PETROLOGIC AND PALEOMAGNETIC STRUCTURE OF THE UPPER MESOZOIC TORTUGA OPHIOLITE, FUEGIAN ANDES

Felipe Coloma[1,2], Viviana Avendaño[1], Mauricio Calderón[2], Natalia Astudillo[3], Augusto Rapalini[4]

(1) Departamento de Geología, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Casilla 13518, Correo 21, Santiago, Chile.

(2) Servicio Nacional de Geología y Minería, Av. Santa María 0104, Providencia, Santiago, Chile.

(3) Departamento de Ingeniería en Minas, Universidad de Santiago, Av. Alameda Libertador Bernardo O'Higgins 3363, Estación Central, Santiago, Chile.

(4) Laboratorio de Paleomagnetismo IGEBA, Universidad de Buenos Aires,
Ciudad Universitaria, Pabellón 2, C1428EHA, Buenos Aires, Argentina

Abstract

A mineralogical and paleomagnetic study of the Tortuga Ophiolite, on samples covering different lithologies from extrusive basalts to sheeted dikes and cumulate gabbro, provided insights about the magnetic remanence of oceanic crust generated in back-arc basins that subsequently were obducted onto continental crust. Although the igneous textures within the ophiolitic pseudostratigraphy are well preserved, basalts, diabases and dikes in upper levels are vastly hydrothermally altered. Prevailing Prehnite to Greenschist facies secondary mineral assemblages grade downwards through the ophiolitic section and consist of prehnite, albite, chlorite, epidote, titanite, actinolite, andesine, hornblende, with rare white mica and biotite. Subordinate opaque minerals vary downward, being characteristic pyrrhotite, chalcopyrite, pyrite, limonite and magnetite in basalts; hematite pseudomorphs -after magnetite (maghemite)- pyrrhotite, chalcopyrite, pyrite and limonite in diabases and dikes (6-8%;); and pyrrhotite, chalcopyrite, cubanite, bornite, magnetite, hematite pseudomorphs and limonite in gabbros (2-4%). Paleomagnetic data reveal variations of the low natural remanent magnetization of the thick pillow basalts (c. 0.01 A/m) and diabase-dike layers (c. 0.05 A/m) with higher values in the gabbro layer (c. 2 A/m). Mean magnetic suceptibility is higher in the lower gabbro layer ($66.1*10^{-4}$ SI) compared to that measured in diabase-dikes and basalts ($6.4*10^{-4}$ and $6.7*10^{-4}$ SI, respectively). Remanence demagnetization curves for samples subjected to alternating magnetic fields indicate that “invisible” single and/or pseudo-single domain magnetite and/or low-Ti titanomagnetite is the likely magnetic carrier of the magnetic remanence in the ophiolitic pillow lavas as well as in the underlying dikes and gabbros. The magnetic structure of the Tortuga Ophiolite is thougt to be inherited from the seafloor hydrothermal alteration processes that occurred in the vicinities of a spreading center, in which high thermal gradients and possibly the low permeability prevented the fluid penetration and mineral modification by water–rock interactions in the deep gabbro layer.

Resumen

Un estudio mineralógico y paleomagnético de la Ofiolita Tortuga realizado en muestras de basaltos, diabasas y gabros dentro de la secuencia ofiolítica, provee información acerca de la remanencia magnética de fragmentos de corteza de tipo oceánica generada en cuencas de tras-arco, que posteriormente fueron obductados sobre corteza continental. Aunque las texturas ígneas están bien preservadas, basaltos y diabasas de los niveles superiores se encuentran ampliamente afectados por alteración hidrotermal. En éstas, y hacia abajo en la sección ofiolítica, predominan asociaciones minerales de facies Prehnita a

