



GPS NETWORK FOR LOCAL DEFORMATION MONITORING IN THE ATLAS MOUNTAINS OF MOROCCO

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Abstract: The Atlas Mountains of Morocco have been the target of several geophysical studies: gravity, refraction and MT surveys carried out during the 80's and 90's have helped to establish some of the main characteristics of this intracontinental orogen, such as its overall structure and modest crustal thickness. Later studies, based on structural geology, higher resolution gravity surveying and multidisciplinary potential field modelling indicated that the High Atlas crust is too thin to support its topography and that a mantle contribution is required. An asthenospheric upwelling, which triggered the Eocene-to-recent Atlas magmatic activity was then proposed as the main cause of its topography. Crustal thickness happens to be the key to establish the position of the lithosphere-asthenosphere boundary and therefore, to assess the real contribution of the mantle to the topography and accordingly the actual uplift. In the frame of a multidisciplinary project covering the described issues, a non-permanent GPS network have been established around the Ouarzazate Basin and surveyed for the first time in September 2007. This network is aimed to control the recent vertical and horizontal movements that affect the area in an attempt to constrain the current deformation rates in the Atlas system.

1. INTRODUCTION

The High Atlas is an ENE-WSW-trending mountain chain located in the south-western part of the Atlas System (Morocco) (Figure 1). It developed as a consequence of the tectonic inversion of a Mesozoic rift due to the N-S migration of the African plate during the Tertiary (Mattauer et al., 1977). Its simple structure, characterized by smooth folds and thrusts, contrasts with its overall high elevation, generally above 2000 m and locally in excess of 4000 m. The origin of the High Atlas elevation has been a matter of debate for a long time. The small amount of shortening (< 24%) calculated for this mountain range on the basis of restored cross sections (Figure 1) seems unable to develop such topography (Teixell et al., 2003). Accordingly, an asthenospheric upwelling has been proposed to contribute to the elevation of the Atlas cordillera (Seber et al., 1996; Teixell et al., 2003, 2005, Arboleya et al., 2004; Ayarza et al., 2005; Zeyen et al., 2005).

