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Large earthquakes and active faulting in the Gafsa-Metlaoui region (South Tunisia): Implications for the seismic hazard assessment

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Abstract. The main purpose of this work is the estimation of seismic hazard and earthquake occurrence rates from the characterization and modeling of active fault parameters in southern Tunisia. The aim is to determine the slip rate of faults which are capable to generate large magnitude earthquakes (Mw> 6), and to characterize the annual occurrence rates generated by these faults. This is considered as an alternative to standard models based on seismicity catalogs.

Keywords: Metlaoui, earthquakes, mechanical and elastic modeling, shortening rate, seismic hazard model.

1 Introduction

The Metlaoui and Gafsa regions in southern Tunisia have been the site of shallow and damaging earthquakes in 1989 (Mw 4.9) and 1992 (Mw 4.7) related to the Africa – Eurasia plate convergence (Fig. 1 and Table 1). The seismic activity of this region is generated not only on the NW-SE trending and right-lateral Gafsa strike-slip fault, but also on E-W striking fold-related faults that also mark the limit between the Maghrebian Mountain ranges and the African platform of the Nubian plate. Although this region was in focus of several neotectonic and seismotectonic studies [1], the active fold-related faults received limited attention and the rate of active deformation of seismogenic structures was poorly explored.

2 Materials and Methods

We conduct earthquake geologically investigation along with structural and neotectonic studies including mechanical and elastic modeling of active folds of southern

Tunisia. Our approach consists in the study of active tectonic structures at the crustal level (seismogenic layer) using kinematic-mechanical and elastic modeling. The comparison between these two methods may provide some constraints on the characterization of seismogenic structures and their rate of active deformation.

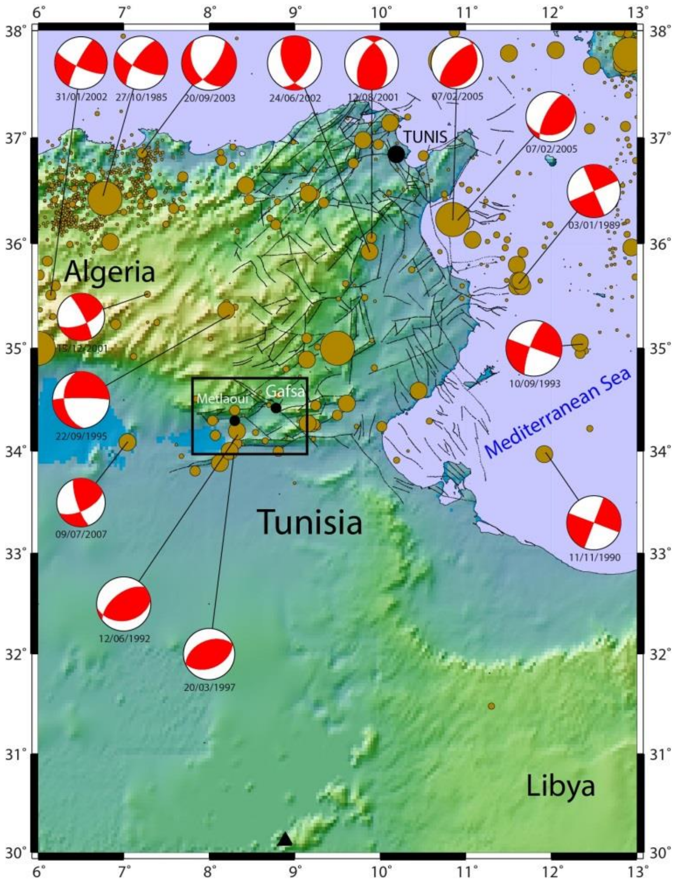

Fig.1: Seismotectonic map of Tunisia [1]. Black lines are for faults and topography is from ASTER-DEM (1 m resolution). Box is the study area.

