SCEC Final Technical Report

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SCEC Community Earth Models (CEMs)	*None*

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Marine geohazard assessment in the Outer California Borderland: fault network and mass wasting investigation
SCEC Final Technical Report

We completed high-resolution mapping of faults and submarine landslides in the Outer California Borderland (OCB), offshore from southern California. Offshore active fault systems and submarine landslides pose a major hazard to infrastructure and high density coastal areas, while being little researched and difficult to study (Carter et al. 2014; Forsberg et al. 2016; Pope et al. 2017). Southern California's coastal communities may be impacted by offshore faults through earthquakes and tsunami waves they may generate. Furthermore, submarine slumps and debris slides can also produce tsunamis with equally devasting long-range impacts. The California Continental Borderland (CCB), which constitutes the westernmost portion of the Pacific North American plate boundary across southern California, is an ideal location to research the complex relationship between active fault systems and seafloor mass wasting. We conducted comprehensive geophysical mapping and characterization of faults and mass transport deposits (MTDs) in the OCB to assess the relationship between mass wasting and seismicity. We combined existing data from Cortes Basin and Velero Basin, with data from two additional research cruises covering San Nicolas Basin, Tanner Basin, San Clemente Basin, and the Ferrelo fault zone. Our results include detailed fault mapping across several basins with newly mapped and recently active faults, and mapping and characterization of MTDs in several basins. The data from the most recent research cruise (February 2026) are still being analyzed but will eventually contribute to a comprehensive dataset for the region. Results from Cortes Basin were published in JGR Solid Earth (Fabbrizzi et al., 2026) and results from Velero Basin are in press with Marine Geology journal (Fabbrizzi and Maloney, 2026). The data also supported an MS student thesis, two undergraduate class research projects, and an undergraduate student thesis. The work was organized into four primary tasks, which are detailed in the sections below.

<u>*Task 1.*</u> The goal of this task was to collect high-resolution geophysical data from OCB basins with the objective to identify faulting and mass transport deposits. Two possible survey areas were identified as options for a planned research cruise (SR2502):

1. Survey Site 1: This survey was designed to image the Ferrelo fault zone from its southern extent up to the ODP Leg 167 Core 1014 for stratigraphic and age correlation. Additionally, the survey would connect the dataset collected within the Cortes and Velero basins (SR2303).

2. Survey Site 2: This survey would map the San Nicholas Basin with full coverage of multibeam bathymetry and sub-bottom profiles. We would investigate the East Santa Cruz Basin fault zone and image the San Nicholas slide, which is a large landslide visible at the seafloor, with new targeted high-resolution geophysics, aimed to provide an accurate volume estimate and approximate age. The survey would cross the Leg 167 Core 1013 for age correlation.

During the award period, we were awarded a second cruise from the UC Ship Funds program and were able to map both survey sites (SR2502 - Survey Site 2; and SR2602 - Survey Site 1) (**Figure 1**). Both cruises were aboard the *R/V Sally Ride,* which is fitted with a hull-mounted Kongsberg EM124 for multibeam bathymetry and a Kongsberg SBP29 for sub-bottom profiles (2-9 kHz Chirp pulse). In total we collected 3366 km of sub-bottom survey and 3847 square km of multibeam bathymetry data. We also collected 6 gravity cores in San Nicolas Basin, 2 in Cortes Basin, and 1 in San Clemente Basin (**Figure 1**). Postdoctoral researcher Andrea Fabbrizzi served as the chief scientist for the research cruises with

