Earth and Planetary Science Letters 486 (2018) 141–154

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Unexpected earthquake hazard revealed by Holocene rupture on the Kenchreai Fault (central Greece): Implications for weak sub-fault shear zones

Alex Copley *, Christoph Grützner [1], Andy Howell [2], James Jackson, Camilla Penney, Sam Wimpenny

COMET, Bullard Labs, Department of Earth Sciences, University of Cambridge, Cambridge, UK

ARTICLE INFO

Article history:
Received 27 November 2017
Received in revised form 15 January 2018
Accepted 18 January 2018
Available online xxxx
Editor: R. Bendick

Keywords:
normal faulting
ductile shear zones

ABSTRACT

High-resolution elevation models, palaeoseismic trenching, and Quaternary dating demonstrate that the Kenchreai Fault in the eastern Gulf of Corinth (Greece) has ruptured in the Holocene. Along with the adjacent Pisia and Heraion Faults (which ruptured in 1981), our results indicate the presence of closely-spaced and parallel normal faults that are simultaneously active, but at different rates. Such a configuration allows us to address one of the major questions in understanding the earthquake cycle, specifically what controls the distribution of interseismic strain accumulation? Our results imply that the interseismic loading and subsequent earthquakes on these faults are governed by weak shear zones in the underlying ductile crust. In addition, the identification of significant earthquake slip on a fault that does not dominate the late Quaternary geomorphology or vertical coastal motions in the region provides an important lesson in earthquake hazard assessment.

© 2018 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

1. Introduction

Horizontal extension by normal faulting often results in arrays of fault-bounded blocks that have rotated about horizontal axes as their bounding faults slip (so-called 'domino' or 'bookshelf' faulting) (e.g. Gilbert, 1928; Proffett, 1977; Morton and Black, 1975; Jackson and McKenzie, 1983). However, questions remain over what controls whether faults positioned across-strike from each other are active simultaneously or sequentially, and how this may vary between different extensional settings (e.g. Jackson et al., 1982; Dart et al., 1995). Additionally, in cases where the location of dominant slip activity migrates across-strike between faults, it is not known whether this transition is sudden or gradual, or what controls the direction of migration (e.g. Goldsworthy and Jackson, 2001). Addressing these questions will reveal important information about the mechanics and behaviour of faults, and will also highlight whether multiple faults in arrays of parallel structures need to be considered as sources of earthquake hazard. In addition, understanding the behaviour of arrays of faults will allow us to probe the properties of the underlying ductile layer. Specifically, we can address the controversy of whether strain accumulation at faults is governed by flow in a laterally-homogeneous viscoelastic material (e.g. Meade et al., 2013), or whether lateral contrasts in effective viscosity are the dominant control (e.g. Yamasaki et al., 2014). We address these questions by making new observations of Holocene fault slip on the Kenchreai Fault on the south side of the Gulf of Corinth in central Greece.

The Kenchreai Fault bounds the south side of the isthmus between the Gulf of Corinth and the Saronic Gulf (Fig. 1). The northern, hangingwall, side of the fault is occupied by the Corinth Terraces – a series of marine terraces, dating from ∼0.5 Ma to the present, that have been uplifted by motion on the Heraion (also known as Xylokastro) and Pisia faults to the north (e.g. Armijo et al., 1996). This northern fault system ruptured in M_w6.7 and 6.4 earthquakes in 1981 (e.g. Jackson et al., 1982). The uplift of the Corinth Terraces relative to the sea-level highstands at which they formed (e.g. Armijo et al., 1996) shows that the Heraion and Pisia faults have been more active over the last ∼400 kyr than the Kenchreai and Loutraki Faults, motion on which would produce hangingwall subsidence in the region of the terraces. It is likely that the Kenchreai Fault was the most active fault in the region in the early/mid Pleistocene, because the sediments currently exposed in the cutting of the Corinth Canal (Fig. 1; Collier and Dart, 1991) represent a series of climatically-controlled sea-

* Corresponding author.
E-mail address: acc41@cam.ac.uk (A. Copley).

[1] Pressent address: Friedrich Schiller University Jena, Institute of Geological Sciences, Burgweg 11, 07749 Jena, Germany.

