Latin American Journal of Aquatic Research, 50(5): 767-774, 2022
DOI: 10.3856/vol50-issue5-fulltext-2870

Short Communication

Geomorphology and sedimentary features of the Simpson Submarine Canyon (44ºS), southern Chilean margin

Cristián Rodrigo[1], Matías Fernández[1], Ximena Contardo[1] & Rodrigo Fernández[2]
[1]Geología, Facultad de Ingeniería, Universidad Andrés Bello, Santiago, Chile
[2]Departamento de Geología, Universidad de Chile, Santiago, Chile
Corresponding author: Cristián Rodrigo (cristian.rodrigo@unab.cl)

ABSTRACT. This note analyzes for the first time the geomorphology and sedimentary features of the Simpson Submarine Canyon (SSC), located between Chiloé Island and the Taitao Peninsula. For that purpose, multibeam bathymetric data were obtained in 2018. The SSC has a unique orientation compared to most canyons on the Chilean margin. Slope escarpments, topographic irregularities, and sinuosity of the canyon could be associated with regional tectonics. Sediment transport and deposition along the axis define the transversal morphology. On the canyon walls, erosion and transport processes dominate, evidenced by gullies, channels, and mass removals, which leave debris on the axis. We report a large landslide from a canyon wall, which could be due to a high-energy event such as an earthquake; and the generation of a large sediment wave field outside the canyon mouth, indicating a great activity by sedimentary processes. All the above could indicate that the canyon is continuously evolving.

Keywords: bathymetry; submarine geomorphology; submarine canyon; sedimentary process; turbidity current; sediment wave; Chilean continental margin

Submarine canyons are narrow valleys that cut the continental shelf and slope (Rodrigo 2010), located on both passive and active continental margins (Harris & Whiteway 2011). A typical canyon has a transverse "V" shape and steep walls, constituting an important conduit for transporting terrigenous sediments from the coast to greater depths (Rodrigo 2010). In dimensions and shape, submarine canyons are comparable to large continental analogs. However, their origin and evolution differ from the latter (Shepard 1981). The origin of submarine canyons is attributed to various causes, but the main one is slope erosion due to massive removal events (landslides and debris flows) and turbidity currents (Shepard 1981). Recently, interest in the exploration and study of submarine canyons has increased due to the need to install submarine cables and pipelines. Also relevant is the study of the deposits created in the mouth because they sometimes form a sedimentary fan that can accumulate minerals of economic importance (Clark et al. 1992, Walker 1992). In addition, it is important to analyze the impact of its headwaters on the coast; and the impact on oceanographic processes and ecosystems (e.g. Piper 2005, Fernández-Arcaya et al. 2017) as the main transport channel for nutrients, organic carbon, garbage, and pollutants (Shepard 1981, Micallef et al. 2014). The ability of the canyons' processes to generate changes in the seafloor morphology and suspended sediments represent a geological hazard since they could affect the benthic communities and alter the properties of the water column.

Furthermore, the generation of tsunami waves by local landslides or the change of distant tsunami waves towards the adjacent coast would affect coastal localities in a way that departs from model predictions (Matsuyama et al. 1999, Ioualalen et al. 2007). The pre-

Corresponding editor: Gonzalo Yáñez

sence of canyons can also be a beneficial factor for marine productivity due to the generation of upwellings and the rise of nutrients that favor the development of the trophic chain (Sobarzo et al. 2001). The internal dynamics of the canyons constrain the local environment to create a unique ecosystem in which organisms could constitute a source of genetic resources and a contribution of nutrients to abyssal depths.

Identifying submarine landslides can contribute to understanding mechanisms that could be useful for assessing geological hazards. During offshore geological investigations of the Chile-Peru Trench (Thornburg & Kulm 1987, Thornburg et al. 1990), it was possible to identify and map for the first time submarine valleys, canyons, and sediment fans with a satisfactory resolution at several locations of the central and southern Chilean continental margin. Rodrigo (2010) identified 18 important submarine canyons in that region, which generally are associated with river mouths. The most studied being the San Antonio Canyon (Hagen et al. 1996, Laursen & Normark 2002) and the Biobío Canyon (Pineda et al. 1999, Bernhardt et al. 2015). These studies show that these canyons are active, and their heads are very close to the coast. However, within the southern Chilean margin, namely between Chiloé Island and Taitao Peninsula (Fig. 1), there are still poorly surveyed submarine canyons, and, possibly, there are some undiscovered minor ones. This region's lack of high-resolution bathymetry and geological sampling has not allowed the morphological and geological characterization of these canyons or other similar structures, such as valleys or major submarine channels. Specifically, four important submarine canyons have been identified using the available bathymetry (e.g. GEBCO 2014), from north to south: Chacao, Cucao, Simpson, and Darwin (Fig. 1). Among them, only the Chacao Canyon has been well mapped with high-resolution multibeam bathymetry (Rodrigo 2010). Considering that in this area, the largest earthquake recorded in history (Mw 9.5) has occurred (Ruiz & Madariaga 2018), the arrangement and geomorphology of the canyons can give clues about regional tectonic processes (e.g. Micallef et al. 2014). In this way, this note focuses on the geomorphological characterization of the Simpson Submarine Canyon (SSC) (~44°S), located between the Guafo and Guamblin islands (Fig. 1), as a first step to help to elucidate the geological and tectonic processes of the region.

