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11. Data Report: High-Resolution Site Survey Seismic Reflection Data for ODP Leg 198 Drilling on Shatsky Rise, Northwest Pacific[1]

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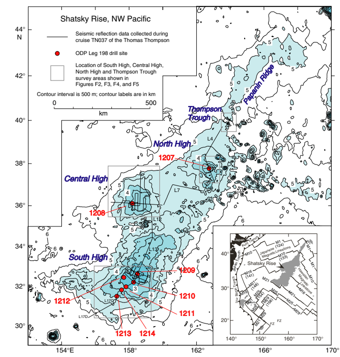
ABSTRACT

In 1994, we conducted a marine geophysical and geological survey of Shatsky Rise in the northwest Pacific. The primary objective of this cruise was to investigate the formation and evolution of the rise as well as to collect site survey data required for ocean drilling. During this cruise, we collected >3200 km of seismic reflection data, which forms the primary seismic data set on which Leg 198 drill sites are located. This paper presents the seismic reflection data collected during this survey.

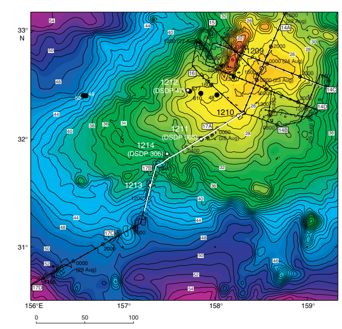
INTRODUCTION

Ocean Drilling Program (ODP) Leg 198 returned to Shatsky Rise in the northwest Pacific, revisiting the South High drilled during Deep Sea Drilling Project (DSDP) Legs 6, 32, and 86, as well as ODP Leg 132 (Figs. F1, F2; Fischer, Heezen, et al., 1971; Larson, Moberly, et al., 1975; Heath, Burkle, et al., 1985; Storms, Natland, et al., 1991). In addition, Leg 198 also occupied one site each on the Central and North Highs (Figs. F1, F3, F4). A high-resolution seismic reflection survey was carried out in 1994 to determine the origin and evolution of the rise and to obtain site survey data required for ocean drilling. The purpose of this paper is to present these seismic reflection data as a first step toward inte-

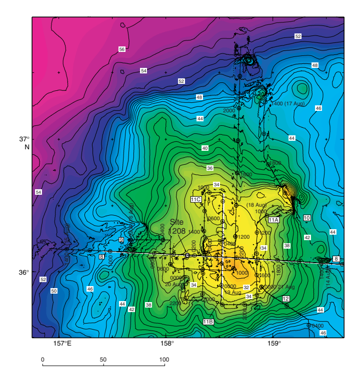
F1. Bathymetric map of Shatsky Rise, p. 7.



F2. South High survey area, p. 8.



F3. Central High survey area, p. 9.



[1]Examples of how to reference the whole or part of this volume.
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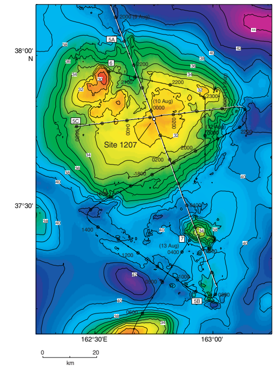
grating the regional seismic reflection data set with the Leg 198 coring and logging data.

F4. North High survey area, p. 10.



REGIONAL GEOLOGIC SETTING

Shatsky Rise is a large (450 km long, 1650 km wide) oceanic plateau located in the northwestern Pacific 1600 km east of Japan (Fig. **F1**). Magnetic lineations (Fig. **F1** inset) show that the Pacific Plate near Shatsky Rise was formed during the Jurassic and Early Cretaceous at two spreading ridges that met at a triple junction (Larson and Chase, 1972; Hilde et al., 1976; Handschumacher et al., 1988; Sager et al., 1988; Nakanishi et al., 1989, 1999). The northeast-trending Japanese lineation set formed at the spreading ridge separating the Pacific from the Izanagi plate to the northwest. The southeast-trending Hawaiian lineations formed at the ridge separating the Pacific from the Farallon plate to the northeast (Woods and Davies, 1982). Tectonic reconstructions indicate that this part of the Pacific Plate formed near the equator (e.g., Larson and Chase, 1972).

The regional seafloor surrounding Shatsky Rise is deep (5.5–6.0 km) and sediment cover is thin, typically a few hundred meters (Houtz and Ludwig, 1979; Ludwig and Houtz, 1979). Sediments on the top of Shatsky Rise are much thicker, up to 1.2 km (Ewing et al., 1966; Zdorovenin et al., 1972; Neprohnov et al., 1984; Karp and Prokudin, 1985; Khankishieva, 1989; Sliter and Brown, 1993; Klaus et al., 1995) and are composed of Cretaceous pelagic carbonates deposited above the calcite compensation depth when the rise was younger and nearer the equator (e.g., Sliter and Brown, 1993).

Shatsky Rise is a thick igneous construct with a seismic velocity structure similar to oceanic crust, but thickened by several times under the highest parts (Den et al., 1969; Gettrust et al., 1980; Kogan, 1981). This suggests that the rise has a composition similar to oceanic crust and that dredges have recovered basalts from basement outcrops on the rise (Kashintsev and Suzymov, 1981; Sager et al., 1999). The huge size of the igneous pile, however, indicates that it was not formed by typical seafloor spreading.

A relationship between Shatsky Rise and the Pacific-Izanagi-Farallon triple junction has long been suspected because the Japanese and Hawaiian magnetic lineations converge at the rise axis (Larson and Chase, 1972; Hilde et al., 1976). Magnetic bights occur in many places within the lower parts of the rise, implying that the triple junction was composed of spreading ridges (Fig. **F1**) (Nakanishi et al., 1999). Because its size implies a large amount of volcanism, several authors have suggested that the rise formed as the result of a mantle plume (Sager et al., 1988; Nakanishi et al., 1989; Sager and Han, 1993; Sager et al., 1999). A predominantly reversed magnetic polarity over the southwestern part of the South High suggests a short formation period and an extremely high magma eruption rate similar to those of flood basalts and postulated for plume heads (Sager and Han, 1993).

There are few age dates for Shatsky Rise because basalts dredged from it are typically too altered for radiometric dating. Despite several attempts at drilling basement prior to Leg 198, no borehole has penetrated basement to obtain fresher rocks. The oldest well-dated sediments recovered from drilling the rise, which are at DSDP Site 306 on the southwest side of the South High (Fig. **F2**), are Berriasian (earliest Cretaceous; 137–144 Ma [timescale of Gradstein et al., 1994]) and were recovered ~80 m above a reflector thought to represent basement (Larson, Moberly, et al., 1975). Late Jurassic magnetic lineations M21 (148 Ma) to M19 (145 Ma) bracket the South High, so this massif must have formed near the end of the Jurassic or beginning of the Cretaceous. The Central High, North High, and Papanin Ridge must be younger because the magnetic lineations indicate that the lithosphere beneath is younger than early Berriasian (Fig. **F1** inset). Shatsky Rise gravity data indicate Airy-type isostatic compensation typical for features emplaced near spreading ridges (Watts et al., 1980; Sandwell and MacKenzie, 1989), suggesting an age for the rise near that of the underlying lithosphere. These observations imply that the age of the rise becomes younger to the northeast (Sager and Han, 1993).

Volcanism occurred on Shatsky Rise after the main shield-building volcanic phases. Both the South and Central Highs have late-stage volcanic ridges on their top; the one on the South High rises ~1 km above the level at which shallow-water fossils were dredged. Assuming that this ridge formed below sea level (it shows no obvious subaerial erosion), the high subsided as normal lithosphere (Johnson and Carlson, 1992), and the fossils are autochthonous, the depth difference implies a time gap of ~8 to 9 m.y. In addition, basalts dredged from Toronto Ridge on top of the South High are trachytes and trachyandesites (Tejada et al., 1995), which are typical of fractionated, late-stage eruptions (Macdonald and Abbott, 1970).

TECTONIC EVOLUTION

Sager et al. (1999) inferred that Shatsky Rise was formed by plume-related volcanism near a triple junction from about M21 to M1 (147 to 124 Ma). The three large highs and the normal lithosphere between them imply that volcanism was episodic, with separate pulses building each of the highs. The volume trend implies that the first eruption was extraordinarily large and that subsequent eruptions were of diminishing size.

As indicated by the narrow time gap between the age of the underlying lithosphere and oldest sediments drilled at Site 306, Shatsky Rise evidently began forming near the Jurassic–Cretaceous boundary with rapid, massive eruptions that formed the South High (Sager and Han, 1993). This nearly coincided with an 800-km eastward jump of the Pacific-Izanagi-Farallon triple junction and a reorientation of the Pacific-Izanagi Ridge between M21 and M19 (148-145 Ma) (Sager et al., 1988). Whether this large jump was caused by the eruption of the South High is unclear, but morphology and anomaly positions imply that the volcanic edifice formed slightly off-ridge and affected the ridge positions (Sager et al., 1999). Ridge jumps also occurred at about the time of formation of the Central and North Highs (M16-MI5 and M14, 138 and 136 Ma, respectively), moving the triple junction farther northeast (Nakanishi et al., 1999). The shape of the rise implies that the plates were moving rapidly southwest relative to the mantle plume (~1400 km in the 22 m.y. between M20 and M1), so the ridge jumps may have occurred to keep the spreading ridges located atop or near the plume (Sager et al., 1999).

