water sedimentary rocks similar to those at Site U1435; seismic data are insufficient to discern this at Site 1148. The combined findings at Sites 1148 and U1435 therefore suggest that along this part of the outer SCS margin, rapid subsidence from shallow- (or even lacustrine) marine deposition to a deepwater environment started around the Eocene/Oligocene boundary (~34 Ma). However, the cored sequences at both Sites 1148 and U1435 (in particular) cannot easily, or at all (Site U1435), be traced more regionally.

Margin structure within the Expedition 367/368 drilling transect

Our planned drilling transect is located ~50 km west of Site U1435 (Figure **F2**) at the northern SCS margin of the East Subbasin. This location was chosen for both scientific reasons and because of the availability of high-quality seismic reflection data. The oldest magnetic anomaly identified on this part of the margin is Anomoly C11 (~30 Ma), slightly younger (~1–2 million years) than the interpreted location of Anomaly C12 further to the northeast.

Regional interpretation of the industry seismic data, including 3-D coverage, shows that the transect is centrally located within a tectonic segment along the margin that exhibits a broad zone (~150–200 km) of crustal necking and hyperextension prior to breakup. Further to the east around Site U1435, the zone of crustal necking may be narrower, implying a more rapid change from continental to oceanic crust, which would be consistent with the Site U1435 results. Interestingly, similar margin segmentation occurs along the Iberia-Galicia Bank margin, with the Iberia margin exhibiting a wide zone of crustal necking and the Galicia margin having a narrower one (Sutra and Manatschal, 2012).

The Expedition 367/368 drilling transect is defined by a grid of high-quality, industry-acquired seismic data (Figures **F2**, **F3**, **F4**, **F5**). With new data acquired in 2015, the dip-line spacing is ~12.5 km, and new crossing lines clearly image the margin-parallel structure through the proposed drill sites. These data define three distinct ridges in the distal margin or COT area (see below) and an outer margin high (OMH), each of which we target in this drilling program (Figure **F3**).

We define the COT as the zone in which the outermost, extended continental lithosphere is replaced by crust (and lithosphere) that formed within a focused zone (i.e., spreading ridge) in a steady-state fashion. The latter can include continuous tectonic exhumation, with or without serpentinization, of rising asthenospheric mantle (not subcontinental); accretion of normal igneous ocean crust; or a mixture of these two processes. So when we refer to ocean crust, this does not necessarily imply igneous ocean crust.

Clear Mohorovicic seismic discontinuity (Moho) reflections (Figures **F3**, **F4**, **F5**) show distinct thinning of the continental crust toward the COT. A general layering of upper, middle, and lower crust is imaged on these profiles. The lower crust is acoustically transparent and only about 6 km thick. Lower crust with a similar thickness and acoustic appearance is reported from the northeastern SCS margin (McIntosh et al., 2013, 2014; Lester et al., 2013). This lower crust is indicated to thin toward the COT, but seismic data are not conclusive in this regard.

The upper crust shows numerous extensional, low-angle detachment faults soling out at mid-crustal level. This fault system generated a number of deep half-grabens filled with synrift sediment, subsequently covered by postrift sediment. The synrift sediment is topped by a breakup unconformity (T70 in Figure **F4**). Distant industry wells (cuttings and log data only) combined with Site U1435 results suggest the breakup unconformity is ~32 Ma, but this needs to be verified directly by coring data (Figure **F3**). This unconformity reflects the end of the main crustal extension, but it is not necessarily synchronous across the margin and could be younger toward the outer margin. A younger, widely distributed unconformity (T60) is also shown in Figures **F4** and **F5** and likely reflects differentiation into a shallower continental margin and a true, deep oceanic basin. The unconformity may correspond to a hiatus at ~23 Ma found at Site 1148 (Wang, Prell, Blum, et al., 2000) and may coincide with a spreading center ridge jump (Briais et al., 1993).

The distinct OMH of Line 1555 (Figure **F5**) is also well developed on Line 15ecLW8 (Figure **F4**). These basement structures are quite reminiscent of the structure drilled at Site U1435. However, on our transect they are located more inland of the interpreted magnetic Anomaly C11 (Figure **F2**). This would be consistent with the interpretation of a wider zone of crustal necking within this margin segment, compared to that at Site U1435.

Seaward of the OMH, both profiles (Figures **F4**, **F5**) show the presence of basement highs within the COT, close to but landward of the interpreted boundary between continental and oceanic lithosphere. The nature of these basement highs seems different from that of the OMH fault blocks. The structure is more dome-like and lacks clearly defined normal faults or synrift half-grabens on their landward-facing sides (proposed Site SCSII-1A and alternate targets). Note that magnetic Anomaly C11 is projected to almost overlap (seaward part) with this structure (Figures **F4**, **F5**; e.g., near proposed Site SCSII-9B). Excluding sediment, the crust below this outermost basement high is only ~6.4–8 km thick (about <2.0–2.5 s two-way travel time [TWT]) based on ocean-bottom seismometer (OBS) velocity constraints of Yan et al. (2001), Wang et al. (2006), and Wei et al. (2011). Seaward of the COT, the crust exhibits a fairly uniform thickness of just less than ~6 km (2 s TWT), consistent with the interpretation of this being oceanic crust (Yan et al., 2001). Sampling this COT is a key objective of our proposed drilling.

A summary of key tectonic features based on Line 1555 is shown in Figure **F6**. In this interpretation, the normal faults of the upper, brittle crust sole out within a main detachment zone located above or within the middle crust. It may seem counterintuitive that faulting is not penetrating deeper into ductile lower crust. Despite the generally high data quality, this could simply be an imaging problem, or it could indicate strong decoupling between upper and lower crustal extension. The deeper crust, except for the base of the crust, is not well imaged below the COT (Figures **F4**, **F5**). Hence, deep crust-cutting faults may be present, but unable to be imaged in this location.

Another possibility is that the main detachment zone itself became exhumed during final breakup. This would imply that (1) the former position of the main detachment zone actually was over the top of the outermost basement high (i.e., proposed Site SCSII-1A and its alternates), (2) its further seaward (i.e., original downward dip) continuation is to be found oceanward of proposed Site SCSII-1A around proposed Site SCSII-8B, or (3) perhaps the main detachment zone was even transposed onto the conjugate margin during final breakup. If the main detachment fault actually has been exhumed, the outermost continental part of the COT around proposed Site SCSII-1A must consist of either lower crust or serpentinized subcontinental mantle lithosphere. An apparent seaward continuation of the Moho (most clear in Figure **F4**) might indicate lower crust is present at proposed Site SCSII-1A. Alternatively, the Moho in this zone below the COT may be a serpentinization front. Sampling of basement at proposed Site SCSII-1A is therefore pivotal to constrain crustal structure and critical aspects of the extension process.

In summary, these data show the COT to be constrained to a 40 km wide zone at the distal margin. Deep sampling of the distinct basement structures defined by the seismic data is required to determine the true nature of the COT and test if the SCS margin is another example of the Iberia-type margin or not. Our detailed drilling strategy is thus designed to test the following model predictions.

Model predictions to be tested in drilling transect

Huismans and Beaumont (2008, 2011) modeled two scenarios for the formation of rifted margins in the absence of anomalously hot asthenospheric mantle. One scenario (Type-I of Huismans and Beaumont, 2008, 2011) is the Iberia-Newfoundland-type margins in which preferential lithosphere thinning initially occurs in the (upper) crust, with extensional faults eventually cutting into the mantle and mechanically weakening the mantle by serpentinization. Key aspects of their modeling results are summarized in Figure **F7**.

Similarities between the modeling (Figure **F7**) and the interpretation of the general margin structure of the SCS (Figure **F6**) are quite striking. However, Huismans and Beaumont (2011) proposed an alternative (Type-II) model in which initial and preferential stretching of the mantle lithosphere and lower crust leads to plate rupture without exhumation of the subcontinental mantle and associated serpentinization during breakup. The two models result in distinctly different structures across the outer continental margin and into the ocean crust.

The Iberia-type model (Type-I) is predicted to show a significant hiatus between the final breakup and development of truly igneous oceanic crust. Correspondingly, a wide zone of mainly serpentinized asthenospheric mantle makes up the new ocean crust, similar to crust forming at ultraslow-spreading centers (Cannat et al., 2009; Dick et al., 2003, 2010). This would be consistent with the very slow spreading rate (~0.6 cm/y; half-rate) of early ocean crust off Iberia-Newfoundland (Whitmarsh, Sawyer, Klaus, and Masson, 1996; Péron-Pinvidic and Manatschal, 2009; Tucholke et al., 2007). However, these initial low spreading rates by themselves could be speculated to be, if not the main, then a supplementary driver for the extensive formation of crust formed by serpentinization of the mantle.

The other model (Type-II) predicts that a spreading center generating igneous ocean crust will form shortly, if not instantly, after breakup. This is because thinning of the mantle lithosphere initially is favored over crustal thinning, allowing the asthenospheric mantle to rise and melt at an earlier stage within the process of breakup. This latter difference also manifests itself in a different thermal and subsidence history, and potential for rift-related magmatism (Huismans and Beaumont, 2011; Brune et al., 2014).

In summary, two simplified models might exist:

1. One COT would have serpentinized subcontinental lithospheric mantle being replaced seaward by serpentinized asthenospheric mantle and farther seaward by igneous oceanic crust, and
2. Another COT would show thin continental crust being replaced seaward by igneous oceanic crust.

Whereas the location of the COT is basically the same in the two models, the structure and composition of the COT is very different. Only drilling can differentiate between these fundamentally different models for plate rupture. Three drilling locations across the COT (Figures **F5**, **F6**, **F7**) target these critical details of the COT. A fourth high-priority site (SCSII-41A) is located landward of the COT and will sample syn- to postrift sediment to constrain the timing and the rates of extension as well as margin subsidence history. These parameters are needed for kinematic control on the mechanics of plate rupture. The site may also provide information on the thermal history of the margin during rifting.

Scientific objectives

This drilling transect across the SCS margin (Figures **F1**, **F2**, **F3**, **F4**, **F5**, **F6**) was chosen to investigate the processes of rifting and rupturing of the continental crust at a magma-poor rifted margin. Four primary and sixteen alternate drill sites across a well-imaged rifted margin and COT zone are proposed (Figures **F1**, **F2**, **F3**; Tables **T1**, **T2**, **T3**). Three deep primary sites will determine the nature of critical crustal entities within the COT, constrain postbreakup crustal subsidence, and constrain how soon after breakup igneous crust started to form. The fourth site on the distal continental margin landward of the COT will constrain the timing of rifting, rate of extension, and crustal subsidence.

If serpentinized mantle is found within the COT, this will lend support to the notion that the Iberia-type margin is not unique and, hence, that weakening of the lithosphere by introducing water into the mantle may be a common process during continental breakup. If serpentinite is not found, and alternatively, scientific drilling results for the first time are gained in support of an alternative model, this would be an equally important accomplishment. Given that a whole sequence of sediment from rifting to breakup as well as the basement rocks will be sampled, this project will fulfill the following research objectives in four major themes:

1. To determine the nature of the basement within critical crustal units across the COT of the SCS rifted margin in order to discriminate between different competing models of breakup at magma-poor rifted margins. Specifically, to determine if the subcontinental lithospheric mantle was exhumed during plate rupture.
2. To determine the time lag between plate rupture and asthenospheric upwelling that allowed decompression melting to generate igneous ocean crust.
3. To constrain the rate of extension and vertical crustal movements.
4. To improve the understanding of the Cenozoic regional tectonic and environmental development of the Southeast Asia margin and SCS by combining Expedition 367/368 results with existing ODP/IODP sediment records and regional seismic data.

Seismic studies/Site survey data

The supporting site survey data for Expeditions 367 and 368 are archived at the IODP Site Survey Data Bank. Data can be accessed at **http://ssdb.iodp.org/SSDBquery/SSDBquery.php** by selecting the appropriate proposal number. All seismic data used to define the drilling locations for Proposal 878-CPP were acquired with relatively long streamers (~7000 m; >480 channels), moderately-sized tuned air gun arrays (3680–4100 inch^3), 1 or 2 ms sample intervals, and broad recording bandwidth (no low-cut and up to 400 Hz high-cut filters). Seismic data processing, performed by industry service companies, successfully emphasized multiple attenuation and prestack time migration. These data were acquired and processed for CNOOC in various surveys between 2004 and 2015. The earlier data were used to define the originally proposed sites for Proposal 878-CPP, and more recent data acquisition and processing in 2015 provided strike profiles through the proposed sites, reduced dip-profile spacing to ~12.5 km, and were used to identify new primary and alternate drilling sites.

Proposed drill sites

This section contains the essential information about each of the proposed sites (see also **Site summaries**). A complete set of site survey data can be found in Addendum 3 of Proposal 878-CPP (878-Add3; available at **http://iodp.tamu.edu/scienceops/expeditions/south_china_sea_II.html**). Our primary proposed sites are organized here in order of increasing distance from the shoreline (Figures **F1**, **F2**, **F3**).

Primary proposed Site SCSII-41A

Proposed Site SCSII-41A is located on the OMH (Figures **F2**, **F3**, **F5**, **F7**, **AF2**, **AF3**) and is in the shallowest water of the four sites (2870 m water depth). This site will penetrate postrift sediment (Reflectors T30–T60; extending to ~23 Ma), synrift sedimentary rocks (containing Reflector T80 [~38 Ma] and Reflectors T82 and T83 [unknown age]), and into basement below the Tg reflector. The site was chosen based on seismic reflection Profiles 15ecLW1 and 15ecLW8 (Figures **AF2**, **AF3**), which show that this is a region of relatively flat seafloor with a relatively thin postrift sequence so that we can access the synrift section and underlying basement. The postrift section appears to be relatively complete. The synrift section and basal reflector (Tg) are tilted and faulted beneath the Reflector T60 unconformity, but these structures do not deform the strata above Reflector T60. The drill site location was chosen to avoid some smaller faults observed in the synrift section.

Proposed Site SCSII-41A is a high priority for addressing Objectives 3 and 4 because the sedimentary section will constrain the age, duration, and environment of rifting and breakup, as well as the subsidence history. Below the basal reflector (Tg) in the acoustic basement, we may encounter upper or lower continental crust, or perhaps, prerift continental rocks that include older continental sedimentary rocks.

Proposed Site SCSII-41A is located ~75 km away from Site U1435 drilled during Expedition 349. Proposed Site SCSII-41A is thought to be located on a different rift segment than Site U1435, but Site U1435 nevertheless provides important guidance regarding what we might expect to find at the new site. At Site U1435, there was a minimum ~300 m thickness of synrift sedimentary section separated by the breakup unconformity (~33 Ma) from overlying, postrift marine sediment (Li et al., 2015a,2015b). The synrift sediment was predominantly sandy shallow-marine sediment with a 25° dip. Detrital zircons with an age range of 34–38 Ma (Shao et al., 2015, unpubl. data) provide an upper limit on the age of these strata. Below these strata at Site U1435, black silty sediment of unknown age was recovered and underlying basement was not reached.

As an operational contingency, three alternate sites to proposed Site SCSII-41A are included: proposed Sites SCSII-42A, SCSII-40A, and SCSII-43A. Alternate proposed Sites SCSII-40A and SCSII-42A have slightly less synrift sediment preserved compared to proposed Site SCSII-41A. Alternate proposed Site SCSII-43A has more synrift sediment preserved but would require more operational time to reach the basement.

Primary proposed Site SCSII-1A

Proposed Site SCSII-1A (Figures **F1**, **F2**) is located on a basement high (Ridge A) clearly visible in the map of traveltime to basement (Figure **F3**) and is well imaged on seismic Lines 04ec1555 and 15ecLW3 (Figures **F4**, **F6**, **AF21**, **AF22**). This site is a high priority for Objectives 1, 2, 3, and 4 mentioned above. At the bottom of the seismic stratigraphic package, seismic Reflectors T60 and T70 are seen on seismic Line 04ec1555, bracketing a relatively transparent seismic package and underlain by a less transparent package between Reflectors T70 and Tg (basement) below it. This site location was chosen because of two key characteristics: these lower seismic stratigraphic units are preserved and the underlying basement is shallower than elsewhere.

This site is enigmatic in terms of possible basement composition; it could be exhumed mantle (serpentinized or not), upper or lower continental crust (basement), or, less likely, igneous oceanic rock (e.g., basalt and gabbro). The model schematically shown in Figure **F6** shows the basement at proposed Site SCSII-1A as possibly corresponding to lithospheric mantle with serpentinization, but this could also be lower continental crust or upper continental crust, depending on the rheological differences among these various units during the rifting process. Figure **F8** shows that there is a broader spectrum of possible magma-poor rifted margin structure that may form, depending on the initial rheologic structure of the extending lithosphere.

We expect the upper sedimentary section to be deep-marine siltstone and sandstone based on published data for Site 1148 (e.g., Clift et al., 2001) and correlation of seismic stratigraphic facies. However, the nature of the lower sedimentary section, including Paleogene synrift and possible prerift strata, is poorly constrained and may be shallow- to deep-marine rocks. Recovery of core from the lower synrift sedimentary section is important here because this constrains the timing and depositional environment of final breakup as well as the subsidence history.

Alternate sites located along Ridge A include proposed Sites SCSII-11A, SCSII-14A, SCSII-15A, SCSII-16A, SCSII-17A, and SCSII-18A.

Primary proposed Site SCSII-8B

Proposed Site SCSII-8B (Figures **F1**, **F2**) is located on a basement high (Ridge B) that is farther seaward but clearly visible in the map of traveltime to basement (Figure **F3**) and is well imaged on crossing seismic Lines 04ec1555 and 15ecLW4 (Figures **F4**, **F5**, **AF10**, **AF11**). The sedimentary section here is interpreted to be sandstone and siltstone containing major seismic Reflectors T32–T60 in the postrift sequence and a variable thickness of sedimentary rock below Reflector T60 and above the basement Reflector Tg. The site is located along Ridge B where the basement is shallowest and the sedimentary rocks older than Reflector T60 are relatively thin so that basement can be reached most easily.

This site will principally address Objectives 1 and 2, to test the nature of the basement at this part of the COT. The basement might be serpentinized subcontinental or asthenospheric mantle, as shown in the evolutionary model in Figure **F6**, but it could also be upper or lower continental crust or oceanic igneous rock such as basalt and/or gabbro (Figure **F7**, **F8**). Because the Moho is not clearly imaged here on the seismic profiles, this leaves open several possible models, including diverse combinations of continental or oceanic lithosphere with or without magmatic intrusions or serpentinization.

Proposed Sites SCSII-20A and 21A are considered to be possible alternate sites for proposed Site SCSII-8B.

Primary proposed Site SCSII-9B

Proposed Site SCSII-9B (Figures **F1**, **F2**) is located on the most seaward basement ridge that is being targeted in this transect (Ridge C; Figure **F3**). The sedimentary section is well imaged on seismic Lines 08ec1555 and 15ecLW5 (Figures **F4**, **F6**, **AF27**, **AF28**, **AF29**). Seismic Reflectors T30, T32, and T60 are regionally correlated into this area. Reflector Tg on top of basement is cut by faults on Line 08ec1555, but faults are absent from Line 15ecLW5 because this line is oriented parallel to the inferred strike direction of the faults. This site addresses Objectives 1 and 2.

Subbasement acoustic layering (below the Tg reflector) is seen on both seismic profiles and is interpreted to correspond to layering developed in oceanic crust Layer 2. On Line 08ec1555, the Moho is interpreted to be present beneath Ridge C and extending seaward (Figure **F4**) into crust with oceanic magnetic anomalies interpreted as Chrons 10 and 9 (Briais et al., 1993). The reversed polarity interval (Chron 10r), slightly older than Chron 10, is inferred to approximately coincide with Ridge C. The subbasement layering suggests robust production of magmas needed to produce oceanic crustal Layer 2. Therefore, the most likely interpretation is that proposed Site SCSII-9B will recover reversely magnetized oceanic crust and not serpentinized mantle rocks. Analyses of this oceanic crust and the overlying sediment should constrain the timing and nature of breakup and whether there is a delayed onset of melt production after rifting and breakup. This will be key to discriminate among different models of timing of early rifting versus onset of seafloor spreading.

Proposed Sites SCSII-30A and SCSII-31A are considered to be possible alternate sites for proposed Site SCSII-9B.

Operations

Drilling and coring strategy

Operations for this SCS rifted margin science program are distributed across Expeditions 367 and 368 of the *JOIDES Resolution* (Tables **T1**, **T2**) and are designed to drill, core, and log through thick sediment sections and significantly into underlying basement. The overall operational approach at each site is similar and consists of two holes per site.

The first hole at each site will be cored with the advanced piston corer (APC) and extended core barrel (XCB) systems to ~650 m below seafloor (mbsf) for science. This APC/XCB hole will also document borehole and formation conditions to help determine the length of casing that will be drilled into the seafloor in the second hole. The final operation in this hole will be to collect downhole wireline log data using the triple combo and Formation MicroScanner (FMS)-sonic tool strings. All full APC cores will be oriented using the Icefield MI-5 orientation tool, and formation temperature measurements will be made using the advanced piston corer temperature tool).

The second hole at each site will begin with drilling-in a seafloor reentry system with casing extending to ~640 mbsf or to the depth determined in the first hole. This is intended to enhance our chances of achieving our deep objectives. Coring using the rotary core barrel (RCB) system will extend from the base of the casing, through the sediment and into the underlying basement. Multiple pipe trips to install new RCB bits will be made as required. Upon completion of the coring objectives, the RCB bit will be dropped either in the bottom of the hole or on the seafloor so that downhole wireline log data can be collected. For this deeper logging, we plan to use the triple combo and FMS-sonic tool strings as well as the Versatile Seismic Imager (VSI) tool string to conduct check shots (see below).

Logging/downhole measurements strategy

The downhole logging plan for Expeditions 367 and 368 aims to provide continuous stratigraphic coverage of in situ formation properties at the proposed sites. Three tool string configurations are planned for each site, but the logging program may be modified depending on hole conditions and available time. Details of the logging tools are available at **http://iodp.tamu.edu/tools/logging/index.html**.

The triple combo tool string measures density, neutron porosity, resistivity, and natural gamma radiation (NGR), along with borehole diameter (caliper log). The FMS-sonic tool string measures NGR, sonic velocity, and oriented high-resolution electrical resistivity images, along with two orthogonal directions of borehole diameter. The NGR data will be used to depth-match the different logging runs. The compressional velocity logs can be combined with the density logs (and core data as required) to generate synthetic seismograms for detailed seismic-log correlations.

A third tool run in the deeper, second hole at each site will consist of a check shot survey with the VSI, which is used to acquire a zero-offset vertical seismic profile. The objective is to establish a direct link between lithostratigraphic depths in the borehole and reflectors in the seismic profiles. The seismic source for the check shots will be a generator-injector air gun, and its deployment is subject to the IODP marine mammal policy; the check shot survey would have to be postponed or canceled if policy conditions are not met.

Risks and contingency

There are a number of challenges associated with drilling, coring, and logging through thick sedimentary sections and, significantly, into underlying basement in deep water that could impact the operations strategy of this expedition.

Weather is always a potential issue, as sea state and the resulting heave can have adverse effects on drilling operations. It also can significantly affect core quality and recovery. Although this should not seriously hamper operations, the expedition could experience some weather delays depending on conditions during critical operations, such as casing and reentry system deployment and RCB basement coring. We anticipate that weather problems might be more likely during Expedition 367, in which case some drilling at primary sites may be completed during Expedition 368.

The highest priority science objective is to document rift margin development by obtaining core and log data from basement and the deeper sediment section. Hole stability is always a risk during coring operations and the risk is higher when there are longer sections of open (not cased) hole. Poor hole conditions, such as loose unconsolidated material or collapsing holes, can prevent our ability to penetrate deeply and may prevent logging. Routine drilling procedures to maintain hole conditions such as circulating drilling mud and wiper trips are included in the plan; however, more time for these procedures may be required to achieve the objectives.

The first hole at each site will consist of an APC/XCB cored and logged hole to ~650 mbsf for science. This hole will also document borehole and formation conditions to help determine the length of casing that will be drilled into the seafloor in the second hole. The second hole at each site starts with drilling-in a seafloor reentry system with casing extending to no more than 10 m less than the APC/XCB penetration. This is intended to enhance our chances of achieving our deep objectives as it will mitigate the risk of hole collapse in the shallower section and provide a smaller annulus for improved annular velocity for hole cleaning.

At proposed Site SCSII-41A, where the sedimentary section is relatively thin (792 m), it is possible that we might achieve the basement objectives without installing the drill-in casing system; this might take less overall time. At proposed Site SCSII-9B, the sediment thickness to be penetrated is quite large (1570 m). Therefore, a single drilled-in casing system may not be sufficient. If required, we plan to have sufficient hardware to install two casing strings at this site. This additional casing work, however, would require ~5 days longer to accomplish. At all sites, a significant amount of formation must be penetrated below casing. Poor hole conditions in this "open" uncased hole may prevent reaching deeper sediment and/or basement. Penetration, core recovery, and logging in basement sections are often problematic and may result in either not achieving the objectives or taking much longer to achieve them.

If one of the casing installation operations fails, or if it is installed but its hole must be abandoned, each expedition will have one additional backup seafloor structure and a limited length of casing.

Hole cleaning also becomes a problem in the deeper sections of the hole, particularly when dense basement material is cored. Additional mud sweeps with larger volumes of mud have been planned for this section. Potential lower annular velocities can make hole cleaning more difficult in the deeper sections of these holes. Increasing flow rates to ensure hole cleaning could result in washed-out sections of sediment further up the hole. This can also cause hole stability problems toward the end of the drilling, coring, and logging process.

Although we do not anticipate using a free-fall funnel (FFF) for any of the expedition sites, we have the ability to deploy one to reduce the amount of time required to reach the planned objective if there is not enough operational time for the other reentry systems. There are several risks associated with FFF deployment: the FFF can be dislodged while pulling out of the hole, the FFF can become buried or impossible to use for reentry, and the use of the FFF leaves the open-hole section open longer, which can contribute to hole instability.

A stuck drill string is always a risk during coring operations and can consume expedition time while attempting to free the stuck drill string or, in the worst case, severing the stuck drill string. This can result in the complete loss of the hole, lost equipment, and lost time while starting a new hole. The *JOIDES Resolution* carries sufficient spare drilling equipment to enable the continuation of coring, but the time lost to the expedition can be significant.

Contingency plans

If Expedition 367 completes its primary objectives and there is time remaining, then the highest priority would be initiate the Expedition 368 operations—likely the APC/XCB coring at each site. This could allow more time for Expedition 368 to accomplish its primary objectives. If sufficient time is available, we might choose to occupy alternate proposed Site SCSII-43A, which has thicker synrift sediment, instead of proposed Site SCSII-41A.