Multibeam bathymetric data were acquired during the CIMAR-F 24 cruise to study the submarine geomorphology of the SSC between September 24 and October 18, 2018, aboard the AGS-61 "Cabo de Hornos" vessel. The data were obtained using a Kongsberg EM122 multibeam echosounder (12 kHz). The bathymetric data processing included manually removing spikes and bathymetric artifacts and checking the navigation and positioning using the MB-System

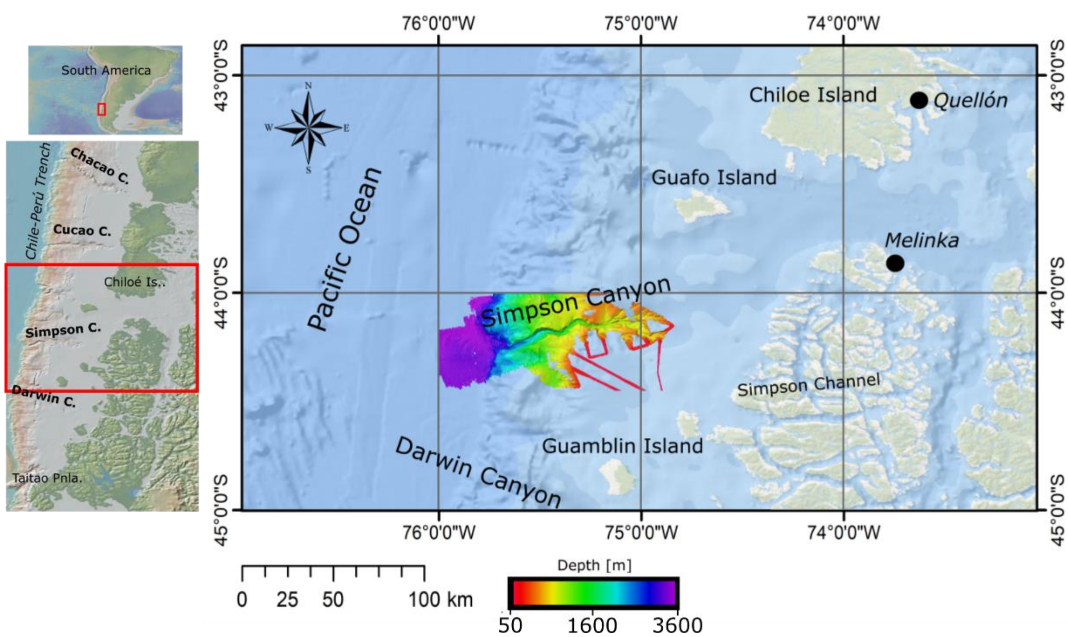

Figure 1. The study area and the Simpson Submarine Canyon bathymetry at the southern Chilean margin (GeoMapApp map, Ryan et al. 2009).