Esquistos Verdes, que incluyen asociaciones de prehnita, albita, clorita, epidota, titanita, actinolita, andesina, hornblenda, con mica blanca y biotita ocasional. Minerales opacos subordinados varían desde pirrotina, pirita, calcopirita, limonita y magnetita en basaltos; pseudomorfos de hematita - como reemplazo de magnetita (maghemita) -pirrotina, calcopirita, pirita y limonita en diabasas y diques (6-8%); y pirrotina, calcopirita, cubanita, bornita, magnetita, pseudomorfos de hematita y limonita en gabros (2 - 4%). Los datos paleomagnéticos revelan variaciones en la magnetización remanente natural de los basaltos almohadillados (alrededor de 0,01 A / m) y el nivel de dique de diabasa (c. 0,05 A / m), con respecto a valores más altos registrados en la capa de gabros (c. 2 A / m). La susceptibilidad magnética media es mayor en el nivel de gabros (66.1 * 10^{-4}SI) con respecto a lo obtenido en los diques y basaltos (6.4 * 10^{-4} y 6.7 * 10^{-4} SI, respectivamente). Las curvas de desmagnetización de remanencia para las muestras sujetas a campos magnéticos alternos indican que granos “invisibles” de magnetita y/o titanomagnetita baja en Ti, de dominio simple y/o pseudo-simple, son los portadores de la magnetización que controla la remanencia magnética en la sección ofiolítica. Los nuevos datos revelan una estructura magnética de 2 capas, caracterizadas por una mayor contribución magnética de la capa de gabros en comparación a niveles superiores de basaltos y diques. La estructura magnética de la Ofiolita Tortuga posiblemente fue heredada de los procesos de metamorfismo o alteración hidrotermal de fondo oceánico que ocurrió en las cercanías de un centro de expansión, en el cual los altos gradientes termales y posiblemente la menor permeabilidad en la capa profunda de gabros controló la penetración de fluidos y modificación de minerales por interacción agua-roca.

Introduction

Ophiolite complexes, the igneous constituents of the oceanic-type crust and upper lithospheric mantle, comprise a succession of basaltic lava flows grading downward to levels of sheeted dike complexes, massive diabase and gabbroic units, and ultimately ultramafic rocks at the base (Penrose conference; Anonymous 1972). Discontinuous exposure of ophiolitic complexes along the southernmost Andes of South America (Fig.1), host critical information about the early break-up of southwestern Gondwana margin and the Jurassic-Cretaceous Rocas Verdes rift/back-arc basin evolution. The Tortuga Ophiolite (55ºS) has been considered to record the advanced evolutionary stage of a back-arc basin opening in a mid-ocean ridge-type spreading center (cf.. Stern and de Witt, 2003) which was closed and partially obducted onto continental crust in the Late Cretaceous. The study of the Rocas Verdes basin ophiolites provide important insights about magnetic remanence of oceanic-type crust generated in back-arc settings (de Wit and Stern, 1976, Singer et al., 2005) that can be useful when trying to understand the origin and model the structure of the marine magnetic anomalies in marginal basins.

Methodology

The Tortuga Ophiolite crops out in the south-western area of the Isla Navarino, and along the central part of the Isla Milne Edwards (Fig. 1). Deep and shallow constituents of the ophiolite pseudostratigraphy crop out to the west, suggesting that the ophiolitic block was gently tilted to the east. Different layers of the exposed ophiolite pseudostratigraphy (lacking ultramafic rocks) were visited and sampled. Metamorphosed mafic rocks were investigated under the microscope (22 samples) to determine the secondary mineral assemblages, including silicates and opaque minerals. A paleomagnetic study was performed in order to establish both the carrier of remnant magnetization and the petrological and magnetic structure of the Tortuga ophiolite. Core samples sliced into standard 2.2 cm long specimens, were obtained from oriented blocks from the three different levels of the ophiolite pseudosection. All measurements were carried out at the Paleomagnetic Laboratory of the IGEBA (University of Buenos Aires). Remanence was measured with a DC squids 2G cryogenic magnetometer. Demagnetization was performed either with 3 axis automatic static degausser attached to the magnetometer or with a dual-chamber ASC non-magnetic furnace. The type of demagnetization was fundamentally AF (alternating fields), but also some samples were demagnetized with thermal method. Analysis of anisotropy of magnetic susceptibility were performed on a susceptibilimeter AGICO MFK-1A.