Sixteen alternate sites have been identified (see above) that can be occupied if problems are encountered during drilling of the primary sites or if time allows for additional drilling. In general, we have not established a priority list for the alternate sites because their relative importance will be established by the drilling results of Expeditions 367 and/or 368 up to that point. Should significant time remain after all primary sites are completed, several alternate sites may allow for additional key stratigraphic or basement sampling opportunities. Alternate proposed Site SCSII-44A is proposed as a reoccupation of IODP Site U1435 to sample the deeper sedimentary section and recover basement rock. This is considered a contingency site where potentially significant results, such as COT basement sampling, may be obtained in 2–3 days.

Sampling and data sharing strategy

Shipboard and shore-based researchers should refer to the IODP Sample, Data, and Obligations Policy and Implementation Guidelines (**http://www.iodp.org/doc_download/4038-iodp-sample-data-and-obligations-policy**). This document outlines the policy for distributing IODP samples and data. The document also defines the obligations that scientists incur if they receive samples and data. The Sample Allocation Committee (SAC) will work with the entire scientific party to formulate a formal expedition-specific sampling plan for shipboard and postexpedition sampling. The SAC is composed of the Co-Chief Scientists, Expedition Project Manager/Staff Scientist, and IODP Curator on shore or curatorial representative on board the ship. In the case of Expeditions 367 and 368, the four Co-Chief Scientists, two Expedition Project Managers/Staff Scientists, and IODP curatorial representatives will make up a combined SAC that will oversee the distribution of samples across both expeditions.

Every member of the science party is obligated to carry out scientific research for the expedition and publish the results. All shipboard scientists, and any potential shore-based scientists, are required to submit a research plan and associated sample and data request. These are due at least 4–5 months before the expedition using the IODP Sample and Data Request Database (**http://iodp.tamu.edu/curation/samples.html**). Based on shipboard and shore-based research plans submitted by this deadline, the SAC will prepare a tentative sampling plan, which will be revised on the ship as dictated by recovery and cruise objectives. The sampling plan will be subject to modification depending upon the actual material recovered and collaborations that may evolve between scientists during the expedition. The SAC must approve modifications of the strategy during the expedition. Given the specific objectives of the South China Sea Expeditions 367 and 368, great care will be taken to maximize shared sampling to promote integration of data sets and enhance scientific collaboration among members of the scientific party so that our scientific objectives are met and each scientist has the opportunity to contribute. 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 may be unavoidable, but minimizing the duplication of measurements among the shipboard party and identified shore-based collaborators will be a major factor in evaluating sample requests. Substantial collaboration and cooperation will be required.

Shipboard sampling will be restricted to shipboard measurements, any samples that are ephemeral, and possibly very limited, very low resolution samples for personal research that are required to define plans for the postcruise sampling meeting. Whole-round samples may be taken for, but not limited to, interstitial water measurements, microbiology, and petrophysical measurements as dictated by the shipboard sampling plan that will be finalized during the first few days of each expedition. We plan that nearly all sampling for postexpedition research will be postponed until a shore-based sampling meeting that will be implemented ~3–5 months after the end of Expedition 368 at the Gulf Coast Repository in College Station, Texas, USA.

If some critical intervals are recovered, there may be considerable demand for samples from a limited amount of cored material. These intervals may require special handling, a higher sampling density, reduced sample size, or continuous core sampling for the highest priority research objectives. The SAC may require an additional formal sampling plan before critical intervals are sampled and a special sampling plan will be developed to maximize scientific participation and to preserve some material for future studies. The SAC can decide at any stage during the expedition or during the moratorium period, which recovered intervals should be considered critical.

During the expeditions, all archive halves will be permanent archives and will not be sampled. Following both expeditions, the curator will finalize the archive halves designated as permanent over any intervals recovered from multiple holes at a site.

Following Expeditions 367 and 368, cores will be delivered to the IODP Gulf Coast Repository in College Station for the postcruise sampling meeting. One combined sampling meeting will be held for both expeditions. All collected data and samples will be protected by a 1 y moratorium period following the completion of the postexpedition sampling meeting. During this moratorium, all Expeditions 367 and 368 data and samples will be available only to the expedition shipboard scientists and approved shore-based participants.

Expedition scientists and scientific participants

The current list of participants for Expeditions 367 and 368 can be found at **http://iodp.tamu.edu/scienceops/expeditions/south_china_sea_II.html**.

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Table T1. Operations plan, Expedition 367. EPSP = Environmental Protection and Safety Panel. APC = advanced piston corer, XCB = extended core barrel. FMS = Formation MicroScanner, VSI = Versatile Seismic Imager. HRT = Casing Hanger/Running Tool.

Site	Location (latitude longitude)	Seafloor Depth (mbrf)	Operations Description	Transit (days)	Drilling & Coring (days)	Wireline Logging (days)
Starting Port: Hong Kong			Begin Expedition 5.0		port call	
			Transit ~255 nmi to SCSII-1A @ 10.5 kts	1.0		
SCSII-1A	18.45472° N	3769	Hole A - APC/XCB to refusal (~650 mbsf) Logging with triple combo and FMS-sonic		5.7	1.1
pending EPSP	116.13167° E		Hole B - Reentry Installation - Drill in 10.75" casing with HRT system		3.5	
approval			RCB coring from 650 mbsf to 1467 mbsf - Logging with triple combo, FMS-sonic, VSI		14.3	1.8
			(sediment-basement contact at 1217 mbsf)			
			Sub-Total Days On-Site: 26.4			
			Transit ~10 nmi to SCSII-8B @ 10.5 kts	0		
SCSII-8B	18.30518° N	3809	Hole A - APC/XCB to refusal (~650 mbsf) Logging with triple combo and FMS-sonic		5.6	1.1
pending EPSP	116.21953° E		Hole B - Reentry Installation - Drill in 10.75" casing with HRT system		3.4	
approval			RCB coring from 650 mbsf to 1566 mbsf - Logging with triple combo, FMS-sonic, VSI		15.6	1.8
			(sediment-basement contact at 1316 mbsf)			
			Sub-Total Days On-Site: 26.3			
			Transit ~265 nmi to Hong Kong @ 10.5 kts	1.1		
End Port: Hong Kong			End Expedition	2.1	48.0	5.9

Port Call:	5.0	Total Operating Days:	56.0
Sub-Total On-Site:	53.9	Total Expedition:	61.0

Table T2. Operations plan, Expedition 368. EPSP = Environmental Protection and Safety Panel. APC = advanced piston corer, XCB = extended core barrel. FMS = Formation MicroScanner, VSI = Versatile Seismic Imager. HRT = Casing Hanger/Running Tool.

Site	Location (Latitude Longitude)	Seafloor Depth (mbrf)	Operations Description	Transit (days)	Drilling & Coring (days)	Wireline Logging (days)
Starting Port: Hong Kong			Begin Expedition 5.0		port call	
			Transit ~223 nmi to SCSII-41A @ 10.5 kts	0.9		
SCSII-41A	18.88488° N	2868	Hole A - APC/XCB to refusal (~650 mbsf) Logging with triple combo and FMS-sonic		4.9	1.1
pending EPSP	115.76571° E		Hole B - Reentry Installation - Drill in 10.75" casing with HRT system		3.2	
approval			RCB coring from 650 mbsf to 892 mbsf - Logging with triple combo, FMS-sonic, & VSI		4.5	1.3
			(sediment-basement contact at 792 mbsf)			
			Sub-Total Days On-Site: 15.0			
			Transit ~54 nmi to SCSII-9B @ 10.5 kts	0.2		
SCSII-9B	18.14383° N	3862	Hole A - APC/XCB to refusal (~650 mbsf) Logging with triple combo and FMS-sonic		5.5	1.1
pending EPSP	116.31410° E		Hole B - Reentry Installation - Drill in 10.75" casing with HRT system		3.5	
approval			RCB coring from 650 mbsf to 1670 mbsf - Logging with triple combo, FMS-sonic, & VSI		15.1	2.0
			(sediment-basement contact at 1570 mbsf)			
			Sub-Total Days On-Site: 27.2			
			Contingency time		11.6	
			Transit ~276 nmi to Hong Kong @ 10.5 kts	1.1		
End Port: Hong Kong			End Expedition	2.2	48.3	5.5

Port Call:	5.0	Total Operating Days:	56.0
Sub-Total On-Site:	53.8	Total Expedition:	61.0

Table T3. Primary and alternate proposed site locations, Expeditions 367 and 368. SCS = South China Sea.

Site	Latitude	Longitude	Water depth (m)	Penetration (m)			Brief site specific objectives
				Sediment	Basement	Total	
SCSII- 41A	18.88488°N	115.76571°E	2870	792	100	892	Recover synrift and postrift sediments; constrain age, duration, and environment of rifting and breakup; determine subsidence history. High priority for Objectives 3 and 4.
SCSII-3D	18.91761°N	115.85897°E	2930	1220	100	1320	Recover synrift and postrift sediments; constrain age, duration, and environment of rifting and breakup; determine subsidence history. High priority for Objectives 3 and 4. Alternate to SCSII-41A.
SCSII-40A	18.883819°N	115.74777	2890	564	100	664	Recover synrift and postrift sediments; constrain age, duration, and environment of rifting and breakup; determine subsidence history. High priority for Objectives 3 and 4. Alternate to SCSII-41A.
SCSII-42A	18.87879°N	115.75434°E	2920	684	100	784	Recover synrift and postrift sediments; constrain age, duration, and environment of rifting and breakup; determine subsidence history. High priority for Objectives 3 and 4. Alternate to SCSII-41A.
SCSII-43A	18.89011°N	115.87523°E	2890	1196	100	1296	Recover synrift and postrift sediments; constrain age, duration, and environment of rifting and breakup; determine subsidence history. High priority for Objectives 3 and 4. Alternate to SCSII-41A.
SCSII-44A	18.55578°N	116.61029°E	3252	508	100	608	Recover synrift and postrift sediments; constrain age, duration, and environment of rifting and breakup; determine subsidence history. High priority for Objectives 3 and 4. Alternate to SCSII-41A.
SCSII- 1A	18.4547167°N	16.13167°E	3748	1217	250	1467	Determine nature of basement: exhumed serpentinized mantle? upper/lower continental crust or igneous basement? Determine time and environment of final breakup and subsequent subsidence. High priority for Objectives 1, 2, 3, and 4.
SCSII- 1B	18.44379°N	116.13824°E	3762	1211	250	1461	Determine nature of basement: exhumed serpentinized mantle? upper/lower continental crust or igneous basement? Determine time and environment of final breakup and subsequent subsidence. High priority for Objectives 1, 2, 3, and 4. Alternate for SCSII-1A.
SCSII-11A	18.41089°N	115.88519 °E	3770	1132	250	1382	Determine nature of basement: exhumed serpentinized mantle? upper/lower continental crust or igneous basement? Determine time and environment of final breakup and subsequent subsidence. High priority for Objectives 1, 2, 3, and 4. Alternate for SCSII-1A.
SCSII-14A	18.40952°N	115.85979°E	3770	813	250	1063	Determine nature of basement: exhumed serpentinized mantle? upper/lower continental crust or igneous basement? Determine time and environment of final breakup and subsequent subsidence. High priority for Objectives 1, 2, 3, and 4. Alternate for SCSII-1A.
SCSII-15A	18.45816°N	115.99908°E	3760	1373	250	1623	Determine nature of basement: exhumed serpentinized mantle? upper/lower continental crust or igneous basement? Determine time and environment of final breakup and subsequent subsidence. High priority for Objectives 1, 2, 3, and 4. Alternate for SCSII-1A.
SCSII-16A	18.4701°N	116.22724°E	3768	596	250	846	Determine nature of basement: exhumed serpentinized mantle? upper/lower continental crust or igneous basement? Determine time and environment of final breakup and subsequent subsidence. High priority for Objectives 1, 2, 3, and 4. Alternate for SCSII-1A.
SCSII-17A	18.46453°N	116.23063°E	3772	730	250	980	Determine nature of basement: exhumed serpentinized mantle? upper/lower continental crust or igneous basement? Determine time and environment of final breakup and subsequent subsidence. High priority for Objectives 1, 2, 3, and 4. Alternate for SCSII-1A.
SCSII-18A	18.45679°N	116.23505°E	3773	918	250	1168	Determine nature of basement: exhumed serpentinized mantle? upper/lower continental crust or igneous basement? Determine time and environment of final breakup and subsequent subsidence. High priority for Objectives 1, 2, 3, and 4. Alternate for SCSII-1A.
SCSII-8B	18.30518°N	116.21953°E	3811	1316	250	1566	Determine nature of basement: exhumed serpentinized mantle or igneous ocean crust? Determine paleodepth and initial subsidence of the very earliest SCS ocean basin. High priority for Objectives 1 and 2.
SCSII-20A	18.29°N	116.08056°E	3797	1467	250	1717	Determine nature of basement: exhumed serpentinized mantle or igneous ocean crust? Determine paleodepth and initial subsidence of the very earliest SCS ocean basin. High priority for Objectives 1 and 2. Alternate for SCSII-8B.
SCSII-21A	18.32794°N	116.31058°E	3826	1640	250	1890	Determine nature of basement: exhumed serpentinized mantle or igneous ocean crust? Determine paleodepth and initial subsidence of the very earliest SCS ocean basin. High priority for Objectives 1 and 2. Alternate for SCSII-8B.
SCSII-9B	18.14383°N	116.31410°E	3880	1570	100	1670	Determine nature of oceanic crust: was a robust mantle-melting regime established shortly after breakup or not? High priority for Objectives 1 and 2.
SCSII-30A	18.13798°N	116.2753°E	3863	1600	100	1700	Determine nature of oceanic crust: was a robust mantle-melting regime established shortly after breakup or not? High priority for Objectives 1 and 2. Alternate for SCSII-9B.
SCSII-31A	18.16994°N	116.39837°E	3890	1612	100	1712	Determine nature of oceanic crust: was a robust mantle-melting regime established shortly after breakup or not? High priority for Objectives 1 and 2. Alternate for SCSII-9B.

Figure F1. Seismic data coverage and magnetic anomalies of South China Sea Basin. Black lines = ocean-bottom seismometer data. Other seismic lines are mostly multichannel seismic reflection data. Red solid stars = primary proposed Expedition 367/368 drill sites; yellow stars = alternate proposed sites. Site names are abbreviated by deleting the prefix "SCSII-". ODP Leg 184 and IODP Expedition 349 drill sites are shown with site numbers. For more details, see Figure **F2**.

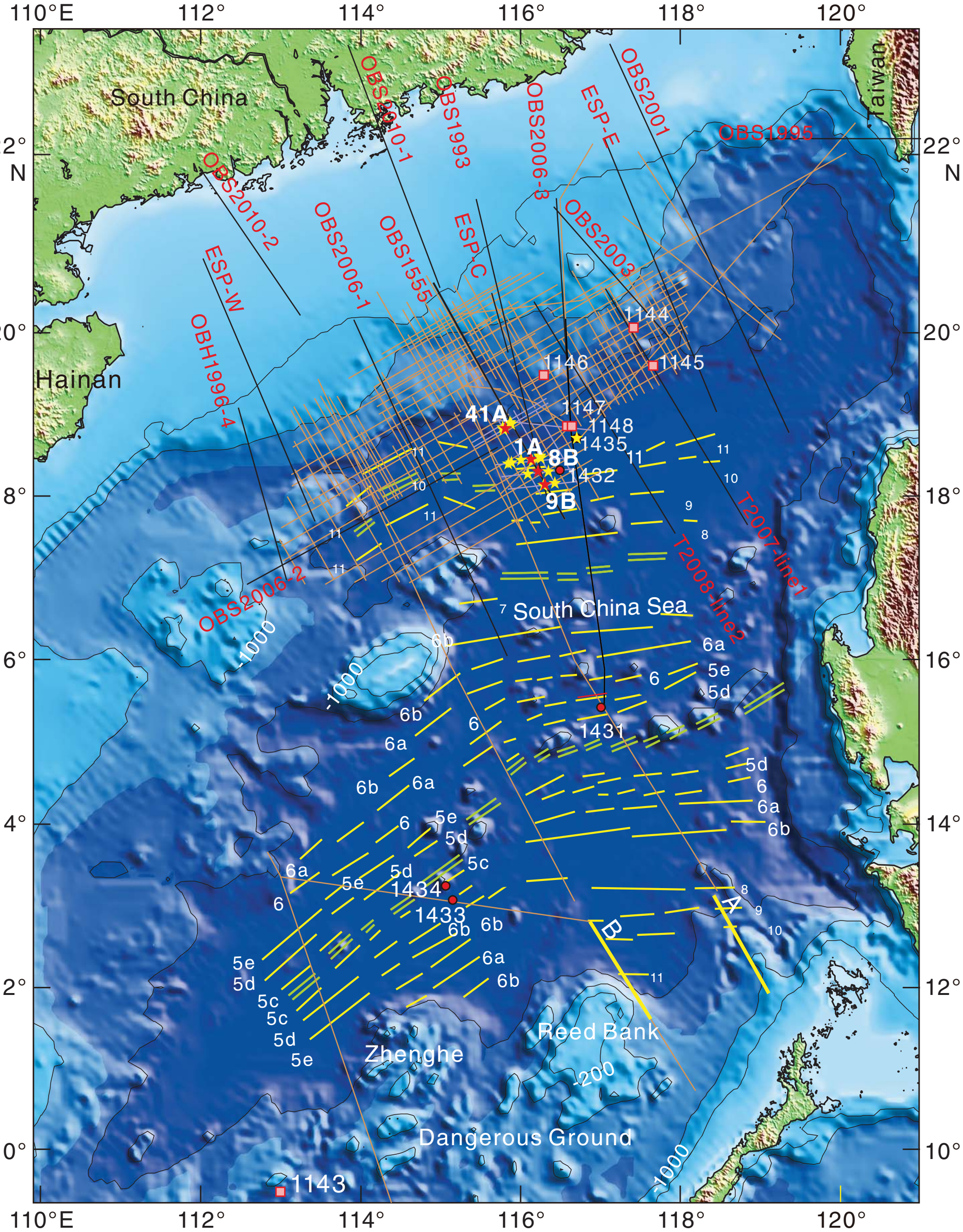


Figure F2. Northern South China Sea rifted margin with seismic coverage of 2-D, time-migrated multichannel seismic reflection seismic data and ocean-bottom seismometer data (3-D data not shown). Key seismic lines used for planning of the drilling transect are marked in thick blue and shown in Figures F3 and F4. Proposed Expedition 367/368 drill sites are shown (red solid stars = primary proposed sites, white stars = alternate proposed sites). Previous ODP Leg 184 and IODP Expedition 349 sites are shown as orange or yellow squares. Magnetic lineations within the ocean crust are shown in red with interpreted chrons after Briais et al. (1993).

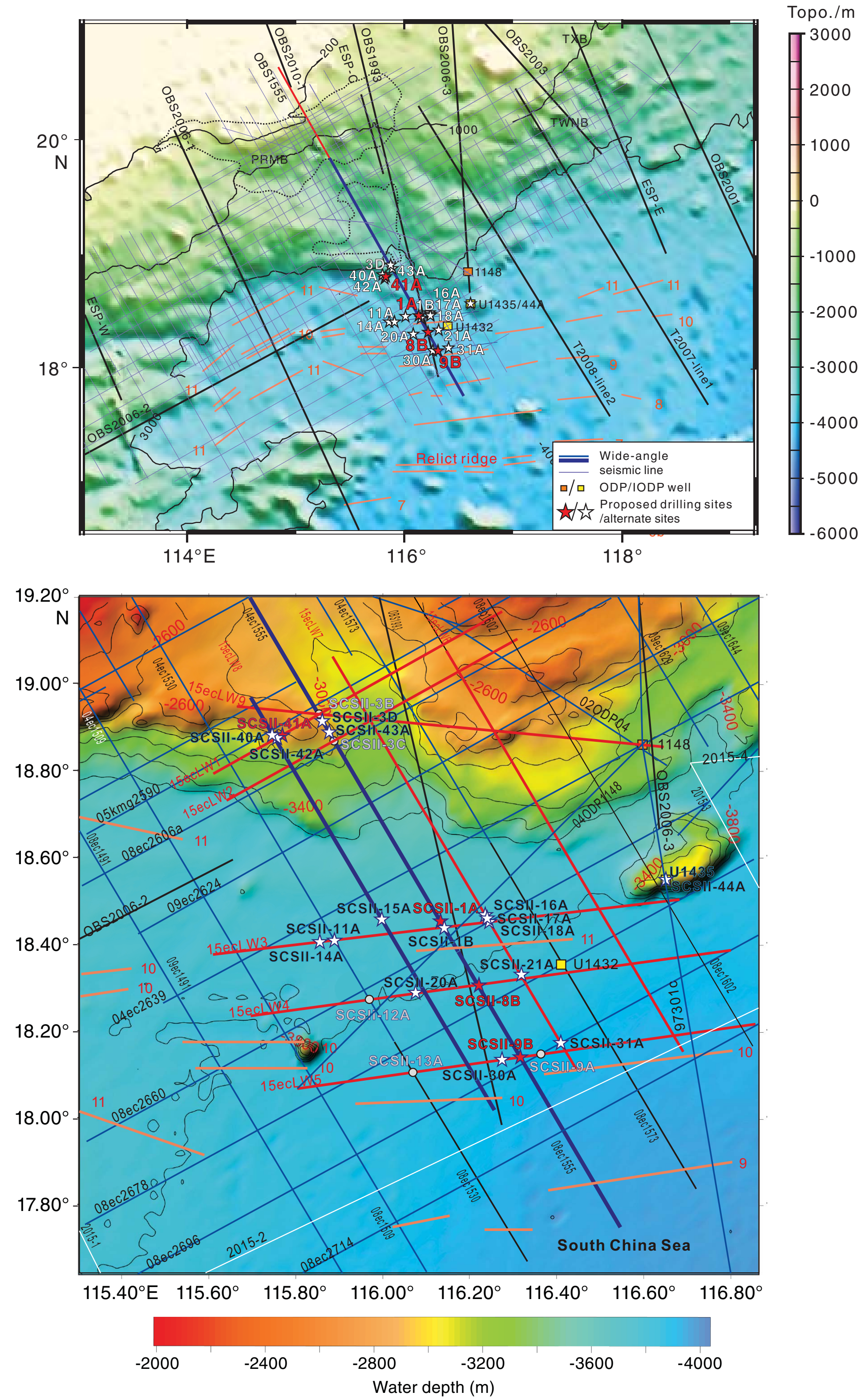


Figure F3. Two-way traveltime to (A) basement (Tg unconformity) and (B) Reflector T60. The proposed drilling transect (thick black line) is located approximately at the center of a margin segment bounded to the southwest by a transform fault (thick gray dashed line). The northeastern boundary of the margin segment is located around Expedition 349 Site U1435 (also named alternate proposed Site SCSII-44A in this prospectus). In this location, the outer margin high and Ridge A seem to coalesce, and Ridges B and C of the continent–ocean transition become indistinct toward the northeast within the next margin segment. Note that the outer margin high is slightly oblique to parallel Ridges A, B, and C.

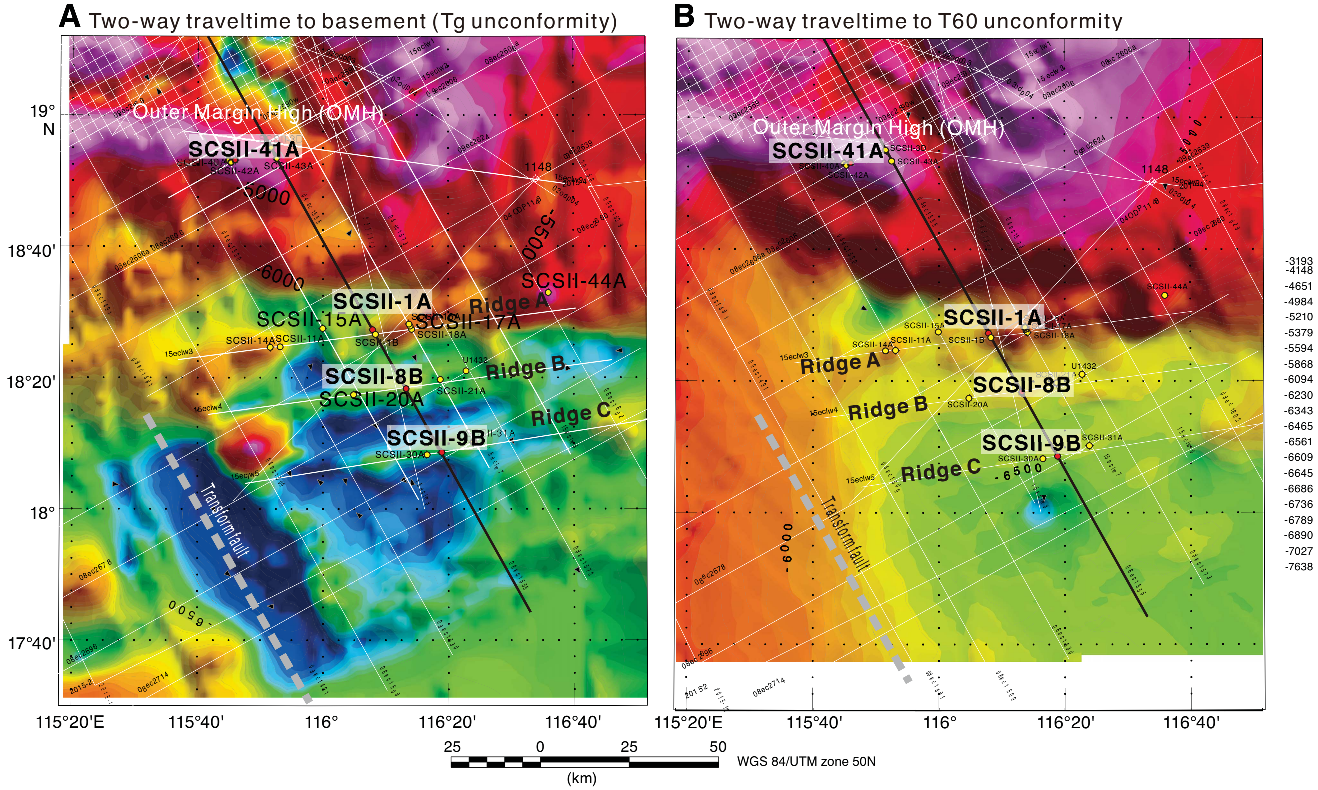


Figure F4. Deep crustal time-migrated seismic reflection data (A) without interpretation and (B) with interpretation. Note the rather thin lower crust (two layers) above a strong Mohorovicic seismic discontinuity (Moho) reflector that can be followed oceanward. Moho reflection is weak to absent seaward from around the interpreted continent–ocean transition (COT). Wide-angle seismic data (Yan et al., 2001) confirm ~6 km thick ocean-type crust to be present seaward of the COT. A large detachment fault ~150 km inland of the COT separates more stable crust landward from that of highly extended crust seaward. An outer margin high is a fairly consistent feature along this margin segment. Key seismic unconformities are shown in purple (T70; ~32 Ma breakup unconformity?) and blue (T60; ~23 Ma regional basin event). These ages are inferred from long distance (>100 km) correlation of seismic unconformities with industry holes and ODP Leg 184 Site 1148 (T60). These ages need confirmation by coring, and are only tentative. Tg unconformity (green) is basement. Approximate position of seafloor magnetic anomalies with chron numbers are shown by arrows. See Figure **F6** for a schematic interpretation of the entire profile. Seismic data is from Line 04ec1555-08ec1555 (courtesy of the Chinese National Offshore Oil Corporation). Location of line is shown in Figure **F2**.