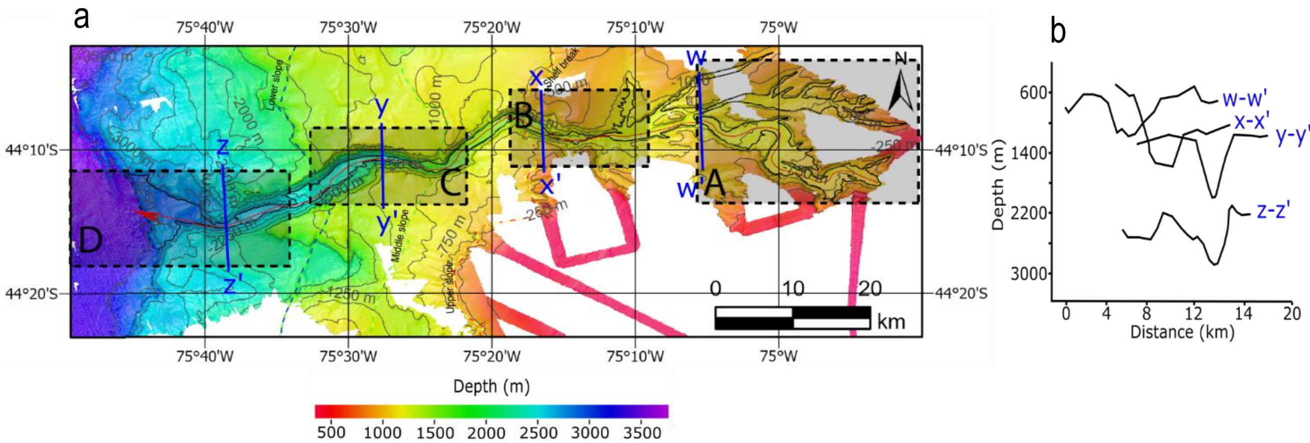

Figure 2. Bathymetry and geomorphology of the Simpson Submarine Canyon. a) With red line and arrow is indicated the general sedimentary flow, b) bathymetric profiles transverse the canyon axis are shown (from w-w' to z-z'). Geomorphologic descriptions for canyon segments: A (Fig. 4), B (Fig. 5), C (Fig. 6), and D (Fig. 7).

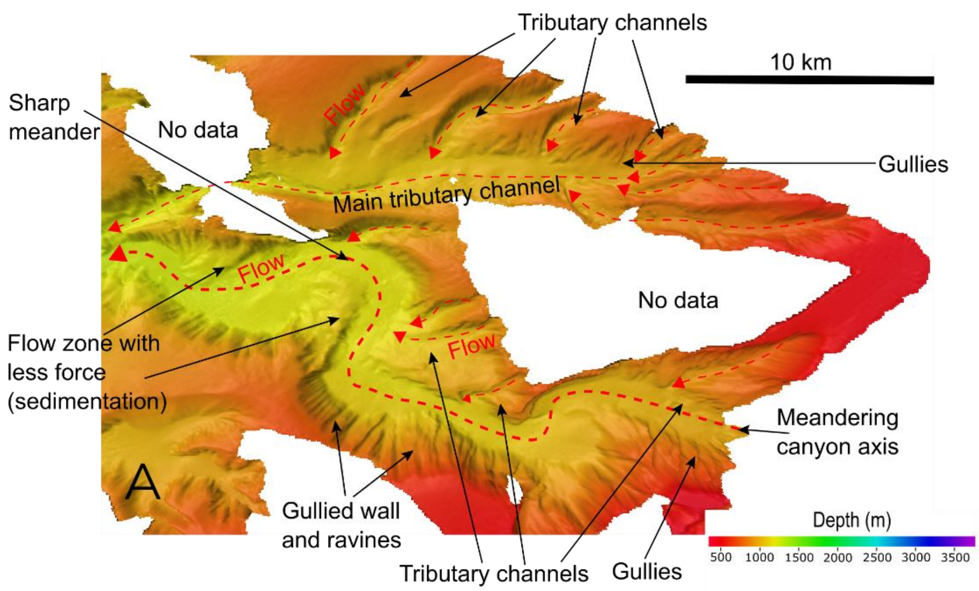

Figure 3. Head segment (A in Fig. 2). Bathymetry and geomorphology of the Simpson Submarine Canyon. Tributaries to the main canyon axis and several submarine landforms associated with erosion and transport, such as gullies and channels. Red segmented lines and arrows indicate the sedimentary flow.

software (Cares & Chayes 2017). A digital grid of the bathymetric model was produced with a resolution of ~30 m and was created using a Gaussian weighted average algorithm. The maps and 3D models were visualized with the QPS Fledermaus software.

The results showed that the SSC cuts the continental shelf starting at 37.8 km from the coast at a water depth of ~720 m according to the survey (Fig. 1). The main channel has a maximum length of 86 km until it reaches the trench, at depths close to 3300 m. It has a well-defined NNW-SSE orientation up to ~25 km of the length of the channel, where it changes its course to a ~NE-SW direction (Fig. 2). It presents a sinuosity coefficient (Ks) of 1.21, similar to the other submarine canyons mentioned earlier (Rodrigo 2010). The geomorphological results can be grouped according to their segments from east to west as follows (Fig. 2).

Head and upper segment

The canyon head area comprises several tributary channels north of the canyon axis. The main tributary channel is between 44°6'46.36''S and 74°53'21.84''W, with a Ks of 1.10 and an average slope of 2.15°, which receives the flows of the northern tributaries (Fig. 3).

