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Abstract

The reflection initiated here, is in connection with an area poorly known from the geological point of view as it is composed of clayey, silty turbiditic sediments and structurally characterized by different geological domains (Saiss basin, Middle Atlas Mountain and Prerif ridges). Furthermore it is also characterized by the frequent mass movements of different nature and volume and a variety of erosion processes (such as rockfalls and rockslides, subsidence and collapse of roads, landslides, gully erosion and rain). We face here a unique chance to have a better geological and geomorphological control due to the construction of the new Fez-Taza highway in northern Morocco. Consequently, this study shows that mass movements are quite important especially in the Prerif ridge, where clayey rocks (clay-stones, marls, shales, muds, flyschs) newly outcrop on both side of this new highway. The factors that affect their occurrence are especially geology and soils, neotectonic movements and climate. The combination of satellite data interpretation, detailed mapping surveys, geophysical investigation, Digital Topographic Model, morphological and finally precise fieldwork campaigns, integrated within a Geographic Information System (GIS) helped to create geo-mapping documents for multi-source developer's in order them to pay attention to the potentially dangerous areas and to optimize safety works along such roads in some sections of the highway. At least such works lead us to differentiate Neotectonics and landslides (*s.l.*) and therefore simplify the passed and recent neotectonic history of the studied area.

Keywords

Mass movement • Neotectonics • Highway • Fez-Taza • Morocco

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17.1 Introduction

Important part of the Moroccan highway system, the Fez-Oujda highway connection extends the highway Rabat—Fez to form eventually a large structuring West–East axis that integrates with the existing network and major roads projects as Taza—Al Hoceima connection and Oujda—Nador. It is also an important section of the Maghreb highway which originates in Nouakchott, capital of Mauritania, and serves the major cities of North Africa to reach Tobruk in Libya.

The drawing of the highway connects the two cities of Fez and Taza over a distance of 127 km through a difficult and mountainous area. The axis of the tracing was chosen to follow the crests of hills encountered, to avoid as much as possible crossing wadis and to ensure the presence of hydraulic works for the drainage of rainwater. However, even after as much as possible the natural terrain, this track involves great heights of cuts and fills exposing beautiful outcrops and exposures in this geologically poorly known area. The trace crosses many wadis, the main ones being: Oued Sebou, Hamri, Bou Zemlane, Matmata, Bou Hellou, Zireg, Inaouène (3 crossings).

The Fez-Taza highway is situated in a continental climate relatively temperate with an average annual rainfall varying from 390 mm to 740 mm. Rainfall events are generally brutal and the greatest rainfall are concentrated in few days of the wet season. The close succession of exceptional rainfall events, are sources of risks to such kind of environments.

The new Fez-Taza highway cross three geological domains: the Saïss basin, the Middle Atlas Mountain and the Prerif ridge. In the Prerif, landslides are mainly mudslides and flows landslides (flowslides) (Tribak et al. 2012). Their genesis is the combination of several factors: geometric (related to the inclination of the topographic surface), lithological (related to marly land beneath the superimposed hard rocks), and structural (complexity of the structure and their deformation). However, in the Middle Atlas, these movements are instead represented by rockfalls of Liassic sandstones, limestones and dolomites. In the Saïss basin, the extension of marl land is an obstacle to carriers and structure determination. The highway route offers a unique chance to have better geological and geomorphological control. The trenches show rich outcrops teaching since they permit to better constrain the differences between landslide and neotectonic.

The studies of mass movement and neotectonic in the Fez-Taza highway are considered through a successive process. Visual interpretation of satellite data (Landsat, as well as High resolution data 60 cm ground resolution such as GeoEye) allowed delineating the various types of mass movements (landslides, rock and debris falls, earth flows). The differentiation of rock and debris falls was done with the aid of ancillary data (geology and Digital Topographic Model). Draping all the images on the DTM surface has

clarified zones of detachment from zones of accumulation. Also, by superimposing, in a Geographic Information System (GIS), the available geological maps (Taza, Tahala and Sefrou at 1/50.000 scale), on the processed images, discrimination between features and facies that undergo rock and debris falls was possible. Field truthing campaigns were raised to detect and delineate earth creep. The resulting study, comprising mass movements that were known before our study, plus those newly discovered, are presented herein. Their studies will be considered through the analysis of the processes and factors governing the instability.

In this paper, we present a general geology review and a detailed description of the different types of mass movement across the new Fez-Taza highway, and the factors that affect their occurrence.

17.2 Geological Framework

The Fez-Taza highway crosses from west to east, three important domains: (1) the Saïss basin, (2) the northern side of the Middle Atlas Mountain and (3) the Prerif ridges south of the Rif mountain front.

