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A geological and geophysical crustal section across the Magallanes–Fagnano fault in Tierra del Fuego

A. Tassone[a,*], H. Lippai[a], E. Lodolo[b], M. Menichetti[c], A. Comba[a], J.L. Hormaechea[d], J.F. Vilas[a]

[a]*Dpto. de Geología, Instituto de Geofísica Daniel A. Valencio, FCEyN, UBA-CONICET, Buenos Aires, Argentina*
[b]*Istituto Nazionale di Oceanografia e Geofisica Sperimentale, Trieste, Italy*
[c]*Istituto di Geodiamica e Sedimentologia, Università di Urbino, Urbino, Italy*
[d]*Estación Astronómica Rio Grande, UNLP-CONICET, Rio Grande Argentina*

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Abstract

Geophysical and geological field surveys carried out in the central and eastern part of the Argentinean Tierra del Fuego Island on the Magallanes–Fagnano fault system (MFS) delineate its main structural features and tectonic setting. Gravity and magnetic data provide critical information for those areas lacking good exposures and support a present-day transtensional tectonic regime for the MFS. In the surveyed area, the MFS segments have a clear morphological expression and are associated with localized gravity minima interpreted as pull-apart basins. In the southeastern corner of Lago Fagnano, the magnetic data suggest a prominent crystalline body in the subsurface, partially exposed in Cerro Hewhoepen. The shape and position of this intrusive body suggest that its emplacement was localized in a releasing bend. Two-dimensional density modeling along a 40 km long N–S section east of Lago Fagnano suggests a deep duplex similar to that exposed in the western part of the island. The obtained model, combined with available surface data, implies the subsurface configuration of geological units and structures, in which the structure of the deep duplex is similar to that exposed in the western part of the Island. The model indicates the southward deepening of the basement from 5 to 7 km and provides further support for the piston shape of the Hewhoepen intrusive.

Keywords: Gravity; Magnetic; Tierra del Fuego; Transtensive tectonics

Resumen

Se ha desarrollado un estudio geofísico y geológico, en la parte central de la Isla de Tierra del Fuego en sector argentino, a través del sistema de Fallas Magallanes–Fagnano (MFS), con el objeto de delinear sus rasgos estructurales y ambiente tectónico. Los datos de gravedad y magnetismo obenidos aportan información crítica para este sector casi totalmente cubierto por sedimentos cuaternarios. Nuestros datos apoyan un modelo tectónico transtensivo para el actual límite de placas representado por el MFS. En el sector estudiado el MFS, tiene una clara expresion morfológica superficial y está asociada con la localización de mínimos gravimétricos, interpretados como cuencas de pull-apart. En la parte SE de la cabecera del Lago Fagnano, los datos de anomalía magnética sugieren la presencia de al menos un cuerpo intrusivo en subsuelo, parcialmente expuesto en el cerro Hewhoepen. Su forma y localización sugieren que se habría emplazado en correspondencia con un área de distensión. Se ha realizado un modelado numérico, utilizando los datos de anomalía de Bouguer, a lo largo de una sección de unos 40 km de largo y 10 km de profundidad, localizada en el extremo Este del Lago Fagnano. El modelo obtenido combinado con nuestros datos geológicos de superficie nos permitieron inferir: (a) la disposición de las diferentes unidades geológicas y continuidad de estructuras principales en subsuelo; (b) la estructura en duplex en profundidad que resulta similar a la expuesta en la parte oeste de la isla; (c) el modelo en profundidad también aporta datos acerca de la profundización hacia el Sur del basamento de 5 a 7 km; y (d) permite caracterizar el intrusivo del Cerro Hewhoepen como un cuerpo cilíndrico.

* Corresponding author. Tel.: +54 11 4576 3300/09x292; fax: +54 11 4788 3439.
E-mail address: atassone@gl.fcen.uba.ar (A. Tassone).

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1. Geological and tectonic outline

The present-day tectonic architecture of Tierra del Fuego Island (Fig. 1) is the result of the long, complex evolution of southernmost South America since the early Mesozoic, when a subduction zone located at the adjacent southern South America and Antarctic Peninsula was active along the Pacific margin of Gondwanaland (Dalziel and Elliot, 1973; Dalziel, 1982). After the Middle Jurassic, the southern part of the continent underwent extension associated with the Gondwana breakup, as depicted by the widespread silicic volcanism of the large igneous province of Patagonia and the Antarctic Peninsula (Pankhurst et al., 2000), production of oceanic crust in backarc basins (e.g. Tortuga and Sarmiento ophiolitic complexes), and subsequent deposition of quasi-marine sequences (Rocas Verdes assemblages; Dalziel et al., 1974; Dalziel, 1981). At approximately 100 Ma, a general phase of compressional tectonics led to the closure of the Rocas Verdes Basin and the contemporaneous development of the Magallanes Basin as a foreland basin with the deposition of clastic sediments from the cordillera (Natland et al., 1974). From the late Mesozoic to the Tertiary, the Tierra del Fuego region underwent continentward propagation of the Magallanes fold-and-thrust belt (Winslow, 1982; Biddle et al., 1986; Alvarez-Marron et al., 1993). This belt includes thrusting of the Mesozoic units over early Cenozoic deposits, as well as many thrusts within the Mesozoic sequences of the Magallanes Basin (Ramos, 1989). The tectonic event may have developed in conjunction with strike-slip shear zones that may accommodate the relative motion between the South American and Antarctic continents since the early Cretaceous (Diraison et al., 2000).

1.1. Magallanes–Fagnano fault system

The South America–Scotia plate boundary in the Tierra del Fuego region is represented by a mainly strike-slip lineament, known as the Magallanes–Fagnano fault system (MFS), that runs from the western part of the north Scotia ridge to the Chile trench south of 50°S (Fuenzalida, 1972; Dalziel, 1989). The MFS substantially splits Tierra del Fuego Island into two continental blocks and runs from the Pacific entrance of the Magallanes Strait to the Atlantic coast of the Island (Fig. 1), where significant deformation related to left-lateral strike-slip faults has been studied both on- and offshore (Winslow, 1982; Cunningham, 1993; Klepeis and Austin, 1997; Cerredo et al., 2000; Diraison et al., 2000; Lodolo et al., 2002a,b).