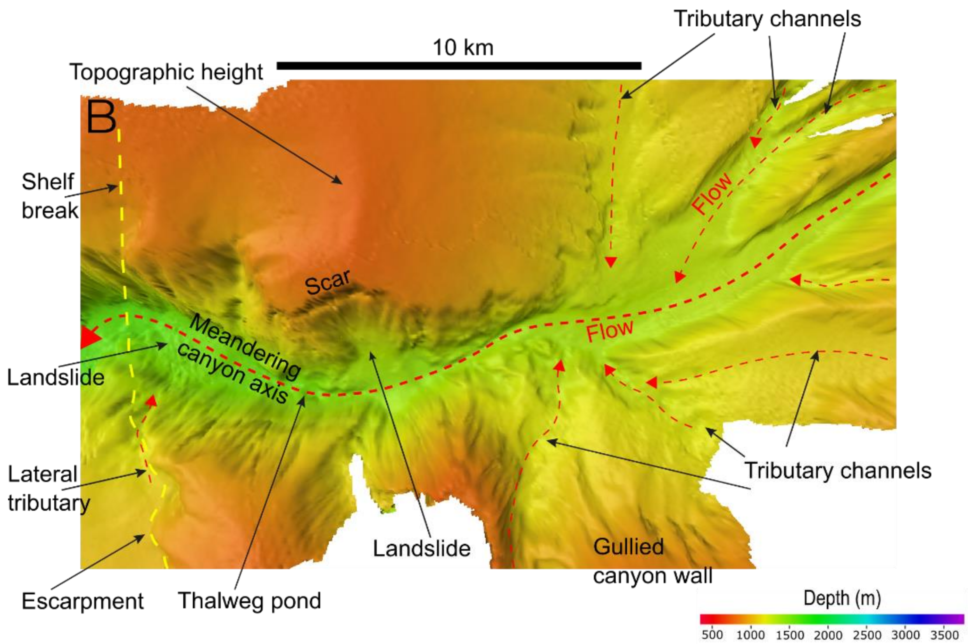

Figure 4. Upper segment (B in Fig. 2). Bathymetry and geomorphology of the Simpson Submarine Canyon. Red segmented lines and arrows indicate the sedimentary flow. The convergence of tributaries in the main axis and landslides stands out.

The canyon axis on the shelf is meandering. Some mounds border the channel, having a U-shape with a maximum width of ~3.5 km at its base (Fig. 2, profile w-w'). The main axis has a Ks of 1.27 and an average slope of 1.14°. Also, in this segment, gullies and ravines can be identified. Close to the center of the segment, various tributary channels converge in a common confluence area towards a narrower canyon axis (Fig. 4), bounded by markedly higher canyon flanks. Many gullies are observed in the upper part of these flanks, where, in addition, landslides of their walls are identified, leaving debris on the canyon axis (Fig. 4).

Middle segment

In this sector, the canyon has a single main axis. It runs 23.3 km along the upper and middle slopes (Figs. 1, 5). The canyon cuts the upper slope with an SW bearing, its cross-sectional profile U-shaped near the upper segment. Its course then changes to the NW, and at the limit between the middle and the lower slope, it changes its course back to SW. Here, its main channel becomes narrower and acquires a V-shaped section (Fig. 2, profile y-y'), with a maximum width of ~4 km. Along this segment, the canyon has a Ks of 1.18 with an average slope of 1.79°. In the middle segment, it is also possible to identify a series of ridges, interpreted as escarpments, outside the canyon on the continental slope (Laursen & Normark 2002, Mountjoy et al. 2009). Especially on the north side, creating terraces between them (Fig. 5). Apparently, these escarpments could constitute a barrier to sedimentary flow on the slope and allow a flow towards the canyon's interior on its walls using gullies. The escarpments generate a step-like morphology on the continental slope. A larger landslide was observed on the southern flank of the canyon, which left debris on the canyon seafloor (Fig. 5).

Mouth and trench segment

The canyon mouth segment is on the lower slope (Figs. 1, 6). This segment begins with the main channel with a V-shaped profile (Fig. 2, profile z-z'). As it approaches the mouth, this shape becomes wider, which begins with a 1 km width of the main channel seafloor, then decreases to 0.5 km, and finally increases to 1.5 km at the mouth. In this segment, the canyon shows steep and rugged walls reaching 700 to 1000 m. There are parallel escarpments-oriented N-S on the canyon flanks that divide intra-slope basins with areas of 18.2 and 7 km^2 on the southern flank. Approaching the trench, the mouth of the canyon adopts a complex morphology from the escarpment wall to the west (Fig. 6), which covers a surface of ~34 km^2. In this area, highly developed ravines can be seen where lateral tributaries take their course to the mouth. A barrier rising over 50 m is found on the seafloor of this area