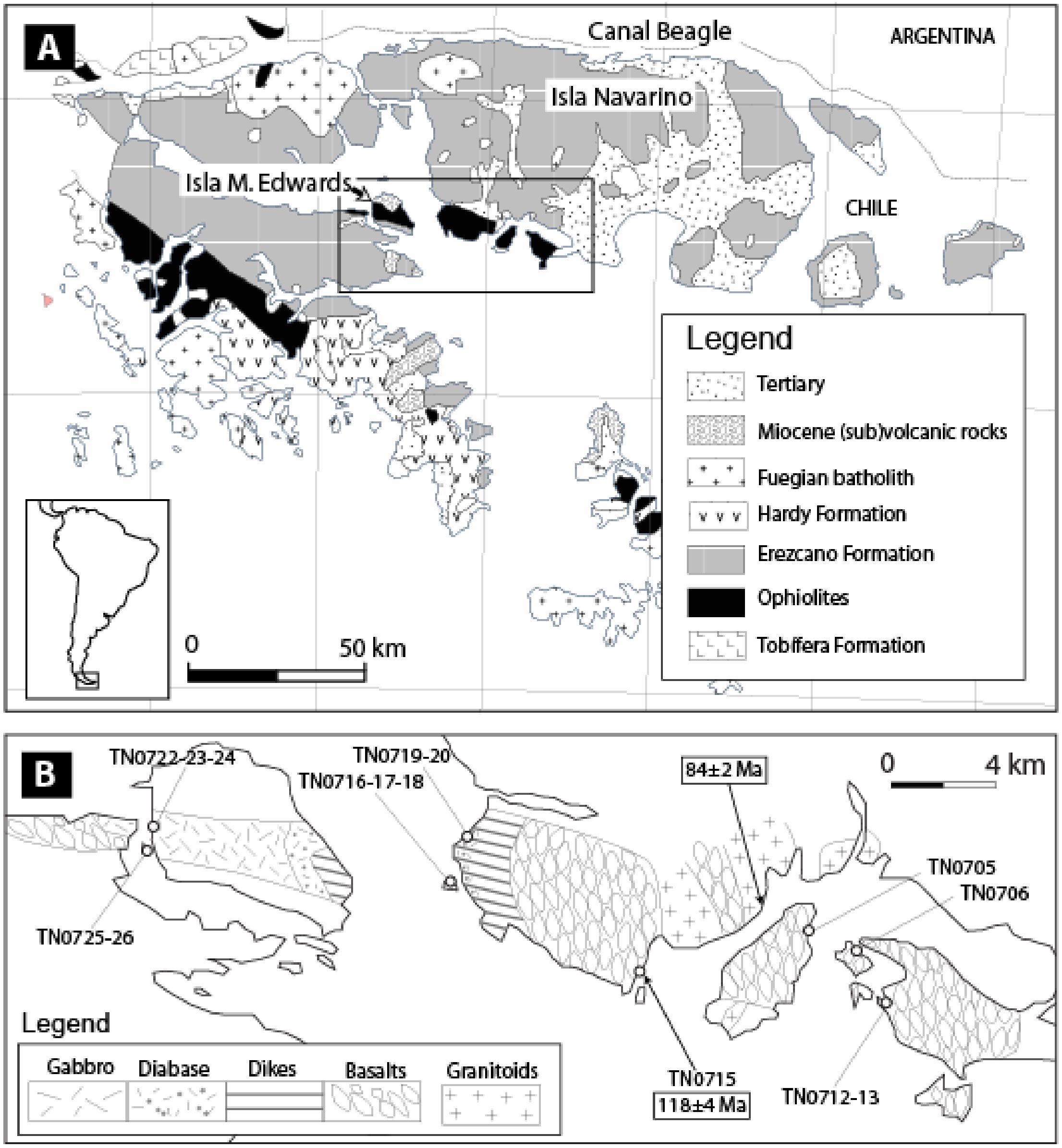

Figure 1. Geological map of the study area. Location of studied samples are indicated.

Results

Petrography

Igneous textures within the ophiolitic pseudostratigraphy are well preserved, and basalts, diabases and dikes in upper levels are vastly hydrothermally altered. Prevailing secondary minerals that grade downwards from Prehnite to Greenschist facies assemblages through the ophiolitic section. A comprehensive summary of silicate and opaque mineral phases in presented in Figure 2.

