The Emplacement of the Nahuelbuta Batholith in an Active Continental Margin (Central Chile)

André Steenken[1], Osvaldo Rabbia[2], Laura Hernández[2]

[1]Universidad Nacional Jorge Basadre Grohmann, Escuela de Ingeniería, Geológica-Geotecnia, Miraflores s/n, Tacna, Perú, asteenken@gmail.com
[2]Universidad de Concepción, Instituto de Geológica Económica Aplicada (GEA), Concepción, Chile, rabbia@udec.cl, lahernan@udec.cl

1. Introduction

The Nahuelbuta Batholith (S 37° 10' – S 38° 15') forms part of the Chilean Coastal Batholith that intruded the Metamorphic Complex of Eastern Series during the Permo-Carboniferous (Deckart et al 2014; Steenken et al. unpublished data) in a subduction tectonic setting (Fig. 1). Most of the igneous rocks are of metaluminous (I-type) character, with plagioclase, quartz, biotite, amphibole and alkali feldspar. The rock bears magmatic epidote, which suggests crystallization at mid-crustal levels. Smaller domains of fine-grained peraluminous (muscovite-bearing) rocks are also present. The protoliths of the Eastern Series together with the Western Series are turbidites that were deposited during the Upper Carboniferous at the end of the Gondwanan Cycle (Mpodozis & Ramos 1990). Those belts were interpreted as a palaeoaccretionary wedge with a paired metamorphic belt (González-Bonorino & Aguirre 1970). Subduction of the oceanic crust was active since the Carboniferous (Bahlburg and Hervé 1997; Kleiman & Japas 2009). SHRIMP U/Pb zircon ages of the batholith indicate that the magmatic activity hold on from 311 Ma for 13 Ma (Deckart et al., 2014; Steenken et al. unpublished data). The emplacement depth has a pressure of at least 450 MPa (Schmidt & Poli 2004). The Batholith was exhumed before the Upper Triassic where the Santa Juana Formation was deposited with the eroded blocks of the intrusive rocks.

We are working on the emplacement mechanism of the Nahuelbuta Batholith in order to define the displacement between the oceanic plate and the continental basement in the time of intrusion. The fabrics are determined by the anisotropy of magnetic susceptibility (AMS). The bulk susceptibility can be below $300*10^{-6}$ SI. In this the case, the fabric of the sample is controlled by paramagnetic minerals (Rochette 1987) while when values are above that value, the fabric is controlled by ferromagnetic minerals. Besides the directions of the fabric, the AMS technique allows to quantify the foliation and lineation. This results in a degree of anisotropy (P, P') and the shape parameter (T) which can be prolate or oblate depending on the values for the lineation (l) and foliation (s).

Microstructures are investigated in order to see, if the intrusive rock shows a magmatic or sub-magmatic flow fabric or if the flow fabric was overprinted by a solid state fabric. When the fabric is developed under high temperature, it is related to the emplacement, while if it is developed below 400°C, the fabric has to do with the exhumation or the effects of another orogenic cycle.

2. Microstructures

Most of the samples show magmatic to sub-magmatic fabric, which is indicated by the imbrication of euhedral plagioclase, biotite and amphibole with quartz and alkali feldspar in the interstices. Plagioclase has a normal oscillatory zonation due to the addition of magma and the fractionation of melt. Quartz is characterized by large grain-size in mm-scale. They show lobate grain boundaries and dissection microstructures which are all indicative of grain-boundary migration (GBM) recrystallization of high temperature (500°-600°C). Some quartz show chess-board extinction pattern over the entire grain which is an indication of high temperature solid-state deformation. At the margin of the batholith, few myrmekite microfabrics are present in alkali feldspar which further indicates high-temperature solid-state deformation. Quartz grains show a bulging recrystallization which normally occurs between 270° and 400°C.

