Jurassic magmatism in Patagonia, Mauritania and Mali: Examples of silicic and basaltic Large Igneous Provinces

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Abstract

During Jurassic times three Large Igneous Provinces (LIPs) were formed in the context of the break-up of Pangea. Two of them, the Central Atlantic Magmatic Province (CAMP) with a dominant mafic composition, and the Patagonian Province mainly felsic, are studied in this project. Their characterization and comparison will contribute to the knowledge of the LIPs and the processes involved in their origin. Preliminary results suggest that sills from Mauritania and Mali, have a composition from basalts to andesites and contents of trace and major elements that correlate with the CAMP, formed at c. 200Ma. In contrast, Patagonian rocks vary from basalts to rhyolites and occurred between 186Ma to 154Ma spread along old re-activated extensional structures. Although both Provinces are related with episodes of continental break-up, the possible influence of an active subduction zone in the origin of Patagonian rocks is explored in this research.

1. Introduction

“Large Igneous Provinces are magmatic provinces with areal extents >0.1 Mkm$^2$, igneous volumes >0.1 Mkm$^3$ and maximum lifespans of ~50 Ma that have intraplate tectonic settings or geochemical affinities, and are characterised by igneous pulse(s) of short duration (~1–5 Ma), during which a large proportion (>75%) of the total igneous volume has been emplaced” (Bryan and Ernst, 2008). During the Late Triassic–Early Jurassic three major continental LIPs were formed (Marzoli et al. 1999; Riley & Knight 2001; Riley et al. 2001; Vaughan and Storey, 2007) (fig1) (1) tholeiitic basaltic magmatism of the Central Magmatic Atlantic Province (CAMP), outcrop over more than 10 x 10$^6$km$^2$ and formed in a few million years, with peak activity at 201 Ma (Marzoli et al, 2011). (2) Southern African Karoo basalts (2.5 x 10$^6$km$^3$), Antarctic Ferrar gabbro and Kirkpatrick basalts (0.5 x 106km3) that were emplaced at c. 180 Ma (Storey & Kyle 1997; Riley & Knight 2001; Jourdan et al., 2004); (3) the silicic magmatic province (2.35 x 10$^5$ km$^3$) of South America and the Antarctic Peninsula, which formed between 188 and 153 Ma ago (Feraud et al., 1999.; Riley et al., 2001; Vaughan and Storey, 2007). Outburst of the CAMP and the Gondwana Large Igneous Provinces (2,3) occurred during break-up of the Pangea supercontinent and coincide with two major mass extinction events at 200Ma (Tanner et al., 2004; Marzoli et al., 2004) and c 183Ma (Aberhan & Fursich 2000).

This research is based on a petrological study of two cases representative of LIPs: 1) Mafic sills part of the CAMP from Hodd, Hank and Kaarta regions, in Mauritanina and Mali, and 2) Silicic magmatism from Chon Aike, Marifil and Bajo Pobre Formations of the Silicic Magmatic Province of Patagonia, Argentina. Both cases were formed in the frame of extensive settings during continental break up. However the relative influence of a paleo- subduction zone at the western margin of South America have been suggested by previous authours (Mpodozis and Ramos, 2008) and is also explored in this project. An integrative geochronological and geochemical study using melt inclusions analyses will provide a reliable record of the evolving magmas, as well as the possibility to recognize and estimate primordial characteristics of the source and large scale processes involved in the origin of the rocks from both cases of study. The results from this project will contribute to understand the relation between magmatic processes and tectonic settings as well as its influence on the origin of LIPs.
Kaarta, Hodh and Hank sills from Maurtania and Mali