The local geology with detailed stratigraphic log (mostly from wells), the geophysical results (seismicity distribution and gravity), and its structural characteristics provide the tectonic background for the preparation of balanced cross-sections. The tectonic structures visible at the surface and inferred at depth are used for the kinematic and mechanical modeling using the Trishear software [2].

The elastic modeling is performed based on the constitutive formula of dislocation of Okada [5]. It allows the characterization of the parameters of coseismics ruptures such as the fault dimensions, the coseismic displacement, the seismic moment Mo

(Mo=μ*LW*Ū) and thus the associated moment magnitude Mw. Field observations associated to the mechanical and elastic modeling allow to better estimate the size of potential future large earthquakes (with M>6) and constrain their occurrence rate, the seismic zoning, and seismic hazard assessment.

3 Results

The E-W trending fold structures in northern Africa are associated with transpressive tectonic movements that associate right-lateral slip with NE-SW shortening [3]. Active folds are asymmetrical, with southern vergence along fault segments that may reach 40 km in length and ~550 m topographic offset.
The balanced cross-sections of the Metlaoui fold-related fault with thick sedimentary units on the hanging block indicate the evolution of pre-Miocene normal faulting (Fig. 2). The modeling proceeds with the high-angle (~50° north dipping) reverse fault segments and its evolution during the Plio-Quaternary.

Table 1. A list of significant earthquakes of southern Tunisia from 1989 to 2018.

Date (M, D, Y)	**Long.**	**Lat.**	**Depth (km)**	**M** (INM M_L, CMT M_W)	**Ref.**
110789	8.4	34.33	12	4.4	INM
061292	8.44	34.21	15	5.2	CMT
091093	12.44	34.99	26	5.3	CMT
051194	8.45	34.22	5	4.6	INM
032996	9.53	34.82	10	4.4	INM
010598	10.18	33.85	16	4.7	INM
050698	9.25	34.22	15	4	INM
050901	10.5	33.9	14	4	INM
052118	9.69	34.19	12	5	CMT

The kinematic and mechanical modeling of fold-related faults using the Trishear code [2] allowed the model of active deformation during the Plio-Quaternary taking into account the stratigraphic succession, tectonic characteristics and fault geometry [1, 6 and 7]. The modeling of successive fault displacement and folding deformation lead to 0.7 ± 0.1 mm/yr. shortening rate which is in agreement with results of recent GPS surveys [4].