The E–W MFS sinistral transform system is composed of many splays and diverse subparallel faults that overprint the fold-and-thrust belt (Fig. 1). The age of the strike-slip deformation along the MFS in most major faults is unknown and contentious. A 30 Ma age has been proposed (Barker and Burrell, 1977), coincident with the early stages of the development of the western Scotia Sea, but others claim an older regime of transcurrent motion between southern South America and the Antarctic Peninsula was active at approximately 100 Ma (de Witt, 1977; Grunow et al., 1991, 1992). Recent studies of the seismicity along the transform boundary (Wiens et al., 1998; Vuan et al., 1999) report low, shallow seismicity (<3.5 magnitude), consistent

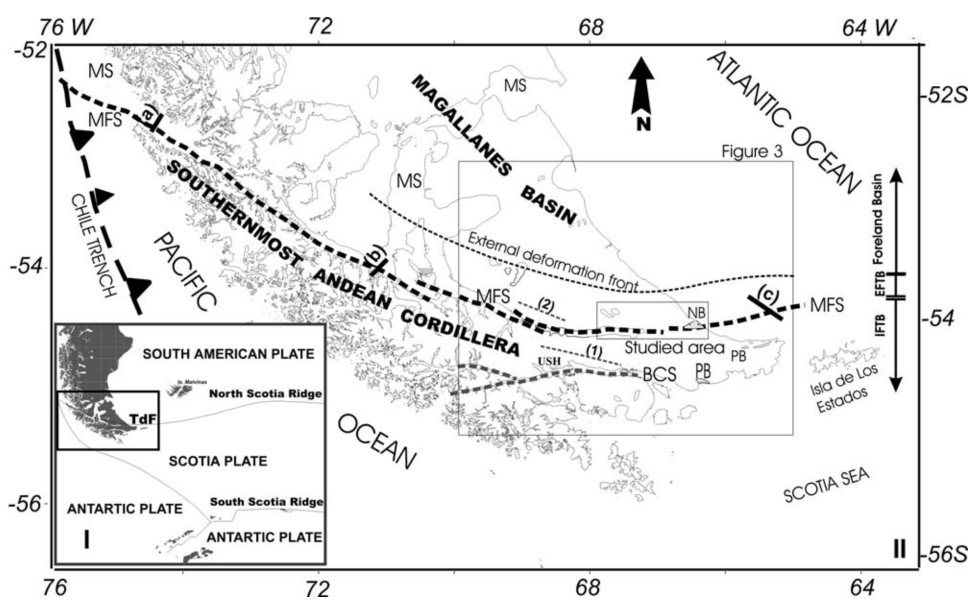

Fig. 1. (I) Regional tectonic map with plate boundaries. (II) Simplified geological map of Tierra del Fuego Island with the main tectonic provinces and locations cited in the text. EFTB, external fold-and-thrust belt; IFTB, internal fold-and-thrust belt; NB, Neogene basin; PB, Paleogene basin; (1), Valley Carabajal fault zone; (2), Lago Deseado fault zone; MS, Magallanes Strait; MFS, Magallanes–Fagnano fault system; BCS, Beagle Channel fault system; and USH, Ushuaia. The study area box refers to Fig. 2 and the following corresponding figures: Bouguer anomaly map (Fig. 5), magnetic map (Fig. 6), topography map (Fig. 7), and simplified geologic map (Fig. 3). Also shown is the location of the major documented strike-slip faults in Tierra del Fuego region. (a), (b) and (c) refer to seismic profiler of Fig. 11.

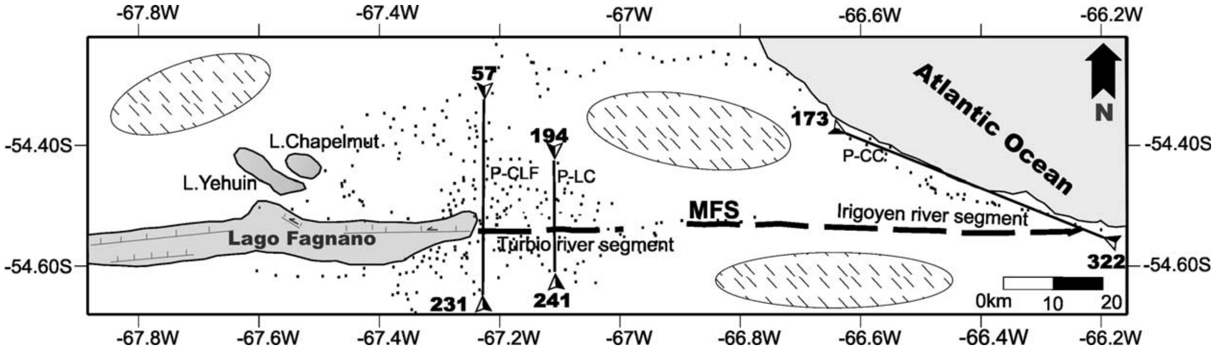

Fig. 2. Map of the studied area (location in Fig. 1) showing the data distribution (gravity, magnetic, and GPS stations indicated by points) and profile locations. The stations at the ends of the profiles are identified by the same numbers as the corresponding profiles in Fig. 8. The trace of the P-CLF corresponds to the location of the gravity model (Fig. 9) and interpreted geologic section (Fig. 10). The main segments that make up the MFS are indicated. Shaded and dashed areas indicate unsurveyed zones.

with differential global positioning system (DGPS) measurements that show that the relative motion between the South America and Scotia plates along the MFS is 6.7 (Perdomo et al., 2002) or 6.6 mm/yr (Smalley et al., 2003).