DATA ACQUISITION AND PROCESSING

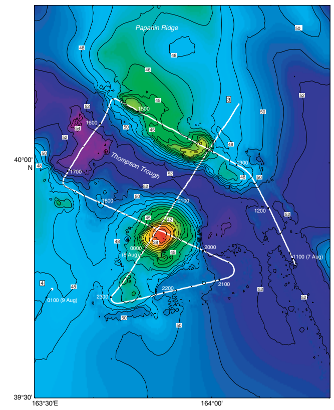
In 1994, we conducted a geophysical and geological survey of Shatsky Rise (cruise TN037 of *Thomas G. Thompson*). We collected seismic reflection, swath bathymetric (Hydrosweep), and potential field (magnetic, gravity) data, as well as a number of dredges and cores. The bathymetric and magnetic data and their interpretations have been published elsewhere (Nakanishi et al., 1999; Sager et al., 1999). In this paper, we present the results of seismic reflection data acquisition.

A total of 3213 km of seismic reflection data were collected over Shatsky Rise using a six-channel streamer and air gun sources (Figs. **F1, F2, F3, F4, F5**). The acquisition geometry, recording parameters, and processing sequence are summarized in Figure **F6** and Table **T1.** The 6-channel Teledyne streamer consisted of a 70-m tow leader, a 5-m weighted section, a 25-m stretch section, six 25-m active sections, and two additional spare active sections (Fig. **F6**). Two different air gun sources were used. A single generator-injector (45/105 in^3) air gun was used primarily when conducting long profiles between survey areas over the highs. This source could be towed at relatively high speeds (~7 nmi/hr) and produced two-fold data. The second source, an array of four air guns (80, 108, 150, 200 in^3), was used to conduct most of the detailed surveys over the South, Central, and North Highs. Profiles collected with this array were run at ~5 nmi/hr, resulting in three-fold coverage. We recorded the seismic reflection data at 1 ms in SEGY format on 4-mm (DAT) and 8-mm (Exabyte) tapes using "a2d" seismic acquisition software on a Sun workstation. Following the cruise, the data were completely processed through migration using the steps shown in Table **T1**. The entire seismic reflection data set collected over Shatsky Rise is presented in Figures **F7, F8, F9, F10, F11, F12, F13,** and **F14**.

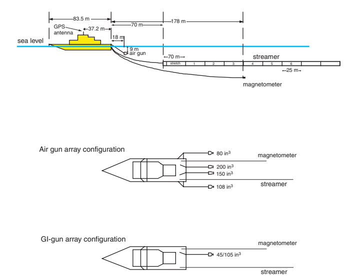
ACKNOWLEDGMENTS

We thank the captain, crew, and technical staff of the *Thomas Thompson*. Perry Crampton and Seth Mogk from Scripps Institution of Oceanography (University of California, San Diego) provided seismic data acquisition services. A number of scientists (Masao Nakanishi of the Ocean Research Institute, University of Tokyo, in particular), student watch standers, and Earthwatch volunteers contributed to the shipboard data collection. Michael Holzrichter provided invaluable expertise and attention to detail while processing seismic data. Mauricio Canon assisted with seismic figure preparation. Adam Klaus acknowledges the Ocean Drilling Program (ODP) for supporting his involvement throughout the project. We used GMT software (Wessel and Smith, 1995) to produce the maps. This work funded by National Science Foundation (ODP) grant OCE93-14229.

F5. Thompson Trough survey area on Papanin Ridge, p. 11.



F6. Seismic data acquisition geometry, sources, and receivers used on *Thomas Thompson* cruise, p. 12.



T1. Field acquisition, recording, and processing parameters, p. 21.

F7. Seismic lines 5A, 5C, and 11B, p. 13.

F8. Seismic lines 14A, 14C, 17A, and 17B, p. 14.

F9. Seismic lines 3 and 4, p. 15.

F10. Seismic lines 5B, 6, and 7, p. 16.

F11. Seismic line 9, p. 17.

F12. Seismic lines 10, 11A, and 11C, p. 18.

F13. Seismic lines 12, 13, 14B, and 14C, p. 19.

F14. Seismic lines 15, 16, 17C, and 17D, p. 20.

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Figure F1. Bathymetric map of Shatsky Rise showing the locations of seismic reflection profiles collected for this study (solid lines). Gray rectangles show the outline of study areas shown in Figures F2, p. 8, F3, p. 9, F4, p. 10, and F5, p. 11. Bathymetric map is from Sager et al. (1999). L4, L7, L12, and L13 show the locations of seismic profiles not shown in Figures F2, p. 8, F3, p. 9, F4, p. 10, and F5, p. 11. ODP Leg 198 drill sites (1207–1214) are shown in red. Inset: Location of Shatsky Rise in the northwest Pacific showing a simplified magnetic lineation interpretation of Nakanishi et al. (1999). Numbers in parentheses below "M" anomaly labels indicate age in Ma (based on the timescale of Gradstein et al., 1994).

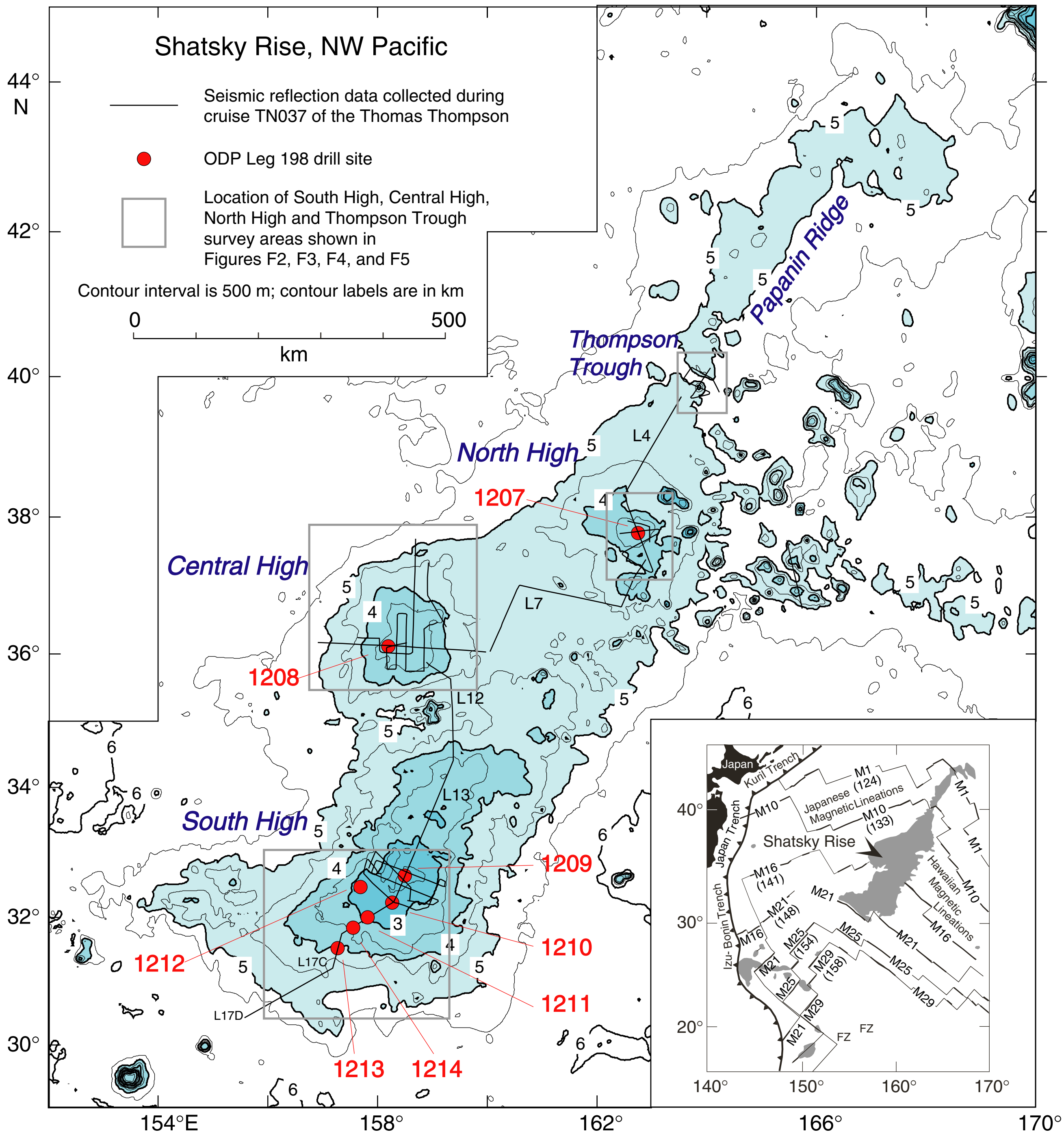

Figure F2. The South High (TAMU massif of Sager et al., 1999) survey area showing the locations of seismic reflection profiles collected for this study and ODP Leg 198 drill sites (1209–1214). Numbers in boxes indicate seismic line numbers. Bold white lines show seismic profiles that are shown in Figure F8, p. 14. The remaining seismic profiles are shown in Figures F13, p. 19, and F14, p. 20. Bathymetric data are from Sager et al. (1999), and depth units are meters × 10^2. The location of the South High survey area is shown in Figure F1, p. 7.