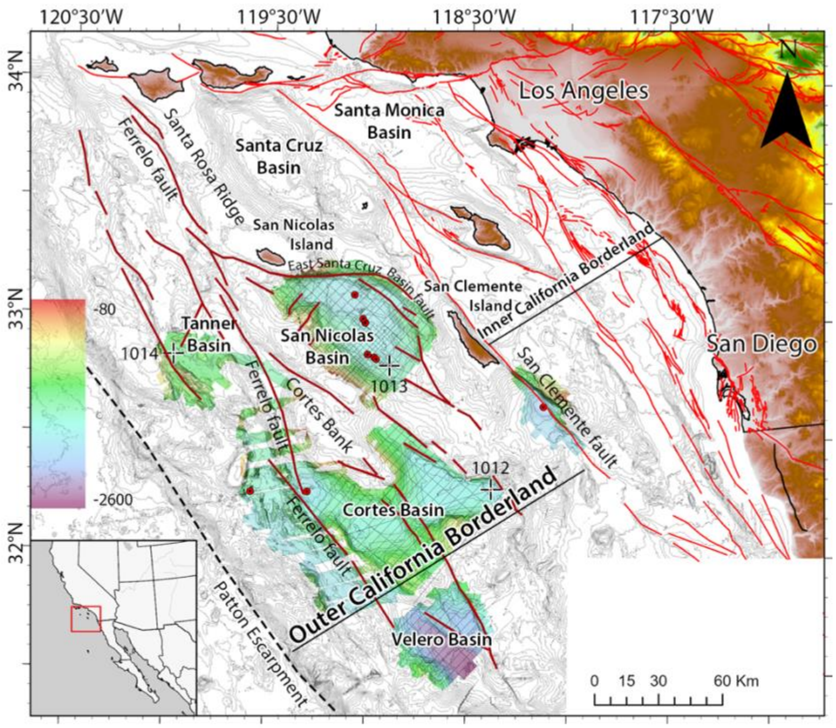

Figure 1. Regional bathymetric map of the California Continental Borderland (CCB), showing the Inner California Borderland (ICB) and Outer California Borderland (OCB). Colored areas show bathymetric coverage collected during our R/V *Sally Ride* cruises: SR2303 (Oller, 2023, dataset), SR2502 (Fabbrizzi, 2025, dataset), and SR2602 (Fabbrizzi, 2026, dataset; surveyed February 2026). Red dots indicate gravity core locations obtained during SR2502 and SR2602. Black crosses mark Ocean Drilling Program (ODP) sites. Thin black lines are ship tracklines from our surveys. Light red lines show fault traces from USGS (2023) and Fletcher et al. (2014), which are included in the Community Fault Model (CFM). Dark red lines show OCB faults (Legg et al., 2015) not currently included in the CFM. The base map is Environmental Systems Research Institute (ESRI) bathymetry. Inset: Regional map showing the tectonic interactions between the Pacific and North American plates.

PI Jillian Maloney serving as the faculty mentor. The science crews also included 15 undergraduate, 4 MS, and 2 PhD students from SDSU between the two cruises.

Task 2. The goal of this task was to process and analyze the shipboard multibeam bathymetric data and sub-bottom data, including mapping observed faults and MTDs, calculating MTD volumes, creating an age model for sub-bottom stratigraphy, and producing quality images of the data. Multibeam data were processed using Qimera software, which generated seafloor digital elevation models at 20 m grid resolution (**Figure 1**). Sub-bottom profiles were imported to IHS Kingdom suite for seismic processing and interpretation. Most of the processing was completed aboard the research vessel during cruises SR2502 and SR2602 by student cruise participants who learned the workflow and conducted various processing and interpretation steps at work stations set up in the computer lab. Subsequent processing and interpretation were completed by the PI, post-doc, and graduate students. Our previously collected bathymetry and CHIRP sub-bottom data from Cortes**,** Velero, and San Nicolas basins (**Figures 1** and **2**) revealed previously unknown MTDs in the seafloor, repeated MTDs below the seafloor, and linkages between faulting and MTDs in the OCB. Results are summarized for each of three primary basins below with an overview of the datasets shown in **Figure 2**.