1.2. Main geologic feature of the study area

The study area (Fig. 2) is located in the central northern side of the Fueguian Andes, where the structures of the external thrust front represent thin-skinned tectonics and propagate to the Magallanes foreland in a fold-and-thrust belt system (Fig. 1). The main structures consist of a system of N-verging, ESE–WNW-trending, asymmetric folds and thrusts, due to mostly N–S, Late Cretaceous–Tertiary shortening. The surveyed area exposes marine sequences of the Rocas Verdes marginal basin (Yahgan Formation) and, locally, its volcaniclastic basement. Both constitute an imbricate wedge that thins to the north. The overlying syntectonic sedimentary wedge (Figs. 3 and 4) consists of the siliciclastic succession of the Magallanes foreland basin. Progressive deformation that affects the Magallanes foreland basin ranges in a N–S sense from the horizontally layered sequences (Cabo Peña Formation) to a series of E–W-oriented folds (La Despedida Group and Río Claro Formation) with limbs that dip 45–70° (Figs. 3 and 4).

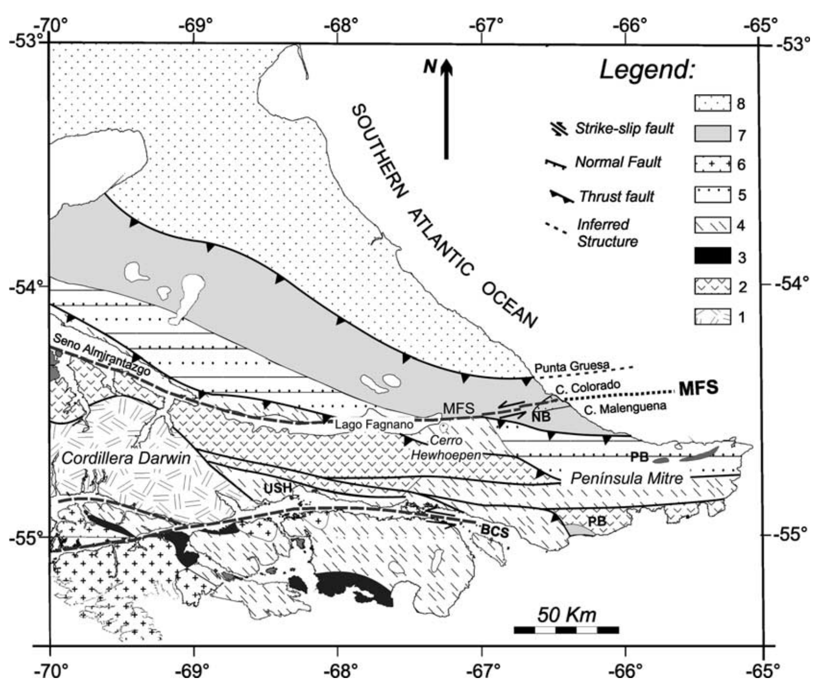

Fig. 3. Simplified geologic sketch of the eastern half of Tierra del Fuego Island, adapted from Caminos and Nullo (1979), Caminos et al. (1981), Olivero and Martinioni (2001) and Ghiglione (2003). For location, see Fig. 1. Major structures interpreted from SPOT images, aerial photographs, and field structural surveys. NB, Neogene basin; PB, Paleogene basin; MFS, Magallanes–Fagnano fault system; BCS, Beagle Channel fault system; and USH, Ushuaia. Legend: (1), Basement complex; (2), Lemaire Formation (Argentina)/Tobifera Formation (Chile); (3), Tortuga complex; (4), Lower Cretaceous deposits (Yahgan and Beauvoir Formations); (5), Upper Cretaceous deposits; (6), Patagonian batholith; (7), deformed tertiary deposits; and (8), undeformed Tertiary deposits.

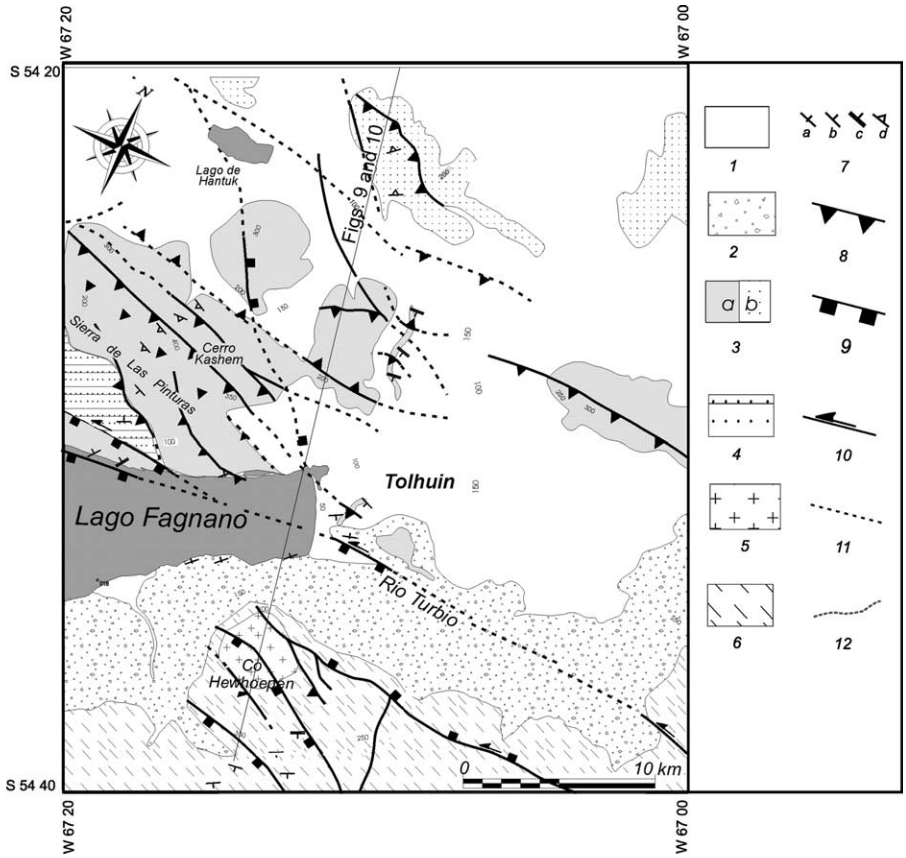

Fig. 4. Geological map of eastern part of Lago Fagnano. (1) Undifferentiated Quaternary lacustrine and glaciolacustrine deposits; (2) Pleistocene glaciolacustrine sequences; (3a) Rio Claro Formation, (3b) La Despedida Group, Tertiary fine-grained sandstone and marl; (4) equivalent to Matrero Co. Formation, Upper Cretaceous, feldspathic wackes and conglomerates; (5) Hewhoepen intrusive; (6) Yahgan Formation, Early Cretaceous, dark mudstone and limestone; (7) bed attitude with following dip classes: (a) 0–30°, (b) 30–45°, (c) 45–60°, and (d) 60–85°; (8) thrust fault, barbs in hangingwall; (9) normal fault, barbs in hangingwall; (10) strike-slip faults; (11) inferred tectonic lineaments; and (12) Highway 3.