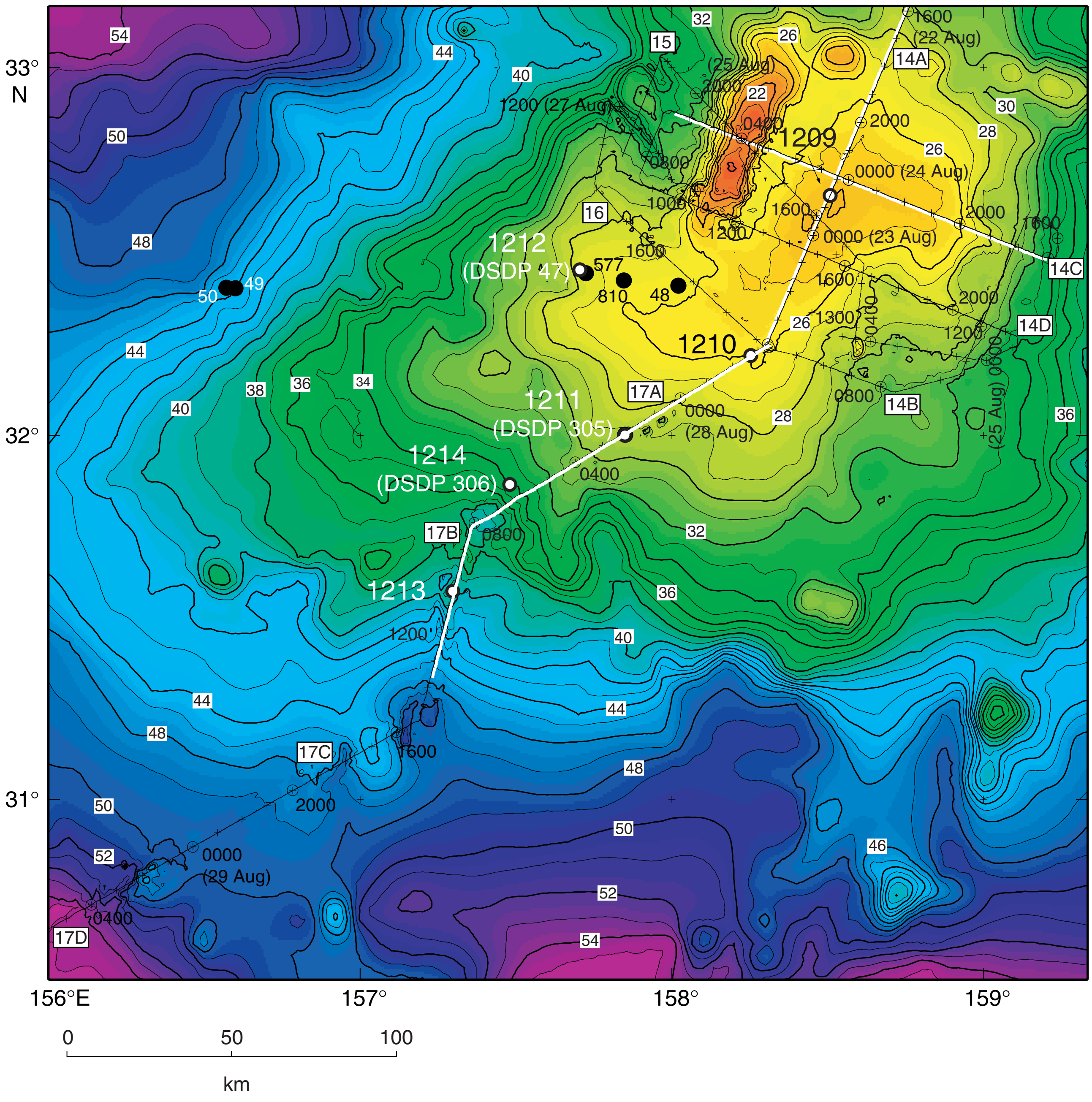

Figure F3. The Central High (ORI massif of Sager et al., 1999) survey area showing the locations of seismic reflection profiles collected for this study and ODP Leg 198, Site 1208. Numbers in boxes indicate seismic line numbers. Bold white lines show seismic profiles that are shown in Figure F7, p. 13. The remaining seismic profiles are shown in Figures F11, p. 17, F12, p. 18, and F13, p. 19. Bathymetric data are from Sager et al. (1999), and depth units are meters × 10^2. The location of the survey area is shown in Figure F1, p. 7.

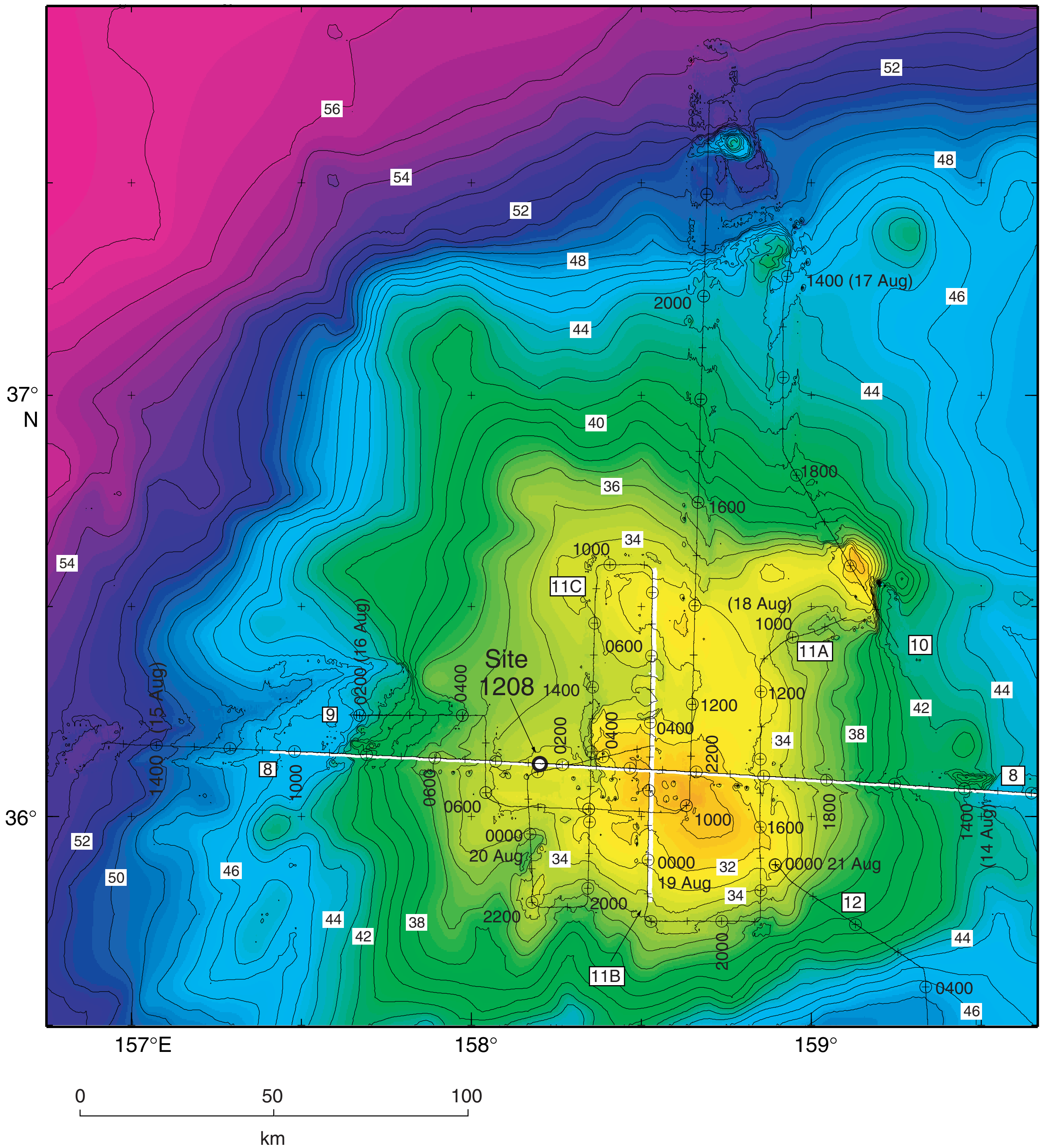

Figure F4. The North High (Shirshov massif of Sager et al., 1999) survey area showing the locations of seismic reflection profiles collected for this study and ODP Leg 198, Site 1207. Numbers in boxes indicate seismic line numbers. Bold white lines show seismic profiles that are shown in Figure F7, p. 13. The remaining seismic profiles are shown in Figure F10, p. 16. Bathymetric data are from Sager et al. (1999), and depth units are meters × 10^2. The location of the survey area is shown in Figure F1, p. 7.

