Date Modified: February 10, 2022

Seismic processing routine for MGL1803 South Island Subduction Initiation Experiment (SISIE) multi-channel and ocean-bottom seismic data

Processing done by Dr. Brandon Shuck; bshuck@ldeo.columbia.edu

Please cite the following article when referring to the depth-migrated SISIE MCS data:
Shuck, B. D., Van Avendonk, H. J. A., Gulick, S. P. S., Gurnis, M., Sutherland, R., Stock, J., et al. (2021). Strike-slip enables subduction initiation beneath a failed rift: New seismic constraints from Puysegur Margin, New Zealand. Tectonics, 40, e2020TC006436. https://doi.org/10.1029/2020TC006436

South Island Subduction Initiation Experiment (SISIE) Data Acquisition

The South Island Subduction Initiation Experiment (SISIE) took place in February and March, 2018. Using the R/V *Marcus Langseth*, the shipboard party collected multichannel seismic (MCS), ocean-bottom seismometer (OBS), 2-6 kHz chirp, 12 kHz multi-beam bathymetry, gravity, and magnetometer data across the Puysegur margin. For seismic imaging, the acoustic source consisted of an array of 36 Bolt airguns, with a total source volume of ~6600 in^3, shot at intervals of 50 m for MCS and 150 m for OBS acquisition. A 12.6 km hydrophone streamer containing 1008 channels was used to collect an initial 717 km of MCS data (SISIE-1/MCS14, SISIE-2/MCS01, SISIE-3/MCS23AB, SISIE-4/T01, SISIE-5/MCS03A); however, severe weather of up to 7 meter swells forced the collection of the remaining 535 km to be with a 4.05 km streamer containing 324 channels (SISIE-6/MCS17BC and SISIE-8/MCS19A). In total, 1252 km of MCS data were acquired along seven 2D lines. Short-period four-component OBSs from the University of Texas Institute for Geophysics were used for a total of 43 deployments spaced approximately 15 km apart on two east-west oriented transects, SISIE-1 and SISIE-2. Seismic data were successfully recovered from 39 of these instruments. More details of the marine expedition can be found in the MGL1803 cruise report: MGL1803_DataReport_Ver1.1.pdf. Raw and processed geophysical data from cruise MGL1803 are available from the Marine Geoscience Data System http://www.marine-geo.org/tools/search/entry.php?id=MGL1803.

Ocean Bottom Seismometer Data Processing

Following recovery of the OBSs, a GPS clock synchronization corrected for clock drift, and seismic data were cut into 60-second-long records and then converted to SEG-Y format. The OBS data are generally high quality and show distinct seismic reflections and refractions from the crust and mantle on most instruments. To enhance the clarity of these arrivals, a bandpass filter of 6-14 Hz with 48 dB/octave drop-off was applied. A predictive deconvolution filter with a 160 ms gap was applied to help enhance the refracted arrivals. The hydrophone channel has higher signal/noise ratio than the vertical and horizontal geophone channels, and thus was used for a majority of the OBS data interpretation. To ensure accurate source-receiver offsets, the precise location of all instruments on the seafloor were determined using direct water-wave arrivals.

Multichannel Seismic Reflection Data Processing

Seismic processing of the SISIE MCS data utilized the Echos and Geodepth software packages from Emerson/Paradigm Geophysical. First, the SEGD traces were input into Echos and resampled to 4 ms. Noise reduction consisted of trace editing to remove noisy channels and bandpass filtering (7-85 Hz). Interpolation was applied first to shot gathers to fill in missing channels, and then in the receiver domain to recover signal from low-energy shots recorded during marine mammal shutdowns. We used a simplified marine 2-D geometry of 50 m shot spacing and 12.5 m receiver group spacing resulting in 6.25 m CMP spacing. Semblance-based velocity analysis was performed approximately every 250 CMPs (~1.5 km) or at a denser interval where complex structure was present. Multiple suppression comprised a combination of surface-related multiple elimination (SRME) in the shot domain followed by parabolic radon transforms in the CMP domain, and finally a dip filter to remove undercorrected multiple arrivals and out-of-plane energy. Velocity models for Kirchhoff pre-stack depth migration algorithms were derived from the RMS stacking velocities. For MCS lines coincident with OBS data, a merged velocity section with MCS-derived velocities for shallow sediments and OBS-derived velocities for crust and mantle structure produced the best images. Kirchoff pre-stack depth migrations were performed using an Eikonal travel-time fitting algorithm with a migration aperture of 1000, 2000, or 4000 CMPs. Larger aperture migrations produced better images of dipping primary energy (tilted strata, faults) but also resulting in severe smearing of residual multiples. On the other hand, smaller aperture migrations limited residual multiple smearing and improved imaging of shallow structure, but weakened the coherency of crustal reflectivity. Velocity models were iteratively updated until the final depth-migrated image gathers were flattened across the profiles. A constant velocity of 1.495 km/s was used for the water column above the picked seafloor reflection on a time migrated section. Outside muting removed stretched reflections at far offsets and inside muting removed residual multiple energy. The depth-migrated gathers were bandpass filtered, mixed with 3 adjacent traces, and then stacked. The result of our processing workflow yields pre-stack depth migrated (PSDM) sections across the Puysegur margin.

Seismic profile nomenclature and merging

- SISIE-1: MCS14, southern major dip line across the margin.
- SISIE-2: MCS01, northern major dip line across the margin.
- SISIE-3: MCS23AB, southern large strike line within Solander Basin. This profile was shot in two segments due to a marine mammal shutdown. Shots from the two segments, MCS23A and MCS23B, were merged and processed as a single profile, MCS23AB.
- SISIE-4: T01, transit line crossing Snares Zone.
- SISIE-5: MCS03A, dip line crossing the Snares Zone and Solander Basin. Three large marine mammal shutdowns made it challenge to process this profile.
- SISIE-6: MCS17BC, northern large strike line within Solander Basin. This profile was reshot in three segments due to marine mammal shutdowns and bad weather. MCS17A was not processed to depth migration because it was too short and could not be merged with the other segments. MCS17B and MCS17C are the two segments that were processed to depth-migrated images. These were processed as separate segments since the overlapping shots were not closely co-located in the cross-profile direction.
- SISIE-7: T03, short transit line in northern Solander Basin. This segment was not processed through depth-migration due to its short length.
- SISIE-8: MCS19A, dip line along northern Solander Basin.

Interpreted PSDM sections of SISIE-1, SISIE-2, SISIE-3, SISIE-6, and SISIE-8 are shown in the Shuck et al. (2021) *Tectonics* paper, as well as seismic tomography models from inversion of OBS data. Initial shipboard cruise images were published in Gurnis et al. (2018) and stratigraphic interpretations of these images are shown in Patel et al. (2020).