Episodic displacement on a sackung scarp in Benasque Valley (Central Spanish Pyrenees). Paleoseismic record?

Desplazamiento episódico de un escarpe sackung en el Valle de Benasque (Pirineos centrales). Registro paleosísmico?

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Abstract: A sackung scarp has been investigated by trenching in the El Ubago glacial valley (central Spanish Pyrenees). The scarp is located 18 km to the SW of the North Maladeta Fault, which was the source of the Mw 5.3 Vielha earthquake of 1923. Three displacement events have been inferred based on colluvial wedge stratigraphy and fault truncation. Event X at ca. 16.9 ka created the sackung. Events Y and Z have been constrained at 15-8.3 and 8.3-5.3 ka. The timing of event Y partially overlaps with that of a faulting event recognised in a previously investigated sackung at about 2 km. A minimum vertical slip rate of 0.18 mm/yr has been calculated for the sackung. The spatial association of the sackung features in this sector of the Pyrenees with the North Maladeta Fault and the millennial recurrence of the inferred displacement events (5.6 kyr) suggests that the kinematics of the studied sackung has been controlled by seismic activity. Demonstrating in future investigations that the sackung features in the area constitute archives of large paleoearthquake would be of great interest for seismic hazard assessments. They might help to improve the catalogue of paleoearthquakes and might provide information on earthquake recurrence intervals and the age of the MRE (most recent event).

Key words: sackung, antislope scarp, trenching, paleoearthquakes, secondary evidence.

Resumen: *Se ha investigado un escarpe tipo sackung mediante la excavación de una zanja en el valle glaciar de El Ubago (Benasque, Pirineos centrales). Este sackung está situado a 18 km al SO de la Falla Norte de la Maladeta, fuente del terremoto de Vielha (*Mw 5,3*) de 1923. Se han inferido tres eventos de desplazamiento. El evento X, datado entorno a 16,9 ka, creó el sackung. Los eventos Y y Z han sido acotados temporalmente en 15-8,3 y 8,3-5,3 ka. El rango de edad del evento Y se solapa parcialmente con el de un evento de desplazamiento inferido previamente en otro sackung situado a unos 2 km. Se ha estimado una tasa mínima de desplazamiento de 0,18 mm/año para el escarpe. La asociación espacial de los sackung con la Falla Norte de la Maladeta en este sector del Pirineo y la recurrencia de los eventos de desplazamiento (ca. 5,6 kyr) suguieren que la cinemática del sackung estudiado ha estado controlada por paleoterremotos. Demostrar que los sackung de la zona constituyen fuentes de información paleosísmica sería de gran interés para las evaluaciones de paleogrosidad sísmica. Éstos ayudarían a mejorar el catálogo paleosísmico y podrían aportar información sobre recurrencias y la edad del evento más reciente.*

Palabras clave: *sackung, trincheras, paleoterremotos, evidencia secundaria, peligrosidad sísmica.*

INTRODUCTION

Gravitational spreading in rock slopes may be accommodated through the development of failure planes dipping into the slopes with extensional displacement. These brittle structures, generally parallel to the ridge crests and contour lines, produce uphill-facing scarps and linear depressions lying at their foot, commonly designated as sackung (e.g. Ward, 2003). Several works illustrate that information on the chronology and kinematics of sackung structures can be inferred studying the stratigraphy, structure and geochronology of the sediments filling these sediment traps (e.g. McCalpin and Irvine, 1995; McCalpin and Hart, 2002). The large number of accounts that document the generation and reactivation of sackung features during large historic earthquakes support the idea that the kinematics of these morpho-structures may be controlled by strong seismic shaking (e.g. McCalpin and Hart, 2002).

In this work we present the results of a trench dug across an antislope sackung scarp in the El Ubago glacial valley (Benasque, central Spanish Pyrenees). The trench is located at about 2 and 7 km from two previously studied sackung trenches in Vallibierna and

Estós valleys, respectively (Gutiérrez-Santolalla *et al*., 2005) (Fig. 1A). The trenches of Vallibierna and Estós sites revealed that the formation of the sackung occurred more than 5 kyr after the deglaciation of the valleys and that the sackung in Vallibierna has undergone episodic displacement (Gutiérrez-Santolalla *et al*., 2005).