Cortes Basin
In Cortes Basin (**Figure 1**), bathymetric data (**Figure 2**a-b) revealed previously unmapped fault-related seafloor deformation and slide scarps (**Figure 2**b), some of which exhibit evidence for Holocene activity, and CHIRP imaging resolved multiple stacked MTDs (**Figure 2**c) documenting repeated slope-failure events over the past ~750 kyr (Fabbrizzi et al., 2026). Additionally, several MTD intervals coincide with offset reflections and fault growth, supporting an interpretation of earthquake-triggered mass wasting. However, clustering of MTDs at sea-level extremes suggests

a secondary glacio-eustatic influence on slope stability. The association of the Cortes Basin mass wasting history with major strike-slip faults, including the Ferrelo fault, suggests that slope-failure events may be linked to contemporaneous processes in adjacent basins, such as the San Nicolas and Velero basins. This regional connectivity underscores their potential tsunamigenic significance and demonstrates the feasibility of using MTDs as proxies to constrain earthquake rupture scenarios and fault connectivity. These results are published in Fabbrizzi et al., 2026).

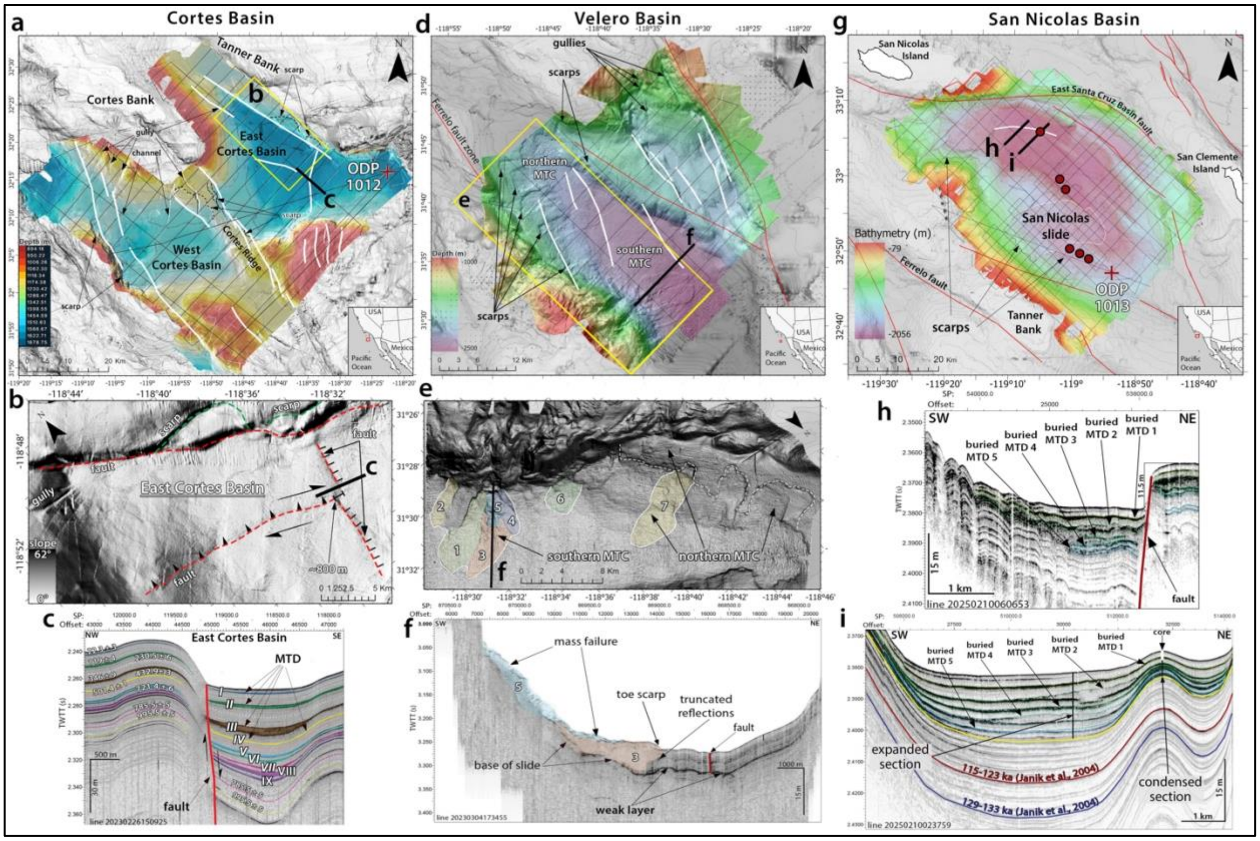

Figure 2. High-resolution geophysical data synthesis from our R/V Sally Ride cruises SR2303, SR2502, and SR2602, compiled to demonstrate the exceptional quality and coverage of the collected datasets, and illustrate some of the significant findings. The figure highlights bathymetry and sub-bottom profiler data, showing the ability to resolve fault offsets, multiple types of MTDs, and the relationships between faulting and MTDs. (a, d, g) Bathymetry of Cortes, Velero, and San Nicolas Basins, respectively with survey lines (black), previously mapped faults (red), newly mapped faults (white), and gravity cores (red dots) (b) Slope gradient map. Slide scarps (green), faults (red) with black arrows to show kinematic interpretation. (c) CHIRP sub-bottom showing nine MTDs (I–IX). (e) Slope map highlighting a mass transport complex (MTC) and five MTD lobes. (f) CHIRP sub-bottom profile showing MTD 3 and 5 (h–i) CHIRP sub-bottom profiles showing depositional relationship between faults (red) and buried MTDs (1–5). Red and blue horizons are dated reflections from ODP Site 1013. See regional map in Figure 1 for location.