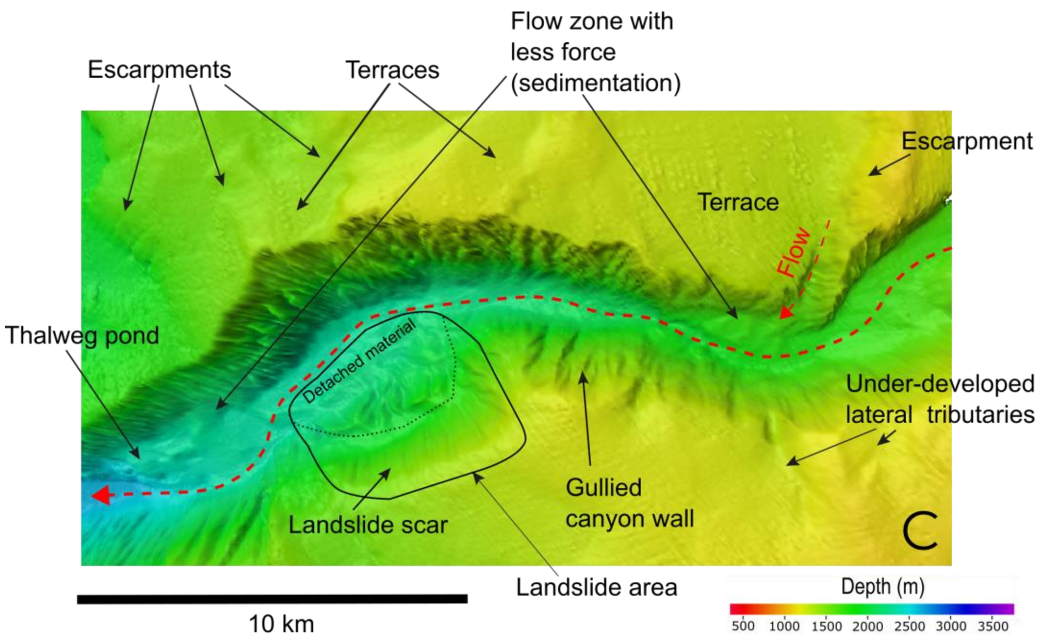

Figure 5. Middle segment (C in Fig. 2). Bathymetry and geomorphology of the Simpson Submarine Canyon. Red segmented lines and arrows indicate the sedimentary flow. Large inner landslide (continuous line), detached material area (dotted line), terraces, and escarpment are shown.

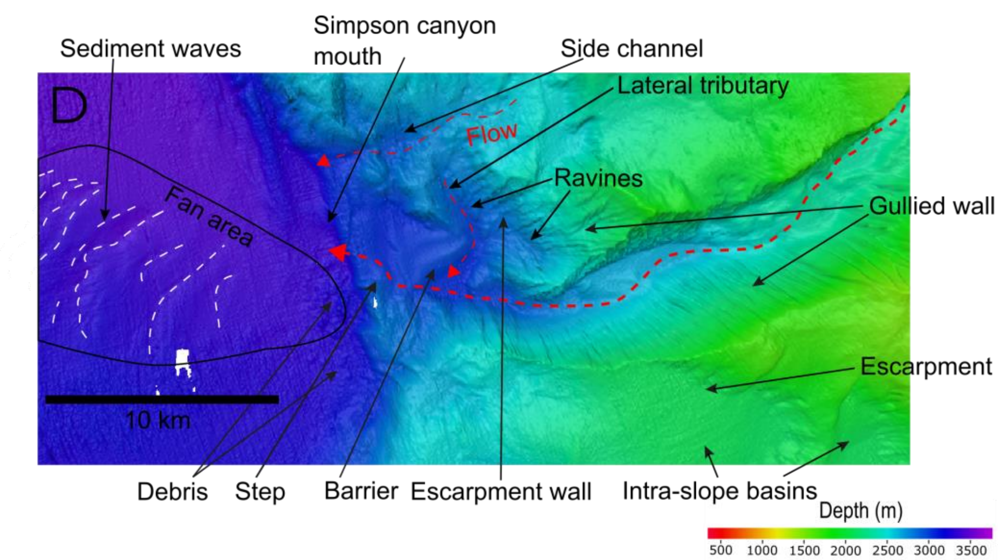

Figure 6. Mouth and trench segment (D in Fig. 2). Bathymetry and geomorphology of the Simpson Submarine Canyon. The topographic barriers at the canyon mouth and the sediment wave field on the fan area are shown. Red segmented lines and arrows indicate the sedimentary flow.

and is perpendicular to the sediment flow that comes from the main channel. Then, the mouth seafloor shows a flat shape for about 2.3 km until it reaches a significant morphological step ~200 m high on the transition to the trench, which is also a barrier. To the west of the lower slope limit (~5 km of distance), there is a large abyssal fan morphology with a surface larger than 100 km^2. In this area, the seafloor morphology displays laterally elongated mounds, interpreted as sediment waves (sand and mud, *unpubl. data* from a sediment core) with NE-SW course widths ranging from 1.5 to 3 km and lengths larger than 6.6 km (Fig. 6).