GEOLOGY AND GEOMORPHOLOGY

The studied sackung is located in the Axial Pyrenees, at about 18 km to the SW of the E-W trending North Maladeta Fault. This 17.5 km long normal fault has been identified as the most probable source of the M_W 5.3 Vielha earthquake of 1923, and as a possible source for the Ribagorza earthquake of 1373 (Ortuño *et al*, 2008) (Fig. 1A).

The bedrock at the trench site is primarily composed of tightly folded Silurian and Lower Devonian black slates with limestone intercalations. The bedding has a general dip into the slope and strikes roughly parallel to the ridge crest.

The northern slopes of the El Ubago glacial valley have been affected by post-glacial gravitational deformation and landslides (Fig. 1B). Deep-seated gravitational slope deformation is manifested at the surface by outward bulging, ridge top depressions, twin ridges, uphill- and down-hill facing scarps, a large graben depression and a collapse sinkhole. The length of the antislope scarps range from 60 to 720 m. The area affected by gravitational deformation covers approximately 4.4 km^2 and may involve a volume as large as 600 hm^3 (Fig. 1B).

TRENCH INTERPRETATION

The trench was excavated with pick and shovel across a sackung scarp and trough situated at 2380 m a.s.l. (42° 35’ 21.91’’N; 0° 35’ 22.4’’E) (Fig. 2A, B y C). It revealed that these landforms have been created by normal dip slip displacement on at least two major N-dipping faults (F1 and F2) and tilting of the drownthrown blocks. The trough fill, more than 3 m thick, shows three depositional sequences, each consisting of a lower colluvial wedge unit and an upper lacustrine unit (Fig. 2A). These sequences record scarp creation or rejuvenation events with free face formation and colluvial wedge deposition, followed by long quiescence periods of scarp degradation and expansion of lacustrine deposition.

Three displacement events have been inferred based on the colluvial wedge stratigraphy and fault truncation relationships observed in the trench (Fig. 2D). The first displacement event (event X) corresponds to the faulting event that created the sackung scarp and trough. A rough estimate of ca. 16.9 ka can be obtained for the age of the sackung by extrapolation to the bottom of the trough fill using the sedimentation rate calculated with the two youngest calendar ages. The timing of the PE (penultimate event) and the MRE (most recent event) faulting events (events Y and Z) have been constrained at 15-8.3 and 8.3-5.3 ka. The scarcity of datable material in the trough fill has not allowed us to provide tighter bracketing ages. The age range of event Y partially overlaps with the time interval assigned to a faulting event inferred at Vallibierna site.

The amount of deformation increases in each successive event. This trend could be related to the progressive weakening of the slopes caused by recurrent slope failure events. The available data has allowed us to calculate a minimum vertical slip rate of 0.18 mm/yr for the sackung scarp and a recurrence interval of about 5.6 kyr for the faulting events.

DISCUSSION

Episodic displacement in the studied sackung with a millennial recurrence interval and the spatial association of the sackung features in this sector of the Pyrenees with the North Maladeta Fault (M. Ortuño, pers. comm.) suggest that the generation and reactivation of the sackung scarps in the area could be controlled by strong seismic shaking. Such a potential secondary paleoseismic record could be of great utility for seismic hazard assessments in the Pyrenees, where intense glacial erosion and possibly the buried character of seismogenic faults makes difficult to perform conventional paleoseismic investigations.

ACKNOWLEDGEMENTS

The investigation has been founded by the Integrated Action “HI2005-0250 Landslide hazard assessment for a proper land-use planning in alpine areas under tourist pressure” founded by the Spanish and Italian governments.

