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SEISMOTECTONICS OF THE 1755 MEKNES EARTHQUAKE (MOROCCO)

CONTENTS

ABSTRACT

The November 1st, 1755 Lisbon earthquake has been largely studied, its source constrained to be a 200 km long structure, its magnitude estimated around 8.7, and the stress regime argued as a NNW-SSE directed compression. Less well known is the Meknes earthquake, occurred a few days later in Morocco and considered the effect of a strong aftershock in Portugal. It had destructive effects in the Meknes region, along the E-W trending *Rides Prérifaines*, the main frontal thrust of the Rif. Historical data indicate an E-W elongation of the epicentral macroseismic area, where we surveyed the major recent faults. Historical descriptions of the earthquake indicate ground ruptures in two areas of the *Rides Prérifaines*. Field work and air photo interpretation allowed us to relate these ruptures with the local thrust front, so that they may be assumed to correspond to coseismic surface faulting of the Meknes earthquake.

KEY WORDS: Seismotectonics, surface rupture, earthquake, *Rides Prérifaines*

1. INTRODUCTION

The November 1st, 1755 Lisbon earthquake, accompanied by a large tsunami wave, has been the most devastating historical event affecting the Atlantic coasts of Iberia and Morocco. This largely studied event had a magnitude estimated between 8.5 and 9.4 (*e.g.* SOUSA MOREIRA, 1983; BAPTISTA *et alii*, 1998 and references therein) and its source has been constrained to be an up to 200 km long structure in the offshore west of Cabo de S. Vincente (Fig. 1c), where active reverse faults have been individuated through seismic investigation (ZITELLINI *et alii*, 1999; GRÀCIA *et alii*, 2003). A few days later on November 18 or 27, according to different historical sources, another major earthquake took place in Morocco, with large destructive effects mainly in the town of Meknes (from where it is referred to as the "Meknes earthquake") and, subordinately, in Fes. European historical sources tend to confuse this event with an aftershock of the major Lisbon earthquake, occurred on November 18 with more or less the same epicentre. The Arab sources clearly indicate the earthquake to have stroke on November 27. This and the localised macroseismic area (LEVRET, 1991 and references therein, Fig. 1c), allow to identify this event as a different local earthquake. Historically, this event was well known as it heavily damaged also the famous Roman site of Volubilis. In this paper we analyse the active structures of the Meknes area, in order to define the seismogenic structure of the 1755 earthquake and relate them to the geodynamics of the Iberian-Maghrebian area.

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2. GEODYNAMIC AND SEISMOTECTONIC CONTEXT

The distribution of earthquakes in the Iberian-Maghrebian area clusters in the Alboran Sea and in correspondence of the structures delineating the Gibraltar Arc, the Betic Cordillera to the north and the Rif to the south (Fig. 1b). Local seismicity was investigated collecting and analysing the spatial distribution of instrumental earthquakes (ISC on-line Catalog), and the focal solutions available in literature, using the "EMMA" database proposed by GASPERINI & VANNUCCI (2003) and VANNUCCI & GASPERINI (2003). P and T deformation axes were obtained from the compute of the seismic moment sum, applying a regular latitude and longitude grid with mesh of one degree (Fig. 1a). The revised focal mechanisms in the region indicate active shortening oriented NNW-SSE to N-S (Fig. 1a, b).

The E-W trending *Rides Prérifaines* are a series of ridges mainly composed of Jurassic limestones, bounded to the south by E-W-trending south-verging thrusts (Fig. 2b) affecting the Neogene sediments of the foreland Meknes basin. These structures represent the surface expression of the southernmost active frontal thrust of the Rif, the southern border of the Alboran Sea and Gibraltar Arc geodynamic area. In Northern Morocco clustering of seismicity occurs both along NNE-SSW to NE-SW-oriented zones (e. g.: HATZFELD *et alii*, 1993; MEDINA, 1995) and in correspondence of the external thrusts outlining the Gibraltar Arc (Fig. 1a, b), thus suggesting activity of these structures. From a field survey performed in the Rif-Atlas system of Morocco, it appears that the E-W-oriented main thrusts of the *Rides Prérifaines* and of the High Atlas are active and tend to thrust onto the NE-SW oriented Middle Atlas structures (Fig. 2a). In particular, structural-geological fieldwork, remote sensing analysis and hydrothermal activity indicate that the E-W-oriented thrusts of the *Rides Prérifaines* are active. Active thermal sources are located along the two *Rides* of *Jebel Zerhoun* and *Jebel Zalagh*, north of Meknes and Fes, and travertine deposits have been observed presently in deposition in the overlap zone between them (MORATTI *et alii*, 2003) (Fig. 2b).