The Central Atlantic Magmatic Province (CAMP) is defined by tholeiitic basalts that crop out in once-contiguous parts of North America, Europe, Africa, and South America and are associated with the breakup of Pangea (Marzoli et al., 1999). Extensive dyke swarms and sills partly distributed in the western margin of Africa are described as part of this Province (Bertrand, 1991; Marzoli et al., 1999; Marzoli et al., 2004; Verati et al., 2005; Chabou et al., 2010). Sills were formed as large accumulations of tubular magma piles of fissural origin intruding different levels of sedimentary rocks of Paleozoic age (Bertrand, 1991). A few major dikes of more than 100 km length are present in the northern part of the margin. Instead, southward several swarms of generally shorter dykes form dense networks dominating the area. Sills are highly variable in thickness and extension. The most important are tabular and are widespread in Guinea, Southwest Mali (Diallo et al., 1976; Dars, 1961 in Bertrand 1991) or in South East Mauritania (Hodh area). The Kaarta sill, at the south west of Mali, is one of the best exposed (over 7000 km²; Rossi 1982; Bertrand and Coffrant 1986 in Bertrand, 1991). Some others exhibit numerous secondary ramifications (Lajoinie and Bonifas 1961 in Bertrand, 1991), or are cut by associated dyke swarms. Others are dyke-like elongated, such as Tourist and Azlaf sills in the Hank region in Mauritania (Villemur, 1967 in Bertrand, 1991). Petrographically and mineralogically sills and dykes from the North West of Africa have been described as dolerites and microdolerites by Bertrand (1991). A relative age was established based on the correlation with the extensional activity during the aperture of the Atlantic ocean and progressive continental fragmentation at 200 Ma. Some Ar-Ar, K-Ar and U-Pb analysis in the Taoudeni region, exhibit ages between 190 Ma and 198Ma. These data are supported by some other Ar-Ar radioisotopic ages on mafic intrusive rocks from Mauritania that also reflect CAMP magmatism (Usui et al., 2010; Callegaro, pers. comm., 2011).

Petrography

Most of the rocks exhibit a porphyric texture with an intersertal matrix defined by the presence of fine acicular euhedral to subhedral plagioclase and occasionally devitrified glass (palagonite) intergrown with clinopyroxenes. Glomerocrysts of plagioclase and clinopyroxene (augite) are also present embedded in a microfelsitic or glassy matrix. The occurrence of faneritic samples is also common, especially in Kaarta. They are composed mainly by cumulitic plagioclase intergrown with clinopyroxene forming ofitic and subofitic textures. Alteration is scarce and is most of the time affecting the matrix. The main secondary phases are sericite and chlorite.

Geochemistry

27 samples from Kaarta, 16 from Hodh and 25 from Hank were analyzed for geochemistry of major elements by x-ray fluorescence at ENS-Lyon. They consist of basalts, basaltic andesites and andesites (SiO₂ = 51.9wt% to 58.2wt% in Hodh, 50.46wt% to 53.49wt% in Kaarta, and 49.34wt% to 53.80wt% in Hank). The magnesium number (Mg#) varies in the three regions from 67.98 to 22.64, 68.25 to 34.28, and 69.74 to 43.28, respectively. The TiO₂ content varies in a large range with the more depleted values in the Hank rocks (0.39wt%) and the more enriched in Hodh (2.29wt%). Three groups can be recognized with respect to the content of TiO₂. Two of them, the low TiO₂ (0.39-0.86wt%) and intermediate TiO₂ (0.93-1.62wt%) match with the ranges observed for the CAMP in Marocco (Marzoli et al., 2004) and with the Taoueddi dyke swarm (Verati et al., 2005). A third group characterized by high TiO₂ (1.71-2.29wt%) akin to some CAMP dykes of Guyana (Nomade et al, 2002; Deckart et al., 2005) and Brazil (Merle et al., 2011).
Trace element abundances of 10 samples from Kaarta and 13 from Hank were obtained by ICP-MS at Brest University. An enrichment of lithophile elements and light rare earth elements (LREE) is in general recognized with respect to the heavy rare earth elements (HREE). Negative anomalies of Nb-Ta, Sr, and Eu are recognized as well as a positive anomaly of Pb. Samples from Hank exhibit homogeneous compositions whereas those from Kaarta are more fractionated and distributed in a wider range of compositions. La/Yb ratios vary from 4.69 to 5.36 in Hank and from 3.64 to 6.68 in Kaarta. Values of La/Yb >6 in Kaarta suggest the presence of an enriched group. Nb/Zr (> 0.1 in Kaarta) and Th/Y ratios (>0.11) also support this observation. Samples with more depleted values are in agreement with those from Hank.