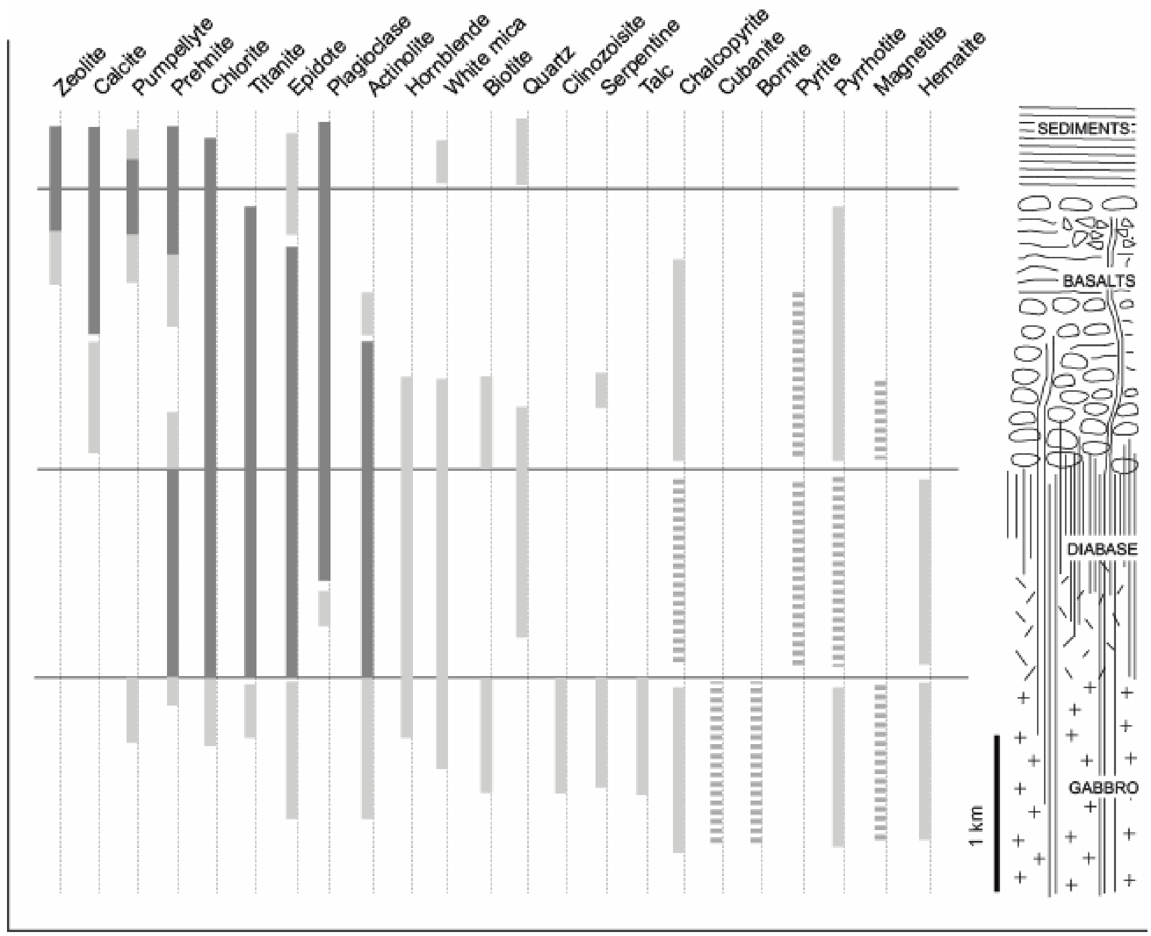

Figure 2. Tortuga Ophiolite pseudostratigraphy and schematic distribution of mineral parageneses in mafic rocks. Heavy lines show major phases and dashed lines show minor, or trace phases.

Magnetic properties

Bulk susceptibility (k)

A AGICO MFK1-A susceptometer was used to measure susceptibility of each specimen. In the basalts and diabase levels, the susceptibility values obtained were in the same range. The basalts varies between 3 x 10-4 SI and 7,5 x 10-4 SI, while in the diabases, 8,52 x 10-4 SI was the maximum value obtained. Meanwhile, in the gabbros, the values for susceptibility vary from 4 x 10-3 SI to 1.5 x 10-2 SI.

