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The Sparta Fault, Southern Greece: From segmentation and tectonic geomorphology to seismic hazard mapping and time dependent probabilities

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ABSTRACT

The Sparta Fault system is a major structure approximately 64 km long that bounds the eastern flank of the Taygetos Mountain front (2407 m) and shapes the present-day Sparta basin. It was activated in 464 B.C., devastating the city of Sparta. This fault is examined and described in terms of its geometry, segmentation, drainage pattern and post-glacial throw, emphasising how these parameters vary along strike. Qualitative analysis of long profile catchments shows a significant difference in longitudinal convexity between the central and both the south and north parts of the fault system, leading to the conclusion of varying uplift rate along strike. Catchments are sensitive in differential uplift as it is observed by the calculated differences of the steepness index k_{sn} between the outer (k_{sn}<83) and central parts (121<k_{sn}<138) of the Sparta Fault along strike the fault system. Based on fault throw-rates and the bedrock geology a seismic hazard map has been constructed that extracts a locality specific long-term earthquake recurrence record. Based on this map the town of Sparta would experience a destructive event similar to that in 464 B.C. approximately every 1792 ± 458 years. Since no other major earthquake M ~ 7.0 has been generated by this system since 464 B.C., a future event could be imminent. As a result, not only time-independent but also time-dependent probabilities, which incorporate the concept of the seismic cycle, have been calculated for the town of Sparta, showing a considerably higher time-dependent probability of 3.0 ± 1.5% over the next 30 years compared to the time-independent probability of 1.66%. Half of the hanging wall area of the Sparta Fault can experience intensities ≥ IX, but belongs to the lowest category of seismic risk of the national seismic building code. On view of these relatively high calculated probabilities, a reassessment of the building code might be necessary.

1. Introduction

In 464 B.C. a major earthquake devastated the city of Sparta (~20,000 fatalities, ≥X MS intensity Galanopoulos, 1961; Papazachos and Papazachou, 1997), causing great social unrest. This event is regarded as the oldest well-defined event in the Hellenic historical record and is described by plethora of ancient authors such as Thucydides, Diodoros, Aelianos and Plutarch (e.g. Galanopoulos, 1961; Papazachos and Papazachou, 1997). This major event is clearly associated with the Sparta Fault (Armijo et al., 1991), which is located only a few km westwards from the city of Sparta and forms the only major seismic source that can generate such a strong earthquake.

Despite this strong event, the area of Sparta is characterised by low seismicity over the last 25 centuries since no other major event has occurred in the town of Sparta since 464 B.C. (Papanastassiou, 1999). Therefore, since sufficient time has elapsed for stress to gradually re-accumulate, a future event on the Sparta Fault could be imminent. This is also supported by cosmogenic isotope dating techniques applied on the Sparta bedrock scarp, showing that the central and southern part of this fault did rupture repeatedly (at least six times over the past 13 kyr), with time intervals ranging from 500 to 4500 yr (Benedetti et al., 2002).

This fault is studied based on its post-glacial scarp, the analysis of the drainage network and the major catchments that are influenced by footwall uplift. In addition, we provide a seismic hazard map based on the geological fault slip-rate data from the Sparta Fault and estimate how many times the town of Sparta has received enough energy to shake at intensities ≥IX since the last glaciation. Moreover, by combining the long-term earthquake recurrence record with the historical record and the paleoseismological data, we have extracted time-independent and time-dependent probabilities for large (characteristic) earthquakes. Time dependent probabilities incorporate the most basic physics of the earthquake cycle, are thus

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important considering the prolonged elapsed time since the last event on the Sparta Fault.

2. The Sparta Fault system

The Sparta Fault system (Figs. 1–3) bounds the eastern flank of the Taygetos Mt (2407 m) and shapes the western boundary of the Sparta–Evrotas basin (Fig. 2). This fault zone belongs to the arc parallel normal faults with a NNW–SSE to N–S trend from the Ionian to the Aegean Sea that create the alternation of neotectonic horsts (Methoni, Taygetos/Mani, Parnon) and grabens (Kalamata/Messiniakos Gulf, Sparta/Lakonicos Gulf) (Mariolakos and Papanikolaou, 1981; Lyon-Caen et al., 1988; Papanikolaou et al., 1988). The Taygetos Mt is a tectonic horst that is constantly uplifted and bounded by the Sparta and Kalamata Fault systems eastwards and westwards, respectively (Mariolakos and Papanikolaou, 1981). Both fault systems ruptured in historical times. The 1986 (Ms = 6.2) Kalamata earthquake ruptured one of the segments of the Kalamata Fault system producing surface ruptures over a few km and a maximum displacement of 20 cm (Lyon-Caen et al., 1988; Mariolakos et al., 1989).