It was observed that the general heading of the Simpson canyon is WSW-ENE, which is not typical for the canyons of the Chilean continental margin that tend to have an NW-SE heading (Rodrigo 2010). On the

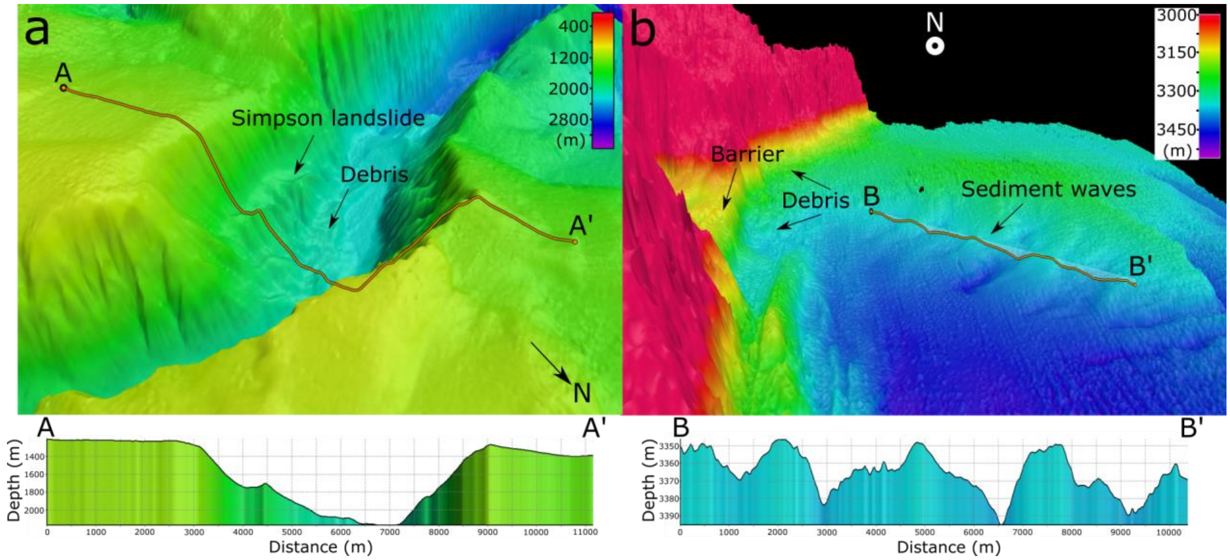

Figure 7. Details of the bathymetry and geomorphology for Figures 5-6. a) The Simpson landslide and bathymetric profile A-A' at the canyon middle segment, b) sediment waves and bathymetric profile B-B' at the mouth-trench area.

other hand, the presence of escarpments on the lower slope could be associated with the presence of thrust faults typical of an accretionary prism (Bangs et al. 2020), which could also reorganize or modify the general arrangement of the canyon (e.g. Micallef et al. 2014), in addition to forming intra-slope basins. These claims should be confirmed with local seismic studies.

The variability of sedimentary processes in the canyon axis and the adjacent areas are evident through characteristic bedforms. On the continental shelf near the coast, the gullies and submarine channels that flow into the canyon would transport sediments by gravity flows (e.g. Yu & Chuang 2002). Unlike the submarine canyons of the central Chilean margin (e.g. Laursen & Normark 2002, Rodrigo 2010), large fluvial systems are absent at the head of this canyon. In contrast, Simpson Canyon is fed by channels from the fjord area, so a smaller contribution of terrigenous sediments is expected, given the distance from the headwaters to the coast. Nevertheless, the U-shape of the canyon reflects important sediment deposition, possibly coming from bottom currents that go through the platform, and the tributaries and canyon act as a trap for these (Xu et al. 2008).

On the other hand, mass wasting from the canyon flanks is important for the final deposition on the axis (Masson et al. 2011). The large landslide in the canyon's central sector left a significant scar on the flank and debris in its axis, which has not been completely removed by the action of the currents in the axis. This landslide (called here "Simpson," Fig. 7a) presents a total area of ~14 km^2, while the loose material presents an area of ~9 km^2 (Fig. 6). Whether the landslide was produced by the 1960 or another earthquake is uncertain. However, it demonstrates the vulnerability of the canyon structure to energetic events, which could affect ecosystems and generate secondary tsunamis (Lee et al. 2003, Völker et al. 2011).