In the southern region of the studied area, most rocks are sedimentary and volcaniclastic in origin (Early Cretaceous Yahgan and Late Jurassic Le Maire Formations, Rocas Verdes marginal Basin). Southeast of Lago Fagnano, the mudstones of the Yahgan Formation are intruded by a monzodioritic body (Cerro Hewhoepen) that occupies an approximately 2×2 km^2 area and coincides with an isolated relief approximately 800 m high. This intrusive is affected by both the transtensional structures related to the Lago Fagnano pull-apart basin and contractive tectonics (Figs. 3 and 4).

A system of Oligocene–Quaternary, E–W, left-lateral strike-slip faults with an extensional component overprints the contractional structures and is responsible for the main depression of the Lago Fagnano (Lodolo et al., 2003). The Pleistocene glaciolacustrine sediments of the eastern shore of Lago Fagnano are deformed by several sets of E–W, subvertical, S-dipping normal faults with a prevalent left-lateral transtensional component. In this sector, fluvial drainages are clearly influenced by the presence of the E–W structures related to the strike-slip faults with several capture corners, as in the upper part of the valleys that host the Turbio and Lainez Rivers (Menichetti et al., 2001; Lodolo et al., 2002a). A system of right-lateral, strike-slip, Quaternary, N–S faults crosses these structures and probably represents the present-day deformation in the eastern part of the island.

2. Geophysical study

This study was designed to provide geophysical evidence about the geometries and orientation of the geological units in the subsurface, as well as the nature of the transform tectonics of the MFS from eastern Lago Fagnano to the Atlantic (Figs. 1 and 2). Within this area, exposures are restricted to the Lago Fagnano and Atlantic coasts; the vast remainder of the central zone is dominated by forests and areas in which both magnetic and gravity data provide critical information. Our analysis of geological data from the exposures, combined with the acquired geophysical information, enables us to present various N–S sections that display the main geological features associated with the MFS.

2.1. Data acquisition and processing

In 1998–2002, four geophysical and geological field surveys were carried out in remote areas of the central

Table 1
Measured values of magnetic susceptibility for each geologic unit

Geologic unit	Age	Susceptibility (m^3/kg)
Le Maire Fm.	Upper Jurassic	0.00000015
Yaghan/Beauvoir Fm.	Lower Cretaceous	0.00000159
Matrero/Kami Fm.	Upper Cretaceous	0.00000086
Hewhoepen Intrusive	Upper Cretaceous	0.00013568
Rio Claro Fm.	Paleocene	0.00000540
Punta Torcida Fm,	Eocene	0.00000119
Cabo Colorado Fm.	Eocene	0.00000093
Leticia Fm.	Eocene	0.00000085
Cabo Peña Fm.	Miocene	0.00000267

Note the contrast between the values for the Hewhoepen intrusive and the other units.

eastern part of Tierra del Fuego Island with difficult access (Fig. 2). The acquired DGPS-fixed data included gravity, magnetic, and magnetic susceptibility measurements.

Due to the lack of accurate topographic information that could provide complete coverage of the studied area, SAR images (acquired from ERS-1 and ERS-2) were used to produce a DEM to perform the topographic corrections to the map of the Bouguer anomaly. Furthermore, the DEM combined with SPOT images and aerial photographs (1:30,000, Servicio de Hidrografia Naval of Argentina) helped determine the regional-scale lineations (Figs. 1–4).

Rock samples and structural data provide a preliminary geological map (Fig. 4) that follows the stratigraphy of Buatois and Camacho (1993), Olivero et al. (1999), Olivero and Medina (2001), Olivero (2002) and Olivero and Martinioni (2001). A schematic N–S section through the eastern Lago Fagnano was prepared by combining the available lithological and structural data with numerical modeling of the gravity data.

2.1.1. Gravity measurements

Gravity data were acquired with a LaCoste-Romberg gravimeter. The absolute gravity base was Ushuaia, which is linked to the IGSN71 system (Morelli et al., 1974; Gantar, 1993). Instrument drifts were corrected for through daily reoccupation of the established base stations. Small changes in the readings at these bases were attributed to instrument drift, and a drift correction was applied to the intervening observations by linear interpolation. Tidal corrections (related to the attraction of the sun and moon) also were applied for every gravity measurement.

2.1.2. Magnetic measurements

Magnetic data were acquired from all GPS-fixed point stations with an EG&G Geometrics and a Scintrex proton magnetometer ($\pm 0.1\gamma$ sensibility, $\pm 1\gamma$ reproducibility). Data were corrected for diurnal variations, which we obtained from the Falkland Island Bulletin for 1998–2001, for the period of data acquisition. The international geomagnetic reference field (IGRF) was removed from the acquired data so that the residual magnetic anomalies were due solely to geology. A detailed, closely spaced magnetic survey (data acquired every $\sim$500 m) was performed in the area southeast of Lago Fagnano. Within this area, a paleomagnetic and MSA survey was performed on the exposures of the Cerro Hewhoepen intrusive, as described by Baraldo et al. (2002).

Measurements of magnetic susceptibility were performed at each good exposure with a Bartington susceptibility meter MS2, which includes two types of sensors: a field survey with 185 mm diameter (MS2D) for surface measurements and a probe with 15 mm diameter (MS2F) for high resolution surface measurements. Measurements were recorded in low frequency with 1.0 sensibility in the SI system. In the laboratory, a MS2B sensor with dual frequency was employed. The results for each geologic unit are displayed in Table 1.