- The Saïss basin constitutes with the Gharb basins a large depression that extends eastward from the Atlantic to the Taza Strait. The Saïss basin opened in Late Miocene after the collapse of the northern edges of the Western Meseta and the Middle Atlas (Bargach et al. 2003). It behaved as a subsiding marine basin during the Late Miocene, and then was lacustrine during Late Pliocene and Quaternary (Taltasse 1953; Feinberg 1986). The Prerif thrust sheets are interfingered with Upper Miocene rocks in the eastern part of the basin, and with Pliocene rocks in its western part (Moratti and Chalouan 2006).
- In the northern extremity of the tabular Middle Atlas, sub-horizontal Lower Liassic dolostones and limestones are covered by unconformable Plio-Quaternary conglomerates and the lacustrine limestones formations of the Saïss Basin or by the Quaternary fluvial or travertine formations (Charrière 1990; Gourari 2001; Ahmamou 2002; Hinaje 2004).
- The Prerif thrust sheets form the frontal part of the Rif Cordillera. They are a tectonic-sedimentary complex, thrust over the South-Rif corridor (former foreland basin) or the Middle Atlas. The Prerif Ridges comprise elongated hills, formed mainly by Jurassic to Miocene rocks. The ridges are interpreted as part of the Meseta-Atlas cover of the foreland, involved in thrusts of the External Rif—due to the contraction of the African margin during compression from Late Miocene extending to Middle Pliocene (Faugères 1978; Zizi 1996; Moratti and Chalouan 2006).

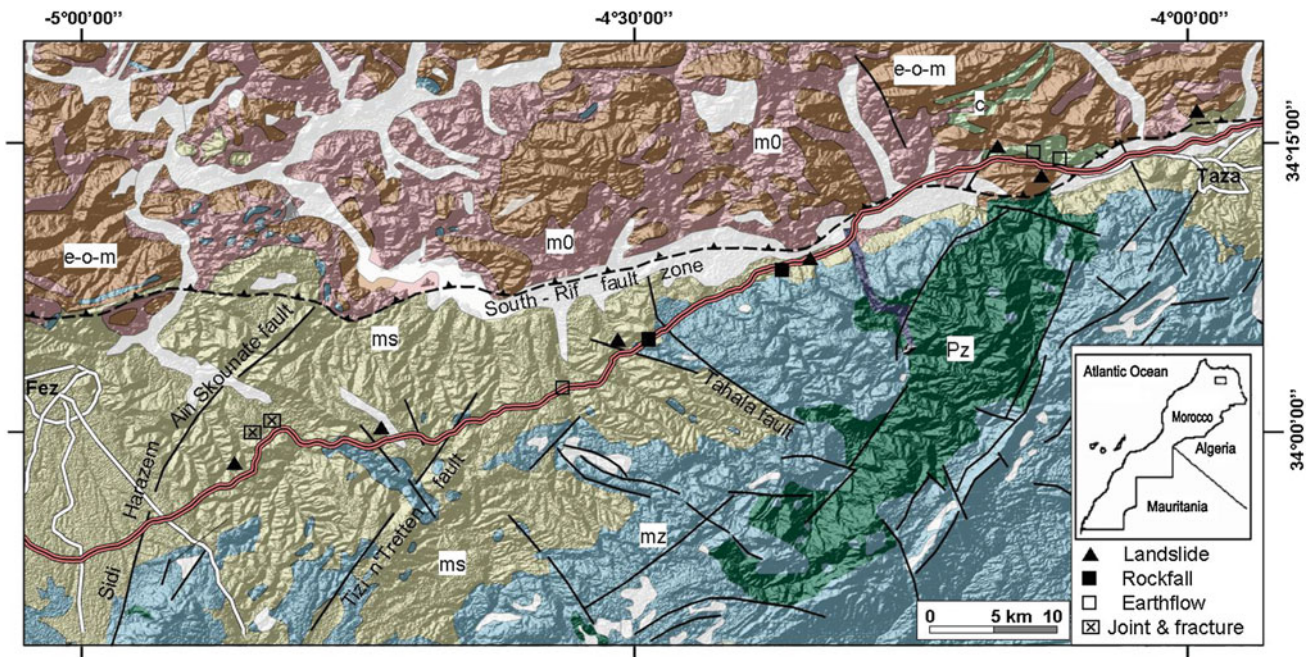


Fig. 17.1 Position of mass movements on the Fez-Taza highway on a geological and geomorphological background. *Pz* Palaeozoic, *mz* Mesozoic, *c* Cretaceous, *e-o-m* Eocene-Oligocene and Miocene, *m0* Middle Miocene, *ms* Upper Miocene

The structures recognized result of the effect of the overlapping tectonic layers recognized in the Rif area with folding-axis oriented WSW-ENE spilled southward and a brittle tectonic oriented NE-SW typical of Middle Atlas and associated with vertical syndimentary movements, promoting subsidence and uplift of blocks (Sabaoui 1987). The major discontinuities correspond to (Fig. 17.1): (1) the south-Rif accident is an ENE-WSW-trending narrow elongated Prerif ridge, (2) the Tizi n'Tretten fault zone oriented NE-SW, (3) the Sidi Harazem—Ain Skounate fault zone is a set of parallel faults trending NE-SW (4) the Tahala fault oriented NW-SE confronts the liassic formation in the north to the upper Miocene marl cover in the south (Fassi Fihri and Feskaoui 1998).