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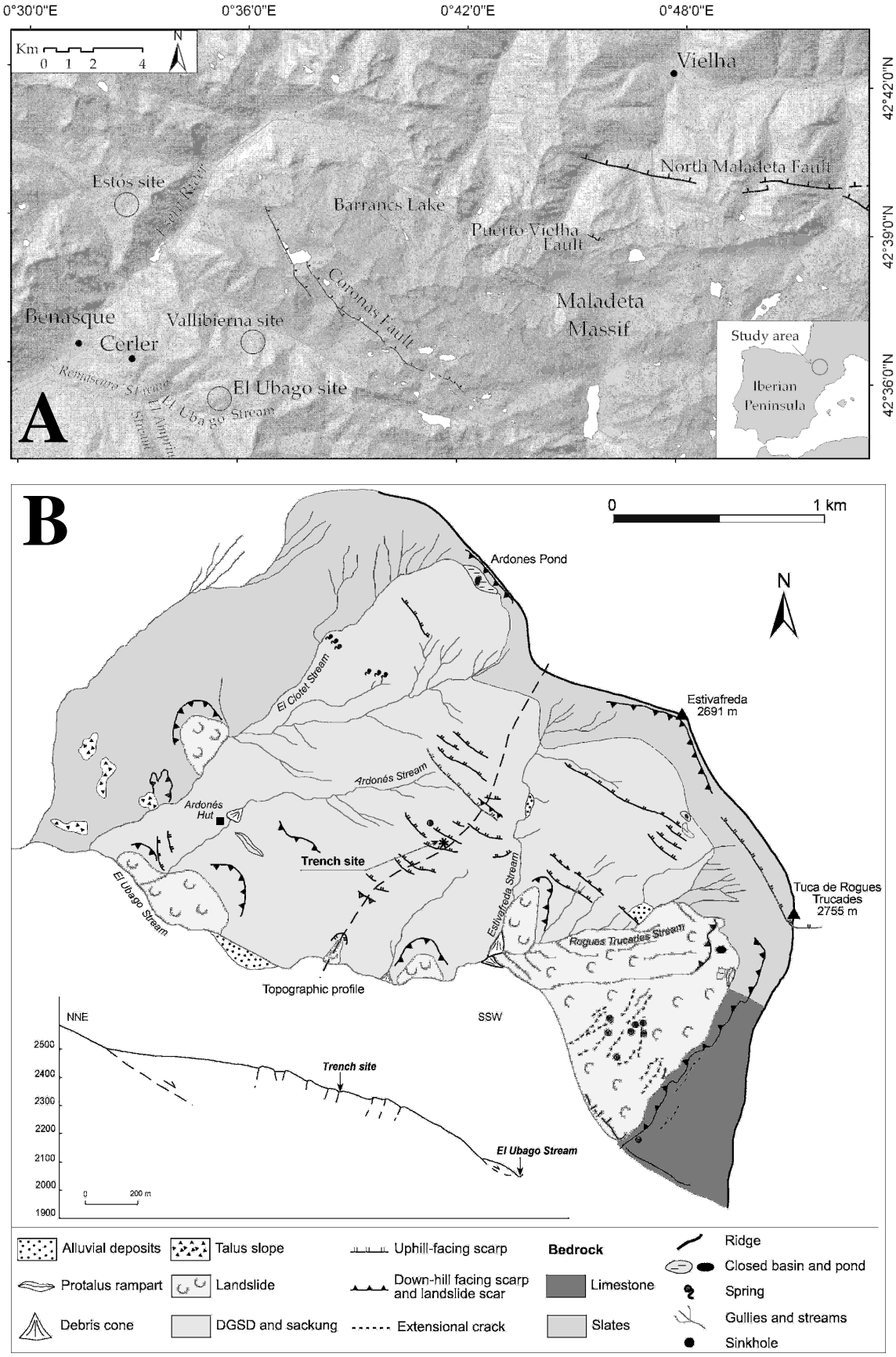

FIGURE 1. *A. Location of the El Ubago, Estós and Vallibierna trench sites. B. Geomorphological sketch of the study area and longitudinal profile of the sackung slope. Trace of the profile is indicated in B.*