Nd and Pb isotopes were measured in 9 samples from Kaarta, 1 from Hodh and 7 from Hank. Sr isotopes were obtained on 9 samples from Kaarta. All the analysis were performed at the Laboratory of Radiogenic Isotopes, University of Geneva. Initial $^{87}\text{Sr} / ^{86}\text{Sr}$ and $^{143}\text{Nd} / ^{144}\text{Nd}$ ratios (calculated for 200 Ma) vary in Kaarta from 0.70590 to 0.70812 and from 0.51228 to 0.51247, respectively. $^{143}\text{Nd} / ^{144}\text{Nd}$ ratios in Hank range from 0.51224-0.51228. A clear distribution between Kaarta and Hodh can be recognized from the $^{143}\text{Nd} / ^{144}\text{Nd}$ values, being the Kaarta higher in $^{143}\text{Nd} / ^{144}\text{Nd}$ with respect to Hank rocks. It is also relevant that the more radiogenic samples from Kaarta belong also to the enriched group (La/Yb >6). Hank samples in contrast show a scarce variation of the isotopic and trace elements content. A good correlation is observed from the lead isotope diagrams where the Kaarta samples always exhibit the largest variations compared with Hank rocks.

From a preliminary characterization and comparison of geochemical data from Hank, Hodh and Kaarta (HHK) and the literature of the CAMP in Africa, it is possible to make some statements: 1) Data from major elements from HHK match with the CAMP in Africa. 2) contents of TiO$_2$ in HHK represent the large range of compositions of the CAMP in Africa, this can be related with fractionation processes or the influence of the source. 3) The Ti enriched group is comparable with the Guyana and Brazil dykes also part of the CAMP. 4) The large variability of trace element compositions of Kaarta contrast with the homogeneity of Hank. 5) Good correlations between pairs of incompatible elements suggest a process of dynamic melting. The influence of one or several sources is still studied.

**Geochronology**

Ar-Ar dating will be performed on pure concentrates of plagioclase at the Curtin University, Perth, Australia. In order to achieve high quality data, three samples were prepared according with rigorous proceedings that included crashing, washing with de-ionized water, separation of minerals using the magnetic separator Frantz and hank picking of pure crystals of plagioclase.

**Silicic Magmatic Province of Patagonia**

The Silicic Magmatic Province of Patagonia extends from the Atlantic Coast to the Chilean Andes (Pankhurst et al., 1998) and is correlated with the Jurassic volcanic rocks of the Antarctic Peninsula (Riley and Leat, 1999 in Bryan et al., 2002). It covers an area of about $1 \times 10^6$ km$^2$ and in many places it has a minimum thickness of 500m (Pankhurst et al., 1995). It is composed by a thick sequence of magmatic rocks of predominant felsic composition mainly recorded by Chon Aike and Marifil (or Grupo Bahia Laura) Formations in the eastern margin. In the Andean region, the magmatism is represented by deformed, tilted and altered rocks of the Ibañez, Tobífera and El Quemado Formations (Pankhurst et al., 1995; Bryan et al., 2002) The lithology is dominated by ignimbrites, rhyolites, debris flow, fallout and epiclastic deposits. Chemically, the province exhibit a bimodal composition with a clear predominance of the felsic events. The intermediate magmatism is represented by the Bajo Pobre Formation, underlying the Marifil and Chon Aike Formations (Guido et al., 2006). Most of the magmatism is related to graben
and hemigraben structures distributed along the Province and related with the extension event of the Gondwana break up (Feraud et al., 1999). Available K-Ar, Ar-Ar, Rb-Sr and U-Pb ages evidence a period of magmatic activity that ranges between c. 184Ma and c. 154Ma (Uliana et al., 1985; Varela et al., 1991; Panhkurst et al., 2000, Feraud et al., 1999).

