Cruise Report
Research Vessel Thomas G. Thompson
Walvis Ridge Geophysical Surveys

Research Vessel Thomas G. Thompson University of Washington photo

Cruise TN-373
5 November – 7 December 2019
Montevideo, Uruguay to Walvis Bay, Namibia

Cruise TN-374
10 December 2019 – 5 January 2020
Walvis Bay, Namibia to Cape Town, South Africa

Chief Scientists
William W. Sager Hua-Wei Zhou Sriharsha Thoram
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Funded by the US National Science Foundation

Cruise TN-373 Science Personnel

Agostine, Royhon – Seismic technician – Scripps Institution of Oceanography
Carlin, Croy – Marine technician – University of Washington
Contreras, Edgar – graduate student – University of Houston
de Abreu, Elita – geophysicist – Petrobras
Duff, Patrick – graduate student – University of South Carolina
Fiero, Max - Protected species observer – Scripps Institution of Oceanography
Garcia, Alan – graduate student – University of Houston
Hatton, Ray - Seismic technician – Scripps Institution of Oceanography
Jalickee, Stephen – Marine technician – University of Washington
Li, Zhehao – graduate student – University of Houston
Mendenhall, Brenden - Seismic technician – Scripps Institution of Oceanography
Pedrie, Kolby - Seismic technician – Scripps Institution of Oceanography
Penny, Doug - Seismic technician – Scripps Institution of Oceanography
Portas Arroyal, Alejandro – graduate student – University of Houston
Sager, William - professor & co-chief scientist – University of Houston
Stafford, Mandy – Protected species observer – Scripps Institution of Oceanography
Sullivan, Taylor - Protected species observer – Scripps Institution of Oceanography
Taylor, Laura – student – University of Houston
Thoram, Sriharsha – graduate student – University of Houston
Vila, Alec – graduate student – University of Houston
Welsh, Jennifer – graduate student – University of Houston
Zhou, Hua-Wei – professor & co-chief scientist – University of Houston

Cruise TN-373 Ship's Crew

Barnaby, Bruce – Chief mate
Bartcell, David – 3rd engineer
Bean, David – Oiler
Bielenberg, David – AB seaman
Blusk, Pamela – AB seaman
Crump, Todd – 2nd mate
Dixson, Emmett – AB seaman
French, John – AB seaman
Haroldson, Eric – Captain
Huffman, Niki – 2nd cook
Johnson, Mark – 1st engineer
Kilgore, Caleb – AB seaman
Lyons, Lance – 1st engineer
Minsull, Andrew – Oiler
Montague, Daniel – Oiler
Myers, Scott – 2nd engineer
Schwartz, Todd – 3rd mate
Singerline, Terrance – Mess
Spetla, Frank – AB seaman
Vasquez, Arnel – Oiler
Zacharias, Freda - Steward

Cruise TN-374 Science Personnel

Alam, Malik – graduate student – University of Houston
Bhakta, Ritesh – graduate student – University of Houston
Brugger, Sonia – Marine technician – University of Washington
Chang, Benjamin – graduate student – University of Houston
Cornelison, Brendan - graduate student – University of Houston
Ghosh, Avradip – graduate student – University of Houston
Jalickee, Stephen – Marine technician – University of Washington
Merchant, Bhavya – student – University of Houston
Moleele, Tshiamo – graduate student – University of the Western Cape
Ngcobo, Luyanda – graduate student – University of the Western Cape
Pascali, Amanda – student – University of Houston
Sager, William – professor and co-chief scientist – University of Houston
Thoram, Sriharsha – gradate student and co-chief scientist – University of Houston
Yakimova, Veselina – graduate student – University of Alaska, Fairbanks

Cruise TN-373 Ship's Crew

Baily, James – AB seaman
Barnaby, Bruce – Chief mate
Bielenberg, Denis – AB seaman
Castner, Dominic – Chief engineer
Crump, Todd – 2nd mate
DeVaney, Bruce – Captain
Dickgieser, Geoff – 3rd engineer
Eldred, Brian – Oiler
French, John – AB seaman
Kilgore, Caleb – AB seaman
Lyons, Lance – 1st engineer
Minshall, Andrew – Oiler
Montague, Daniel – Oiler
Myers, Scott – 2nd engineer
Sampson, Kyle – Oiler
Schwartz, Todd – 3rd mate
Singerline, Terece - Mess
Welsh, Jeremy – 2nd cook
Wicker, Sarah – Steward
Wicker, Thomas – AB seaman
Wilson, James – AB seaman

TN-373 Science Party

Left to right: William Sager, Max Fiero (seated), Royhon Agostine, Kolby Pedrie, Elita de Abreu (seated), Brendan Mendenhall, Hua-Wei Zhou, Jennifer Welsh, Patrick Duff, Taylor Sullivan (front), Mandy Stafford, Laura Taylor, Edgar Contreras, Alec Vila, Alan Garcia, Alejandro Portas (front), Zhehao Li (back), Doug Penny, Sriharsha Thoram.

TN-374 Science Party

Left to right: William Sager, Benjamin Chang, Bhavya Merchant, Matthew Sexton, Tshiamo Moleele, Sriharsha Thoram (back), Ritesh Bhakta, Amanda Pascali, Veselina Yakimova, Brendan Cornelison, Malik Alam (rear), Luyanda Ngcobo, Avradip Ghosh.

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Summary

Cruises TN-373 and TN374 funded by the US National Science foundation to study Walvis Ridge as a site survey for International Ocean Discovery Program Expedition 391 as well as a geophysical study of the formation of this hotspot trail. The cruises, onboard the R/V *Thomas G. Thompson,* were done in late 2019 and early 2020. Their purpose was to collect seismic, magnetic, gravity, and bathymetric data over portions of Walvis Ridge. Owing to environmental regulations, seismic data were collected on one cruise (TN-373) and multibeam echosounder data, magnetic data, and other geophysical data were collected on the subsequent cruise (TN-374). Cruise TN-373 started from Montevideo, Uruguay on 5 November 2019 and crossed the south Atlantic to Walvis Ridge. It used the Scripps Institution of Oceanography portable multi-channel seismic system to collect profiles. This system used a 96-channel streamer with 2 small G-I airguns as source. A short, 114 km length seismic practice line was shot across southeastern Rio Grande Rise. After arrival in the Walvis Ridge Guyot Province, 13 seismic lines were run over guyots in three survey areas, totaling 717 km of profiles. At Valdivia Bank, an additional 13 seismic lines were run across this plateau feature, totaling 2,229 km of profiles. Altogether, the total number of seismic shots fired was 120,616 and the total length of profiling was 3015 km. Cruise TN-373 was finished on 7 December 2019 after arrival at Walvis Bay, Namibia, where technical and science crew changes were made and the seismic gear was removed from the ship. Cruise TN-374 began on 10 December 2019 when the Thompson returned to Valdivia Bank. From 12 December 2022 to 2 January 2020, 20 magnetic profiles, oriented approximately E-W were run over Valdivia Bank and adjacent seafloor. The total lengths of magnetic profiles over Walvis Ridge was 10,574 km. Cruise TN-374 ended on 5 January 2020 when the *Thompson* arrived at Cape Town, South Africa.

Background

Walvis Ridge is an archetypical hotspot track, located in the southeast Atlantic Ocean offshore of Namibia (Fig.1). It is thought to have begun with eruptions of the Etendeka continental flood basalt in Africa at ~132 Ma and ends in two active volcanoes, Tristan Island and Gough Island, located west of the Mid-Atlantic Ridge (MAR) (O'Connor and Duncan, 1990). Owing to its prominence and early indications of an age progression, it was one of the first hypothesized hotspot tracks used as evidence of plate motion relative to the mantle (Morgan, 1971; 1981). Moreover, as the most prominent hotspot track of the African plate, it is the keystone for the plate motion model of Africa over the hotspots (Duncan, 1981). Because of its central position in the Gondwana continents, Africa is often used as the foundation for global plate motion models (e.g., Müller et al., 1993; DeMets et al., 2010) and thus African motion relative to the hotspots affects models for many other plates. Walvis Ridge is also important because it lends support to the model that hotspots are manifestations of thermal plumes formed at the edges of large low shear velocity provinces (LLSVP), which occur at the base of the mantle (Burke et al., 2008). It is the most prominent of several south Atlantic hotspot tracks that appear to have formed over the edge of the "Tuzo" LLSVP (Burke, 2011; O'Connor et al., 2012).

Although it is commonly viewed as a hotspot track, Walvis Ridge is more complex than the archetypical Hawaiian-Emperor chain (O'Connor and Jokat, 2015a; Sager et al., 2021). Its morphology changes dramatically along its length. From the continental margin offshore to ~8°E, Walvis Ridge consists of a linear ridge, named Frio Ridge (Fig. 1) with embedded fault blocks parallel to the paleo-MAR (O'Connor and Jokat, 2015a, b). At 6°E, Walvis Ridge bends ~90° and turns into a N-S oriented ocean plateau, named Valdivia Bank (Fig. 1). It continues southwest from Valdivia Bank at 5°E as a series of N-S oriented linear ridges (Fig. 1) to the "Trident" at 3°E, where it splits into three seamount chains (O'Connor and Jokat, 2015a, b). The northernmost seamount chain (Tristan Track) appears to have formed by interaction of the hotspot with the MAR whereas the middle (Center Track) and southern (Gough Track) seamounts appear to have formed by progressive volcanism from the Tristan-Gough hotspot (O'Connor and Jokat, 2015a). When reconstructed to past times, Valdivia Bank and Rio Grande Rise (Fig. 1) formed at the MAR during the Late Cretaceous (O'Connor and Duncan, 1990; Sager et al., 2021). Both large igneous provinces (LIPs) have complications with later (Eocene) volcanism (Rohde et al, 2013; O'Connor and Jokat, 2015a; Homrighausen et al, 2018; 2019). These oceanic plateaus formed as a long-offset transform fault located north of Frio Ridge degenerated into several smaller offset transform faults farther south during a plate reorganization. This reorganization caused ridge jumps and probably formed a microplate between Rio Grande Rise and Valdivia Bank (Sager et al., 2021). These complications indicate that the development of both LIPs is incompletely understood.

Geophysical data over Walvis Ridge is sparse, in particular, the region is lacking in modern seismic data and magnetic tracks are few. Data sparsity limits our understanding of Walvis Ridge formation. The cruises reported here were funded by the National Science Foundation for a project entitled "Tectonic evolution of the Rio Grande Rise - Walvis Ridge hotspot twins using magnetic anomaly and seismic reflection data". The goal of the project was to collect seismic and magnetic data to better understand the tectonics of Walvis Ridge. In addition, seismic data were to be used as site survey data to better document previously-proposed drill sites for International Ocean Discovery Program (IODP) Expedition 391 and to find new sites to propose for that drilling program.

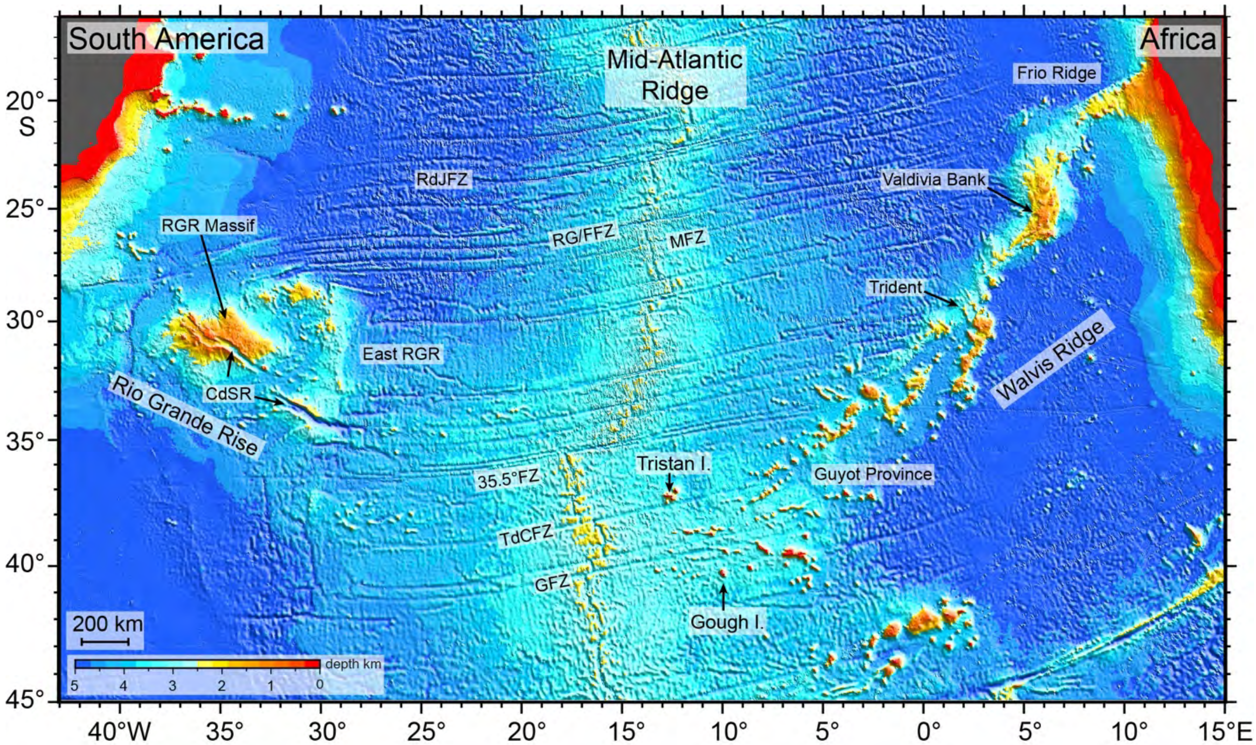


Figure 1. Overview of south Atlantic bathymetry and feature names. Plot shows bathymetry estimated from satellite altimetry (Smith and Sandwell, 1997).

Cruise Design and Rationale

The project cruise was proposed as a single 45-day expedition with the collection of both seismic and underway geophysical data. Unfortunately, current interpretations of regulations meant to protect vulnerable marine organisms during seismic operations dictate that sonar data collection is not allowed when the seismic system is not in use. This meant that a single cruise could not accomplish objectives of the project. Consequently, the cruise was split into two legs (Fig. 2), one for seismic data collection (Cruise TN-373) and the other for multibeam sonar and underway geophysical data collection (Cruise TN-374). The project was scheduled on the R/V *Thomas G Thompson* and the previous cruise was located on the eastern margin of South America, necessitating a dead-head transit across the south Atlantic to Africa. To accommodate the subdivision of the cruise, seismic data collection was added to the transit, to become Cruise TN-373. This cruise ended in Walvis Bay, Namibia, the closest major port to the study area. This stop also had the beneficial result that seismic gear and technical personnel could depart the ship earlier than planned and additional personnel could join the ship. After removal of the seismic gear and departure of seismic technicians and protected species observers, multibeam bathymetry and other geophysical data were collected during the second leg, Cruise TN-374.

Cruise Plan

The plan for the cruise was to collect a number of short seismic lines over three guyots in the "Guyot Province" of middle Walvis Ridge and to collect a number of longer lines crossing Valdivia Bank. The three guyots are sites planned for drilling on IODP Expedition 391, with one each in the Tristan Track (TT), Center Track (CT), and Gough Track (GT). Because collecting multiple lines over small guyots requires many turns, seismic lines numbers were generally changed when the ship made a sharp turn (>45°), but not for gentle turns, which may be needed to line up on a target site. For Valdivia Bank, seismic lines were much longer and zig-zagged back and forth across the plateau to make long crossings and to move from one end to the other. In addition to the guyot and Valdivia Bank sites, one additional line was run over an exceptional rift in southeast Rio Grande Rise for a practice line.

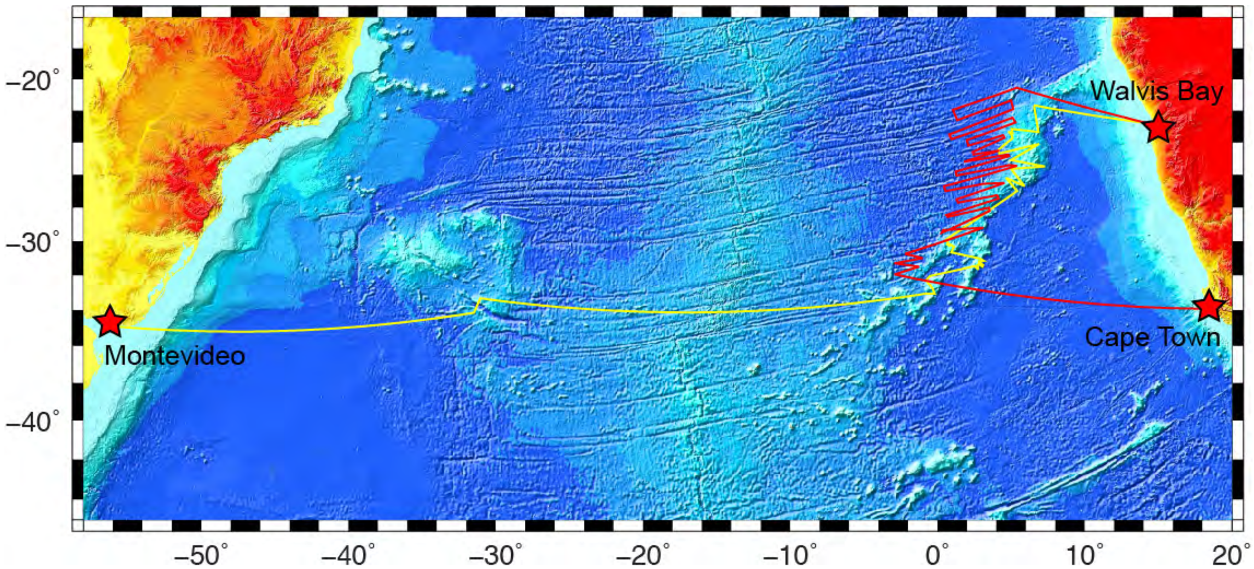


Figure 2. Overview plot showing the planned tracks of cruises TN-373 (yellow line) and TN-374 (red line). Plot shows topography and bathymetry (Smith and Sandwell, 1997).

The initial plan was for the test line (RGR-1) to be 50 nm (93 km) in length and take ~10 hours. The CT guyot survey was planned to be first, extending 122 nm (226 km) and taking ~34 hours. The GT guyot survey was second, and about the same length. The third survey was for the TT guyot, with a length of 94 nm (174 km) and ~28 hours. The Valdivia Bank survey was considerably longer, covering 1186 nm (2,194 km) and taking ~295 hours (12.3 days).

Initially, we planned to use a faster profiling method for the guyot sites. This technique used only one airgun and a short streamer, but profiled at a speed of 8 kt (14.8 km/hr). The idea was that for the guyot sites, it was only necessary to record the basement interface and that sediments would be thin. This rapid profiling would allow additional time for surveys elsewhere. This system was tried on the first guyot seismic line, CT-1, but the result was poor and this technique was shelved. However Line CT-1 was not reshot. Five seismic lines were planned for the CT guyot, nine for the GT guyot, and five for the TT guyot. A total of 13 seismic lines were planned for Valdivia Bank (Table 1).

The goal of the TN-374 cruise was race back and forth over Valdivia Bank and the area to the west for the primary purpose of collecting magnetic and multibeam bathymetry data. Prior research indicated that this area contains critical magnetic anomalies that illustrate the tectonic reorganization which occurred during the Late Cretaceous (Sager et al., 2021). The cruise was initially planned for a conservative speed of 10 kt (18.5 km/hr), but transit during cruise TN-373 showed that Thompson can routinely sail at 12 kt (22.2 km/hr). Thus, the survey was revamped with longer, more ambitious lines. The survey plan contained 20 lines with nearly E-W trends, ranging in length from 125-380 nm (231-703 km), connected by short turn lines, with lengths of 7-42 km (13-78 km). The total length of the survey lines was 5920 nm (10,952 km) not including transits to and from the study area (Table 2). This ambitious plan meant that keeping up the ship's speed was critical to completing the survey and took the chance that bad weather could keep the cruise from attaining the goal. However, good luck held and the survey was completed as planned. With transits of 1327 nm (2455 km) added, the total length of planned ship tracks was 7253 nm (13,418 km).

Equipment, Instruments, and Data Collection

Multibeam Echosounder

Swath bathymetry was collected using the ship's Kongsberg EM302 30-kHz multibeam echosounder, whose transducers are mounted on the hull. The EM302 is capable of producing up to 432 soundings per ping across the swath width, but often the full width was not filled out. The instrument specification says that it can collect a swath approximately 5.5 times water depth, but in practice the swath width was less, especially in deep water where the sonar switched (automatically) to deep mode. Data were collected in Kongsberg "*.all" file format using Kongsberg Seafloor Information System v.4.3.2 software. Subsequent to collection data were processed using Caris HIPS SIPS v.10.4 software. Processing mostly consisted of deleting spurious soundings to provide a cleaner (less noisy) seafloor surface. Soundings were especially suspect on the outer edges of the swath. Processed data were exported as latitude, longitude, depth triplets in text files.

Wide-beam Echosounder

Subbottom depth profiles were collected using the ship's Knudsen Model 3260 CHIRP sonar using a frequency of 3.5 kHz to provide subbottom penetration. Data were collected using Knudsen Sounder Suite: Echo Control Client v. 4.09 software and saved in several common formats: SEGY, KEB (Knudson proprietary binary), and KEA (ascii). The transmit pulse was set to 8.0 ms and no time varying gain was applied. The ping rate was determined by water depth, but was typically once every few seconds. Data quality was usually good with penetration of 50-100 m where soft sediments were present. Depth control was kept in manual mode with a 1000-m window, requiring watchstanders to adjust window depth as the ship passed over slopes.

Magnetometer

Magnetic data were collected while in transit using a Marine Magnetics SeaSpy2 overhauser magnetometer. The sensor was towed astern with a layback of 342 m from the winch and approximately 390 m from the GPS antenna. The magnetometer cable was deployed and recovered with a small, portable winch that was mounted near the center of the fantail, between the two seismic streamer reels. The winch and magnetometer were supplied by the Woods Hole Oceanographic Institution MISO facility. The cable was towed from a "Yale" grip that was fastened to an eyebolt secured to the deck. The cable was passed over the stern in a plastic, v-shaped roller that kept the cable from chafing on the deck. Typical tow speeds during magnetic data collection were 10-12 kt. The magnetometer performed well, except for rare, spurious spikes occasionally in rough seas. Magnetic data were not collected during cruise TN-373 on seismic lines because of concern that the magnetometer cable would tangle with the seismic streamer.

Data were collected on a PC using Marine Magnetics "BOB" software at a rate of one reading per second, with a precision of 0.1 nT. The ship's GPS navigation was recorded at the same rate and merged with the magnetic data by the BOB software. For archiving, data were decimated to one reading per minute (approximately every 180 m at 12 kt speed) and corrected using the current International Geomagnetic Field (IGRF 12; Thébault et al., 2015). Archived data were not corrected for layback in part for simplicity and in part to keep from confusing future users because most marine magnetic data have no layback correction.

Gravimeter

Gravity data were recorded using a Bell BGM-3 gravimeter with serial number S225, installed on Thompson in August of 2019. The sensor table was located in the computer lab on the main deck, approximately 4 m astern of the door, against the wall closest to the passageway. Although the gravimeter was checked with every watch, the system ran automatically and recorded data on the ship's server. Gravity ties were completed by University of Washington technicians from the ship to shore reference stations at WHOI in August 2019, in Montevideo, Uruguay in November 2019, and in Cape Town subsequent to cruise TN-374 during early January, 2020. Technicians were unable to make a gravity tie during the Walvis Bay port call because they could not find the reference mark. Gravity tie information is given in Appendix 1.

