Marine Geology 271 (2010) 156–164

Contents lists available at ScienceDirect

Marine Geology

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

Geological and geomorphological evidence of recent coastal uplift along a major Hellenic normal fault system (the Kamena Vourla fault zone, NW Evoikos Gulf, Greece)

Andrew B. Cundy [a,*], K. Gaki-Papanastassiou [b], D. Papanastassiou [c], H. Maroukian [b], M.R. Frogley [d], T. Cane [d]

[a] School of Environment and Technology, University of Brighton, Brighton, BN2 4GJ, UK
[b] Department of Geography-Climatology, University of Athens, Gr 15784 Athens, Greece
[c] Institute of Geodynamics, National Observatory of Athens, Gr 11810 Athens, Greece
[d] Department of Geography, University of Sussex, Brighton, BN1 9QJ, UK

ARTICLE INFO

Article history:
Received 30 March 2009
Received in revised form 21 January 2010
Accepted 5 February 2010
Available online 12 February 2010

Communicated by G.J. de Lange

Keywords:
coastal uplift
central Greece
earthquakes
coastal stratigraphy
normal faulting
sea level

ABSTRACT

The active normal faulting region of central Greece has been the focus of intense study, due to its relatively high rates of tectonic deformation, and the frequent occurrence of damaging, moderate magnitude earthquakes. The structure of central Greece is dominated by a series of roughly WNW–ESE-trending extensional faults which have created a series of half-grabens, the most prominent of which are the Gulf of Corinth and the Evoikos Gulf. Of these two structures, the Evoikos Gulf, and particularly its northern part, remains poorly understood in terms of its geodynamic structure and tectonic significance. Here, we use exposed coastal sediment sequences and coastal geomorphological indicators to examine the pattern of historical sea-level change in the northern Evoikos Gulf, specifically in the hangingwall of the prominent Kamena Vourla fault system, to better constrain recent coastal elevational changes and tectonic activity in this area. In particular, we describe and analyse a series of exposed coastal sections which contain recent (<3000 year BP) marginal marine sedimentary units, apparently uplifted to elevations of >1 m above contemporary high water level. These deposits occur in the hangingwall of the prominent Arkitsa (normal) fault strand, and indicate a local uplift rate possibly exceeding 1 mm/year, significantly greater than long-term regional uplift rates. The pattern of uplift of these coastal sections is most consistent with recent coseismic uplift on an offshore, shore-parallel, fault strand north of Arkitsa.

1. Introduction

The active normal faulting region of central Greece has been the focus of intense study, due to its relatively high rates of tectonic deformation and the frequent occurrence of damaging, moderate magnitude ($M_s \approx 6$–7), earthquakes. The structure of central Greece is dominated by a series of roughly WNW–ESE-trending extensional faults (accommodating extension of 15–20 mm/year) which have created a series of half-, asymmetric, grabens (Billiris et al., 1991; Eliet and Gawthorpe, 1995). The most prominent of these extensional structures are the Gulf of Corinth and the Evoikos Gulf, both of which are WNW–ESE-trending graben systems about 100 km long, and bordered by discontinuous normal faults (Roberts and Jackson, 1991; Stefatos et al., 2002; Moretti et al., 2003; Sakellariou et al., 2007). Of these two structures, the Evoikos Gulf, and particularly its northern part, is relatively poorly understood in terms of its geodynamic structure and tectonic significance (e.g. Makris et al., 2001). The northern Evoikos Gulf (Fig. 1) is a zone of accommodation between the two stress fields of the North Aegean Trough (the extension of the North Anatolian fault system) and the Gulf of Corinth (see regional summary in Papanikolaou and Royden, 2007). The interaction between these stress fields is not well-constrained (Hollenstein et al., 2008, based on recent GPS measurements, confirm the presence of a relatively low magnitude extensional stress field in the northern Evoikos Gulf), but generally the development of large faults is prohibited, and consequently the magnitudes of earthquakes in the north Evoikos Gulf and its immediate vicinity are of limited to moderate values. Indeed, recent research indicates that seismic stress in this area may not necessarily be released with strong earthquakes, but instead with intense microearthquake activity, usually in seismic swarms (Papanastassiou et al., 2001; Papoulia et al., 2006). Despite this, the area is characterised by a series of very prominent tectonic landforms, notably the large (ca. 1000 m elevation) footwall ridge of the Kamena Vourla fault system (Fig. 1).