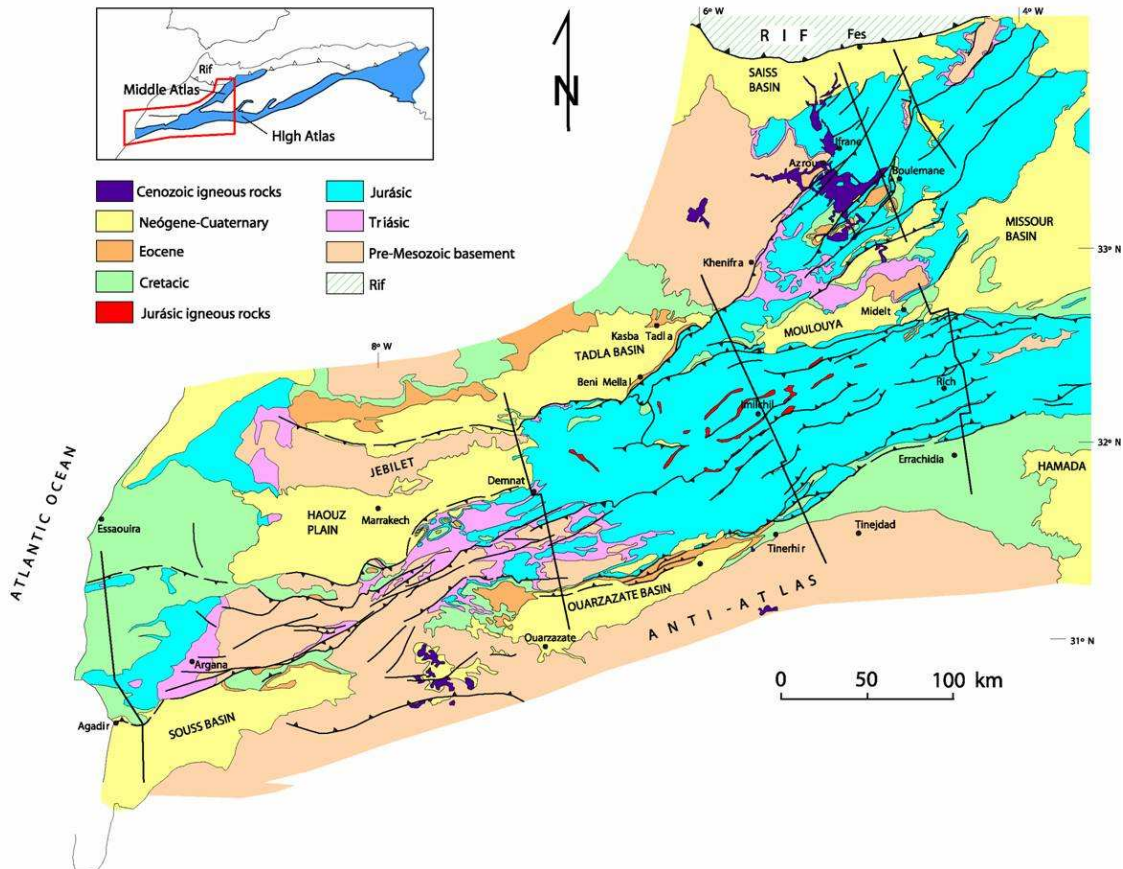


Figure 1 - Simplified geological map of the High Atlas (after Teixell et al., 2007). The location of the cross sections used by Teixell et al. (2003) and those studied by Arboleya et al. (2004) to estimate the shortening of Middle and High Atlas are shown. See also the location of the Ouarzazate basin.

The Ouarzazate basin is the best preserved foreland basin developed adjacent to the High Atlas and contains the best record of syn-orogenic sediments. It is bounded to the N by the south Atlas thrust front, which concentrates most of the deformation and shortening affecting the High Atlas. This thrust system, probably active from the Oligocene to the Quaternary, affects sediments from the Triassic to the Upper Eocene. The shortening ratio in this area has been calculated after detailed tectonic follow up and cross section restoration and has proven to be slow: 0.3 mm/year (Tesón and Teixell, 2006). However, this is an average velocity calculated from the Oligocene, and shortening velocities might be higher in some periods of time.

The asthenospheric upwelling affecting the High Atlas might respond for as much as 50% of its present day elevation (Teixell et al., 2005, 2007). This uplift may have been, however, partly compensated by flexural subsidence linked to the thrust load and led to the scarce development of foreland basins (Garcia-Castellanos et al., 2007). The age of this uplift is controversial. Geomorphologic evidences related with the present day elevation of undeformed marine and lacustrine sediments suggest that the mantle related uplift might have started 5 Ma ago (Babault et al., in press). That leads to an uplift rate of 0.2 mm/year on average, although again, this is an average and might have reached temporally higher values.

The seismic activity affecting the Ouarzazate basin from 1900 is a witness of the present day tectonic activity in the area (Figure 2). Earthquakes from magnitudes $M=2-4.5$ have been common in the basin as well as in the rest of the mountain range. The accessibility of the basin together with its seismic activity has been to key to choose it as the home of a non-permanent GPS network aimed to track the actual rate of shortening and uplift.

2. NON-PERMANENT GPS NETWORK AND DATA PROCESSING

The first survey has been carried out in September 2007, tracking the GPS constellation throughout a five-day campaign with 24-hour sessions over baseline lengths of approximately 20 Km. For data acquisition we used 6 dual frequency carrier phase GPS receivers Leica System 1200, consisting of GX1230 receivers and AX1202 antennas. Site design forms a special centred device and consists of a threaded nail anchored to rock and a 0,5 m long steel bar. On the top, the GPS antenna is fitted (Figure 3).

The network was tied to Maspalomas, Rabat, San Fernando and Villafranca sites. All of them belong to the IGS (International GPS Service) network. From these stations, the coordinates of network central point, 4400, were computed. The network solution finally computed for each day is a stochastically-constrained solution, based on coordinates and RMS of IGS stations. Then, coordinates of the regional network were obtained by a least squares adjustment. In the following, the results of this regional network adjustment are presented.

The GPS data processing was performed by using Bernese 5.0 software (Beutler et al. 2006) in the following way: single sessions were computed in multibaseline mode. The first step (pre-processing) related to receivers clocks calibration, performed by code pseudoranges, and detection and repair of cycle slips and removal of outliers, was carried out simultaneously for L1 and L2 data. The final solution for each session was obtained using the iono-free observable with precise ephemeris (Dow et al., 2005) and absolute antenna phase centre variation files. The fixed solution of the coordinates was estimated using the QIF method to fix integer ambiguities. Site specific troposphere parameters with horizontal troposphere

gradients were estimated for all but the central station. From these results we used an intermediate program to produce GPS baselines with their covariance matrixes. Using the NETGPS software (Crespi, 1996) that performs the adjustment of GPS baselines accounting for their full covariance matrixes, a minimal-constrained network adjustment was done.

