



**DYNAMICS OF CONTINENTAL RIFTING IN THE SE AFAR DEPRESSION.  
TECTONIC AND MAGMATIC PROCESSES FROM PRESENT TO 30MY IN THE PLAIN OF DJIBOUTI AND  
ALI SABIEH-DANAKIL ZONES.**

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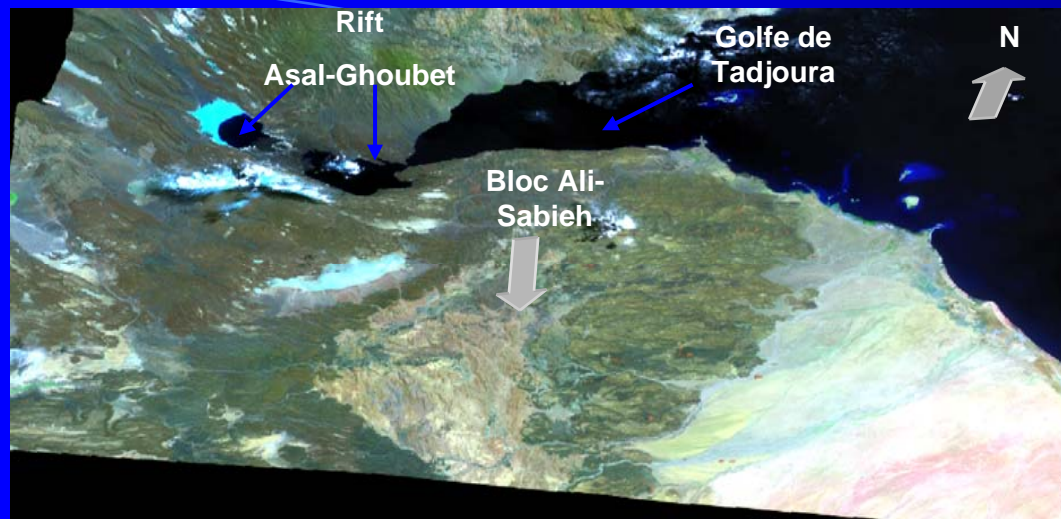
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**Co-tutors:** René Maury and Joel Rolet (UBO)

UMR-CNRS 6538 'Domaines Océaniques', IUEM, Brest, France

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CERD Djibouti



## SCOPES OF THE THESIS :

- (1) Elaborate a kinematic rift model for the western extremity of the Gulf of Aden propagator throughout the Tadjoura Gulf and its onshore margins. (*see Paper 1, submitted*).
- (2) Precise the tectonic and magmatic processes at an early stage of continental rifting in the Afar Depression. Records from the Danakil and Ali Sabieh domains during the time period 30-5 Ma. (*see Paper 2, submitted*).
- (3) Define the paleo-stress field conditions during the initial stages of rifting in the Afar extensional system. Evidence from the old synrift magmatic series in the Ali Sabieh zone. (*see Paper 3, in progress*).
- (4) Discuss the type of melting processes at depth in the context of the Afar mantle plume from the geochemistry of Quaternary basalts related to the Tadjoura rift system. (*see Paper 4, submitted*).
- (5) Establish an overall kinematic model to the SE part of the Afar rift Triangle where successive and oblique rift systems are superimposed since ~30 Ma.

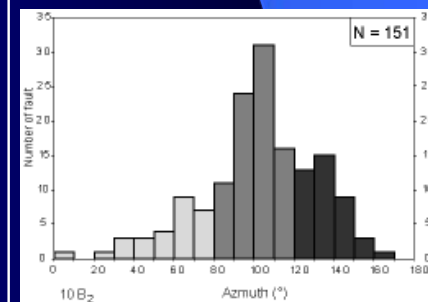
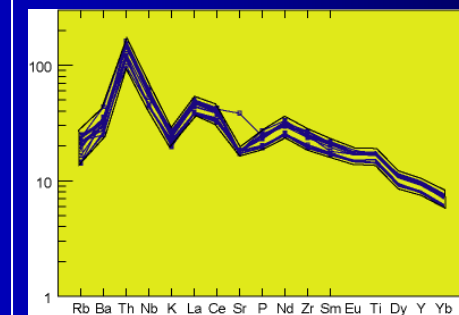
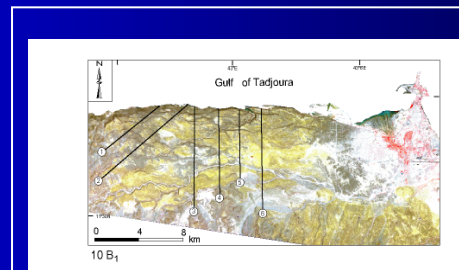
# METHODOLOGY