2.2. Results and geophysical interpretation

2.2.1. Geophysical profiles and maps

The Bouguer anomaly map (Fig. 5) shows a southward decreasing regional trend, which suggests the deepening of the basement to the south. Onshore, the gravity field is characterized by anomalies that range from -10 to -50 mGal. A local positive anomaly (CH) is related to

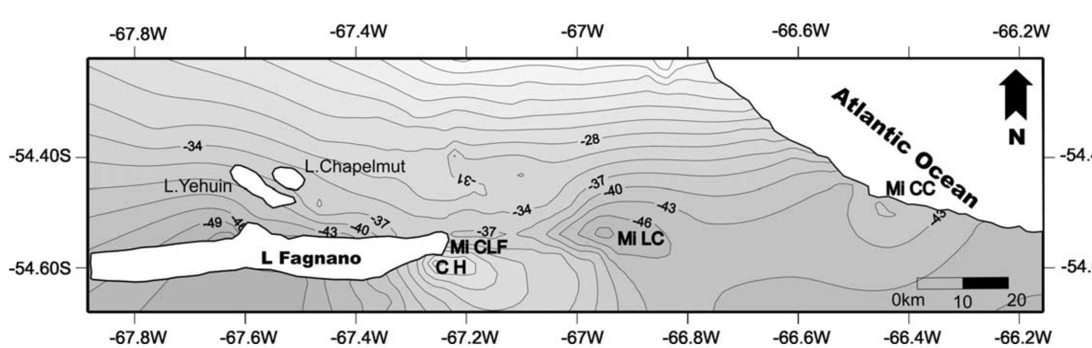

Fig. 5. Complete Bouguer gravity map of the central part of Tierra del Fuego Island (for location, see Fig. 1). Contour lines each 3 mGal. Mi CLF, Bouguer minimum anomaly in eastern Lago Fagnano that corresponds with a sag pond at the Turbio River estuary; Mi LC, Bouguer minimum anomaly in the eastern sector that corresponds with the eastern termination of the valley occupied by the Turbio River; Mi CC, Bouguer minimum anomaly in Cabo Colorado; and CH, Bouguer maximum anomaly in the Cerro Hewhoepen.

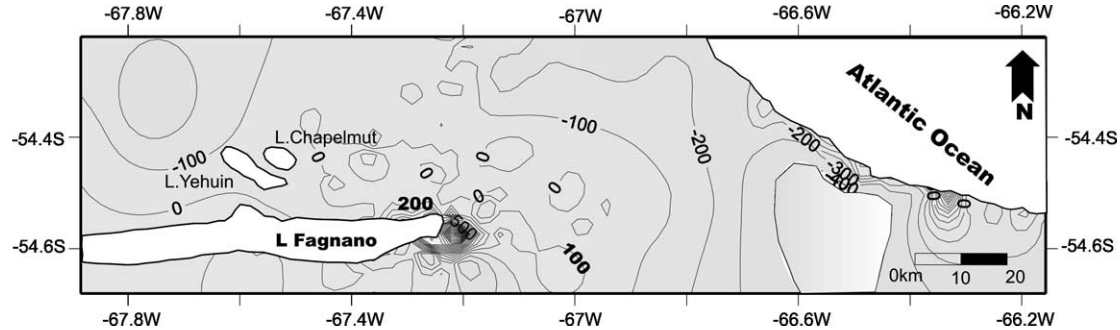

Fig. 6. Magnetic map of survey area (for location, see Fig. 1). Contour lines each 100 nT. The main positive magnetic anomaly is located immediately ESE of Lago Fagnano.

the Cerro Hewhoepen monzodioritic intrusion. Between Lago Fagnano and the Atlantic coast, two negative anomalies clearly appear, one located south of Cabo Colorado (Mi CC) and the other at the eastern termination of the Turbio River valley (Mi LC). Another minimum (Mi CLF) corresponds with a sag pond at the estuary of the Turbio River. These three minima are arranged roughly E–W strike. The E–W regional anomaly also can be observed in the free-air anomaly map in central Tierra del Fuego Island (Tassone et al., 1999), which has been correlated with the free-air anomaly obtained from satellite images in the Atlantic offshore (Sandwell, 1995).

The magnetic map (Fig. 6) shows anomaly values that vary between −500 and 2500 nT. The map displays one main maxima anomaly, southeast of Lago Fagnano. This magnetic maximum corresponds to the intrusive exposed at Cerro Hewhoepen, where the anomaly shows a WNW–ESE trend and the strongest gradients in the ENE–WSW direction. These elevation measurements were used to build a topographic sketch (Fig. 7) in which the most prominent high corresponds to the Cerro Hewhoepen.

Gravimetric and magnetic data were combined with the corresponding N–S and NW–SE topographic profiles to correlate the information along three main sections (Fig. 8). Each section shows one gravimetric minimum, located along the MFS in the Irigoyen River valley (Figs. 2 and 5), and shows gradients up to 5 and 4 mGal (profile P-CLF/Lago Fagnano and profile P-LC/La Correntina, respectively). These minima are interpreted as due to the presence of low-density bodies (possibly shallow basins) with widths of 8–10 and 5–7 km (profiles P-LC/La Correntina, P-CC/South Cabo Colorado and profile P-CLF/Lago Fagnano, respectively; Fig. 8).

The gravity plots display the regional decreasing trend of a Bouguer anomaly. Three relative minima are identified in the regional decreasing trend: between stations 272 and 231 in profile P-CLF/Lago Fagnano (Fig. 8), stations 195 and 28 in profile P-LC/La Correntina (Fig. 8), and stations 173 and 322 in profile P-CC/south Cabo Colorado (Fig. 8). The gravimetric and magnetic maxima in the P-CLF/Lago Fagnano profile correspond to the Cerro Hewhoepen intrusive.