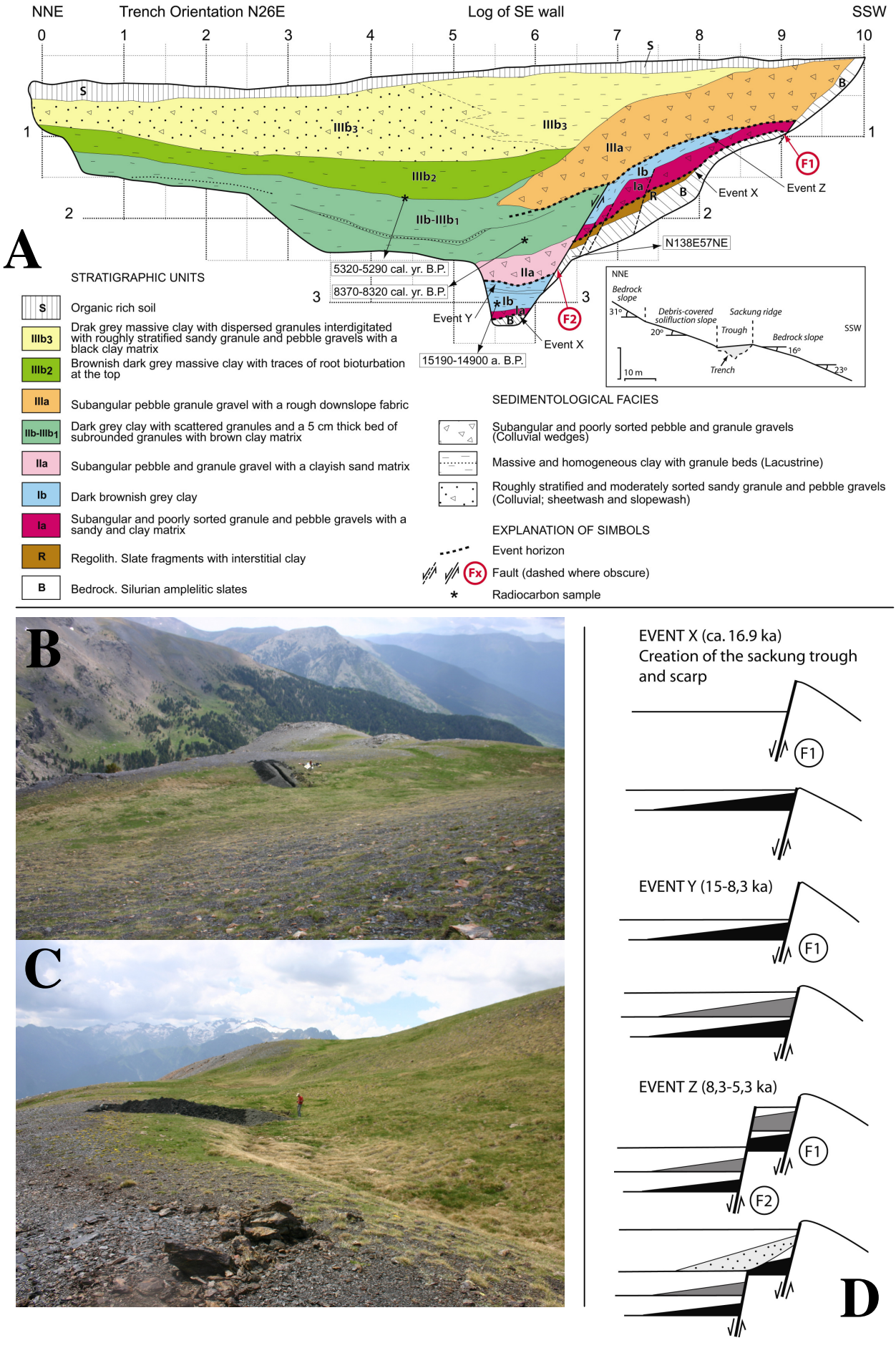

FIGURE 2. A. *Trench log. Datings at 1σ error. B and C. Images of the studied sackung. D. Simplified retrodeformation analysis.*