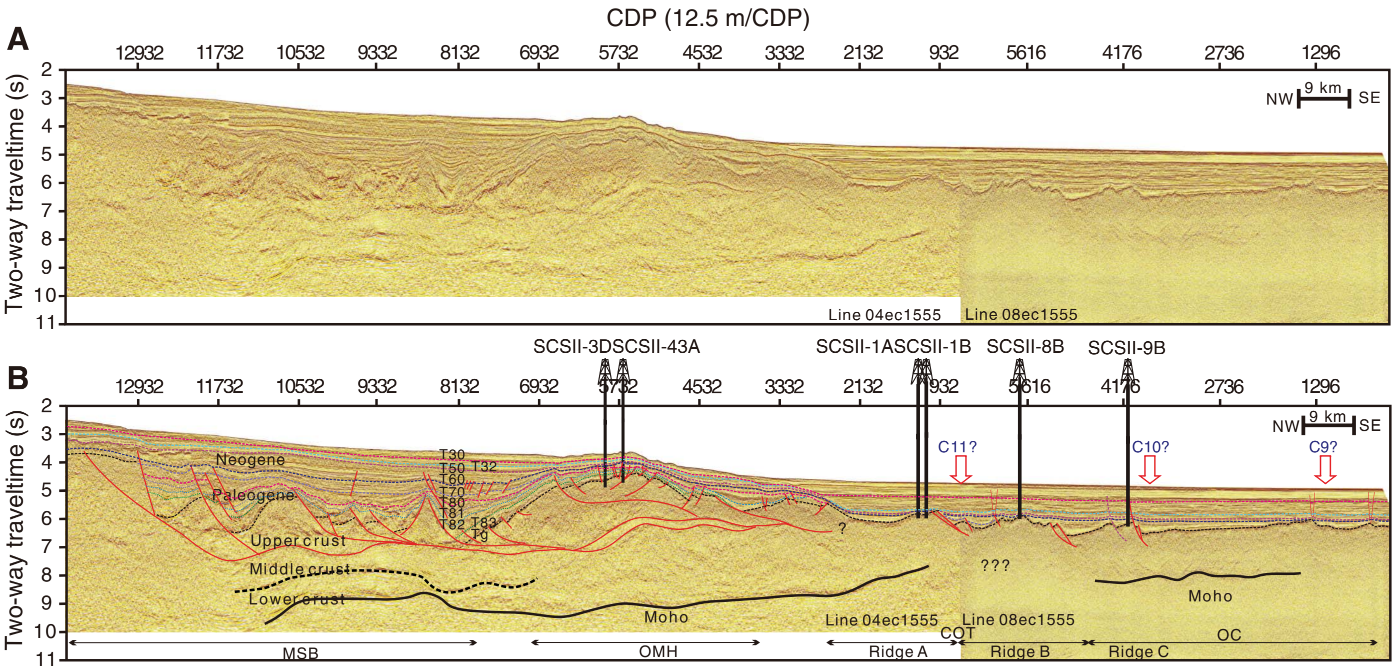


Figure F5. New (2015) deep crustal time-migrated seismic reflection Profile 15ecLW8 (A) without interpretation and (B) with interpretation. The line is located parallel to and ~12.5 km southwest of Line 1555 shown in Figures **F2** and **F3**. The crustal structure shown by the two lines is quite similar. However, the Mohorovicic seismic discontinuity is better imaged from below the outer margin high and across the continent–ocean transition on this profile. Key seismic unconformities are shown in purple (T70; ~32 Ma) and black (T60; ~23 Ma). See also Figure **F4**. Tg unconformity (black) is basement. Alternate proposed drill sites are shown on this profile, but primary proposed Site SCSII-41A is located ~2 km northeast from alternate proposed Site SCSII-42A, along Line 15ecLW1 (Figures **F2**, **F3**). Data courtesy of the Chinese National Offshore Oil Corporation.

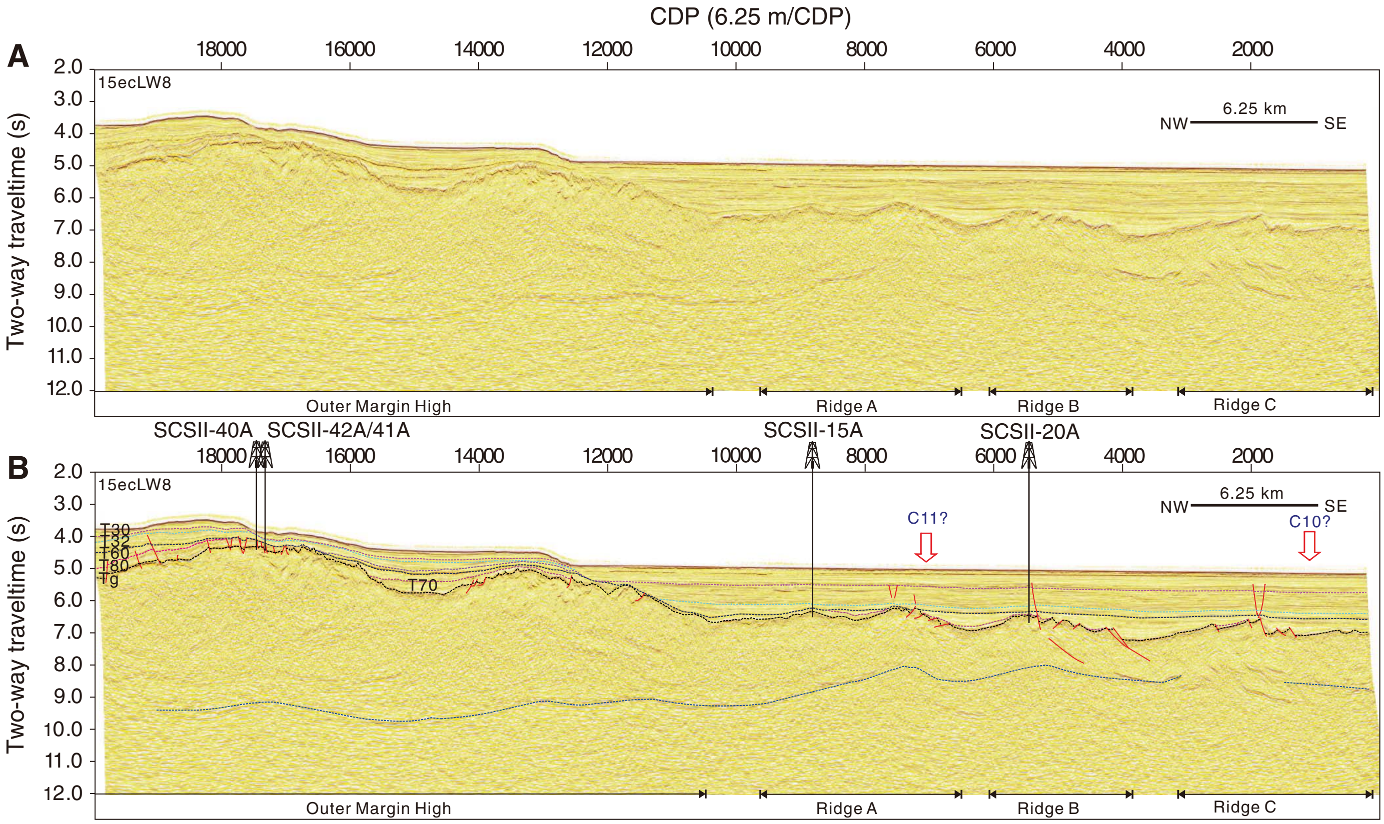


Figure F6. Simplified interpretation of seismic data shown in Figure **F4**. Note the seaward shallowing of the Mohorovicic seismic discontinuity (Moho) and presence of major detachment faults that seem to sole out between the upper and middle/lower crust. Although the general location of the continent–ocean transition (COT; white with question marks) is well constrained by both seismic profiles (Figures **F3**, **F4**), the details of crustal structure within the COT are not well constrained. The seismic line in Figure **F5** images this zone slightly better, in particular regarding the Moho.

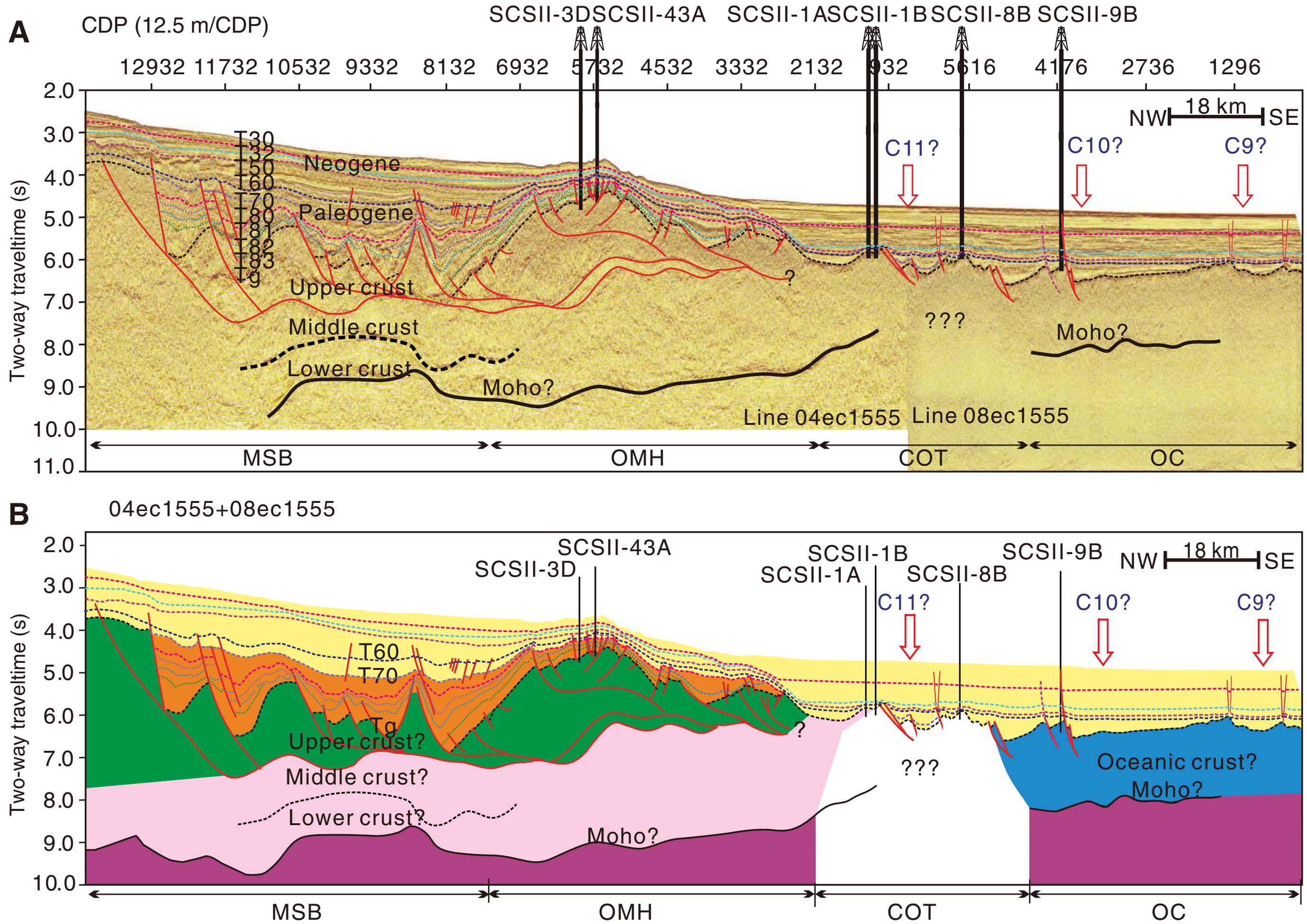


Figure F7. A–D. Schematic development of continental breakup initiated by a simple shear along a deep, low-angle fault with generalized locations of proposed drill sites (bottom). B–D are slightly modified from Huismans and Beaumont (2011) and illustrate modeling based stages of extension at magma-poor rifted margins of the Iberia-Newfoundland type.Key features of the final margin structure are thinning of the lower crust, juxtaposition of upper crustal structural units to lower crust or serpentinized mantle (proposed Site SCSII-1A), and a fairly wide zone of serpentinite crust (proposed Sites SCSII-8B and SCSII-9B?) between the outer margin and igneous oceanic crust. The northern South China Sea margin shows a striking general similarity to the left side of the upper plate margin in D. However, only sampling by drilling of the key structural units can discriminate between this and other possible models. UP = upper plate, LP = lower plate.

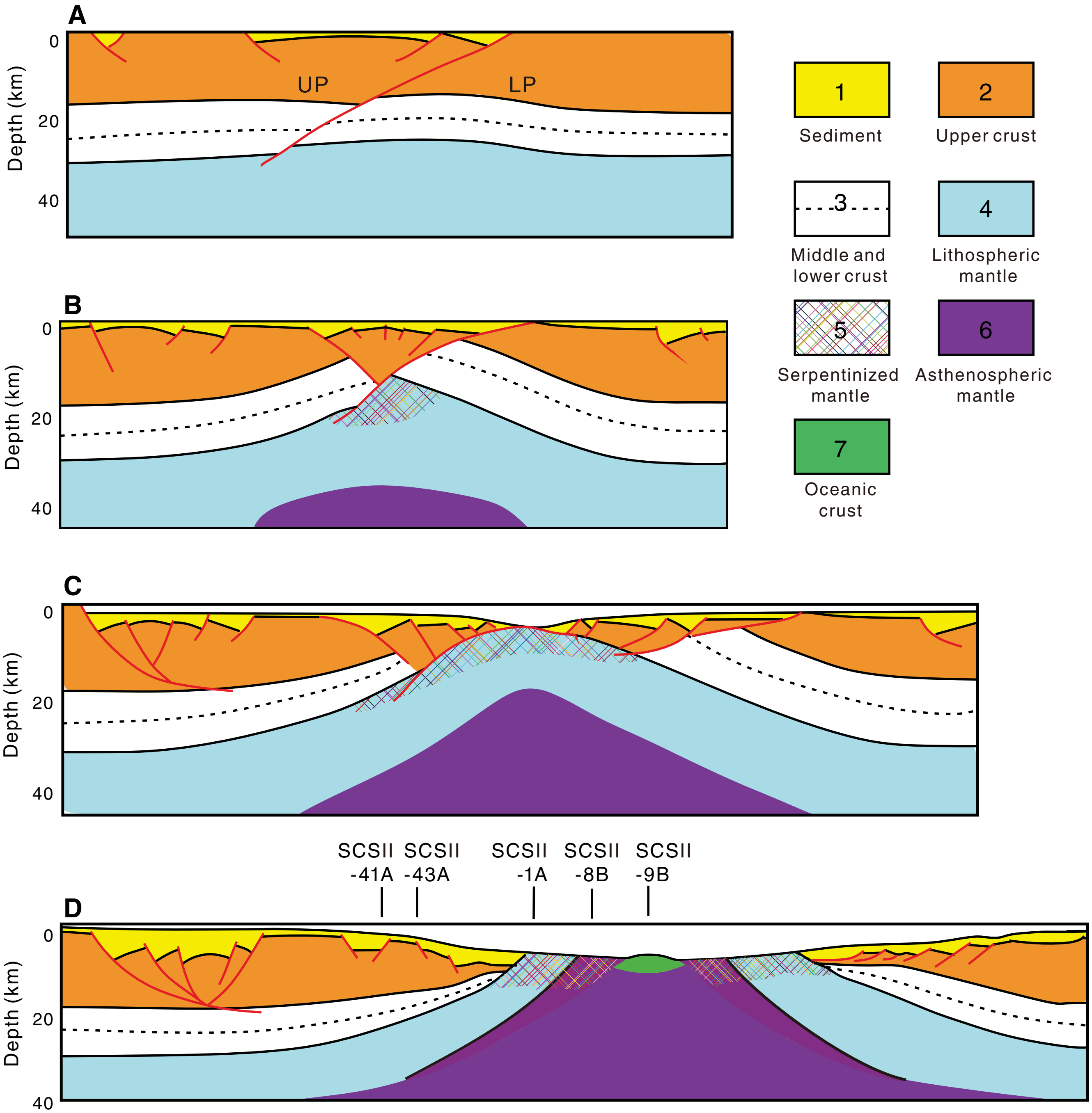
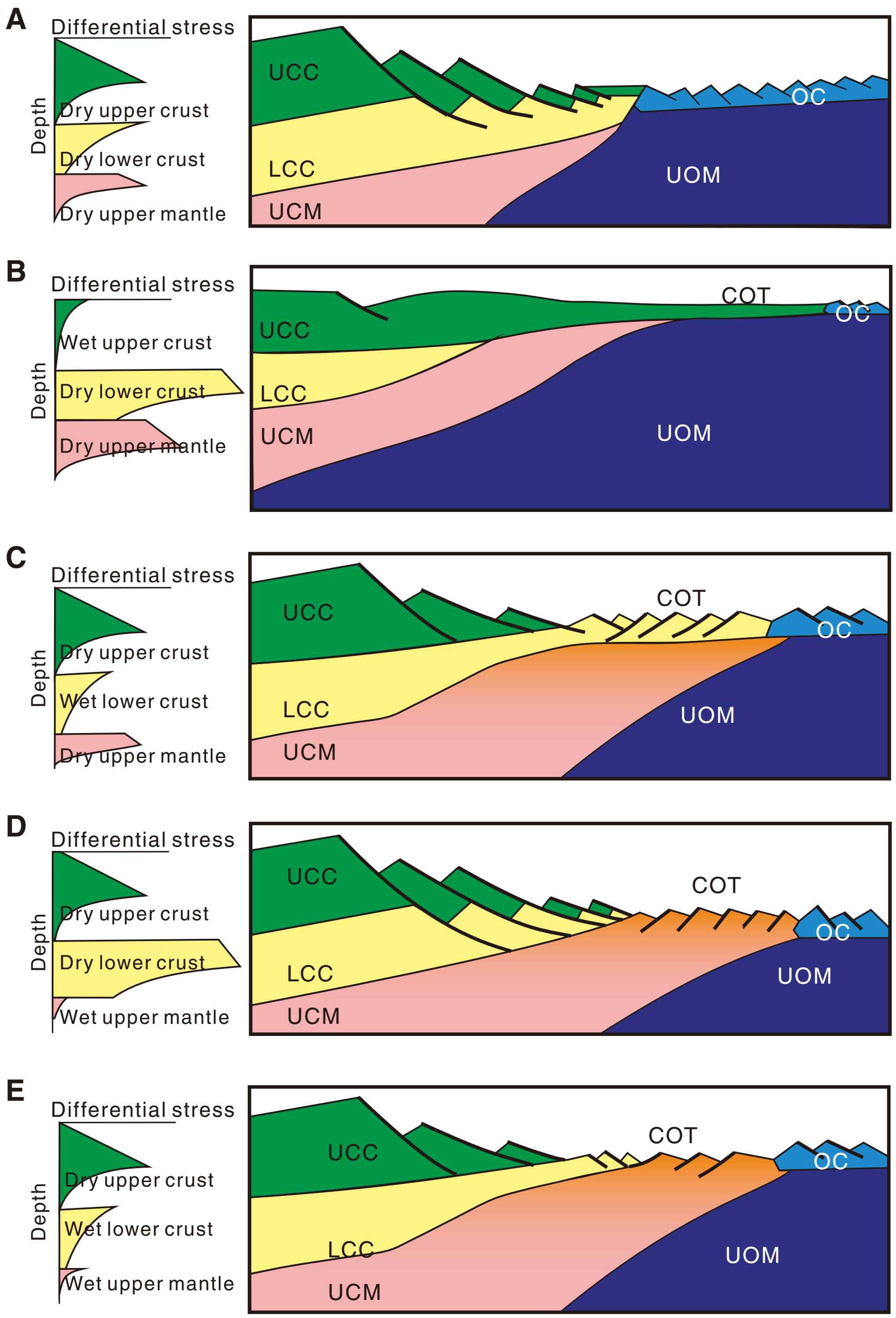


Figure F8. A–E. Composite figures redrawn from models in Huismans et al. (2011), Sibuet and Tucholke (2012), Makris et al. (2012), and Sun et al. (2016) showing the spectrum of possible magma-poor rifted margin models that can be tested with the proposed drilling transect. The variations in the models are due to different initial rheologies in the upper and lower crust and in the upper mantle; these rheologic differences cause variations in stretching of the various lithospheric layers. Model in D features a strong lower crust overlying a weak, wet upper mantle, resulting in upper subcontinental (serpentinized) mantle dominating the continent–ocean transition (COT). A particularly interesting alternative is shown in C, in which moderately weaker lower crust leads to its exhumation in the COT. UCC = upper continental crust, LCC = lower continental crust, UCM = upper continental mantle, UOM = upper oceanic mantle, OC = oceanic crust.



Site summaries

Site SCSII-41A

Priority:	Primary
Position:	18.88488°N, 115.76571°E
Water depth (m):	2870
Target drilling depth (mbsf):	892 (792 sediment; 100 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF2**) Primary and crossing seismic lines (Figure **AF3**)
Objective(s):	Recover synrift and postrift sediment; constrain age, duration, and environment of rifting and breakup; determine subsidence history. High priority for • Constraining the rate of extension and vertical crustal movements, and • Improving the understanding of the Cenozoic regional tectonic and environmental development of the Southeast Asia margin and SCS by combining Expedition 367/368 results with existing ODP/IODP sediment records and regional seismic data.
Drilling program:	Hole A: APC/XCB to refusal (~650 mbsf) Hole B: reentry Installation (drill in 10.75 inch casing with HRT system) RCB coring from ~650 to 892 mbsf Sediment/basement contact at ~792 mbsf
Logging/Downhole measurements program:	Triple combo and FMS-sonic of entire section VSI experiment only in deep section (below casing)
Nature of rock anticipated:	Deep- to shallow-marine mudstone, siltstone, and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Site SCSII-3D

Priority:	Alternate to SCSII-41A
Position:	18.91761°N, 115.85897°E
Water depth (m):	2930
Target drilling depth (mbsf):	1320 (1220 sediment; 100 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF4**) Seismic lines: primary (Figure **AF5**) and crossing (Figure **AF6**)
Objective(s):	Recover synrift and postrift sediment; constrain age, duration, and environment of rifting and breakup; determine subsidence history. High priority for • Constraining the rate of extension and vertical crustal movements, and • Improving the understanding of the Cenozoic regional tectonic and environmental development of the Southeast Asia margin and SCS by combining Expedition 367/368 results with existing ODP/IODP sediment records and regional seismic data.
Drilling program:	Same as site SCSII-41A
Logging/Downhole measurements program:	Same as site SCSII-41A
Nature of rock anticipated:	Deep- to shallow-marine mudstone, siltstone, and sandstone; granite, gneiss, or metamorphic rock continental crust

Site SCSII-40A

Priority:	Alternate to SCSII-41A
Position:	18.883819°N, 115.74777°E
Water depth (m):	2890
Target drilling depth (mbsf):	664 (564 sediment; 100 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF2**) Primary and crossing seismic lines (Figure **AF3**)
Objective(s):	Recover synrift and postrift sediment; constrain age, duration, and environment of rifting and breakup; determine subsidence history. High priority for • Constraining the rate of extension and vertical crustal movements, and • Improving the understanding of the Cenozoic regional tectonic and environmental development of the Southeast Asia margin and SCS by combining Expedition 367/368 results with existing ODP/IODP sediment records and regional seismic data.
Drilling program:	Same as site SCSII-41A
Logging/Downhole measurements program:	Same as site SCSII-41A
Nature of rock anticipated:	Deep- to shallow-marine mudstone, siltstone, and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Site SCSII-42A

Priority:	Alternate to SCSII-41A
Position:	18.87879°N, 115.75434°E
Water depth (m):	2920
Target drilling depth (mbsf):	784 (684 sediment; 100 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF2**) Primary and crossing seismic lines (Figure **AF3**)
Objective(s):	Recover synrift and postrift sediment; constrain age, duration, and environment of rifting and breakup; determine subsidence history. High priority for • Constraining the rate of extension and vertical crustal movements, and • Improving the understanding of the Cenozoic regional tectonic and environmental development of the Southeast Asia margin and SCS by combining Expedition 367/368 results with existing ODP/IODP sediment records and regional seismic data.
Drilling program:	Same as site SCSII-41A
Logging/Downhole measurements program:	Same as site SCSII-41A
Nature of rock anticipated:	Deep- to shallow-marine mudstone, siltstone, and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Site SCSII-43A

Priority:	Alternate to SCSII-41A
Position:	18.89011°N, 115.87523°E
Water depth (m):	2890
Target drilling depth (mbsf):	1296 (1196 sediment; 100 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF4**) Seismic lines: primary (Figure **AF5**); crossing (Figure **AF7**)
Objective(s):	Recover synrift and postrift sediment; constrain age, duration, and environment of rifting and breakup; determine subsidence history. High priority for • Constraining the rate of extension and vertical crustal movements, and • Improving the understanding of the Cenozoic regional tectonic and environmental development of the Southeast Asia margin and SCS by combining Expedition 367/368 results with existing ODP/IODP sediment records and regional seismic data.
Drilling program:	Same as site SCSII-41A
Logging/Downhole measurements program:	Same as site SCSII-41A
Nature of rock anticipated:	Deep- to shallow-marine mudstone, siltstone, and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Site SCSII-44A

