Tierra del Fuego Island: A natural laboratory for geological and paleoclimatic studies

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The Tierra del Fuego Island, the southernmost limb of the South America continent, is a tectonically active region, being adjacent to several plate boundaries and cut by one, and is the only land mass directly in the core of the Southern Hemisphere globe-encircling westerly wind system, and immediately north of the Antarctic polar front.

The region is active from a geological point of view, and this provides an opportunity, because the relationship between regional tectonics and climate change is of fundamental importance in the Earth system processes. Terrestrial records from this key area can provide unique insight into mid- to high- latitude Southern Hemisphere paleoclimatology. This region recorded the glacial and interglacial history of southern South America and represents one of the best sites to reconstruct the late Quaternary climate change.

A suite of field surveys was carried out both onshore and offshore by a team of Italian and Argentinean scientists in the Tierra del Fuego region since 1998 to analyze, from a geological and geophysical point of view, this remote region of our planet (Lodolo et al., 2002a, 2002b, 2003; Tassone et al., 2005; Menichetti et al., 2007). One of the main targets of these researches was the 600-km-long Magallanes-Fagnano fault system (MFS), a left-lateral tectonic lineament that developed on continental crust. This fault system represents the western segment of the South America-Scotia plate boundary and practically splits the Tierra del Fuego Island into two continental blocks (Fig. 1). Identifying and analyzing the morphological and structural elements related to the MFS, understanding mechanisms of slip along the fault, image the deep structural features associated to the MFS, and reconstruct the morphobathymetric features of the 110 km-long Lago Fagnano, a main basin formed within the principal deformation zone of the MFS, are among the principal goals of our studies.

The MFS traverses southernmost South America between the Chile Trench to the west and the submerged North Scotia Ridge to the east through the western arm of the Strait of Magellan, Seno

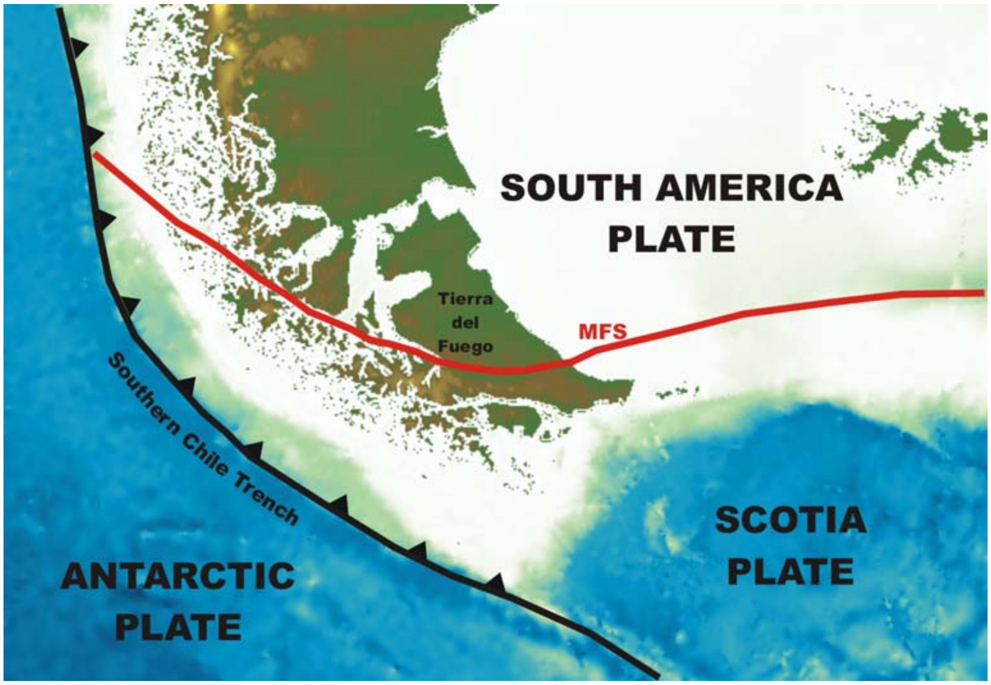

Fig. 1. General tectonic sketch of the southern South America. MFS indicates the Magallanes-Fagnano continental transform fault, that traverses the Tierra del Fuego Island.

Almirantazgo and Lago Fagnano. Recently-active fault scarps marking the South America-Scotia plate boundary can be traced into the Lago Fagnano from both the west and the east (Klepeis, 1994; Lodolo et al., 2002a, 2002b). There is a recorded history of earthquakes along the fault since 1879; a particularly strong event with magnitude 7.5 occurred on 1949, which caused several damages in the Lago Fagnano area and in the Chilean side of the MFS (Lomnitz, 1970). The exact location of activity, the structure of the plate boundary, and the history of faulting can best be studied by work on Lago Fagnano because of its bottom sediment record. Geophysical studies and analysis of the sedimentary record in this basin may elucidate the structure and history of an active plate boundary near population centers, past variability in the westerly wind system, timing of deglaciation, and late Quaternary climate change. The paleoclimate data obtained will bear on the role of the Southern Ocean in forcing glacial-interglacial change, the question of hemispheric synchronicity or otherwise of deglaciation and hence its cause.

