The AMIGO Project: Present-Day Crustal Deformation of the Western Section of the Africa-Eurasia Plate Boundary Zone

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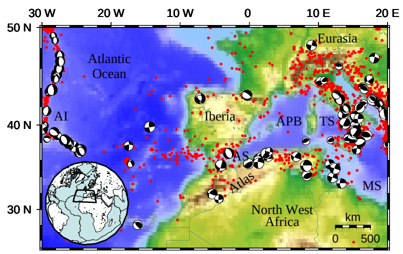
Introduction

The AMIGO (Atlantic and Mediterranean Interdisciplinary Geophysical Observations) Project is a scientific collaboration among researchers involved in GPS (Global Positioning System) activities along the western section of the Africa-Eurasia plate boundary zone. This section extends west-east from the Azores triple junction on the Mid-Atlantic Ridge to Tunisia and southern Italy. In a generalized scheme, recent major tectonic processes along this plate boundary result from a north-northwestward directed push of Africa against Eurasia. Examples of the vast variety of tectonic features and processes in this region include:

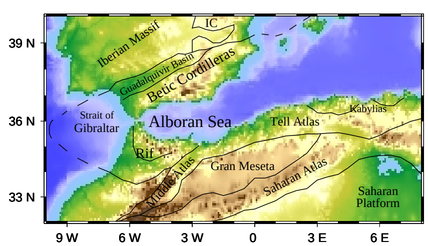
- Mountain Building (e.g., Betic-Rif Cordilleras, Pyrenees, Alps)
- Basin Formation (e.g., Alboran Sea, Algero-Provençal basin)
- Ocean Subduction and Back-Arc Spreading (Tyrrhenian Sea and Calabrian Arc)
- Intracontinental Mountain Belt (Atlas)



Western section of the Africa-Eurasia plate boundary zone. Red dots are epicenters from the USGS earthquake data base and focal mechanisms are from the Harvard CMT catalog. AI-Azores Islands, APB-Algero-Provençal Basin, AS-Alboran Sea, MS-Mediterranean Sea, TS-Tyrrhenian Sea.

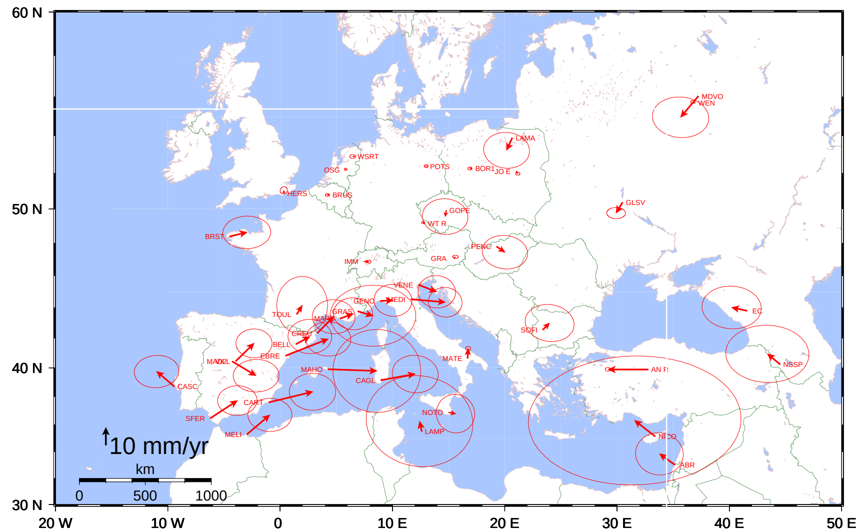
This section contains a unique transition zone from an oceanic-oceanic lithosphere boundary in the West (Azores to approximately Gibraltar) to a continental-continental lithospheric boundary in the East (Gibraltar to southern Italy). Whereas the seismicity is well defined and narrowly concentrated along the oceanic boundary, it is rather diffuse in the continental boundary, where it extends over a wide area of more than 1000 km that covers most of Iberia and the northern coast of Africa. This marked contrast is possibly due to the difference in rheology between oceanic and continental lithosphere. Data from the AMIGO GPS networks will give us a unique opportunity to test these and other hypothesis.

This regions also comprises the Alboran Sea and Betic-Rif mountain belt, where extensional processes still coexist within a compression framework, and for which several formation mechanisms and geodynamic models have been proposed. To date no direct geodetic observations have been acquired and integrated in a comprehensive manner with other geological and geophysical observations in this region. Data from AMIGO will be used to constrain models for the geodynamic processes responsible for deformation in this region.