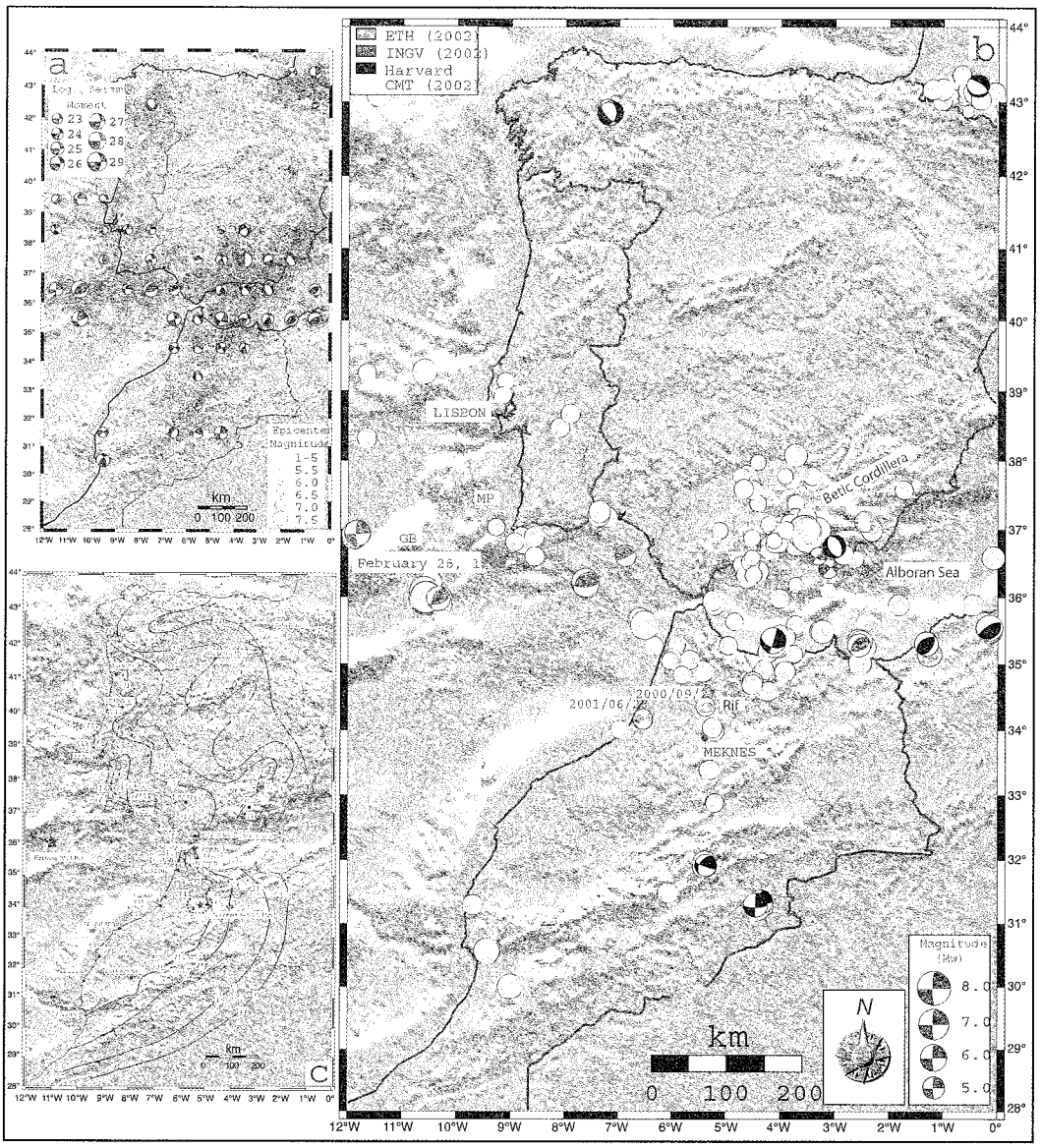

Fig. 1 - a) Instrumental seismicity of the Iberian-Maghrebian area, starting from 1910, from ISC (2002) Catalogue (open circles) and focal solutions related to the moment tensor sum obtained within a regular latitude and longitude grid with mesh of one degree. Size of symbols is directly related to the magnitude of the events. b) Focal mechanisms in the Iberian-Maghrebian area recomputed from different on-line catalogues and literature (see MORATTI *et alii*, 2003 for a complete reference list on seismicity data). GB = Gorringe Bank. MP = Marques de Pombal. c) Comparison between the effects of the two earthquakes of November 1st, 1755 and February 28, 1969. Black isoseismals (MSK Scale) show the macroseismic field of November 1st, 1755 (from SOUSA MOREIRA, 1983 for Portugal, and MARTINEZ SOLARES *et alii*, 1979, for Spain), while dashed isoseismals (MSK Scale) show the effects of February 28, 1969 earthquake. Source of the two earthquakes (big black star) is considered the same (see text). For Morocco, isoseismal lines of the November 1st, 1755 earthquake are extrapolated from the isoseismals of February 28, 1969 event. Black thick line indicates the damage area of November 18 or 27, 1755 Meknes earthquake (small black star).