Priority:	Alternate to SCSII-41A
Position:	18.55578°N, 116.61029°E
Water depth (m):	3252
Target drilling depth (mbsf):	608 (508 sediment; 100 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF8**) Primary and crossing seismic lines (Figure **AF9**)
Objective(s):	Recover synrift and postrift sediment; constrain age, duration, and environment of rifting and breakup; determine subsidence history. High priority for • Constraining the rate of extension and vertical crustal movements, and • Improving the understanding of the Cenozoic regional tectonic and environmental development of the Southeast Asia margin and SCS by combining Expedition 367/368 results with existing ODP/IODP sediment records and regional seismic data.
Drilling program:	Same as site SCSII-41A
Logging/Downhole measurements program:	Same as site SCSII-41A
Nature of rock anticipated:	Deep- to shallow-marine mudstone, siltstone, and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Site SCSII-1A

Priority:	Primary
Position:	18.4547167°N, 116.13167°E
Water depth (m):	3748
Target drilling depth (mbsf):	1467 (1217 sediment; 250 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF10**) Primary and crossing seismic lines (Figure **AF11**)
Objective(s):	• Determine the nature of the basement within critical crustal units across the COT of the SCS rifted margin in order to discriminate between different competing models of breakup at magma-poor rifted margins to determine if the subcontinental lithospheric mantle was exhumed during plate rupture. • Determine the time lag between plate rupture and asthenospheric upwelling that allowed decompression melting to generate igneous ocean crust. • Constrain the rate of extension and vertical crustal movements. • Improve the understanding of the Cenozoic regional tectonic and environmental development of the Southeast Asia margin and SCS by combining Expedition 367/368 results with existing ODP/IODP sediment records and regional seismic data.
Drilling program:	Hole A: APC/XCB to refusal (~650 mbsf) Hole B: Reentry installation (drill in 10.75 inch casing with HRT system) RCB coring from ~650 to 1467 mbsf Sediment/basement contact at ~1217 mbsf
Logging/Downhole measurements program:	Triple combo and FMS-sonic of entire section VSI experiment only in deep section (below casing)
Nature of rock anticipated:	Deep- to shallow-marine mudstone, siltstone, and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Site SCSII-1B

Priority:	Alternate to SCSII-1A
Position:	18.44379°N, 116.13824°E
Water depth (m):	3762
Target drilling depth (mbsf):	1461 (1211 sediment; 250 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF10**) Primary and crossing seismic lines (Figure **AF11**)
Objective(s):	• Determine the nature of the basement within critical crustal units across the COT of the SCS rifted margin in order to discriminate between different competing models of breakup at magma-poor rifted margins to determine if the subcontinental lithospheric mantle was exhumed during plate rupture. • Determine the time lag between plate rupture and asthenospheric upwelling that allowed decompression melting to generate igneous ocean crust. • Constrain the rate of extension and vertical crustal movements. • Improve the understanding of the Cenozoic regional tectonic and environmental development of the Southeast Asia margin and SCS by combining Expedition 367/368 results with existing ODP/IODP sediment records and regional seismic data.
Drilling program:	Same as site SCSII-1A
Logging/Downhole measurements program:	Same as site SCSII-1A
Nature of rock anticipated:	Deep- to shallow-marine mudstone, siltstone, and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Site SCSII-11A

Priority:	Alternate to SCSII-1A
Position:	18.44379°N, 116.13824°E
Water depth (m):	3770
Target drilling depth (mbsf):	1382 (1132 sediment; 250 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon; IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF12**) Primary and crossing seismic lines (Figure **AF13**)
Objective(s):	• Determine the nature of the basement within critical crustal units across the COT of the SCS rifted margin in order to discriminate between different competing models of breakup at magma-poor rifted margins to determine if the subcontinental lithospheric mantle was exhumed during plate rupture. • Determine the time lag between plate rupture and asthenospheric upwelling that allowed decompression melting to generate igneous ocean crust. • Constrain the rate of extension and vertical crustal movements. • Improve the understanding of the Cenozoic regional tectonic and environmental development of the Southeast Asia margin and SCS by combining Expedition 367/368 results with existing ODP/IODP sediment records and regional seismic data.
Drilling program:	Same as site SCSII-1A
Logging/Downhole measurements program:	Same as site SCSII-1A
Nature of rock anticipated:	Deep marine siltstone, sandstone; Serpentinized mantle, or upper/lower continental crust, or igneous basement

Site SCSII-14A

Priority:	Alternate to SCSII-1A
Position:	18.40952°N, 115.85979°E
Water depth (m):	3770
Target drilling depth (mbsf):	1063 (813 sediment; 250 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF12**) Primary and crossing seismic lines (Figure **AF13**)
Objective(s):	• Determine the nature of the basement within critical crustal units across the COT of the SCS rifted margin in order to discriminate between different competing models of breakup at magma-poor rifted margins to determine if the subcontinental lithospheric mantle was exhumed during plate rupture. • Determine the time lag between plate rupture and asthenospheric upwelling that allowed decompression melting to generate igneous ocean crust. • Constrain the rate of extension and vertical crustal movements. • Improve the understanding of the Cenozoic regional tectonic and environmental development of the Southeast Asia margin and SCS by combining Expedition 367/368 results with existing ODP/IODP sediment records and regional seismic data.
Drilling program:	Same as site SCSII-1A
Logging/Downhole measurements program:	Same as site SCSII-1A
Nature of rock anticipated:	Deep-marine siltstone and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Site SCSII-15A

Priority:	Alternate to SCSII-1A
Position:	18.45816°N, 115.99908°E
Water depth (m):	3760
Target drilling depth (mbsf):	1623 (1373 sediment; 250 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF14**) Primary and crossing seismic lines (Figure **AF15**)
Objective(s):	• Determine the nature of the basement within critical crustal units across the COT of the SCS rifted margin in order to discriminate between different competing models of breakup at magma-poor rifted margins to determine if the subcontinental lithospheric mantle was exhumed during plate rupture. • Determine the time lag between plate rupture and asthenospheric upwelling that allowed decompression melting to generate igneous ocean crust. • Constrain the rate of extension and vertical crustal movements. • Improve the understanding of the Cenozoic regional tectonic and environmental development of the Southeast Asia margin and SCS by combining Expedition 367/368 results with existing ODP/IODP sediment records and regional seismic data.
Drilling program:	Same as site SCSII-1A
Logging / Downhole measurements program:	Same as site SCSII-1A
Nature of rock anticipated:	Deep- to shallow-marine mudstone, siltstone, and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Site SCSII-16A

Priority:	Alternate to SCSII-1A
Position:	18.4701°N, 116.22724°E
Water depth (m):	3768
Target drilling depth (mbsf):	846 (596 sediment; 250 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF16**) Seismic lines: primary (Figure **AF17**); crossing (Figure **AF18**)
Objective(s):	• Determine the nature of the basement within critical crustal units across the COT of the SCS rifted margin in order to discriminate between different competing models of breakup at magma-poor rifted margins to determine if the subcontinental lithospheric mantle was exhumed during plate rupture. • Determine the time lag between plate rupture and asthenospheric upwelling that allowed decompression melting to generate igneous ocean crust. • Constrain the rate of extension and vertical crustal movements. • Improve the understanding of the Cenozoic regional tectonic and environmental development of the Southeast Asia margin and SCS by combining Expedition 367/368 results with existing ODP/IODP sediment records and regional seismic data.
Drilling program:	Same as site SCSII-1A
Logging/Downhole measurements program:	Same as site SCSII-1A
Nature of rock anticipated:	Deep-marine siltstone and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Site SCSII-17A

Priority:	Alternate to SCSII-1A
Position:	18.46453°N, 116.23063°E
Water depth (m):	3772
Target drilling depth (mbsf):	980 (730 sediment; 250 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF16**) Seismic lines: primary (Figure **AF19**); crossing (Figure **AF18**)
Objective(s):	• Determine the nature of the basement within critical crustal units across the COT of the SCS rifted margin in order to discriminate between different competing models of breakup at magma-poor rifted margins to determine if the subcontinental lithospheric mantle was exhumed during plate rupture. • Determine the time lag between plate rupture and asthenospheric upwelling that allowed decompression melting to generate igneous ocean crust. • Constrain the rate of extension and vertical crustal movements. • Improve the understanding of the Cenozoic regional tectonic and environmental development of the Southeast Asia margin and SCS by combining Expedition 367/368 results with existing ODP/IODP sediment records and regional seismic data.
Drilling program:	Same as site SCSII-1A
Logging/Downhole measurements program:	Same as site SCSII-1A
Nature of rock anticipated:	Deep- to shallow-marine mudstone, siltstone, and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Site SCSII-18A

Priority:	Alternate to SCSII-1A
Position:	18.45679°N, 116.23505°E
Water depth (m):	3773
Target drilling depth (mbsf):	1168 (918 sediment; 250 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF16**) Seismic lines: primary (Figure **AF20**); crossing (Figure **AF18**)
Objective(s):	• Determine the nature of the basement within critical crustal units across the COT of the SCS rifted margin in order to discriminate between different competing models of breakup at magma-poor rifted margins to determine if the subcontinental lithospheric mantle was exhumed during plate rupture. • Determine the time lag between plate rupture and asthenospheric upwelling that allowed decompression melting to generate igneous ocean crust. • Constrain the rate of extension and vertical crustal movements. • Improve the understanding of the Cenozoic regional tectonic and environmental development of the Southeast Asia margin and SCS by combining Expedition 367/368 results with existing ODP/IODP sediment records and regional seismic data.
Drilling program:	Same as site SCSII-1A
Logging/Downhole measurements program:	Same as site SCSII-1A
Nature of rock anticipated:	Deep- to shallow-marine mudstone, siltstone, and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Site SCSII-8B

Priority:	Primary
Position:	18.30518°N, 116.21953°E
Water depth (m):	3811
Target drilling depth (mbsf):	1566 (1316 sediment; 250 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF21**) Primary and crossing seismic lines (Figure **AF22**)
Objective(s):	• Determine nature of basement: exhumed serpentinized mantle or igneous ocean crust? Determine paleodepth and initial subsidence of the very earliest South China Sea ocean basin. • Determine the nature of the basement within critical crustal units across the COT of the SCS rifted margin in order to discriminate between different competing models of breakup at magma-poor rifted margins to determine if the subcontinental lithospheric mantle was exhumed during plate rupture. • Determine the time lag between plate rupture and asthenospheric upwelling that allowed decompression melting to generate igneous ocean crust.
Drilling program:	Hole A: APC/XCB to refusal (~650 mbsf) Hole B: Reentry installation (drill in 10.75 inch casing with HRT system) RCB coring from ~650 to 1566 mbsf Sediment/basement contact at ~1316 mbsf
Logging/Downhole measurements program:	Triple combo and FMS-sonic of entire section VSI experiment only in deep section (below casing)
Nature of rock anticipated:	Deep- to shallow-marine mudstone, siltstone, and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Site SCSII-20A

Priority:	Alternate for SCSII-8B
Position:	18.29°N, 116.08056°E
Water depth (m):	3797
Target drilling depth (mbsf):	1717 (1467 sediment; 250 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF23**) Primary and crossing seismic lines (Figure **AF24**)
Objective(s):	• Determine nature of basement: exhumed serpentinized mantle or igneous ocean crust? Determine paleodepth and initial subsidence of the very earliest South China Sea ocean basin. • Determine the nature of the basement within critical crustal units across the COT of the SCS rifted margin in order to discriminate between different competing models of breakup at magma-poor rifted margins to determine if the subcontinental lithospheric mantle was exhumed during plate rupture. • Determine the time lag between plate rupture and asthenospheric upwelling that allowed decompression melting to generate igneous ocean crust.
Drilling program:	Same as site SCSII-8B
Logging/Downhole measurements program:	Same as site SCSII-8B
Nature of rock anticipated:	Deep- to shallow-marine mudstone, siltstone, and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Site SCSII-21A

Priority:	Alternate for SCSII-8B
Position:	18.32794°N, 116.31058°E
Water depth (m):	3826
Target drilling depth (mbsf):	1890 (1640 sediment; 250 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF25**) Primary and crossing seismic lines (Figure **AF26**)
Objective(s):	• Determine nature of basement: exhumed serpentinized mantle or igneous ocean crust? Determine paleodepth and initial subsidence of the very earliest South China Sea ocean basin. • Determine the nature of the basement within critical crustal units across the COT of the SCS rifted margin in order to discriminate between different competing models of breakup at magma-poor rifted margins to determine if the subcontinental lithospheric mantle was exhumed during plate rupture. • Determine the time lag between plate rupture and asthenospheric upwelling that allowed decompression melting to generate igneous ocean crust.
Drilling program:	Same as site SCSII-8B
Logging/Downhole measurements program:	Same as site SCSII-8B
Nature of rock anticipated:	Deep- to shallow-marine mudstone, siltstone, and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Site SCSII-9B

Priority:	Primary
Position:	18.14383°N, 116.31410°E
Water depth (m):	3880
Target drilling depth (mbsf):	1670 (1570 sediment; 100 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF27**) Seismic lines: primary (Figure **AF28**); crossing (Figure **AF29**)
Objective(s):	• Determine nature of oceanic crust: was a robust mantle-melting regime established shortly after breakup or not? • Determine the nature of the basement within critical crustal units across the COT of the SCS rifted margin in order to discriminate between different competing models of breakup at magma-poor rifted margins to determine if the subcontinental lithospheric mantle was exhumed during plate rupture. • Determine the time lag between plate rupture and asthenospheric upwelling that allowed decompression melting to generate igneous ocean crust.
Drilling program:	Hole A: APC/XCB to refusal (~650 mbsf) Hole B: Reentry installation (drill in 10.75 inch casing with HRT system) RCB coring from ~650 to 1670 mbsf Sediment/basement contact at ~1570 mbsf
Logging/Downhole measurements program:	Triple combo and FMS-sonic of entire section VSI experiment only in deep section (below casing)
Nature of rock anticipated:	Deep- to shallow-marine mudstone, siltstone, and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Site SCSII-30A

Priority:	Alternate to SCSII-9B
Position:	18.13798°N, 116.2753°E
Water depth (m):	3863
Target drilling depth (mbsf):	1700 (1600 sediment; 100 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics.
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF27**) Seismic lines: primary (Figure **AF29**); crossing (Figure **AF28**)
Objective(s):	• Determine nature of oceanic crust: was a robust mantle-melting regime established shortly after breakup or not? • 1. Determining the nature of the basement within critical crustal units across the COT of the South China Sea rifted margin in order to discriminate between different competing models of breakup at nonvolcanic rifted margins, and, specifically, to determine if the sub-continental lithospheric mantle was exhumed during plate rupture. • 2. Examining the scale of time lag between plate rupture and asthenospheric upwelling that allowed decompression melting to generate igneous ocean crust.
Drilling program:	Same as site SCSII-9B
Logging/Downhole measurements program:	Same as site SCSII-9B
Nature of rock anticipated:	Deep- to shallow-marine mudstone, siltstone, and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Site SCSII-31A

Priority:	Alternate to SCSII-9B
Position:	18.16994°N, 116.39837°E
Water depth (m):	3890
Target drilling depth (mbsf):	1712 (1612 sediment; 100 basement)
Approved maximum penetration (mbsf):	Pending EPSP approval
Previous drilling in area:	ODP Leg 184: Asian Monsoon IODP Expedition 349: South China Sea Tectonics
Survey coverage (track map; seismic profile):	Map (Figures **AF1**, **AF30**) Primary and crossing seismic lines (Figure **AF31**)
Objective(s):	• Determine nature of oceanic crust: was a robust mantle-melting regime established shortly after breakup or not? • Determine the nature of the basement within critical crustal units across the COT of the SCS rifted margin in order to discriminate between different competing models of breakup at magma-poor rifted margins to determine if the subcontinental lithospheric mantle was exhumed during plate rupture. • Determine the time lag between plate rupture and asthenospheric upwelling that allowed decompression melting to generate igneous ocean crust.
Drilling program:	Same as site SCSII-9B
Logging/Downhole measurements program:	Same as site SCSII-9B
Nature of rock anticipated:	Deep- to shallow-marine mudstone, siltstone, and sandstone; serpentinized mantle, upper/lower continental crust, or igneous basement

Figure AF1. Bathymetric map with primary (red stars) and alternate (white stars and circles) proposed site locations, Expeditions 367 and 368.

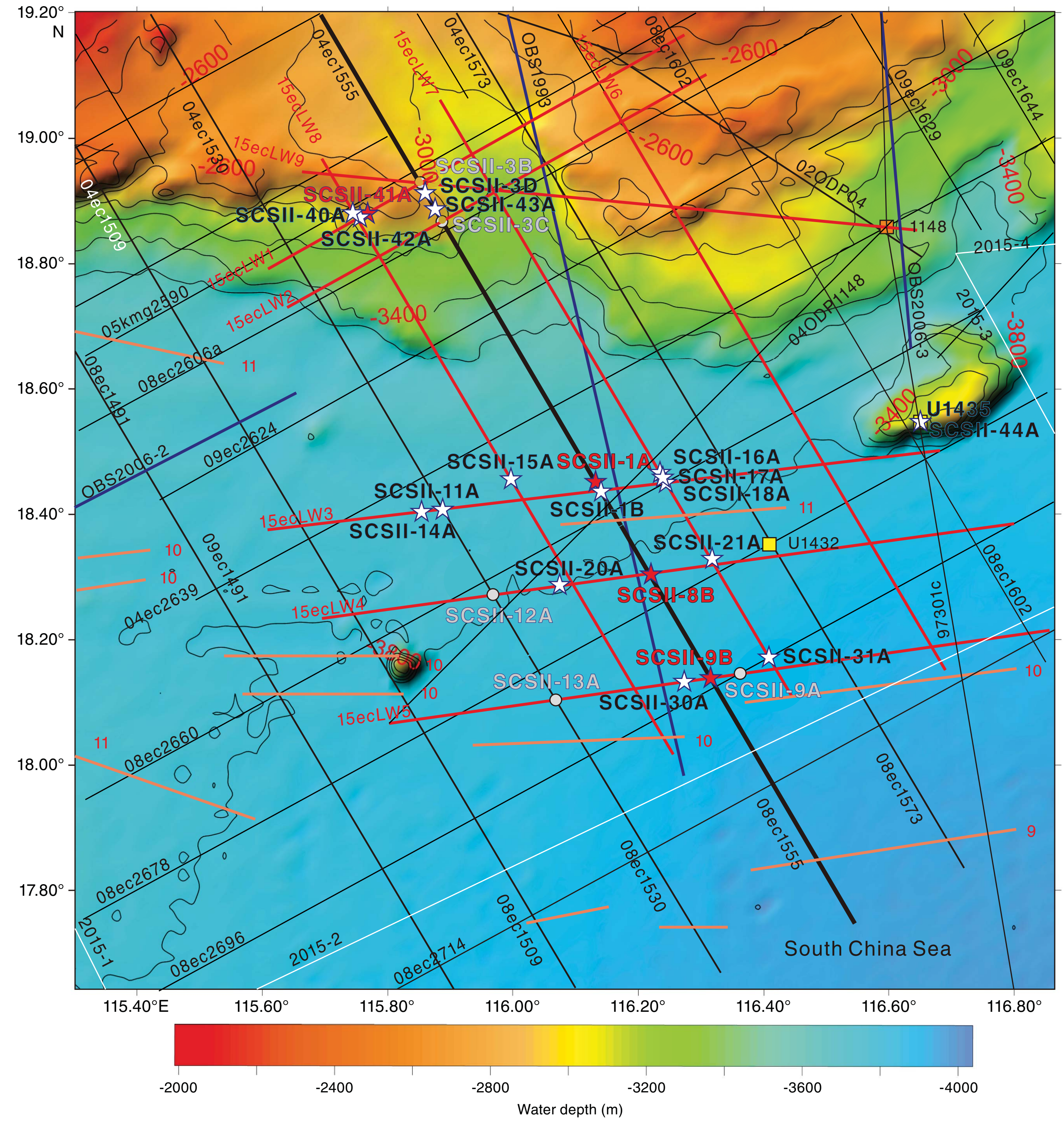


Figure AF2. Bathymetry, proposed Sites SCSII-40A-SCSII-42A.

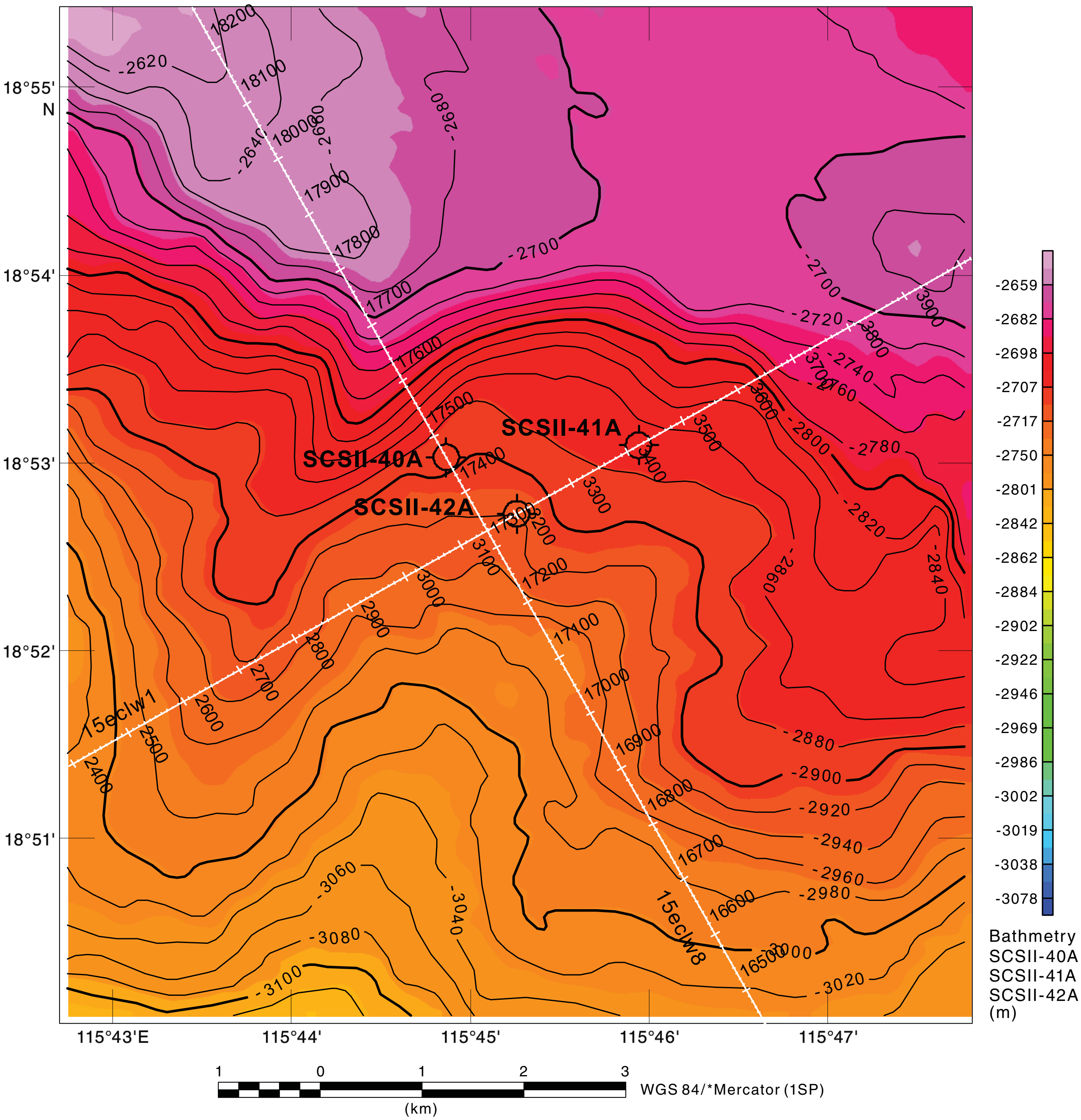
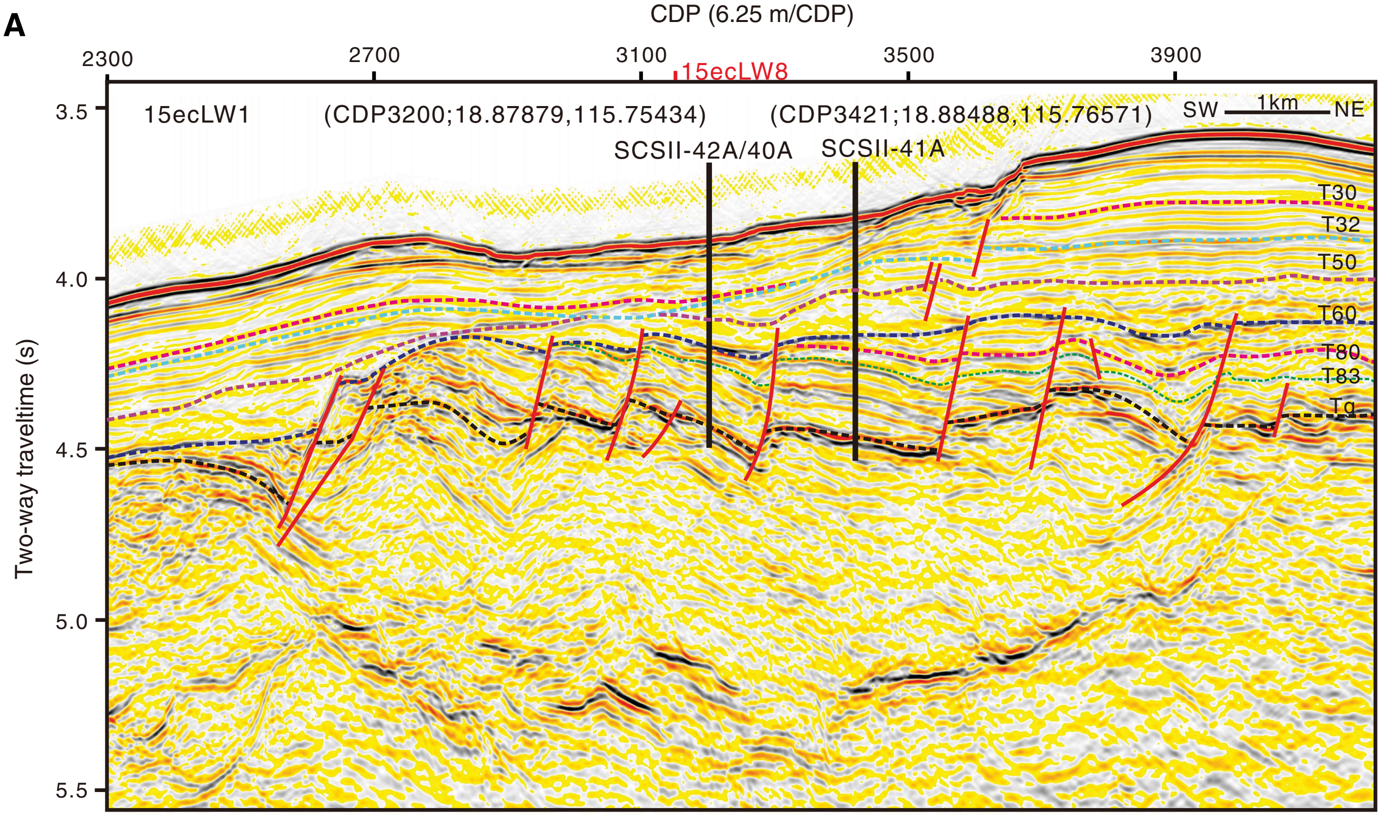


Figure AF3. (A) Primary seismic Line 15ecLW1 and (B) crossing Line 15ecLW8, proposed Sites SCSII-40A-SCSII-42A. CDP = common depth point. Dashed lines = unconformities, solid red lines = faults.