**Multidisciplinary approach** appropriate for addressing the structural and magmatic studies of a volcanic-rich rift system.

- **Petro-geochemistry analysis of volcanic rocks.**
- Whole-rock major and trace elements analyses. ICP-AES Domaines Océaniques Brest (> 100 samples).
- Isotopic analyses. Spectrometer automated electron microprobe (Microsonde Ouest, IFREMER)
  
- **Radiometric age determinations of mafic volcanics.**
- K-Ar Unspiked technique on groundmass samples (LSCE Gif/Yvette).
- 30 age determinations of basalts ranging in age from ~30 to 1Ma.
  
- **Structural analysis at various scales**
- Remote sensing data interpretation (DEM Aster and SPOT). ENVI 4.3 and GEOMATICA 9.0 softwares.
- GIS : ARCGIS 8.3 software.
- Field data : 5 campaigns about 1 month each. Morphological observations, structural cross-sections and microtectonic measurements (emphasis on fault structures).

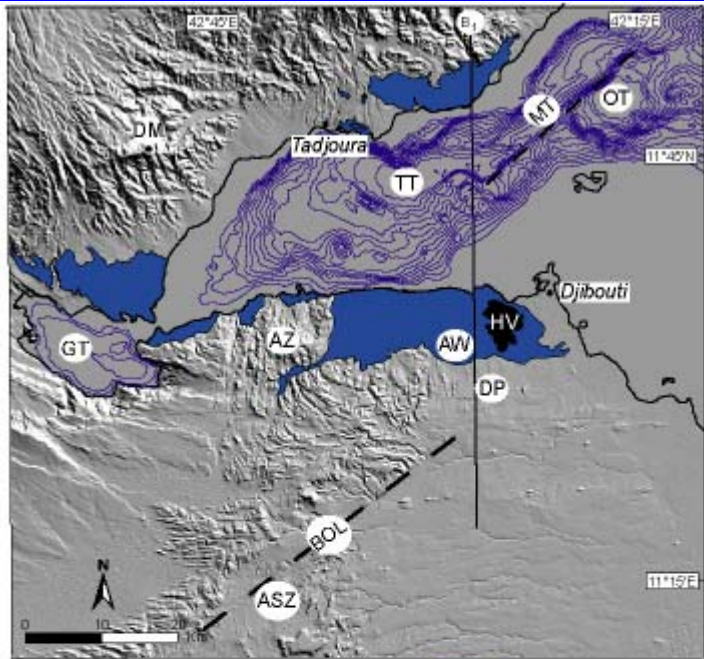
## COLLABORATIONS :

- **LGSE. CEA Gif/Yvette** : H. Guillou (geochronology).
- **CERD Djibouti**: M. Jalludin
- **Energy Ministry of Djibouti**: A. Caminiti
- **UMR 6538** : S. Hautot et P. Tarits (Magneto-telluric), C. Delacourt (Remote sensing)



# Young rift kinematics in the western Gulf of Aden : the Tadjoura-Ghoubbet extensional linked system (Djibouti)

M. A. Daoud<sup>1,2</sup>, B. Le Gall<sup>1</sup>, R.M. Maury<sup>1</sup>, J. Rolet<sup>1</sup> & H. Guillou<sup>3</sup>  
(submitted to **TECTONICS**)