Seismic System

The Scripps Institution of Oceanography (SIO) portable, high-resolution multichannel seismic system was used for collection of seismic data. This system consists of a solid, 96-channel Geometrics Geo-Eel streamer and a source of two GI airguns (Fig. 3). The streamer contains an active section 600 m in length, with 96 channels, each channel a group of 6 hydrophones, spaced 6.25 m apart. Connected to the deck is a 134-m length tow section with fairing and at the end of the streamer is a 125-m stretch section and tow rope with a plastic float at the end. The streamer was attached to the starboard stern bollards by a Yale grip. With this configuration, the first channel was 168.5 m from the stern and the last channel is 768.5 m distant. The distance of the first channel to the GPS receiver was 202.83 m whereas the last channel is at a distance of 802.3 m. Four depth controllers (birds) were attached to the streamer to allow for depth control. Streamer depth was held at 3 m for the RGR-1 test line, but 4 m thereafter.

The source was a cluster of two Sercel GI-210 airguns, with volumes reduced to 45 cubic inches for the generator and 105 cubic inches for the injector. The airguns were hung at a depth of 3 m from a float, which was towed 26.5 m from the stern and 142.5 m from the first streamer channel. The airguns were charged by 3 Stark Industry compressors on the deck, with two of them being used at any time and one held in reserve.

Shot data were recorded in both SEGD and SEGY format. Shots were fired on distance at an interval of 25 m. The ship's speed was 4.5-5.0 kt, giving a fold of about 12, with shots fired every 8-9 seconds. Incoming data were band pass filtered with low and high cuts of 2 and 400 Hz, respectively and digitized at an interval of 1 ms. Data were initially processed and quality controlled onboard by the SIO technicians using RadexPro software. Processing steps included NMO removal, stacking, filtering, and Kirchoff migration using water velocity. Images from this initial processing are those shown in this report. Seismic data were also processed onboard by University of Houston students. This processing is described in Appendix 2.

No Data Collection in the Exclusive Economic Zones (EEZ)

The ship departed from Montevideo, Uruguay and ended in Walvis Bay Namibia for cruise TN-373. Cruise TN-374 started in Walvis Bay and ended in Cape Town, South Africa. Thus, the ship passed through the Exclusive Economic Zone (EEZ) of those three countries. As has become common practice, absent specific permission to collect underway geophysical data, no data were collected in the EEZ. Underway data were collected as soon as the ship cleared the EEZ and were shut down again upon entering the next EEZ.

The single proposed geophysical cruise was divided into two legs to accommodate environmental rules concerning protected marine species. During cruise TN-373, it was determined that the echosounders could not be operated when the seismic equipment was not also in operation. Thus, Knudson echosounder profiles and Kongsberg EM302 multibeam swath bathymetry were only collected during seismic lines. During transits, the ship was blind for determining depths.

SIO Portable Multi-Channel Seismic System Geometry
Cruise: **TN-373**

Technicians:

Brendon Mendenhall, Kolby Pedrie, Doug Penny, Royhon Agostine, Ray Hatton

Vessel: **R/V Thompson**
Date: **Nov – Dec 2019**
Chief Sci: **Will Sager**

Item or Channel	Distance (m) from Stern	Distance (m) from Source	Distance (m) From GPS	Group Spacing	Depth/Height from water
1	168.5	142.5	202.83	6.25	4
96	768.5	742.5	802.83	6.25	4
Source	26.5	0	66.5		3
GPS	40	66.5	0		

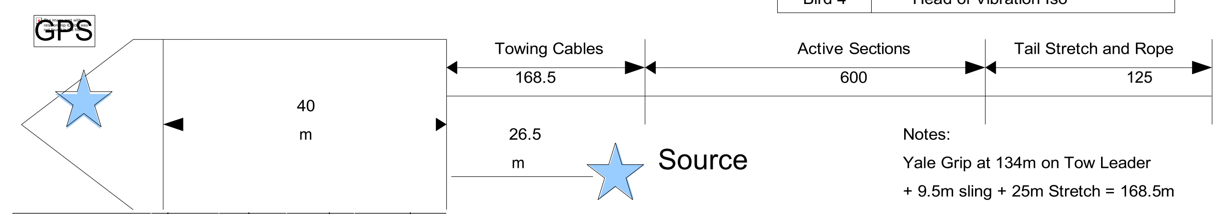
Section	Length (m)	Number of Channels
Towing Cables	168.5	
Active Sections	600	96
Tail Stretch and Rope	125	
Channel Spacing	6.25	

Source:	GI gun	45/105 True GI	**Qty:**	2
Acq. Sys.	GeoEel	**PreAmp Gain:**	18 db	
Sample Int:	1 ms	**# of Channels:**	96	
File Format:	SEGD	D 8058 Rev 1		
Rec. Length:	8 sec	**Shot Interval:**	25m	

FOLD = No. Traces * Grp. Int / 2*(Shot Interval)

Bird Locations (Streamer, GPS Ref Plate)

Bird 1	Head of Vibration Iso
Bird 2	Head of Active 5 Channel 33
Bird 3	Head of Active 9 Channel 65
Bird 4	Head of Vibration Iso



CNAV3050 Offsets	x (+ fwd)	y (+sbd)	z(+dwn)
Streamer Tow Point	-40.1077	7.8344	21.9891
Gun Tow Point	-40.0890	-5.7903	21.9846

* Not drawn to Scale

Figure 3. Diagram of seismic system geometry.

Operations Timeline

This section provides a chronological synopsis of cruise activities. All times are GMT unless noted otherwise.

Cruise TN-373 (5 November – 7 December)

4 November 2019. The *Thompson* departed from Montevideo, Uruguay at 13:00 local time to cross the Rio de la Plata estuary towards Buenos Aires, Argentina to acquire fuel because engineering staff had determined the fuel available in Montevideo was of unacceptable quality.

5 November 2019. During the overnight hours, the Thompson arrived at a fueling area along the coast southeast of Buenos Aires. Fueling was complete by 14:00 local and ship was underway by 14:30 local. Montevideo was passed at approximately 22:00 local (07:00 GMT, 6 November). The time lost in having to refuel in Buenos Aires was approximately 14 hours.

6 November 2019. Thompson sailed eastward over the continental shelf, headed to the first site. At 1200 GMT (09:00 local), the ship was about 30 nautical miles offshore, making a speed of 12.6 kt and heading of 87°.

7 November 2019. At 0000 GMT, the ship's position was -34.8234° (latitude), -50.4740° (longitude) with a speed of 12.2 kt and heading of 83°. Scientists began watches in the computer lab at 03:00 local when the ship cleared the Uruguayan EEZ. Gravity, magnetic field, and navigation were recorded only because the IHA stipulates that no echosounder data can be collected unless the seismic system is also in use. The magnetometer was secured to an eyebolt in the deck by a Yale grip. This this tow point provides 342 m of cable astern.

8 November 2019. Transit continued eastward (Fig. 4). At 0000 GMT, the ship was at -34.5173°, -44.4446° with a speed of 12.3 kt and heading of 90°. Magnetic, gravity, and navigation data were recorded.

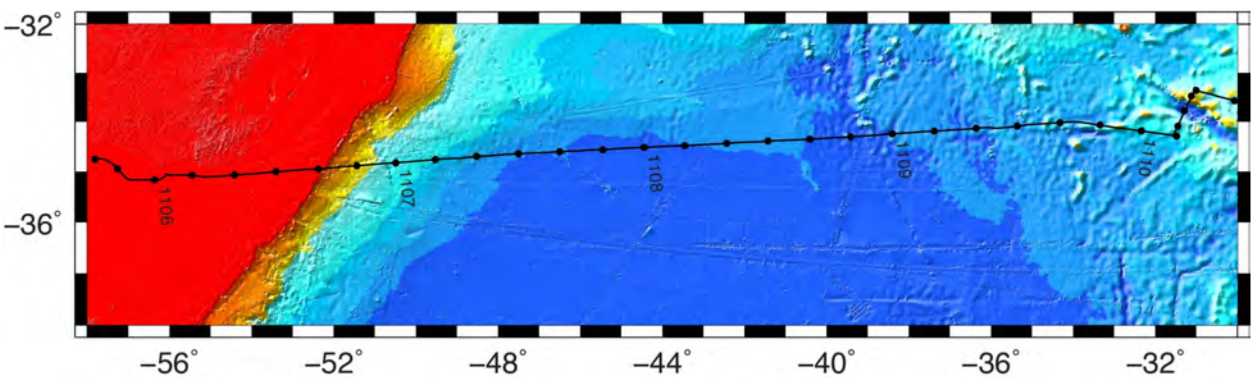


Figure 4. Track line plot for the transit between Montevideo and seismic site RGR-1. Thin line is ship track, with dots plotted at 4 hour intervals. Labels indicate the start of a new day (e.g., 1107 labels 0000 GMT on 7 November 2019). Background plot is estimated bathymetry (Smith and Sandwell, 1997).

9 November 2019. Transit continued eastward. At 0000 GMT, the ship's location was recorded as -32.2448°, -38.3961° with a speed of 13.1 kt and heading of 85°.

10 November 2019. The *Thompson* continued eastward and was located at -34.1872°, -32.3145° at 0000 GMT. Transit to test site RGR-1 was completed at 01:36 GMT and the magnetometer was recovered. A good profile of magnetic data was collected on this transit (Fig. 5). This site was a "practice" seismic section over the deep rift valley in southeast Rio Grande Rise. At 0330 GMT, seismic gear deployment began. The full 96-channel system with 2 GI airguns was used (See "Seismic System" section, Fig. 3). End points for this and other seismic lines are given in Table 1.

Seismic acquisition was concluded at 1801 GMT and produced a good seismic profile and multibeam data (Figs. 6-8) The seismic gear was back on deck by 2000 GMT and the magnetometer was deployed at 2010 GMT to continue transiting to the Walvis Ridge study area. The RGR-1 seismic line was completed about half a day ahead of schedule because of the time made up by transiting at ~12 kt. During the RGR-1 test line, technicians attempted to deploy the magnetometer. Owing to cable feathering, there was concern that the magnetometer cable might tangle with the seismic streamer or air gun array. After this trial, it was decided not to deploy the magnetometer with the seismic gear. The RGR-1 seismic line was successful and showed a deep canyon with a fault block at its nadir (Fig. 8).

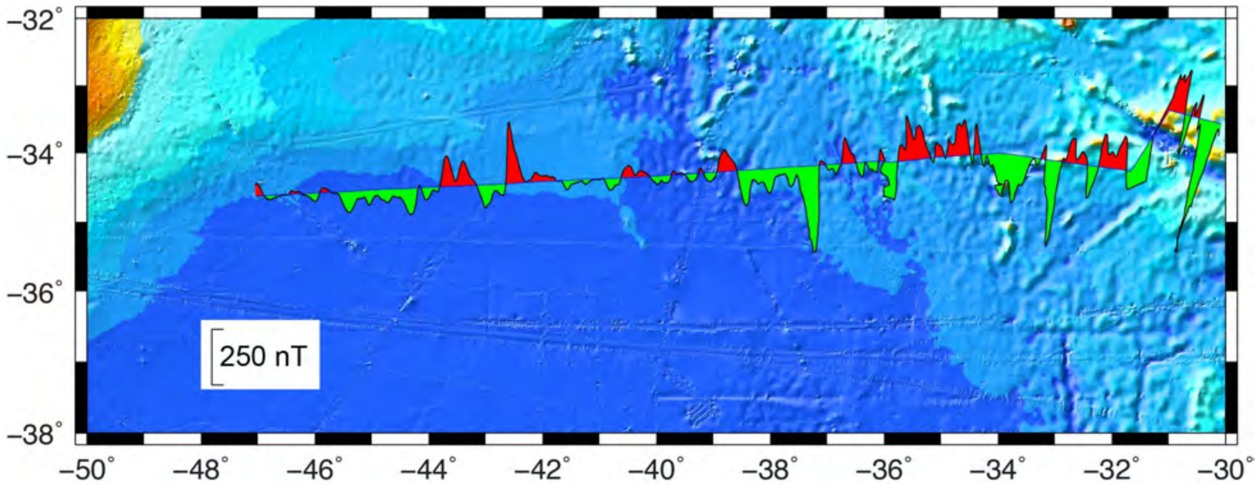


Figure 5. Magnetic anomalies recorded during the transit from Montevideo to Site RGR-1. Anomalies are plotted perpendicular to the ship's track (thin solid line). Positive anomalies are colored red, whereas negative anomalies are colored green. Background is estimated bathymetry (Smith and Sandwell, 1997).

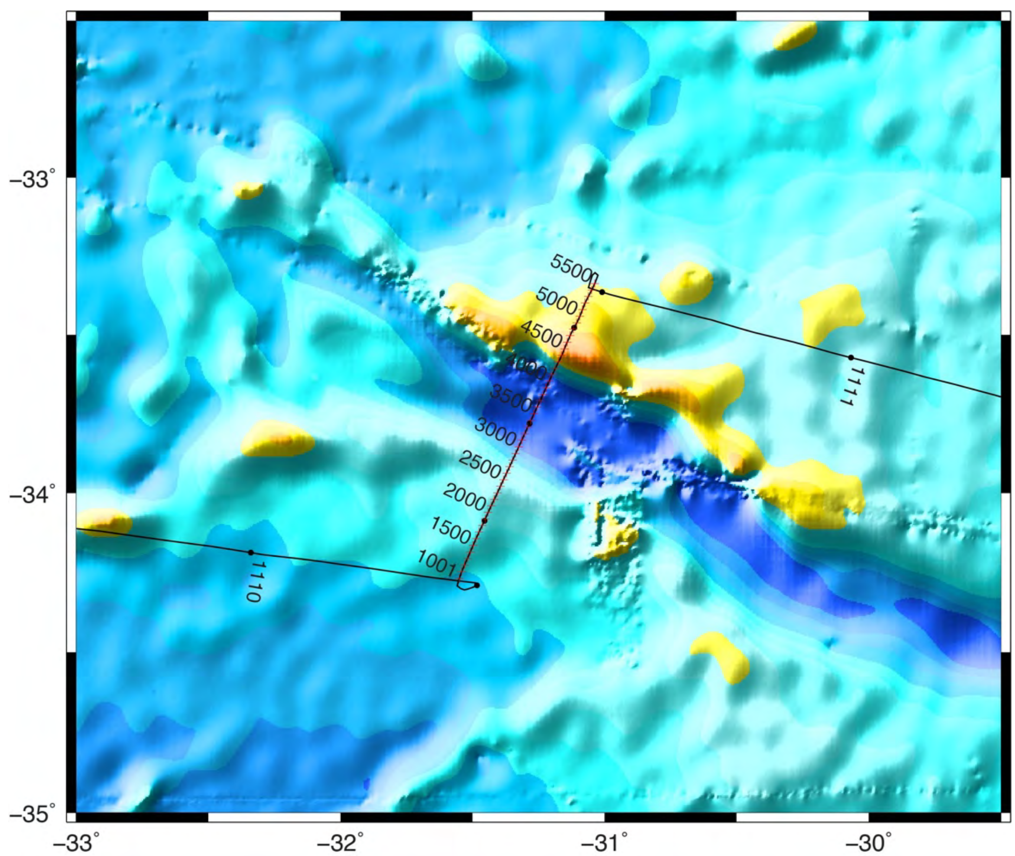


Figure 6. Track line map for seismic line RGR-1. Thin lines show ship's track, with dots plotted at 4 hour intervals. Seismic line is colored red. Numbers next to seismic line indicate shot point numbers; the first shot is 1001. Background is predicted bathymetry (Smith and Sandwell, 1997).

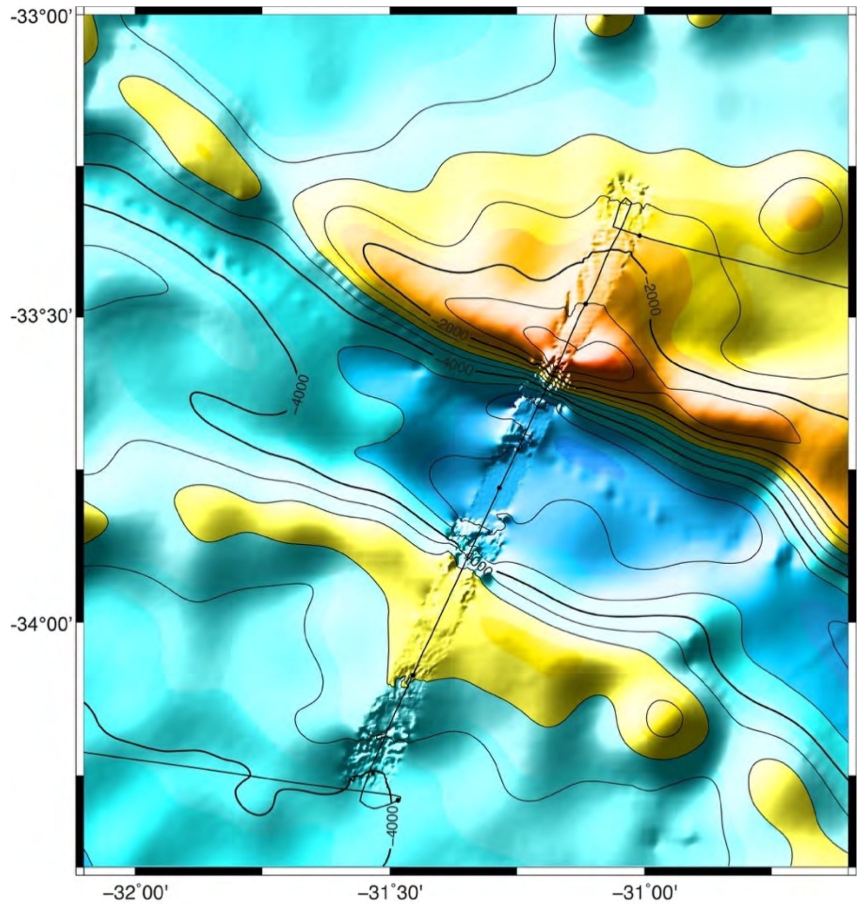


Figure 7. Multibeam data plotted along the RGR-1 seismic line. Multibeam data were merged with estimated bathymetry from satellite altimetery (Smith and Sandwell, 1997).

11 November 2019. The transit from site RGR-1 to the Walvis Ridge study area is the longest transit. It was oriented to follow, as much as possible, single flow-lines across the Atlantic. However, the flow line directly east of the RGR-1 site tracks too far north on the African plate, so we had to go south at some point to stay at the latitude of the guyot sites. It was decided to make this southward shift as the Mid-Atlantic Ridge was crossed, because there are abundant survey data over that feature. This day was the first full transit day. At 0000 GMT, the ship was at -33.5723°, -30.0663°, with a speed of 12.9 kt and heading of 103°.

12 November 2019. The transit continued. The 0000 GMT position was -33.6392°, -24.1534°. The ship's speed was 12.5 kt and heading, 88°.

13 November 2019. The transit continued. The 0000 GMT position was -33.3641°, -18.1343°. The ship's speed was 12.8 kt and heading, 90°.

14 November 2019. The transit continued. The 0000 GMT position was -33.6794°, -12.3023°. The ship's speed was 11.8 kt and heading, 99°.

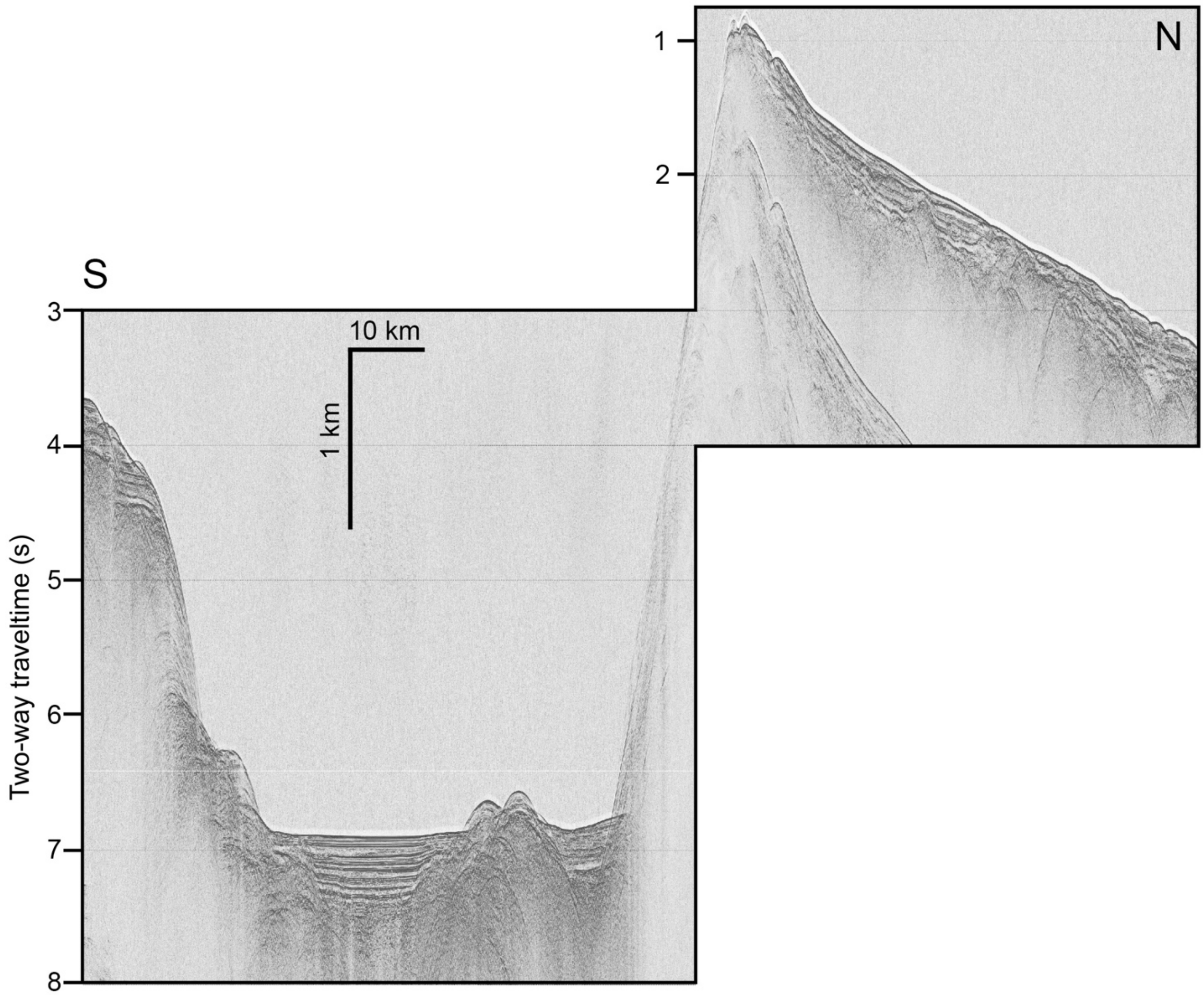


Figure 8. A portion of the RGR-1 seismic line showing a deep canyon in southern Rio Grande Rise. The north side of the canyon is anomalously shallow (~750 m deep) for normal subsidence of Late Cretaceous seafloor. Normal faults are observed on the south wall. A tilted fault block lies at the bottom of the canyon. Vertical exaggeration is 23:1.

15 November 2019. The transit continued. The 0000 GMT position was -33.2003°, -6.6106°. The ship's speed was 12.0 kt and heading, 92°.

16 November 2019. The transit continued. The 0000 GMT position was -33.1800°, -1.3503°. The ship's speed was 10.3 kt and heading, 86°. At 0100 GMT the transit was finished as the ship reached the first guyot survey site, CT ("Center Track") (Fig. 9). The magnetometer was switched off and brought onboard. The transit produced a nice record of magnetic anomalies on both sides of the MAR (Fig. 10). The 16-channel "high-speed" streamer was deployed along with a single air gun. Data were collected on Line CT-01 from 04:24 through 07:31 GMT (Table 1; Figs. 11, 12). The survey speed was approximately 8 kt. At the end of this time the record was judged as being of low quality, showing little in the way of subsurface returns, so the line was aborted mid-way through.

