Global Positioning System Constraints on Active Tectonics in the Alboran Sea Region

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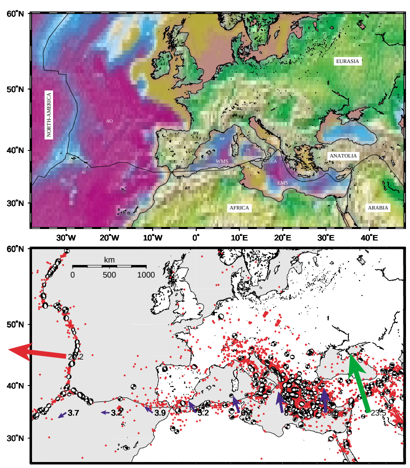
Tectonic Framework

The **Africa-Eurasia plate boundary** zone forms the western section of Alpine-Himalayan collisional belt. The present-day tectonics is dominated by ongoing north-northwestward direct push of the Africa plate against Eurasia. This complex region constitutes a distinct example of distributed deformation at a plate boundary and contains a variety of tectonic processes at various degrees of evolution. The western section of the Africa-Eurasia plate boundary marks the zone that runs from the Azores Islands on the mid-Atlantic ridge, through the Straits of Gibraltar, and into the western and central Mediterranean in Tunisia and southern Italy.

Significant **tectonic processes** in this section include continental collision (Atlas, Betic-Rif Cordilleras, Pyrenees, Alps), ocean subduction (Calabrian arc), basin formation (Alboran, Algero-Provencal, and Tyrrhenian basins), rifting (Azores, Straits of Sicily). Volcanism (e.g., Azores, Madeira, Eolian Islands or Vesuvius) and continuous low-to-moderate (M<5) seismicity, accompanied by a few high destructive earthquakes (e.g., Cape S. Vincente, Portugal, 1969, M=8; El-Asnam, Algeria, 1980, M=7.3), are also commonplace.

The Atlantic and Mediterranean Interdisciplinary GPS Observations (**AMIGO**; http://mat.fc.ul.pt/amigo/amigo.html) collaboration was formed to ascertain better the nature of this boundary using GPS measurements.



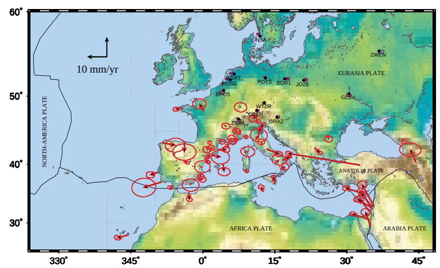
The Africa-Eurasia plate boundary zone

(Top) Topography and bathymetry. The boundaries between major plates (whose names are indicated by lettering on white background) are marked by the thin black line. AO-Atlantic Ocean, AI-Azores Islands, AP-Algero Provencal Basin, AS-Alboran Sea, WMS-Western Mediterranean Sea, EMS-Eastern Mediterranean Sea, TS-Tyrrhenian Sea, GS-Gibraltar Strait, SR-Sicily Rift, AT-Atlas, PY-Pyrenees, AL-Alps, BE-Betic, RI-Rif Cordillera, AD-Adriatic Sea, AE-Aegean Sea, CA-Calabrian Arc.

(Bottom) Epicenters (red dots) from the USGS earthquake data base and focal mechanisms from the Harvard CMT catalog. Arrows indicate NUVEL-1A motions of Africa (blue), Arabia (green) and North-America (red) plates relative to Eurasia. Rates shown at

GPS Geodesy: Present-Day Crustal Deformation

GPS determination of present-day crustal deformation from between 1-3 years of permanent GPS data at several sites in Africa, Europe and the Middle East superimposed on a map colored by elevation. Estimates of horizontal velocities (arrows) and corresponding 95% confidence levels (error ellipses at the arrow tips) for these sites are shown relative to Eurasia.



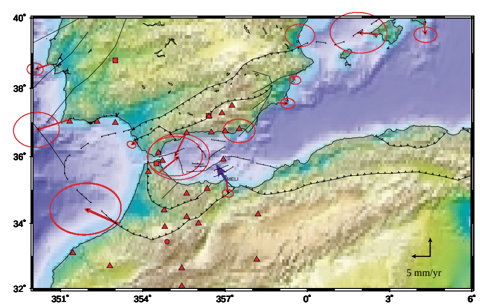
Eurasia Reference Frame: We have realized the Eurasia fixed reference frame by estimating and subtracting from the velocity field that rigid rotation which minimized the residual velocities of the 13 sites (black dots by site names) assumed to define a stable Eurasia plate. The deviations from zero velocity of the north and east components of velocity of these reference sites are all less than 2 and 1 mm/yr, respectively, and the rate weighted root-mean-square is 1.1 mm/yr. The estimated velocities in the eastern Mediterranean are in agreement with other recent geodetic measurements in that region.