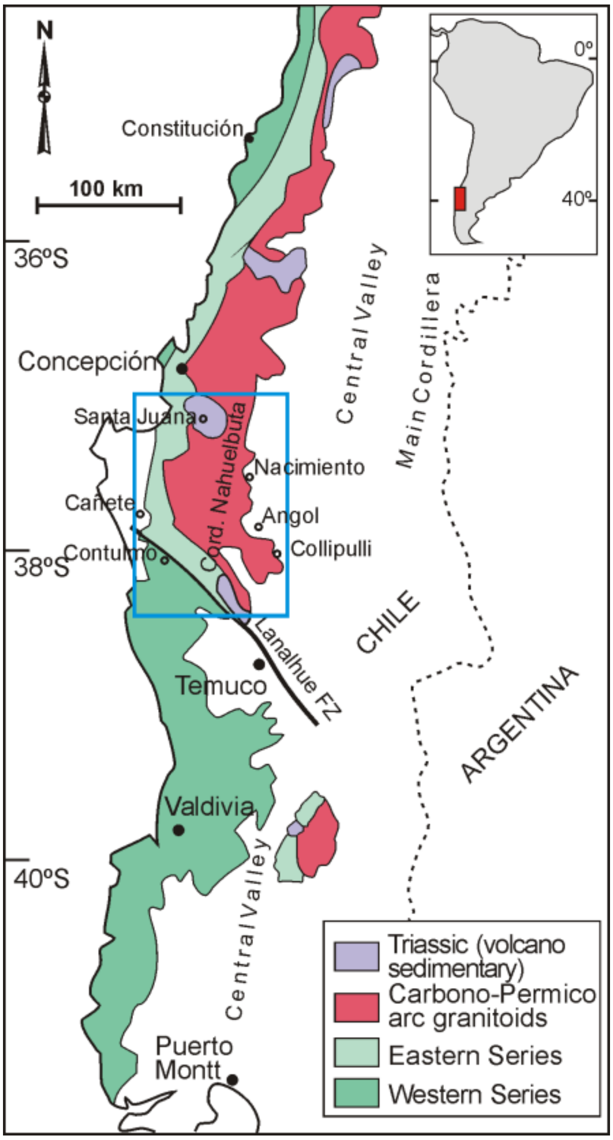

Fig. 1: An overview showing the southern part of the Coastal Batholith, including the Nahuelbuta Batholith and the Metamorphic Complexes of the Eastern and Western Series.

3. Magnetic measurements

3.1. Methodology

We have measured the anisotropy of magnetic susceptibility (AMS) on 39 samples, which corresponds to 1 sample site per 150 km^2. Between 5 and12 rock cylinders were measured for 1 site with the exception of 2 sites where only 3 rock cylinders were measured. Measurements were performed using a Kappabridge MFK1-FA manufactured by AGICO Ltd. (Czech Republic). The AMS ellipsoids were calculated using the program Anisoft 4.2 (Jelínek 1978). For presentation of the magnetic fabric data, the degree of the corrected anisotropy (P') and shape parameters (T; Jelínek 1981) were chosen or used.

3.2. Results

The bulk susceptibility of the Nahuelbuta Batholith covers the range $25*10^{-6}$ to $802*10^{-6}$ SI with the exception of one fine grained sample whose bulk susceptibility is $3710*10^{-6}$ SI. This last value could correspond to a younger intrusion within the Nahuelbuta Batholith. Almost 70% (27 of 39) of the studied samples are paramagnetic controlled, with susceptibility values < $300*10^{-6}$ SI. The directions of the fabric of these paramagnetic controlled samples are parallel to the petrographic fabrics. In 11 sample sites the magnetic fabric is controlled by ferromagnetic minerals but the K_{max} or K_{min} for one sample site plot in the same directions, which indicates that the ferromagnetic controlled sample might be also have the same directions like petrographic ones. The degree in magnetic anisotropy which is < 1.073 also is in accordance with a paramagnetic control of the petrographic fabrics. The values for the magnetic foliation (s) and lineation (l) are 1.052 and 1.053 respectively.

4. Discussion and conclusions on the emplacement

The SW convergence of the oceanic lithosphere during the Upper Carboniferous causes a sinistral shear of the overriding continental crust. The basement rocks that form the host the batholith are of turbiditic origin and were isoclinal folded during in a first deformation event (D_1) and open folded during a second deformation event (D_2). The batholith was emplaced during the second deformation event. Therefore, the NNE-SSW striking F1 fold axes are rotated due to the batholith emplacement. To the east of the batholith, the isoclinal F_1 folds are east-verging, while to the west of the batholith F_1 folds are west-verging. The s_2 foliation is parallel to the subhorizontal west-verging open F_2 folds and dips close to horizontal. The second foliation is related to the emplacement of the batholith.

The magnetic foliations in the igneous rocks are moderate to steep inclined and strike from NW to N. The inclination of the foliation at the margin in the west is towards inside the batholith which indicates a position below the equator level of the body. The vertical distance from the western border to the roof pendant is ~1200 m, which may represent the upper half of the batholith.

The prolate magnetic lineation plunges towards the south or to the north. The plunge of the southward lineation is moderate to flat lying, while the northward plunging lineation is moderate to steep. The magnetic fabric is in accordance with the petrographic data.

The vertical k_{max} axis probably reflects the ascent of the magma. This correlates with some parts of the batholith that have a high density of microgranular mafic enclaves. The microgranular enclaves are a less fractionated magma that marks the feeder zone. They have a prolate shape with the longest axis pointing downwards in the direction from where the less fractionated magma comes. The microgranular mafic enclaves are roughly vertical and have an orientation of strike that is ENE-WSW to NE-SW. This is an indication that the magma was emplaced in a non-coaxial setting with respect to the N-S oriented coastline and the convergence direction of the oceanic plate at the time of the batholith emplacement. The magma ascent is at high angle to σ_1 direction in the plastically deformed crust.