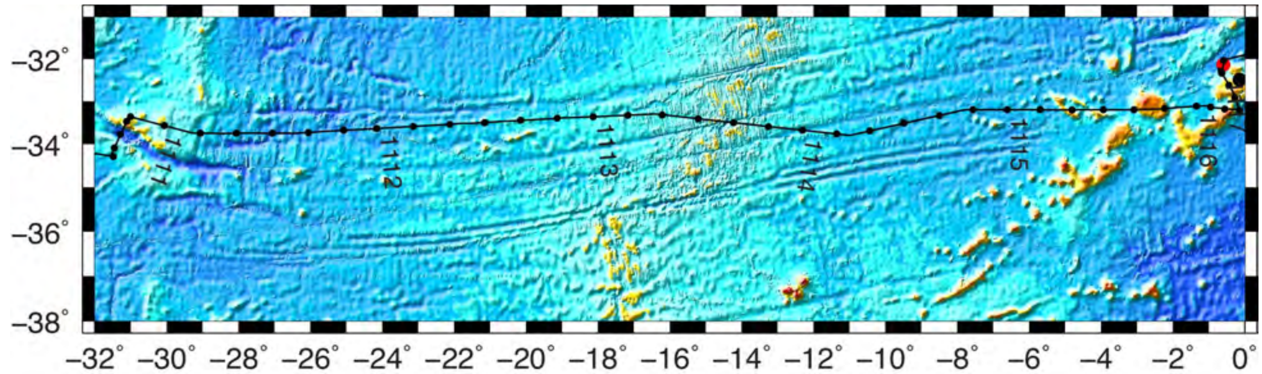


Figure 9. Track line plot for the transit between site RGR-1 and the first guyot site. Thin line is ship track, with dots plotted at 4 hour intervals. Labels indicate the start of a new day (e.g., 1107 labels 0000 GMT on 7 November 2019). Background plot is estimated bathymetry (Smith and Sandwell, 1997).

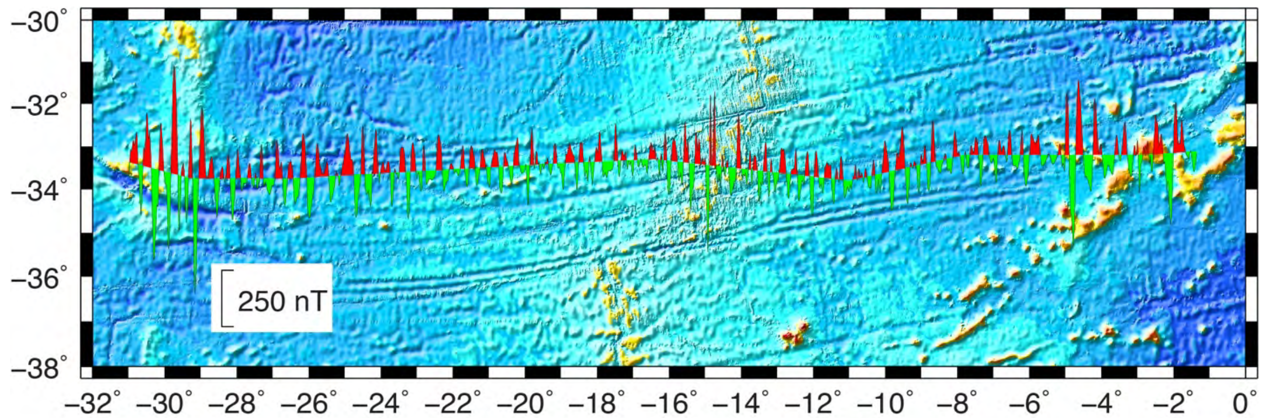


Figure 10. Magnetic anomalies recorded during the transit from Site RGR-1 to the first guyot site, crossing the MAR. Anomalies are plotted perpendicular to the ship's track (thin solid line). Positive anomalies are shaded red, whereas negative anomalies are shaded green. Background is estimated bathymetry (Smith and Sandwell, 1997).

The high-speed system was recovered and the 96-channel system with 2 GI airguns was deployed. Data collection with this system was begun at 12:05 GMT on Line CT-02 (Table 1), which crossed the entire guyot (Figs. 12, 13). This low-speed, high quality system was used for all subsequent seismic lines.

Because of the stipulations of the IHA, it was possible to collect data with the multibeam echosounder and chirp echosounder only while simultaneously collecting seismic data. Thus, on this and subsequent seismic lines, both types of data were collected. However, these systems were switched off for transits in between sites. The multibeam system produced good bathymetry data along the seismic tracks (Fig. 14).

17 November 2019. Line CT-02 was concluded at 0152 GMT. It showed a two-tier guyot with a narrow shallow summit and broader deep platforms (Fig. 13). Line CT-03, a short line that crossed proposed IODP site CT-4A, was commenced at 0352 GMT and finished at 0730 GMT. After the finish of Line CT-03, the seismic gear was recovered and the magnetometer deployed at 0853 GMT. The day ended with the ship arriving at the Gough Track (GT) survey site.

18 November 2018. Seismic Line GT-01 was begun at 0004 GMT (Table 1; Figs. 15, 16), crossing the guyot ridge to the south of proposed IODP drill sites. Line GT-02 was run back up slope to the level of proposed site GT-4A, and then it bent parallel to slope to cross that site. The profile showed a guyot with a small, shallow summit and deeper platforms. Line GT-03 turned back down slope a few miles north of the proposed IODP Sites. It finished at the depth of Site GT-5A and then the ship turned south to cross Site GT-5A with seismic line GT-04. Multibeam data along the lines produce good swaths (Fig. 16). Line GT-05 was begun at 2126 GMT, but it was aborted at 2135 GMT when it was discovered that streamer navigation files were not being written properly. The computer program was restarted and Line GT-05A was begun at 2140 GMT without deviation from the planned line. The day finished with the ship running Line GT-5A.

19 November 2019. Line GT-5A, which crossed the guyot from southeast to northwest on the north side of the proposed IODP sites, was finished at 0558 GMT. This profile shows a guyot summit platform at ~ 2 s (twtt) depth, tilted slightly to the northwest (Fig. 17). At 0710 GMT the magnetometer was back in the water and the ship began transit to the Tristan Track (TT) guyot survey site. The beginning of the survey was reached at 1336 GMT. Seismic gear was deployed at Line TT-01 (Table 1; Figs. 18, 19) was begun at 1552 GMT. This line trended northeast and climbed the south slope of the guyot to the summit. The line crossed proposed IODP site TT-1A. The line was still in progress at the end of the day.

20 November 2019. The day began with the ship on Line TT-01. The seismic profile (Fig. 20) shows a multi-tiered guyot with a summit at ~2.2 s (twtt) depth, a deeper platform at ~2.8 s (twtt) depth, and a ramp with a gentle slope from ~3.2-3.8 s (twttt). At 0130 GMT, the ship turned to begin Line TT-02, a line headed southwest, across proposed IODP site TT-2A (Fig. 18). The line ended at 0749 GMT. The ship turned and began Line TT-03 at 0830 GMT. This line trended northeast towards the lower north flank of the guyot. The line ended at 1400 GMT. It was decided to run an additional short line, TT-04, crossing the north end of Line TT-03 at a low spot between volcanic mounds. Line TT-04 trended northeast. It was begun at 1548 GMT and ended at 1716 GMT. After recovery of seismic gear, the magnetometer was deployed at 1847 GMT the transit to the Valdivia Bank survey site began.

21 November 2019. Much of this day was spent in transit to the southern flank of Valdivia Bank. The ship arrived near the beginning of the first seismic line at 1955 GMT. The magnetometer was recovered and thee seismic gear was deployed. The transits between guyots produced good magnetic anomalies (Fig. 21). Line VB-01 (Table 1), a northwest-trending line crossing the southeast extension of Valdivia Bank was commenced at 2134 GMT (Fig. 22). During the Valdivia Bank seismic lines, the multibeam echosounder collected many swaths across this poorly mapped mountain (Fig. 23).

22 November 2019. Line VB-01 was continued. It crossed a rift graben approximately 1 second in depth, with thick sediments (Fig. 24). The line ended at 1036 GMT on the north side of Valdivia Bank (Fig. 22). The ship turned to the southeast to run Line VB-02, which was begun at 1119 GMT. This line also crossed a rift graben, but one that contained numerous tilted fault blocks (Fig. 25). The day ended with Line VB-02 still in progress.

23 November 2019. Line VB-02 was completed at 0433 GMT on the deep south flank of Valdivia Bank. The ship turned to the north to run Line VB-03, which was started at 0520 GMT. This line was run due north, up the south flank of Valdivia Bank towards its summit. The line imaged many volcanic cones on the upper flank and crossed two rounded summits with sediment caps (Fig. 26).

In between is a swale that is probably a sediment filled extension of the rift that was crossed on lines VB-01 and VB-02. Line VB-03 was finished at 2037 GMT and a short line to the southeast, VB-04 was begun at 2113 GMT (Table 1).

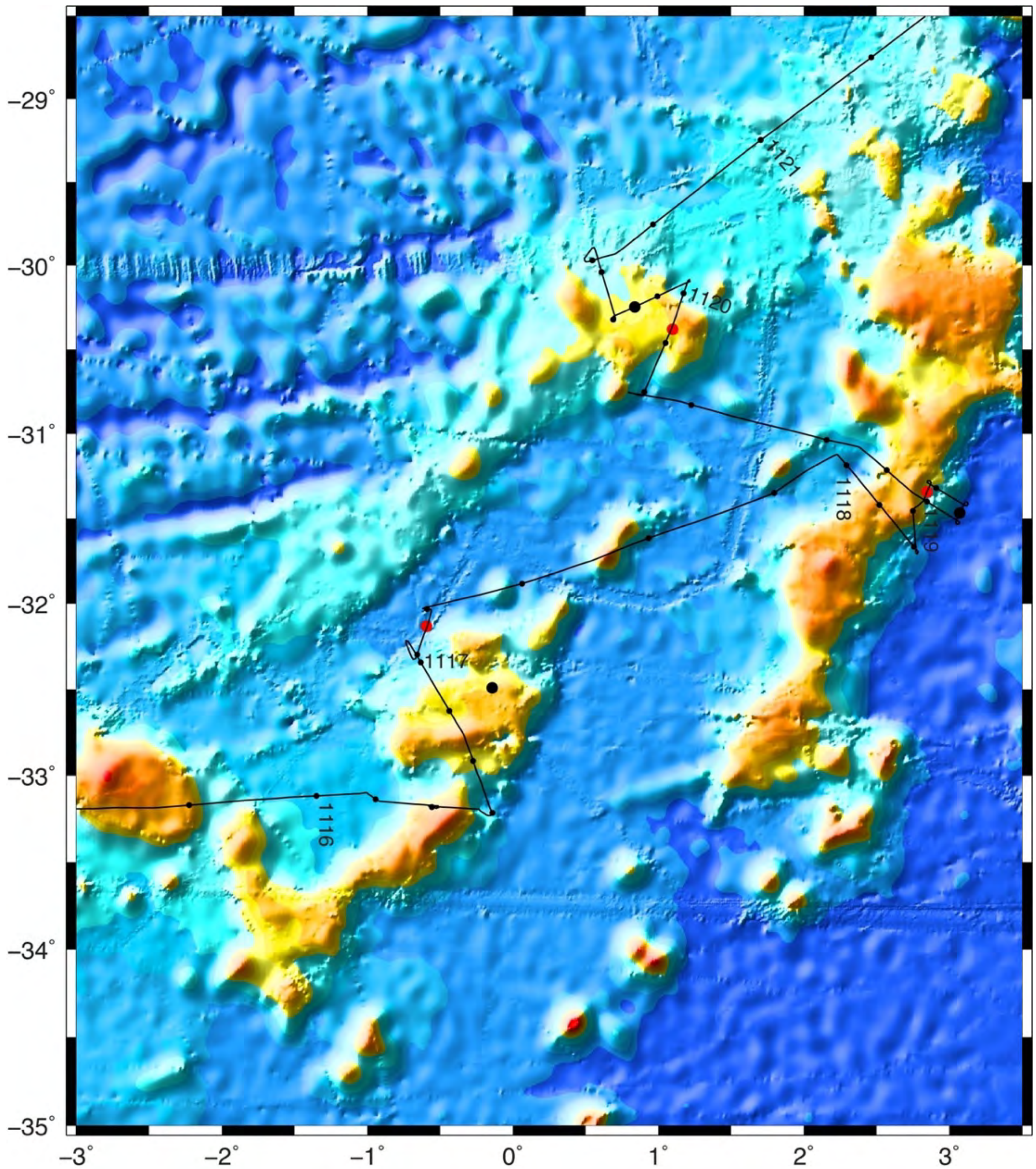


Figure 11. Chart showing shiptracks over the central Walvis Ridge guyots surveyed during cruise TN-373. Thin line is ship track with dots every 4 hours and labels at the beginning of days. The number gives the month and day (e.g., 1116 = 16 November 2019). Red filled circles show proposed drill sites for IODP Expedition 391 that were crossed. Background is predicted SRTM15+ bathymetry (Tozer, 2019).

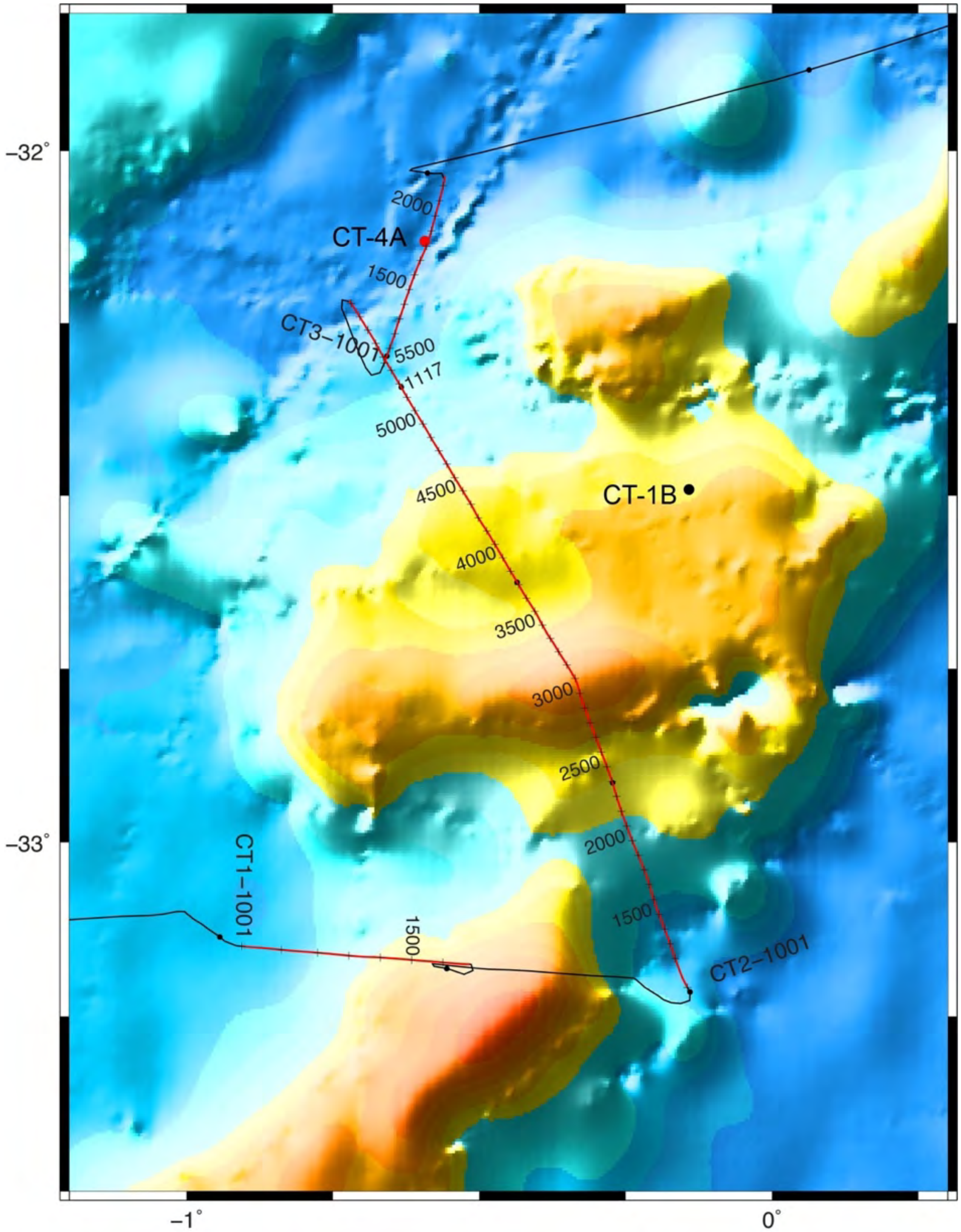


Figure 12. Tracks of the CT guyot seismic lines (Table 1). Thin line indicates the ship's track and is colored red for the seismic lines. Dots are shown every 4 hours. Seismic lines are annotated with shot numbers; each line starts with 1001. Red filled circle and black filled circle show locations of proposed IODP Expedition 391 drill sites. The red filling indicates that Site CT-4A is a primary site, whereas the black filling indicates that Site CT-1B is an alternate site.

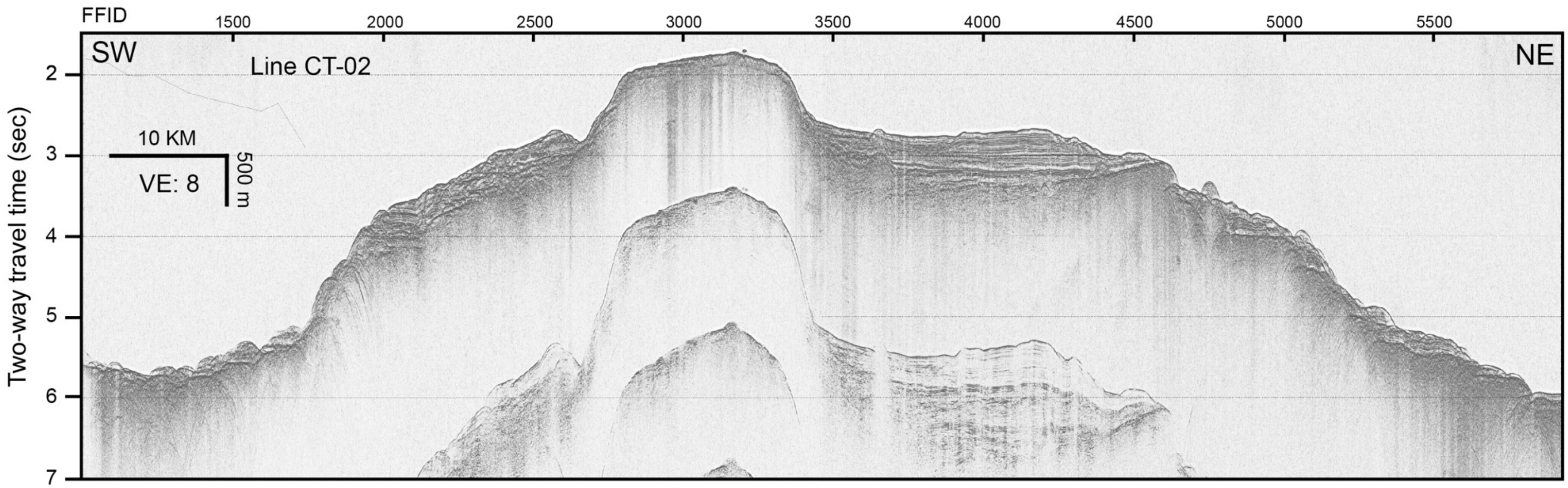


Figure 13. Seismic line CT-02, crossing the center track guyot. Vertical axis is two-way traveltime and horizontal axis is FFID shot number. VE=vertical exaggeration. The profile shows a two-tier guyot, with a nearly flat-topped, truncated summit cone sitting atop a platform at 3-4 sec depth. The deeper platform on the NE side is tilted towards the summit cone, suggesting isostatic loading. The guyot flanks exhibit extensive normal faulting.

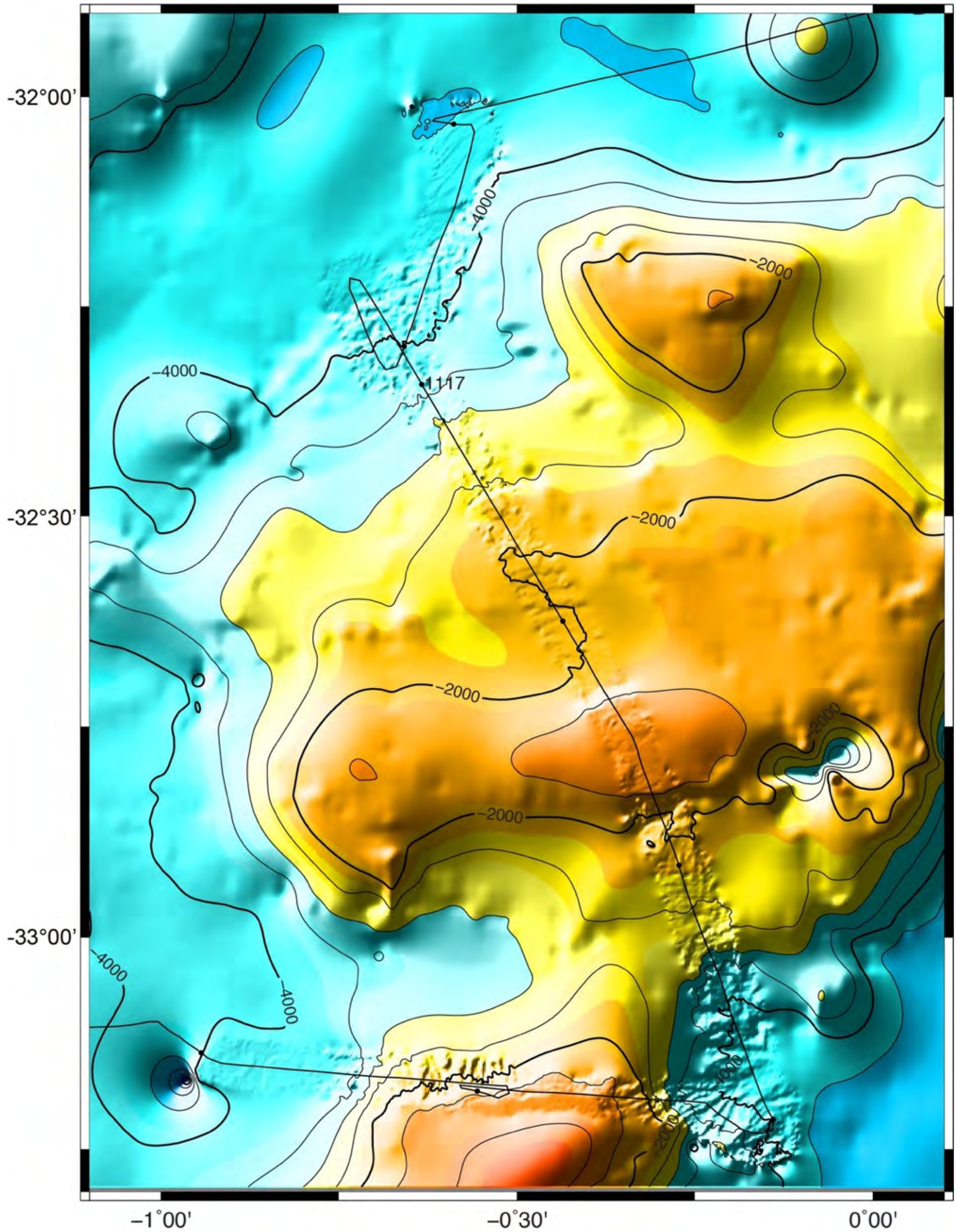


Figure 14. Multibeam bathymetry data for the CT guyot survey. Ship track is thin solid line and is surrounded by multibeam data. Marks for the beginning of each survey day are labeled (e.g., 1117 = 17 November 2019). Multibeam data are merged with background SRMT15+ bathymetry data (Tozer et al., 2019). Contours shown at 500-m intervals.