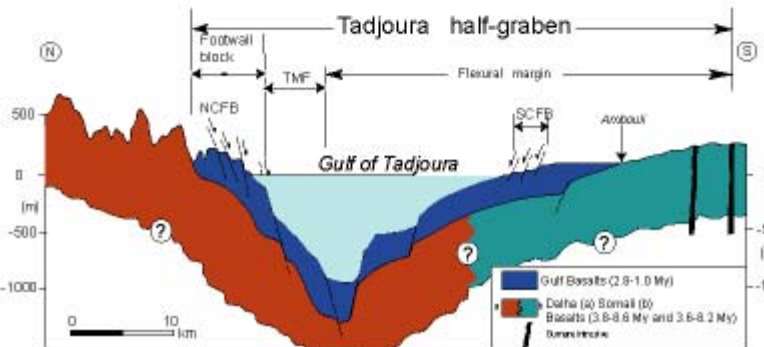
Tadjoura Gulf Basalts

## Scientific goals

- Structural significance of the 1-3 Ma-old Gulf Basalts in the framework of the Tadjoura propagating rift system.
- Structural relationships between the Plain of Djibouti and the surrounding elevated domains to the W (Arta and Ali Sabieh areas).
- Overall kinematic model of rifting at the periphery of the Afar plume.

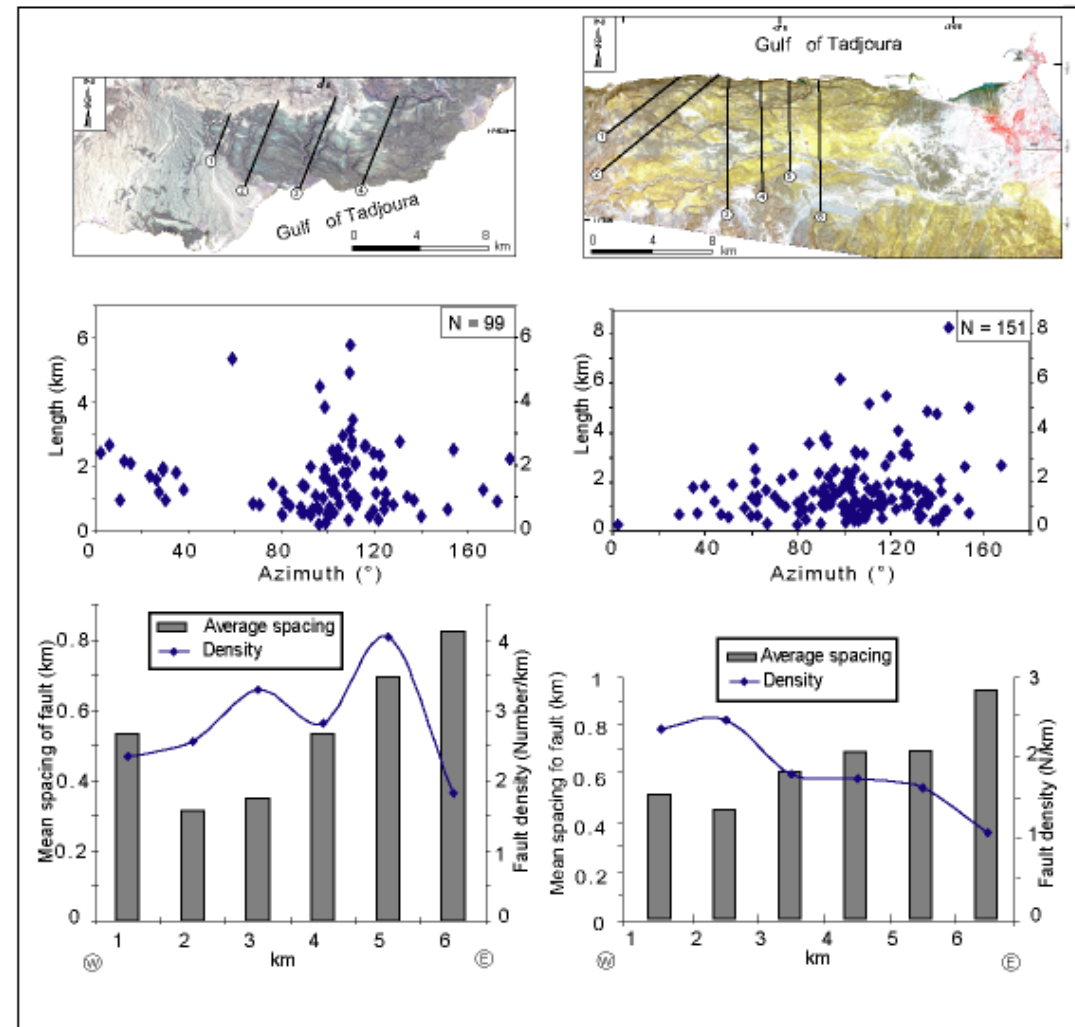
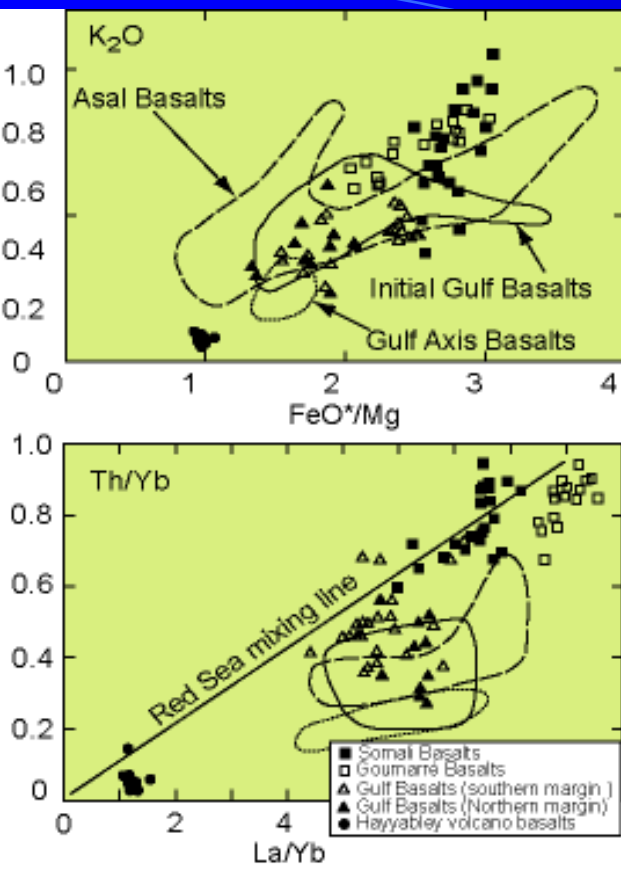
## Main results

