Computers & Geosciences 90 (2016) 156–163

Contents lists available at ScienceDirect

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo

Case study

A 3D measurement of the offset in paleoseismological studies

Marta Ferrater [a,*], Anna Echeverria [a], Eulàlia Masana [a], José J. Martínez-Díaz [b], Warren D. Sharp [c]

[a] RISKNAT Group. GEOMODELS. Departament de Geodinàmica i Geofísica, Facultat de Geologia, Universitat de Barcelona, c/ Martí i Franquès, s/n, 08028 Barcelona, Spain
[b] Departamento de Geodinamica, Universidad Complutense, Instituto de Geociencias IGEO (UCM, CSIC), 28040 Madrid, Spain
[c] Berkeley Geochronology Center, Berkeley, CA 94709, USA

ARTICLE INFO

Article history:
Received 23 December 2015
Received in revised form
15 February 2016
Accepted 29 February 2016
Available online 2 March 2016

Keywords:
3D offset
Paleoseismological trenches
Adjust 3D line
Strike-slip
Buried channel

ABSTRACT

The slip rate of a seismogenic fault is a crucial parameter for establishing the contribution of the fault to the seismic hazard. It is calculated from measurements of the offset of linear landforms, such channels, produced by the fault combined with their age. The three-dimensional measurement of offset in buried paleochannels is subject to uncertainties that need to be quantitatively assessed and propagated into the slip rate. Here, we present a set of adapted scripts to calculate the net, lateral and vertical tectonic offset components caused by faults, together with their associated uncertainties. This technique is applied here to a buried channel identified in the stratigraphic record during a paleoseismological study at the El Saltador site (Alhama de Murcia fault, Iberian Peninsula). After defining and measuring the coordinates of the key points of a buried channel in the walls of eight trenches excavated parallel to the fault, we (a) adjusted a 3D straight line to these points and then extrapolated the tendency of this line onto a simplified fault plane; (b) repeated these two steps for the segment of the channel in the other side of the fault; and (c) measured the distance between the two resulting intersection points with the fault plane. In doing so, we avoided the near fault modification of the channel trace and obtained a three-dimensional measurement of offset and its uncertainty. This methodology is a substantial modification of previous procedures that require excavating progressively towards the fault, leading to possible underestimation of offset due to diffuse deformation near the fault. Combining the offset with numerical dating of the buried channel via U-series on soil carbonate, we calculated a maximum estimate of the net slip rate and its vertical and lateral components for the Alhama de Murcia fault.

1. Introduction

One of the fundamental parameters used to characterize the seismic potential of a fault is its net slip rate, as fast moving faults produce earthquakes more frequently than slow faults (e.g. Masana et al., 2001; Liu-Zeng et al., 2006; Rockwell et al., 2009). In strike-slip faults, the slip rate may be obtained from the offset of a linear feature (not necessarily straight linear) that crosses the fault (such as a channel, a limit of an alluvial fan, fluvial terrace risers, etc.) whose age is constrained (e.g. Gold et al., 2011; Salisbury et al., 2012; Frankel et al., 2007; Van der Woerd et al., 2002; Hall et al., 1999; Wesnousky et al., 1991). Channels are commonly used because they are widespread in the landscape. Moreover, in a simplified way, their intersection with the fault is a point, yielding a unique three-dimensional (3D) restitution (and thus a unique 3D offset) between the two correlated segments of the channel (one in each block of the fault; in the methodological part of this paper, we use "fault block" to refer to either the hanging or the foot wall of a fault). Paleoseismological studies use two different approaches to measure the channel offsets: (1) surface analysis (using tectonic geomorphology) and (2) subsurface analysis of buried stratigraphic sequences in which the offset of a buried channel is estimated (using 3D trenching). These two approaches tend to underestimate the net offset because they often measure only the lateral component of the offset (e.g. Rittase et al., 2014; Liu-Zeng et al., 2006; Chevalier et al., 2016; Cowgill, 2007; Gold et al., 2011).