Field relations

4000km of transect from west to east in the Chubut Province of Patagonia was covered in order to sample and recognize the stratigraphic and structural relations of the main Jurassic volcanic units. Seven different formations were identified and 54 samples collected. The set of rocks included: Andesites, basalts, gabbros, riolythes and ignimbrites from the Formations Lago la Plata, Loncotrapial, Piltriquitrón, Cañadón Asfalto, Cresta de los Bosques, Marifil. These units are distributed in four main sectors named as Cordillerano, Pre-Cordillerano, Cañadon Asfalto Basin and Somuncura Massif. Each sector represent a different structural and lithological domain characterized by the regional tectonics.

Petrography and mineral chemistry

Ignimbrites from the Marifil Formation show a pumicitic matrix with fiammae, inequigranular and subhedral phenocrystals of quartz which occasionally are bipiramidal and present melt inclusions. Anhedral and fine biotite is less frequent but still present. Rhyolites from Marifil and Piltriquitron Formations have a glassy matrix of reddish-brown color, sometimes layered, with subhedral fenocrystals of quartz, plagioclase (An0.7-An45) feldspar and biotite. Some sporadic xenocrystals embedded by the glassy matrix are also present. They consist of skeletal mafic minerals, possibly olivine and/or pyroxene completely altered with spinel inclusions still preserved. Zircon and apatite are accessory minerals.

Samples from Bajo Pobre Formation are mainly basaltic andesites which consist of intersertal texture formed by acicular and fine plagioclase (An86-An60) intergrowth fine crystals of pyroxene. Glomeroporffids and random crystals of subhedral augite (Mg# 57.5 - 81.1) and scarce olivine (Fo54-Fo62) are present in almost all samples. Ti-magneteite and chromite appear as inclusions in olivine and pyroxene. Apatite is present as an accessory phase. Glassy melt inclusions in plagioclase, olivine and clinopyroxene are also recognized.

Samples from Cañadòn Asfalto Formation are texturally similar to those from Bajo Pobre Formation, however the concentration of olivine is more frequent in this unit with a slightly more primitive composition (Fo63-Fo70) and heterogeneous plagioclase (An50-85). Contrasting with Bajo Pobre formation, clinopyroxene (Mg#65.4-78.7) and orthopyroxene (Mg# 56.4 - 80) coexist in several samples.

A cumulitic gabronorite from the Cresta de los Bosques Formation is composed by coarse plagioclase (An88) intergrowth with orthopyroxene (Mg# 78.3-84.0) and clinopyroxene (Mg#84) in poikilitic arrangements. Chromite is a common phase overgrowth on pyroxene.

Potential temperatures of the mantle using Putirka (2008) model were calculated from clinopyroxene of the Bajo Pobre Formation. Results indicate temperatures about 1078°C and 1162°C.
SUMMARY OF ACTIVITY IN THIS YEAR

Courses:


Communications:

Talk: “Magmatismo felsico en Patagonia y cuerpos máficos en Mauritania y Mali: Ejemplos de grandes provincias ígneas” March 29th 2012. Facultad de Ciencias Naturales, Universidad Nacional de la Patagonia “San Juan Bosco”.

Other:

Feb-March 2012. Field work in Patagonia and sample preparation at the Universidad Nacional de Patagonia, Comodoro Rivadavia, Argentina.

May - Jul. 2012. Fellowship by the Humboldt Foundation for a research stay at the University of Bonn.

4. References


Callegaro, S. 2011. Personal communication.