Sediment wave fields in several submarine canyons and channels in their thalweg have been found (e.g. Chen et al. 2017, Li et al. 2020). In our case, it is a large wave field of sediment on the outer canyon area (not on the axis) (Fig. 7b). Possibly related to active turbidity current flows (Muñoz et al. 2017). To our knowledge, this kind of sediment wave field has been reported for the Chilean margin for the first time. Seismic events could also contribute to the triggering of turbidity currents (Gavey et al. 2017). According to Mountjoy et al. (2018), the dominant sediment transport process in an active continental margin is triggered by earthquakes that activate the canyon flushing instead of other possible sedimentary processes. Considering that the largest recorded earthquake has occurred in this area, its role in the process of creating the sediment wave field, in addition to the landslides observed, cannot be ruled out. All the above indicate that the canyon continually evolves and could induce geological hazards.

ACKNOWLEDGMENTS

This study was funded by the C24F18-01 CIMAR-F 24 Program of the Comité Oceanográfico Nacional

(CONA) and the Hydrographic and Oceanographic Service of the Chilean Navy (SHOA by its Spanish acronym). We thank the captain and crew of the AGS-61 "Cabo de Hornos" vessel of the Chilean Navy and the group of researchers on board from the University of Chile. Special thanks to J.J. Fierro and P. Alvarez from CONA.

REFERENCES

Bangs, N.L., Morgan, J.K., Tréhu, A.M., Contreras-Reyes, E., Arnulf, A.F., Han, S., et al. 2020. Basal accretion along the south central Chilean margin and its relationship to great earthquakes. Journal of Geophysical Research: Solid Earth, 125: e2020JB019861.

Bernhardt, A., Melnick, D., Jara-Muñoz, J., Argandoña, B., González, J. & Strecker, M.R. 2015. Controls on submarine canyon activity during sea-level highstands: The Biobío canyon system offshore Chile. Geosphere, 11: 1226-1255.

Cares, D.W. & Chayes, D.N. 2017. MB-System: mapping the seafloor. [https://www.mbari.org/products/research-software/mb-system]. Reviewed: October 1, 2020.

Chen, H., Zhan, W., Li, L. & Wen, M. 2017. Occurrence of submarine canyons, sediment waves, and mass movements along the northern continental slope of the South China Sea. Journal of Earth System Science, 126: 73.

Clark, J.D., Kenyon, N.H. & Pickering, K.T. 1992. Quantitative analysis of the geometry of submarine channels: implications for the classification of submarine fans. Geology, 20: 633-636.

Fernandez-Arcaya, U., Ramirez-Llodra, E., Aguzzi, J., Allcock, A.L., Davies, J.S., Dissanayake, A., et al. 2017. Ecological role of submarine canyons and need for canyon conservation: a review. Frontiers in Marine Science, 4: 5.

Gavey, R., Carter, L., Liu, J.T., Talling, P.J., Hsu, R.T., Pope, E.L. & Evans, G. 2017. Frequent sediment density flows during 2006 to 2015, triggered by competing seismic and weather events: observations from subsea cable breaks off southern Taiwan. Marine Geology, 384: 147-158.

General Bathymetric Chart of the Oceans (GEBCO). 2014. GEBCO 2014 Grid. [https://gebco.net/news_and_media/gebco_2014_grid.html]. Reviewed: February 7, 2022.

Hagen, R., Vergara, H.P. & Naar, D.F. 1996. Morphology of San Antonio submarine canyon on the central Chile forearc. Marine Geology, 129: 197-205.

Harris, P. & Whiteway, T. 2011. Global distribution of large submarine canyons: geomorphic differences between active and passive continental margins. Marine Geology, 285: 69-86.

Ioualalen, M., Pelinovsky, E., Asavanant, J., Lipikorn, R. & Deschamps, A. 2007. On the weak impact of the December 26 Indian Ocean tsunami on the Bangladesh coast. Natural Hazards and Earth System Sciences, 7: 141-147.

Laursen, J. & Normark, W.R. 2002. Late Quaternary evolution of the San Antonio submarine canyon in the central Chile forearc (33°S). Marine Geology, 188: 365-390.

Lee, H., Kayen, R., Gardner, J. & Locat, J. 2003. Characteristics of several tsunamigenic submarine landslides. In: Locat, J. & Mienert, J. (Eds.). Submarine mass movements and their consequences. Kluwer, Amsterdam, pp. 357-366.