- Identification of an asymmetric half-graben (Tadjoura), where the Gulf Basalts were emplaced, and showing typical N-S (axial) age progression of strain (inward younging).
- Role of inherited structures *versus* new transform faults during rift propagation : Kinematics of recent-active rift propagation (jump and transfer) from the Tadjoura half-graben to the Ghoubbet-Asal rift system is directly controlled by earlier rift discontinuities striking NS (Red Sea polarity).
- The so-called Arta-Asamo NS discontinuity has recorded vertical fault movement resulting in the general downthrow of the Plain of Djibouti during the last 1 My.



## Main results

- Discrimination of the Gulf, Somali and Goumarré Basalts series from specific morphostructural evidences, geochemical signatures, and age determinations.



- Geometrical and statistical analysis of synrift fault populations shows a marked EW gradient in terms of fault density, displacement, ....

- The overall structure of the recent basaltic series in the Djibouti Plain is precised. (Possible implication for **Mawari** hydrogeological purposes).

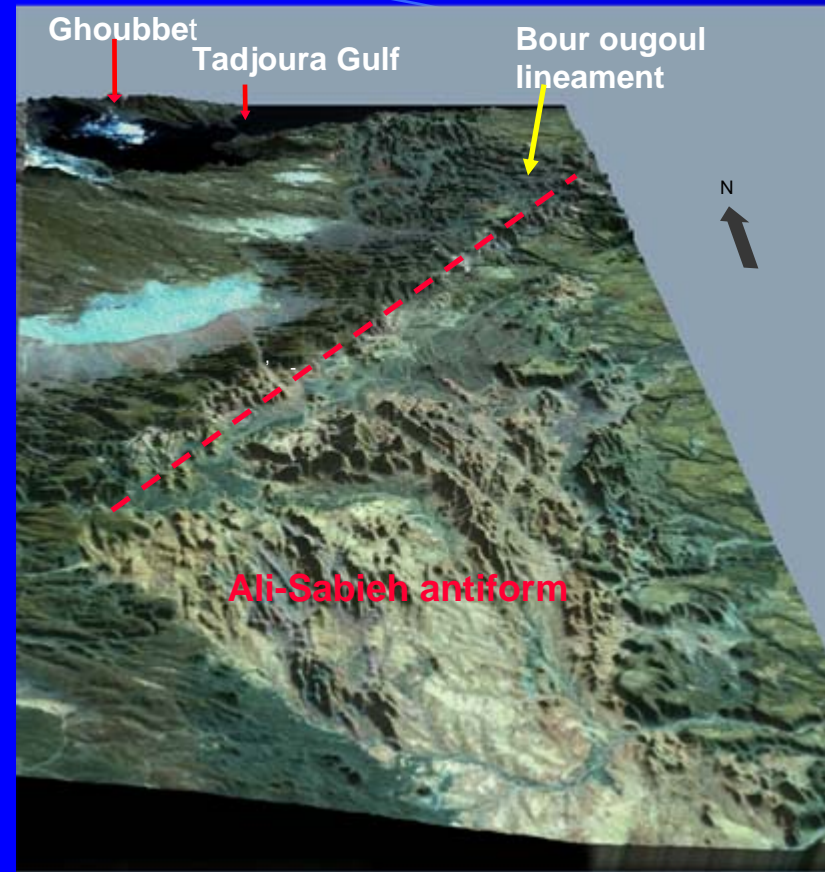
# Magmatic emplacement during early rifting in the Danakil and Ali Sabieh zones, Afar Depression, Djibouti.

B. Le Gall<sup>a</sup>, M.A. Daoud<sup>a,b</sup>, J. Rolet<sup>a</sup>, R. Maury<sup>a</sup>, H. Guillou<sup>c</sup>

(submitted to **JOURNAL OF STRUCTURAL GEOLOGY**)

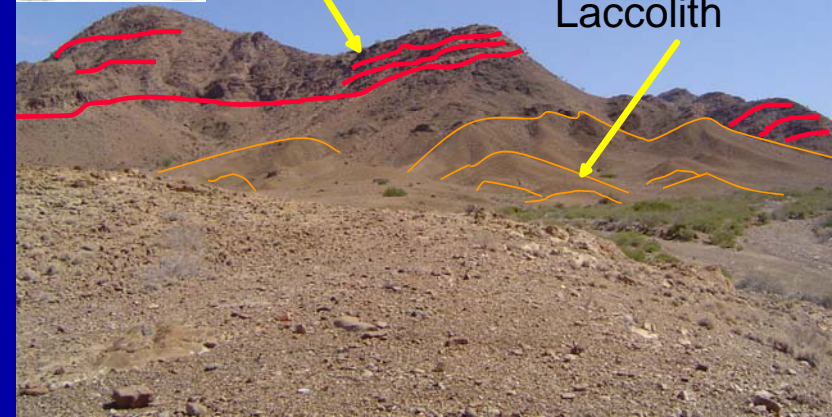
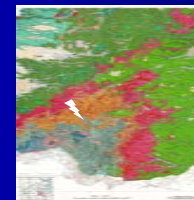
## Scientific goals

- Precise the nature and causal mechanisms for the Ali Sabieh and Danakil reliefs (micro-plates, blocks, horsts, anticlines, ...?).
- Precise the early rift evolution (magmatic and tectonic) of the Afar extensional system (30-5 Ma.) from the oldest magmatic rift series exposed in the Ali Sabieh and Danakil reliefs.



## Results

- Evidence for mafic laccolith emplacement, and associated dyke-sill complexes (the so-called Ali Sabieh series), during initial magmatism (~25 Ma) in the Ali Sabieh area.
- The dominantly-mafic Ali Sabieh series are not the equivalent counterpart of the Oligocene flood basalts forming the Ethiopian Plateau to the W.
- The laccolith emplacement caused the large wavelength doming of the Mesozoic country-rocks envelop.