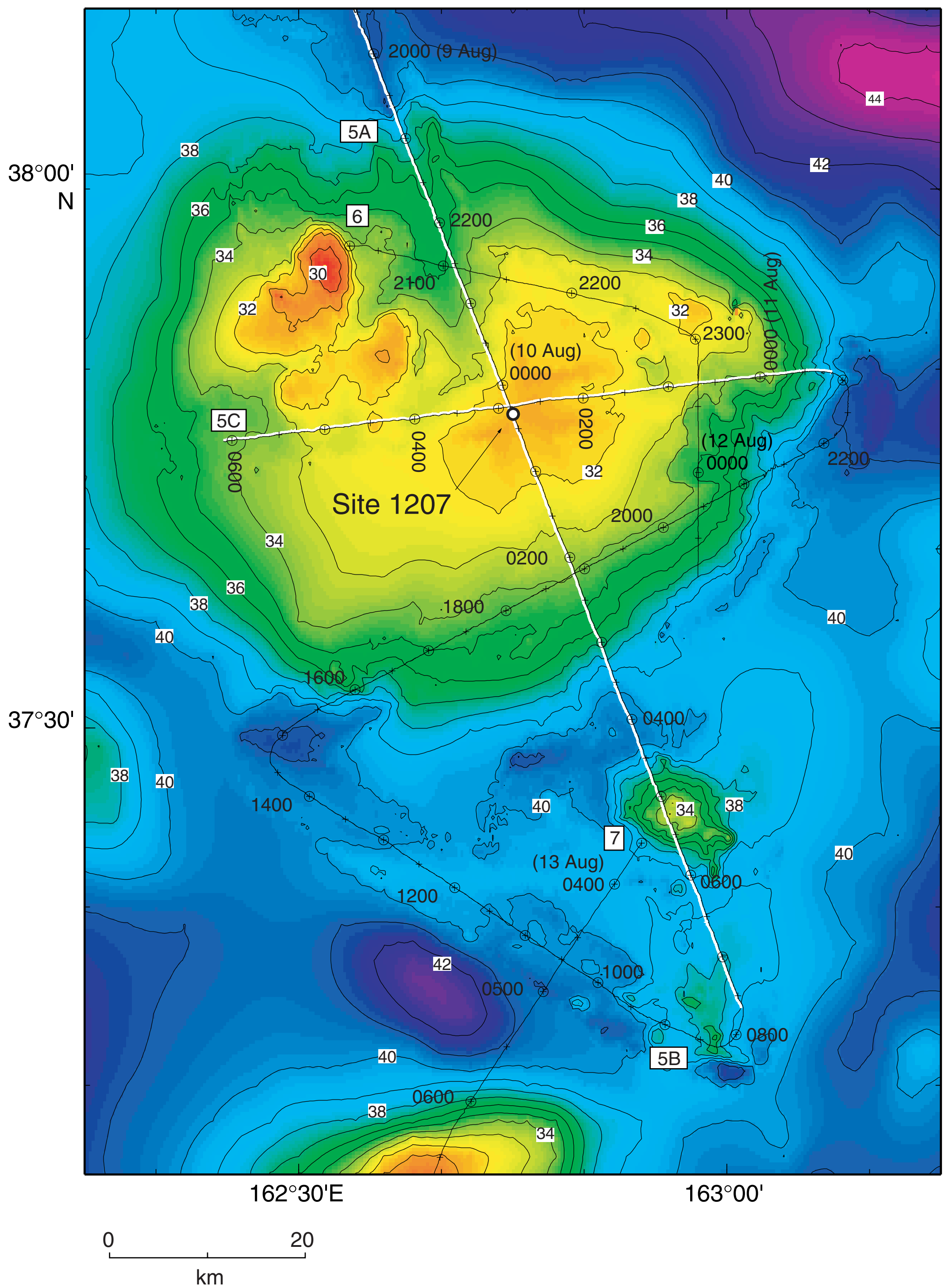

Figure F5. The Thompson Trough survey area on Papanin Ridge showing the locations of seismic reflection profiles collected for this study. Numbers in boxes indicate seismic line numbers. Seismic profiles are shown in Figure F9, p. 15. Bathymetric data is from Sager et al. (1999), and depth units are meters × 10^2. The location of the survey area is shown in Figure F1, p. 7.

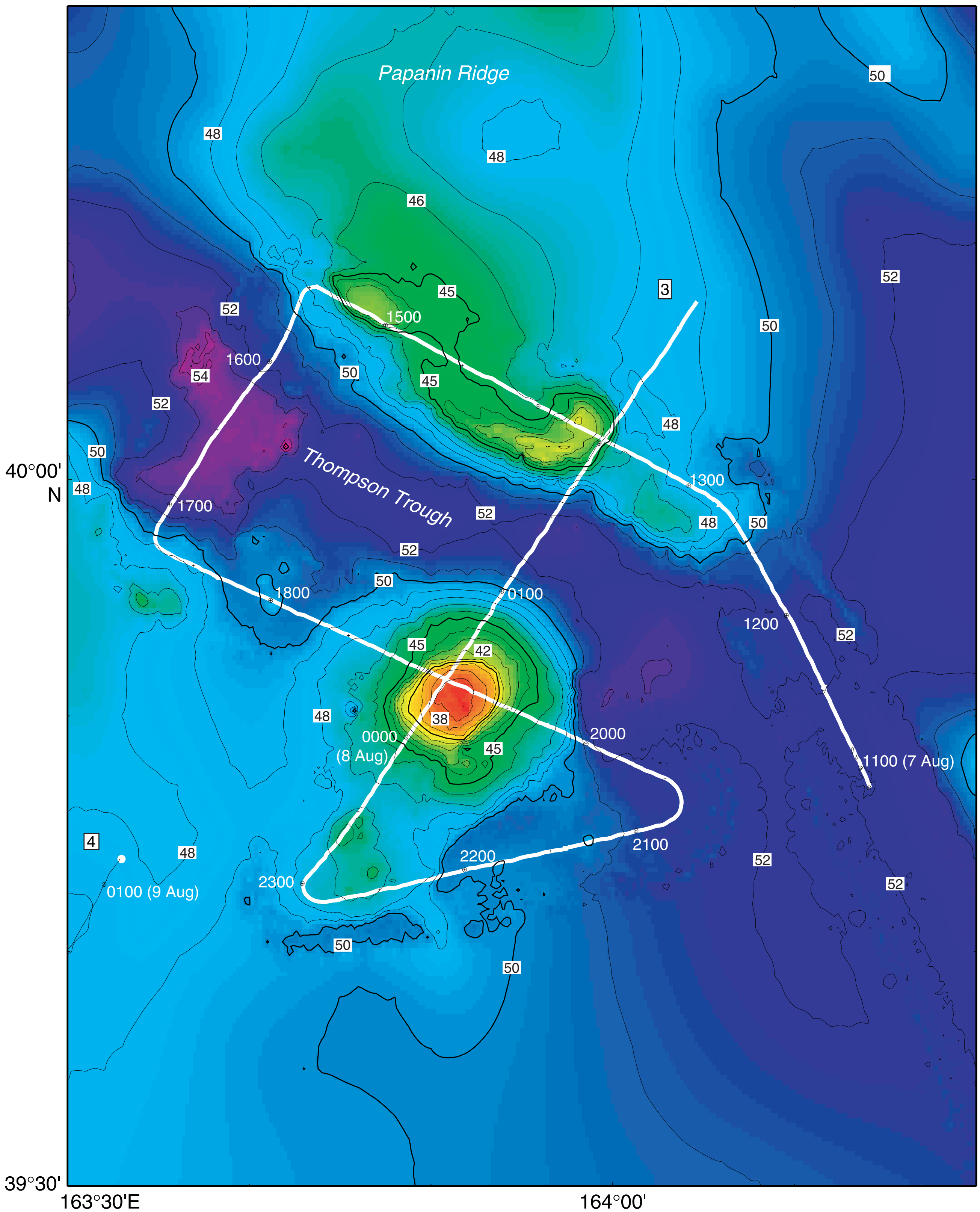

Figure F6. Seismic data acquisition geometry, sources, and receivers used on the *Thomas Thompson* cruise TN037 over Shatsky Rise. GI = generator injector, GPS = Global Positioning System.