In order to analyze the morphological expression of the submerged segment of the Magallanes-Fagnano fault system, a bathymetric map of the entire Lago Fagnano was for the first time derived from data collected along DGPS-fixed profiles (Lodolo et al., 2007). The resulting bathymetric map, superposed onto the Digital Elevation Model of the surrounding region, is presented in Fig. 2; it delineates the main morphological features of the Lago Fagnano. The floor is divided into distinct parts, which suggests that the basin is composed of different sub-basins. In most areas, the basin floor is highly asymmetric in shape, with flat depocentral areas. The most pronounced asymmetry of the basin is seen in the eastern end of the lake, where there is also the deepest depression (maximum water depth of 206 m). The steeper slope of the basin, along the northern shore of the Lago Fagnano, also coincides with the most pronounced regional topographic gradient. Strands of the transform on both sides probably border the central, symmetrical part of the lake floor. The eastern-half of the lake presents a maximum water depth of 165 m. This part of the basin is broadly symmetric in shape and, like the eastern part of the lake, presents a relatively flat depocentral area. Along the westernmost part of the Lago Fagnano, two major, sub-parallel tectonic lineaments control the shape of the floor. Onshore, those lineaments define large graben structures, and bound on both sides a tilted sliver of crust (Monte Hope). The peculiar morphology of Lago Fagnano, and its location within the principal displacement zone of the MFS contrast in part with the postulated glacial origin for the lake as proposed by some authors (see discussion in Bujalesky et al., 1997). However, the glacial activity, in combination with the tectonic activity, has played an important role in shaping the morphology of the Lago Fagnano basin. The general morphology of Lago Fagnano is clearly controlled by the tectonic activity along the MFS and its geometry most probably reflects its sub-bottom structure. It represents the surface expression of at least two large pull-apart basins, formed by strands of the MFS.

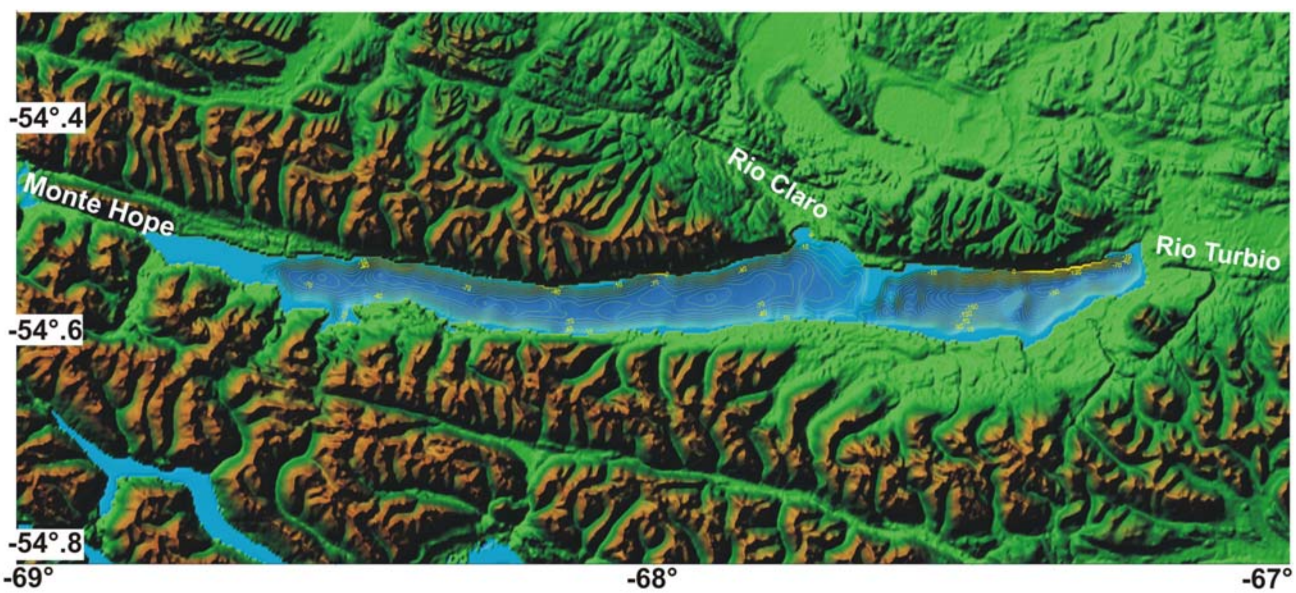

Fig. 2. Shaded-relief bathymetric map of the Lago Fagnano, derived from data collected along DGPS-fixed transversal profiles and longitudinal tie-lines, for a total of more than 600 km of acquisition tracks, and Digital Elevation Model of the surrounding region (from Lodolo et al., 2007).

