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Study of the Sarmiento ophiolite magnetic minerals: Contribution to the reconnaissance of a metamorphic overprint

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Introduction

The Sarmiento Ophiolitic Complex (SOC), located in the southern Andes of Chile (Fig.1), represents the mafic portion of the Late Jurassic (Calderón et al, 2004) to Early Cretaceous (Stern and De Wit, 2003) oceanic-type floor of a marginal basin closed and uplifted in the Mid Cretaceous (Dalziel, 1981). Its igneous pseudostratigraphy consists of mainly mafic pillow lavas, dikes, and gabbros. These rocks underwent a non - deformative " ocean floor metamorphism" which developed secondary mineral assemblages in a vertical steep metamorphic gradient passing from zeolite to actinolite facies, followed by a transition to fresh gabbros (Elthon and Stern, 1978). Syntectonic phengite, stilpnomelane, chlorite and actinolite in mylonitic rocks bordering the thrust slices that expose the SOC (Calderón et al, this volume), represent a different metamorphic event, that probably occured before the latest Cretaceous (ca. 75 Ma, Rapalini et al, 2004). Incidence of the mentioned metamophic processes on the natural remanent magnetization of the ophiolite was evaluated thru a susceptibility survey and a study of ferromagnetic (s.l) minerals. As a part of a classic paleomagnetic study (Rapalini et al, 2004) , the ophiolite was sampled (drilled) at 14 sites distributed regionally (about 100 Km N-S) on different stratigraphic levels.

Magnetic Susceptibility and natural remanent magnetization

The bulk magnetic susceptibility (K) of any given material is defined by $K = M / H$ where, M is the induced magnetization in the material by a weak magnetic field of constant strength (H), being dimensionless in the *Systeme International* (SI). In particular, within a rock, each forming mineral contributes with its own susceptibility and concentration to the total susceptibility of the rock, although if magnetite is present, even at low concentrations, it controls this property due to its very high susceptibility. As a consequence, rock susceptibility gives us a first idea of the contribution of magnetite to it. Taking into account this later concept, informal classification schemes based on the magnetic susceptibility have been established to assign a magnetic behavior to each rock (Clark, 1999). Site arithmetic means (*Kmean*) in the SOC and their standard deviation are summarized in Table 1 showing ,with few exceptions, homogeneous values of low K . On the other hand, paleomagnetic results from all sites (Rapalini et al, 2004) indicate that most (11 out of 14 sites) have a post-tectonic characteristic remanent magnetization. The rock magnetism experiments (unpublished results) suggest that remanence is carried by few SD and/or PSD Ti-poor magnetite grains below the optical resolution of the microscope.