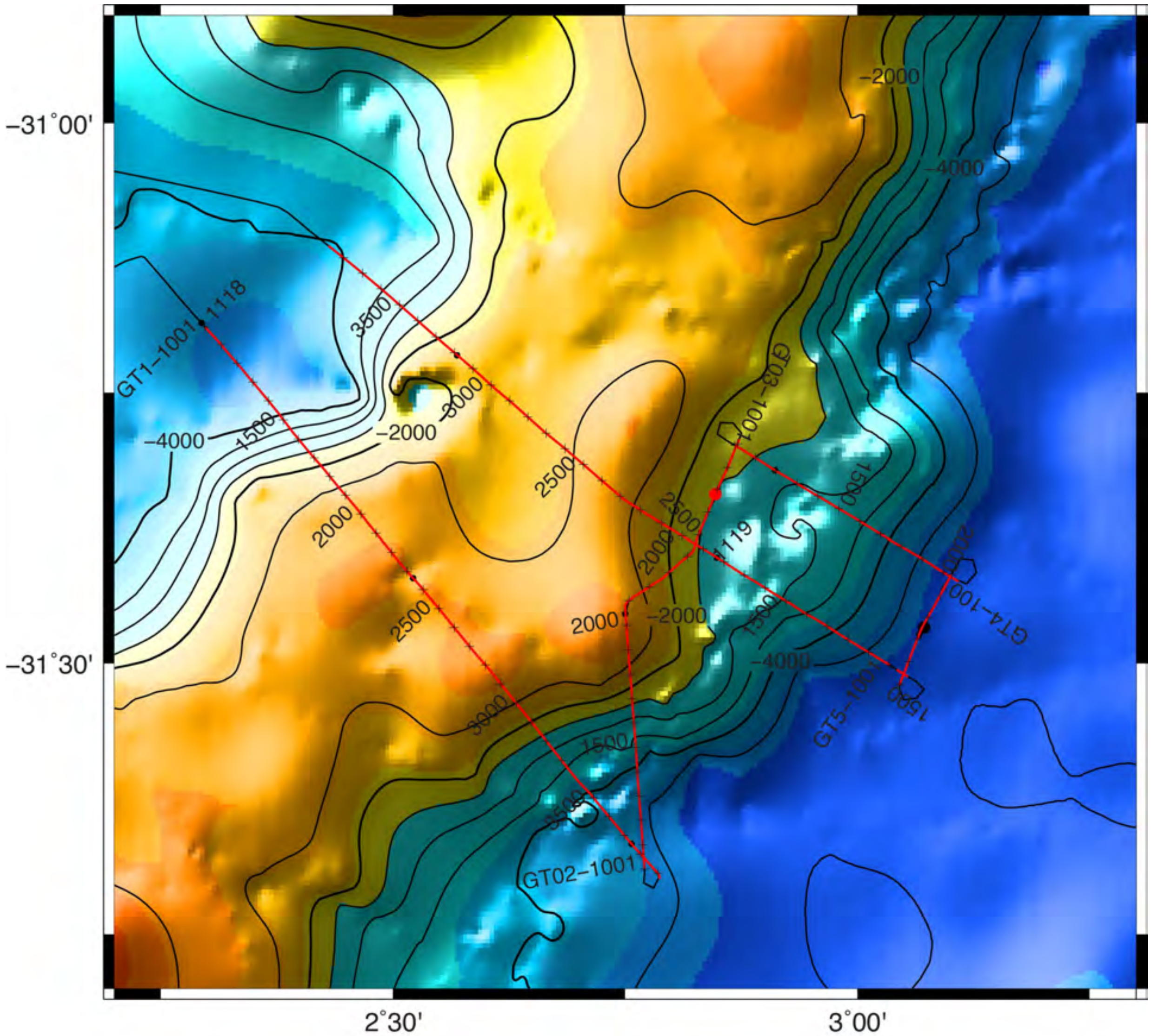


Figure 15. Tracks of the GT guyot seismic lines. Thin line indicates the ship's track and is colored red for the seismic lines. Dots are shown every 4 hours. Seismic lines are annotated with shot numbers; each line starts with 1001. The red filled circle indicates the location of IODP primary drill site GT-4A, whereas the black filled circle indicates alternate drill site GT-5A. Background is SRTM15+ predicted bathymetry (Tozer et al., 2019). Contours shown at 500-m intervals.

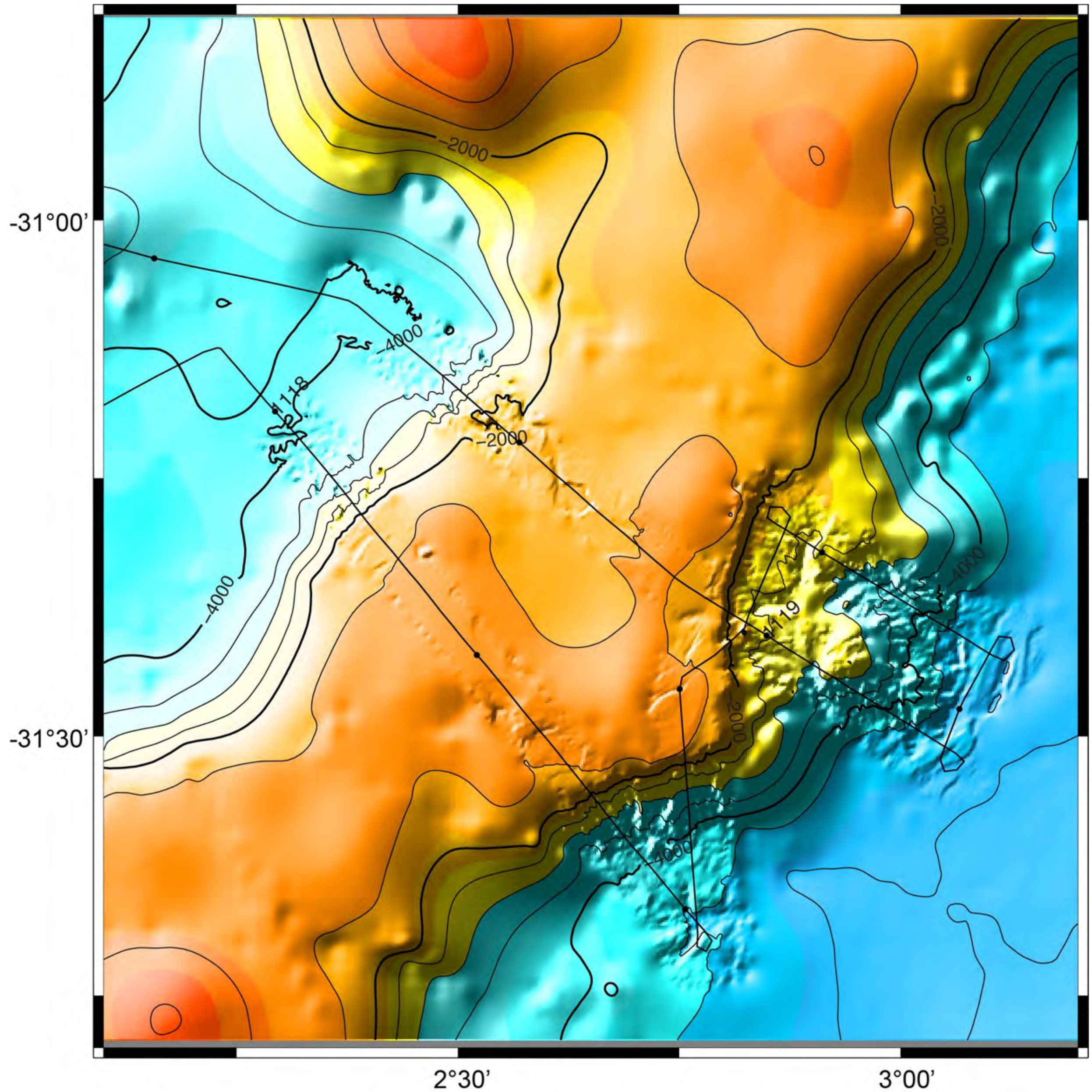


Figure 16. Multibeam bathymetry data for the GT guyot survey. Ship track is thin solid line and is surrounded by multibeam data. Marks for the beginning of each survey day are labeled (e.g., 1118 = 18 November 2019). Multibeam data are merged with background SRMT15+ bathymetry data (Tozer et al., 2019). Contours shown at 500-m intervals.

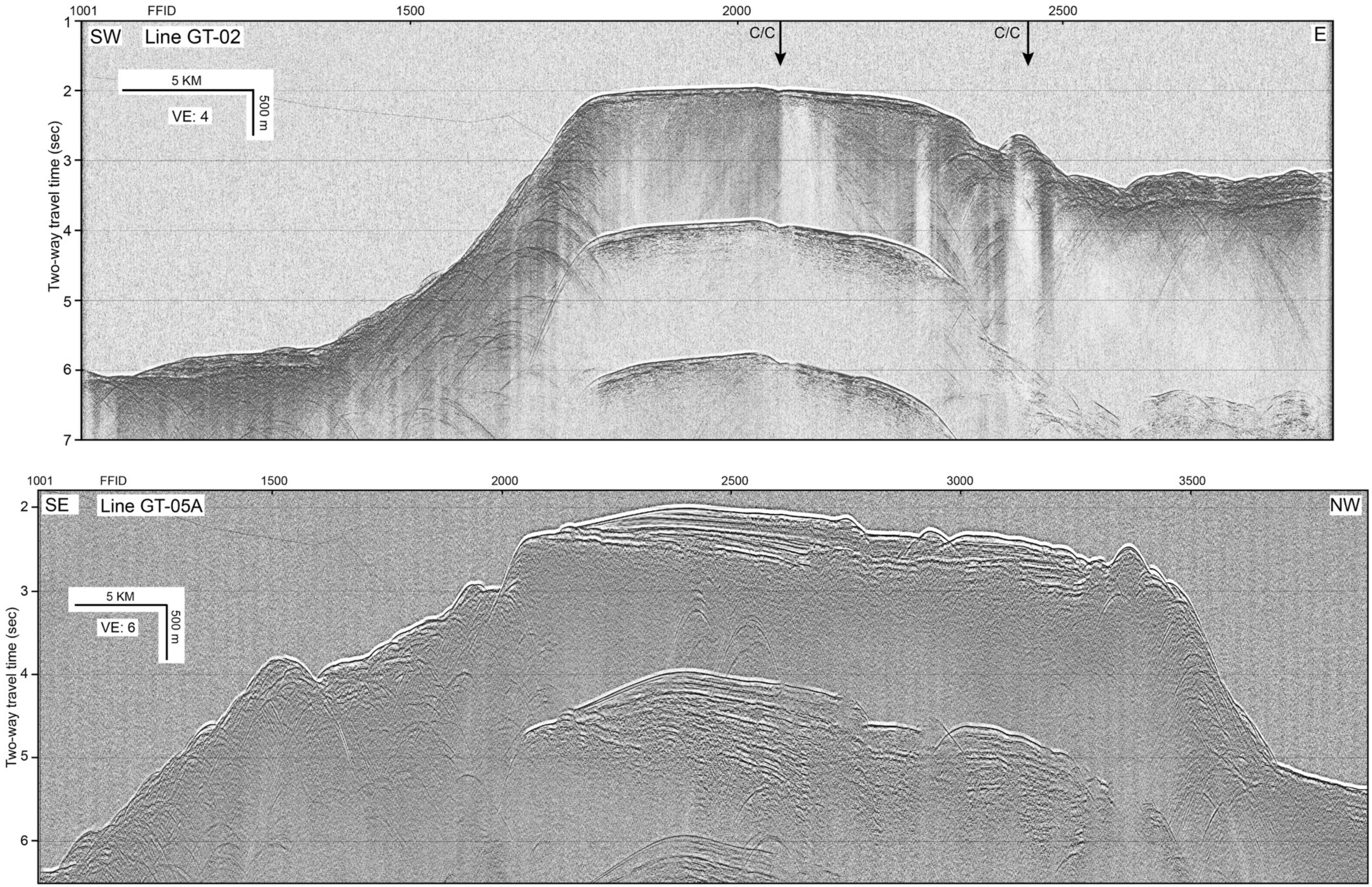


Figure 17. Seismic lines GT-02 (top) and GT-05A (bottom). Vertical axes give two-way traveltime; horizontal axes are shot number (FFID). VE = vertical exaggeration. C/C = course change. Line GT-02 turns before reaching guyot top. Line GT-05A shows tilted summit platform of guyot.

24 November 2019. The day began with the end of Line VB-04, which was completed at 0034 GMT. The ship turned to the east northeast to run Line VB-05, which started at 0116 GMT. Line VB-05 was planned to follow the centerline of the December 14, 2020 total solar eclipse, so that the scientists on the drill ship can watch the eclipse if the line provides an appropriate site and details can be worked out. After beginning on the high, sediment covered summit, the line showed a steep escarpment on the east side of Valdivia Bank (Fig. 26). Acoustic basement dropped to a deep level (deeper than 5 seconds two-way travel time) and remained nearly flat for much of the remainder of the line. As the planned end point of the line was approached late in the day, the seafloor began to deepen, so the line was continued past the planned endpoint. The wait was well worth the time because acoustic basement dropped hundreds of meters at an abrupt escarpment, beyond which the seafloor is likely adjacent abyssal plain. Line VB-05 ended at 1920 GMT. The ship turned around to run a west-northwest trending seismic line across the summit of Valdivia Bank. This line began at 2007 GMT.

25 November 2019. The entire day was spent shooting Line VB-06, which crossed another rift, also with buried, tilted fault blocks, near the summit. This line was run from the east side of Valdivia Bank to its west side (Fig. 22).

26 November 2019. Line VB-06 was completed on the lower west flank at 0628 GMT. The ship turned to run a northeast-trending line across the summit. After a broad turn around, line VB-07 was started at 0702 GMT. It was still in progress at the end of the day.

27 November 2019. Line VB-07 was finished at 1827 GMT. Both lines VB-06 and VB-07 imaged partly-filled rift valleys on the east side of Valdivia Bank (Fig. 27).The ship turned to run a long east to west line across Valdivia Bank. Line VB-08 began at 1955 GMT. It was in progress at the end of the day.

28 November 2019. While the ship's crew celebrated Thanksgiving, the ship continued Line VB-08. It was still in progress as the day ended.

29 November 2019. Line VB-08 crossed through proposed IODP Site VB-4B near its end. It was finished at 0917 GMT. The ship turned back eastward to run a northeast-trending seismic line. Line VB-09 was commenced at 1031 GMT. This line was not planned to cross the entirety of Valdivia Bank because there was a need to double back and cross other proposed IODP sites on the west side of the edifice. Thus, Line VB-09 ran up to the summit on the north side and turned. Both lines VB-08 and VB-09 displayed additional evidence of widespread faulting (Fig. 28).

30 November 2019. Line VB-09 was completed at 710 GMT. Line VB10 was begun at 0752 GMT. As the line progressed, a dramatic half graben was noted (Fig. 29). A cross line was hastily planned and Line VB-10 was stopped at 1303 GMT. The plan was to shoot a short cross line, VB-11, and then to resume Line VB-10 as originally planned, Line VB-10A. After a wide turn, line VB-11 was shot from 1517 to 1644 GMT. *Thompson* made another wide turn to get back on the original line with some overlap. Line VB-10A was started at 1810 GMT.

1 December 2019. Line VB-10A was finished at 0425 GMT. At some point near its end, it crossed proposed IODP Site VB-1B (Fig. 22). The ship made a wide turn to align the next line with another proposed IODP site, Site VB-2B. Line VB-12 began at 0522 GMT and crossed the proposed drill site shortly thereafter. At the end of the day, Line VB-12 was still in progress.

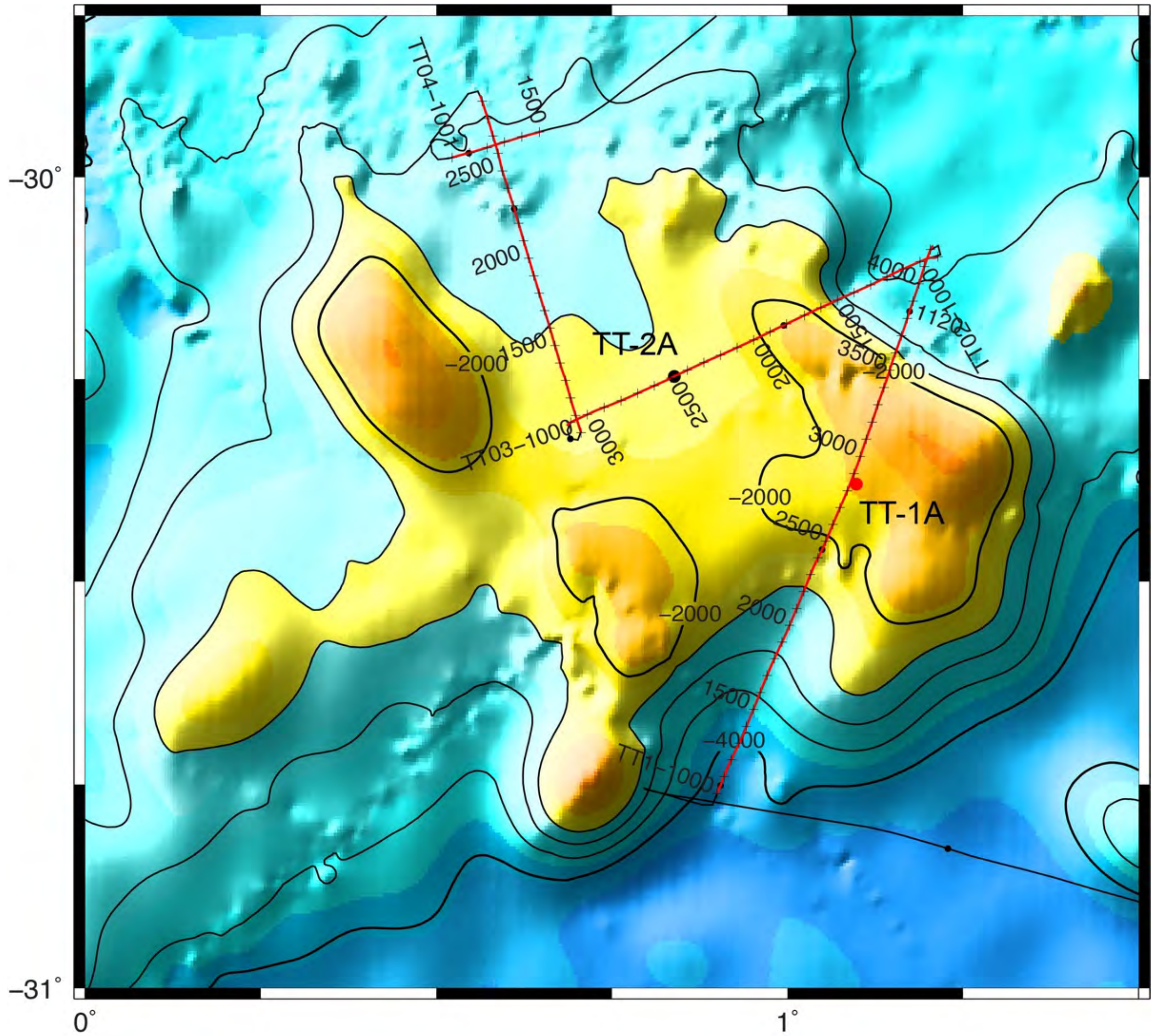


Figure 18. Tracks of the TT guyot seismic lines. Thin line indicates the ship's track and is colored red for the seismic lines. Dots are shown every 4 hours. Seismic lines are annotated with shot numbers; each line starts with 1001. Red filled circle and black filled circle show locations of proposed IODP Expedition 391 drill sites. The red filling indicates that Site TT-1A is a primary site, whereas the black filling indicates that Site TT-2A is an alternate site. Background is predicted SRTM15+ bathymetry (Tozer et al., 2019). Contours shown at 500-m intervals.

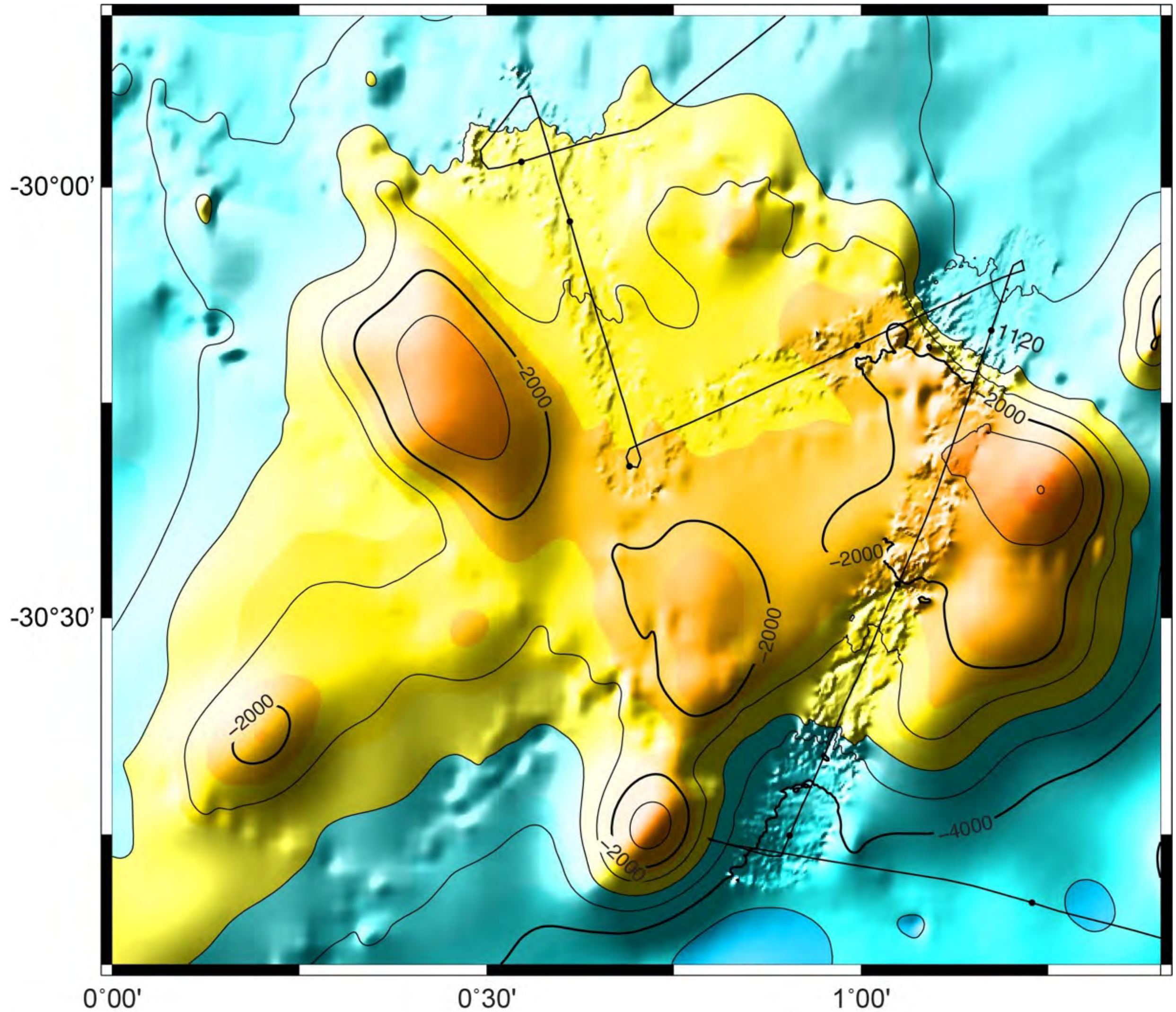


Figure 19. Multibeam bathymetry data for the TT guyot survey. Ship track is thin solid line and is surrounded by multibeam data. Marks for the beginning of each survey day are labeled (e.g., 1120 = 20 November 2019). Multibeam data are merged with background SRMT15+ bathymetry data (Tozer et al., 2019). Contours shown at 500-m intervals.