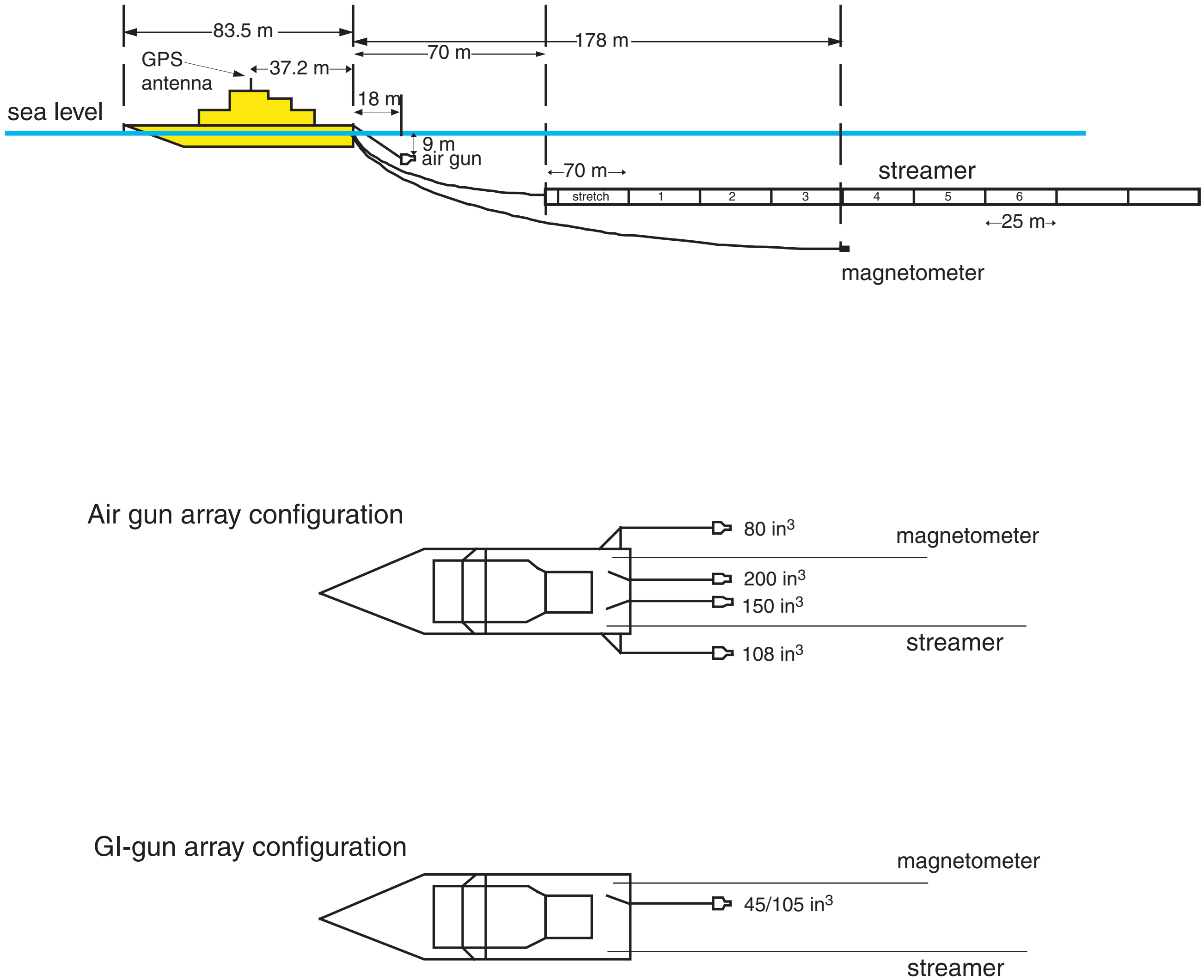

Figure F7. Top: Seismic lines (5A and 5C) collected over the North High showing the location of Site 1207. Bathymetric map displays the location of all North High seismic lines collected; bold white lines show the location of seismic lines 5A and 5C. Seismic lines not shown in this figure (5B, 6, and 7) are shown in Figure **F10,** p. 16. Bottom: Seismic lines (8 and 11B) collected over the Central High showing the location of Site 1208. Bathymetric map displays the locations of all Central High seismic lines collected; bold white lines show locations of seismic lines 8 and 11B. Seismic profiles not shown in this figure (10, 11A, 11C, and 12) are shown in Figures **F11,** p. 17, **F12,** p. 18, and **F13,** p. 19. This figure is available in an **oversized format.**

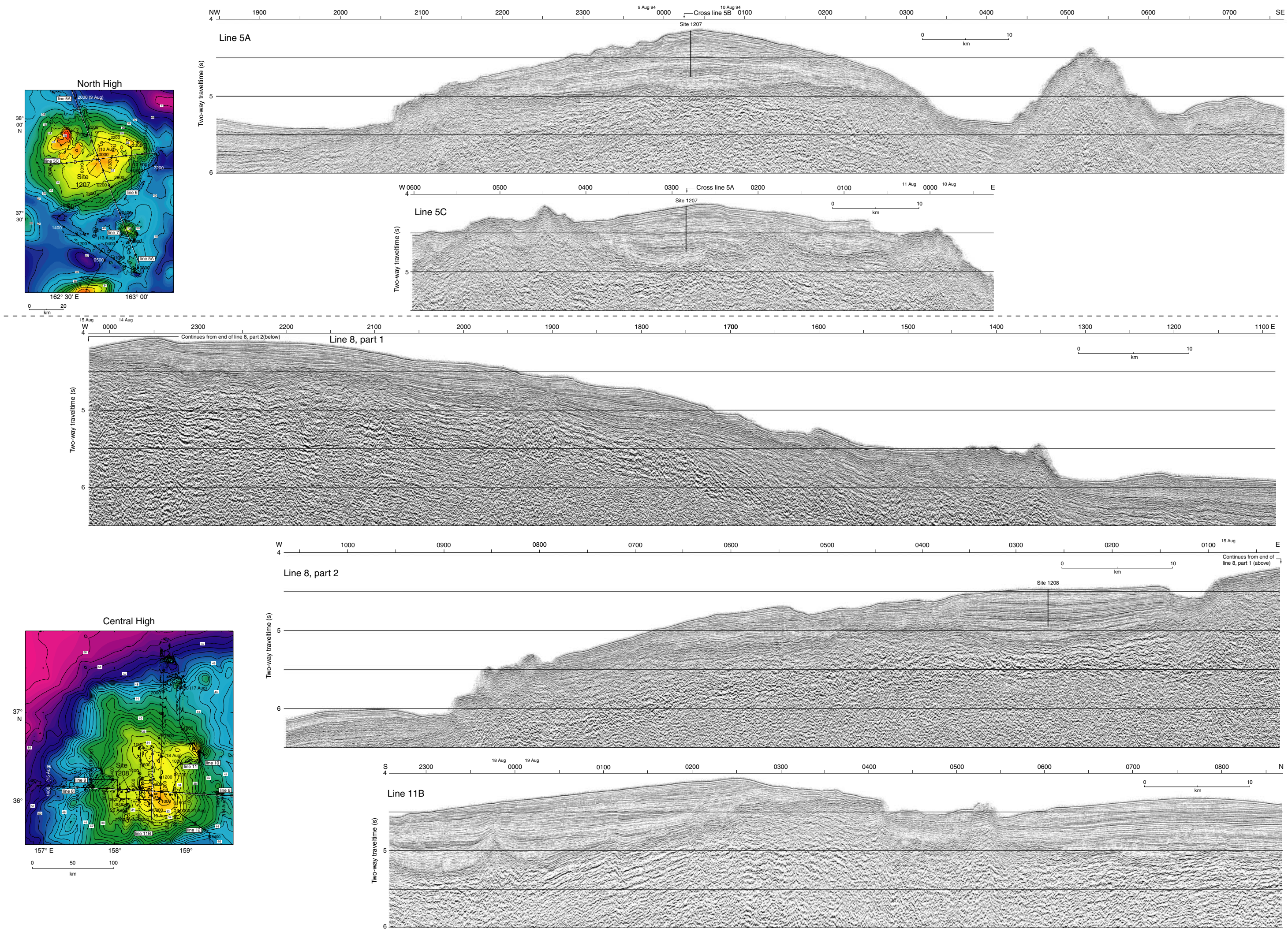

Figure F8. Seismic lines (14A, 14C, 17A, and 17B) collected over the South High showing the locations of Sites 1209, 1210, 1211, 1213, and 1214 (Site 1212 is not located on one of our seismic lines). Bathymetric map shows the locations of all the South High seismic lines collected. Seismic lines not displayed in this figure (14B, 14D, 15, 16, 17C, and 17D) are shown in Figures **F13,** p. 19, and **F14,** p. 20. This figure is available in an **oversized format.**