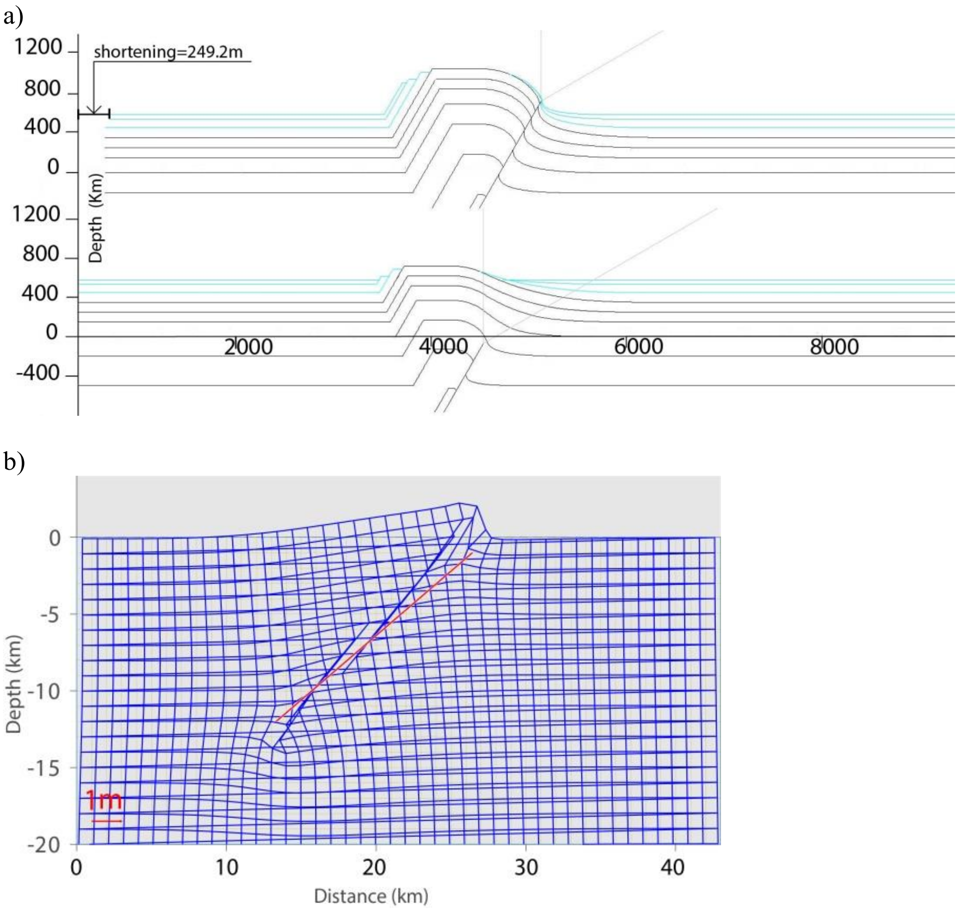

Fig. 2: a) Balanced cross-sections of the Metlaoui fault-related fold. The comparison of the cross sections allows the determination of the ~ 249.2 m of shortening. The folded and faulted tectonic structures involve alluvial terraces dated 300 ±50 ka [6] and imply a minimum 0.7 mm/yr. shortening rate. b) Elastic modeling based on 1992 earthquake data (Table 1 and Fig. 1). The modeling of geological units suggests an estimate of the late Quaternary shortening rate.

4 Discussion

Active folds in southern Tunisia and SE Algeria may generate strong crustal movements and tectonic deformation such as the Gafsa - Metlaoui earthquakes (1989-1992) and Biskra (1869). These earthquakes are controlled by the movements of the fold related faults. The active zone of Metlaoui presents a transpressive tectonics which associates NW-SE to E-W trending, right-lateral strike-slip faults with fold-related fault. The high-angle reverse faulting confirms the assumption of the tectonic inversion of the pre-Miocene normal faults during the Plio-Quaternary. This is also attested by the uplifting of alluvial terraces with artefacts (tools) dated at Mousterian (~150-

350 ka). The Metlaoui fault length estimated at ~40 km implies an earthquake magnitude of Mw > 6.5, according to Wells and Coopersmith empirical relation [8].

Unfortunately, the historical seismicity catalogue does not mention any earthquake on the Gafsa region. The estimation of the earthquake occurrence rate is still with uncertainty in the Gafsa-Metlaoui region. In order to better refine our estimated 0.7 ± 0.1 mm/yr. shortening rate and return period of large earthquakes (Mw > 6), the elastic and mechanic modeling needs to be combined with investigations in tectonic geomorphology and paleoseismology.

In order to establish the relationship between the earthquake generation at depth and surface deformation, we also proceed with the elastic deformation using the elastic dislocation modeling [5]. Using previous seismological studies of past earthquakes, we observe that coseismic rupture initiation may occur at 6 – 8 km depth in agreement with the mechanical properties of the upper crust. The elastic modeling also conforms the seismic parameters such as the fault dimensions, average coseismic slip, seismic moment and estimated maximum moment magnitude Mw 7 on the active fold-related folds.

5 Conclusions

Our study of active folds in the Gafsa-Metlaoui region combines kinematic and elastic modeling using geological, geophysical, tectonic and seismological data. The seismic and tectonic parameters obtained from earthquake studies and field observations on the deformation of Quaternary deposits allow us to determine the 0.7 ± 0.1 mm/yr. shortening rate across the Metlaoui active fold. Field observations, seismotectonic and geodetic results, and modeling of the active deformation constrain the size and rate of large earthquake generation, and lead to a new model of seismic hazard assessment in Tunisia.

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