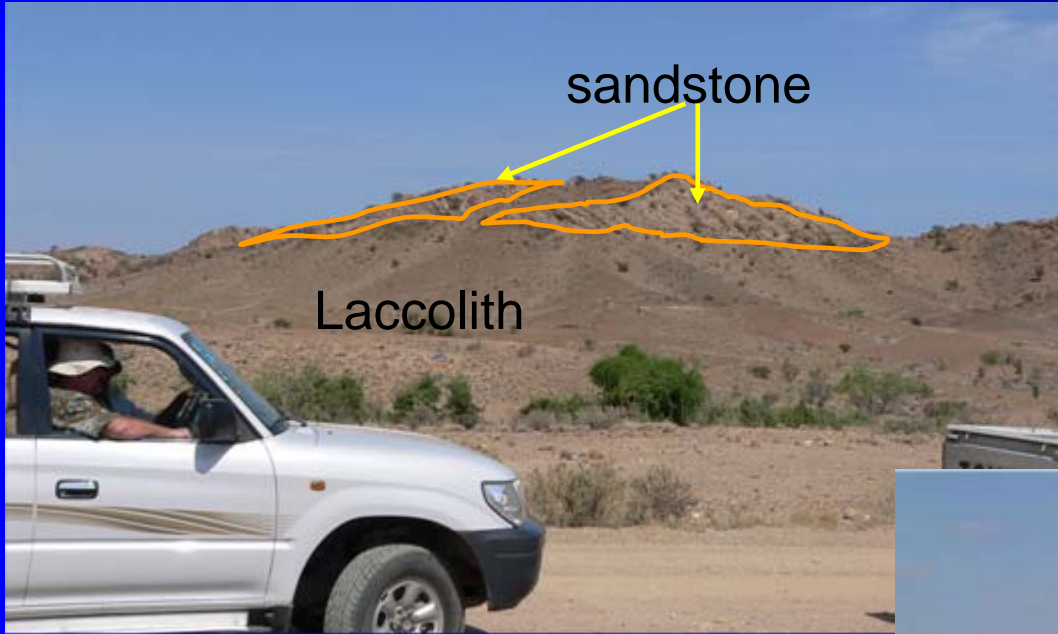


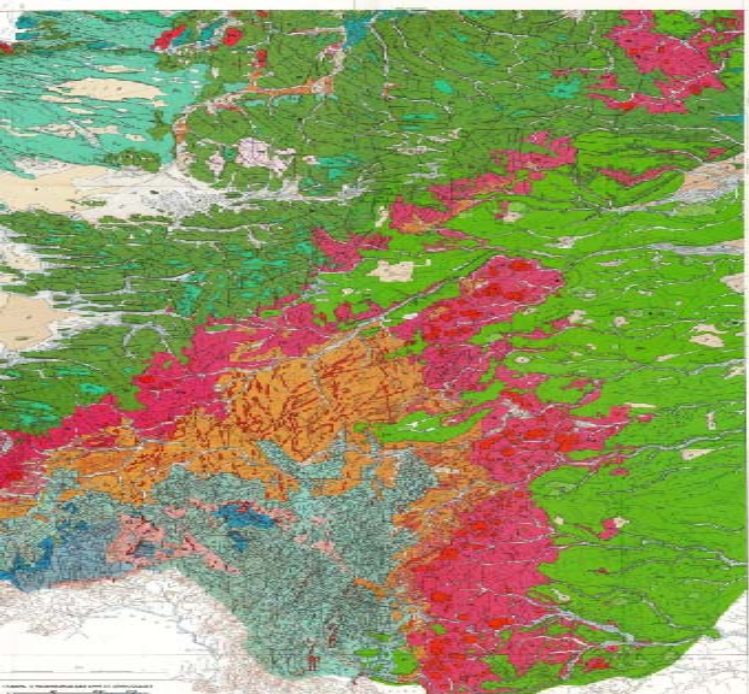
Western flank  
Cretaceous sandstone  
Laccolith

The numerous country-rocks xenoliths evidenced at various scales (m up to km) within the Ali Sabieh laccolith indicate a roof-pendant process.

- Magmatism-strain relationships are also documented at a later stage of rifting (20-Recent) in the South Danakil mountains.

Evidence for tectono-magmatic cycles involving (1) magmatic intrusion, (2) large-scale doming, (3) erosion-incision, and (4) infill of preserved paleo-valleys by younger effusive material, are observed.





