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HOLOCENE REACTIVATION OF THE KOUDIET ES SBAA DEEP-SEATED LANDSLIDE: SEISMIC TRIGGERING VS. CLIMATIC FORCING.

REACTIVAÇÃO HOLOCÉNICA DO DESLIZAMENTO PROFUNDO DE KOUDIET ES SBAA: DESENCADEAMENTO SÍSMICO VS. ACÇÂO CLIMÁTICA

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ABSTRACT

The Rif Mountains extend along the northern coast of Africa forming the south western-end of the Betic-Rif-Tell orogen. The Koudiet es Sbaa landslide develops along the northern slope of the Tisiren thrust front, approximately 50km east of Chefchauen. It attains 6690m in length and covers an area of 5.02km^2. It shows characteristics of a deep-seated rotational landslide in the upper sectors of the slope, splitting in two fronts along the drainage divide of the Audour and Bouhia rivers. Several lakes and poorly drained areas, in association with reverse slope morphology, allow the reconstruction of the different deformation phases by dating lake sediments. In this work we present the results from the analysis of a road cut located downslope from Lake Azaib and discuss the mechanisms and climatic setting in which slope failure occurred.

RESUMO

As montanhas do Rif estendem-se ao longo da costa setentrional de África, formando a terminação ocidental do orogeno Bético-Rif-Tell. O deslizamento de Koudiet es Sbaa desenvolve-se a partir da frente de carreamento da nappe de Tiziren, estendendo-se por 6690km e ocupando uma área de 5.02km^2. Demonstra características de um deslizamento rotacional profundo nos sectores superiores da vertente. A presença de lagos e áreas mal drenadas no interior da massa deslizada permite reconstruir diferentes fases de deformação por datação de sedimentos lacustres. No presente trabalho são apresentados os resultados da análise de um corte localizado a jusante do lago de Azaib, discutindo o contexto climático e os mecanismos responsáveis pela sua reativação no Holocénico.

1. INTRODUCTION

The study of landslides at different timescales is a key objective in landslide research. Significant effort has been put over the years to study the link between climate and present day landslide activity. Nevertheless, problems tend to emerge with the correlation of landslides with climatic signals on a Pleistocene-Holocene scale, particularly when working along active mountain chains where earthquake activity is independent of climatic oscillations.

In this work evidence is presented for reactivations of a deep-seated landslide located in the central Rif Mountains, with probable seismic triggering for the first event. AMS ages place slope deformation on the transition between early and late-Holocene, in agreement with an increase of annual precipitation between 6 and 4ka to values similar to those observed today.

2. STUDY AREA

The Rif Mountains extend along the northern coast of Africa forming the south western-end of the Betic-Rif-Tell orogen. This mountain system reaching over 2000m has been uplifting over the last 70 million years due to the convergence between the African and the Eurasian plates. The present-day tectonic setting is characterized by ongoing subduction (revealed by deep and shallow seismic activity) along the northern border of the mountain system in the Alboran Sea (Chalouan et al., 2008). The structure of the Rif is characterized by northward dipping thrust faults and folds forming tectonic *nappe* complexes. The study area is located within the contact between the *Maghrebian Flyschs* (J. Tisiren and Beni Ider *nappes*) and the *External Zones* (Intrarif - Tanger Unit).

The present climate of the Rif is under Atlantic and Mediterranean influences. The hot and dry summers are dependent upon the seasonal shift of the subtropical high-pressure belt, while winter rainfall is determined by the southward displacement of the northwesterly cyclonic activity. The main source of precipitation over Morocco is the Atlantic Ocean, from which air masses traveling to the east reach the barrier of the Rif creating orographically-enhanced precipitation on the southern flank and a rain-shadow effect on the northern side. Annual precipitation at the study area can reach a maximum of 3000mm/yr and is strongly concentrated during the Autumn-Winter months (November to February), with the December-January precipitation exceeding more than half of the annual precipitation. According to Reille (1977) in December 1963 the rainfall amounted to 1120mm in 20 days, reaching values of over 110mm/day in a five-day period.

Holocene climate variability in northern Morocco is relatively well constrained through the study of lake sediments (Damnati, 2000) and pollen analyses (Reille, 1976, 1977; Lamb et al., 1995; Cheddadi et al. 1998). A clear climatic contrast is observed between the early and late Holocene, with precipitation being closer to present-day values after 5.5ka (Cheddadi et al. 1998) (Fig.1). The middle Holocene (7 to 4.5ka) was characterized by humid conditions responsible for soil formation in response to the hygric and thermal climate optimum (Schutt & Krause, 2009). Around 3ka, precipitation reached its highest Holocene values, about 60mm/yr above present rainfall. Another peak of precipitation occurred at about 2.2ka, with equivalent troughs in winter and summer temperatures. After 2ka the pollen-based palaeoclimate reconstruction may not be reliable due to human activity (Fig.1).