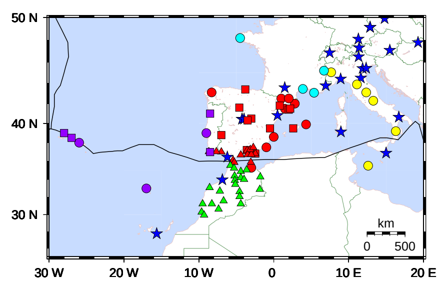


Tectonic sketch map of the Alboran Sea and surrounding regions. IC-Iberian Chain.

Geodetic Investigations



Estimates of horizontal velocities relative to stable Eurasia for sites in Africa, Europe and the Middle East. (arrows). Error ellipses at the arrow tips represent 95% confidence level. We used data from roughly 6 months of continuous GPS networks of the Real Observatorio de la Armada San Fernando (ROA), Institut Cartogràphic de Catalunya (ICC), Spanish Instituto Geográfico Nacional (IGNE), Agenzia Spaziale Italiana (ASI), and French Institut Geographique Nationale (IGNF), and roughly 3 years of data from the International GPS Service (IGS). Part of this data was procured through the European Reference Frame (EUREF) project. Site velocities are plotted with respect to the Eurasia fixed reference frame, which we realized by estimating and subtracting from the velocity field that rigid rotation which minimized the residual velocities of the 13 sites assumed to define a stable Eurasia plate.



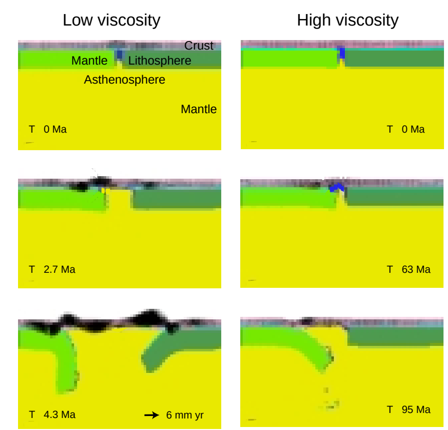
Summary of GPS networks used for AMIGO investigations. IGS sites are indicated by stars. Circles indicate continuously operating GPS sites, as of June 1999, in Spain (red) of ROA, ICC, and IGNE, in Portugal (purple) of Faculdade de Ciências da Universidade de Lisboa (FCUL) and Instituto Português de Cartografia e Cadastro (IPCC), in Italy (yellow) of ASI, and in France (blue) of IGNF. Squares indicate planned continuous GPS sites for which funding has been secured. Triangles indicate campaign GPS sites.

The NUVEL-1A plate motion model for this region indicates that the Africa plate is moving northwest relative to Eurasia at a rate of 4-6 mm/yr. In spite of its presently low resolution, our velocity field is in agreement with NUVEL-1A. In the following months, we will not only be able to resolve the relative motion between Africa and Eurasia, but also we will be able to determine the detailed distribution of present-day crustal deformation and strain using data from new continuous GPS stations that are coming on line and GPS campaigns that we are performing in this region. We will use these determinations to investigate models for deformation and to constrain geophysical parameters that control deformation along this plate boundary zone.

For example, we have performed preliminary studies with a general active tectonics finite element lithospheric model to determine whether it is feasible to use geodetic techniques to obtain a quantitative understanding of lithosphere slab detachment process hypothesized to be ongoing in the Alboran Sea.

Geodynamic Modeling

We have performed simulations with a geodynamic model for crustal deformation caused by a lithospheric slab detachment process similar to the process that presumably originated the Alboran Sea and Betic-Rif mountain belt.



Example of two time sequences of surface deformation rates (black lines) from a plane-strain, arbitrary Lagrangian-Eulerian finite element simulation of the lithosphere-mantle system that incorporates a slab detachment process. This analytical block model contains four layers: crust (pink), mantle lithosphere (both greens), low-viscosity channel and asthenosphere (yellow). Both sequences are based on a 150 km thick lithosphere, 40 km of which represents the crust and 110 km the mantle lithosphere, and 600 km of mantle proper. The physical dimensions of the solution space of each graph are 1200 km width and 600 km depth. The surface deformation rate in this model is quite sensitive to mantle lithospheric viscosity. From left to right, a two order of magnitude increase in lithospheric viscosity has been applied to illustrate the effect. This model produces a geodetically detectable deformation pattern. Maximum magnitude of the velocity vectors (bottom left panel) are 4.4 mm/yr for the horizontal component and 6.3 mm/yr for the vertical.

Future Work

Apply three-dimensional crustal deformation rates from AMIGO GPS data to constrain geodynamic models and geophysical parameters that control deformation in the western section of the Africa-Eurasia plate boundary zone. Develop parametrized models and apply inverse methods to determine values and uncertainties for the geophysical parameters of interest.

Acknowledgments

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