Velero Basin

In Velero Basin (**Figures 1** and **2**), two morphologically distinct mass transport complexes (MTCs) were identified (**Figure 2**d-e): a southern MTC characterized by five, shallow-rooted debris lobes and rockfalls (**Figure 2**e-f; MTDs 1–5), and a northern MTC indicating multi-phase, basinward-progressive slope collapse and two distinct MTDs at the seafloor (**Figure 2**e; MTDs 6 and 7). The stratigraphic record includes deeply buried landslides, such as a >200 m-thick Late Miocene–Pliocene slide (>3.7 Ma), an early Pleistocene MTD (~1.2 Ma), and several recent deposits up to 60 m thick. CHIRP profiles reveal that MTDs preferentially infill fault-generated accommodation, while a regionally mapped turbidite reflection may have acted as a basal weak layer facilitating slope failure (**Figure 2**f). Additionally, we identified an MTD in Velero basin that appears synchronous with an MTD in the Cortes basin, dated ~721.4 ± 6 ka, indicating a regionally extensive trigger, such as a large magnitude earthquake. These observations demonstrate that local geology, stratigraphy, and fault activity jointly control slope instability in the OCB, and are published in Fabbrizzi and Maloney (2026).

San Nicolas Basin
In San Nicolas basin, multibeam bathymetry and CHIRP sub-bottom profiles reveal at least five minor, repeated MTDs (**Figure 2**h-i) and one major near-surface MTD, the San Nicolas Slide (**Figure 2**g), interbedded with hemipelagic sediments. These deposits record recurrent slope instability since the Late Pleistocene and are interpreted as primarily earthquake-triggered, based on their spatial association with nearby faults (**Figure 2**h). Improved age control and sedimentological and physical-property analyses of core material is planned for correlation of dated events with adjacent basins. This correlation will strengthen regional reconstructions of seismic history and improve assessment of geohazard potential. Fault mapping in San Nicolas basin also identified five new faults, with some showing recent activity through seafloor offset, while others appear as folds and ridges on the seafloor. Hazards associated with these active quaternary faults include 7+ magnitude earthquake potential and tsunamigenic risk based on observed vertical offset (Sigworth, 2026).