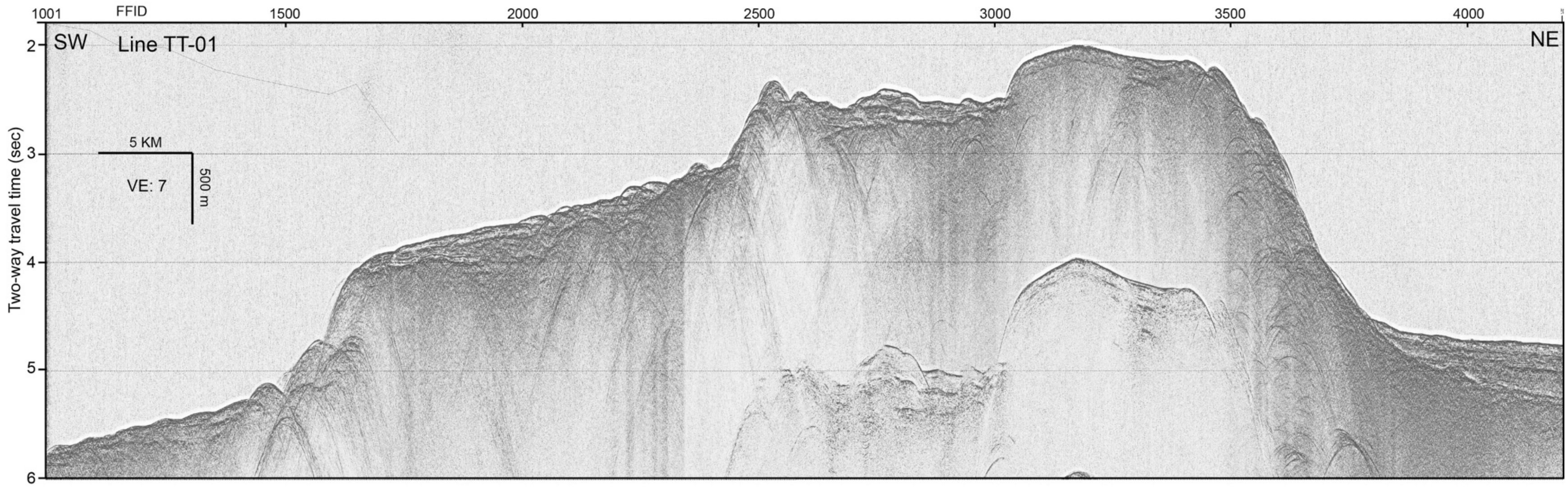


Figure 20. Seismic line TT-01, crossing the guyot summit. Vertical axis is two-way traveltime and horizontal axis is shot number (FFID). VE=vertical exaggeration. Profile shows two-tier flat summit and deep platform on the southwest side.

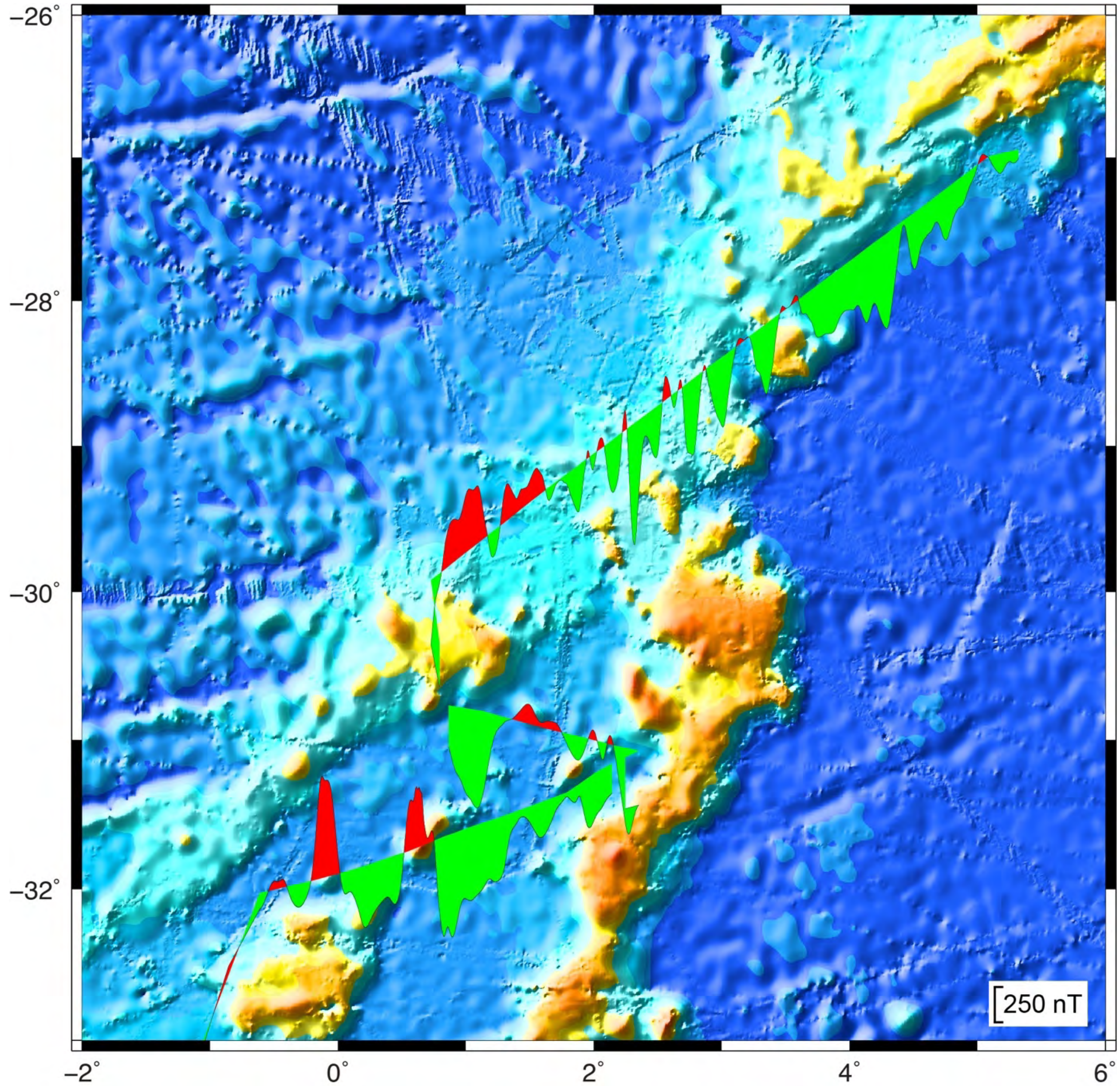


Figure 21. Magnetic anomaly data collected between guyots. Anomalies are plotted perpendicular to the ship's track (thin solid line). Positive anomalies are shaded red, whereas negative anomalies are shaded green. Background is estimated bathymetry (Smith and Sandwell, 1997).

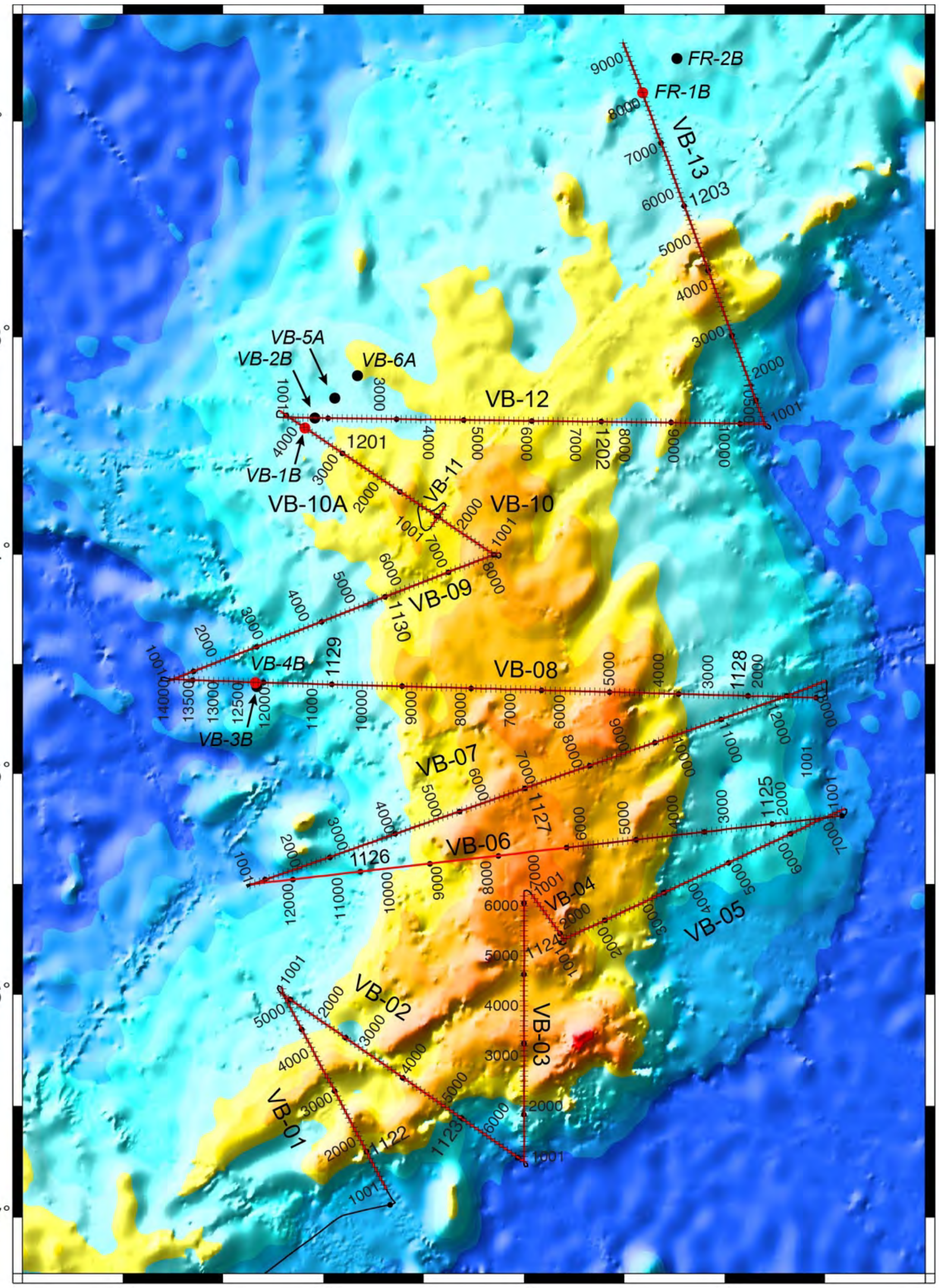


Figure 22. Valdivia Bank seismic lines. Thin line indicates the ship's track and is colored red for the seismic lines. Dots are shown every 4 hours, with an annotation at the beginning of each day (e.g., 1127 = 27 November 2019). Seismic lines are annotated with shot numbers; each line starts with 1001. Large letters, e.g., VB-01, are line numbers. Red filled circles and black filled circles show locations of proposed IODP Expedition 391 drill sites; red indicates a primary site and black, an alternate site. Background is predicted SRTM15+ bathymetry (Tozer et al., 2019)

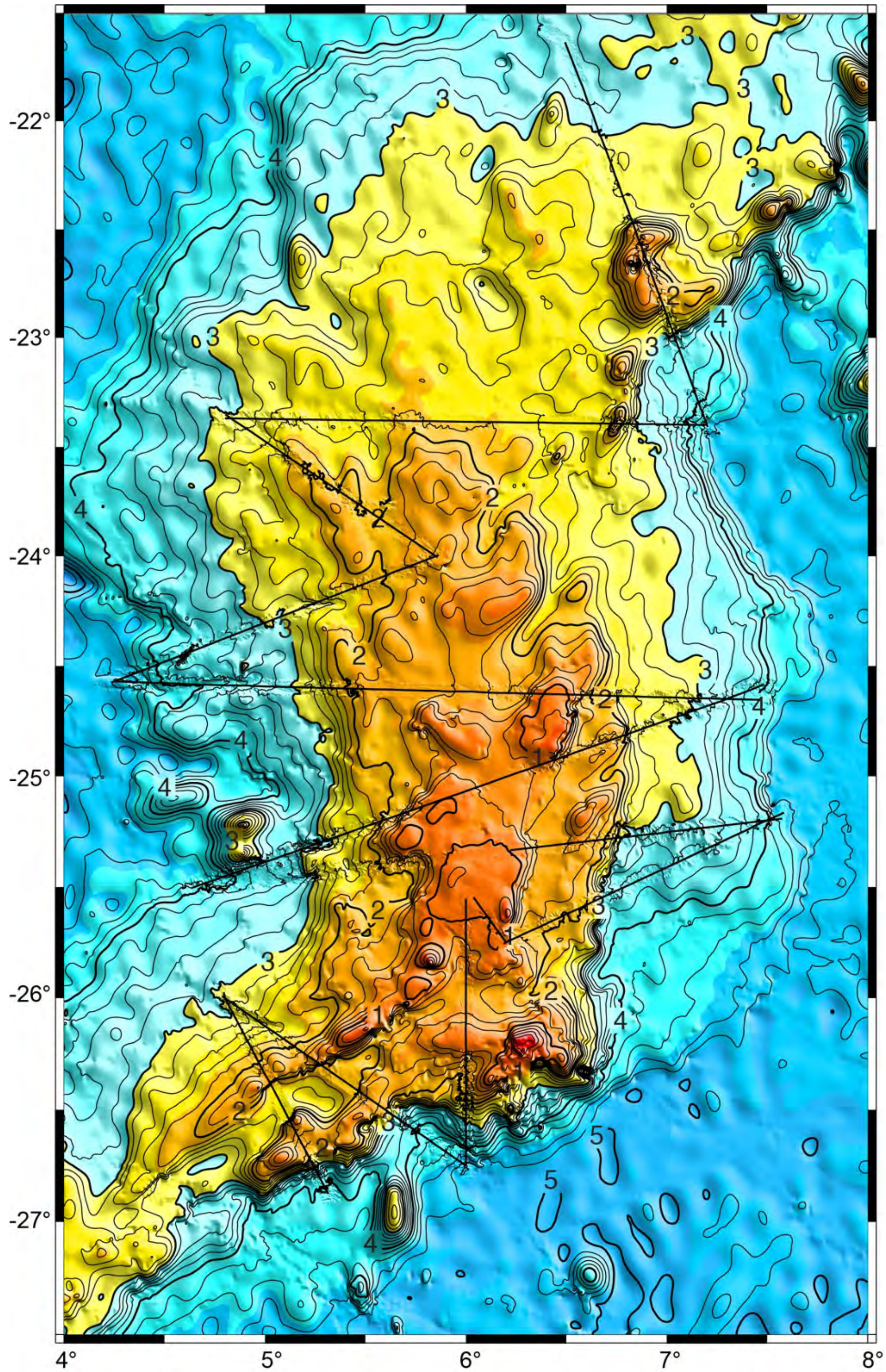


Figure 23. Multibeam bathymetry data for the Valdivia Bank survey. Ship track is thin solid line and is surrounded by multibeam data. Multibeam data are merged with background SRMT15+ bathymetry data (Tozer et al., 2019). Contours shown at 200-m intervals.

2 December 2019. After crossing the north end of Valdivia Bank, line VB-12 was brought to conclusion at 1031 GMT. It displayed broad, low undulating basement of the plateau, with a tall, flat-topped secondary cone on the east end (Fig. 30). As do most seismic lines, this one also imaged normal faults. The final line, trending just west of north, VB-13, was begun at 1016 GMT. It continued through the rest of the day.

3 December 2019. Line VB-13 finished at 1016 GMT. It imaged a narrow, shallow summit with a rough top, surrounded by steep slopes that lead to nearly horiztonal basement of the lower flanks (Fig. 30). The seismic gear was recovered, taking a bit of extra time for proper cleaning. The magnetometer was deployed at 1256 GMT with the idea of running a zig-zag line to the south, following the east side of Valdivia Bank to finish up the survey (Fig. 31). Initially, data were collected at the usual 12 kt transit speed but high winds caused rough seas, so the ship's speed was slowed to 7-9 kt.

4 December 2019. The day was spent in rough seas collecting magnetic data at a speed of 7-8 kt. The 00:00 GMT position was -22.6369, 6.8027 and the 12:00 GMT position was -23.8935, 6.4860.

5 December 2019. Magnetic profiling continued to the east of Valdivia Bank (Fig. 31). Transit began to Walvis Bay at approximately 2000 GMT.

6 December 2019. Magnetic profiling continued. The ship entered the EEZ at 0156 GMT and data recording was shut down (Fig. 31).

7 December 2019. The Thompson arrived outside Walvis Bay during early morning. There being no dock space available, the ship had to anchor and await an opening. Science personnel and departing crew were transferred to shore by launch. Thus ended cruise TN-373.

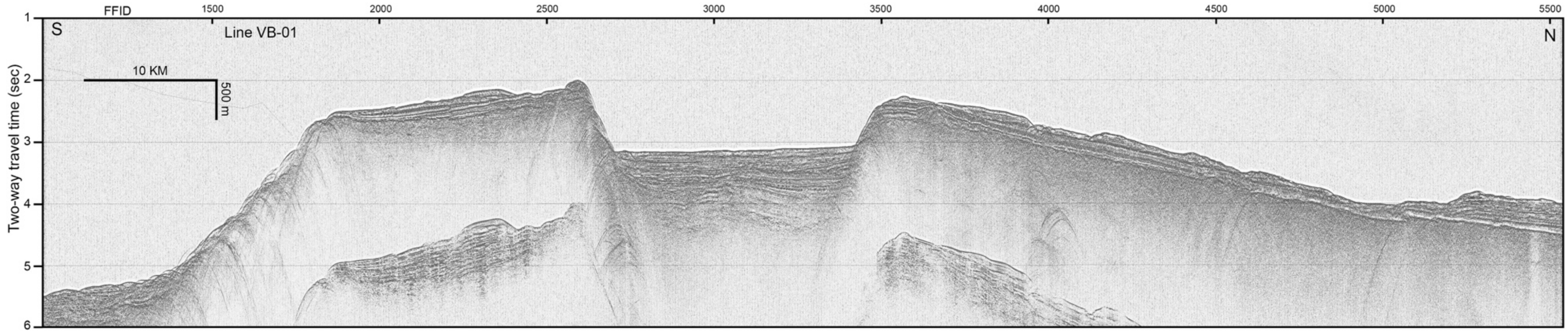


Figure 24. Seismic line VB-01, over southeast Valdivia Bank. Vertical axis is two-way traveltime; horizontal axis is shot number (FFID). VE=vertical exaggeration. Profile shows flank asymmetry and a deep rift graben containing rotated fault blocks.

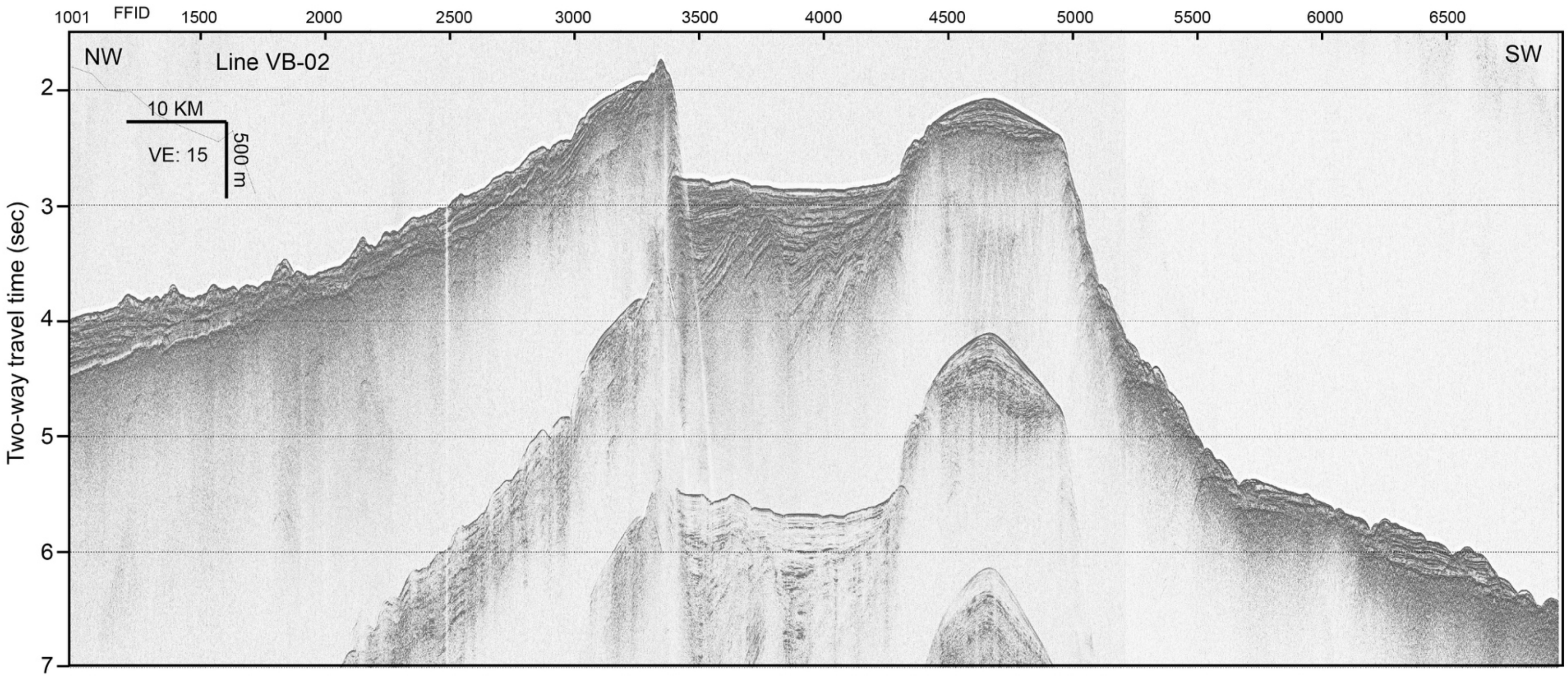


Figure 25. Seismic line VB-02, over southeast Valdivia Bank. Vertical axis is two-way traveltime; horizontal axis is shot number (FFID). VE=vertical exaggeration. Profile shows flank asymmetry and a deep rift graben containing rotated fault blocks.

