Earthquakes, subaerial and submarine landslides, tsunamis and volcanoes in Aysén Fjord, Chile

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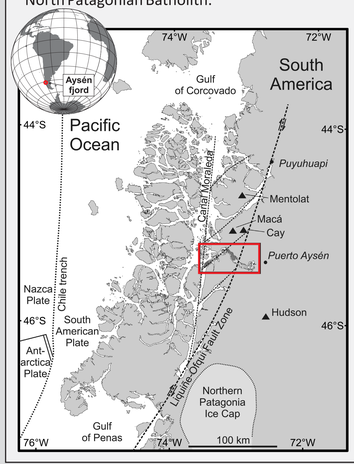
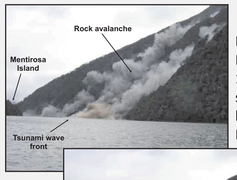
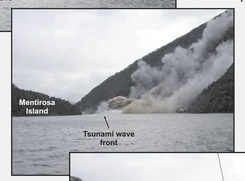
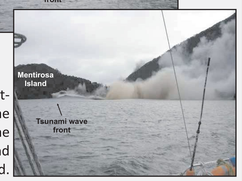
The **Aysén fjord**, 65 km long and east-west oriented, is located in Chilean Patagonia, at approximately 45º20'S and 73º10'W, with a maximum water depth of 345 m. It is the maritime access route to Puerto Chacabuco and Puerto Aysén, and hosts many salmon farms, the most important economic activity of the region. The fjord receives the **riverine input** of Aysén, Pescado, Condor and Cuervo rivers, which drain the surrounding up to 2000 m high Patagonian Andes, which include the Macá, Cay and Hudson **volcanoes**, and it opens to the west to Canal Moraleda. The fjord is crossed by a number of faults associated to the **active** Liquiñe-Ofqui **Fault Zone**, a major trench parallel intra-arc fault system. The geomorphology of the region is controled by tectonics with **glacial landscaping** superimposed, with U-shaped valleys and steep >30º slopes covered by shallow volcanic soils mostly overlying the North Patagonian Batholith.



An **Mw 6.2 earthquake** on 21 April 2007 triggered dozens of **subaerial landslides** along the steep fjord flanks. Some of the landslides reached the fjord water mass and/or involved a subaqueous component. These generated a series **tsunami-like displacement waves** that impacted the adjacent coastlines with 3-12 m, and up to 50 m, high run-ups, causing ten fatalities and severe damage to salmon farms.



