MAGMAFAR
OCT & Magmatic Accretion in Afar

The ANR MAGMAFAR project (2021-2025) is advertising 3 PhD projects

The ANR MAGMAFAR project has 3 open PhD fellowships on the general topic of magmato-tectonic interplay during final stage of continental break-up, on the example of the Afar triple junction (Ethiopia). The 3 positions encompass various specific profiles:

- **PhD 1 (CRPG Nancy): volcanic geomorphology & rift architecture**
- **PhD 2 (ISTEP Paris): tectonics & long-term magmatic evolution**
- **PhD 3 (LGO Brest): igneous petrology/geochemistry & plumbing system**

The positions are planned to start in October 2021, see details and specific contacts for applications in the next pages. The 3 PhD thesis will be conducted in close collaboration and will interact with the whole team of MAGMAFAR (17 researchers | 5 laboratories in France).

Project summary: *contact: raphael.pik@univ-lorraine.fr)*

Afar is presently experiencing the final stage of continental break-up and progressive onset of steady magmatic spreading (process already completed in the lateral Red Sea and Gulf of Aden). The three main active, contrasted and complementary segments of Afar (Erta Ale, Dabbahu-Manda Hararo, Asal) offer the opportunity to study both mantle and crustal processes, and will allow to decipher fundamental parameters that control focussing of tectonic and magmatic activity until the complete removal of the continental lithosphere. The MAGMAFAR project is designed to make a breakthrough into the key and first order fundamental scientific issue of continental break-up in magmatic context, and rift transition to the onset of Mid Oceanic Ridges (MOR). This project focus on: (i) how do magmatic and tectonic processes control the styles and morphologies of magmatic segments? what are the parameters responsible for the characteristics of proto, steady-state spreading processes? (ii) why and how do stable magma production and organized/focussed transfer to the crust start and led to break-up?

By combining multiple scientific objectives and various specific approaches, the MAGMAFAR project will produce a significant number of deliverables that will gradually cover the description and understanding of magmatic OCT from individual processes to general models. MAGMAFAR has been designed to provide the community with new key datasets, to add constraints and quantify geological processes occurring during the recent geological record (since 4 Ma) of this rift system. Such an integrated and multidisciplinary approach, based on the combination of numerous complementary skills (petrology / geochemistry / geochronology / remote-sensing / structural geology / thermomechanical modelling), will be focused on the comprehensive description of these unique active segments, in order to bridge timescales and processes across the entire Afar Rift System: the short- vs long-term timescales of various processes, a better integration of magmatic vs tectonic dynamics and their feedbacks, and the spatial variations of processes and their controls. In order to tackle those questions, we will combine high resolution quantification of both tectonic and igneous processes in: (i) the active and (ii) plio-quaternary natural systems, which will serve in turn to calibrate (iii) an integrated thermo-mechanical modelling (see details in the attached MAGMAFAR project).

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PhD1: Detailed architecture of magmatic segments in Afar (Ethiopia): how magmato/tectonic interplay controls individual rifts morphologies and large-scale segmentation?

Advisors & contact for application: Raphaël Pik (CRPG/Université de Lorraine - geochemistry, volcanology and cosmogenic datings, raphael.pik@univ-lorraine.fr) & Nicolas Bellahsen (ISTEP/Sorbonne Université - structural geology and tectonics)

Direct collaborations : Jessica Flahaut (CRPG/Université de Lorraine - remote sensing), Alain Rabaute (ISTEP/Sorbonne Université - remote sensing), Irenne Schimmelpfennig (CEREGE - ^{36}Cl dating), Christophe Cloquet (CRPG/Université de Lorraine - isotopic geochemistry), Dereje Ayalew & Gezahegn Yirgu (Addis Ababa University - igneous petrology), and other potential collaborations with the MagmAfar team.

The thesis subject (PhD 1) will focus on active magmatic segments (< 300 ka) in the Afar depression (Dabbahu-Manda Hararo / Assal-Ghoubbet/ Erta Ale) which present various morphologies, crustal thicknesses and magma production rates. In order to understand the various controls and causes of magmatic accretion, the general strategy of the project is to describe how magmas are produced, and how they are subsequently transferred through the crust below these segments. This specific thesis subject will focus attention on the detailed architecture of the segments by providing a precise volcanological, geomorphological, tectonic and temporal frame. One of the main goals will be to identify the location, and then investigate the functioning and persistence, of magma reservoirs at the axis of these active system. This approach will allow to precisely determine: (i) the lateral organisation of the plumbing systems and their potential interconnections, (ii) the interplay between volcanic/tectonic processes and its control on shaping rift topography (i.e. accommodation of divergence by intrusion vs thinning/extrusion), (iii) how these various processes control the first and second order apparent segmentation in Afar, (iv) the stability and recurrence of these systems.

More specifically this thesis project will combine complementary approaches of (i) precise and comprehensive mapping of volcanic and tectonic structures using remote sensing and field investigations, (ii) cosmogenic dating (^{3}He and ^{36}Cl) of volcanic and tectonic scarps surfaces, and (iii) composition of volcanic products (major and trace elements, possibly isotopic geochemistry), in order to constrain the temporal frame and the dynamics of magmatic and tectonic processes. This quantitative approach will probably be focussed on the under-documented Manda Hararo and Erta Ale segments.

These data will be integrated in order to understand the way the nascent spreading segmentation is organized and controlled, and how those parameters eventually govern the final break-up and future MOR spreading. The thesis project will have close interactions with other companion studies focussed on the vertical organisation of the active segments (PhD 3) and the tectono/magmatic evolution of Afar since 4 Ma and the integration through time of these processes (PhD 2).