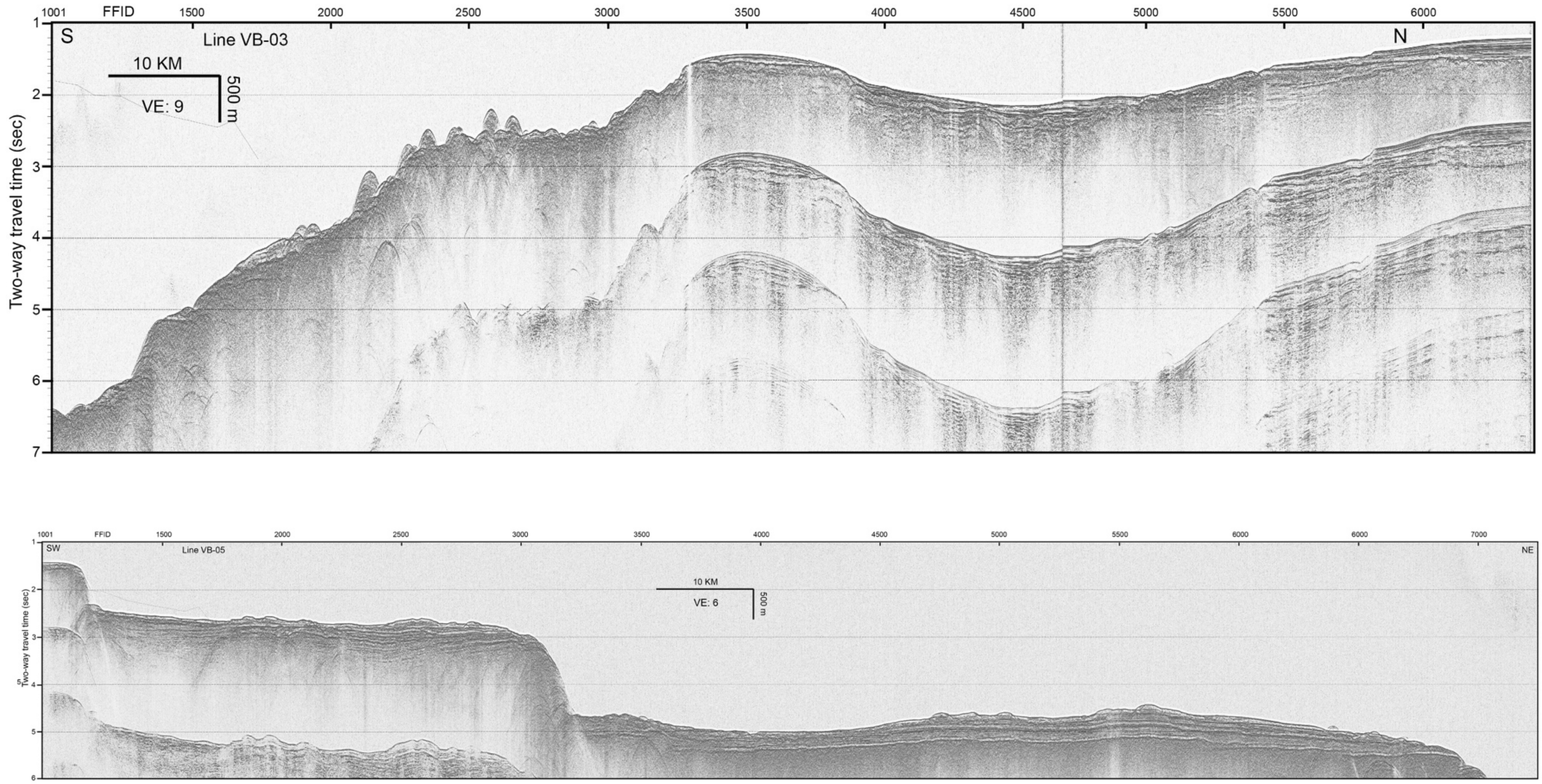


Figure 26. Seismic line VB-03 (top), over south Valdivia Bank and line VB-05 (bottom), over southeast Valdivia Bank. Vertical axis is two-way traveltime; horizontal axis is shot number (FFID). VE=vertical exaggeration. Profile VB-03 crosses flat-topped south summit and the main summit and shows a filled trough in between. A field of volcanic cones is observed on the mid-depth south flank. Profile VB-05 shows steep fault scarps and blocks with flat basement on the east side of the edifice.

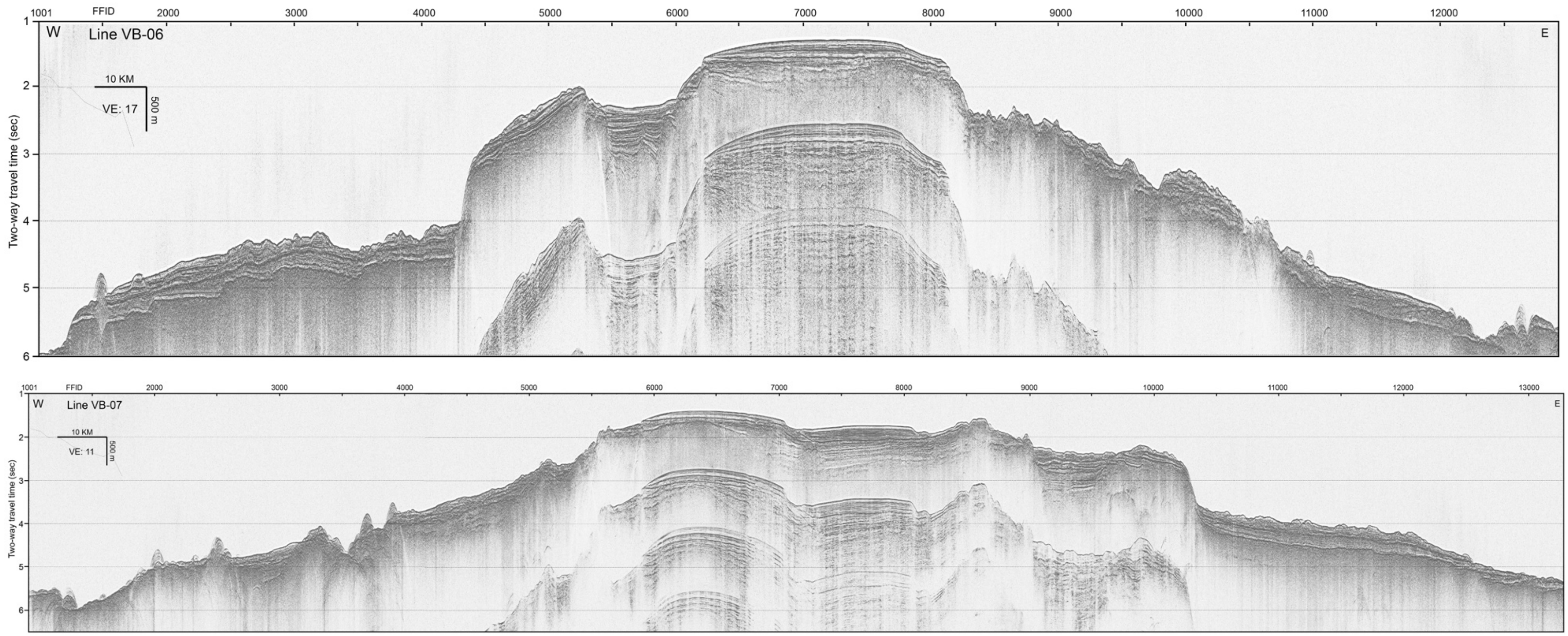


Figure 27. Seismic lines VB-06 (top) and VB-07 (bottom), over central Valdivia Bank. Vertical axis is two-way traveltime; horizontal axis is shot number (FFID). VE=vertical exaggeration. Both lines display nearly horizontal basement blocks on the east side of the edifice (top: at left, bottom: at right) and a rift graben on the east side of the summit. Both profiles show numerous normal faults offsetting basement.

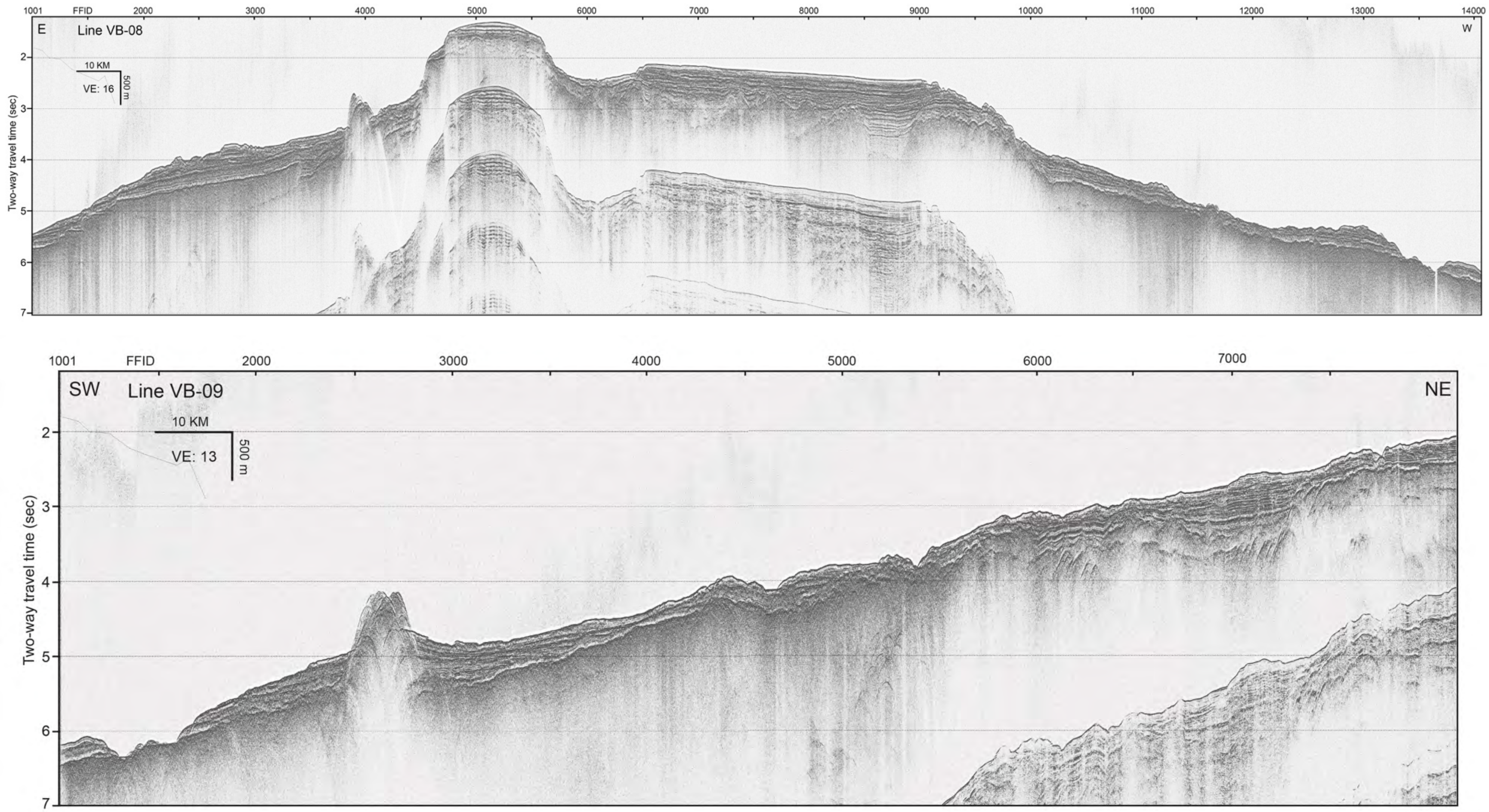


Figure 28. Seismic lines VB-08 (top) and VB-09 (bottom), over north central Valdivia Bank. Vertical axis is two-way traveltime; horizontal axis is shot number (FFID). VE=vertical exaggeration. Line VB-08 shows a high summit and lower summit and basement offsets implying normal faults. Line VB-09 illustrates sediment cover and a satellite cone over the north eastern flank. Numerous basement offsets on NE side of profile imply a fault zone.

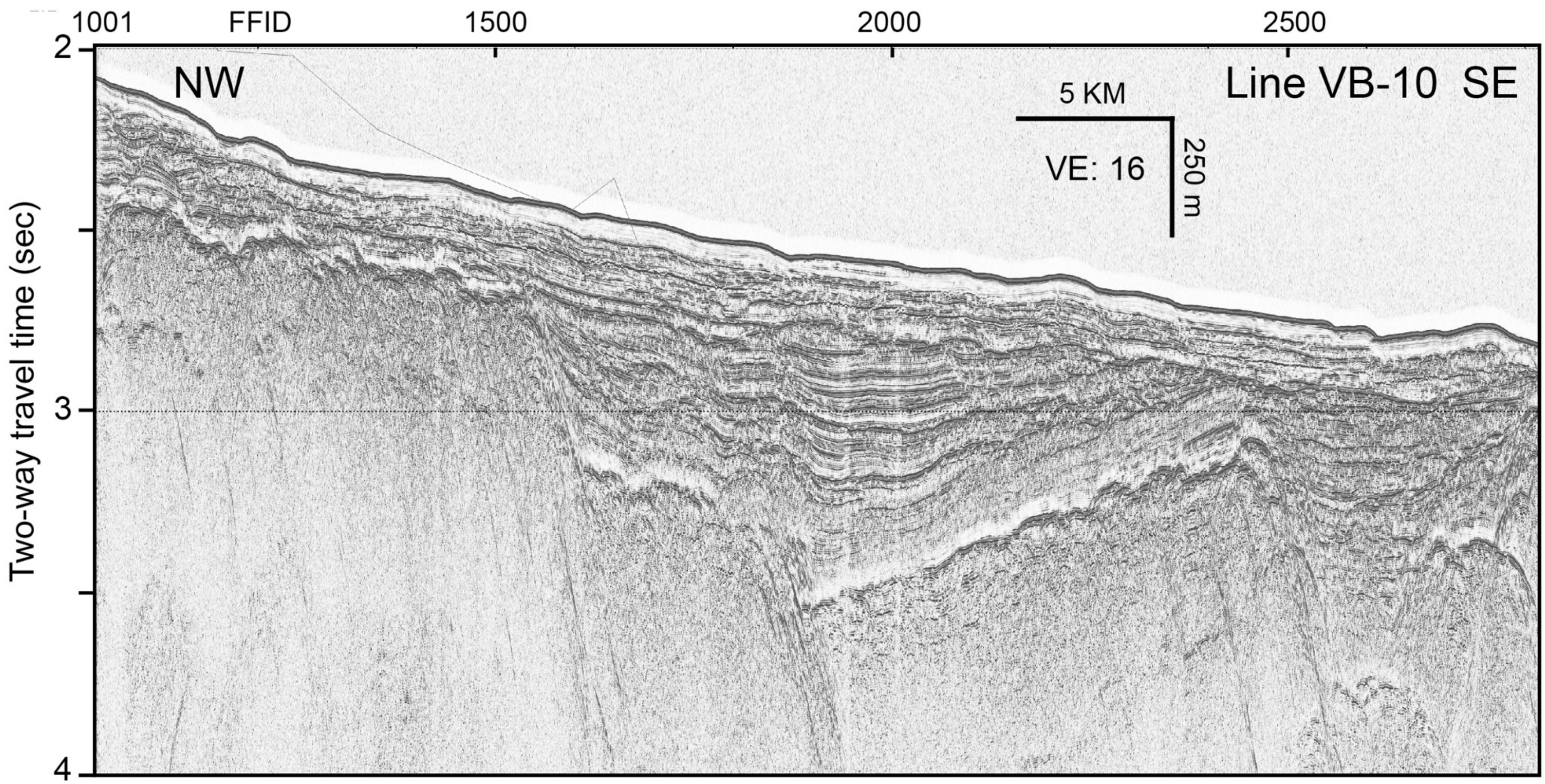


Figure 29. Seismic line VB-10, located over northwest Valdivia Bank. Vertical axis is two-way traveltime; horizontal axis is shot number (FFID). VE=vertical exaggeration. Profile shows a buried, tilted fault block (tilt ~1°). The record indicates a layer of sediments is parallel to basement on the block, indicating a layer deposited before faulting occurred.

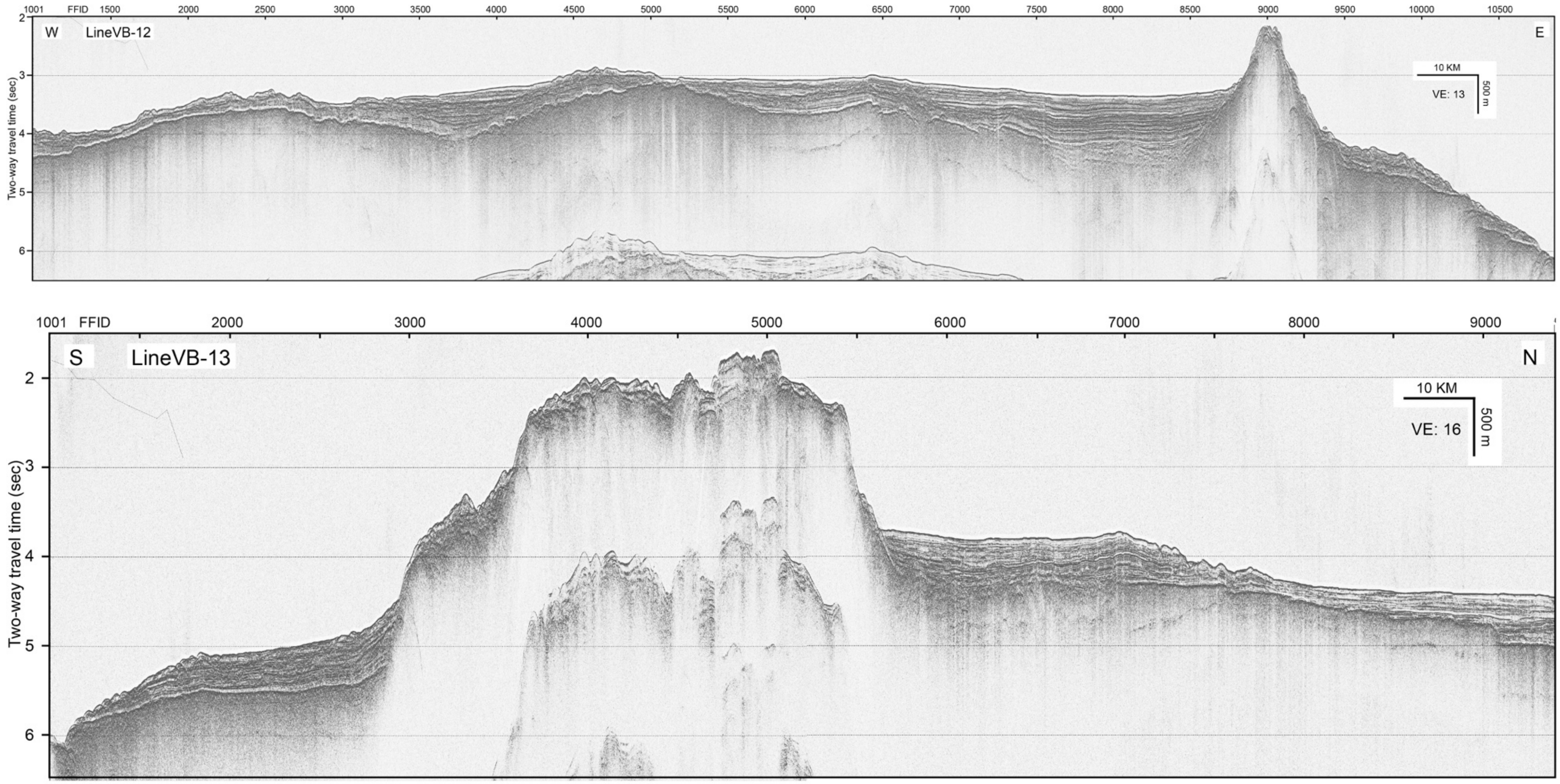


Figure 30. Seismic lines VB-12 (top) and VB-13 (bottom), located over northern Valdivia Bank. Vertical axis is two-way traveltime; horizontal axis is shot number (FFID). VE=vertical exaggeration. Line VB-12 shows a profile over the low northern flank of the Valdivia Bank edifice, with a tall, flat topped secondary cone on the east side. A fault graben in basement is observed between FFID 6500-7200. Line VB-13 shows a north-south profile across a tall, rough top summit on northern Valdivia Bank. Both northern and southern flanks are nearly horizontal with steep offsets on the perimeter of the high. Normal fault scarps appear on both sides near the ends of the line.

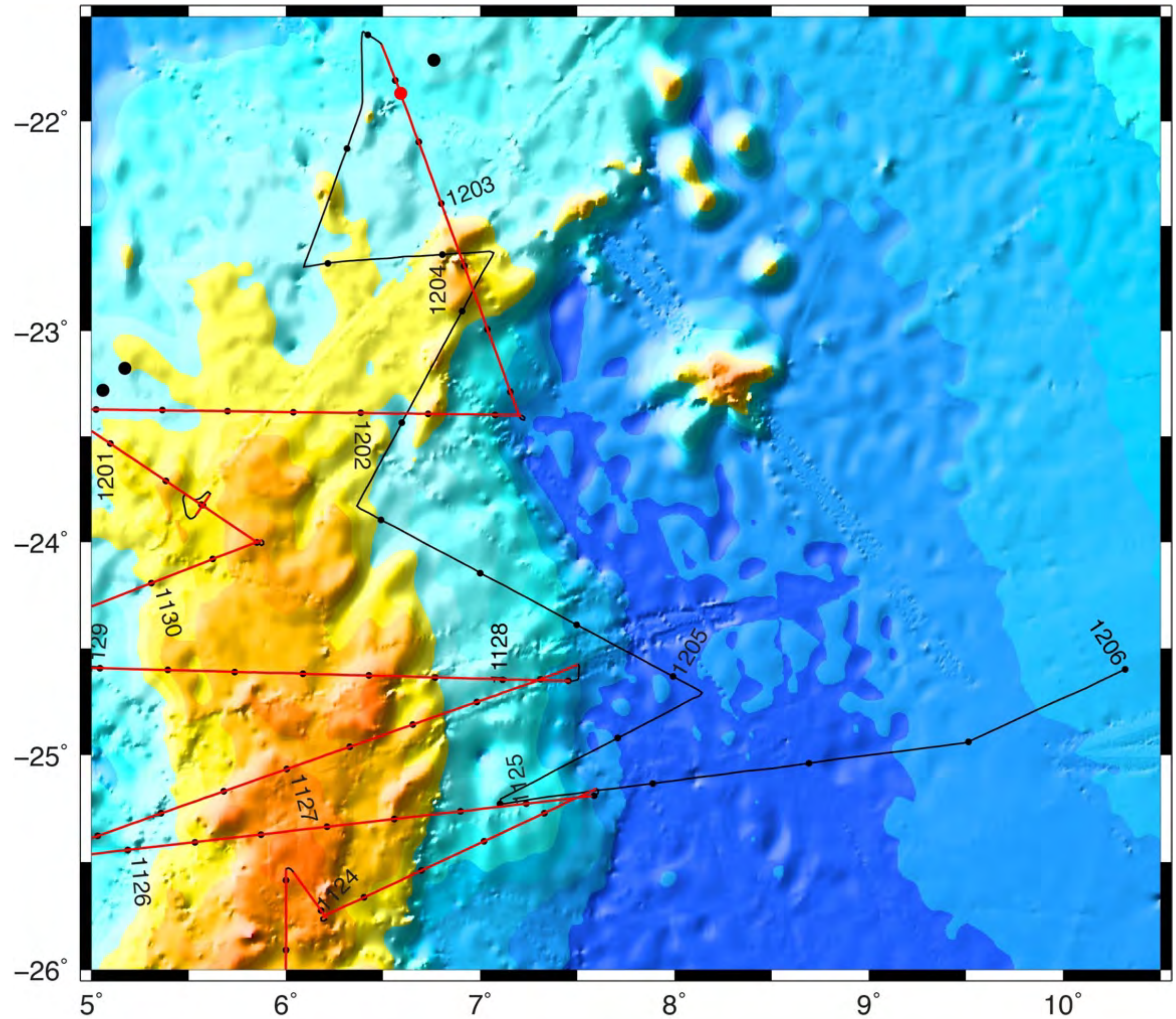


Figure 31. Track line for magnetic profiling on the east side of Valdiva Bank at the end of the cruise. Thin black line is ship's track, with dots plotted every 4 hours, and annotations at the beginning of each day (e.g., 1206 = 6 December 2019). The track ends just after the beginning of 6 December because data recording was halted upon entering the EEZ. Red lines show seismic lines (Table 1, Fig. 22).

Table 1. Cruise TN-373 Seismic Lines.