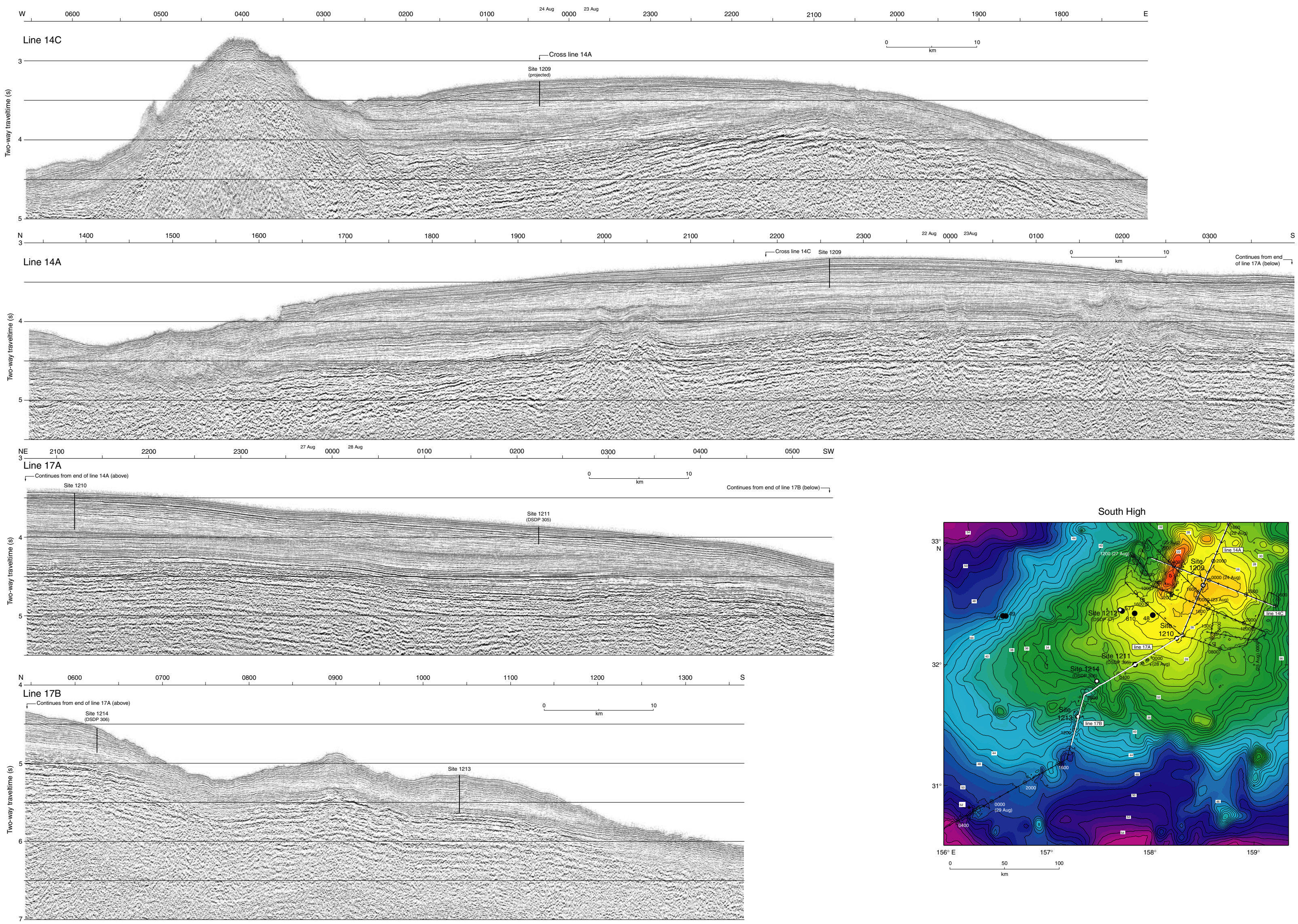

Figure F9. Top: Seismic line 3 collected over the Thompson Trough on the Papanin Ridge. Location of the seismic line is shown in Figure F5, p. 11. Bottom: Seismic line 4 collected during the transit from the Thompson Trough to the North High survey area. The location of the seismic profile is shown in Figure F1, p. 7. C/C = change in ship's heading. This figure is available in an **oversized format.**

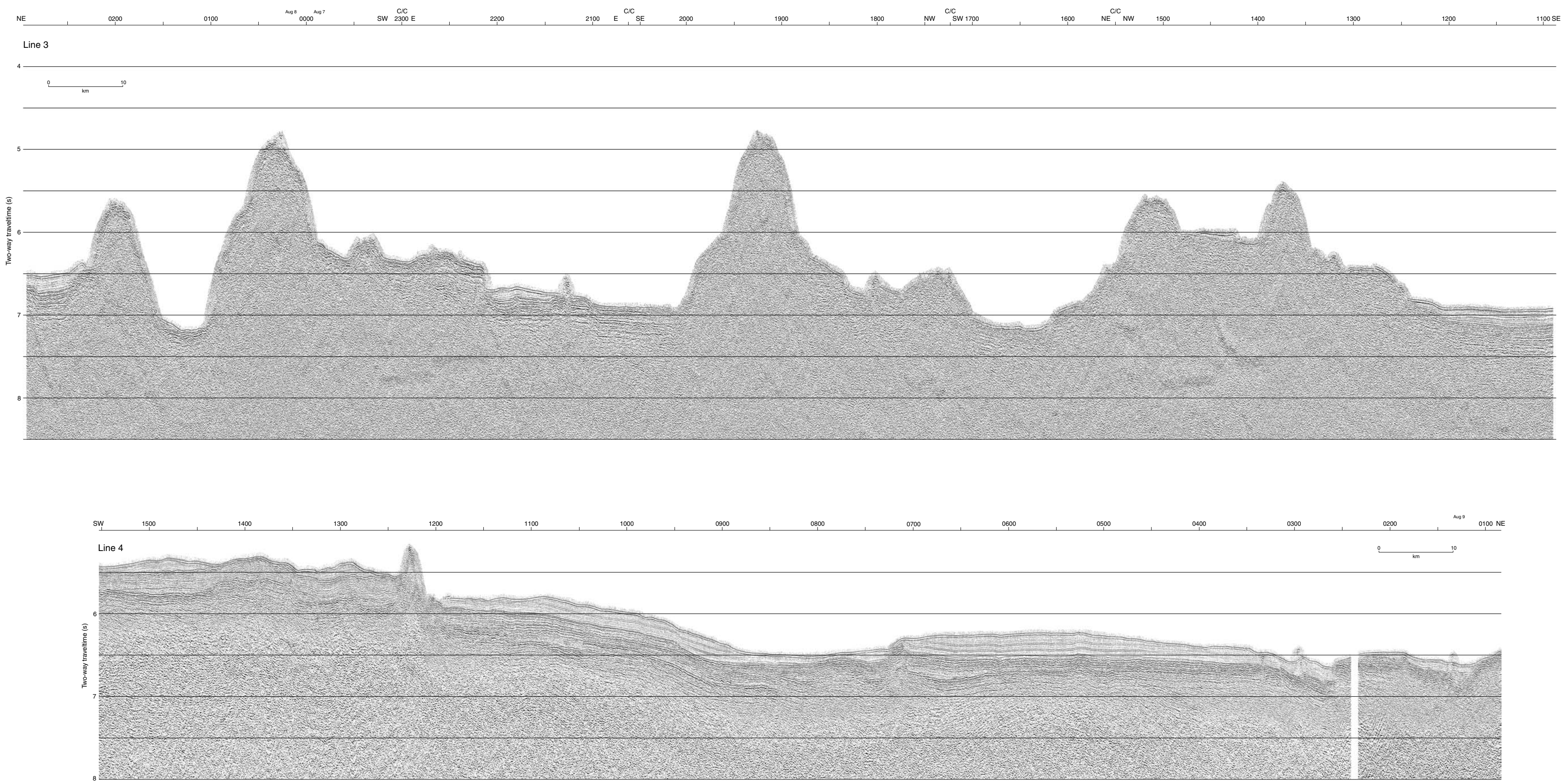

Figure F10. Top: Seismic lines 5B and 6 collected over the North High. The locations of seismic profiles are shown in Figure **F4**, p. 10. Middle and bottom: Seismic line 7 collected during the transit from the North High to the Central High. The location of the seismic profile is shown in Figure **F1**, p. 7. C/C = change in ship's heading. This figure is available in an **oversized format.**

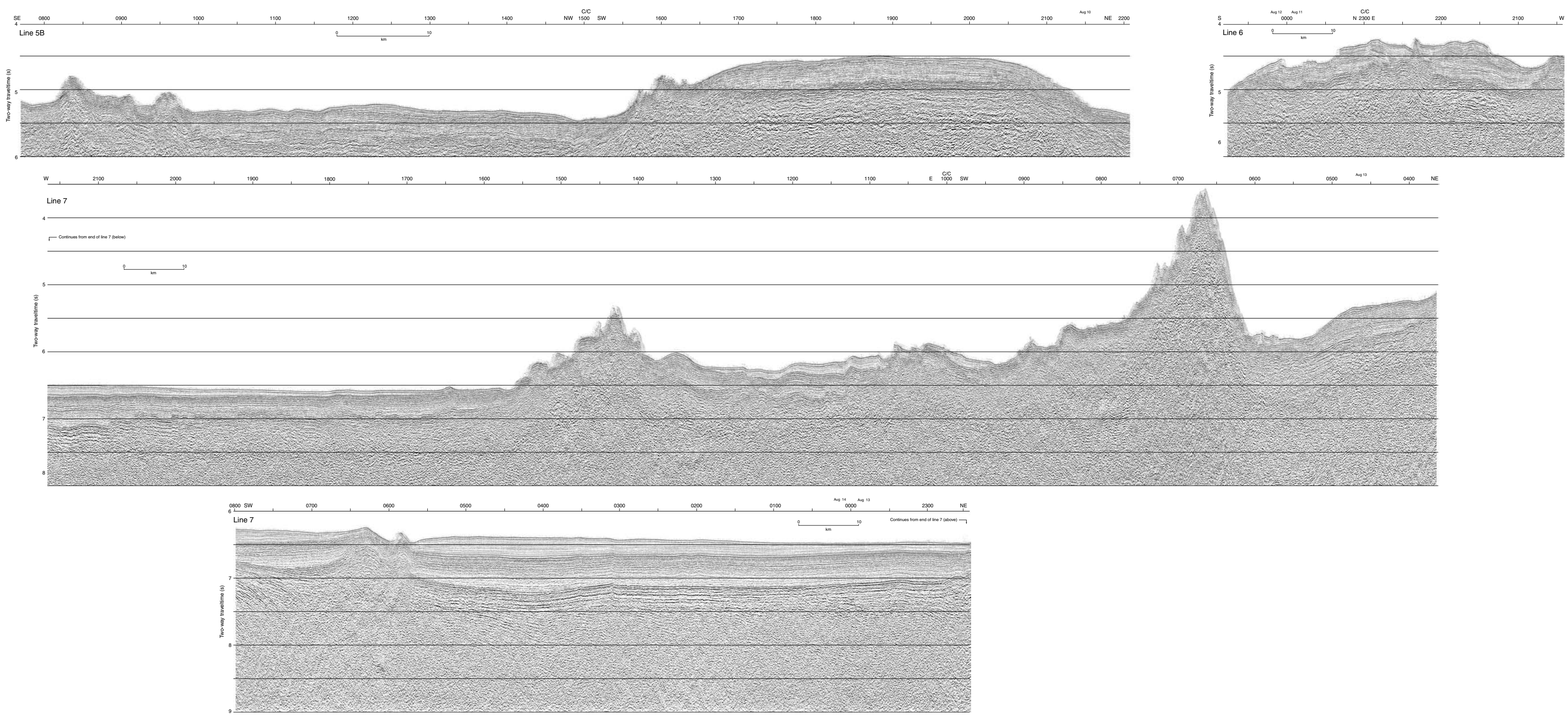

Figure F11. Seismic line 9 collected over the Central High. The location of the seismic profile is shown in Figure F3, p. 9. C/C = change in ship's heading. This figure is available in an **oversized format.**

