Geophysical Research Abstracts, Vol. 8, 09089, 2006
SRef-ID: 1607-7962/gra/EGU06-A-09089


# Forecasting the M6.9 Kythera earthquake of 8 January 2006: A step forward in earthquake prediction research?

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Tzanis and Vallianatos (*Natural Hazards and Earth System Sciences, 3, 1–17, 2003*), have identified a region of definite accelerating seismic release rates at the SW Hellenic Arc and Trench system, off Peloponnesus, and to the south-west of the island of Kythera (Greece). The identification was made after detailed, parametric time-to-failure modelling on a 0.1° square grid over the area 20ºE– 27ºE and 34ºN – 38ºN. The observations were strongly suggestive of critical point behaviour, leading to a large earthquake with magnitude 7.1±0.4, to occur at time 2003.6±0.6. In addition to the region of accelerating seismic release rates, an adjacent region of decelerating seismicity was observed. The acceleration/deceleration pattern appeared in such a well structured and organised manner that was strongly suggestive of causality. The given explanation was that the observed characteristics of distributed power-law seismicity changes were produced by stress transfer from a fault to a region already subjected to stress inhomogeneities. Around the fault that was going to rupture, there would be bright spots (regions of increasing stress) and stress shadows (regions of relaxing stress): Whereas acceleration should be observed in bright spots, deceleration is expected in the shadows. After due (albeit not exhaustive) fault modelling, it was concluded that the observed seismic release patterns could possibly be explained with a family of NE-SW oriented, right-lateral, strike-slip to oblique-slip faults, located to the S of Kythera and between Kythera and Antikythera islands, capable of producing earthquakes with magnitudes $M_S \sim 7$. Time-to-failure modelling and empirical analysis of earthquakes in the stress bright spots yielded a critical exponent of the or-

der 0.25 as expected from theory, and a predicted magnitude and critical time perfectly consistent with the figures given above. Although an approximate location, time and magnitude for an upcoming earthquake event was determined, we were reluctant to declare a prediction for reasons discussed in that publication. However, our results, as well as similar independent observations by another research team (Papazachos, et al., *Bull. Seism. Soc. Am.*, 92**,** 570-580, 2002), indicated that a strong earthquake could occur at the SW Hellenic Arc, within a few years.

Caution was indeed required inasmuch as the expected earthquake did not occur within specified time interval. In fact, re-evaluation of the data at the epochs 2003.3 and 2004.3 showed that while the geographical distribution and characteristics of power-law seismicity changes remained the same, the critical time was deferred to 2004.6 and 2006.3 respectively. In addition, the 'predicted' magnitudes had grown (*Tzanis and Vallianatos, Precursory acceleration of seismicity: from the theoretical elegance to the practical difficulties, Extended Abstract, 10$^{th}$ Congress Geol. Soc. Greece,15-17 April 2004, Thessaloniki, Greece, 631 – 632, 2004*). Inspection of the observed time-to-failure curves showed that the activated area might have been going through a series of time-local loadings / relaxations that complicated our attempts to model and interpret them.

It appears than the expected earthquake did occur at 11:34:52.60 UTC of 8 January 2006. It had an $M_S$ magnitude of 6.9 (Athens), epicentre at approximately (36.31ºN, 23.25ºE) and hypocentre at $\sim$60km. It was generated by a NNE-WSW to NE-SW oriented, right-lateral, oblique-slip to reverse fault located at about 50 km to the north of our predicted location.

Appraising our results, we note that although we were almost confident that the area was undergoing dynamic self-organization, we could not estimate precisely enough, the critical time and the magnitude. On the other hand, we've been able to forecast some characteristics of the fault that produced the earthquake. These were the orientation, sense of motion, approximate location and depth. We expected a right-lateral oblique-slip fault and got a right-lateral oblique-slip to reverse fault. As it turns out, when the NNE nodal plane of the observed fault is used, the resulting distribution of stress transfer matches the observed acceleration / deceleration pattern much better than the prediction. In fact, an *a posteriori* time-to-failure analysis with pre-shock data up to epoch 2004.3, located within the bright spots of the *observed* fault, show a strong clustering of the predicted critical time at 2006.1 and a much better approximation of the observed magnitude (7.2).

We believe we have demonstrated that, in this case at least, the preparation of the earthquake involved the transfer of positive / negative stress from a fault to its surrounding area, which in turn induced acceleration /deceleration of precursory seismic release rates. Thus, we have been able to introduce tectonic information to the prediction. These observations we possible because opposite to the established wisdom, that only the largest magnitude pre-shocks should be taken into consideration (usually $M_S \geq 4.5 – 5$), we have introduced smaller magnitude events in our time-to-failure analysis.

We do not know as yet, whether our results represent the rule or the exception! Nevertheless, if shown repeatable, they could be a significant step forward in medium-term earthquake prediction research, because they pin down the physical process that initiates the dynamic self-organization of the fault network and controls the evolution of seismicity changes. This however, under the reservation that the Critical Point model may not always or everywhere be the fittest description of the seismogenetic process.

**ACKNOWLEDGEMENT:** This work was supported by the project ARCHIMEDES I: "Support of Research Teams of Technological Educational Institute of Crete", subproject "Multidisciplinary Seismic Hazard monitoring in the Hellenic Arc Front" conducted in the framework of the Operational Programme for Education and Initial Vocational Training.