17.3 Mass Movements Across the New Fez-Taza Highway

Landslides are complex phenomena that we attempt to explain by a number of relatively simple mechanisms resulting from topographic, geological, hydrological and climate condition. Some of these conditions may change over time. The analysis of these mechanisms in the Fez-Taza highway has led us to distinguish different types of slides. Figure 17.1 includes most mass-movement observed in the field. Some older, highlighted in the literature or by surveys conducted during construction are not included on this map.

In general, the Prerif nappes are the site of frequent mass movements. The factors that affect their occurrence are especially geology and soils, neotectonic movements and climate. Mass movements are quite important where clayey rocks (clay-stones, marls, shales, muds, flyschs) crops out. These rocks are potential shear planes as they retain water. The presence of these rocks types along the route of the Fez-Taza highway promotes various types of mass movements (Fig. 17.1).

17.3.1 Landslide

- The rotational slides (slumping) are very common in the Prerif and the Saiss sections of the highway (Fig. 17.1). The surface of these slides has a concavity upwardly facing with the possible presence of concentric cracks in plan and concave in the direction of sliding. This type of landslide concerns slopes with high steeply sloping (15–45°), consisting in particular of clay or marl materials. The instability is fostered by water infiltration in the most permeable layers or by the presence of swelling clays. This slide is quite common and attests to the renewal of marl and clay reliefs by artificial erosion (highway construction and canals).
- Translational slides are characterized by a shallow surface of rupture. This type of sliding interest slope formation in where predominant clay of Miocene or their

associated alteration coverage. Its mechanism is a translational movement of the field mass, more or less coherent, along a slightly inclined surface. The thicknesses of land set in motion are plurimetric and the debris spread to the base of the slope. These slides are very active and have been recognized in the Prerif at the western entrance of the city of Taza (Koudiate Zar Ramrama, 731 m). Their location is strongly influenced by water infiltration. An inventory of this type occurred during the rains period of February 2013 that showed that the distance could reach an horizontal length equal to two times the height of the slope where the break began.

- The clay flows dominate the reliefs of Koudiet Toumiyat located at the western entry of the city of Taza. These movements are the result of the evolution of deep rotational slides and originate in the downstream parts. This mass movement is recognized easily within the GeoEye images of Google Earth[®]. The clay flow is sometimes large and constitutes a risk due to the spread of debris on the northern side of the highway. The geological nature of the terrain represented by clays and gray marl late Miocene in age combined to steep slopes and to their water saturation, are the main factors triggering these movements and lead to a loss of structures slope stability on the side of the road. Field observations made on two field works (October 2012, February 2013), on the eastern part of Koudiet Toumiyat allowed us to see the growth and expansion of cracks running through the silty gravel formations based on the collapsed parts.
- The subsidence: corresponds to topographic depressions that are bowl-shaped due to the slow and gradual decline of soil without apparent breaks. They are manifested, by occasional vertical displacements of the ground surface in two different places in the Prerif and the Saïss basin. They are usually governed by the nature of clay and marl substrate (increase of the clays plasticity) during heavy rains.

17.3.2 Other Slope Movements

- Joints have been surveyed in the silt of Messinian in two sites in the South of Saïss basin (Region of Bled Cherrada). The joints are predominantly oblique to the horizontal bedding and show preferred directions of N 130° E. They range in thickness from a few centimeters and in lengths up to 10 m. The average thickness of joints and the number per unit volume increases from west to east in the direction of digging of the Sebou River valley, suggesting that stress release of tension and alteration play an important role in fissure and joints genesis. However, the great majority of fissures and joints exhibit a matte surface texture without particles reorientation, with indications of brittle fractures rather than shearing.

- Gravitational displacement: the Jurassic formations of the Middle Atlas (limestones and dolomites rocks, and fractured joints), show traces of gravity moving rocks by translational motion without significant dissociation from the original material. These mountain slides are fossilized by post-Jurassic deposits.

17.4 Conclusions

The new Fez-Taza highway is characterized by frequent mass movements of different nature and volume. This section offers a unique chance to have better geological and geomorphological control. The trenches show rich outcrops teaching since they permit to better constrain the differences between landslide and neotectonic.

The combination of satellite data interpretation, detailed mapping surveys, geophysical investigation, DTM, morphological and finally precise fieldwork campaigns, integrated within a Geographic Information System (GIS) helped to create geo-mapping documents for multi-source developers. This instability corresponds in general to mass movement and dominates in the Prerif area. They are the result of geology and soils, recent and ongoing tectonic activity and climate.

Considering the risks of ground movement on some part of the Fez-Taza highway, the continuation and development of these researches is needed by actions such as the monitoring of movement, stability calculation, establishment of mechanical rupture models, modelling the motion path, research on protection techniques, development of files for each landslide. These actions will improve the understanding of these mass movements and attract the attention of developers on risk areas and potential or actual danger, and also the recommendation of stabilization works.

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