2.2.2. *Two-dimensional gravity model and interpreted geologic section*

Two-dimensional (2D) numeric modeling (Fig. 9) was performed using the data of the total Bouguer anomaly. The model displays a N–S section of approximately 40 km through the upper 10 km (for profile location, see Figs. 2 and 4). The modeling was performed on a vertical plane with IGMAS software (Götze, 1978; Götze and Lahmeyer, 1988; Schmidt and Götze, 1998) based on Won and Bevis's (1987) algorithm. The rock density of each geologic unit, measured with a pycnometer on dry samples, showed good

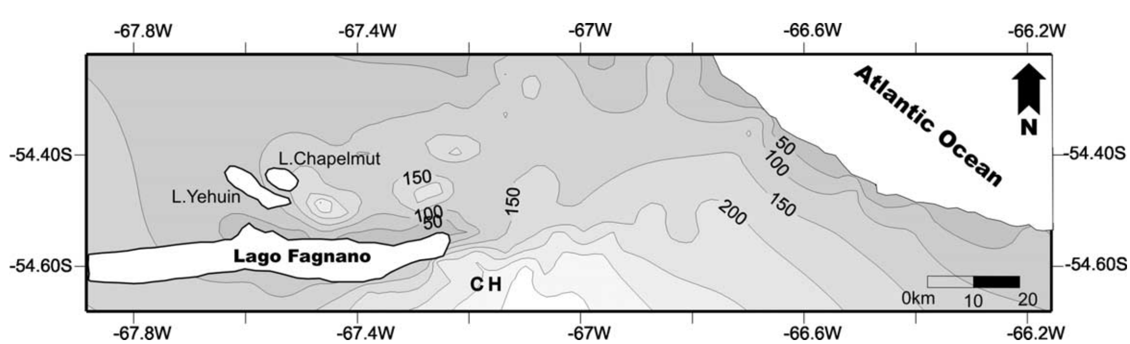

Fig. 7. Topographic sketch with contour lines each 50 m (elevation measurements acquired at each GPS station). Three morphological styles are distinguished: North of Lago Fagnano, topographic highs delineate a NW–SE trend in line with local thrusts (Fig. 4); the highest relief emerges along the southern border of the sketch and corresponds to the foothills of the Fuegian Cordillera; and from Lago Fagnano to the Atlantic (Cabo Colorado) coast, a roughly W–E depressed area corresponds to the location of the MFS. CH, Cerro Hewhoepen.

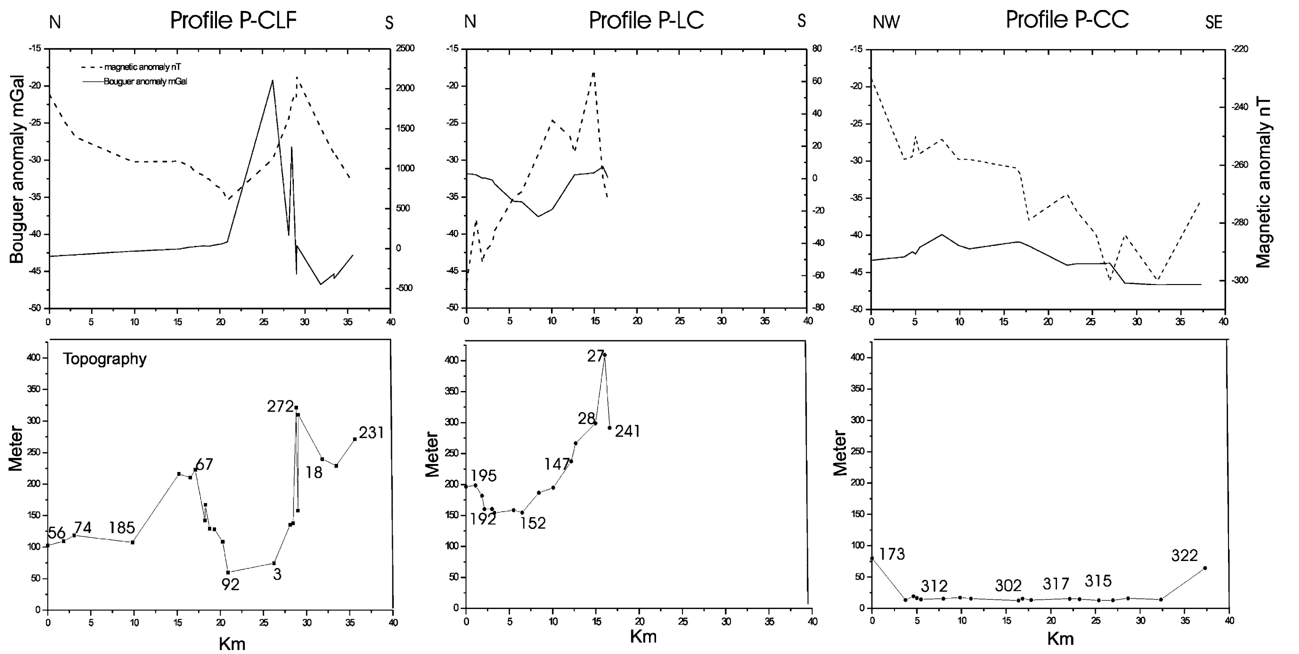

Fig. 8. N–S and NW–SE profiles (for location, see Fig. 2). (Upper diagram) Both the magnetic anomalies (dashed lines, in nT/50) and Bouguer anomaly (solid lines, in mGal) along 40 km N–S profile. (Lower diagram) Corresponding topographic profile (numbers refer to geophysical stations).

agreement with reported values from the literature (Dobrin, 1975). The reference density was 2.67 g/cm^3.

In the modeled section, the MFS is related to the −39 mGal minimum of the gravity plot (upper diagram, Fig. 9). The Lago Fagnano asymmetric basin is interpreted as associated with the MFS. Numeric modeling quantitatively constrains the disposition of Cretaceous and Jurassic units affected by Andean compression, as well as the lateral extension of the synorogenic Tertiary units. A very good fit was observed between the measured and computed values for the Paleozoic basement depth (Fig. 9), whose modeled geometry indicates a southward deepening from 5 to 7 km.