Li, W., Li, S., Alves, T.M., Rebesco, M. & Feng, Y. 2020. The role of sediment gravity flows on the morphological development of a large submarine canyon (Taiwan Canyon), north-east South China Sea. Sedimentology, 68: 1091-1108.

Masson, D.G., Huvenne, V.A.I., De Stigter, H.C., Arzola, R.G. & Le Bas, T.P. 2011. Sedimentary processes in the middle Nazaré Canyon. Deep-Sea Research, 58: 2369-2387.

Matsuyama, M., Walsh, J.P. & Yeh, H. 1999. The effect of bathymetry on tsunami characteristics at Sisano Lagoon, Papua New Guinea. Geophysical Research Letters, 26: 3513-3516.

Micallef, A., Mountjoy, J.J., Barnes, P.M., Canals, M. & Lastras, G. 2014. Geomorphic response of submarine canyons to tectonic activity: insights from the Cook Strait canyon system, New Zealand. Geosphere, 10: 905-929.

Mountjoy, J.J., Barnes, P.M. & Pettinga, J.R. 2009. Morphostructure and evolution of submarine canyons across an active margin, Cook Strait sector of the Hikurangi Margin, New Zealand. Marine Geology, 260: 45-68.

Mountjoy, J.J., Howarth, J.D., Orpin, A.R., Barnes, P.M., Bowden, D.A., Rowden, A.A., et al. 2018. Earthquakes drive large-scale submarine canyon development and sediment supply to deep-ocean basins. Science Advances, 4: 3748.

Muñoz, A., Elvira, E., León, C., Acosta, J. & Jiménez, P. 2017. Examples of sediment waves in and around submarine canyons of the North Alboran Sea. In: Guillén, J., Acosta, J., Chiocci, F. & Palanques, A. (Eds.). Atlas of bedforms in the Western Mediterranean. Springer, Cham.

Pineda, V. 1999. El cañón submarino del Biobío: aspectos dinámicos y ambientales. Tesis de Doctorado, Universidad de Concepción, Concepción.

Piper, D.J.W. 2005. Late Cenozoic evolution of the continental margin of Eastern Canada. Norwegian Journal of Geology, 85: 305-318.

Rodrigo, C. 2010. Cañones submarinos en el margen continental chileno. In: Díaz-Naveas, J. & Frutos, J. (Eds.). Geología marina de Chile. Pontificia Universidad Católica de Valparaíso-Servicio Nacional de Geología y Minería de Chile-Servicio Hidrográfico de la Armada-Comité Oceanográfico Nacional, Valparaíso.

Ruiz, S. & Madariaga, R. 2018. Historical and recent large megathrust earthquakes in Chile. Tectonophysics, 733: 37-56.

Ryan, W.B.F., Carbotte, S.M., Coplan, J.O., O'Hara, S., Melkonian, A., Arko, R., et al. 2009. Global multi-resolution topography synthesis. Geochemistry Geophysical Geosystems, 10: Q03014.

Shepard, F.P. 1981. Submarine canyons; multiple causes and long-time persistence. AAPG Bulletin, 65: 1062-1077.

Sobarzo, M., Figueroa, M. & Djurfeldt, L. 2001. Upwelling of subsurface water into the rim of the Biobío submarine canyon as a response to surface winds. Continental Shelf Research, 21: 279-299.

Thornburg, T.M. & Kulm, L.D. 1987. Sedimentation in the Chile Trench: depositional morphologies, lithofacies, and stratigraphy. Geological Society of America Bulletin, 98: 33-52.

Thornburg, T.M., Kulm, L.D. & Hussong, D.M. 1990. Submarine fan development in the southern Chile Trench: a dynamic interplay of tectonics and sedimentation. Bulletin of the Geological Society of America, 102: 1658-1680.

Völker, D., Scholz, F. & Geersen, J. 2011. Analysis of submarine landsliding in the rupture area of the February 27, 2010, Maule earthquake, Central Chile. Marine Geology, 288: 79-89.

Walker, R.G. 1992. Turbidites and submarine fans. In: Walker, R.G. & James, N.P. (Eds.). Facies models-response to sea level change. Geological Association of Canada, St. John's, Newfoundland, pp. 239-263.

Xu, J.P., Wong, F.L., Kvitek, R., Smith, D. & Paull, C.K. 2008. Sandwave migration in Monterey Submarine Canyon, central California. Marine Geology, 248: 193-212.

Yu, H.S. & Chuang, C.Y. 2002. Morphology and canyon forming processes of upper reach of the Penghu Canyon off southwestern Taiwan. Journal of Terrestrial, Atmospheric and Oceanic Sciences, 13: 91-108.

Received: December 6, 2021; Accepted: September 12, 2022