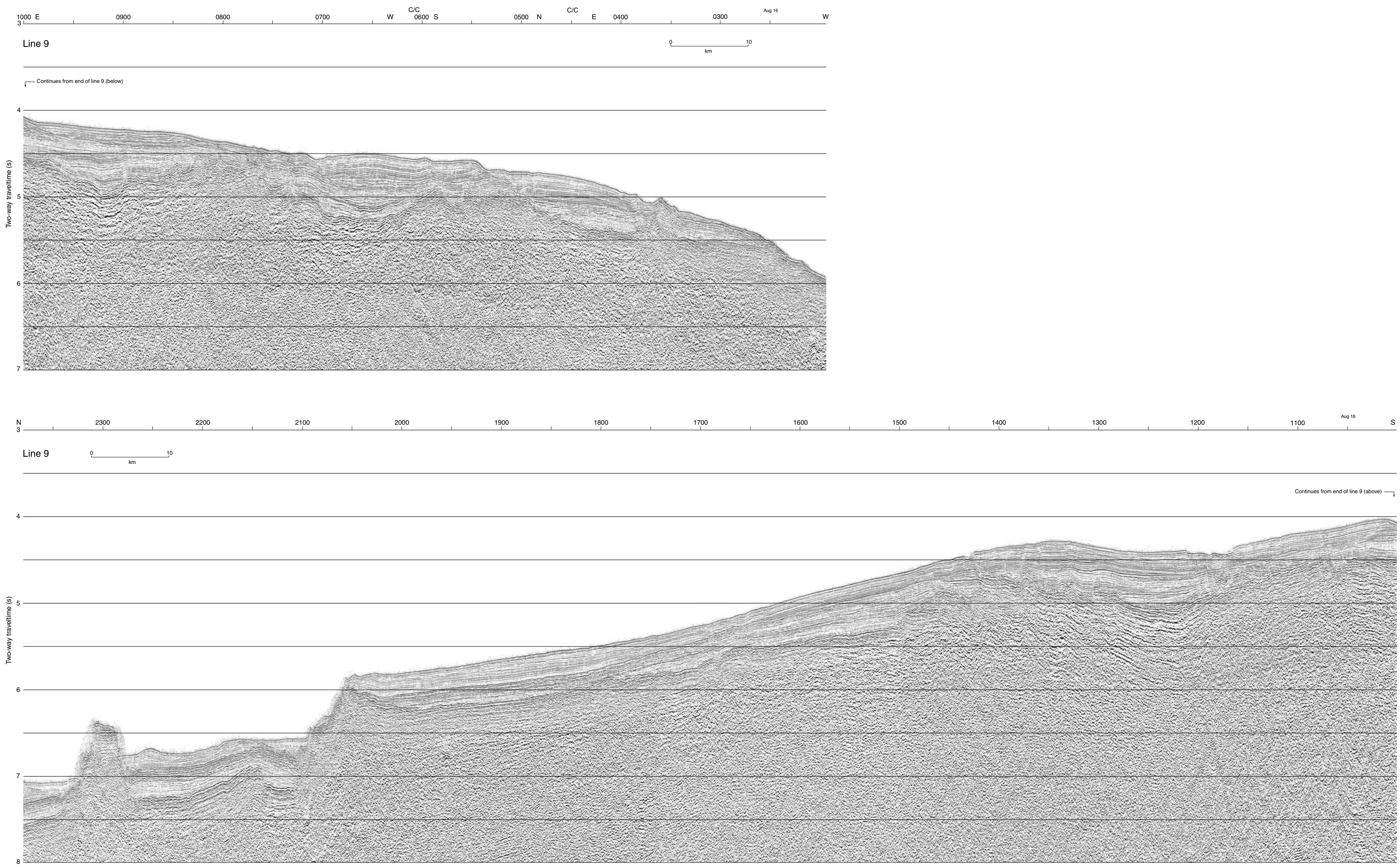

Figure F12. Top, middle, and bottom: Seismic lines 10, 11A, and 11C collected over the Central High. The location of the seismic profile is shown in Figure F3, p. 9. C/C = change in ship's heading. This figure is available in an **oversized format.**

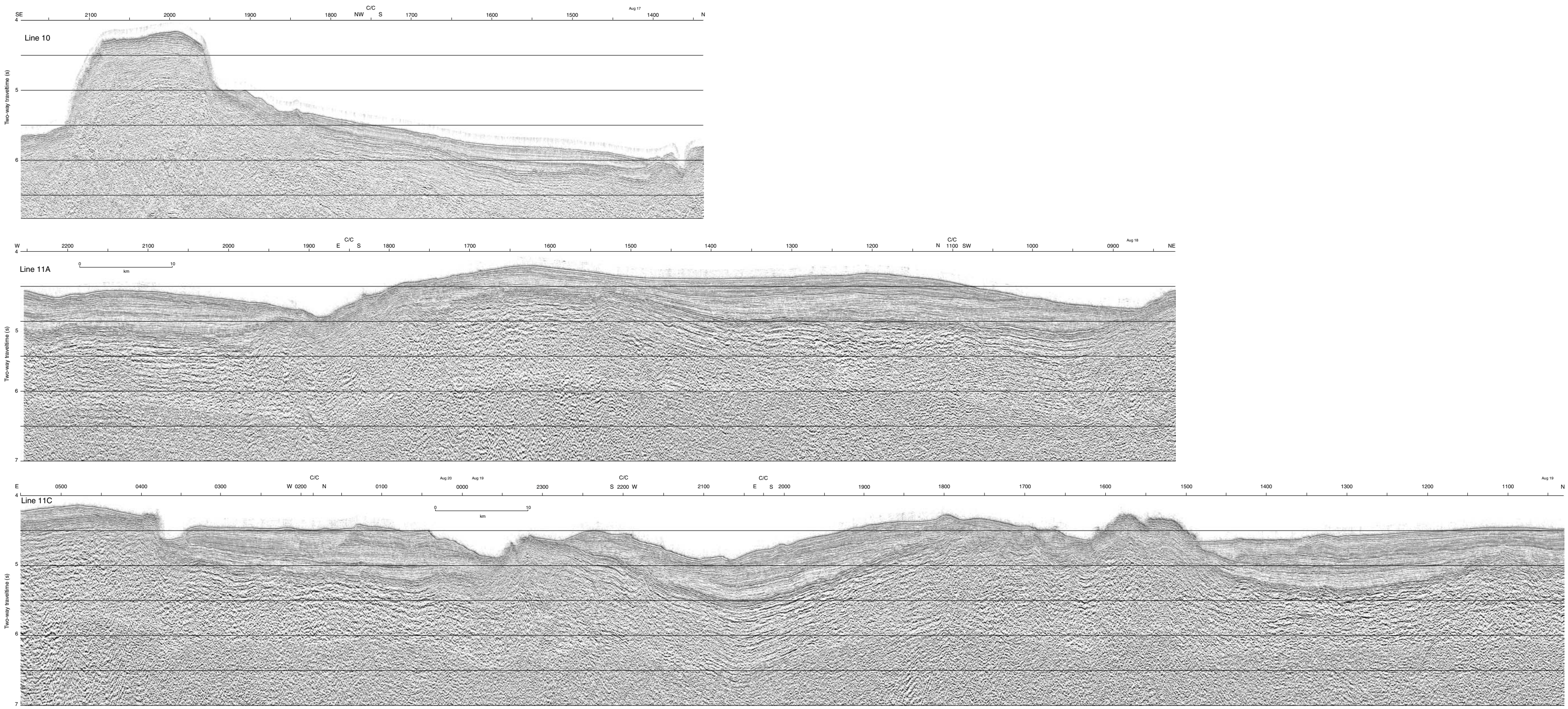

Figure F13. Top: Seismic lines 12 and 13 collected during the transit from the Central High to the South High. The locations of seismic lines are shown in Figure F1, p. 7. Middle and bottom: Seismic lines 14B and 14C collected over the South High. The locations of seismic lines are shown in Figure F2, p. 8. C/C = change in ship's heading. This figure is available in an **oversized format.**