3. FIELD EFFECTS OF THE 1755 MEKNES EARTHQUAKE

The 1755 Meknes earthquake macroseimic area is located in correspondence of the *Rides Prérifaines* and of the northern part of the Meknes basin (LEVRET, 1991; MORATTI *et alii*, 2003) (Figs. 1c and 2b). We studied the epicentral area of the 1755 Meknes earthquake, in order to identify possible coseismic effects related to that event and clearly described in historical reports (SFERN, 1985) and to relate them to the tectonic setting of the area. This shock strongly damaged Volubilis and also triggered a destructive landslide in the town of Moulay Idriss, just a few Km to the north of *Jebel Zerhoun* (Fig. 2b). These data, together with the damages suffered by Meknes and Fes and the ground ruptures indicated at *Jebel Zerhoun* and *Jebel Zalagh* (Figs. 2 and 3), provide, up to now, at least six close localities which individuate a damage area distinct from the general macroseismic field of the Lisbon earthquake (Figs. 1c and 2b).

A re-examination of historical descriptions of the earthquake effects (SFERN, 1985) led us to find indications of ground ruptures in the two areas of *Jebel Zerhoun* and *Jebel Zalagh*, respectively north of Meknes and Fes. The location of the ruptures at *Jebel Zerhoun* is extremely well