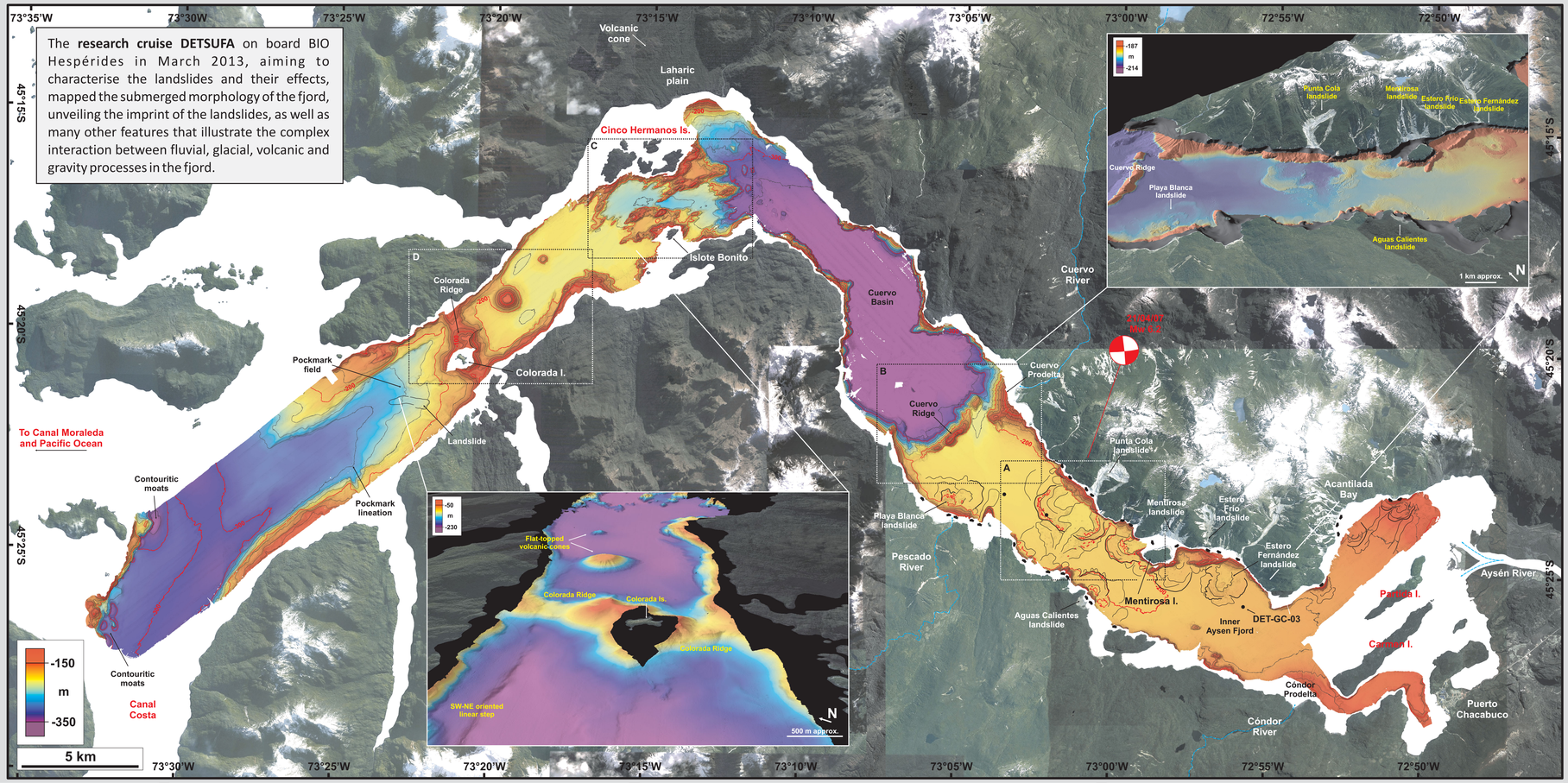


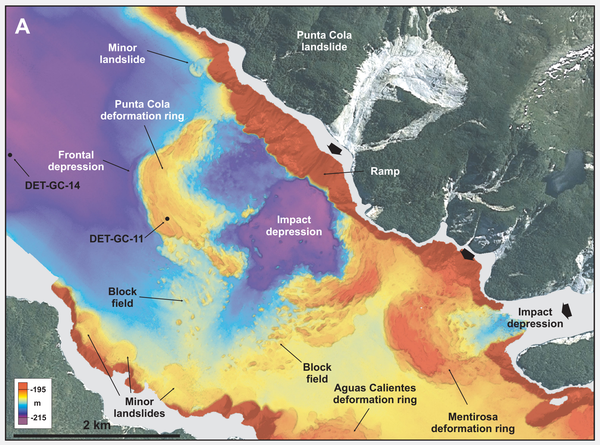


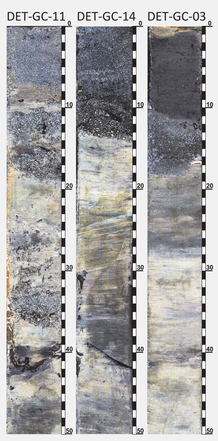
Left and below: Photos taken 10, 16 and 32 seconds after the landslide (credit F. Olivera).

Below: Present-day view of the rock avalanche area behind Mentirosa Island.

The **research cruise DETSUFA** on board BIO Hespérides in March 2013, aiming to characterise the landslides and their effects, mapped the submerged morphology of the fjord, unveiling the imprint of the landslides, as well as many other features that illustrate the complex interaction between fluvial, glacial, volcanic and gravity processes in the fjord.