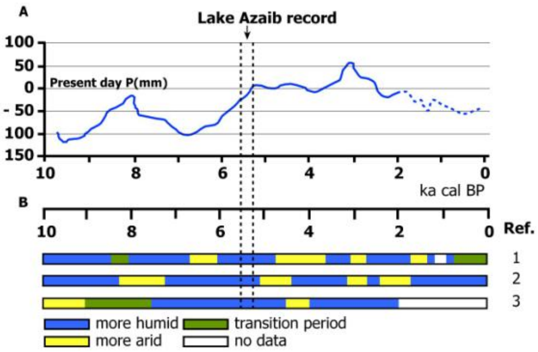

Figure 1 – Holocene climate variability in northern Morocco: 3A) Holocene climate reconstruction for the middle Atlas region according to Cheddadi et al. (1998). Average precipitation above/bellow present day values modeled through modern pollen analogs; 3B) Holocene climate oscillation according to several authors (modified after Schutt & Krause, 2009): Ref.1) Faust et al. 2004; Zielhofer et al. 2004; Ref.2) Lamb et al. 1995; Ref.3) Cheddadi et al. (1998).

3. THE KOUDIET ES SBAA LANDSLIDE

The Koudiet es Sbaa landslide, which develops along the northern slope of the Tisiren thrust front, is 6690m long and covers an area of 5.02km^2. It shows characteristics of a deep-seated rotational slide in the upper sector of the slope, splitting in two earth-flow/earth-slide fronts along the drainage divide of the Audour and Bouhia rivers. Landslide mechanism and kinematics change in the central sector from deep-seated rotational slide to earth-flow as it enters the valley floor. It affects the Tisiren and the Tanger Unit, as well as a thick Quaternary slope deposit. Regional stratigraphy places slope deformation during late Pleistocene (25 to 10ka) but no absolute ages have been yet presented. Several lakes and poorly drained areas, in association with reverse slope morphology, allow the reconstruction of different deformation phases by dating lake sediments. Tension fracture opening, road deformation and house fracturing in response to heavy rain characterize present-day activity.
A road-cut located downslope from Lake Azaib (Fig.2) shows a sedimentary sequence (~1.5m thick) composed of 15 layers of alternating angular to sub-rounded schist gravel (clast size = 1 to 4 cm) in a sandy-clay matrix and grey-colored silty-clay levels containing charcoal fragments. Two angular unconformities plunging to SSE allow the definition of three sedimentary groups.

Silty-clay levels are interpreted as remnants of paleo-lake sediments similar to those found in Lake Azaib. The two angular unconformities (Fig.1B) give evidence to three reactivations of the Koudiet Sbaa landslide (four if we take into account the present lake level).

Bed deformation increases from top to bottom. Levels 2 and 3 show syn-sedimentary deformation (flame structures – probable seismites) (Figs.2A, 2D), indicating probable seismic triggering for the first tilting event. Sandy-gravel beds testified for significant erosion in the upper sector of the slope in between lake sedimentation associated with intense precipitation events. Silty-clay levels correspond to phases of stability post deformation. Charcoal collected from levels 2, 8 and 14 yielded AMS ^{14}C minimum ages of 5410, 5380 and 5490 ± 40 BP. The proximity between the obtained ages probably results from re-sedimentation processes, making it difficult to establish a time frame for the deformation events. Nevertheless, we can infer that in the period from 5530 to 5340 BP three reactivations took place, with probable seismic triggering for the first event.

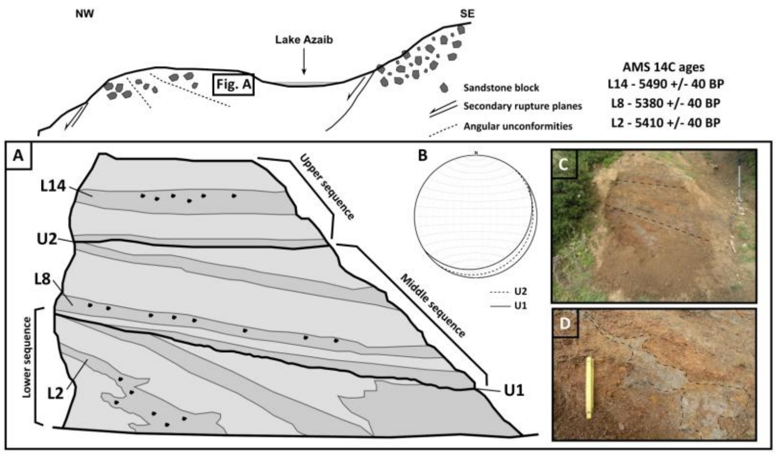

Figure 2 - Lake Azaib and location of the road cut. A) Field sketch of the Lake Azaib road cut (drak grey = silt-clay layers with charcoal fragments); B) Equal-area plot of angular unconformities (U1 and U2); C) Road cut exposure showing angular unconformities; D) Close-up picture showing syn-sedimentary deformation of L2 (probable seismites).