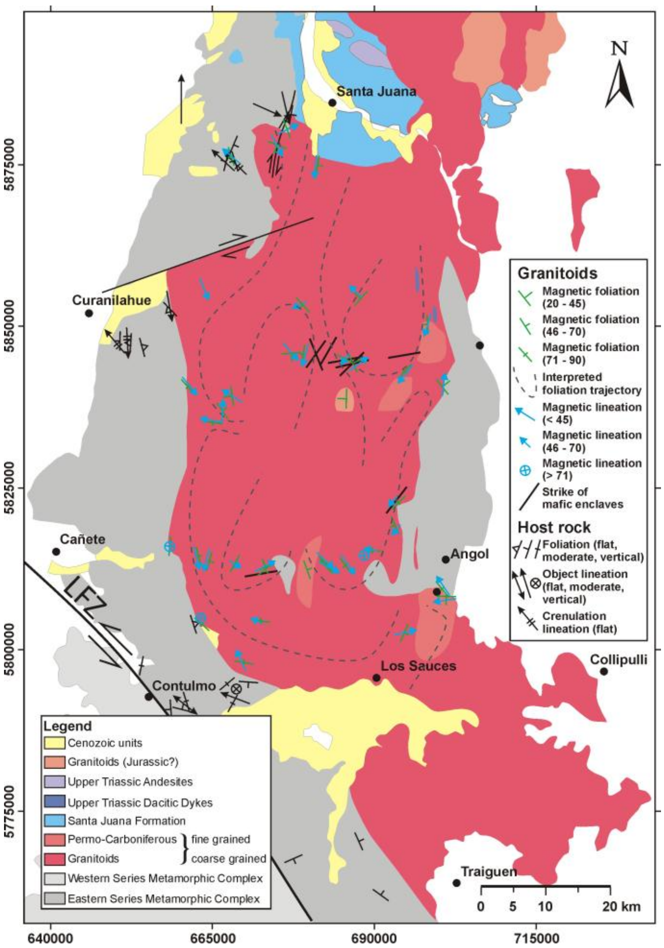

Fig. 2: The Nahuelbuta Batholith with the magnetic foliation and lineation. The host rocks are the Metamorphic Complexes of the Eastern and Western Series. The foliations and lineations in the host rocks are values from the field.

At the northern end of the batholith, near to the village of Santa Juana (Fig. 2) the sub-magmatic foliation has an overprint of a high-temperature solid-state flow. From the microstructures study, it is implied that the solid-state fabrics belong to the final stages of the intrusion. The N-S striking foliation in the igneous rocks is parallel to the foliation in the host rock and discordant with the contact plane which indicates that the foliation of the igneous rocks is part of the regional foliation of the country rock. The foliation is steep to moderate inclined and dips to the E. The metapelitic host rock is a migmatite that bears garnet and sillimanite indicative of upper amphibolite facies conditions. The host metapelites are mylonites with a within-dip lineation that shows an inverse displacement.

The Nahuelbuta batholith used those mylonitic structures for the emplacement process, indicating that the intrusion was in a transpressive setting. Therefore, the ascent was in a non-coaxial deformational regimen, with a sinistral sense of shear. Stoping, as indicated by larger blocks of the country rock within the granitoids, is observed close to the contact.

Acknowledgment

Special thanks to Augusto Rapalini for the use of the magnetic laboratory in Buenos Aires. We are in debt to Scott Giorgis and his knowledge about ascent and emplacement of the magma. We thank Oscar Figueroa for his knowledge about the structures in the region and Luis Vásquez for the introduction in AutoCAD and ArcGIS. This study was supported by FONDECYT Project # 1140669.

References

Bahlburg, H., Hervé, F., 1997, Geodynamic evolution and tectonostratigraphic terranes of northwestern Argentina and northern Chile, GSA Bulletin 109, 869-884

Deckart, K., Hervé, F., Fanning, M.C., Ramírez, V., Calderón, M., Godoy, E., 2014, U-Pb Geochronology and Hf-O Isotopes of zircons from the Pennsylvanian Coastal Batholith, South-Central Chile, Andean Geology 41, 49-82

González-Bonorino, F., Aguirre, L., 1970, Metamorphism of the Crystalline Basement of Central Chile, Geologische Rundschau 59, 979-994

Jelínek, V., 1981, Characterization of Magnetic Fabric of Rocks, Tectonophysics 79, 563-567

Jelínek, V., 1978, 'Statistical Processing of Anisotropy of Magnetic Susceptibility Measured on Groups of Specimens', Studia geophys. geod. 22, 50-62.

Kleiman, L.E. Japas, M.S., 2009, The Choiyoi volcanic province at 34°S–36°S (San Rafael, Mendoza, Argentina): Implications for the Late Palaeozoic evolution of the southwestern margin of Gondwana, Tectonophysics 473, 283-299

Rochette, P., 1987, Magnetic susceptibility of the rock matrix related to magnetic fabric studies, Journal of Structural Geology 9, 1015-1020

Mpodozis, C, Ramos, V. 1990. The Andes of Chile and Argentina. In: Ericksen, G.E., Cañas, M.T., Reinemund, J., (eds.) Geology of the Andes and its relation to hydrocarbon and mineral resources, Circum-Pacific Council for Energy and Mineral Resources, Earth Science Series 11, 59-90

Schmidt, M.W., Poli, S. 2004, Magmatic Epidote, Reviews in Mineralogy & Geochemistry, 56, 399-430