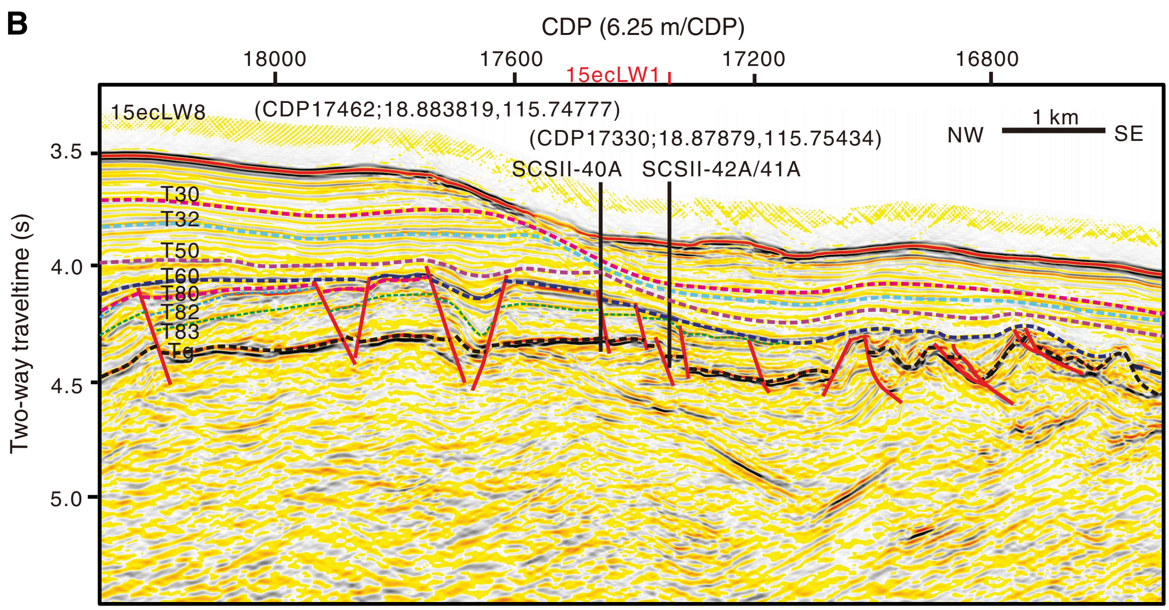


Figure AF4. Bathymetry, proposed Sites SCSII-3D and SCSII-43A.

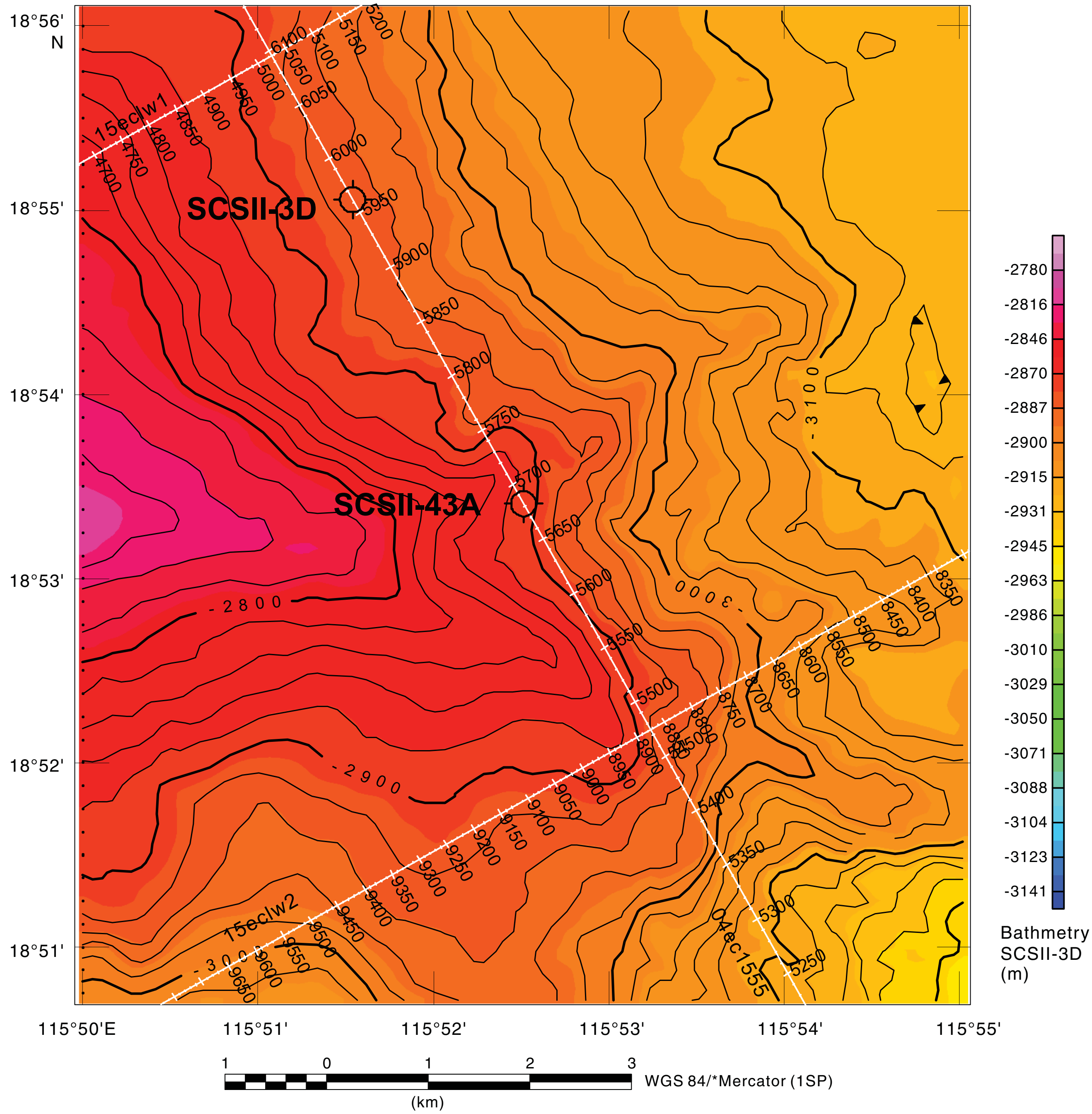


Figure AF5. Primary seismic Line 04ec1555, proposed Sites SCSII-3D and SCSII-43A. CDP = common depth point. Dashed lines = unconformities, solid red lines = faults.

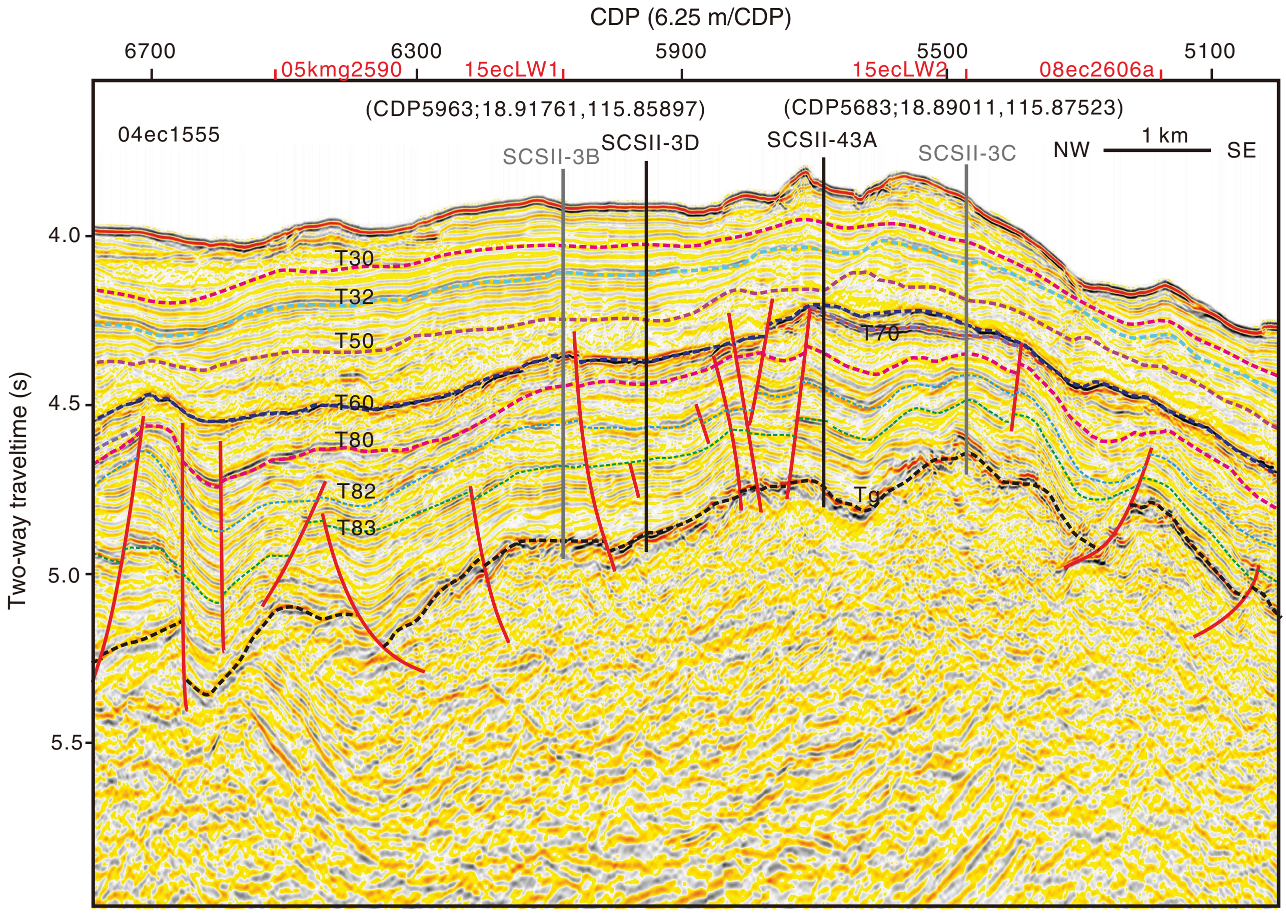


Figure AF6. Crossing seismic Line 15ecLW1, proposed Site SCSII-3D. CDP = common depth point. Dashed lines = unconformities, solid red lines = faults.

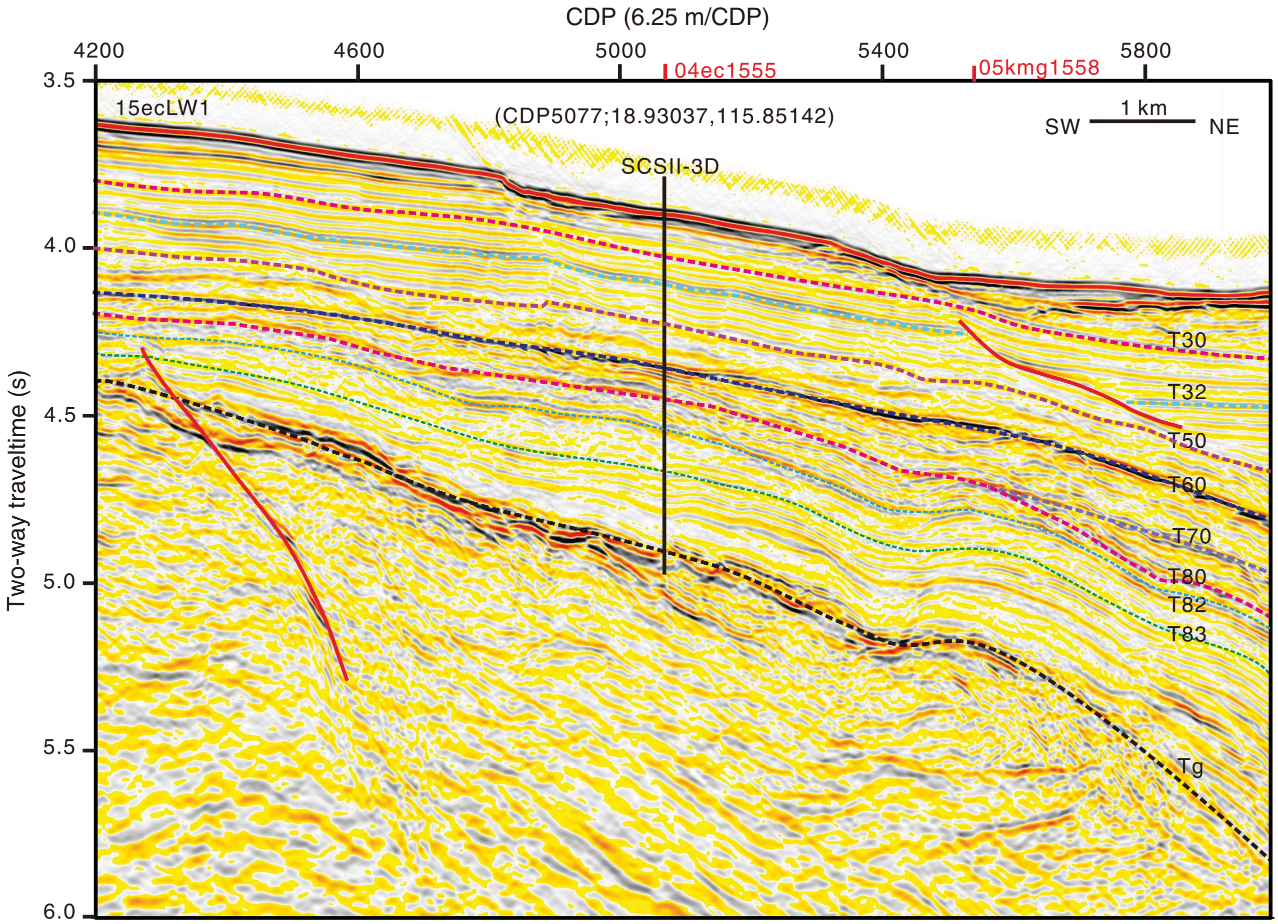


Figure AF7. Crossing seismic Line 15ecLW2, proposed Site SCSII-43A. CDP = common depth point. Dashed lines = unconformities, solid red lines = faults

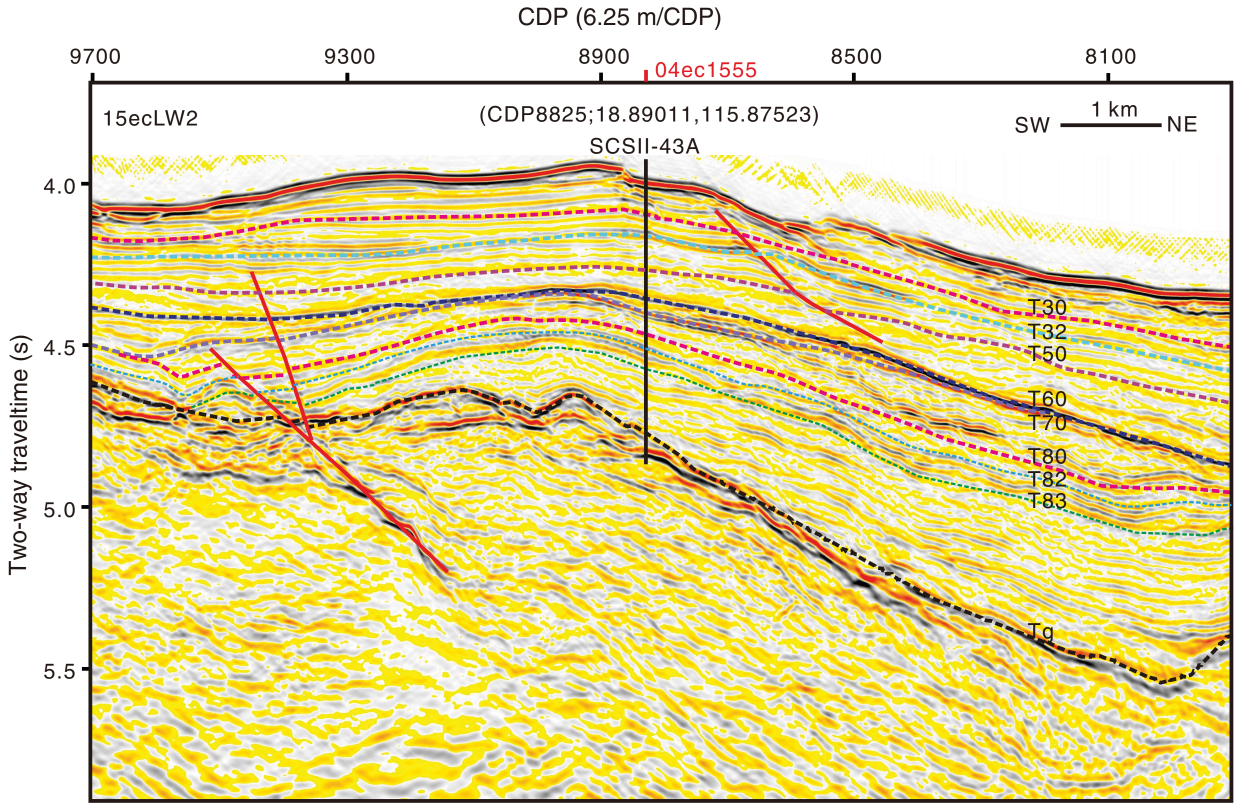


Figure AF8. Bathymetry, proposed Site SCSII-44A.

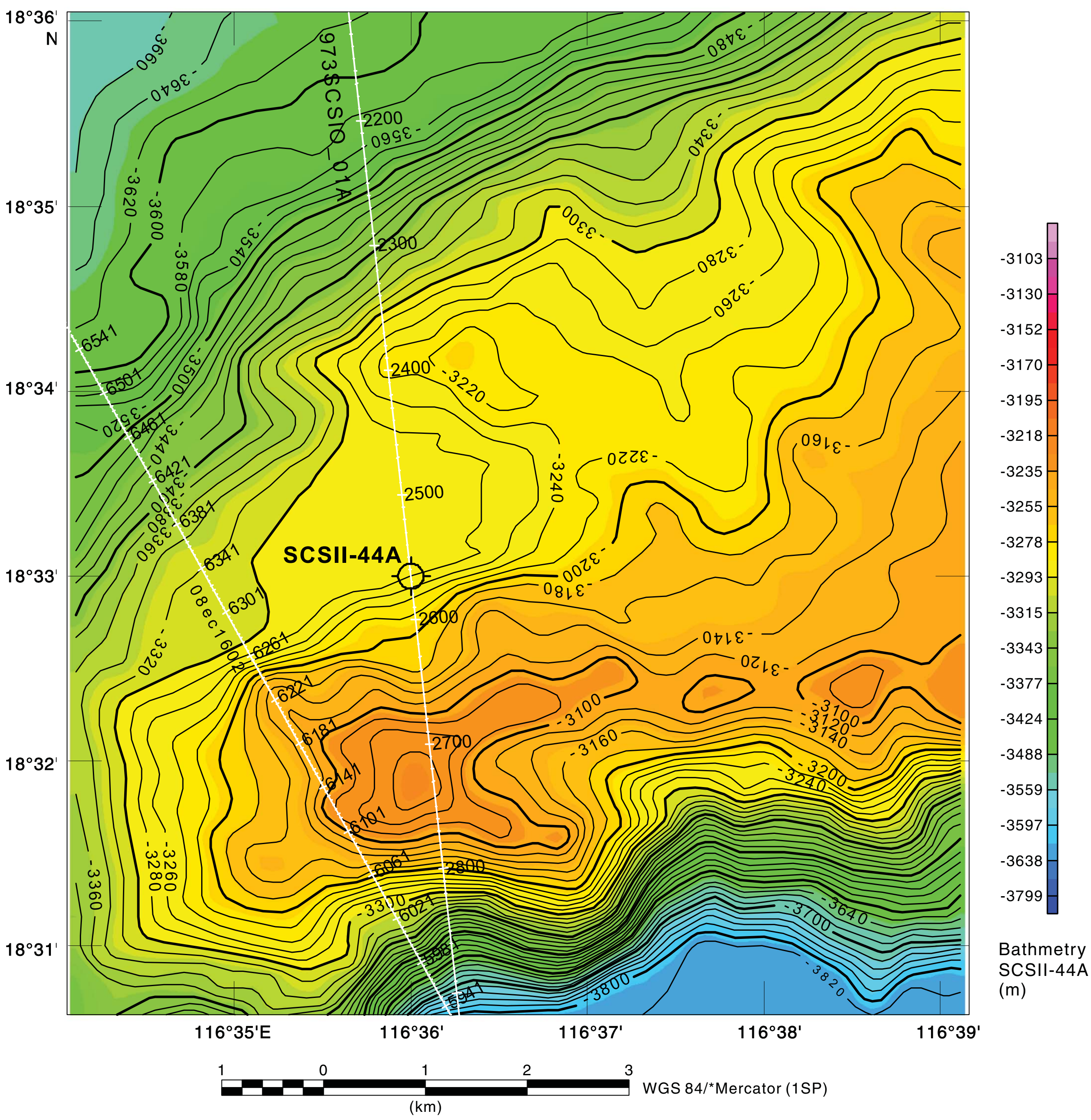


Figure AF9. (A) Primary seismic Line ODP97301c and (B) crossing Line 08ec1602, proposed Site SCSII-44A. CDP = common depth point. Dashed lines = unconformities, solid red lines = faults.

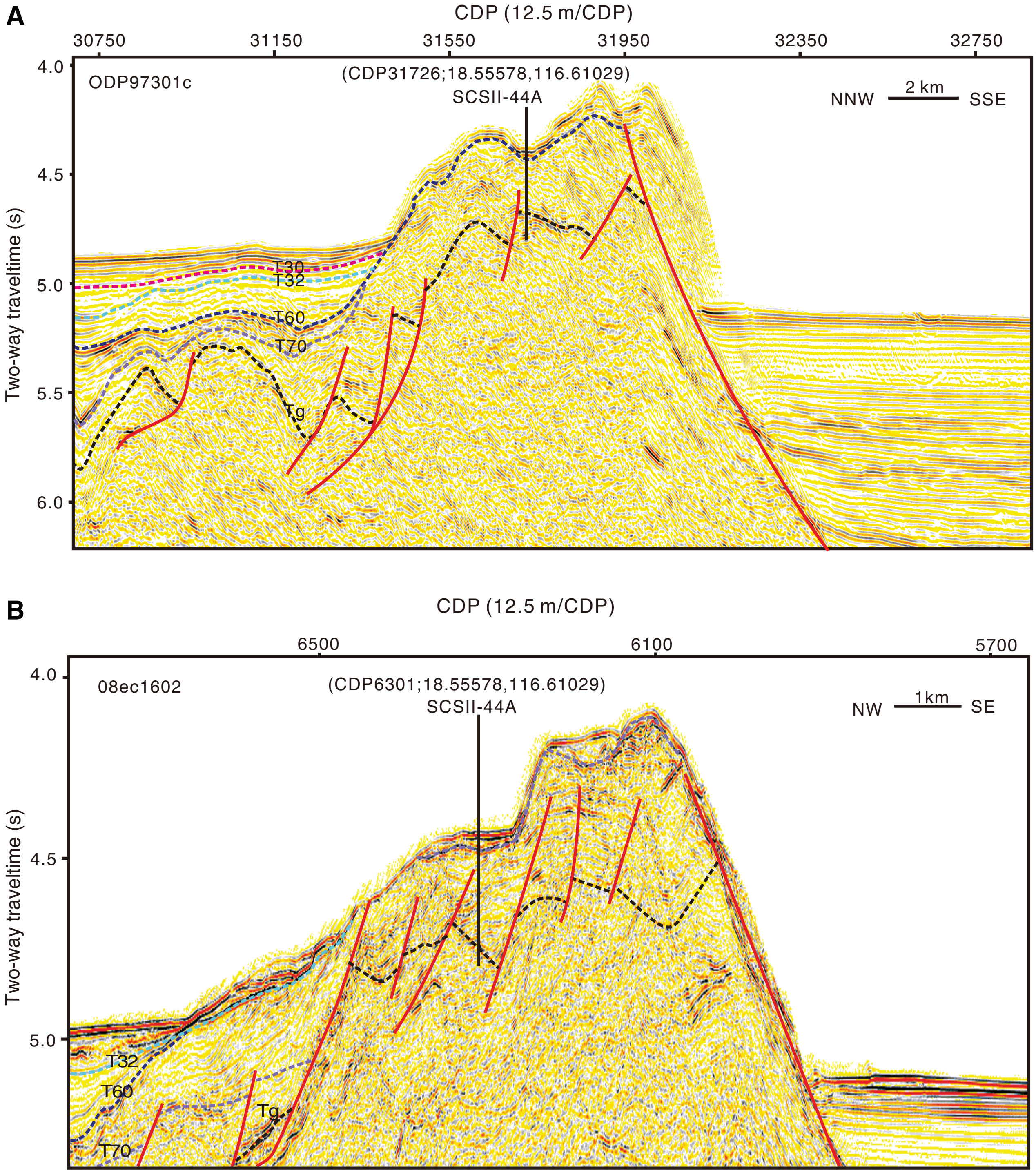


Figure AF10. Bathymetry, proposed Sites SCSII-1A and SCSII-1B.