- How rigid is Eurasia? We detect no deformation within (our definition of) stable Eurasia at the 2 mm/yr (weighted root-mean-square) level with 99% confidence. This deformation (or lack thereof) reveals statistically insignificant strain accumulation rate at the 1 nanostrain/yr level.
- We measure significant deformation along the Africa-Eurasia plate boundary zone. The pattern of deformation changes upon crossing different tectonics provinces. We find our velocity field to be generally consistent with other studies.
- At the level of resolution of our data (~2 mm/yr), there is little motion of the stations in Iberia relative to stable Eurasia. For example, the relative motion between stations immediately north and south of the Pyrenees mountains (sites Toulouse and Bellmunt) is 1.3±1.1 mm/yr (N131°E). Therefore, in the western Mediterranean, the Pyrenees mountains appear to not accomodate any significant deformation at the 2 mm/yr level.
- The weighted mean of the north and east components of velocity of sites within the Iberia peninsula is -0.8 and 0.7 mm/yr, respectively. Their standard deviations are 0.6 and 1.9 mm/yr. Therefore, Iberia, as defined by these sites, seem to behave as a rather coherent block at the ~2 mm/yr level.

The Alboran Sea Region

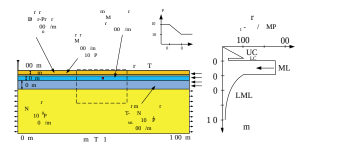
The Alboran Sea region is interpreted as the result of extension that occurred during the Miocene despite continued convergence and shortening of the northern Africa and southern Iberia continental margins. We are using GPS in this region to provide geodetic constraints on the various geodynamic models that have been proposed to explain the coexistence of extensional processes within an overall compressional regime.

Local Deformation: Sites in the Betic-Rif Cordilleras and Alboran Sea with 95% confidence rates (ellipses) of 8 mm/yr or less. Red symbols mark the location of permanent (squares and circles) and campaign (triangles) GPS stations in this region that have not been operating long enough to produce accurate velocity estimates and have not included in this solution yet.
The blue arrow indicate the velocity implied by NUVEL-1A circuit closure relative relative to Eurasia at site MELI, on the southern shore of the Alboran Sea. This velocity differs significantly from our GPS estimate of velocity at that site. Future data will help us resolve the distribution of deformation in this region and compare present-day geodetic estimates of relative motion and values based on geological data.

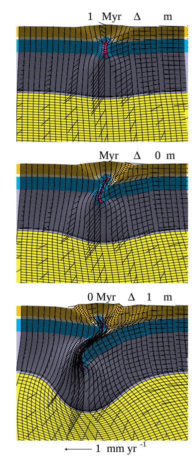


Numerical Studies: Lithospheric Deformation

We have performed preliminary investigations with a finite-element code that models the behavior of the mantle lithosphere. These simulations are only meant to explore "generic" styles of deep lithospheric deformation during tectonic convergence and the surface expressions that may be observed. They do not try to describe the particular setting of the Alboran Sea in any specific way.



Physical properties and initial configuration of a thermomechanical numerical model. Dashed box depicts portion of the full solution space that is shown below. Continental convergence is modeled by introducing new lithosphere at right boundary of box with velocity Vx [Pysklywec et al., 2000].



Temporal snapshots of evolution of the thermomechanical model above with convergence velocity Vx = 1.5 cm/yr. (This velocity, which is of the order of magnitude of the velocities measured in the eastern Mediterranean, is only indicative). Time is relative to onset of convergence imposed on starting model and Δx is cumulative convergence. Vectors indicate instantaneous velocity. The (Lagrangian) grid superimposed on material field shows relative deformation in model. Note formation and present and predicted evolution of collisional orogen.

(Top) The imposed convergence is taken up as pure-shear thickening of the lithosphere at the center of the model.

(Middle) Surface orogen continues to develop as the crust uplifts. A distinct shear zone in the plastic mantle develops. This stage marks the initiation of a subuction-style mode of mantle deformation, with the convergent side underthrusting the stationary portion.

(Botton) Contemporaneous but distinct processes of subduction and dripping (Rayleigh-Taylor instability) compose a mixed behavioral mode of deformation in the mantle lithosphere. These underlying dynamics contribute to the partial collapse of the surface topography

Future Work

Integrate the kinematic results with geological and geophysical data and with the numerical studies to constrain models for deformation in the Alboran Sea region.

Acknowledgements

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