Natural Remanent Magnetization (NRM), grain size and magnetization's carrier

Remanence values were measured for rocks of the 3 pseudostratigraphic levels. At both basalt and diabase levels, the observed values of NRM are low, ranging between 2.5 and 35 mA / m for basalts, and 10 to 17mA / m for diabase. As seen with the susceptibility, the NRM intensities of the gabbros are 1 to 2 orders of magnitude greater with respect to the observed in other rocks, varying from a minimum of 500 mA / to a maximum of 7700mA / m.

Composite alternating field demagnetization up to 100 or 120 mT plus thermal demagnetization up to 600°C (fig.3) permits to define that magnetite or Ti-poor titanomagnetite is the main carrier in all rocks. Very high medium destructive fields, convex to concave –up AF demagnetizing curves (Dunlop and Ozdemir, 1997) and discrete unblocking temperatures, all suggest dominance by PSD or SD grains.

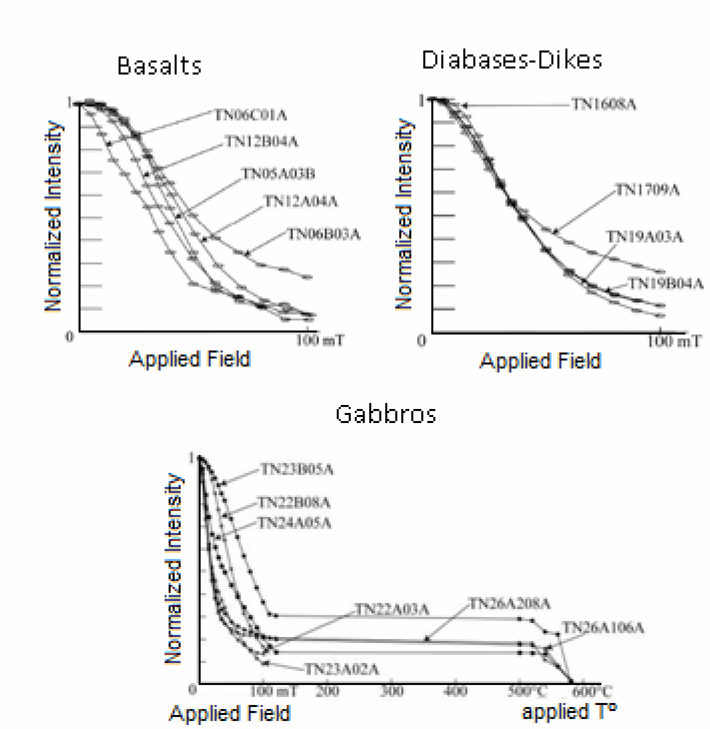

Figure 3. Demagnetization curves of basalts, dikes and gabbros submitted to alternating magnetic fields and thermal demagnetization

Discussions

The intensity of the natural remanent magnetization (NRM) and the average susceptibility of the Tortuga ophiolite are generally low, ranging between 0.01 and 1 A/M and between 0.0001 and 0.01 (SI), respectively. Clark & Emerson (1991) suggest that the greenschist facies metamorphism tends to destroy most of the ferromagnetic minerals, and thus the average susceptibility values decrease. Rapalini et al (2008) argues that this is consistent with the low values of susceptibility observed in the dikes and lavas of the Sarmiento Ophiolitic Complex. Comparison of the susceptibility between both ophiolitic complexes show to be almost in the same range.