We are seeking candidates with a high-level background in geology at the Master level, interested by geodynamic and magmatic processes. Specific theoretical and practical skills in either geochemistry/geochronology or volcanic geomorphology/remote sensing will be greatly appreciated. The recruited candidate will necessarily appreciate chemical and laboratory work, as well as field work in remote area, given the specificities of this PhD project.

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PhD2: Tectono-magmatic evolution of Afar since 4 Ma: the respective role of thinning and magma accretion during ocean-continent transition (OCT)?

Advisors & contact for application: Nicolas Bellahsen (ISTEP/Sorbonne Université - structural geology and tectonics, nicolas.bellahsen@sorbonne-universite.fr), Raphaël Pik (CRPG/Université de Lorraine - geochemistry, volcanology and cosmogenic datings)

Direct collaborations : Hervé Guillou & Sébastien Nomade (LSCE - Université de Paris Saclay, $^{40}A/^{39}Ar$ dating), Jessica Flahaut (CRPG/Université de Lorraine - remote sensing), Alain Rabaute (ISTEP/Sorbonne Université - remote sensing), Sylvie Leroy (ISTEP/Sorbonne Université, geophysics and geodynamics), Cécile Doubre (IPGS - Strasbourg University, active deformations and geophysics), and other potential collaborations with the MAGMAFAR team.

PhD 2 subject aims at documenting the tectono-magmatic evolution of Central and Northern Afar since 4 Ma, a key period to understand the ocean-continent transition. This project will consist of detailed mapping of the volcanic series (both the Stratoïd and the Gulf Basalts) from intense field work and remote sensing in order to unravel their initial and sequential structure. The structural field data will be coupled to geophysical data, acquired in a project linked to the MAGMAFAR project, to provide balance cross sections throughout the area. This structural analysis will also be coupled to dating of the volcanic series by Ar/Ar method. This will provide a temporal framework to quantify the progressive magmatic and tectonic localization in the rift center. Geochemical data on the main volcanic units (old and recent Stratoid and Gulf basalts) will constrain the depth and amount of partial melting between 4 Ma and 400 Kyr (links with PhD3 of the MAGMAFAR project).

The main result will be a 4D model of Central Afar, with a special emphasis on the mode of rifting, its evolution through time and the location and evolution of the magmatic reservoirs. A special attention will be paid to the ratio between magmatic accretion (dyking) vs crustal thinning, and its evolution through time, as this ratio would be a key observable of the switch from rifting to drifting. These data will be used for the thermo-mechanical modelling project (led by a post-doc in the framework of MAGMAFAR). This PhD project will thus provide quantitative data of primary importance for the understanding of the initiation of new, localized diverging plate boundaries.

We are seeking candidates with a high-level background in geology at the Master level, interested by geodynamic and magmatic processes. Specific theoretical and practical skills in either geochronology or structural geology/remote sensing will be greatly appreciated. The recruited candidate will necessarily appreciate field work in remote area, given the specificities of this PhD project.

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PhD3: Magmatism at the ocean-continent transition : magma sources and magmatic plumbing system of the Erta Ale volcanic massif, Ethiopia

Advisors & contact for application: Gilles Chazot (LGO - Université de Bretagne Occidentale, Igneous petrology & geochemistry, gilles.chazot@univ-brest.fr), Lydéric France (CRPG/Université de Lorraine, igneous petrology)

Direct collaborations : Dereje Ayalew & Gezahegn Yirgu (Addis Ababa University - igneous petrology), and other potential collaborations with the MAGMAFAR team.

The main goal of this thesis is focussed on a detailed study of the magma genesis and evolution in a rift segment close to oceanisation: the Erta Ale massif. This segment is the less tectonized and the most magmatic in the Afar depression. In this area, extension is mostly accommodated through dykes.

A petrology and geochemistry study of volcanic rocks from the different volcanic centers in the Erta Ale massif will be conducted. The main objectives are:

- a study of the mantle source heterogeneity between the different volcanic centers from Sr-Nd-Pb isotopes in order to evaluate the respective participation of the lithospheric mantle, the asthenosphere and the Afar mantle plume.
- a study of the magma formation in the mantle, especially based on the estimation of the partial melting degree of the mantle source, from major and trace element compositions.
- a study of the plumbing system beneath the different volcanic centers. Thermobarometry on minerals will be associated with a detailed study of glass inclusions to constrain the evolution and the storage conditions of the magmas in this extensional context. In-situ chemical analyses will provide brand new data from this area and will allow constraining the depth of the magma chambers, the interactions between magmas and hydrothermalized crust, as well as the kinetics of the magma transfer through the crust.

These results will be used to understand how storage and injections of magmas through the crust can accommodate crustal extension and thinning in this area. Some samples are already available, and one or two field trips will be organized to sample more rocks.
Analytical tools necessary for this study are available in Brest as well as in Nancy:

- electronprobe : Centre Microsonde Ouest
- ICP-AES, ICP-MS, HR-ICP-MS, TIMS : PSO Brest
- ionprobe and SARM in Nancy

We are seeking candidates with a high-level background in geology at the Master level, interested by geodynamic and magmatic processes. Specific theoretical and practical skills in geochemistry and igneous petrology will be greatly appreciated. The recruited candidate will necessarily appreciate chemical and laboratory work, as well as field work in remote area, given the specificities of this PhD project.