Table 1 shows the adjusted geodetic coordinates at epoch 2007.6 in ITRF05 and Table 2, the minimum constrained adjustment parameters. 99% confidence regions and height confidence intervals are drawn in Figure 4.

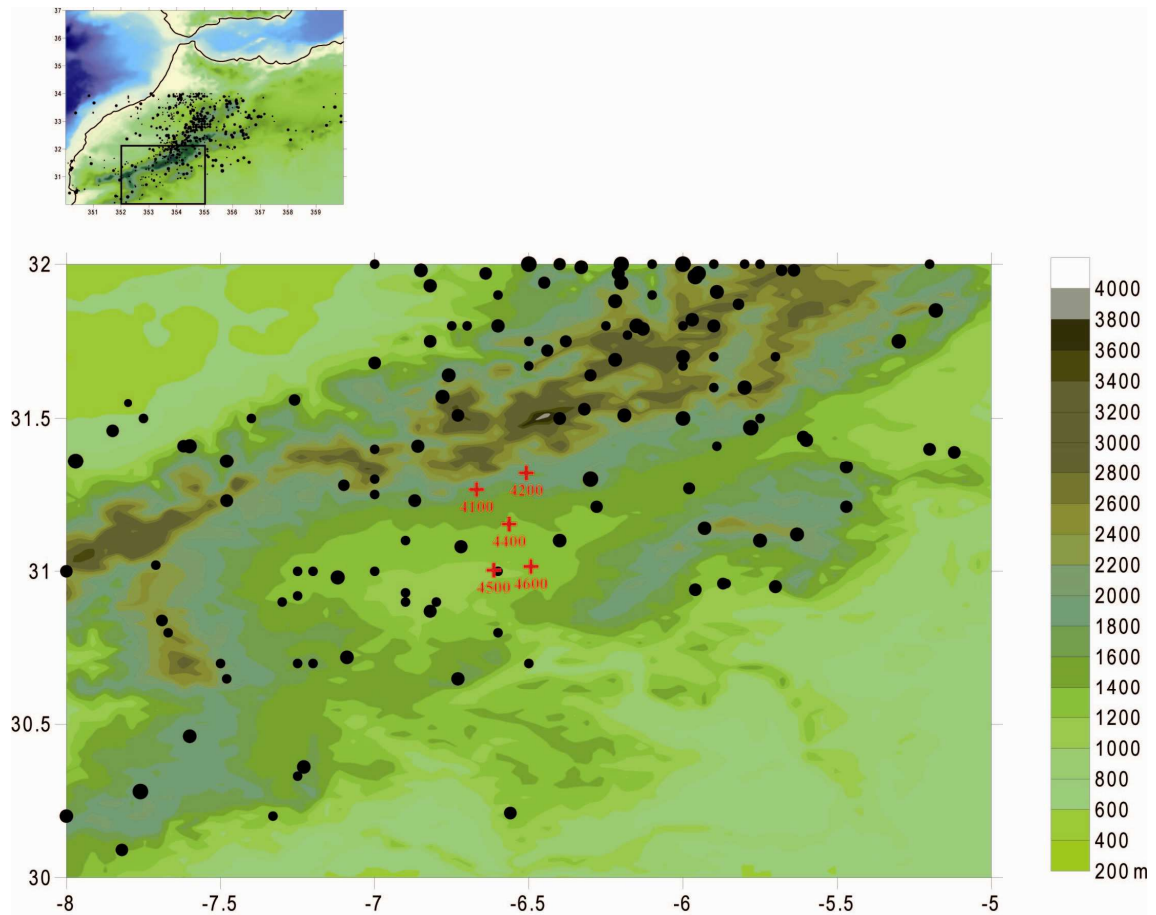


Figure 2- Topographic map of the Ouarzazate basin with the location of earthquake epicentres occurred from 1900 to 2007, as recorded by the Spanish Geographical Institute (black dots). These earthquakes have magnitudes $M < 4.7$ and the size of the dot is related with the size of the earthquake. See also de location of the non-permanent GPS stations (red crosses).