In the geomorphological approach, the offset measurement takes into account the far-field tendency of a channel and projects it into the fault (Wallace, 1968; Sieh, 1978; Salisbury et al., 2012; Zielke et al., 2012; Haddon et al., 2016). In this case, the precise morphology of the channel near the fault is not important. Different methods are used to define the general trending of the channel (or the terrace raisers associated with it) and project this

* Corresponding author.
E-mail address: marta.ferrater@ub.edu (M. Ferrater).

http://dx.doi.org/10.1016/j.cageo.2016.02.024
0098-3004/

tendency onto the fault plane (Van der Woerd et al., 2002; Cowgill, 2007; Gold et al., 2011; Ferrater et al., 2015a). Zielke and Arrowsmith, (2012) created a Graphical User Interface (GUI) for Matlab (Lateral Displacement Calculator, LaDiCaoz) updated recently (LaDiCaoz_v2; Zielke et al., 2015; Haddon et al., 2016) which measures the offset based on the perpendicular profile and the general trending of the channel.

In contrast, the offset of buried paleochannels identified in trenches is measured directly next to the fault by excavation of progressive exposures (examples of 3D trenches in McCalpin et al. (1996)). A long trench is usually dug parallel to the fault in each side to define the target channel and is progressively expanded towards the fault along the channel feature to expose the piercing points on the fault plane. This technique allows measurement of the lateral offset of one (e.g. Wesnousky et al., 1991) or more channels (e.g. Hall et al., 1999; Liu et al., 2004; Liu-Zeng et al., 2006; Marco et al., 2005). Zooming too much into the fault area, as is the case in trenching studies, may underestimate the offset owing to: (1) the possible distributed deformation next to the fault (i.e. not a unique fault line but different secondary faults which may be separated several metres or more from the fault), or (2) the smoothing of the erosive path of the channel within time since materials across the fault are easily eroded (Ouchi, 2004).

In this study, we adapted the geomorphological approach to project the three-dimensional far-field trend of a buried paleochannel onto the fault. Our aim was to avoid underestimation of the net offset produced by disregarding (1) the vertical component of the fault, and (2) near-fault modifications of the channel course (Huang, 1993). In the first part of the paper, we provide a group of modified scripts (Supplementary material, OffsetMeasurement3D) based on Matlab language to automate the calculation of the net, lateral and vertical offsets of buried channels. The proposed methodology includes: (a) the acquisition of the coordinates of the points belonging to a buried channel feature; (b) the adjustment of 3D straight lines to the selected points; (c) the calculation of the intersection points between these lines and the fault; and d) the measurement of the net, lateral and vertical offsets and their uncertainties. The main advantage of these scripts is that they allow assessing the general three-dimensional trending of a likely irregular feature whose exact direction is unknown. In the second part, we apply this method to a 3D paleoseismic trenching study in the seismogenic Alhama de Murcia fault (Southeastern Spain; Martínez-Díaz et al., 2003; Masana et al., 2004; Ortuño et al., 2012), where we identified a buried channel on both sides of the fault. Slip rate calculation of this fault represents a paleoseismological challenge, as (1) the ratio between its lateral and vertical components is unknown and, (2) previous estimations of the slip rate contain large uncertainties.

2. Methodology

The proposed method of offset determination consists of five steps: (1) trench design and excavation, (2) data acquisition, (3) computation of the piercing points and (4) estimation of the uncertainties, and, (5) calculation of the offset value. This approach is trustworthy for channels with low sinuosity or for channels whose sinuosity wavelengths are small, i.e. those cases where a straight line may be adjusted to the channel shape.