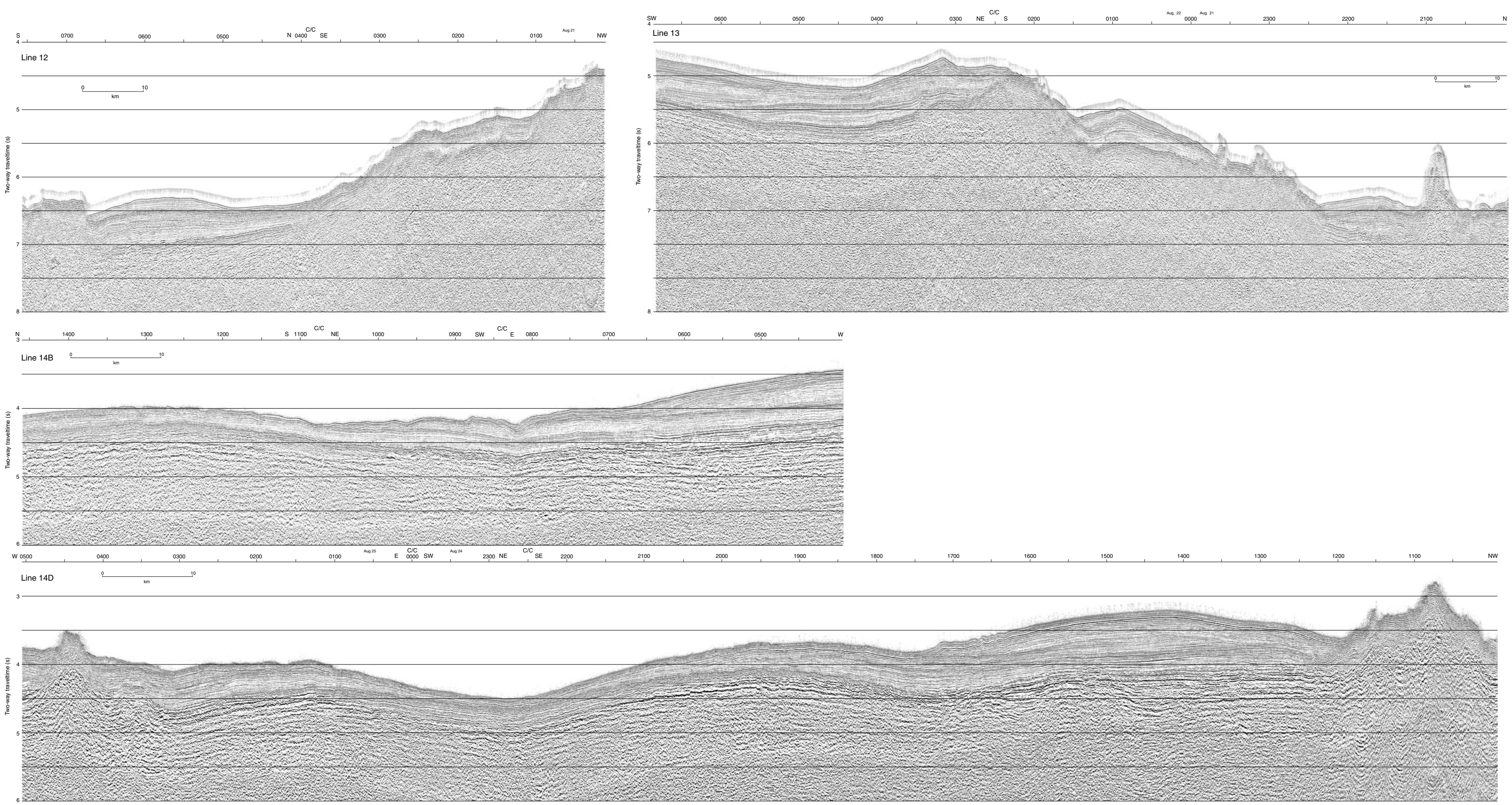

Figure F14. Top and middle: Seismic lines 15 and 16 collected over the South High. The locations of seismic lines are shown in Figure F2, p. 8. Bottom: Seismic lines 17C and 17D collected during the transit from the South High to Guam. The locations of seismic lines are shown in Figures F1, p. 7, and F2, p. 8. C/C = change in ship's heading. This figure is available in an oversized format.

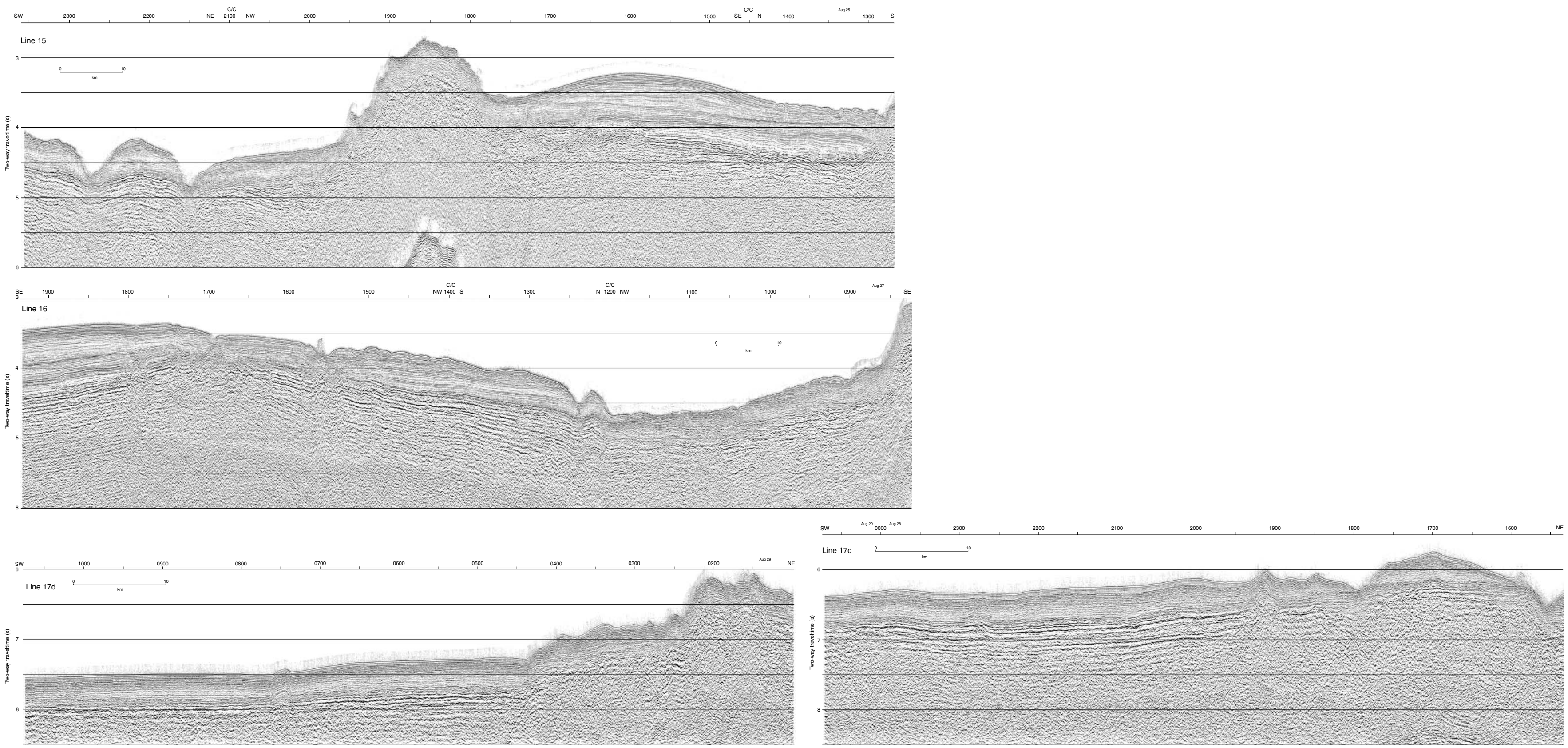

Table T1. Acquisition and processing parameters for TN037 seismic reflection data collected for this study.

Field acquisition:
- Vessel: *Thomas Thompson*
- Cruise: TN037
- Start date: 23 Jul 1994
- End date: 4 Sep 1994
- Source:
  - 1. Air gun array: 200, 150, 108, and 80 in^3
  - 2. GI air gun: 45/105 in^3
- Pressure: 2000 psi
- Shot interval:
  - Maximum: 37 m
  - Minimum: 25 m
- Streamer:
  - Active group length: 25 m
  - Number of groups: 6

Recording:
- Acquisition hardware: Sun SPARC10
- Acquisition software: “a2d”
- Data format: SEGY
- Data length: 6–7 s
- Delay: 2–3 s
- Shot interval: 10 s
- Sample interval: 1 ms
- Filters:
  - Low: 15 hz (24 dB/oct)
  - High: 3khz (24 dB/oct)

Processing sequence:
- Pick water bottom time (WBT)
- Despike
- Bandpass filter 5–200 Hz
- Geometry definition, insert WBT in header
- Mute to water bottom
- Spherical divergence correction
- Resample (2 ms)
- Notch filter (60 Hz)
- Deconvolution
- Velocity analysis
- NMO correction
- Stack
- Pick and apply static correction
- Finite difference migration
- Time-varying filter:
  - Seafloor to 0.25 s: 30–150 Hz
  - 0.25 to 1.0 s: 20–150 Hz
  - 1.0 s to end of record: 6–70 Hz
- Gain (500 ms AGC)
- Mute to water bottom

Notes: Data were processed at the Ocean Drilling Program, Texas A&M University. Processing software: SIOSEIS and PROMAX. Data were processed by Michael Holzrichter and Adam Klaus. NMO = normal moveout. AGC = automatic gain control.