The Sparta Fault trends NNW–SSE and has a length of 64 km. Its southern tip is located close to the Gerakari catchment approximately 3–4 km southwards from the Potamia village, whereas its northern tip towards the Alfios river, a couple of km westwards from the Kamaritsa village in the Megalopolis basin (Fig. 1). This active fault largely follows the Miocene detachment of East Taygetos Mt which

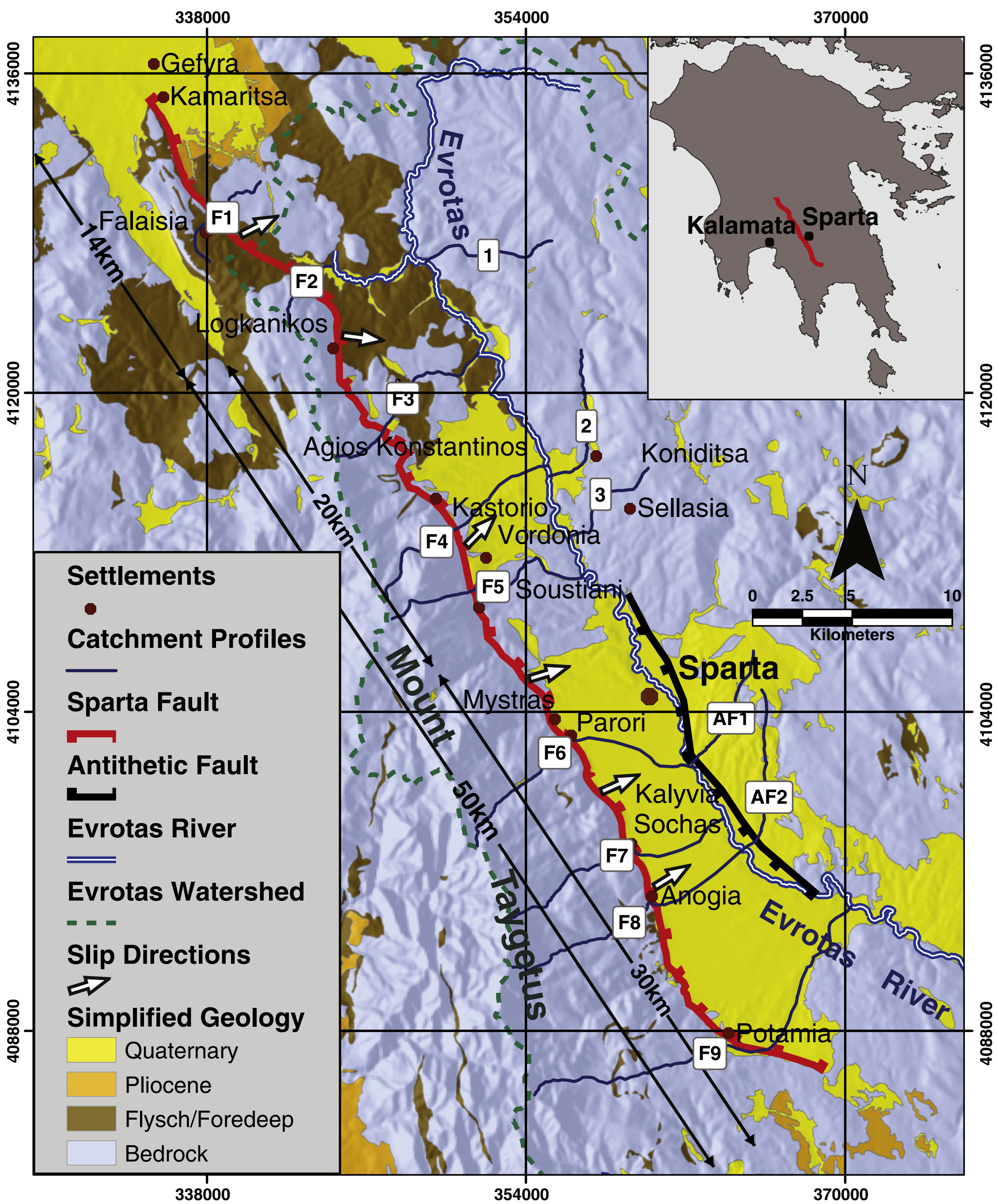

Fig. 1. Simplified geological map of the area of Sparta. Arrows represent fault slip directions. Catchments' profile numbers correspond to Fig. 6. Coordinates are in EGSA 87 which is the official Greek Coordinate System. It is metric, uses GRS 80 as a reference ellipsoid and it is a Transverse Mercator Projection which covers the whole country.