Task 3. The goal of this task was to disseminate the research findings. Postdoctoral scholar, Andrea Fabbrizzi, presented a poster at the SCEC 2025 annual meeting (Meeting #) on results from the San Nicolas Basin. Results from Cortes Basin were published in Fabbrizzi et al. (2026) results from Velero Basin were published in Fabbrizzi and Maloney (2026), and Dr. Fabbrizzi is currently preparing a manuscript on the San Nicolas dataset, with expected submission in fall 2026. Additionally, the San Nicolas Basin dataset was the focus of MS student, Alicia Sigworth's, thesis, which she defended in May 2026 and we expect to submit her manuscript to a peer reviewed journal in fall 2026. Finally, the students aboard the SR2502 cruise used the datasets for class projects and undergraduate theses. The cruise overlapped with PI Maloney's undergraduate sedimentology and stratigraphy class and two student participants continued to work on the geophysical data and presented posters for their class research projects. The sediment cores collected on SR2502 are also the basis for Glenn Jenkin's undergraduate thesis (Jenkins, 2026).

Task 4 is the composition of the final report and publication of the data, which was completed by PI Maloney and Dr. Fabbrizzi.

Conclusions

Intellectual Merit: This research identified repeated MTDs of varying morphology in the OCB, suggesting that low slip-rate offshore faults along California's transform plate boundary are capable of trigging submarine landslides. As such, the repeated MTDs may be useful for reconstructing the paleoseismic history of fault zones in a region where other methods are ineffective.

Broader Impacts: This project supported teaching, training, and learning at SDSU through student participation in the research process. This includes the participation of 15 undergraduate, 4 MS, and 2 PhD students as science crew between the two cruises, an MS Thesis, and a BS Thesis. Additionally, the identification of recently active faults and the potential for earthquake triggered submarine landslides has implications for geohazard assessment in southern California.

Project Participants: Andrea Fabbrizzi, postdoctoral researcher, contributed to data collection, processing, and interpretation and published two peer-reviewed papers; Alicia Sigworth, MS student, contributed to data collection, processing, and interpretation and completed an MS Thesis; Glenn Jenkins, BS student, contributed to data collection, processing, and interpretation and completed a BS Thesis; UC Ship Funds awarded ship time aboard the R/V Sally Ride, the R/V Sally Ride crew operated the ship to achieve our scientific objectives; BS, MS, and PhD students from SDSU contributed to data collection and processing aboard the research cruises.

References

Carter, J. A., Dolan, J. F., Niemi, N. A., and Bennett, R. A. (2014). Integration of offshore faults into seismic hazard frameworks. Bulletin of the Seismological Society of America, 104(5), 2551–2570. https://doi.org/10.1785/0120130182

Fabbrizzi, A., Maloney, J. M., Derosier, B., & Keith, B. 2026. Interplay between tectonics and submarine mass transport deposits in Cortes Basin: New high-resolution geophysics in the Outer California Borderland. Journal of Geophysical Research: Solid Earth, 131: e2025JB032100. https://doi.org/10.1029/2025JB032100

Fabbrizzi, A. and Maloney, J.M**.**, Stratigraphic and structural controls on submarine mass wasting in Velero Basin, Outer California Borderland, in press, Marine Geology (May 2026). https://doi.org/10.1016/j.margeo.2026.107822

Forsberg, R., Olesen, A. V., and Ebbing, J. (2016). Fault modeling and structural interpretation from integrated gravity and topography data. Geophysical Journal International, 204(2), 1125–1138. https://doi.org/10.1093/gji/ggv497

Jenkin, G. (2026) Submarine faulting and mass transport deposits in the San Nicolas Basin, CA, BS Thesis, Geological Sciences, San Diego State University, May 2026.

Pope, E. L., Talling, P. J., & Carter, L. (2017). Which earthquakes trigger damaging submarine mass movements: Insights from a global record of submarine cable breaks? *Marine Geology*, *384*, 131–146. https://doi.org/10.1016/j.margeo.2016.01.009

Sigworth, A. (2026) Character and recency of faulting in a transpressional basin, San Nicolas Basin, Outer California Borderland, USA, MS Thesis, Geological Sciences, San Diego State University, May 2026.