3. CONCLUSION

The High Atlas is an ENE-WSW-trending mountain chain located in the south-western part of the Atlas System (Morocco). An astenospheric upwelling has been proposed to contribute to the elevation of the Atlas cordillera. The Ouarzazate basin is the best preserved foreland basin developed adjacent to the High Atlas and contains the best record of syn-orogenic sediments.



Figure 3 - GPS equipment over one of the network sites.

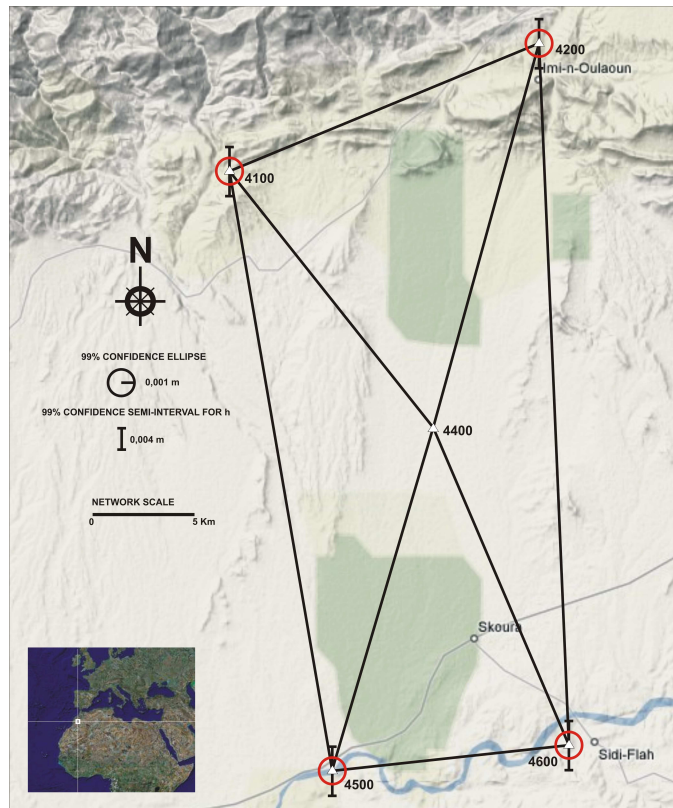


Figure 4 - GPS network and 99% confidence uncertainties for unknown parameters
 From geological and geomorphological evidences, a 0.3 mm/year shortening and 0.2 mm/year uplift have been estimated in the area. With the aim of verify these deformation rates, a non-

permanent GPS network has been established and surveyed for the first time in September 2007 as a result of a collaboration between different specialists in Earth Sciences and Geodetic Engineering from different Spanish and Marocaine universities. In this paper, a description of geologic framework and results we got from the first observation of a non-permanent GPS network have been described. In the next future, more surveys will help to contrast these deformation rates and get a picture of the tectonic behaviour of the area.

Site	latitude [° ‘ ‘’]	σ [m]	longitude [° ‘ ‘’]	σ [m]	h [m]	σ [m]
4100	31 15 58.951171	0.0001	- 6 40 10.014311	0.0001	1761,5700	0.001
4200	31 19 12.124727	0.0001	- 6 30 29.014752	0.0001	1730,0840	0.001
4400	31 9 13.851836	fixed	- 6 33 49.650702	fixed	1378,9050	fixed
4500	31 0 13.103308	0.0001	- 6 36 49.884317	0.0001	1237,5530	0.001
4600	31 0 55.460733	0.0001	- 6 29 35.626620	0.0001	1293,0370	0.001

Table 1 - Adjusted geodetic coordinates at epoch 2007.6 in ITRF05 with their associated standard uncertainties.

Ses	Eq	Unk	Red	σ_0^2	χ^2_{exp}	χ^2_{teo}	σ_X	σ_Y	σ_Z	S_{min}	S_{maj}	CI
5	60	12	60	1.21	69.58	73.68	1	0.1	1	1	1	4

Table 2 - Minimum constrained adjustment parameters. Ses: sessions, Eq: Number of equations, Unk: unknown parameters, Red: redundancy, σ_0^2 : unit weight variance; χ^2_{exp} : experimental χ^2 with “redundancy” degrees of freedom; χ^2_{teo} theoretical χ^2 with “redundancy” degrees of freedom at the 99% confidence level; σ : average SQM values in mm, S_{maj} : semimajor axis of the 99% confidence ellipse in mm. S_{min} : semiminor axis at the 99% confidence level in mm; CI: 99% confidence height interval in mm.

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