The Kamena Vourla fault system is a northward-dipping, active normal fault zone ca. 50 km long, trending E–W along the southern shoreline of the north Evoikos Gulf (Fig. 1). The fault zone consists of three major left-stepping fault segments: the Kamena Vourla, the Agios Konstantinos, and the Arkitsa segments (Roberts and Jackson,

* Corresponding author. Tel.: +44 1273 642270; fax: +44 1273 642285.
E-mail address: A.Cundy@bton.ac.uk (A.B. Cundy).

0025-3227/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.margeo.2010.02.009

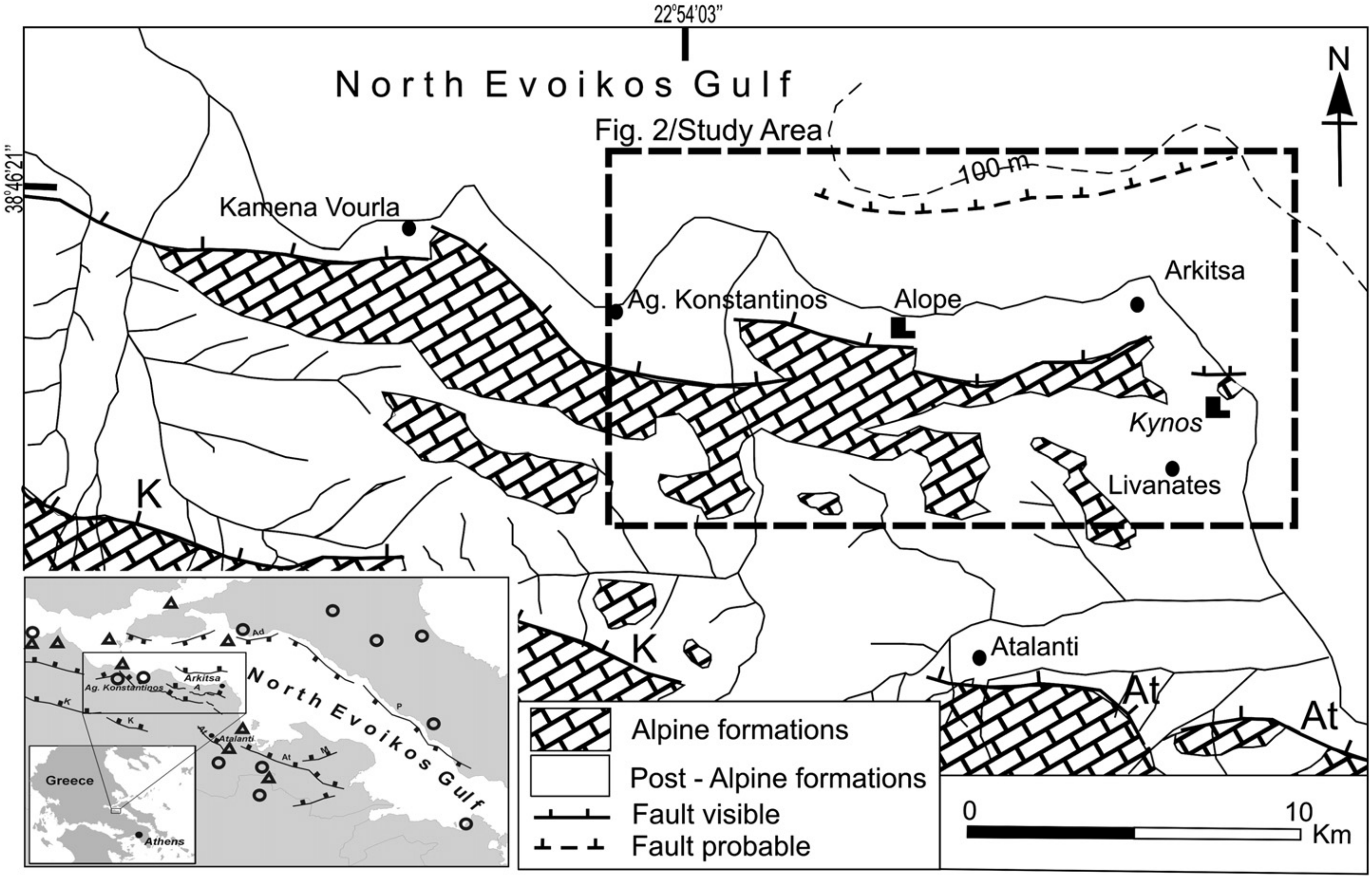

Fig. 1. Geological setting and tectonic structure of the Agios Konstantinos–Livanates coastal zone, north Evoikos Gulf, central Greece. Geological formations are drawn according to the geological maps of IGME. Inset map shows regional tectonic structure: K = Kalidromon fault; A = Arkitsa fault; At = Atalanti fault; M = Malesina fault; and Ad and P = Aedipsos–Politika fault system. Visible and probable faults are shown (Goldsworthy and Jackson, 2001; Sakellariou et al., 2007). Open triangles and circles in inset map show historical (up to AD 1900) and instrumental (after AD 1900) earthquakes respectively, of magnitude greater than or equal to 4.5.

1991; Ganas, 1997; Kranis, 1999). The fault zone displays very fresh tectonic landforms, but is not known to have hosted any major historical earthquakes (Roberts and Jackson, 1991), unlike the adjacent Atalanti (Locris) fault system, which ruptured in an M_s 6.8 event in 1894 and (according to some authors) in 426 BC, although the evidence for the latter is disputed (see Cundy et al., 2000; Pantosti et al., 2001). The evolution of the Kamena Vourla fault zone is poorly constrained, although Goldsworthy and Jackson (2001) argue that it is probably a relatively young system, initiated <1 Ma ago at the expense of the inland Kalidromon fault (Fig. 1). Jackson and McKenzie (1999) identify up to 50 increments of coseismic slip on the Arkitsa fault strand, implying that the Arkitsa segment is the active fault trace in the eastern part of the Kamena Vourla fault zone (Dewez, 2003). Dewez (2003) however identifies a series of uplifted and back-tilted terraces in the hangingwall and footwall of the Arkitsa fault, and argues that the present day dip pattern of these terraces is best