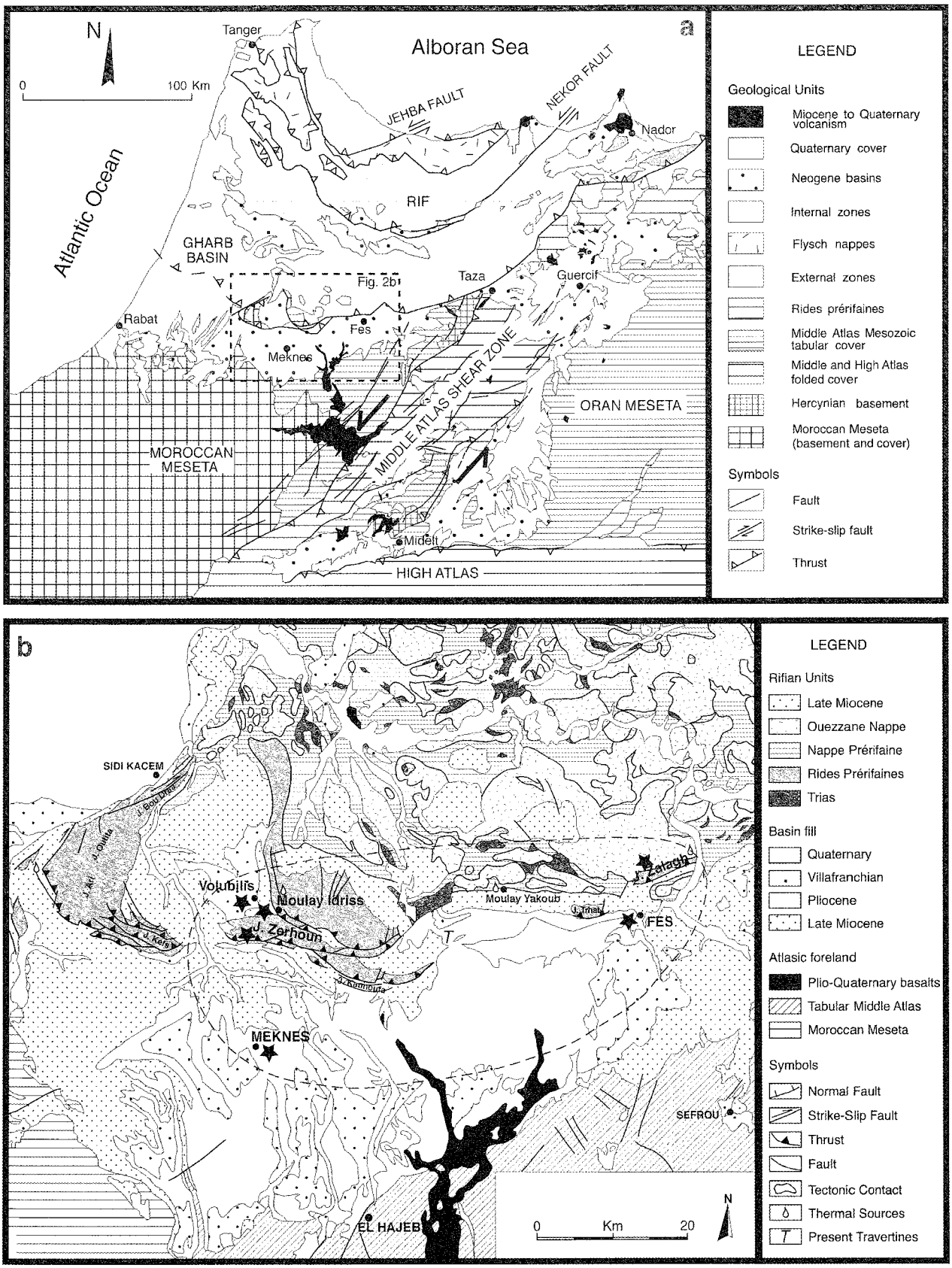

Fig. 2 - a) Structural map of Northern Morocco. b) Structural map of the *Rides Prérifaines*, ridges bounded by south-vergent, E-W-oriented thrusts, part of which are active (redrawn after MORATTI *et alii*, 2003 and references therein). Stars indicate the six damaged localities envisaged from historical reports (SFERN, 1985), which individuate a closed damage area (dashed line) around the towns of Meknes and Fes.