# Paleo-stress field during the Afar continental rifting. Evidence from the initial magmatic series in the Ali Sabieh zone.

C. Sue, MA. Daoud, B. Le Gall, J. Rolet, & RC. Maury.

(in progress, **TERRA NOVA**).

## Scientific goals

The stress field conditions that prevailed in the Afar rift system prior to ~3 Ma. have been poorly investigated, and are badly known. The old strained rift magmatic series, and their Mesozoic substratum, exposed in the Ali Sabieh dome offer the opportunity to analyse striated fault planes, and subsequently to deduce the corresponding stress field(s).

Since most of the series involved in the Ali Sabieh dome show evidence for NS-trending structures (Red Sea trend), the corresponding stress field(s) might testify for dramatic changes in orientation of stress with regards to the recent-active stress field (minimum principal stress at N40°E).

## Results

(Work in progress on the basis of microtectonic measurements acquired during the field trip 12/06)





## Occurrence of a LREE-depleted component in the Afar plume: further evidence from recent basalts of Djibouti

M.A. Daoud<sup>a,b</sup>, J.A. Barrat<sup>a,\*</sup>, R.C. Maury<sup>a</sup>, R.N. Taylor<sup>c</sup>, B. Le Gall<sup>a</sup>, H. Guillou<sup>d</sup>, J. Cotten<sup>a</sup>, J. Rolet<sup>a</sup>

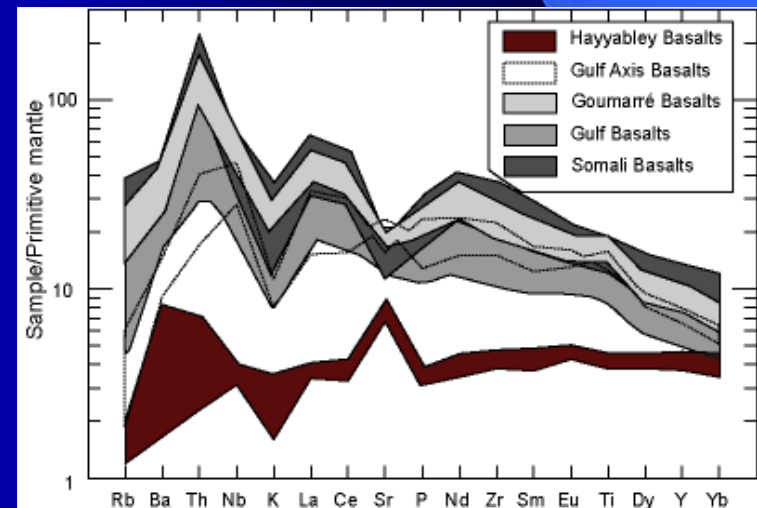
(submitted to LITHOS)

### Scientific goals

- Origin of mantle sources and type of petrogenetic processes for recent mafic magmas in the Afar mantle plume framework.
- Composition and heterogeneity of the Afar mantle plume.

### Results

- New insights provided from the geochemical analysis (Major, trace and isotopes, Sr, Nd, Pb) of basalts emitted from the Hayyabley Quaternary volcano on the margin of the Tadjoura rift.
- Evidence for LREE-depleted (Light Rare Earth Element) basalt lava flows in the Hayyabley volcanics, similar to Oligocene flood basalts from the Ethiopian Plateau and to Quaternary basalts from the Manda Hararo axial edifice.
- Evidence for the initial heterogeneity of the Afar Mantle plume material. The presence of an ancient recycled oceanic crust component within the plume is questioned.