[2] Pressent address: Seequent, Addington, Christchurch, New Zealand.

https://doi.org/10.1016/j.epsl.2018.01.014
0012-821X/© 2018 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

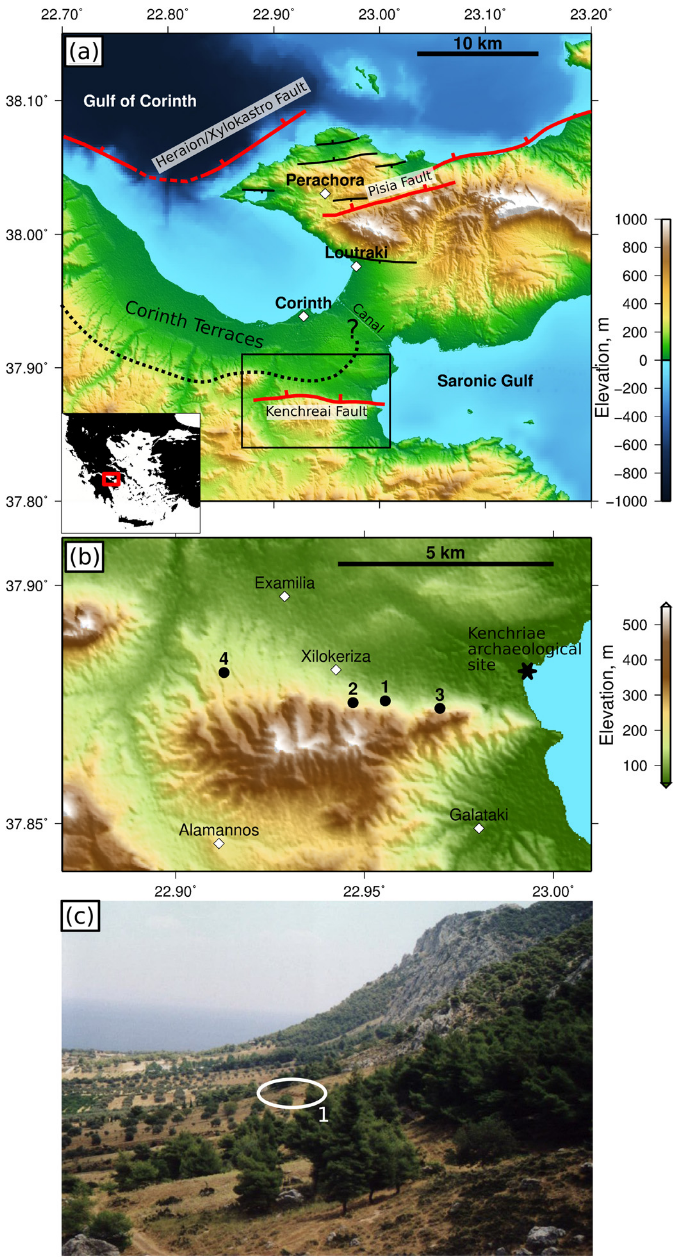

Fig. 1. (a) Overview of the eastern Gulf of Corinth (see inset for location). Red lines show major (∼10 km and longer) active faults. Topography is the SRTM 1-arcsecond dataset. The black dotted line shows the approximate extent of the Corinth terraces, which become indistinct where they are affected by the spoil from the Corinth canal. (b) Shows the Kenchreai Fault, in the area outlined by the black box in (a). Our field sites described in the text are labelled 1–4, and our trench is at site 1. (c) View east from site 2, with site 1 visible in the middle-distance, shown by the white circle. (For interpretation of the colours in this figure, the reader is referred to the web version of this article.)

level cycles superimposed upon tectonic subsidence, of which the Kenchreai Fault is thought to be the cause (e.g. Mack et al., 2009; Charalampakis et al., 2014). The rate of activity on the Kenchreai Fault therefore seems to have reduced since the mid Pleistocene, but questions remain as to whether it has been active at all in the latest Quaternary.