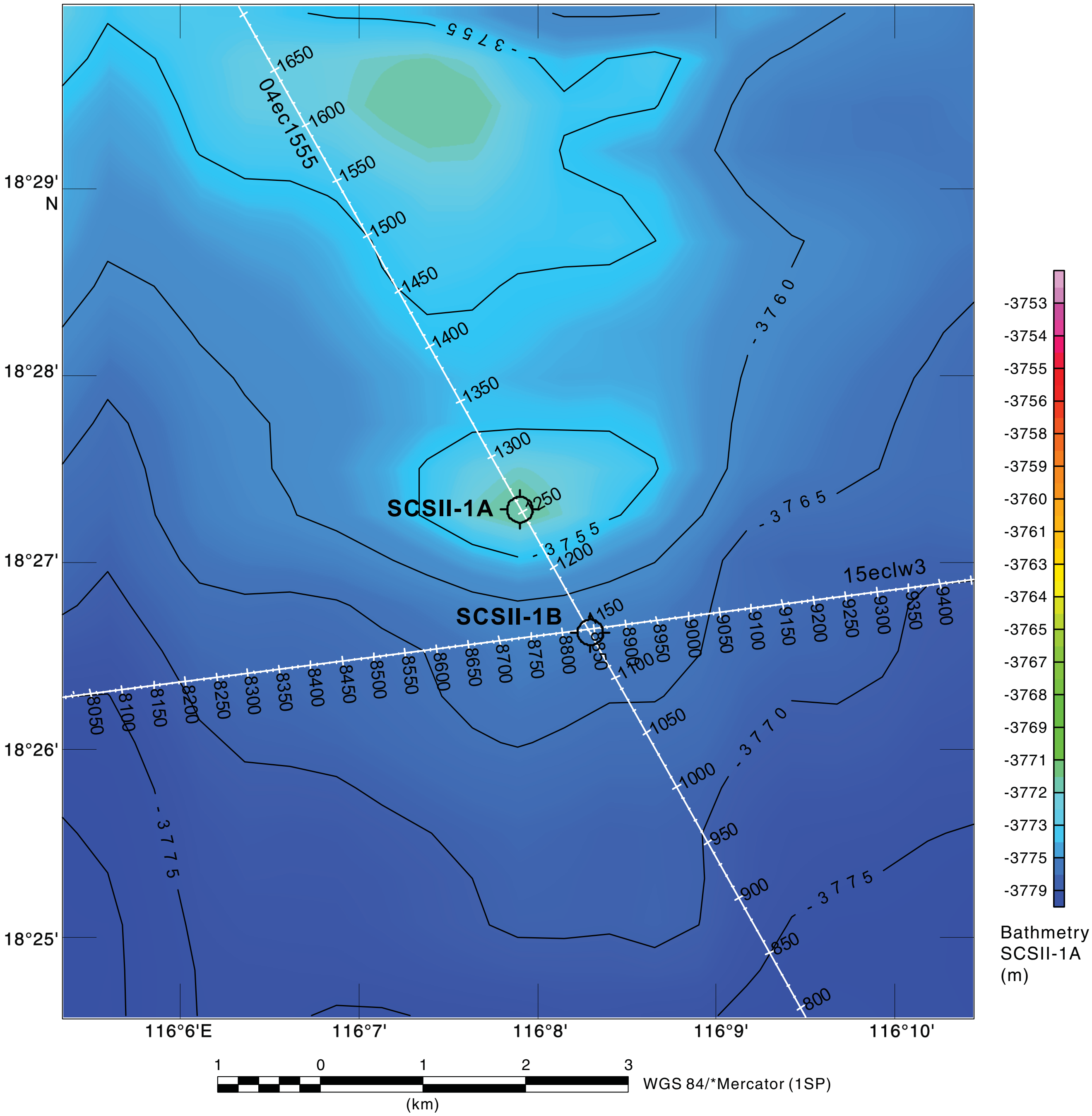


Figure AF11. (A) Primary seismic Line 04ec1555 and (B) crossing Line 15ecLW3, proposed Sites SCSII-1A and SCSII-1B. CDP = common depth point. Dashed lines = unconformities, solid red lines = faults.

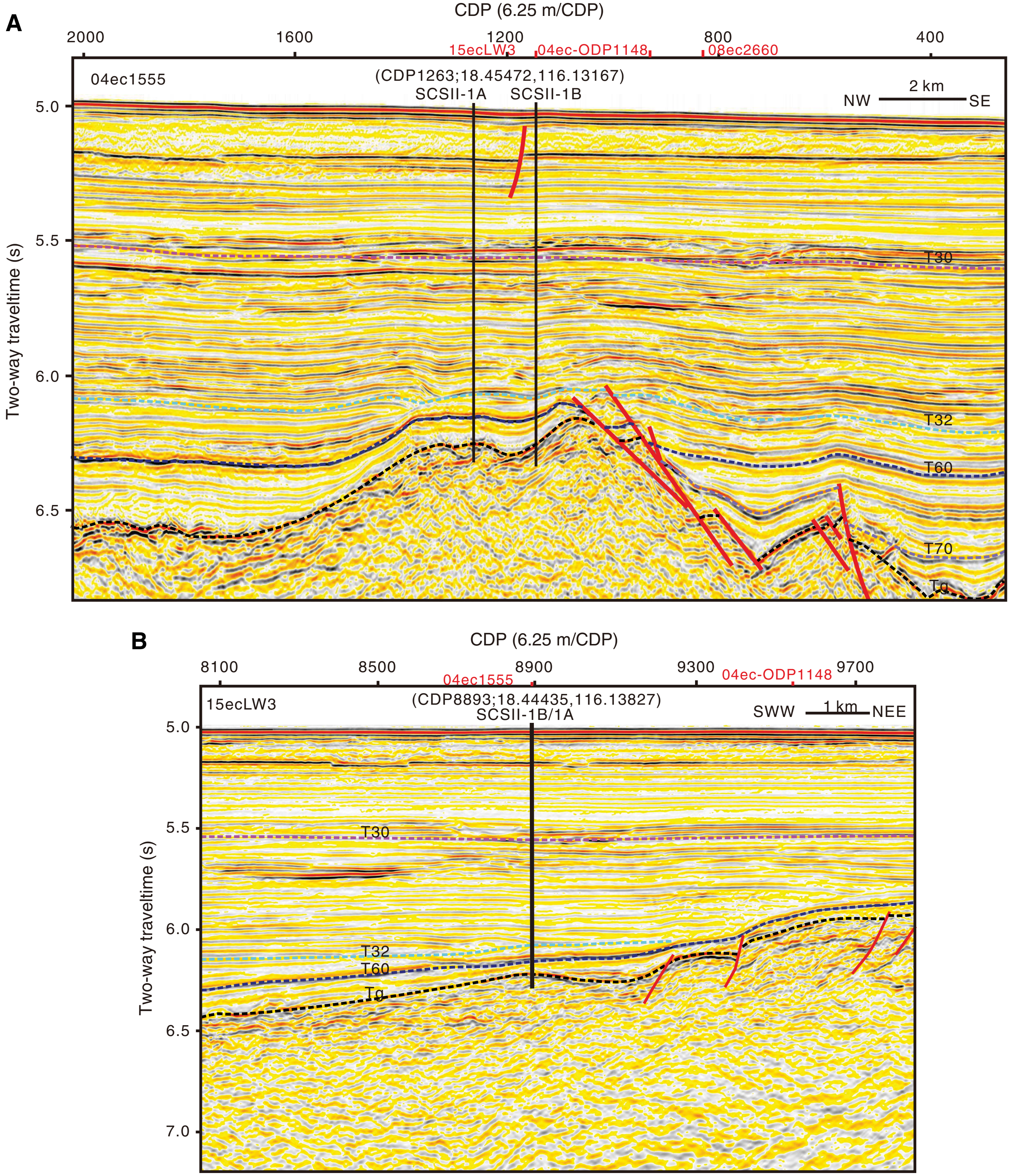


Figure AF12. Bathymetry, proposed Sites SCSII-11A and SCSII-14A.

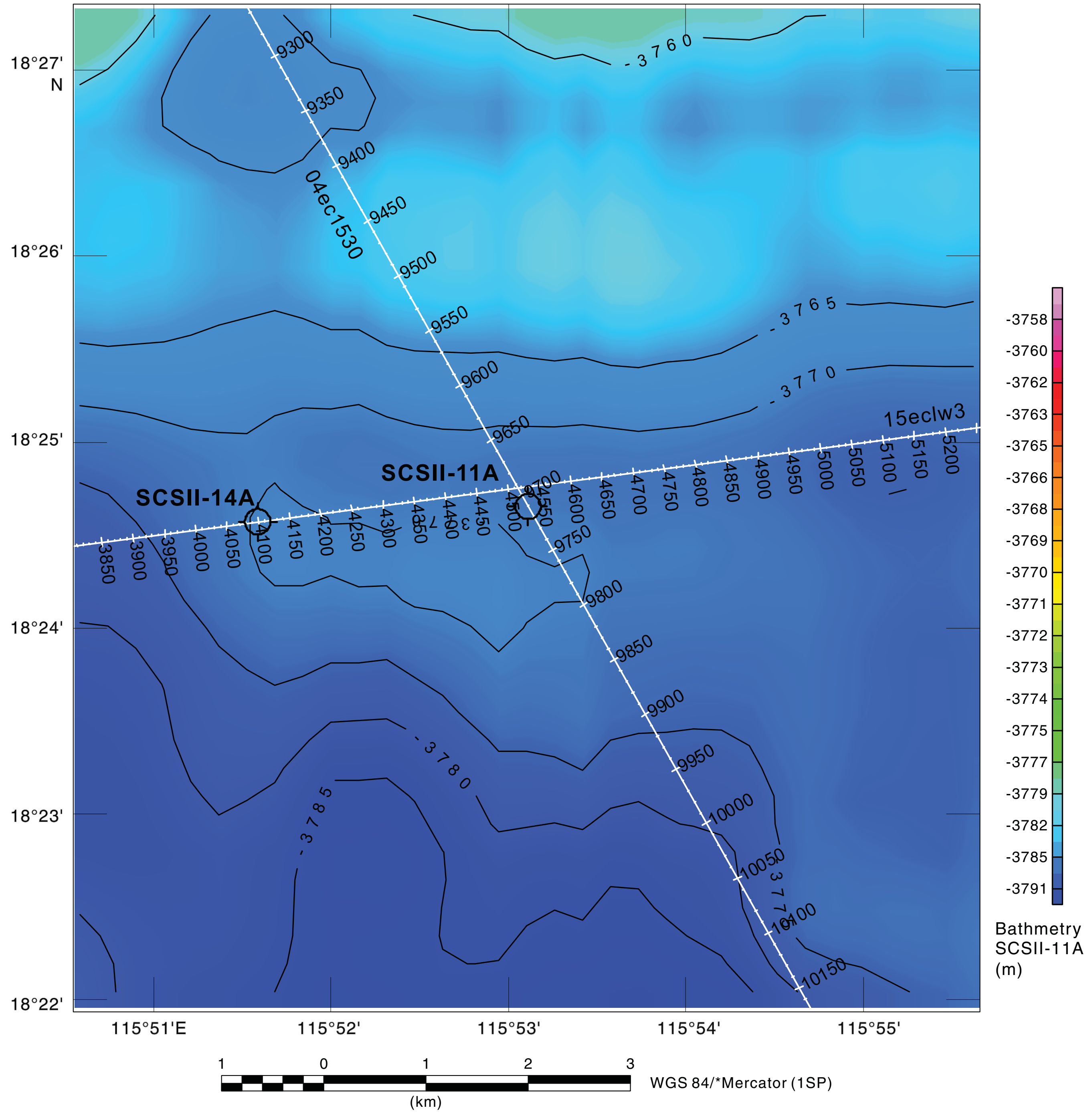


Figure AF13. (A) Primary seismic Line 15ecLW3 and (B) crossing Line 04ec1530, proposed Sites SCSII-11A and SCSII-14A. CDP = common depth point. Dashed lines = unconformities.

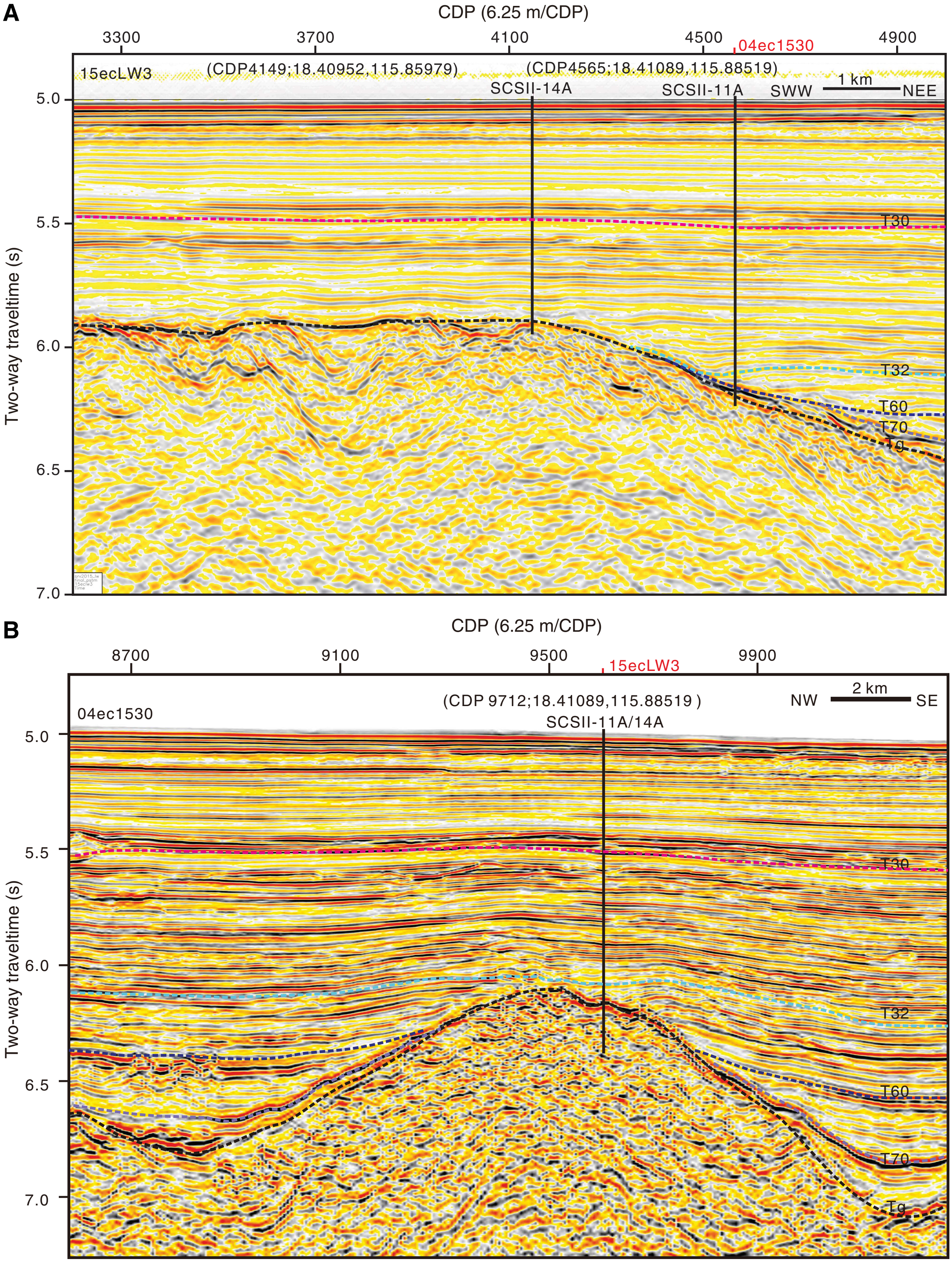


Figure AF14. Bathymetry, proposed Site SCSII-15A.

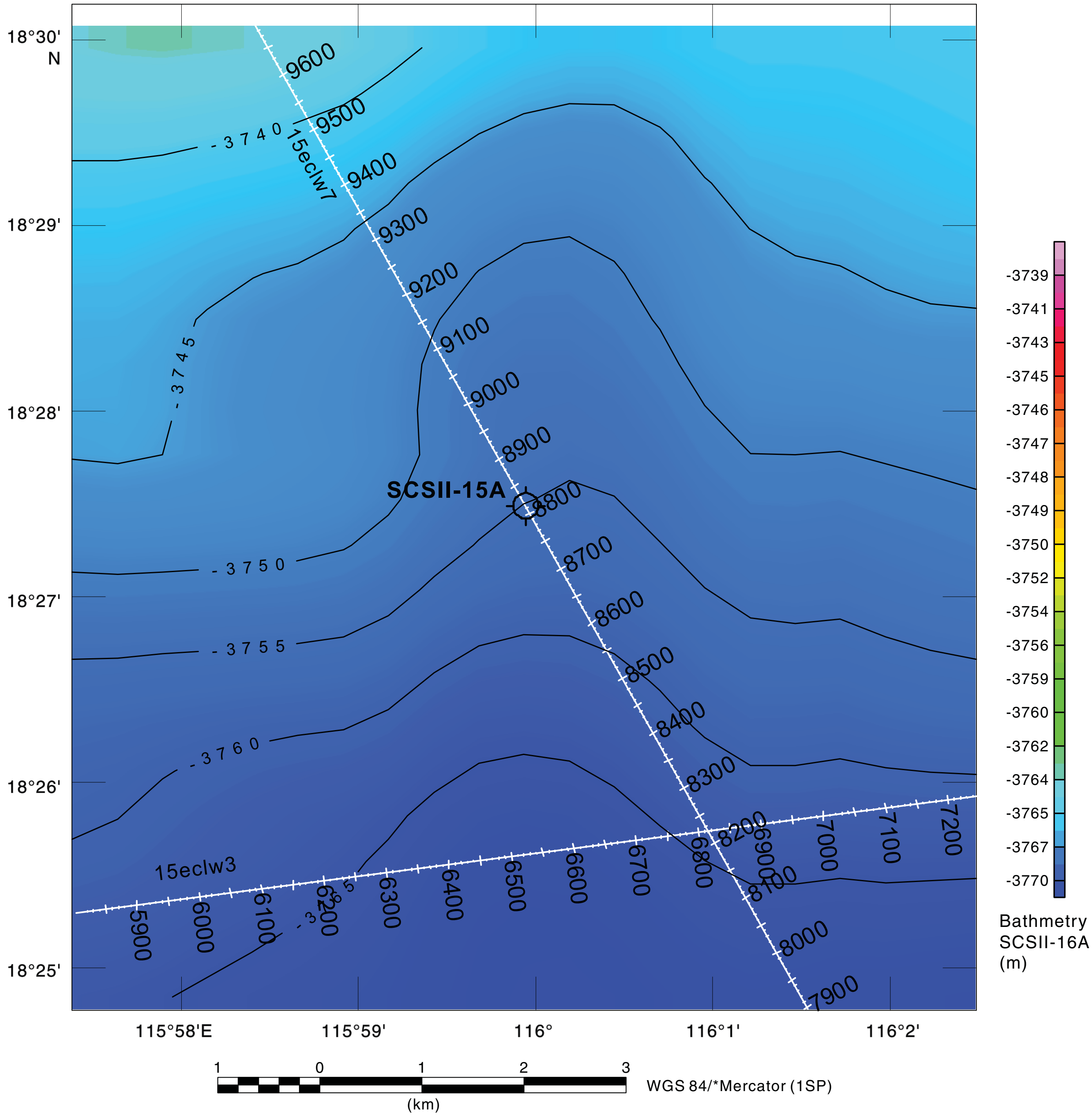


Figure AF15. (A) Primary seismic Line 15ecLW8 and (B) crossing Line 15ecLW3, proposed Site SCSII-15A. CDP = common depth point. Dashed lines = unconformities, solid red line = fault.

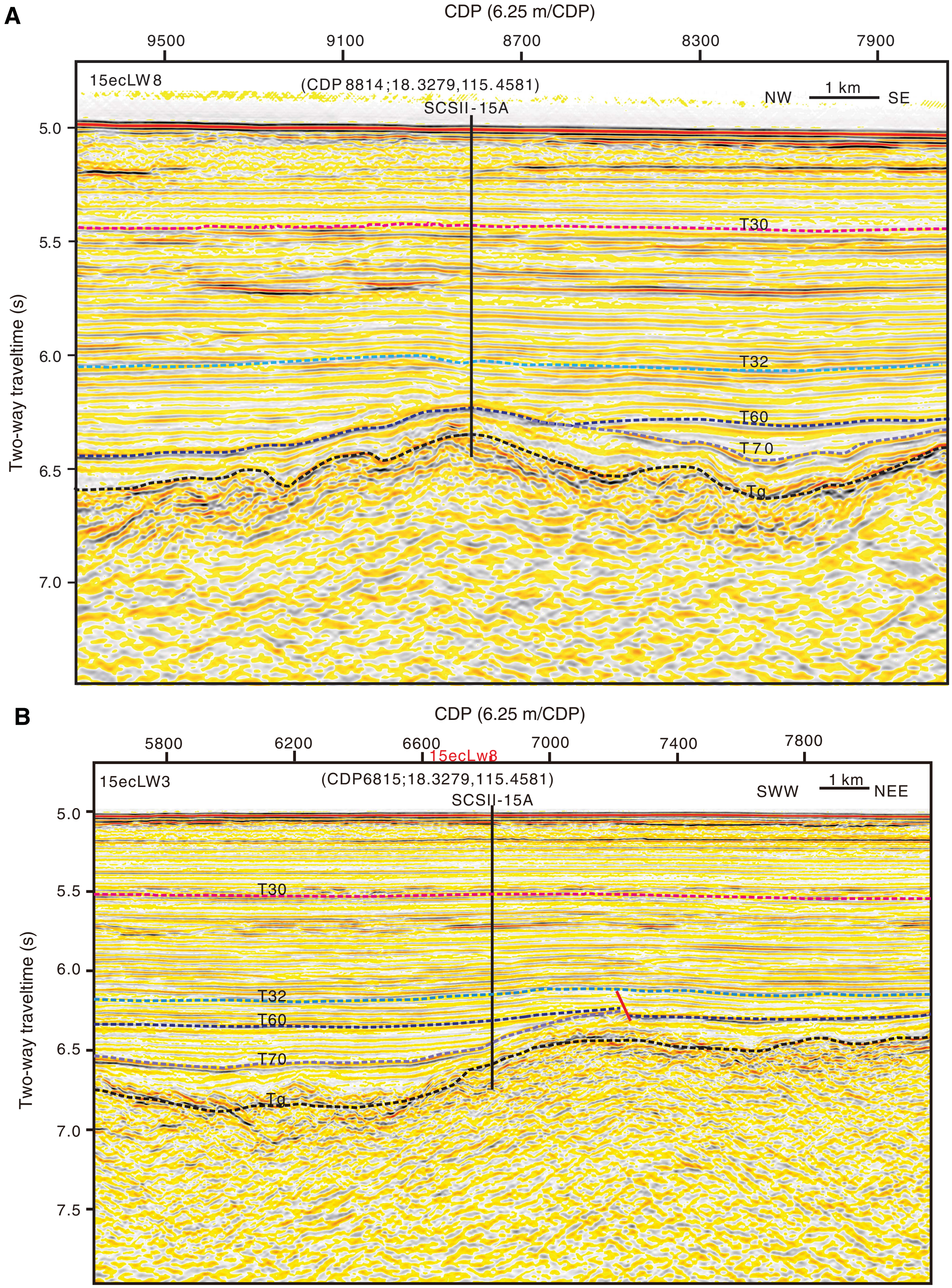


Figure AF16. Bathymetry, proposed Sites SCSII-16A-SCSII-18A.

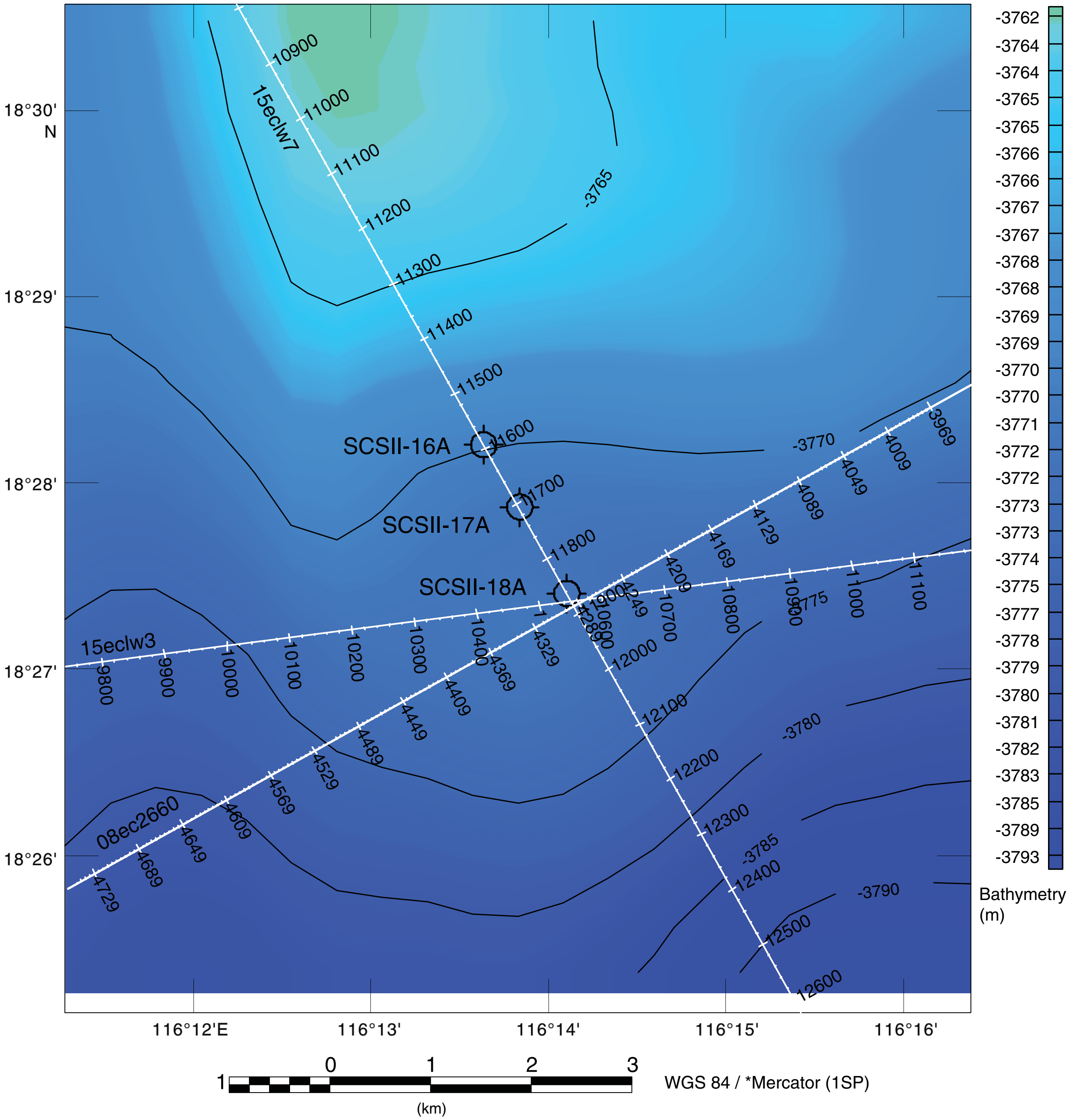


Figure AF17. Primary seismic Line 15ecLW7, proposed Site SCSII-16A. CDP = common depth point. Dashed lines = unconformities, solid red lines = faults.