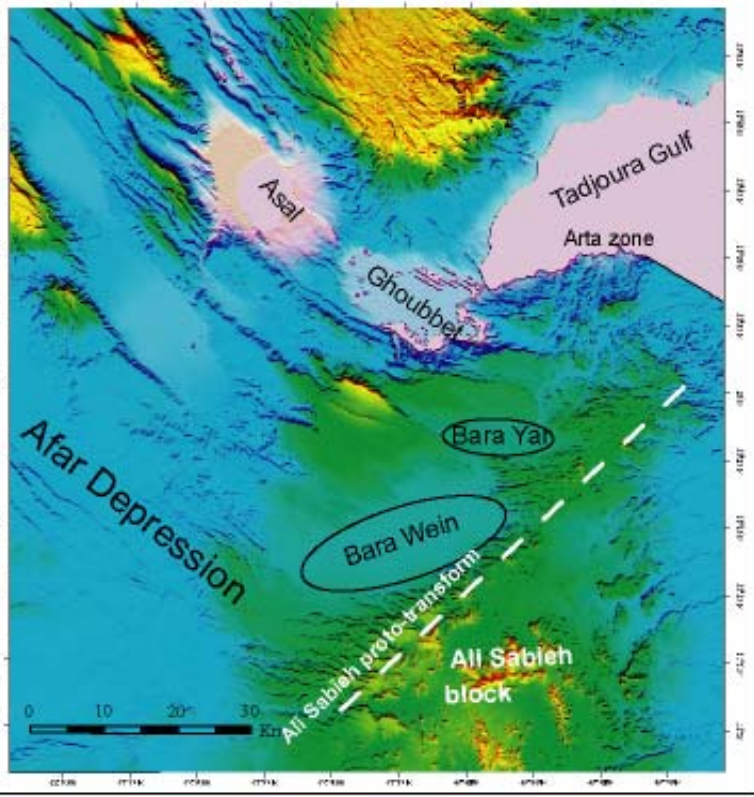


## SHORT-TERM PROJECTS ABOUT THE AFAR RIFT IN DJIBOUTI

### Volcanic targets

- Isotopic analyses of the successive synrift mafic sequences emplaced as laccolith (Ali Sabieh Basalts), trapp series (Dalha and Somali Basalts), or axial rift sequences (Gulf Basalts).

That should supply new data to further discuss the nature of the magma mantle sources, i.e. the relative importance of the mantle plume component as a function of both the spatial and timing distribution of magmatism.



### Tectonic/Geodynamic targets

- (1) The sharp NE-trending boundary between the Asal (Stratoid) recent-active rift system to the NW, and the Ali Sabieh dome to the SE is poorly known. This first-order discontinuity lies in the SE prolongation of the Maskali oceanic transform. It is outlined at the surface by a series of *en echelon* basin-like depressions (the 'baras').

We propose to precise the deep structure of these potential rift basins by ground gravimetric records, in order to get new geometrical constraints that in turn should help understanding the geometry and kinematics of a possible paleo-transform fault structure in the Afar rift.

- (2) Previous studies assessed that large-scale transfer faults occur South of the Ali Sabieh dome, close to the Somalian escarpment, in the onshore prolongation of major oceanic transform faults (Shukra El Sheick) (Audin et al., 2003).

Field structural works should be useful (1) to test the validity of these hypotheses, and (2) to answer the still debatable question about the fixed or rotated (allochthonous) position of the Ali Sabieh-Aisha domains.

## Scientific publications

- Occurrence of a LREE-depleted component in the Afar plume: further evidence from recent basaltic lavas in the Djibouti rift. **MA. Daoud, JA. Barrat, RC. Maury, RN. Taylor, B. Le Gall, H. Guillou, J. Rolet & J. Cotten.** (manuscript sub-terminé, prévu à *Lithos*)
- Recent rift kinematics in the Tadjoura-Ghoubbet extensional linked system, West Gulf of Aden. **MA. Daoud, B. Le Gall, RC. Maury, J. Rolet, & H. Guillou.** (manuscript sub-terminé, prévu à *Tectonics*).
- Dynamics of initial rifting in the Afar Depression. The tectono-magmatic history of the Danakil and Ali Sabieh zones in the time period 3-30 Ma. **B. Le Gall, MA. Daoud, J. Rolet, RC. Maury & H. Guillou.** (manuscript en préparation, prévu à *Journal of Structural Geology*).
- Paleo-stress field during the Afar continental rifting. Evidence from the initial magmatic series in the Ali Sabieh zone. **C. Sue, MA. Daoud, B. Le Gall, J. Rolet, & RC. Maury.** (manuscript en préparation, prévu à *Terra Nova*).
- Petro-geochemical affinities of initial magmatism in the Afar rift. **MA. Daoud, RC. Maury, JA. Barrat, B. Le Gall, H. Guillou, J. Rolet & J. Cotten.**