Lago Fagnano presents an outstanding opportunity to analyze paleoclimate problems because its favourable geographical position within the Fuegian archipelago. This region is directly influenced by tropical and Antarctic oceanic-atmospheric interactions (Cullather et al., 1996; Kreutz et al., 1997).

There are three important time intervals during the late Quaternary, as reconstructed from various proxy records in Tierra del Fuego: Last Glacial Maximum (LGM, ~20,000 cal yrs BP), Late Glacial (LG, ~18,000 to ~10,000 cal yrs BP) and Holocene (~10,000 cal yrs-Present). Different proxy records have been used to reconstruct climate during these time intervals, yet the conclusions drawn regarding the general state of climate do not necessarily agree because these records tend to be discontinuous and of low resolution. Therefore, they do not record variability at the decadal-centennial scale, and are not always in agreement during any given time interval. Data from Lago Fagnano sediments can help provide reconciliation of the present apparently conflicting records. This basin yields a continuous and high accumulation-rate of sedimentary section, mainly constituted by glacio-fluvial and lacustrine material. The information derived from high precision age-dating methodologies and multiple geochemical and biotic tracers, as recorded in piston-cored sediments, is essential for an assessment of the paleoclimate record of the southernmost Andes. Lago Fagnano further illustrates the use of a combined geophysical and sedimentological approach to separate the complex influence of climate and active tectonics on lacustrine sedimentation (Fig. 3). An international program that combines those disciplines, involving European and American scientific teams (Waldmann et al., 2007), is currently underway. This work will lead to the goals of reconstructing the past strength of the westerly winds at their current latitudinal maximum (55° S), developing a precisely dated chronology of the southernmost Andes deglaciation, and determining the high southern latitude late Quaternary variability over a range of timescales. This in turn would contribute to testing the hypotheses regarding the explanation of low CO2 levels during glacial intervals and the onset of climate change associated with deglaciation. It will also lead to a reconciliation of differing conclusions regarding climate reconstruction at the critical LGM, Late Glacial, and Holocene time intervals.

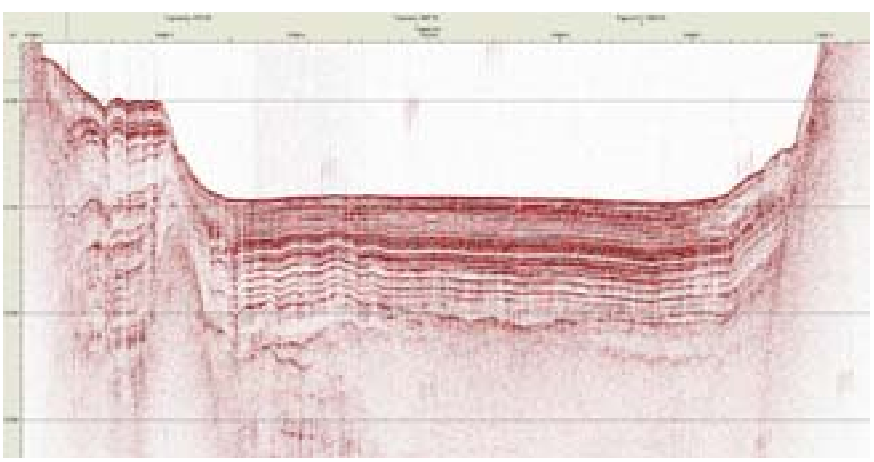

Fig. 3. Example of an uninterpreted 3.5 kHz seismic sections across the eastern part of the Lago Fagnano. Some of these profiles were used to locate gravity cores. This figure is taken from the web site **http://www.ig.utexas.edu/outreach/ttif/lago_fagnano/field_experience.php**

Major international efforts are underway to understand patterns of past global climate variability at all timescales, to establish the pattern of change at all latitudes as revealed by terrestrial and marine records, and to determine primary system controls. Astronomical forcing, instabilities in oceanic circulation and a variety of greenhouse gas, ice and biological feedbacks can be all employed to explain aspects of climate variability in the ~100 ka–1 ka range. It is believed that longer-term changes, for instance the onset of Pleistocene cooling, are mainly related to continental re-organization such as the separation of South America and Antarctica, which led to the development of the Scotia plate (Barker, 2001), and possibly to the onset of the Antarctic glaciation (Zachos et al., 2001; Exxon et al., 2002).

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