The Hewhoepen intrusive appears in the southern part of the model section, coincident with a maximum of

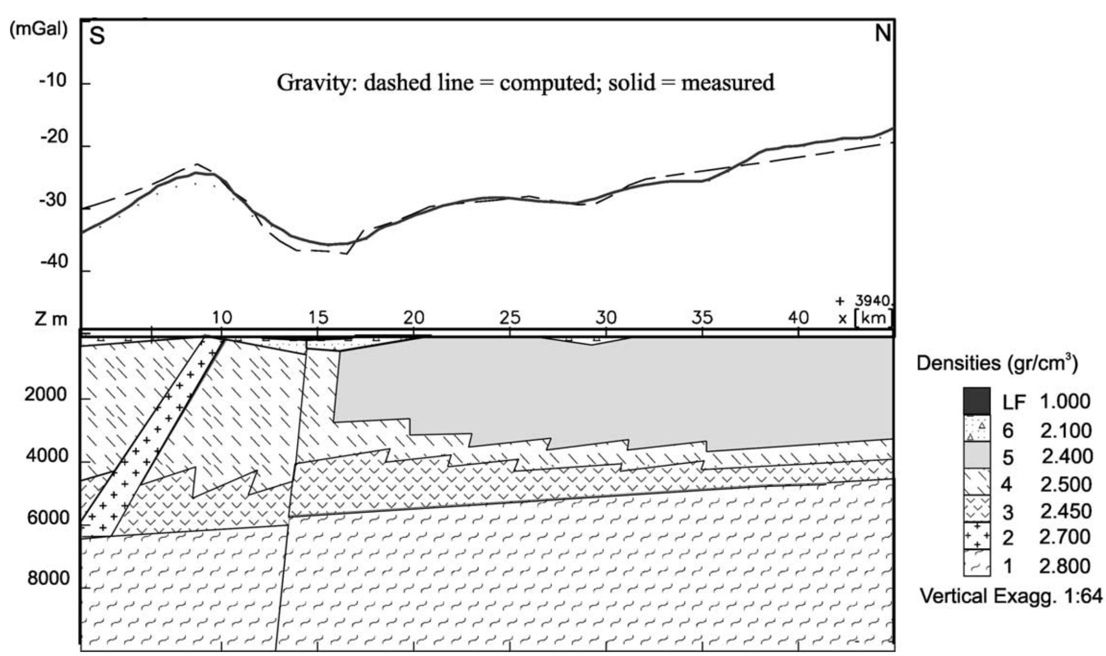

Fig. 9. 2D numeric model created with data from total Bouguer anomaly (see Figs. 2 and 4). Modeling was performed on a vertical plane (2D) with IGMAS software. (1) Paleozoic basement; (2) monzodioritic intrusive (Upper Cretaceous–middle Miocene); (3) Lemaire Formation (Upper Jurassic); (4) Yahgan Formation (Early Cretaceous, dark mudstone and limestone); (5) synorogenic Tertiary sedimentary rocks; and (6) undifferentiated Miocene–Quaternary deposits. LF, Lago Fagnano.

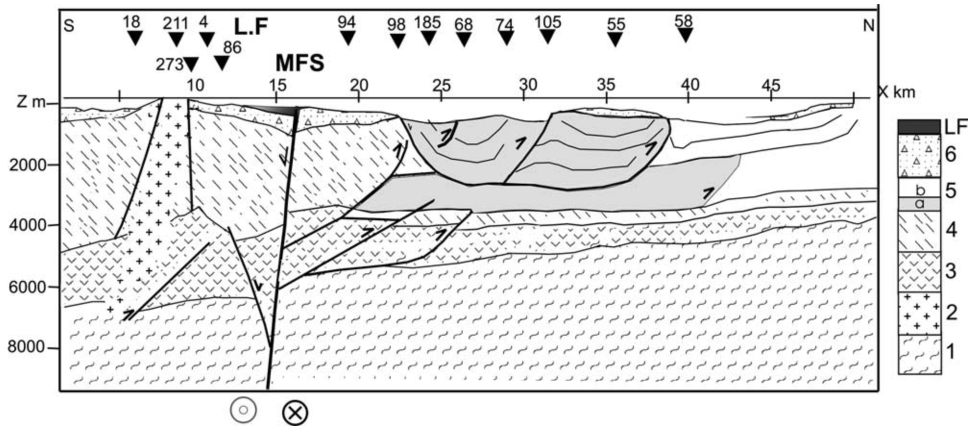

Fig. 10. Interpreted geologic section (Location in Figs. 2 and 4) based on numerical model of gravimetric data (Fig. 9) combined with lithological and structural field data. Solid triangles indicate the location of gravity and magnetic stations. Density of units, as numbered in Fig. 9: (1) 2.8; (2) 2.7; (3) 2.45; (4) 2.5; (5) 2.4 g/cm^3 (a) Río Claro Formation, (b) La Despedida Group; (6) 2.10–1.0 g/cm^3.

−21 mGal (Figs. 5 and 8, and upper diagram, Fig. 9) and 2110 nT (Fig. 8).

The N–S cross-geologic model section of Fig. 10 (location in Figs. 2 and 4) throughout the area combines gravity data with field geological information and the geometry of the deep structures derived from industrial seismic reflection lines in neighboring areas (Alvarez Marrón, 1993; Klepeis and Austin, 1997) and the Atlantic offshore (Galeazzi, 1998; Tassone et al., 2001a, 2003; Lodolo et al., 2002a, 2003; Yagupsky et al., 2003, in press). The model geometry of the deep duplex with the buried leading edge is geometrically similar to the structures exposed in the western part of the Island (Klepeis and Austin, 1997) with the passive roof thrusts and backthrusts that create the triangle zone north of the Lago Fagnano area which is well constrained with geological field data. The lower detachment levels experience up to 40% shortening, whereas the upper structures display less than 20% contraction.

The geometry of the MFS in the geologic and gravity model is similar to the geometry revealed by the seismic images in the Atlantic offshore and the Magallanes Strait (Lodolo et al., 2002a, 2003; Yagupsky et al., 2003; Fig. 11), where half-graben basins typically are associated with distinct segments of the MFS. The offset of the strike-slip faults, toward the plane of the section, constitutes a central reason for the lack of geometrical information. Field geological data and regional considerations indicate that the offset may be a few tens of kilometers.