Line	UTM Zone	Start Date	Time (GMT)	Lat.	Long.	FFID*	End Date	Time (GMT)	Lat.	Long.	FFID*	Length (km)
RGR-1	25S	11/10/19	5:37	-34.2684	-31.5515	1001	11/10/19	18:01	-33.3228	-31.0304	5572	114
CT-01	30S	11/16/19	4:24	-33.1492	-0.9055	1001	11/16/19	7:31	-31.1896	-0.5248	1685	17
Line aborted because of poor data												
CT-02	30S	11/16/19	12:05	-33.2090	-0.1442	1001	11/17/19	1:52	-32.2171	-0.7223	5924	123
CT-03	30S	11/17/19	3:52	-33.3078	-0.6621	1001	11/17/19	7:30	-32.0320	-0.5655	2260	32
GT-01	31S	11/18/19	0:04	-31.1897	2.2983	1001	11/18/19	8:31	-31.6991	2.7867	3923	73
GT-02	31S	11/18/19	9:01	-31.6899	2.7708	1001	11/18/19	14:38	-31.2873	2.8753	2907	48
GT-03	31S	11/18/19	15:25	-31.2983	2.8672	1001	11/18/19	18:25	-31.4245	3.1080	2040	26
GT-04	31S	11/18/19	19:12	-31.4174	3.1016	1001	11/18/19	20:38	-31.5198	3.0451	1509	13
GT-05	31S	11/18/19	21:26	-31.5125	3.0548	1001	11/18/19	21:35	-31.5059	3.0420	1054	1
Line aborted because of navigation problem												
GT-05A	31S	11/18/19	21:40	-31.5024	3.0358	1001	11/19/19	5:58	-31.1139	2.4305	3879	72
TT-01	31S	11/19/19	15:52	-30.7620	0.8996	1001	11/20/19	1:05	-30.0907	1.2033	4245	81
TT-02	31S	11/20/19	1:30	-30.1002	1.2049	1001	11/20/19	7:49	-30.3079	0.6862	3237	56
TT-03	31S	11/20/19	8:39	-30.2976	0.6991	1001	11/20/19	14:00	-29.8993	0.5628	2934	48
TT-04	31S	11/20/19	15:48	-29.9758	0.5218	1001	11/20/19	17:16	-29.9435	0.6488	1512	13
VB-01	31S	11/21/19	21:34	-26.8752	5.3150	1001	11/22/19	10:36	-25.9673	4.7930	5531	113
VB-02	31S	11/22/19	11:19	-25.9910	4.7855	1001	11/23/19	4:33	-26.7550	6.0090	6945	149
VB-03	31S	11/23/19	5:20	-26.7490	5.9990	1001	11/23/19	20:37	-25.5355	5.9998	6386	135
VB-04	31S	11/23/19	21:13	-25.5467	6.0375	1001	11/24/19	0:34	-25.7610	6.2080	2172	29
VB-05	31S	11/24/19	1:16	-25.7560	6.1880	1001	11/24/19	19:20	-25.1588	7.5965	7265	157
VB-06	31S	11/24/19	20:07	-25.1918	7.5754	1001	11/26/19	6:28	-25.5008	4.6334	12935	298
VB-07	31S	11/26/19	7:02	-25.5050	4.6340	1001	11/27/19	18:27	-24.5772	7.5016	13287	307
VB-08	31S	11/27/19	19:55	-24.6538	7.4628	1001	11/29/19	9:17	-24.5692	4.2365	14080	327
VB-09	31S	11/29/19	10:31	-24.5754	4.2343	1001	11/30/19	7:11	-23.9908	5.8760	8154	179
VB-10	31S	11/30/19	7:53	-24.0055	5.8588	1001	11/30/19	13:03	-23.7764	5.4862	2827	46
VB-10a	31S	11/30/19	18:11	-23.7924	5.5134	1001	12/01/19	4:25	-23.3393	4.7842	4593	89
VB-11	31S	11/30/19	15:18	-23.8710	5.5381	1001	11/30/19	16:45	-23.7774	5.6075	1503	13
VB-12	31S	12/01/19	5:23	-23.3697	4.8006	1001	12/02/19	9:35	-23.3999	7.2124	10871	247
VB-13	31S	12/02/19	10:22	-23.4092	7.2033	1001	12/03/19	10:17	-21.6314	6.4926	9414	210

*FFID – Shot number (starting at value 1001); total number of shots = 120,616; total line length = 3015 km

Cruise TN-374 (10 December to 5 January)

10 December 2019. Departure was delayed slightly because the Thompson was unable to dock on the first day of the port call. The ship departed at 1340 local (1140 GMT) and quickly moved out of Walvis Bay and commenced transit to the study area.

11 December 2019. The ship exited the Namibian EEZ at 0900 GMT and began recording data. Gravity and magnetic data as well as EM302 multibeam swath bathymetry and Knudsen 3.5 kHz echosounder data were collected while underway. The cruise plan was to zig-zag back and forth over Valdivia Bank to collect more-or-less E-W trending magnetic lines connecting the regular magnetic anomalies west of Valdivia Bank with the complex anomalies over the rise (Fig. 32)

12 December 2019. Line 1, located to the north of Walvis Ridge (Fig. 33), was started at 0628 GMT (see Table 2 for a list of magnetic line start and end points). The line goes from east to west and crosses an area where the EMAG2v3 data compilation has gaps owing to lack of data (Fig. 34). Data collection was routinely done at a speed of 12 knots. The magnetic anomaly profile shows many positive and negative magnetic anomalies that imply magnetic reversals (Fig. 35).

13 December 2019. Having reached the west end of Line 1 at 0305 GMT, it was decided to add a line about 30 km farther north, which was not originally planned. Line 2 began at 0519 GMT, headed eastward.

14 December 2019. The end of Line 2 was reached at 0300 GMT. Line 3 was commenced, headed westward, at 0845 GMT.

15 December 2019. The end of Line 3 was reached at 0706 GMT. Line 4 was commenced, headed eastward, at 1108 GMT.

16 December 2019. The end of Line 4 was reached at 1423 GMT. Line 5 was commenced, headed westward, at 1711 GMT.

17 December 2019. The end of Line 5 was reached at 1831 GMT. Line 6 was commenced, headed eastward, at 2043 GMT.

18 December 2019. The end of Line 6 was reached at 2253 GMT. As the day ended, Thompson was headed to the beginning of Line 7.

19 December 2019. Line 7 began at 0048 GMT, headed west. The ship spent the entire day steaming along this line.

20 December 2019. The end of Line 7 was reached at 0219 GMT. Line 8 began at 0409 GMT, headed east. The ship spent the rest of the day on this line.

21 December 2019. Line 8 was done at 0654 GMT. Line 9, heading west, was commenced at 1000 GMT.

22 December 2019. Line 9 was finished at 1030 GMT. Line 10, with an east heading, was started at 1136 GMT.

23 December 2019. Line 10 ended at 1500 GMT. West heading Line 11 was begun at 1718 GMT.

24 December 2019. Line 11 ended at 2225 GMT. Line 12 began at 2332 GMT, with the ship headed east.

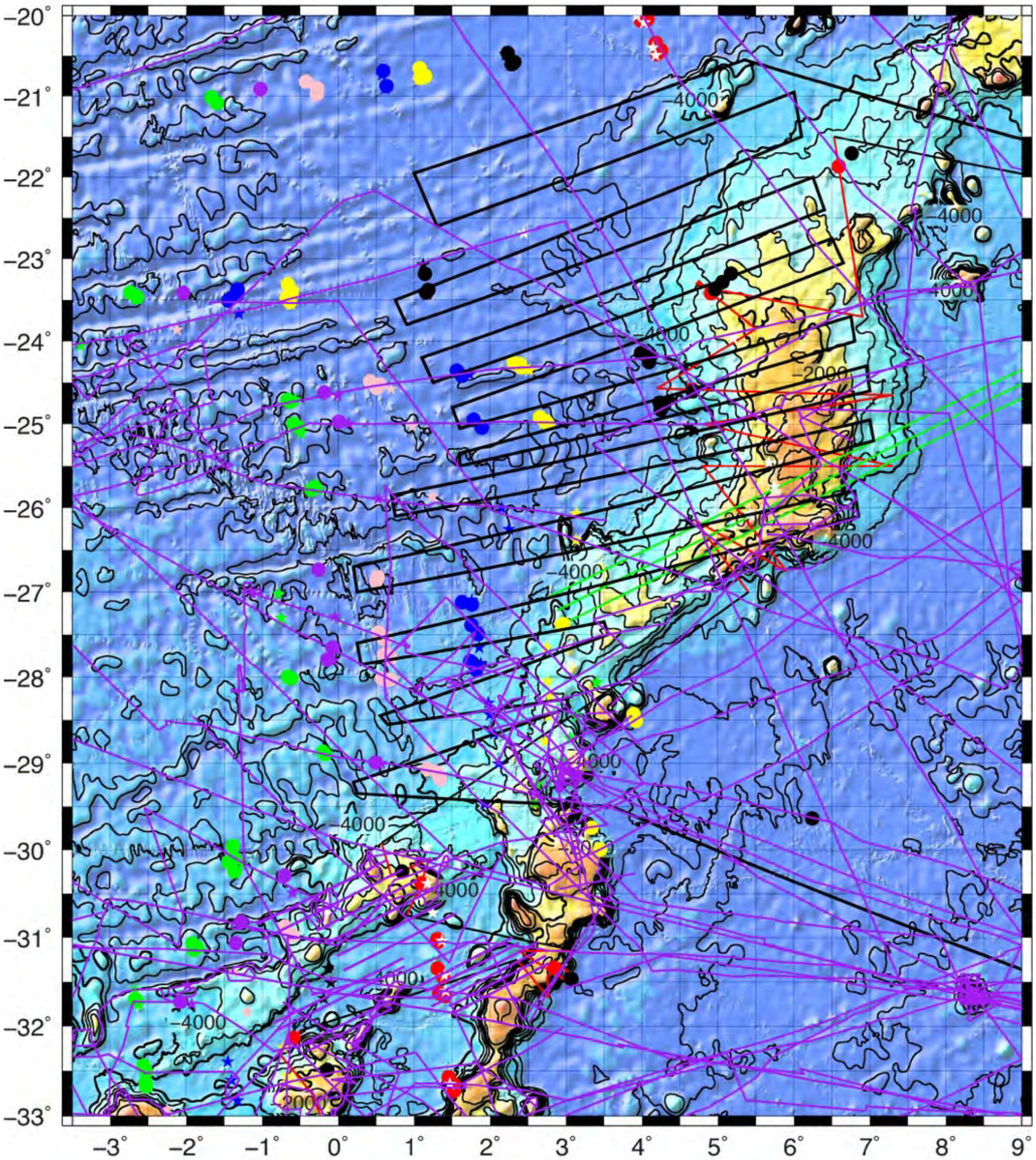


Figure 32. Planned TN-374 cruise tracks compared with existing magnetic data. Planned TN-374 tracks are solid black lines; Pre-existing magnetic track lines are purple lines. Colored circles are magnetic anomaly picks. Background is predicted bathymetry (Smith and Sandwell, 1997).

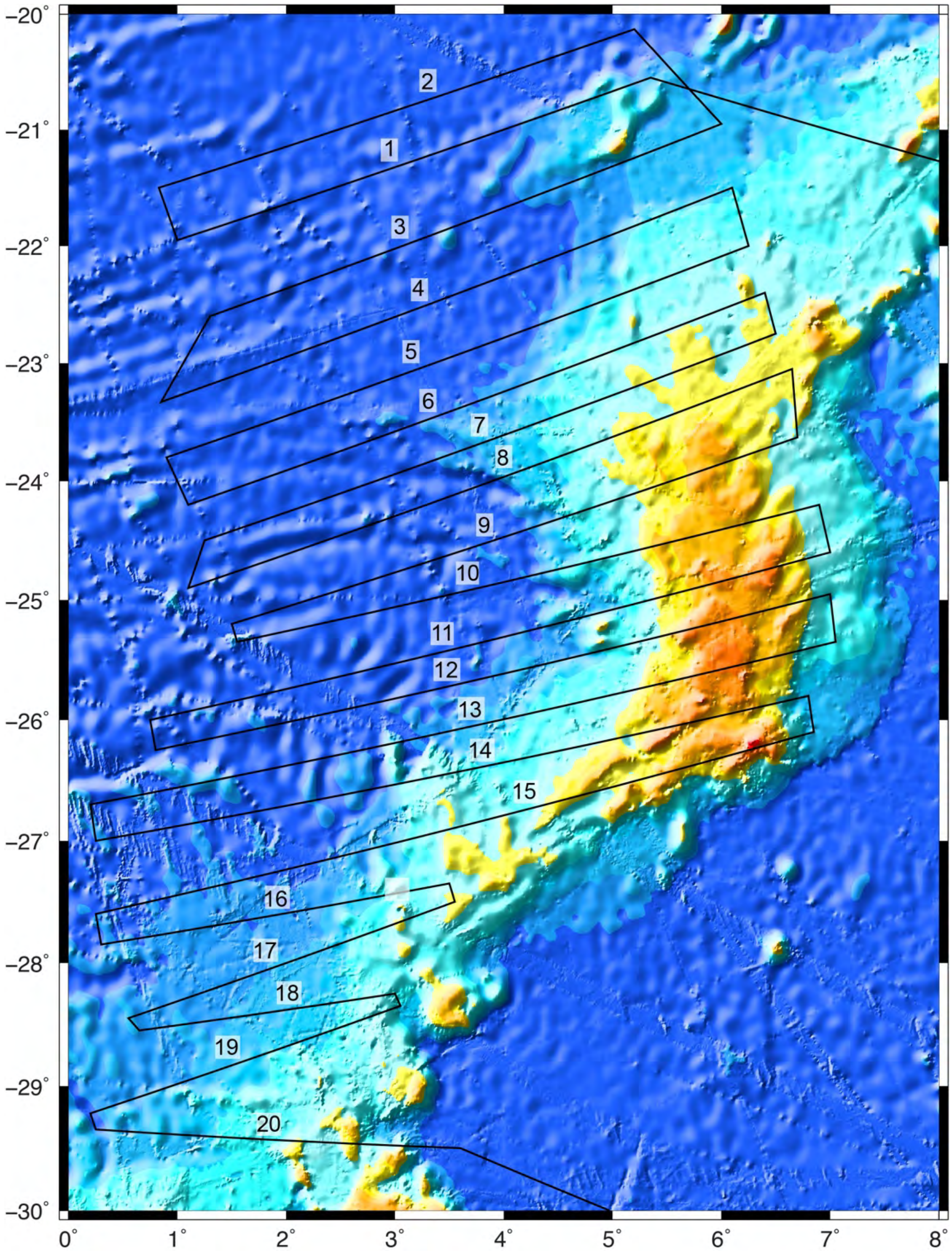


Figure 33. Cruise TN-374 tracks completed. Numbers are line identifiers (Table 2). Background is predicted bathymetry (Smith and Sandwell, 1997).

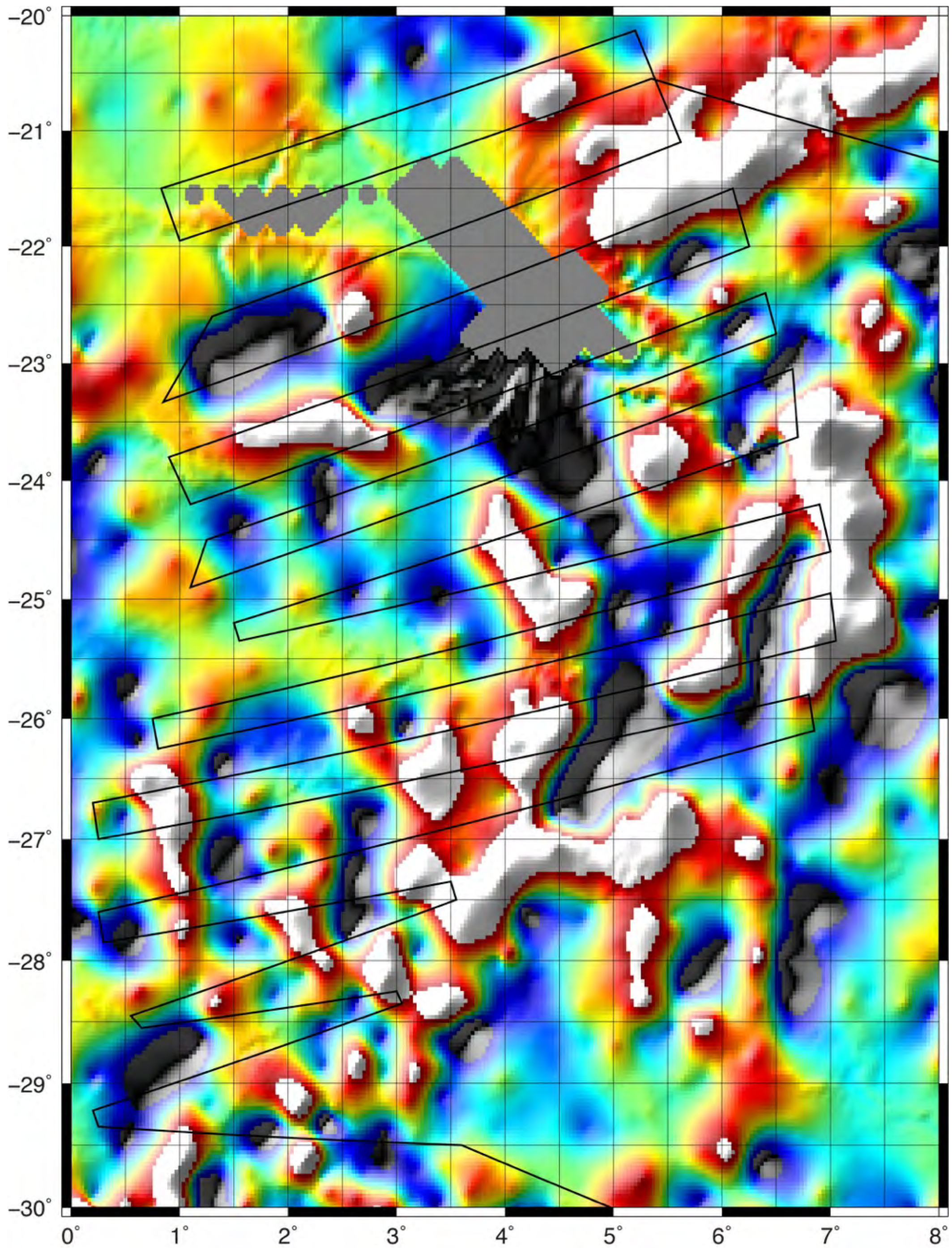


Figure 34. Cruise TN-374 magnetic tracklines compared with EMAG2v3 compilation of magnetic anomalies (Meyer et al, 2017). Red and yellow denote positive magnetic anomalies whereas blue represents negative magnetic anomalies .Solid black lines are cruise tracks. Gray areas show zones where EMAG2v3 has no anomaly owing to lack of data.

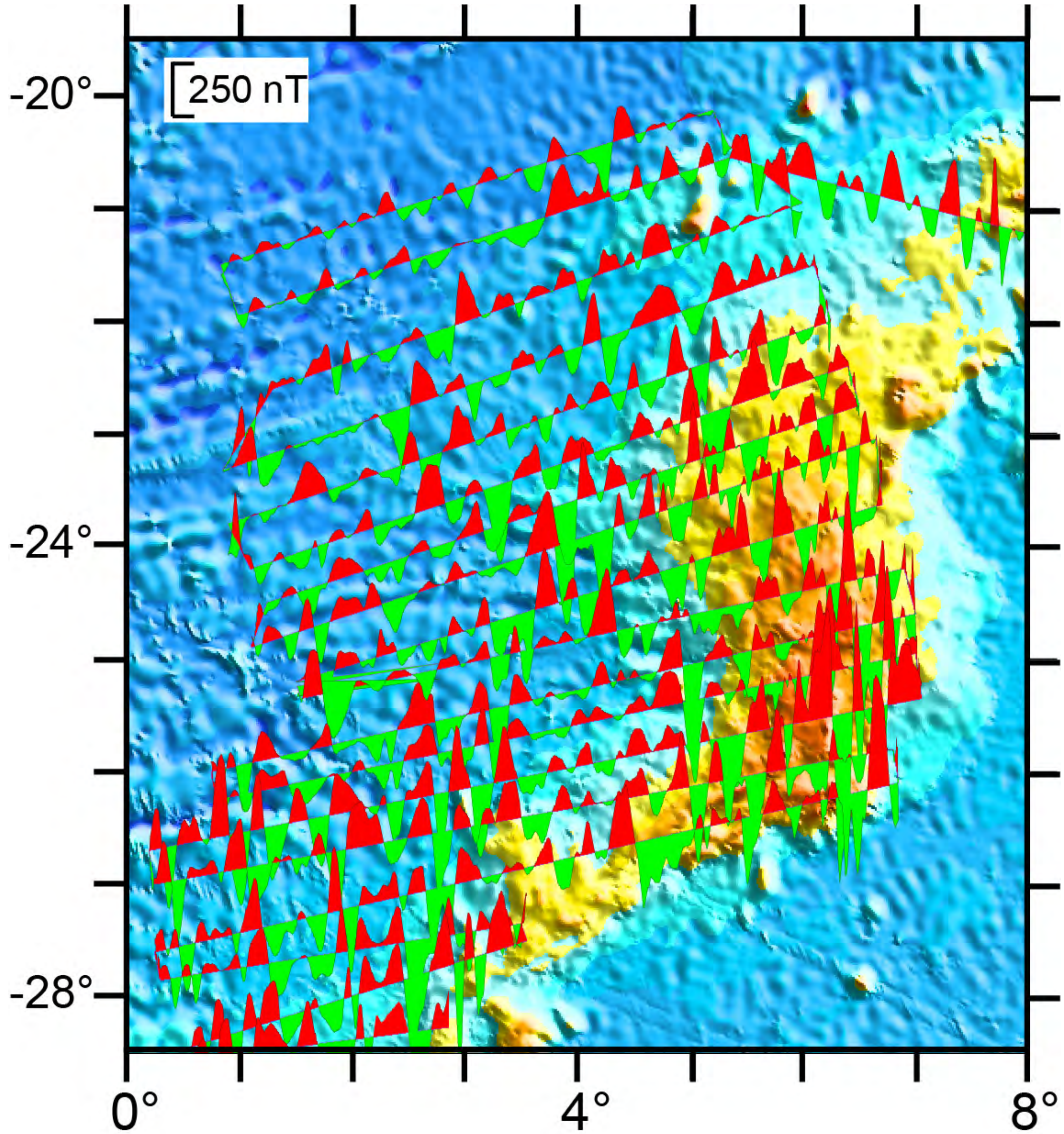


Figure 35. Magnetic anomalies recorded on cruise TN-374 tracks. Thin black lines are ship tracks. Red (green) colored areas dempte positive (negative) anomalies plotted perpendicular to the track. Background is predicted bathymetry (Smith and Sandwell, 1997). Numerous positive and negative anomalies are observed, implying magnetic reversals.

25 December 2019. All of Christmas day was spent steaming along Line 12. The science party built a Christmas tree from miscellaneous materials found around the lab. The weather was good, so a cookout was held on deck aft of the equipment hanger. The scientists held a gift exchange in the lab (Fig. 36).

26 December 2019. Line 12 was brought to an end at 0421 GMT. Line 13 began at 0618, headed west. The day ended with the ship on Line 13.

27 December 2019. Line 13 was underway at the beginning of the day and was finished at 1316 GMT. The ship turned south to cross over to Line 14, which began at 1447 GMT. At the end of the day, the ship was headed east on Line 14.

28 December 2019. The weather began to deteriorate and the ship was slowed to ~10 kt at 0611 GMT. The quality of bathymetry data was adversely affected, but all underway data were still acquired. Line 14 continued throughout the rest of the day.

29 December 2019. Line 14 continued until the end was reached at 0010 GMT. The ship sailed south to begin Line 15. At 0152 GMT, the ship was on Line 15 headed west. At 0430 GMT, the ship passed over the shallowest summit of Valdivia Bank. At 0603 GMT, speed was increased back to ~12 kt as the weather improved.

30 December 2019. Line 15 was underway at the beginning of the day. The end of Line 15 was reached at 0730 GMT. The ship turned south to cross over to Line 16, which was started at 0846 GMT, headed east. The end of Line 16 was reached at 2334 GMT.

31 December 2019. Line 17 was started at 0020 GMT, with the ship again headed west. The end of the line was reached at 1330 GMT. Line 18 was begun at 1409 GMT, headed east.

1 January 2020. The ship was sailing Line 18 at the beginning of the day and the end was attained at 0036 GMT. After a short turn, Line 19 was commenced at 0107 GMT. The end of Line 19 was reached at 1326 GMT and Line 20 began at 1406 GMT. New Year's Day ended while on Line 20.