5. CONCLUSION

Although it is tempting to establish a correlation between landslide reactivation and mid-Holocene climatic forcing, the present data is not convincing enough, especially if we take into account that time-independent processes such as seismic triggering might be present. Nonetheless, the fact that reactivations are shortly spaced in time and within the transition from dryer to wetter Holocene climate condition around 5ka, it can be inferred that there might be a climatic signal forcing changes in the piezometric level and increasing pore-water pressure during winter months.

The presence of gravel deposits separating the lake levels testifies for significant torrential erosion in the upper sectors of the slope. The balance between gravel transport and deposition might be explained through a slow, downslope movement of the landslide mass in-between the four major reactivation allowing sediment accommodation.
The Holocene activity represented by the Azaib record shows the same order of magnitude as presently observed, consisting of partial landslide reactivations. This fact helps to place the major catastrophic slope failure prior to 10ka, probably in association with the humid upper-Pleistocene climatic conditions.

References

Agliardi F., Zanchi, A., Crosta, G.B. (2009). Tectonic vs. gravitational morphostructures in the central Eastern Alps (Italy): Constraints on the recent evolution of the mountain range. *Tectonophysics*, Volume 474, Issues 1–2, pp. 250–270.

Chalouan, A., Michard, A., El Kadiri, K., Negro, F., Frizon de Lamotte, D., Soto, J.I; Saddiqi, O. (2008). The Rif. *In* Continental Evolution: The Geology of Morocco - Structure, *Stratigraphy, and Tectonics of the Africa-Atlantic-Mediterranean Triple Junction*. Michard, A.; Saddiqi, O.; Chalouan, A.; Frizon de Lamotte, D. (Ed.) Springer, 424p.

Cheddadi, R., Lamb, H.F., Guiot, J. & van der Kaars, S. (1998). Holocene climatic change in Morocco: a quantitative reconstruction from pollen data. *Climate Dynamics*, 14, 883– 890.

Damnati, B., (2000). Holocene lake record in the Northern Hemisphere of Africa. *Journal of African Earth Sciences,* 31, 2, pp. 253–262.

Faust, D., Zielhofer, C., Escudero, R.B. and Diaz del Olmo, F., (2004). High-resolution fluvial record of Late Holocene geomorphic change in Northern Tunisia: climatic or human impact? *Quaternary Science Reviews,* 23, pp. 1757–1775.

Korup, O., Clague, J.J., Hermanns, R.L., Hewitt, K., Strom, A.L., Weidinger, J.T. (2007). Giant landslides, topography, and erosion. *Earth and Planetary Science Letters*; 261; 578 – 589.

Lamb, H.F. & van der Kaars, S. (1995). Vegetational response to Holocene climatic change: pollen and palaeolimnological data from the Middle Atlas, Morocco. *The Holocene*, 5, 400– 408.

Reille, M. (1976). Analyse pollinique de sédiments postglaciaires dans le Moyen Atlas et le Haut Atlas marocains: premiers résultats. *Ecologia Mediterranea*, 2, 153–170.

Reille, M. (1977) Contribution pollenanalytique à l'histoire holocéne de la végétation des montagnes du Rif (Maroc septentrional). Recherches Francaises sur le Quatérnaire INQUA 1977. Association Francaise pour l'Etude du Quaternaire, 1, 50, 53–76.

Saadi, M., Hilali, E.A., Boudda, A. (1980). *Carte Géologique de la chaîne Rifaine – echelle 1:500.000*. Ministere de l'Energie et des Mines, Direction de Geologie*, Service de Géologie du Maroc*, Notes et Mémoires, Nº 245ª.

Schutt, & Krause, (2009). Comparison of proxy-based palaeoenvironmental reconstructions and hindcast modelled annual precipitation—a review of Holocene palaeoenvironmental research in the Central Sahara, in Baumhauer, R. & Runge, J. (Ed.) Holocene Palaeoenvironmental History of the Central Sahara, *Palaeoecology of Africa,* Vol. 29, An International Yearbook of Landscape Evolution and Palaeoenvironments

Zielhofer, C., Faust, D., Escudero, R.B., Diaz del Olmo, F., Kadereit, A., Moldenhauer, K.-M. and Porras, A., (2004). Centennial-scale Late Pleistocene to Mid-Holocene synthetic profile of the Medjerda Valley, Northern Tunisia. *The Holocene,* 14, 6, pp. 851–861.