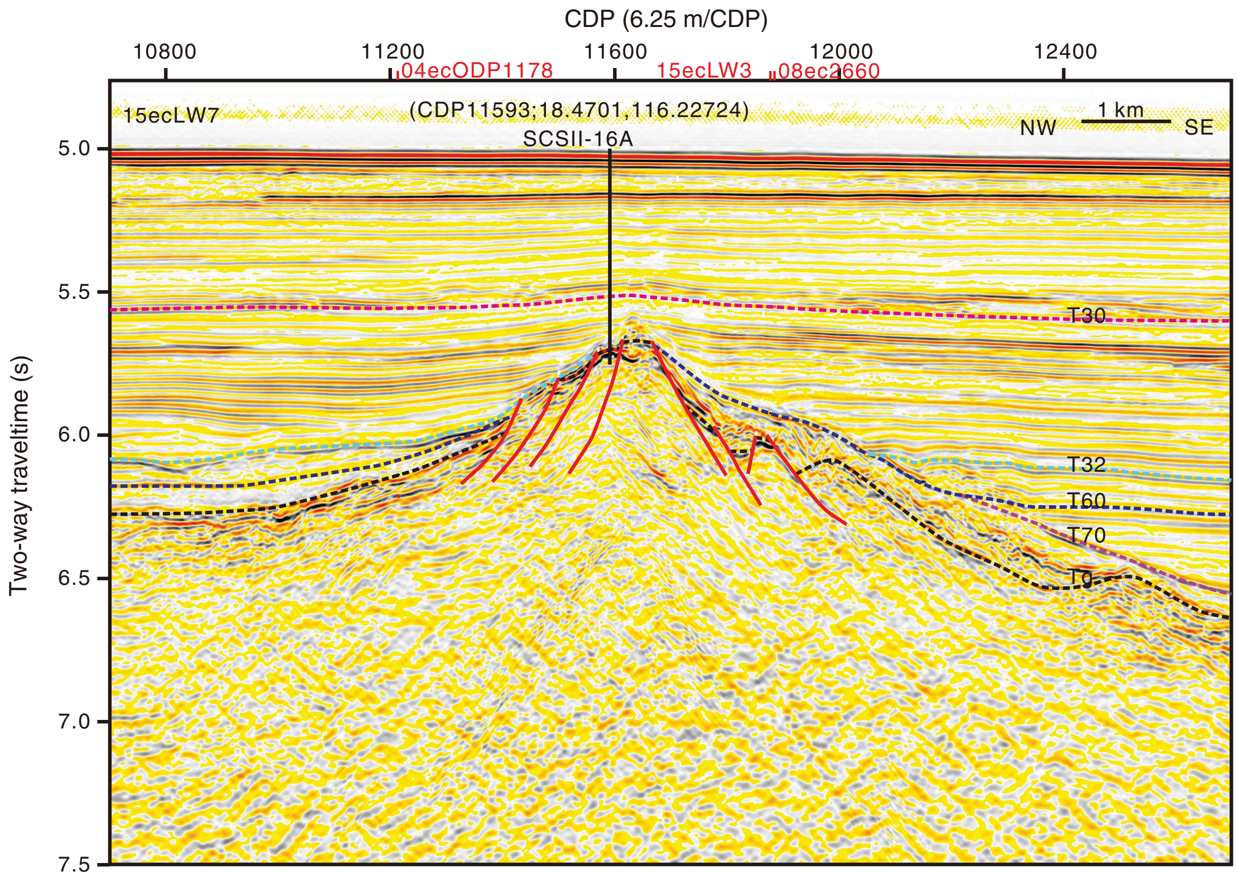


Figure AF18. Crossing seismic Line 15ecLW3, proposed Sites SCSII-16A-SCSII-18A. CDP = common depth point. Dashed lines = unconformities, solid red lines = faults.

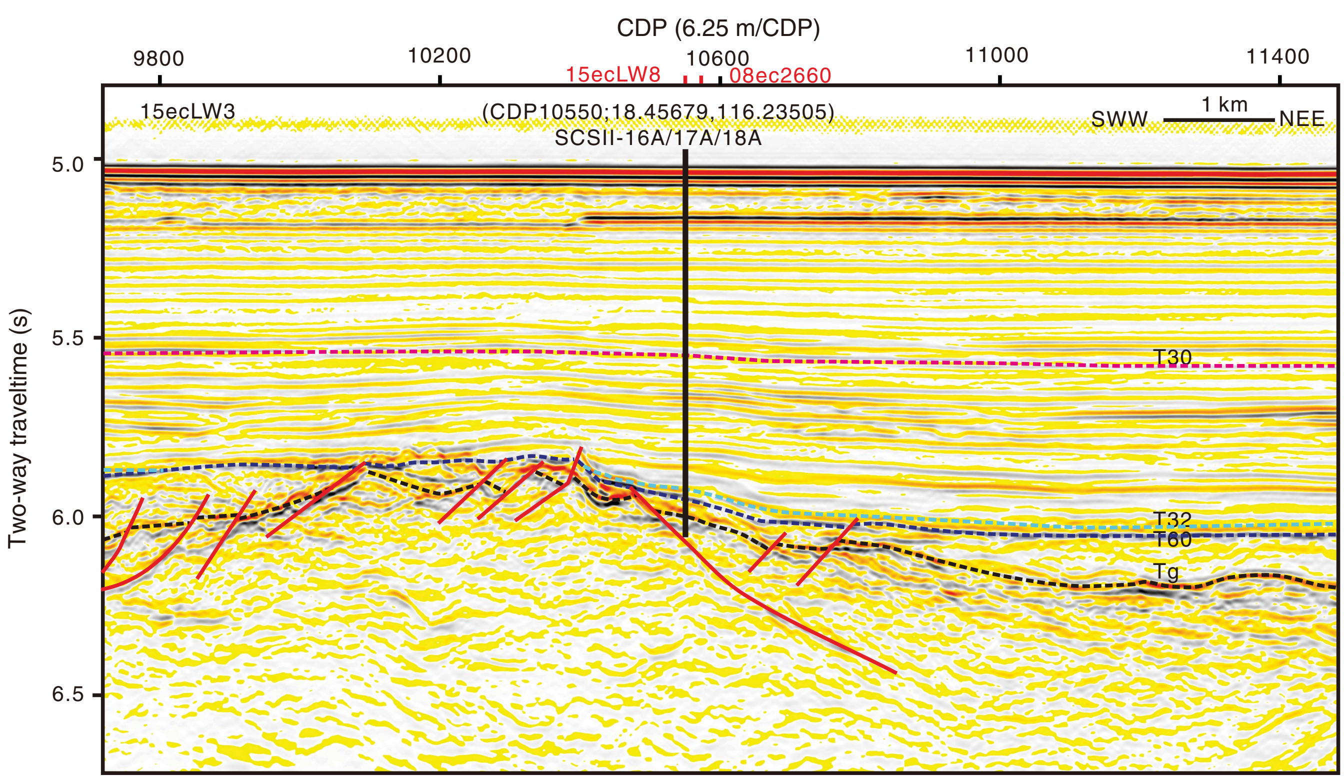


Figure AF19. Primary seismic Line 15ecLW7, proposed Site SCSII-17A. CDP = common depth point. Dashed lines = unconformities, solid red lines = faults.

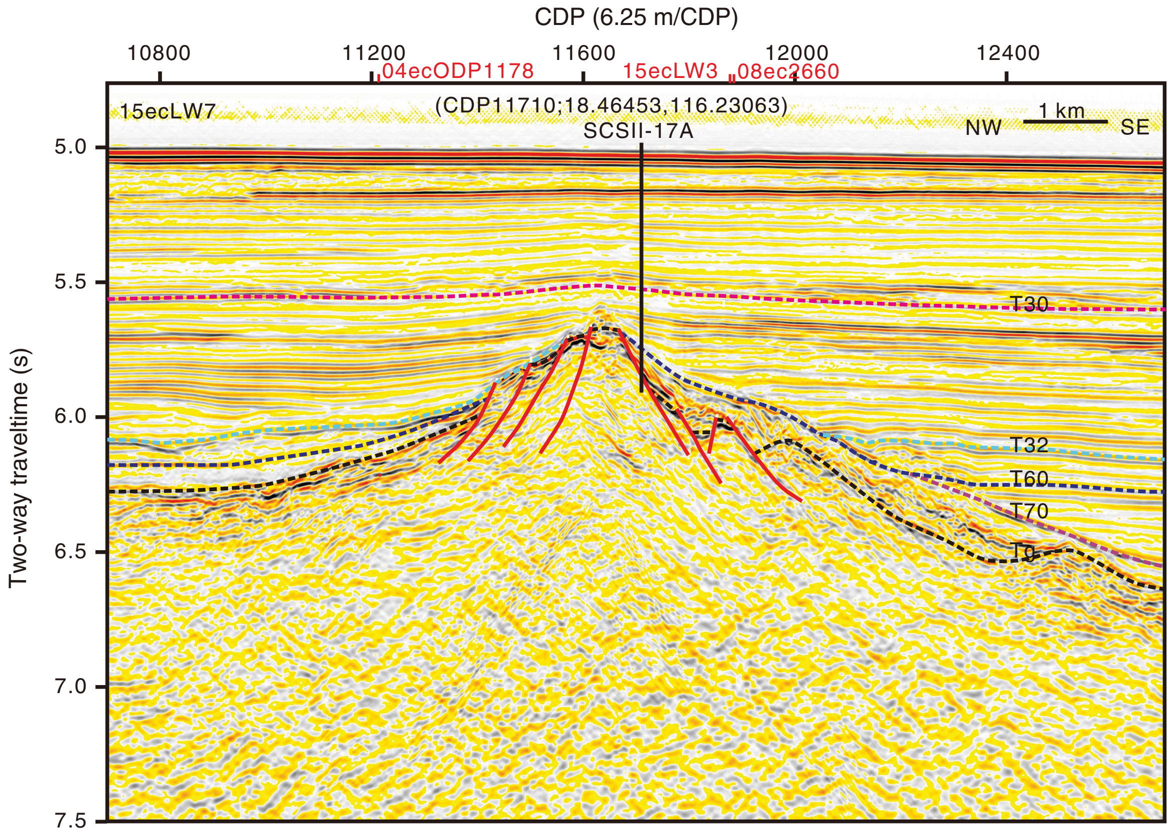


Figure AF20. Primary seismic Line 15ecLW7, proposed Site SCSII-18A. CDP = common depth point. Dashed lines = unconformities, solid red lines = faults.

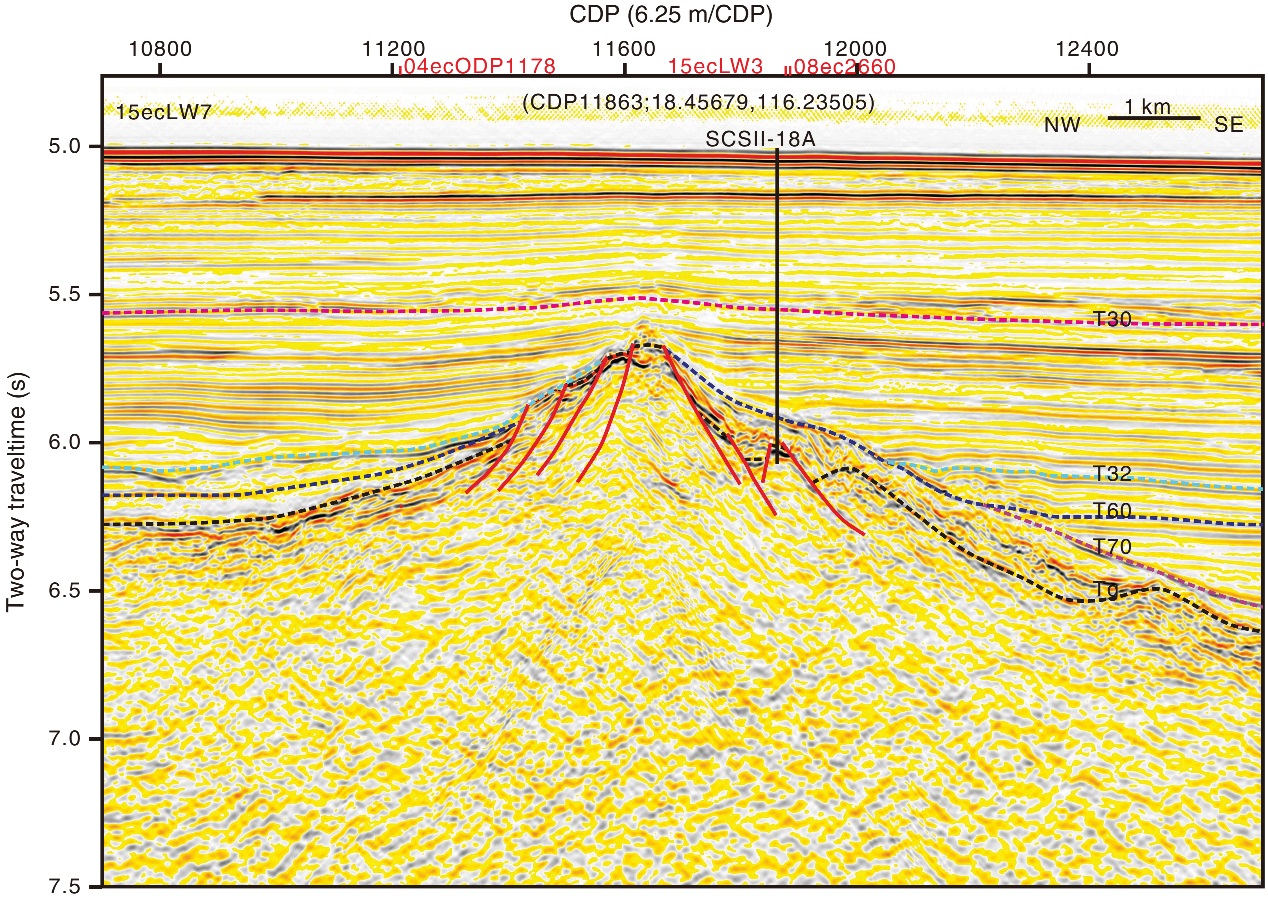


Figure AF21. Bathymetry, proposed Site SCSII-8B.

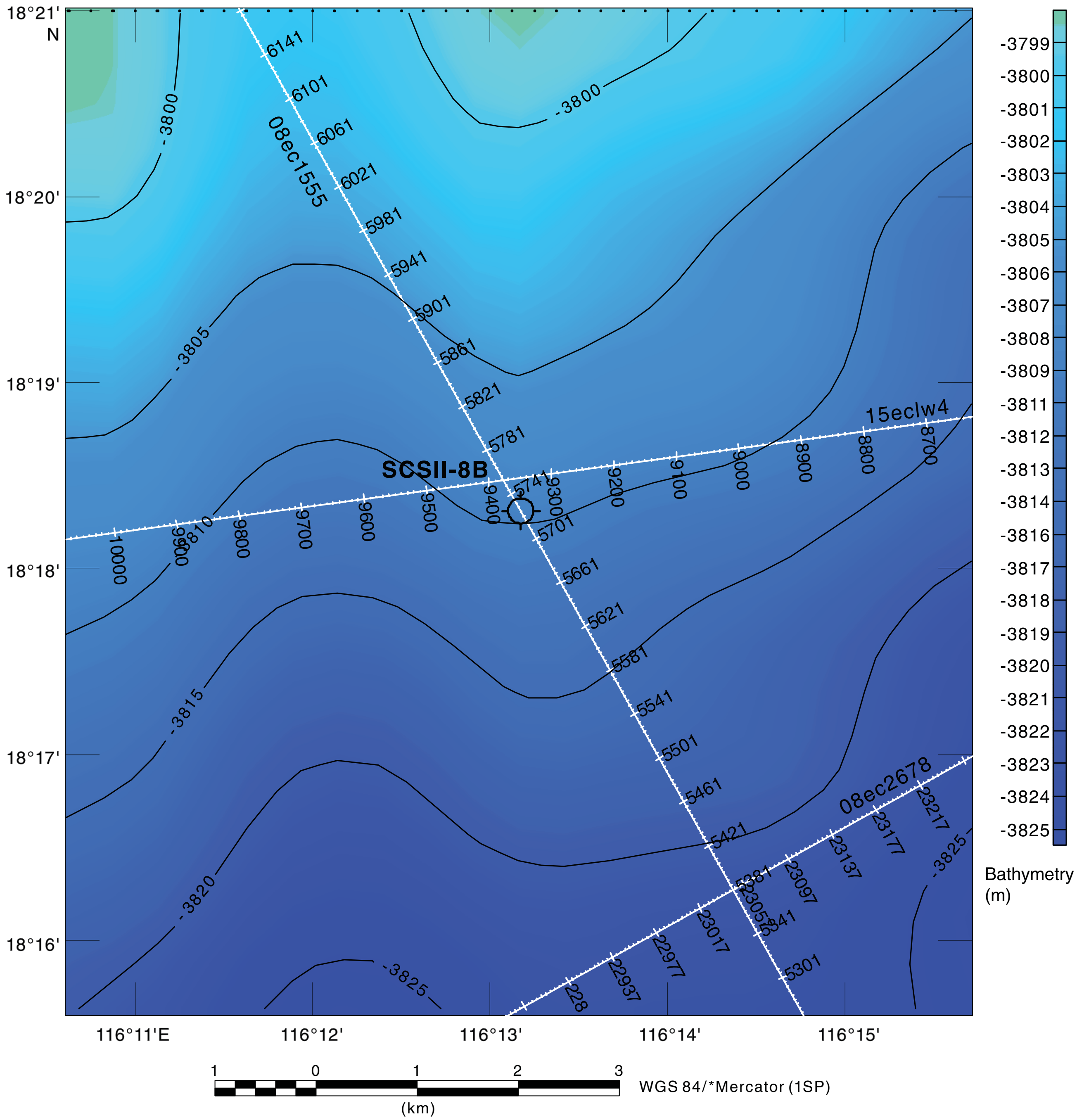


Figure AF22. (A) Primary seismic Line 08ec1555 and (B) crossing Line 15ecLW4, proposed Site SCSII-8B. CDP = common depth point. Dashed lines = unconformities, solid red lines = faults.

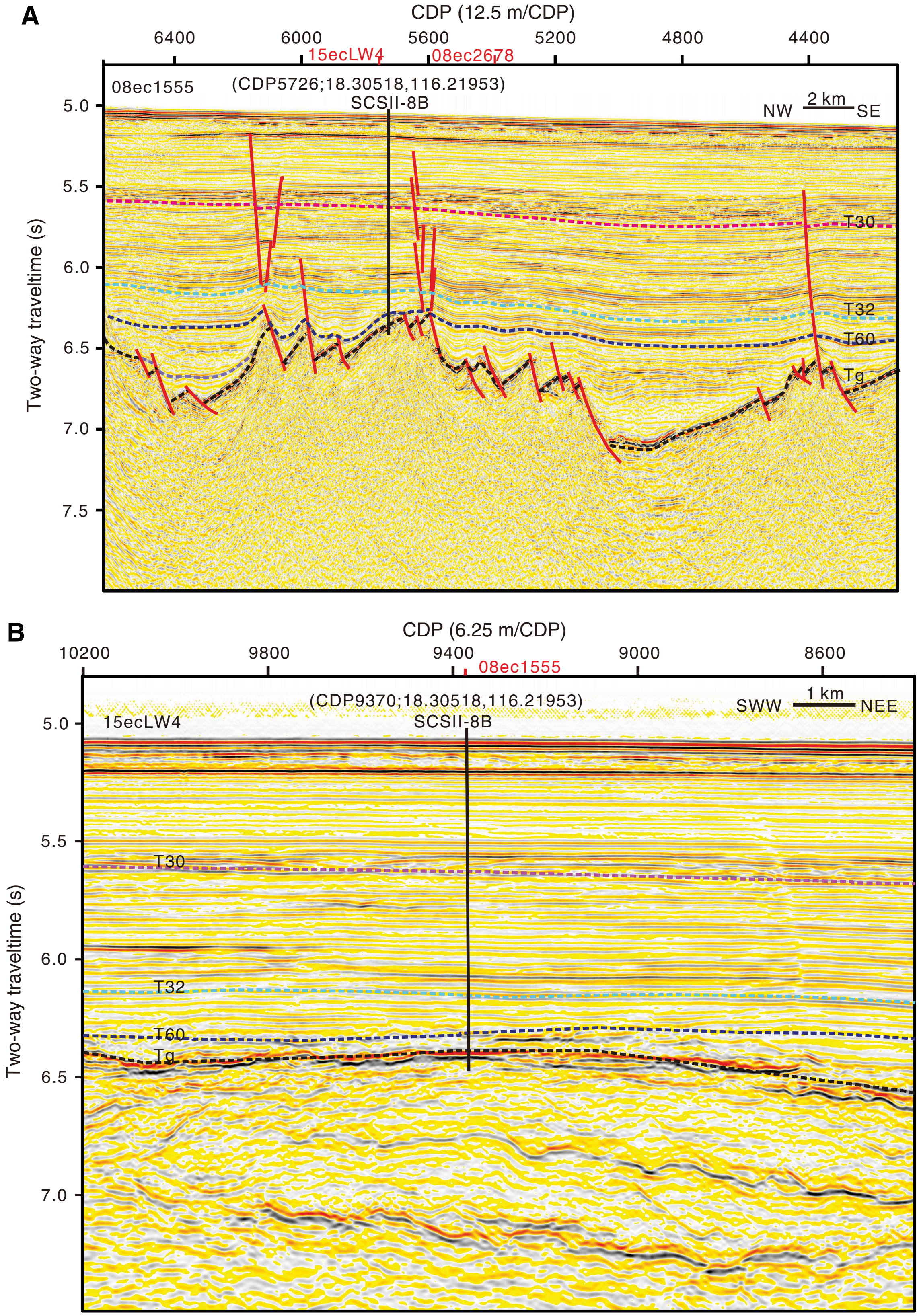


Figure AF23. Bathymetry, proposed Site SCSII-20A.

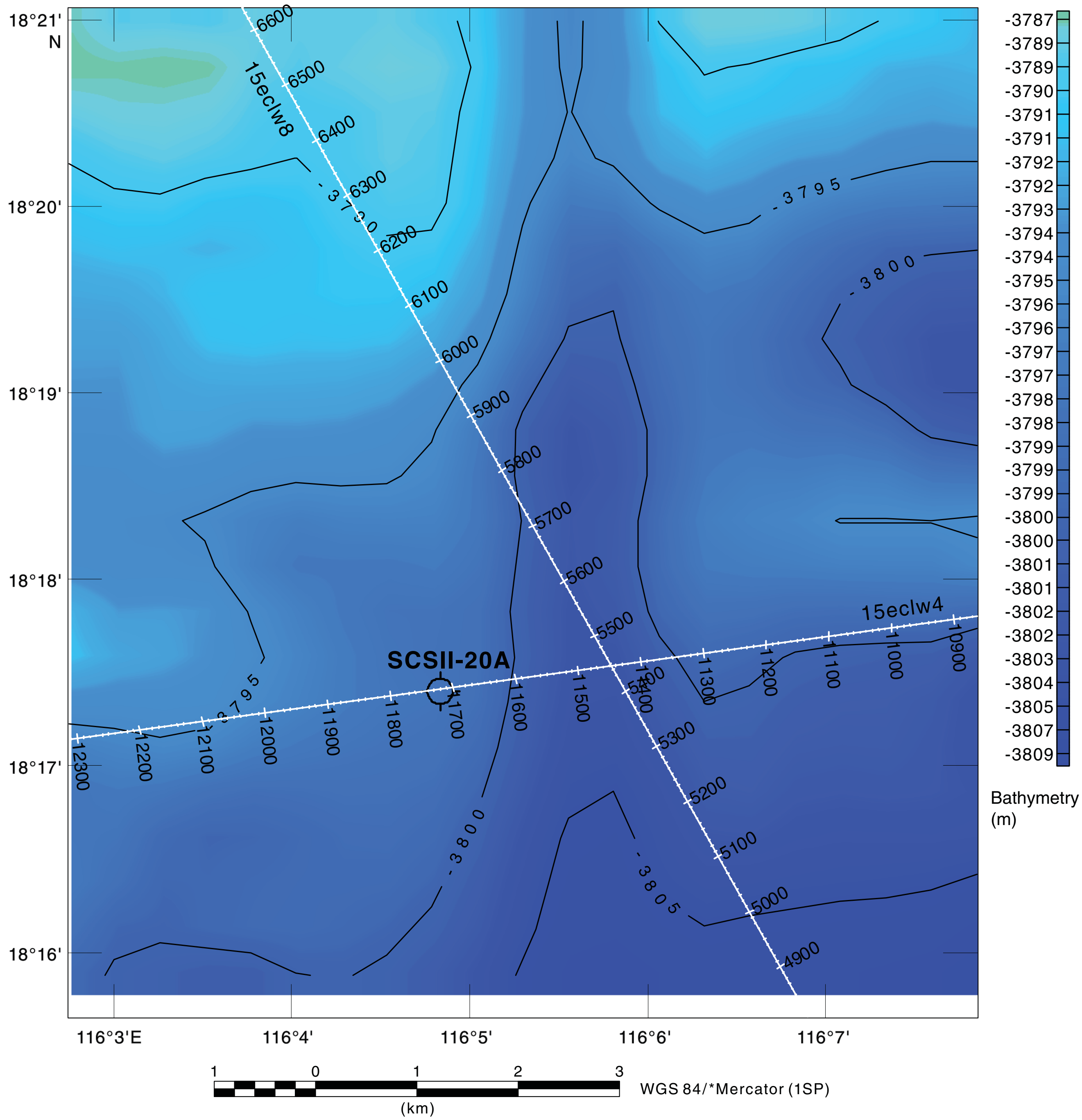


Figure AF24. (A) Primary seismic Line 15ecLW4 and (B) crossing Line 15ecLW8, proposed Site SCSII-20A. CDP = common depth point. Dashed lines = unconformities, solid red line = fault.