constrained in the historical reports (SFERN, 1985), with reference to the 15th km from Meknes along the main contemporary (Sultan) road (Fig. 3a). We could individuate traces of recent ground breaks, clearly visible on air photos and in the field, exactly at the indicated distance from Meknes (Fig. 3b, c). The location of these ruptures and their relationships with the main frontal thrust of the Rif, allowed us to interpret these ruptures as a splay of the local E-W trending thrust front (Fig. 3b, c). In the Zalagh area, instead, no clear historical indication of the rupture location is given. We performed a field survey and evidenced that *Jebel Zalagh*, the main *Ride* north of Fes, is bordered both to the south and to the north by important active faults (Figs. 3d and 3e). The clearest morphostructural evidence of tectonic activity is shown by the E-W oriented fault along the northern margin (Fig. 3e). A striated fault mirror related to this fault system cuts recent slope debris and appears to have been recently reactivated with evidence of a surface fissure filled by more recent deposits (Fig. 3f). Because of these evidences, we consider this fault to be the most probable seat of the described ground breaks. These ruptures may therefore be assumed to correspond to coseismic surface faulting of the Meknes earthquake. As such, our data seem to indicate activation of the E-W oriented thrusts of the *Rides Prérifaines*, located

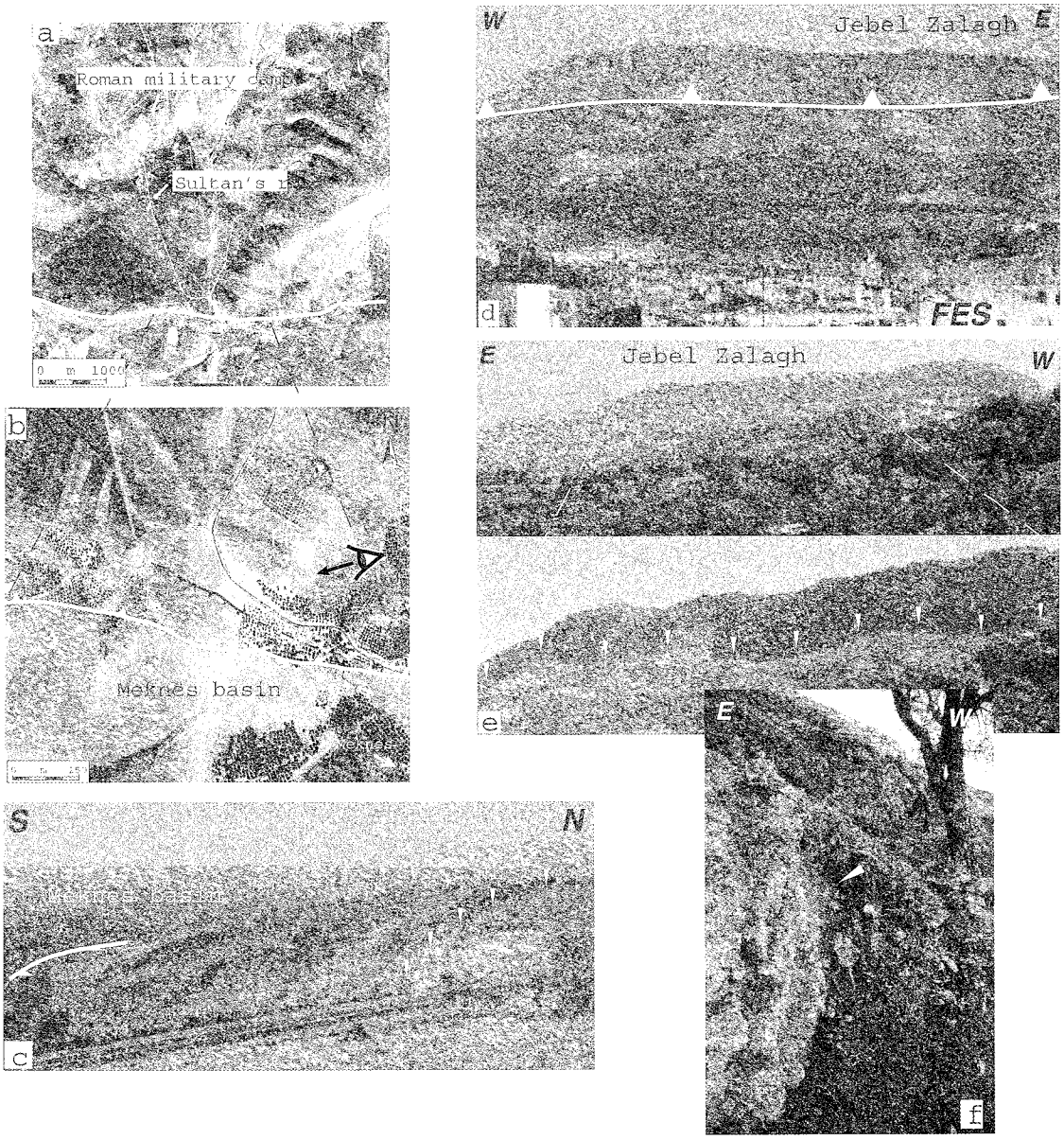

Fig. 3 - a) Aerial photo of the *Jebel Zerhoun* area. b) Detail of the main thrust front (white) and of the ground ruptures (black) related to the 1755 Meknes earthquake. c) View from the NE of the ground ruptures at *Jebel Zerhoun* (white arrows): fieldwork and air-photo interpretation allowed to relate these ruptures with the local thrust front (white). d) E-W-oriented active thrust originating large landslides on the southern margin of *Jebel Zalagh*. e) Trace of the fault (white arrows) bounding *Jebel Zalagh* to the north. f) A fault cutting recent slope debris appears to have been recently reactivated with evidence of a surface fissure filled by more recent deposits (white arrow). This could be the seat of the coseismic breaks related to the 1755 Meknes earthquake referred to in the historical reports (SFERN, 1985).

within the elongated epicentral area, as the most probable cause of the earthquake, under a compressive stress regime mainly N-S oriented. This stress regime is coherent with the indications given by both focal mechanisms (Fig. 1a, b) (MORATTI *et alii*, 2003 and references therein) and neotectonic data (*e.g.* FAURE-MURET & MOREL, 1994).