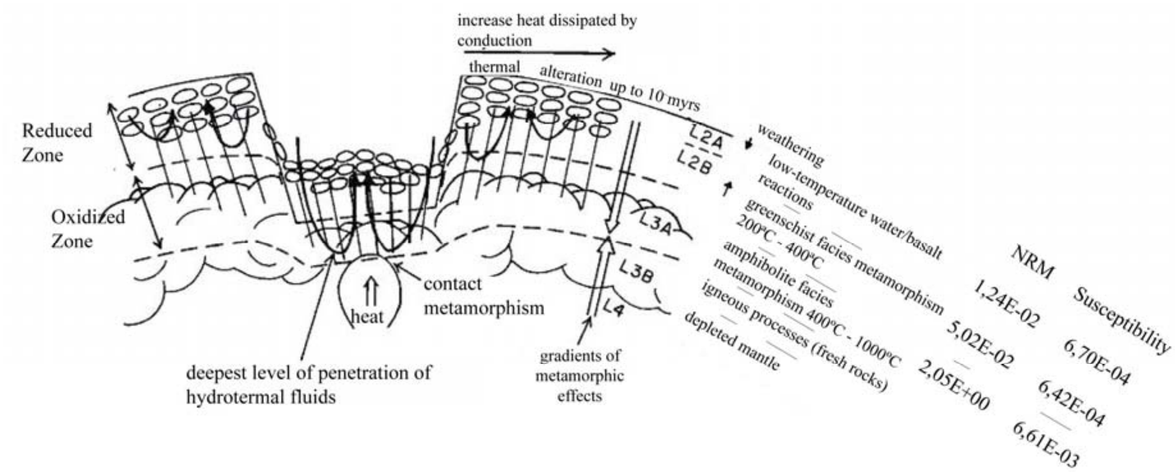

Figure 4. Magnetic structure of the Tortuga Ophiolite; note the differences in the magnetic properties for the pseudostratigraphic section. Modified from Stern et al. 1976.

The fact that the gabbros have greater values of susceptibility and NRM respect to the other rock types may be due either to secondary growth of ferromagnetic minerals like magnetite, or to a lesser degree of metamorphism affecting them and therefore survival of a larger fraction of the original mineral. Avendaño (2008) found that the degree of metamorphism of basalts and sheeted dikes is in the order of ~80%, meanwhile the gabbros have only 30% of its minerals altered. Whether the larger depth of the gabbros or a lower permeability (less water/rock interaction) were factors controlling the differential methamorphism should be investigated

Acknowledgements

This is a contribution to Proyecto Anillo Antartico ACT-105 (CONICYT). The colleagues Leonardo Fadel Cury and Esteban Salazar participated in the field work. Captains Gilles Rigaud and Sebastian Magnen provided a safe trip in the “Morgane” yacht.

Referencias

Avendaño, V. 2008. Petrología del Complejo ofiol{itico Tortuga, Magallanes Chile: Evidencias de un metamorfismo Cret{acico Inferior. Memoria de título geólogo, Universida de Chile, 128 pp.

Butler, R.F. 1992. Paleomagnetism: Magnetic Domains to Geologic Terranes. Blackwell Scientific Publications, Boston, MA. 319 p.

Clark, D.A.; Emerson, D.W. 1991. Notes on rock magnetization characteristics in applied geophysical studies. Explor. Geophys. 22, 547 – 555.

de Wit, M.J.; Stern, C.R. 1976. A model for ocean floor metamorphism, seismic layering and magnetism. Nature 264, 615-619.

Dunlop, D.J.; Özdemir, Ö. 1997. Rock magnetism, fundamentals and frontiers. Cambridge University Press, 573 p.

Rapalini, A.E., Calderón, M., Singer, S., Hervé, F., Cordani, U. 2008. Tectonic implications of a paleomagnetic study of the Sarmiento Ophiolitic Complex, southern Chile. Tectonophysics 452, 29–41.

Singer S., Rapalini A., Calderon, M., Hervé, F., 2005. Study of the Sarmiento ophiolite magnetic minerais: Contribution to the reconnaissance of a metamorphic overprint. 6th International Symposium on Andean Geodynamics ,Extended Abstracts: 673-676

Stern, C.R., de Wit, M.J. & Lawrence, J.R., 1976. Igneous and metamorphic processes associated with formation of Chilean ophiolites and their implications for ocean floor metamorphism, seismic layering and magnetism. Journal of Geophysical Research, 81, 4370-4380.

Stern, C.R.; de Wit, M.J. 2003. Rocas Verdes ophiolites, southernmost South America: remnants of progressive stages of development on oceanic-type crust in a continental margin back-arc basin. In Ophiolites in Earth History (Dilek, Y.; Robinson, P.T.; editors), Geological Society, London, Special Publications 218, 1-19.