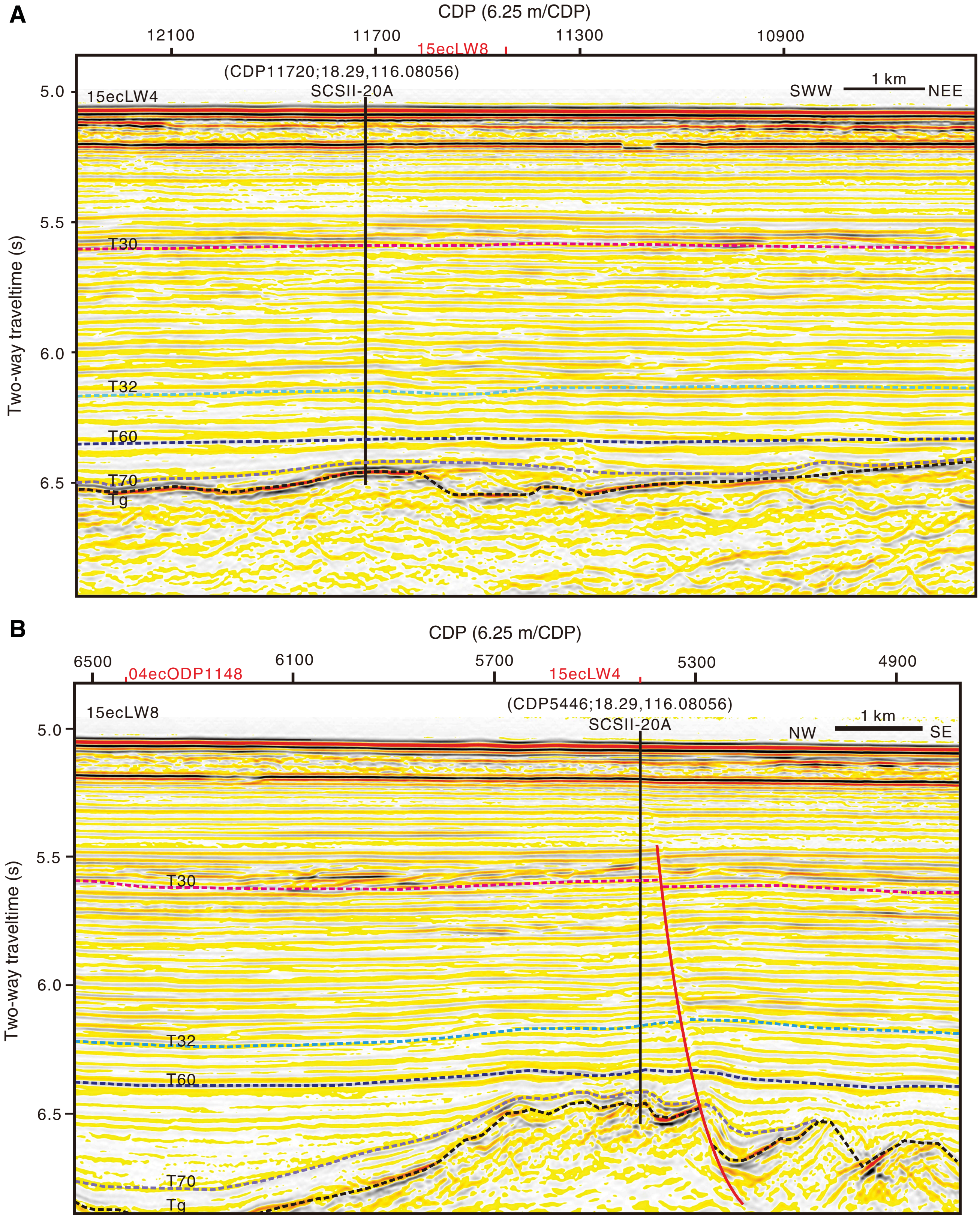


Figure AF25. Bathymetry, proposed Site SCSII-21A.

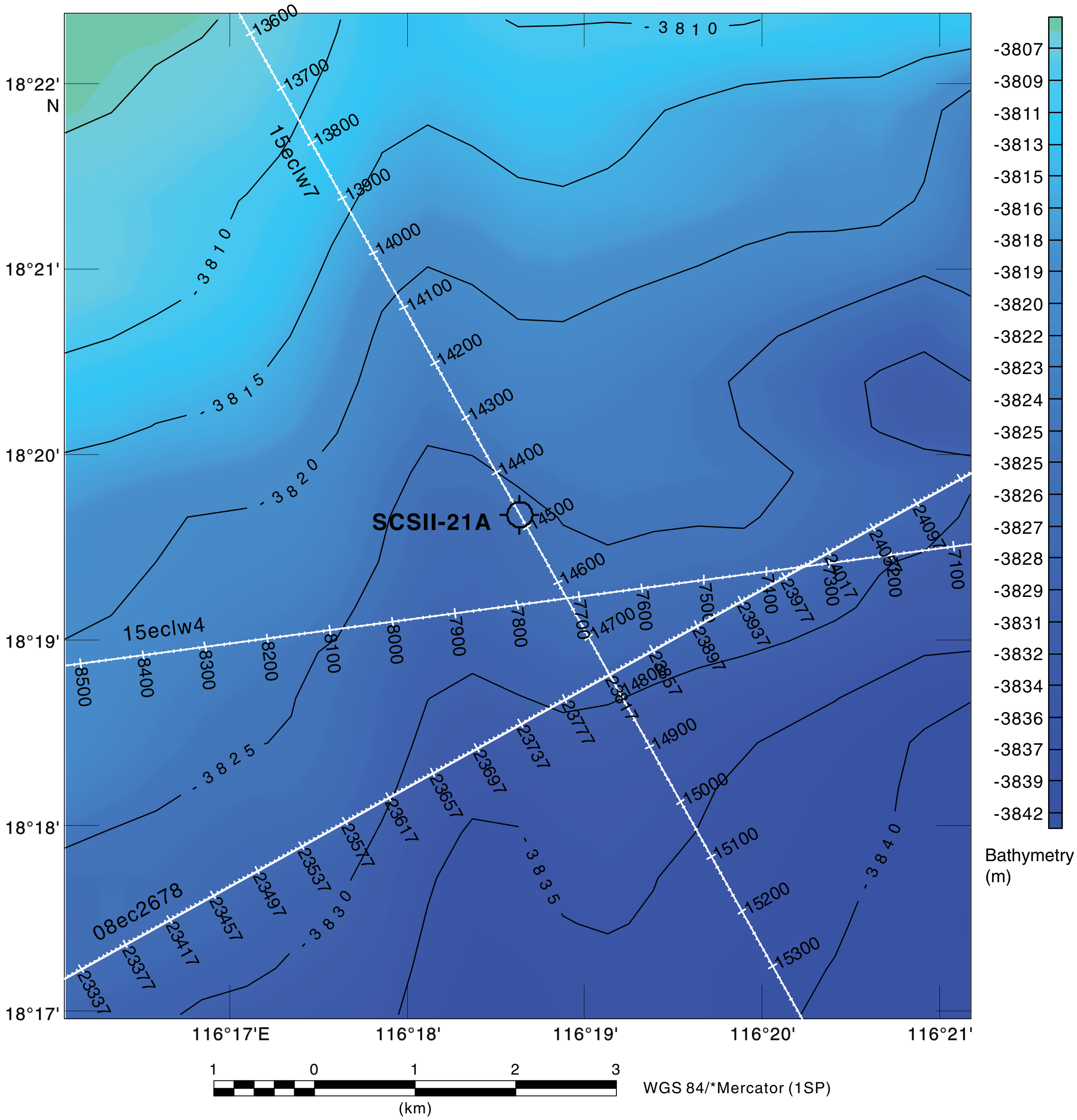


Figure AF26. (A) Primary seismic Line 15ecLW7 and (B) crossing Line 15ecLW4, proposed Site SCSII-21A. CDP = common depth point. Dashed lines = unconformities, solid red lines = faults.

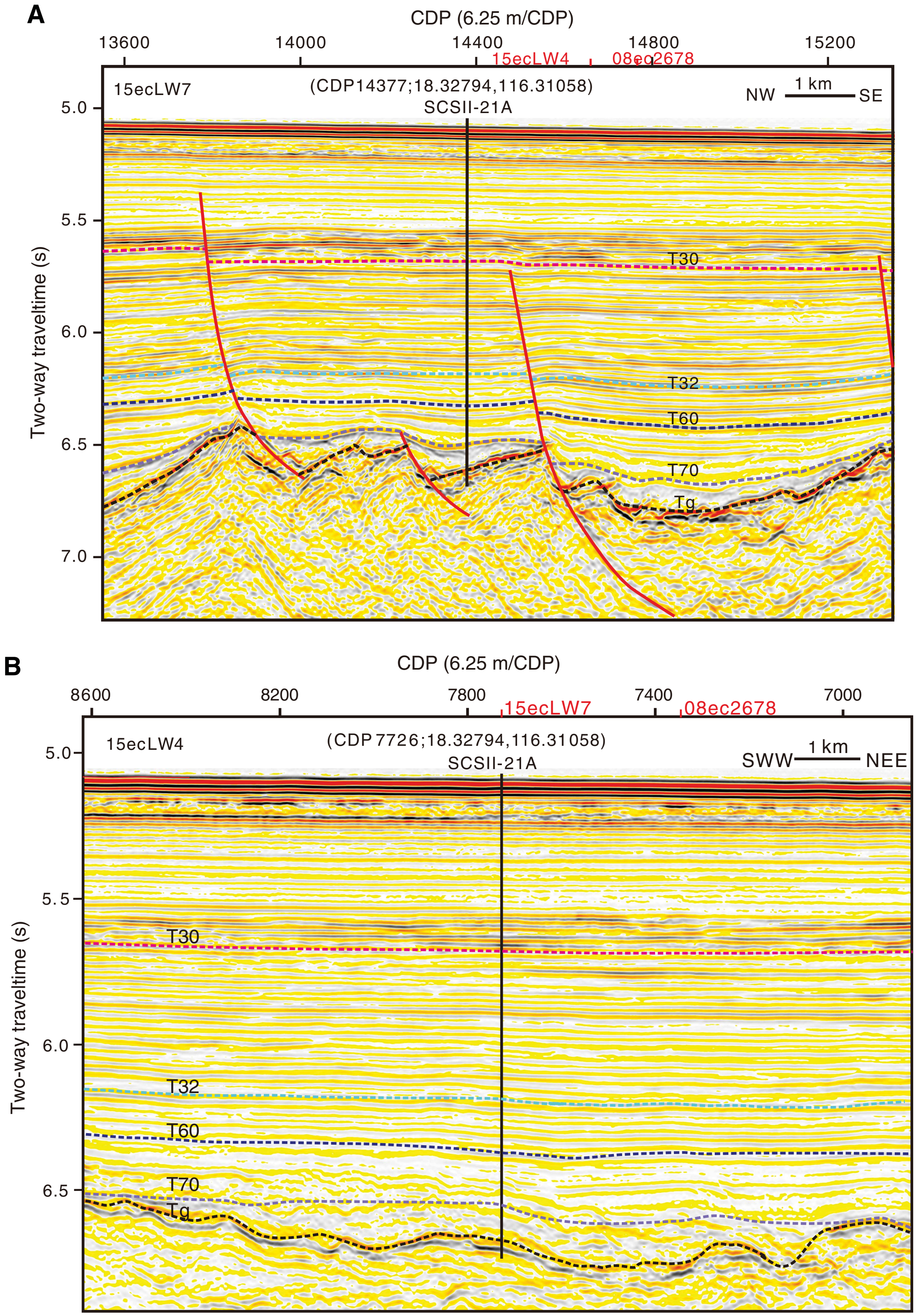


Figure AF27. Bathymetry, proposed Sites SCSII-9B and SCSII-30A.

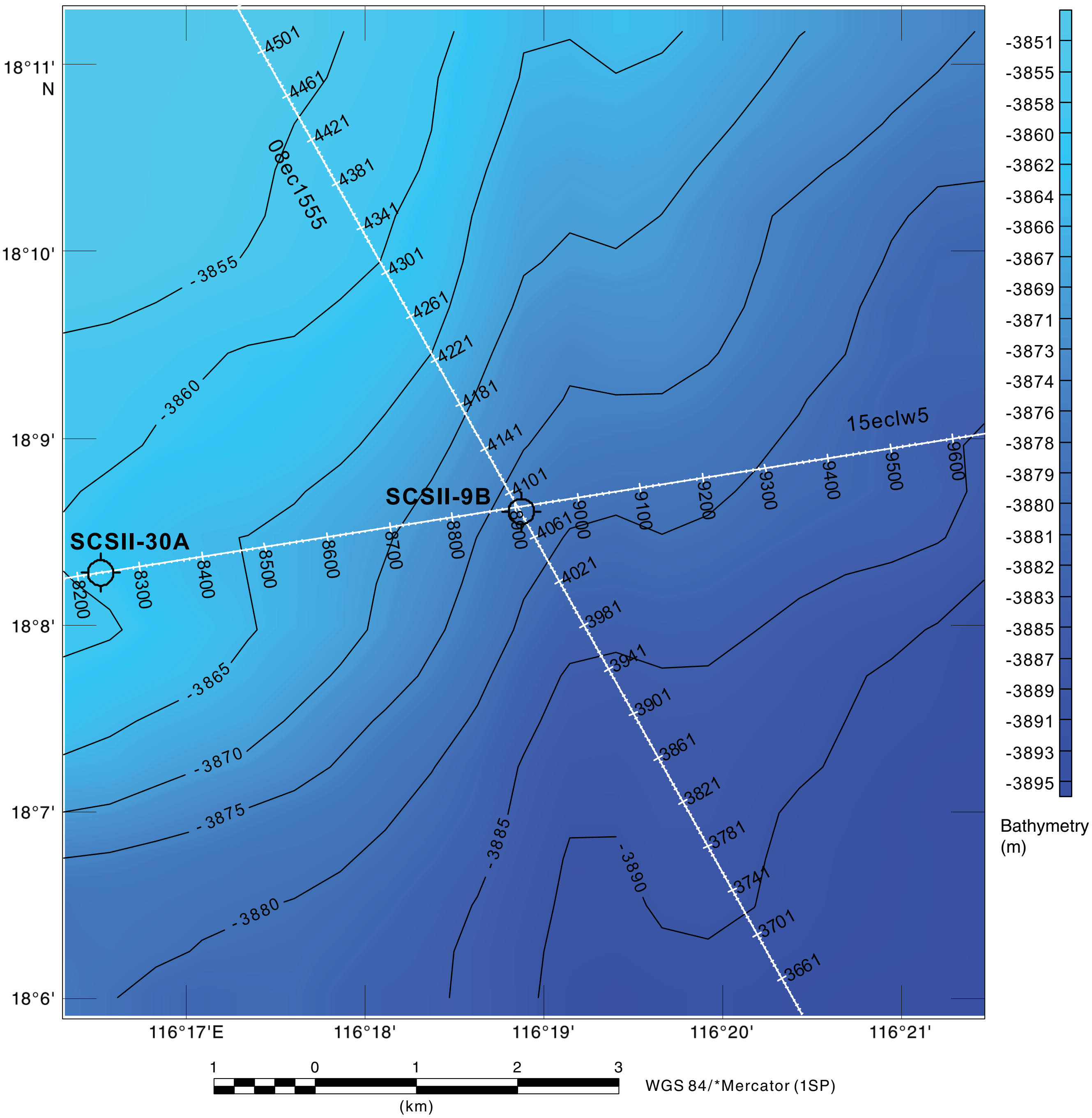


Figure AF28. Seismic Line 08ec1555. Primary seismic line for proposed Site SCSII-9B and crossing seismic line for proposed Site SCSII-30A. CDP = common depth point. Dashed lines = unconformities, solid red lines = faults.

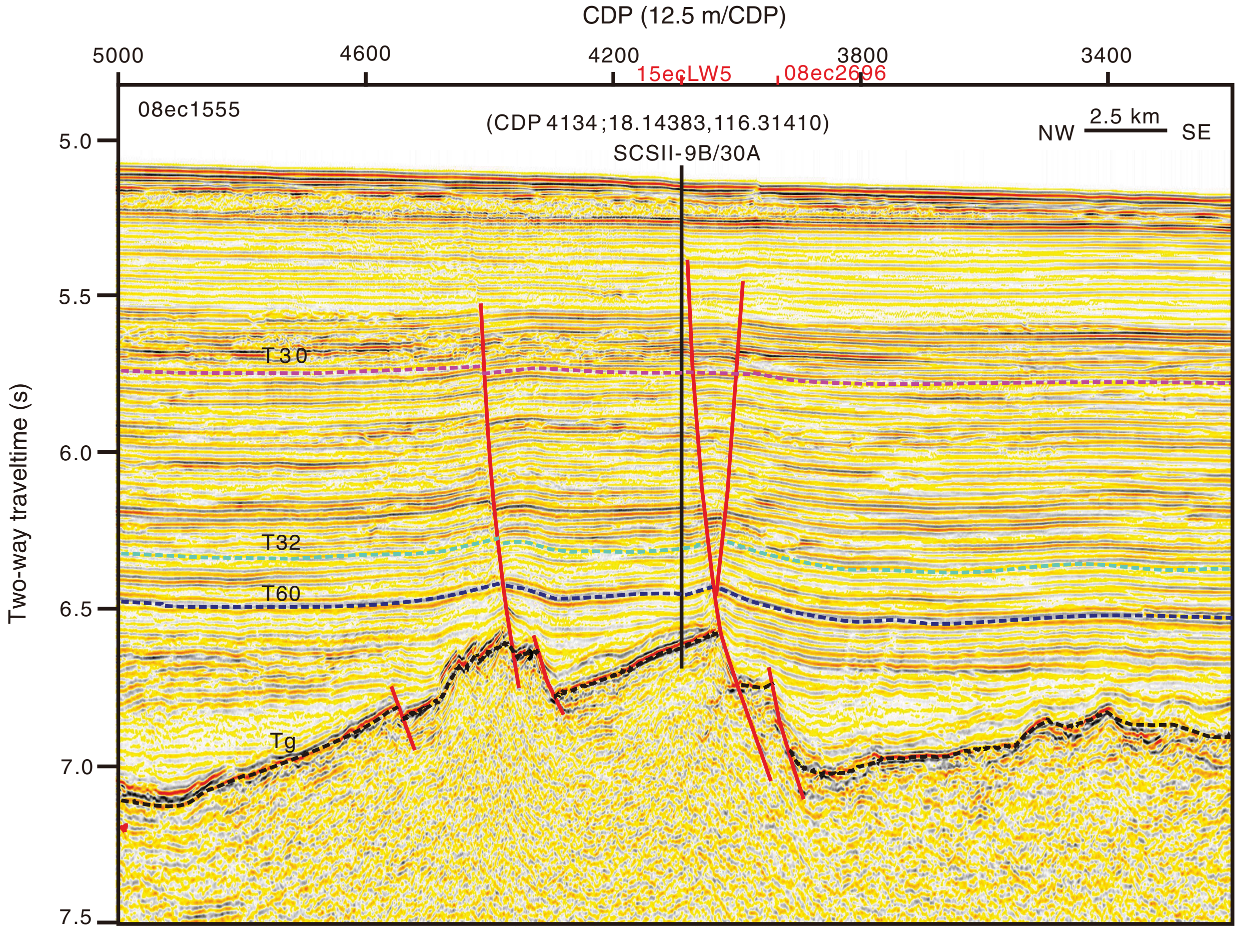


Figure AF29. Seismic Line 15ecLW5. Primary seismic line for proposed Site SCSII-30A and crossing seismic line for proposed Site SCSII-9B. CDP = common depth point. Dashed lines = unconformities.

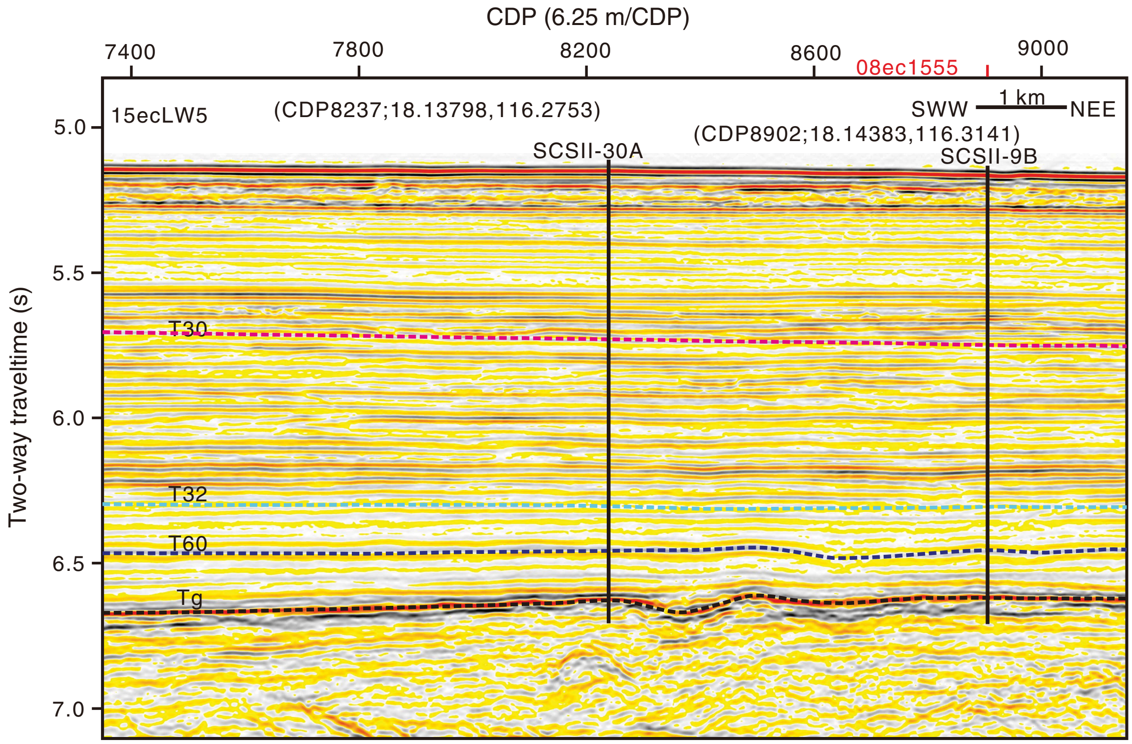


Figure AF30. Bathymetry, proposed Site SCSII-31A.

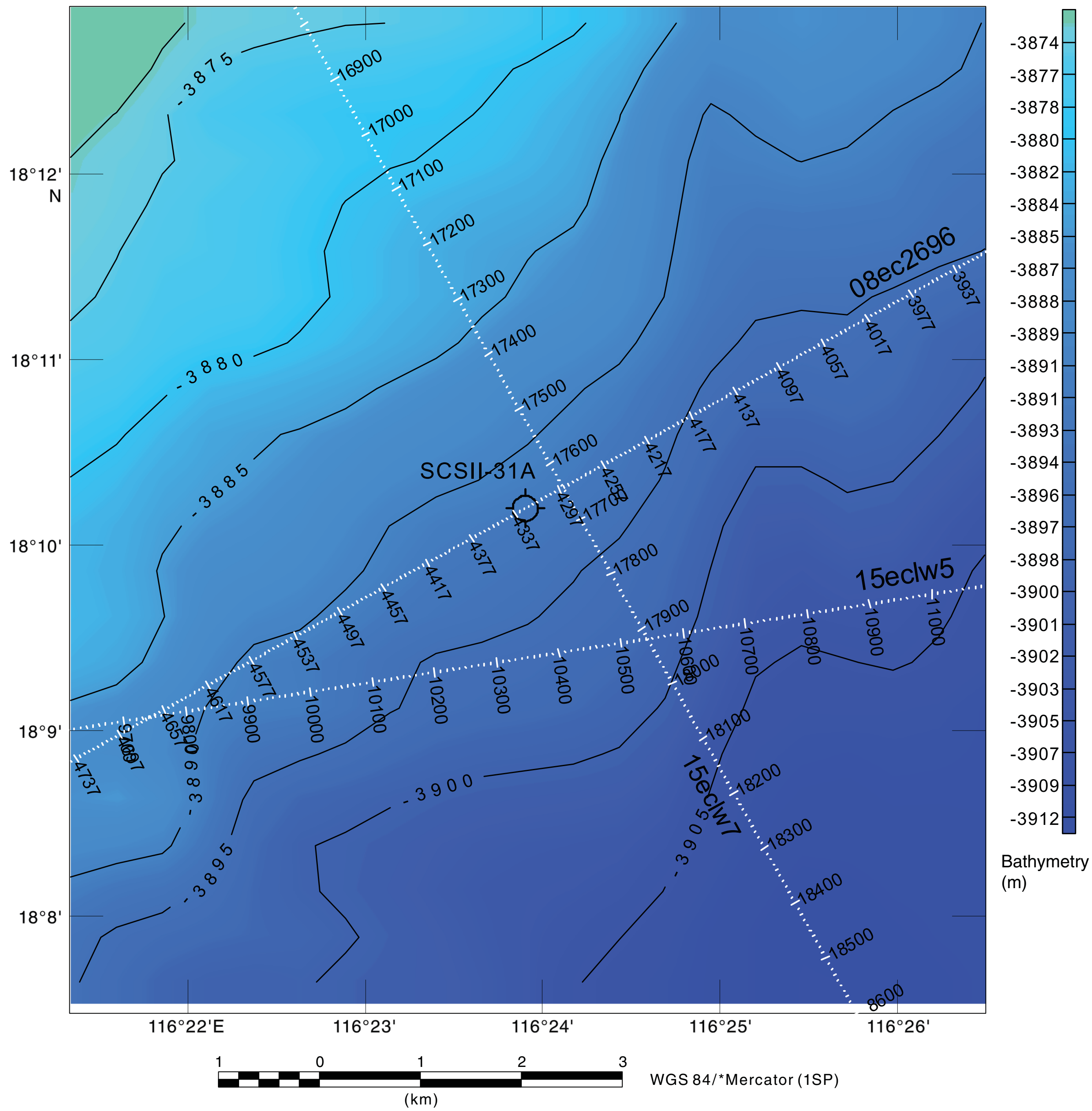


Figure AF31. (A) Primary seismic Line 08ec2696 and (B) crossing Line 15ecLW7, proposed Site SCSII-31A. CDP = common depth point. Dashed lines = unconformities, solid red lines = faults.