2.1. Trenching survey

At least one trench dug perpendicular to the fault is needed to locate the fault. After defining the fault position and its characteristics (orientation, dip and fault zone width), two trenches parallel to the fault, one in each side of the fault, are needed to identify the target channel in the stratigraphic sequence. A minimum of one additional parallel trench is required on each side to yield enough points for the analysis along each piercing line. In this way, the channel should be identified in the sedimentary record in two trenches per fault block, i.e. total of eight trench walls.

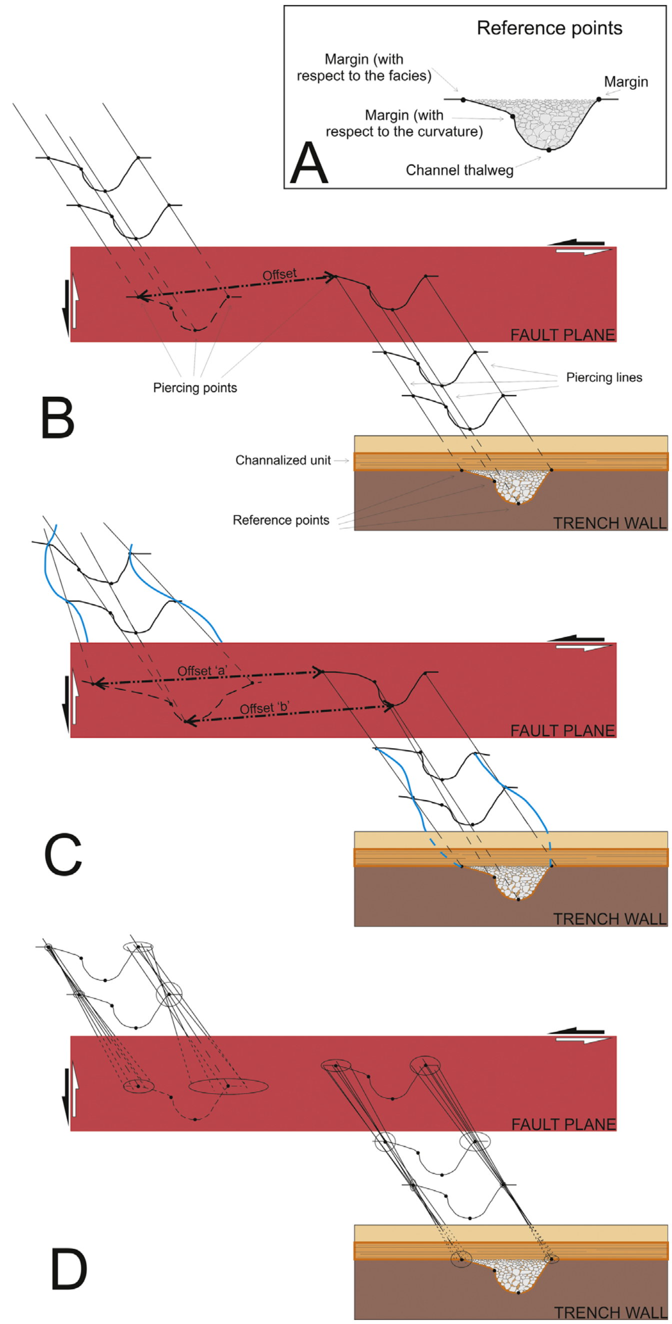

Fig. 1. Theoretical assumptions applied in the methodological workflow. (A) Nomenclature of channel features (reference points in section); (B) nomenclature of all the elements intervening in space (reference points, piercing lines and piercing points), and their situation in the ideal case study; (C) sketch of the resulting piercing lines and channel cross-sections when the channel is slightly sinuous, in this case the offset of the piercing point pairs differs from each other; and (D) schema of how the uncertainties are calculated by projecting them onto the fault: hundreds of random possible piercing lines within the area of the individual reference point uncertainties are projected against the fault.

2.2. Data acquisition

A channel can be simplified into a line (not indispensable to be straight) on a small scale but is more complex at a detailed scale.