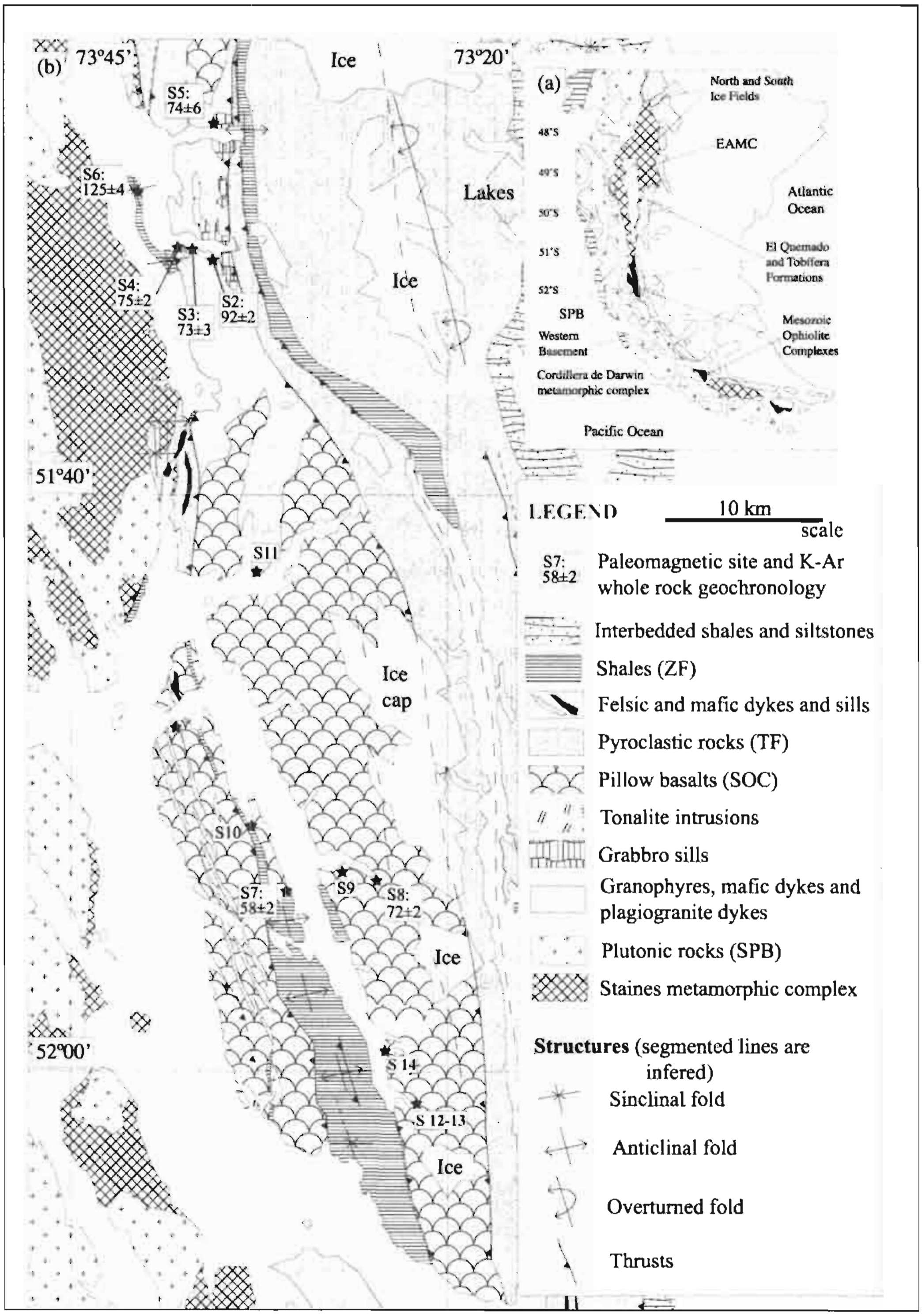

Fig. 1- Geologic map of the Sarmiento Ophiolite and whole-rock K / Ar radimetric ages (Rapalini et al, 2004)

Ferromagnetic (*s.l*) minerals

The studied rocks show metamorphic assemblages consisting of actinolite/tremolite, titanite, epidote, chlorite/smectite, quartz, Na-plagioclase and carbonates in mafic dykes and gabbros of the northen area, and epidote, chlorite/smectite, titanite, actinolite/tremolite, pumpellyte and carbonates in mafic dykes and lavas from the southern area (Fig.1). K-Ar dates of the sites can be looked in the Fig.1. Magnetic minerals were identified by microscope observations under reflected and transmitted light and by energy dispersive X-ray spectrometry (EDAX). The optical observations on each site are the following:

Site 2A : gabbro with abundant ilmenite intergrown with hematite .It is common the presence of ilmenite along to cleavage planes of metamorphic amphiboles and rod - shaped precipitates. These oxides seems formed by uralitization of the pyroxenes during the ocean floor metamorphism. Sulfides are abundant.

Site 2B: dike crosscutting gabbro shows ilmenite crystals rimmed by titanite.In some specimens magnetite-ilmenite intergrowns are observed and possibly have the same metamorphic origin that site2B.

Site 3 : sheeted dike similar to that of site 2B, although the replacement of ilmenite by titanite is greater , including pseudomorphs .

Site 4: sheeted dike with titanomagnetite and ilmenite crystals.

Site 5 and 11 : sheeted dikes with abundant grumous titanite without Fe-Ti oxides. They present sulfides (pyrrhotite-pentlandite? and chalcopyrite grains rimmed by goethite)

Site 6: basic dike (does not belong to the ophiolite) that intrudes discordantly Zapata Formation (Fig.1). Also a greenschist-facies mineral assemblage is found . Sulfides are abundant (large chalcopyrite grains rimmed by goethite, pyrrhotite-pentlandite?). An Mn-Fe oxide of the spinel group (probably jacobsite) is recognized too.

Site 7, 8 , 9 and 10: pillow lavas do not show Fe-Ti oxides. They present titanite and abundant sulfides in veins and cavities.The populations of sulfides belong to little chalcopyrite grains , pyrrhotite-pentlandite? and an undetermined mineral that present cubic morphology and anisotropy under crossed nicols. Possibly, these grains may be pyrite with As, Co, or Ni content. Pillow lavas from sites **12, 13 and 14** are under study.

Discussion

A quick look at the susceptibility values (Table1) shows a similarity among most of sites , independently of litology and age. Those magnetic susceptibilities values are consistent with the microscope observations which indicate that in these rocks metamorphic processes have perfomed strong effects on ferromagnetic minerals . These metabasites are distinctly poor in titanomagnetites, as indicated by their low magnetic susceptibilities, except the metagabbros and some dikes crosscutting gabbros. These later show higher susceptibilities due to both ilmeno-magnetite and hemo-ilmenita generated by uralitization of pyroxenes during the ocean floor metamorphism. Sheeted dikes and pillow lavas show low susceptibilities controled by paramagnetic minerals and they contain titanite as witness of the presence of a primary titanium-bearing mineral. Sulfide mineralization in the Complex requires further studies. The evidence suggest that in these rocks (which contain silicates that can accommodate Fe^{+3} in their structures), equilibria between Fe oxides and Fe^{3+} in silicates has played an important role in determining the occurrence and abundance of titanomagnetites during metamorphism.

Finally, the integration of the foregoing regional information (Syntectonic greenschist facies assemblages in mylonitic rocks bordering the thrust slices that expose the SOC , similar susceptibilities, probable destruction of the primary magnetic minerals and common post- tectonic remanences at most sites) suggest a greenschist facies metamorphic overprint probably during Late Cretaceous . It is likely that chloritization (Eggleton and Banfield, 1985) might be responsable for generating almost pure microcrytalline magnetite as shown by the paleomagnetic study.

Table 1-Site mean magnetic susceptibility and magnetic behavior

Sites	Kmean (10^{-5} SI)	Standard Deviation	Magnetic behavior
2A	246	50	Weakly ferromagnetic gabbro
2B	84	13	Paramagnetic dike crosscutting gabbro
3	88	12	Paramagnetic sheeted dike
4	468	175	Moderately ferromagnetic sheeted dike
5	49	14	Paramagnetic sheeted dike
6	63	4	Paramagnetic lamprophyric dike
7	57	-	Paramagnetic pillow lava
8	59	11	Paramagnetic pillow lava
9	66	5	Paramagnetic pillow lava
10	49	4	Paramagnetic pillow lava
11	64	2	Paramagnetic sheeted dike
12	68	5	Paramagnetic pillow lava
13	61	16	Paramagnetic pilow lava
14	48	5	Paramagnetic pillow lava

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