2 January 2020. The end of Line 20 was reached at 0418 GMT. This ended the planned zig-zag cruise plan. With a slight change in course, the ship began transit to Cape Town. All geophysical data were collected during the transit.

3 January 2020. The transit cruise to Cape Town continued.

4 January 2020. At 0148, the ship crossed into the EEZ. Having no agreement to allow data collection, all data collection was terminated.

5 January 2020. The Thompson arrived at the dock in Cape Town during the morning. Relieved scientists and departing crew scurried off and cruise TN-374 was complete (Fig. 37).

Figure 36. Christmas in the electronics lab. Left to right: Veselina Yakimova, William Sager (back), Tshiamo Moleele, Luyanda Ngcobo, Brendan Cornelison, Amana Pascali, Ben Chang, the Christmas tree, Malik Alam, Bhavya Merchant, Sriharsha Thoram, Avradip Ghosh, Sonia Brugger, Matthew Sexton.

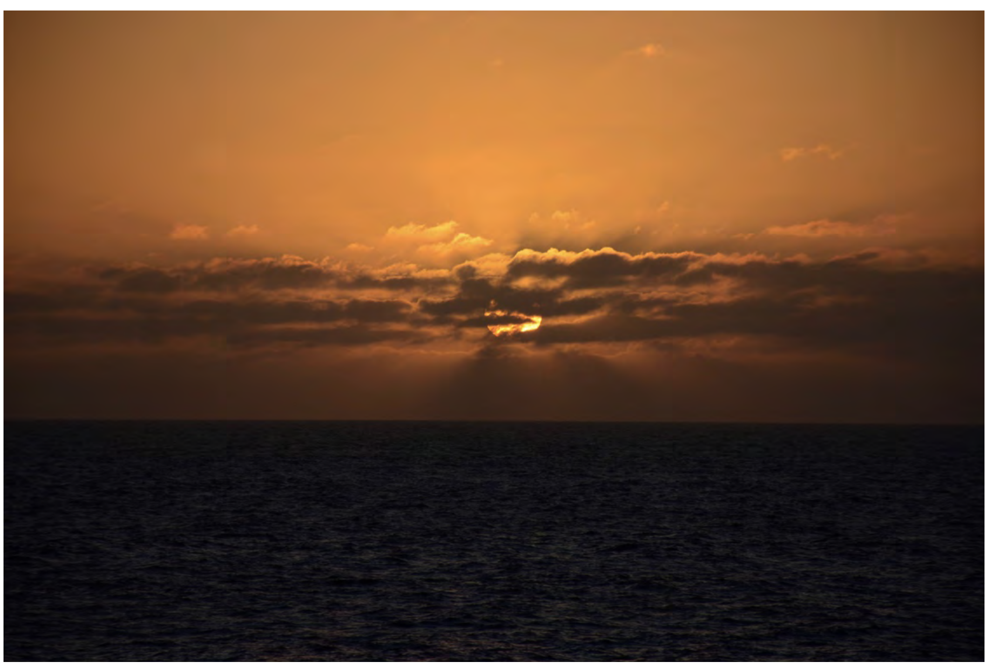


Figure 37. Walvis Bay sunset, 10 December 2019.

Table 2. Cruise TN-374 magnetic lines.

Line*	Start Date	Time (GMT)	Lat.	Long.	Line Direction	End Date	Time (GMT)	Lat.	Long.	Length (km)
1	12/12/19	6:28	-20.55	5.34	W	12/13/19	3:05	-21.95	1.00	476
1T	12/13/19	3:05	-21.95	1.00	N	12/13/19	5:19	-21.50	0.83	53
2	12/13/19	5:19	-21.50	0.83	E	12/14/19	3:00	-20.13	5.20	468
2T	12/14/19	3:00	-20.13	5.20	S	12/14/19	8:45	-20.95	6.00	123
3	12/14/19	8:45	-20.95	6.00	W	12/15/19	7:06	-22.60	1.30	518
3T	12/15/19	7:06	-22.60	1.30	S	12/15/19	11:08	-23.33	0.85	93
4	12/15/19	11:08	-23.33	0.85	E	12/16/19	14:23	-21.50	6.50	576
4T	12/16/19	14:23	-21.50	6.50	S	12/16/19	17:11	-22.00	6.25	58
5	12/16/19	17:11	-22.00	6.25	W	12/17/19	18:31	-23.80	0.90	582
5T	12/17/19	18:31	-23.80	0.90	S	12/17/19	20:43	-24.20	1.10	49
6	12/17/19	20:43	-24.20	1.10	E	12/18/19	22:53	-22.40	6.40	575
6T	12/18/19	22:53	-22.40	6.40	S	12/19/19	0:48	-22.75	6.50	40
7	12/19/19	0:48	-22.75	6.50	W	12/20/19	2:19	-24.50	1.25	568
7T	12/20/19	2:19	-24.50	1.25	S	12/20/19	4:09	-24.90	1.10	47
8	12/20/19	4:09	-24.90	1.10	E	12/21/19	6:54	-23.05	6.65	599
8T	12/21/19	6:54	-23.05	6.65	S	12/21/19	10:00	-23.63	6.70	65
9	12/21/19	10:00	-23.63	6.70	W	12/22/19	10:30	-25.20	1.50	553
9T	12/22/19	10:30	-25.20	1.50	S	12/22/19	11:36	-25.35	1.55	17
10	12/22/19	11:36	-25.35	1.55	E	12/23/19	15:00	-24.20	6.90	554
10T	12/23/19	15:00	-24.20	6.90	S	12/23/19	17:18	-24.60	7.00	46
11	12/23/19	17:18	-24.60	7.00	W	12/24/19	22:25	-26.00	0.75	646
11T	12/24/19	22:25	-26.00	0.75	S	12/24/19	23:32	-26.25	0.80	28
12	12/24/19	23:32	-26.25	0.80	E	12/26/19	4:12	-24.95	7.00	637
12T	12/26/19	4:12	-24.95	7.00	S	12/26/19	6:18	-25.35	7.05	45
13	12/26/19	6:18	-25.35	7.05	W	12/27/19	13:16	-26.70	0.20	699
13T	12/27/19	13:16	-26.70	0.20	S	12/27/19	14:47	-27.00	0.25	34
14	12/27/19	14:47	-27.00	0.25	E	12/29/19	0:10	-25.80	6.80	665
14T	12/29/19	0:10	-25.80	6.80	S	12/29/19	1:52	-26.10	6.85	34
15	12/29/19	1:52	-26.10	6.85	W	12/30/19	7:30	-27.60	0.25	674
15T	12/30/19	7:30	-27.60	0.25	S	12/30/19	8:46	-27.85	0.30	28
16	12/30/19	8:46	-27.85	0.30	E	12/30/19	23:34	-27.35	3.50	320
16T	12/30/19	23:34	-27.35	3.50	S	12/31/19	0:20	-27.50	3.55	17
17	12/31/19	0:20	-27.50	3.55	W	12/31/19	13:30	-28.45	0.55	313
17T	12/31/19	13:30	-28.45	0.55	S	12/31/19	14:09	-28.55	0.65	15
18	12/31/19	14:09	-28.55	0.65	E	1/1/20	0:36	-28.25	3.00	232
18T	1/1/20	0:36	-28.25	3.00	S	1/1/20	1:07	-28.35	3.05	12
19	1/1/20	1:07	-28.35	3.05	W	1/1/20	13:26	-29.22	0.20	294
19T	1/1/20	13:26	-29.22	0.20	S	1/1/20	14:06	-29.35	0.25	15
20	1/1/20	14:06	-29.35	0.25	E	1/2/20	4:18	-29.50	3.60	324

*Line with T suffix is a turn. Total line length is 10,574 km.

Preliminary Results and Observations

Cruises TN-373 and TN-374 were highly successful, achieving all preliminary cruise goals. Cruise TN-373 ran all planned seismic lines, collecting a short practice line over a rift in southern Rio Grande Rise (RGR-1), thirteen seismic lines over the three guyots near in the middle of Walvis Ridge (CT-1 to CT-3, GT-1 to GT-5A, TT1 to TT-4), and thirteen seismic lines were collected over Valdivia Bank. In total, 120,616 shots were fired along 3015 km of seismic profiles. The cruise traveled a total of 5256 km during its 31 day duration. For the purposes of IODP Expedition 391 site survey, seismic lines crossed 5 proposed drill sites in the guyot surveys and 4 proposed sites on Valdivia Bank. Moreover, the new seismic data have been used to propose an addition 14 sites that can be used for the Expedition. Seismic data revealed that the guyots are complex features, often having escarpments on their flanks and summits with more than one platform. Seismic data also revealed Valdivia Bank to be highly complex and asymmetric. Whereas flanks on the west side are mostly gentle, several large escarpments were found on the east side. In addition, seismic data revealed deep, sediment filled rift grabens on the southwest and east sides of the plateau, sometimes containing tilted fault blocks. Normal faults are also found extensively on Valdivia Bank flanks. The implication is that the massif was affected by widespread faulting. The summits are shallow and domal, implying anomalous subsidence and coverage with thick sediment layers. The thick sediments in the rifts and on the summits may be good targets for future paleoenvironmental research. The large-scale magnetic anomaly survey filled in many gaps in magnetic coverage and provide an evenly spaced data set to help with future tectonic studies. Although still sparse owing to wide track spacing, multibeam bathymetry data will allow better morphologic maps of Valdivia Bank to be produced.

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Appendix 1

Gravity Tie Report

TN-373 Seismic Processing Report

Zhehao Li and Alec Vila

TN-373 Collected a total of 25 2D seismic lines for a total of 350GB of data split into 4 different survey areas, the primary sites of interest are the Tristan Track (TT), Center Tract (CT), Gough Tract (GT) and Valdivia Bank (VB). These sites contain important information with regards to the geochemical evolution, microplate and hotspot model for Walvis ridge. Individually, CT has 2 lines, GT has 5 lines, TT has 4 lines and VB has 14 lines (Fig. 1). The source is consisting of 2 air guns firing at 25m interval while the total streamer length is 600m with 6.25m receiver interval (Fig. 2). On average, the depth of the streamer is kept at 4m and the fold is 12. The total survey area is around 3000km and the data was recorded in both SEG-Y and SEG-D formats.

The data was initially processed with preliminary processing steps in the field using GeoEast provided by BGP and Echos provided by Paradigm. The finalized processing was done by using GeoEast. P190 files were generated by NaviPack. We will describe the processing steps in details below (Fig. 3a, 3b).

I. For pre-processing:
The data had problems with duping shot FFIDs, incorrect shot locations and malfunctioning receivers. For problems in the SEG-Y, we removed these problematic sources. However, for duping shot FFID problem in the P190, we checked each shot with respect to navigations GPS files generated by GeoEel. Each shot was then correlated with its relative position and extra shots with incorrect FFIDs were removed. Furthermore, while the streamer has 100 receivers, only the first 96 receivers were recording. After editing the traces, we loaded the P190 files to observe survey geometry. We estimate our error for setting up the geometry to be ±25m.

II. For Statics correction:
We accounted for the delay in source firing by adding a constant 50ms static shifts to the data. This was recommended by the seismic acquisition team on board.

III. For Noise attenuation:
We have used swell noise attenuation, linear noise attenuation and wild noise attenuation to remove ocean swells, linear noise and high amplitude noise, respectively (Fig. 4). A high pass filter of 2Hz was first applied and these noise attenuation techniques were used for signals between the range of 0Hz to 25Hz.

IV. For De-ghosting:
We remove the signal from the source wavelet that was recorded by reflecting from the ocean surface. This step broadens the bandwidth and compensate for the signal in the ghost notches, which was around 125Hz.

V. For De-Bubbling:
We removed the signal from the source wavelet that was caused by air gun gas bubble oscillation (Fig. 5). The survey employs 2 air guns at the depth of 4m. A bubble pulse that directly follows the first break at 100ms can be observed for

each trace. We accomplished De-Bubbling by first calculating the source wavelet from stacking the far offset source signature. The far offset source signature was then edited to remove the gas bubble oscillation and by using a matching filter we were able to remove the bubble pulses.

VI. For Surface related multiple attenuation:
We first regularize the data and reconstructed the traces. Then using SRME modules, we were able to predict the multiples, we then subtract the predicted multiples from the source gathers.

VII. For Velocity analysis:
We preformed semblance analysis on the data and picked velocities every 300 cmp. Water velocity of 1500m/s were used above the seafloor.

VIII. For Stacking:
we applied NMO along with stretch mute and butterworth bandpass filtering ranges from 8 to 200Hz at 18 octaves.

IX. For Post-Stack Time Migration:
We converted RMS velocities to interval velocity and performed Finite difference migration in the X-T domain.

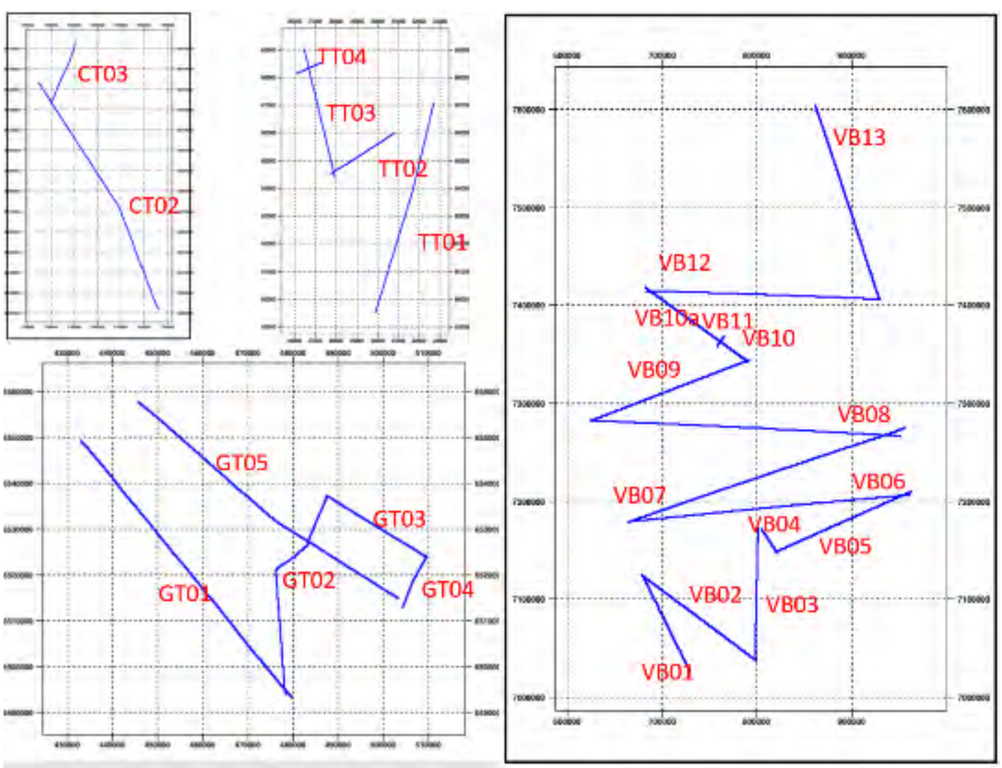

Fig 1. Seismic areas of interest of Tristan Track (TT), Center Tract (CT), Gough Tract (GT) and Valdivia Bank (VB). Note the geometry is set in UTM coordinates and the individual work areas are not in scale.

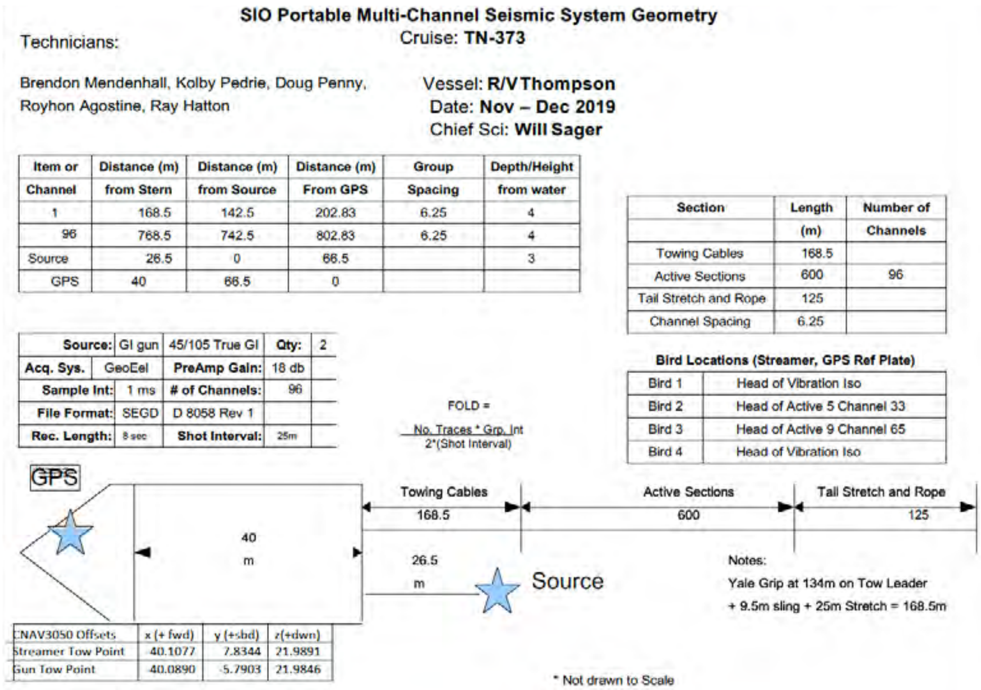

Fig 2. Seismic acquisition system geometry for TN-373.

Fig 3a. Processing flow for TN-373 data visualized. The flow was constructed in GeoEast.

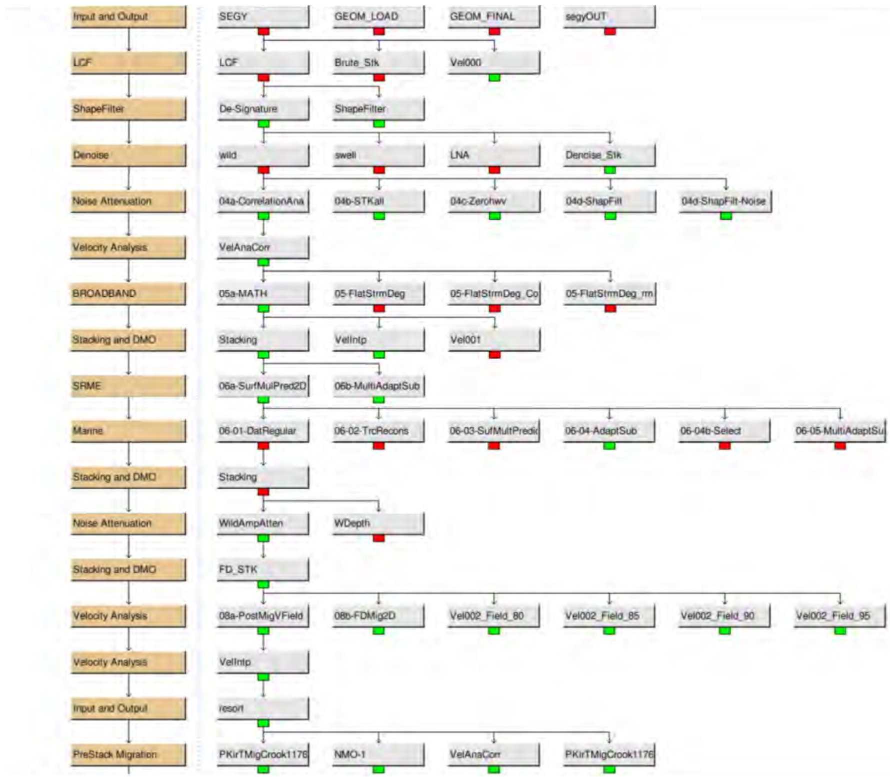

Fig 3b. Processing flow for TN-373 data in GeoEast workflow editor.

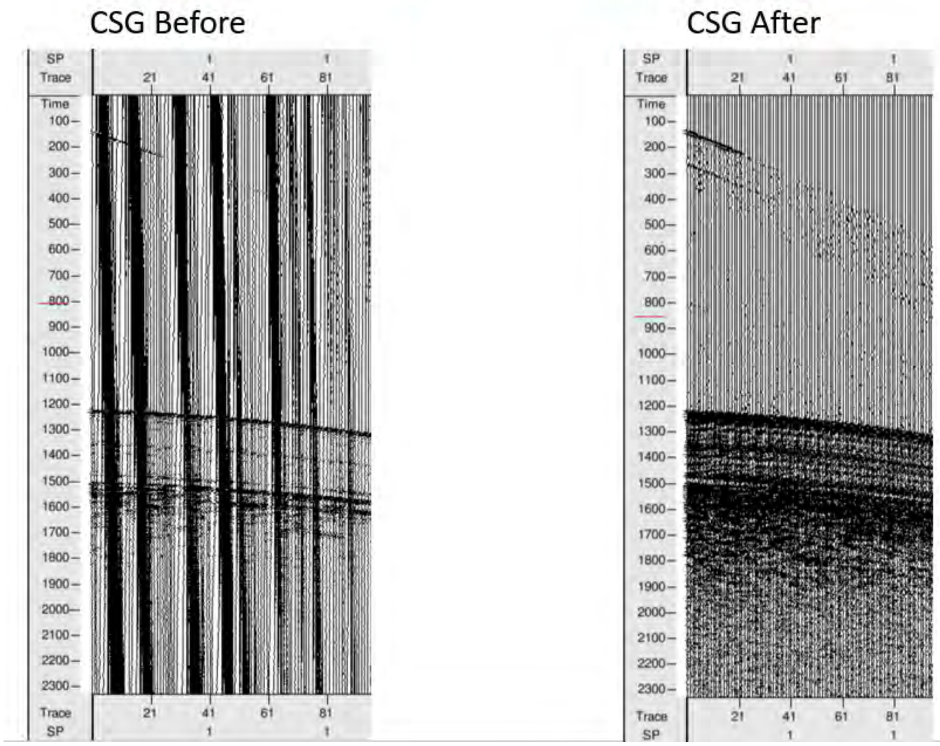

Fig 4. Noise attenuation results after swell noise, linear noise and wild noise attenuation. The common shot gathers before attenuation (Left) and the common shot gathers after attenuation (Right).

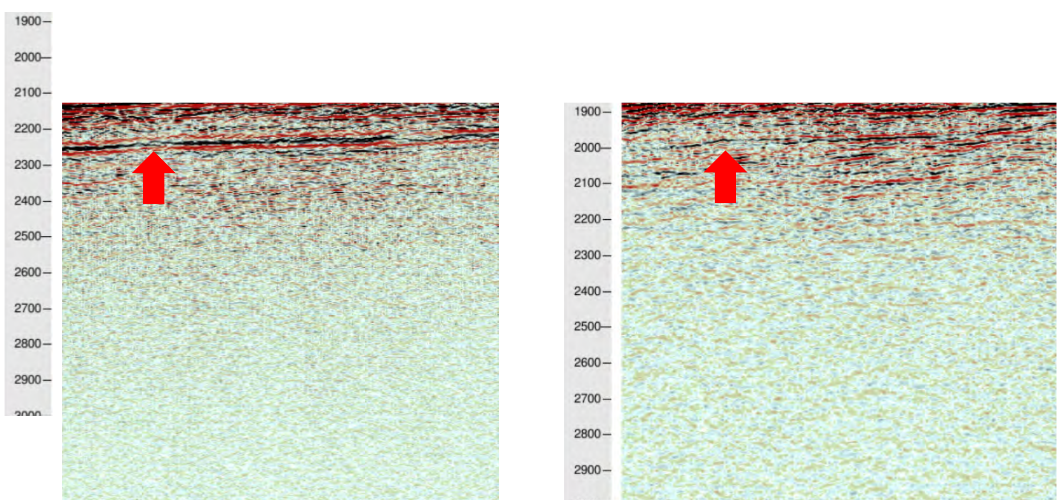

Fig 5. De-Bubbling after matching filter. The stack section before matching filter (Left) and the stack section after matching filter (Right).