3. Discussion and conclusions

Gravimetric and magnetometric data provide critical information about those areas in which rock exposures are lacking. In the surveyed area, the MFS segments have a clear morphological expression and are associated with localized gravity minima. The three recognized gravimetric minima, according to the field structural data, are interpreted as pull-apart basins formed within the MFS's principal displacement zone during a transtensional tectonic regime.

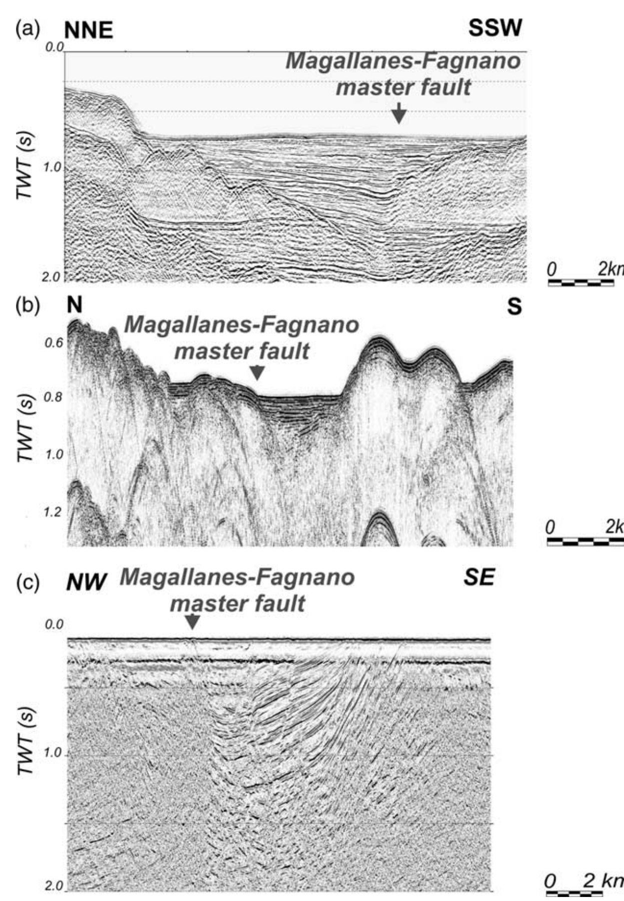

Fig. 11. Seismic profiles across the Magallanes–Fagnano master fault with near-vertical faults and polarities that change along the fault trace (adapted from Lodolo et al. (2003) and Yagupsky et al. (2004)). The profiles (for location, see Fig. 1) show asymmetric basins similar to the Fagnano Basin. The sedimentary architecture reflects a combination of strike-slip motion and transform-normal extension.

At the ESE tip of Lago Fagnano, the monzodioritic Hewhoepen body—intrusive in the Early Cretaceous Yahgan Formation—emerges as an isolated relief. Geophysical modeling reveals a piston shape for this intrusive body, whose emplacement could be favored by a releasing bend area associated with the MFS (Cerredo et al., 2000). In the northern Chilean shore of the Beagle Channel, the post-mid-Cretaceous Yamana granite suite has been interpreted as filled, left-lateral transtensional zones along the main Beagle Channel fault system (Cunningham, 1995).

The magnetic data suggest the existence of intrusive bodies in the subsurface. The magnetic anomaly contour lines for these bodies display oval shapes with NW–SE major axes, which agree with the calculated rotation of the magnetic pole of the intrusive of Cerro Hewhoepen (counterclockwise rotation of $33.4 \pm 7.5°$, inclination anomaly of $39.7 \pm 6.0°$; Baraldo et al., 2002). The anomaly in the magnetic remanence indicates that the body's original position was tectonically modified. The transtensive movements along the MFS may have been responsible for northward tilting around a subhorizontal E–W axis and a counterclockwise rotation around the vertical axis. Furthermore, the MSA values of the intrusive Hewhoepen suggest an EW lineament, which coincides with the transtension direction of the MFS (Baraldo et al., 2002).

The MFS, as indicated by the 2D gravity model and interpreted geologic section, is represented by subvertical faults (Figs. 9 and 10) and a closely associated asymmetric basin that results from simultaneous strike-slip motion and normal extension. This asymmetric basin, similar to those recognized in the Atlantic offshore (Tassone et al., 2001a, 2003; Lodolo et al., 2002a, 2003; Yagupsky et al., 2004; Fig. 11) and the western Tierra del Fuego Island area (Klepeis, 1994; Klepeis and Austin, 1997), postdates both Mesozoic units affected by Andean shortening and Tertiary synorogenic deposits.

The Lago Fagnano Basin presents a highly asymmetric shape; the steepest slope parallels the northern shore, and it reaches a maximum depth of 204 m (Tassone et al., 2001b). This trend follows the ESE–WNW narrow depression located onshore to the east, in which a releasing sidestep corresponds with the eastern shore of Lago Fagnano. This site provides morphological evidence of the Quaternary activity of the fault (Menichetti et al., 2001; Lodolo et al., 2002b).

The sedimentary architecture of the Neogene depocenters, formed along the main displacement zone of the MFS, reflects a close relation between transform normal extension and strike-slip motion. In the Atlantic offshore, the seismic section through the MFS (Lodolo et al., 2003; Yagupsky et al., 2004; Fig. 11) shows a small basin that hosts approximately 2000 m of sediments; the deposits provide a divergent acoustic fabric against the main fault and a fan-shaped geometry that is characterized by changes in the dip and thickness. These elements clearly point to the syntectonic nature of the basin. Similar Paleogene elongated extensional basins that evince sinistral strike-slip have been reported in the Carabajal valley (Caminos et al., 1981; Figs. 1 and 3) and along the northern shoreline of the Beagle Channel (Caminos et al., 1981; Cunningham, 1993, 1995). The Paleogene–Neogene shift of pull-apart basins might be associated with the northward displacement of the South American–Scotia plates boundary. Similar asymmetric basins typically are found along transform plate boundaries and display increasing sedimentary thickness near the fault and normal-strike extension (Ben-Avraham, 1992).

The major transforming structures could be related to movements associated with the Antarctic Peninsula–South America separation during the Upper Cretaceous–Tertiary by the Beagle Channel sinistral fault system, and the MFS could have evolved later in relation to the western Scotia Sea Middle Tertiary evolution.

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