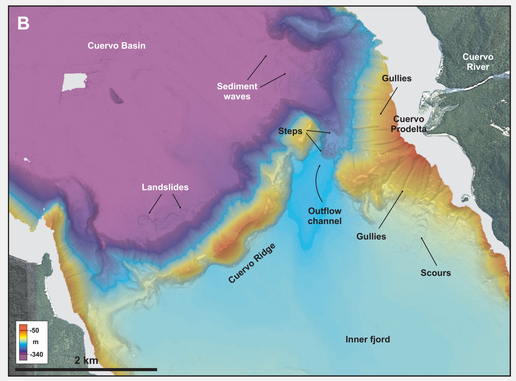




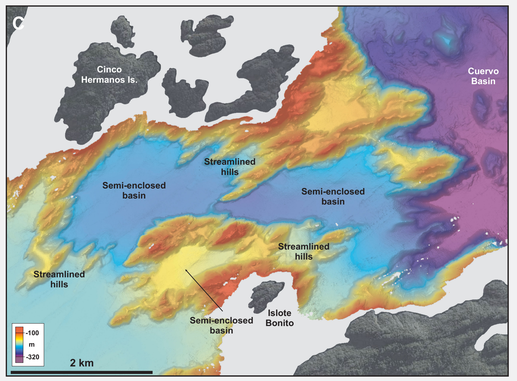


In the inner fjord, multibeam bathymetry (4 m cell size) shows the **deformation structures created by the impact of landslides** in the seafloor. They descended down the flanks, reached the fjord floor at 180-220 mwd, and generated large, 1-10 m deep **impact depressions**. Sediment removed from the depressions moved radially and piled up in deformation rings formed by **compressional ridges** 10-15 m in height, block fields and a narrow frontal depression. Six major >1.5 km^2 structures have been mapped, such as the Punta Cola landslide (above), as well as other minor landslides at the base of the fjord flanks.

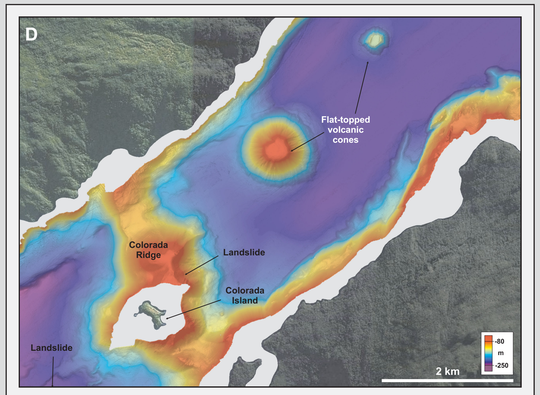
Above: Sediment cores retrieved from the inner fjord record the 21 April 2007 event as massive sands deposited by turbidity currents on top of either a slumped sediment unit corresponding to the deformation ring, or an undeformed hemipelagic mud.



Two **ridges** run across Aysén fjord: Cuervo (above) and Colorada Ridges, located at 25 and 54 km from the fjord-head delta, respectively. Both ridges are **volcanic structures over which recessional moraines deposited** at the retreating margins of tidewater glaciers, formed during still-stands in the deglaciation of Chilean fjords after the Last Glacial Maximum. The Cuervo Ridge reaches a minimum of 58 m water depth. It separates the 220 m-deep inner fjord and the 340 m-deep Cuervo Basin. Small landslides carve the northwestern side of the ridge. Between the Cuervo Ridge and the Cuervo Prodelta, a 350 m-wide **outflow channel** is present.



Beyond the Cuervo Ridge, the fjord floor smoothens and deepens to more than 340 m forming the enclosed Cuervo Basin, which is fed from the north by Cuervo River and other small rivulets draining a laharic plain. The fjord then abruptly turns southeast and shallows some 90 m to a depth of 250 m. There, a field of **streamlined hills** isolate three semi-enclosed basins. The hills display a **drumlin-like morphology**, with a NE-SW orientation. Some of them reach 50-60 m water depth, although Bonito and Cinco Hermanos Islets seem to be the emerged tops of equivalent hills. These hills are interpreted as the result of glacial basal erosion.



Two submerged **flat-topped monogenetic cones** have been mapped in the outer fjord. The larger cone, to the southwest, is 1300 m in diameter, 160 m high and tops at 67 m water depth. The smaller cone is 450 m in diameter, 45 m high and tops at 156 m water depth. Their flat tops are 300 m and 175 m in diameter, respectively. Both cones are aligned with Colorada Island, composed of pyroclastic material. The island and the attached Colorada Ridge display large landslide scars in their flanks. Beyond the ridge, the fjord seafloor show evidences of other active processes in the form of **pockmark trails,** fault alignments and contouritic moats and ridges in Canal Costa.