4. FINAL REMARKS

The activation of the thrusts of the *Rides Prérifaines* is consistent with the stress regime indicated by focal mechanisms at regional scale, and would in turn be similar to the stress field hypothesised as responsible for the November 1st, 1755 Lisbon earthquake. As such, there is the possibility that the Meknes earthquake could have been a consequence of the main shock of November 1st.

Comparing the macroseismic data of 1969, February 28 earthquake (magnitude range from 7.3 to 8.0, according to different authors) and the macroseismic effects of the 1755 Lisbon earthquake, some authors hypothesised the same localisation and mechanism for the seismogenic source (Fig. 1c; *e.g.* LEVRET, 1991). The focal solutions show an E-W trending orientation with a compressional to slightly transpressional component, under a compressive stress regime roughly N-S oriented (Fig. 1b). On the basis of finding of active reverse faults individuated through seismic investigation (ZITELLINI *et alii*, 1999; GRÀCIA *et alii*, 2003) another possible source of the November 1st, 1755 Lisbon earthquake has been considered to be the Marques de Pombal thrust (Fig. 1b). We tried to evaluate the possible triggering of the Meknes earthquake by the Lisbon one. The Coulomb Failure Function (CFF) change models performed, necessarily affected by heavy uncertainties, indicate that no clear static stress variation would have been induced in the Meknes area by the rupture of any of the different seismic sources hypothesised for the Lisbon earthquake (MORATTI *et alii*, 2003). This result supports the hypothesis that the 1755 Meknes earthquake was a local event, as indicated also by the macroseismic field closed around Meknes and Fes (LEVRET, 1991; MORATTI *et alii*, 2003).

We are nonetheless convinced that such a "monster" shock as the 1755 Lisbon earthquake, could easily influence the stress field as far as the Meknes area. It is to be noted, in fact, that that earthquake was strongly felt as far as Scotland, where it originated a violent *seiche* in the Loch Ness with waves up to two meters high (GROOME, Ordnance Gazetter of Scotland, 1891).

The tectonic similarity of the faults hypothesised as responsible for the November 1st, 1755 earthquake and the *Rides Prérifaines* thrust (November 18 or 27) as well as their pertinence to the same geodynamic structure, the Gibraltar Arc, make possible that the Meknes earthquake might have been a local earthquake consequent to the major Lisbon event.

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