Noller et al. (1997) and Goldsworthy and Jackson (2001) described the presence of topographic scarps in alluvial fan surfaces close to the range-front of the Kenchreai Fault, in the locations marked 1 and 2 on Fig. 1b. They interpreted these scarps as having been produced by normal-faulting earthquakes on the Kenchreai Fault. However, there have been suggestions that the scarps may

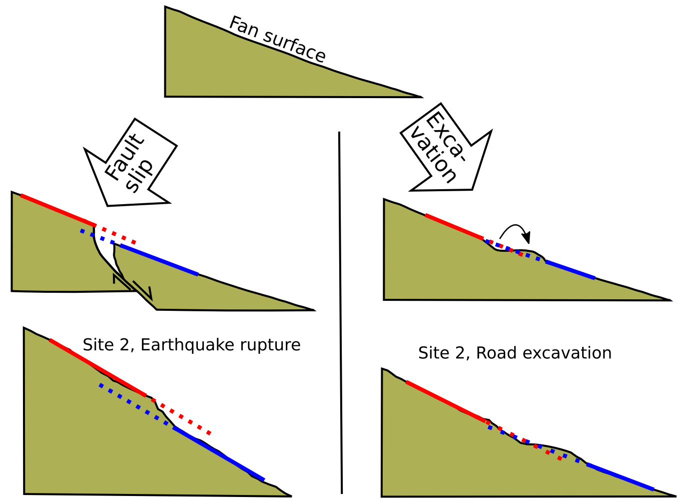

Fig. 2. Examples of the slope morphology formed by earthquake rupture (left) and road excavation or terracing (right) in a fan surface. The lower panels show actual examples of each type of slope morphology from our site 2 on the Kenchreai Fault (Fig. 4d). The earthquake rupture is shown as a shallow tensional fracture in sediments, above the main slip surface, as is often observed in normal-faulting events (e.g. Slemmons, 1957; Jackson and McKenzie, 1983). However, the same principles of slope offset apply in the case of a primary fault breaking the surface.

have been formed instead by human excavation, reinforced by the belief that the Kenchreai Fault is now completely inactive (e.g. Mack et al., 2009; Charalampakis et al., 2014). In this paper we survey in detail the scarps described by Noller et al. (1997) and Goldsworthy and Jackson (2001), and two additional newly-discovered scarps also on the Kenchreai Fault. We also describe evidence for palaeoseismicity in a trench we dug across one of the scarps. We then interpret our results from the perspectives of fault and lithosphere rheology, and of earthquake hazard.

2. Tectonic geomorphology

This section presents new high-resolution topographic models of the scarps described by Noller et al. (1997) and Goldsworthy and Jackson (2001), and of two additional sites along the Kenchreai fault where we observe topographic offsets in recent alluvial fan surfaces. We have used topographic profiles at all four sites to assess whether these apparent offsets are anthropogenic (e.g. agricultural terraces, road cuts), or whether they formed in earthquakes. Scarps formed by excavation will be flanked by slopes with different gradients, as a result of the removal of material, but the undisturbed slopes to either side of the excavation will project onto each other (Fig. 2). Earthquake scarps cutting alluvial fans will have a constant slope angle above and below the scarp, and the slopes will not project onto each other across the scarp, representing the offset of a quasi-planar fan surface (Fig. 2). Fan surfaces generally decrease in gradient with distance from the apex (e.g. Whipple and Dunne, 1992; Staley et al., 2006), so in the following discussion we interpret profiles that are short enough (generally tens of metres) that the longer-wavelength curvature of the fans does not affect our offset estimates.

We produced high-resolution digital elevation models (DEMs) at three of the survey sites using the structure-from-motion technique (Westoby et al., 2012; Johnson et al., 2014; Abdrakhmatov et al., 2016). Each site was systematically photographed from ∼30–40 m height using a digital camera mounted on a drone. Ground control points distributed across the site were located using differential GPS (dGPS), to a horizontal and vertical accuracy of ∼10 cm, to provide a reference frame for the DEM. The photographs were then processed using Agisoft Photoscan to form a dense point cloud with an absolute vertical accuracy of ∼20 cm

Download English Version:

https://daneshyari.com/en/article/8907112

Download Persian Version:

https://daneshyari.com/article/8907112

Daneshyari.com