Tectonophysics 633 (2014) 246–255

Contents lists available at ScienceDirect

Tectonophysics

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

Geodetic evidence for tectonic activity on the Strymon Fault System, northeast Greece

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ARTICLE INFO

Article history:
Received 4 February 2014
Received in revised form 21 June 2014
Accepted 13 July 2014
Available online 22 July 2014

Keywords:
Strymon (Struma) Fault System
Noise in GPS data
Strike-slip fault
Displacement
Earthquakes
Volcanics

ABSTRACT

The current kinematic patterns of northeast Greece remain largely unknown. This is mainly because this region is characterised by low seismicity rates and is poorly covered by GPS stations. Here, we analyse new homogeneous GPS data collected over a period of 5.5 years from the first permanent network in northeast Greece (HEPOS) to shed light in the kinematics of this region. We find that GPS displacement vectors that derive from either side of the natural depression of the Strymon Valley differ significantly in orientation and magnitude. Specifically, we find that across a distance of ca. 30 km the GPS displacement vectors change orientation by >130° (from NNW to SSW), producing a mean horizontal strain rate of 3.3 ± 0.3 mm/yr. We attribute this kinematic translation to result from movement along the Strymon Fault System (SFS), a >200 km-long structure that strikes NW-SE and extends from SW Bulgaria to North Aegean (where possibly abuts against the North Anatolian Fault). Up to date, the SFS was considered to be a major Alpine and Neogene geotectonic boundary of unclear Holocene activity. If the interseismic strain stored currently across the fault system is released seismically, large earthquakes (M > 7) and associated coseismic lateral displacements should be expected in the area. These results call for a better assessment of the earthquake risk in northeast Greece, which is currently evaluated as a low seismic hazard region.

1. Introduction

GPS data have quantified the deformation of Greece and provided evidence of significant displacements, both seismic and aseismic (e.g. McClusky et al., 2000; Müller et al., 2013; Pérouse et al., 2012; Reilinger et al., 2010). However, these data cover mainly the Hellenic Arc or areas of intense seismicity, such as the Gulf of Corinth (Avallone et al., 2004; Bernard et al., 2006; Briole et al., 2000), while the distribution of survey stations in areas of low historic seismicity is poor. Hence, the details of the kinematic patterns that characterise these areas of sparse seismicity remain largely unknown. This is the case particularly for northeast Greece (Thrace and East Macedonia), where most GPS displacements derive from a limited number of continuous and survey stations and as a consequence, the noise in these measurements (that often cover periods of up to ten years) is of the same order of magnitude with the tectonic dislocations (e.g. Reilinger et al., 2010). Seismically quiet areas may, however, produce catastrophic earthquakes. The non-positive relationship between the lack of modern seismicity and long-term activity on a fault has been emphasized recently in New Zealand by the M7.1 and M6.3 Christchurch earthquakes in 2010 and 2011, respectively, which occurred in a region of low seismic hazard (Allen et al., 2010; Van Dissen et al., 2011). Similarly, this has been illustrated in Greece by the catastrophic 1995 M6.5 Kozani-Grevena earthquake which occurred in an area assumed to be aseismic (Stiros, 1998; Fig. 1).

Here, we derive new tectonic information for northeast Greece, by analysing for the first time GPS data from a continuously operating network, the *Hellenic Positioning System* (HEPOS). This network was established in Greece in 2007 and consists of 98 real-time permanent GPS stations (Fig. 1). The uniformity, density, resolution and quality of this dataset provide an excellent opportunity to optimize displacement estimates, even for measurements that derive from areas of relatively low tectonic activity (Fig. 1).

Collectively, we have analysed GPS displacements that derive from 20 continuous HEPOS stations in northeast Greece and span a period of 5.5 years (e.g. from January 2008 till June 2013), to assess the activity of the Strymon Fault System (SFS), a major enigmatic structure in northern Greece and Southern Bulgaria (e.g. Tranos, 2011; Zagorcev, 1992a,b). Our data, in combination with regional tectonic data, reveal that the SFS does not simply represent the boundary between two major Alpine basement units in Greece and Bulgaria (e.g. Bornovas and Rondogianni, 1983), but also forms a significant active left-lateral

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http://dx.doi.org/10.1016/j.tecto.2014.07.012
0040-1951/