explained by dislocation by the Arkitsa fault, followed by activation of, and rotational faulting on, a proposed secondary fault strand at Livanates running along the base of the prominent NNW–SSE trending Livanates escarpment (Fig. 2). Generally however the geodynamics, and notably the seismic hazard, of the tectonic structures in this part of the northern Evoikos Gulf remain poorly defined, as do those of the smaller secondary faults which have formed in the transfer zone between the Arkitsa fault strand and the historically active Atalanti fault zone to the southeast. Here, we focus on this Arkitsa segment, where we examine exposed coastal sediment sequences and coastal geomorphological indicators to assess the magnitude and timing of historical coastal elevational changes in the southeastern part of the Kamena Vourla fault system, and present the first detailed sedimentological evidence for late Holocene (possibly coseismic) coastal uplift in the northern Evoikos Gulf.

2. Methods

2.1. Geomorphology

In tectonically active areas, drainage systems are often influenced by the type, geometry, and recent activity of local faults, causing the development of a range of characteristic tectonic geomorphic features/indicators, including uplifted marine terraces, uplifted beachrocks, intense downcutting, knickpoints, alluvial cones and fans (Schumm, 1986; Leeder et al., 1991; Eliet and Gawthorpe, 1995; Burbank and Anderson, 2001; Gaki-Papanastassiou et al., 2007; Maroukian et al., 2008). In order to examine the influence of tectonism and to draw conclusions about the Quaternary landscape evolution of the Arkitsa area, detailed geomorphological mapping at a scale of 1:5000 was performed focusing on these features. In addition, the coastal slope, sediment size, beachrock formations, coastal stability and longshore drift were also mapped. Data were analysed using GIS technology.

2.2. Stratigraphy

Exposed coastal sedimentary sections were cleaned and logged, and intact shell material sampled for ^{14}C dating. Bulk sediment samples were also collected for macro- and micro-fossil analysis. The elevations of the exposed units were determined using a Jena 020A theodolite unit. In the absence of a reliable elevation benchmark, unit elevation was initially determined relative to a temporary benchmark,