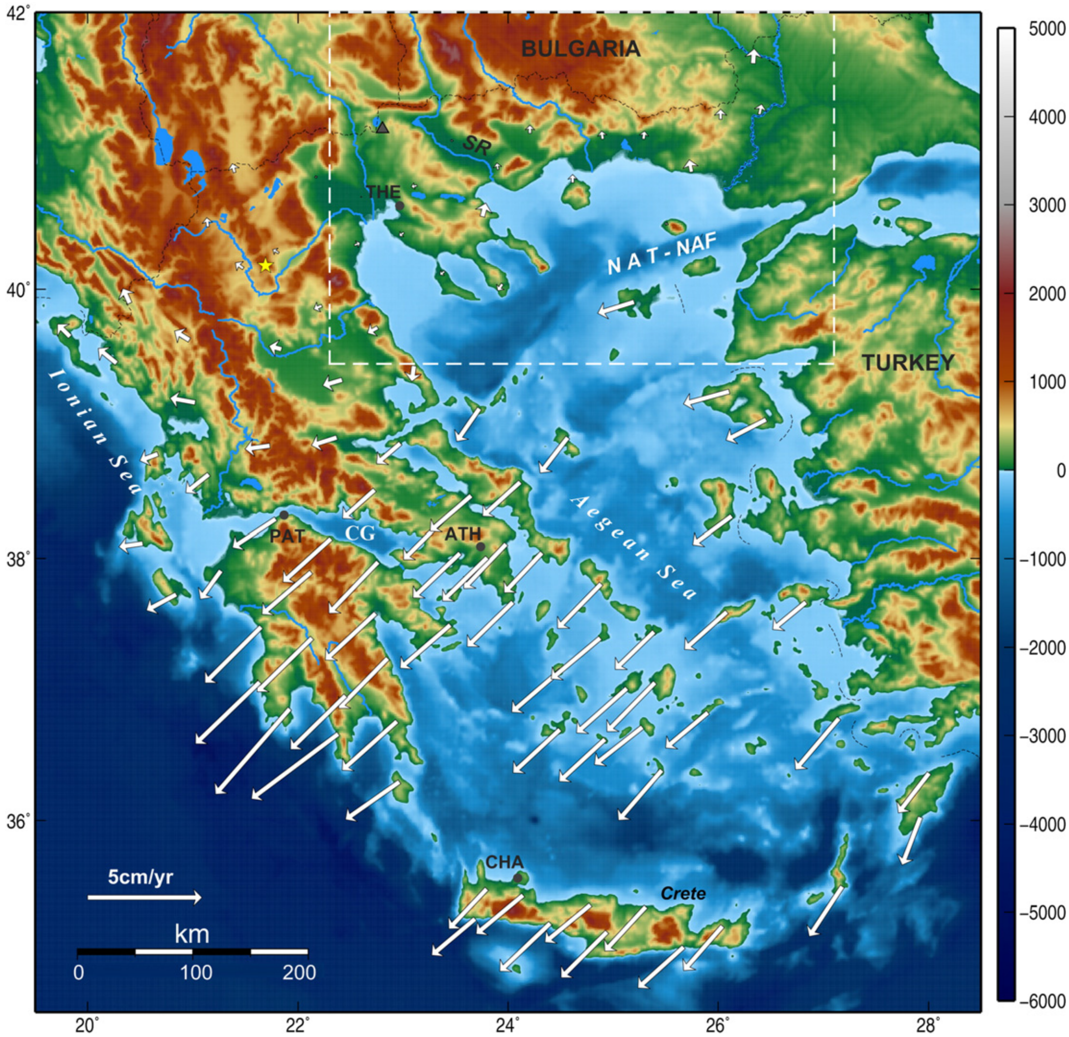

Fig. 1. Annual displacement vectors from the HEPOS GPS network in Greece for the period October 1st, 2007 to December 31st, 2009. The motion is calculated relative to a station located in north Greece and marked by a grey triangle. Some vectors indicate perturbation of the displacement field by seismic displacements. A star indicates the 1995 Kozani-Grevena erthquake. The study area is indicated by a white dashed rectangle. NAT: North Aegean Trough, NAF: North Anatolian Fault, SR: Strymon River, CG: Corinth Gulf. EUREF Stations mentioned are located in ATH (Athens, NOA1), CHA (Chania, TUC2), PAT (Patras, PAT0) and THE (Thessaloniki, AUT1).

strike-slip fault, which operates in conjunction with the faults in the North Aegean Trough, the continuation of the North Anatolian Fault into the Aegean (Taymaz et al., 1991). This result has important implications for the seismic hazard in the region, especially because critical infrastructure (among them the TAP gas pipeline, currently in construction) crosses the Strymon Fault System.

2. Geometry and Kinematics of the Strymon Fault System (SFS)

The ~200 km long and ~40 km wide SFS extends from southwest Bulgaria to the North Aegean Sea (e.g. Strymonikos Gulf) (Fig. 2). The SFS strikes NW-SE, defining a complex system of topographic lows, within which the Strymon (Struma) River flows (Figs. 1 & 2). It comprises numerous individual smaller fault systems, each of which being about 80 km long and up to 5 km wide (Zagorcev, 1992a, 1992b). South of the Greek-Bulgarian border, the SFS traverses northern Greece for about 80 km before it extends offshore into the Strymonikos Gulf, where it may connect with the North Aegean Trough, a feature formed in response to the prolongation of the North Anatolian Fault into the north Aegean Sea (Armijo et al., 1999; Taymaz et al., 1991) (Fig. 2). At its northern end, this segment of the SFS abuts against the E-W trending Belasitsa–Kerkini Fault System (BKFS) (Tranos et al., 2008) (Fig. 2).

The SFS has played a key role in the Mesozoic tectonics of northeast Greece as it formed the boundary between two main alpine tectonic units, that of the Serbomacedonian Massif in the west and the Rhodope Massif in the east (Bornovas and Rondogianni, 1983) (Fig. 2). Several field studies have tried to characterize the kinematics of this large structure, without, however, a universal consensus. Lyberis (1984), for example, suggests that the Strymon Valley formed originally as a Paleogene molasses basin which was subsequently reactivated (in Neogene) due to extensional tectonics. Specifically, Lyberis (1984) recorded three main phases of Neogene extension which are (from the oldest to the youngest): 1) post-middle Miocene extension of NW-SE orientation; 2) post-Lower Pliocene to Lower Pleistocene extension of NE-SW orientation during which the main subsidence took place, with the basin accommodating oblique right-lateral strike-slip movement; and 3) post-late Pleistocene to present extension of N-S orientation. The Neogene subsidence is evidenced by >6 km thick sediments (Lyberis, 1984). By contrast, Zagorcev (1992a, 1992b) argues that the SFS corresponds to a major dextral, oblique-slip fault in the late alpine period (till probably early Miocene), while Dinter and Royden (1993) propose that the SFS represents a major southwest dipping low-angle fault that has accommodated ca. 25 km of extension between middle Miocene and early Pliocene. More recently, Tranos (2011) attributes the formation of the Strymon Valley to movement along a right-lateral strike-