Geophysical Research Abstracts, Vol. 8, 09996, 2006
SRef-ID: 1607-7962/gra/EGU06-A-09996

Spectacular diversity of different types of mass-movements from northern Kea (Cyclades, Greece)

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Kea (also known as Tzia) is an island southeast of Attica in the Aegean Sea. With an area of 131 km2 (and a coast line of 82 km), it is the sixth largest island of the Cycladic islands group. The island is quite mountainous, with the highest peak, Profitis Ilias, reaching 568 m. Narrow valleys are incised into mainly NNE-SSW and WNW-ESE trending mountain ridges. In the coastal areas, vegetation is poor, but the valleys and hillsides in the central part of Kea are fertile and are more wooded than most other Cycladic islands. Kea's climate is typically Mediterranean with relatively cool and dry summers and mild winters. Possibly due to the proximity to Attica, the average annual precipitation (520 mm) is slightly higher than for most other islands of the Cyclades in the central Aegean. About three-fourth of the precipitation occurs during the winter months; rain usually falls in heavy but brief showers. We have investigated the landscape evolution of the northern part of Kea with the assistance of Quickbird satellite imagery, a DEM derived from digitalization of 1:50.000 military maps and classical field work. Lithologically and structurally Kea belongs to the Attic-Cycladic metamorphic belt, which experienced an Eocene high-P/low-T metamorphism, overprinted by Miocene high-T metamorphism linked to extension that form classical metamorphic core complexes in the Aegean (e.g. Naxos, Ios, Serifos). Extension was largely accommodated by low-angle detachment zones, one of which dominates the geology of the northern part of Kea. Strongly simplified, the detachment in the study area delineates a several hundred meter thick low-angle shear zone comprising greenschists and greenschist-gneisses with minor marble intercalations in structurally lower levels.

Tens of meters thick marble ultra-mylonites are found in structurally higher levels, sometimes with phyllites at their base. Ductile and brittle/ductile structures are cross-cut by steep conjugate faults (see the abstracts of Müller et al. and Voit et al. this issue for local geology details). This geological framework places rheologically strong marbles above rheologically weak greenschists and phyllites ("hard on soft"), which has a crucial impact on the rock-slope behavior. Northern Kea shows a spectacular diversity of different types of mass-movements, arguably surprising for an area with quite little precipitation. Most of the mass-movements appear to result from the presence of marbles undergoing frictional behavior structurally above plastically deforming greenschists and phyllites below. The importance of groundwater is also critical. The marble mylonites are characterized by abundant steep faults and strong karstification. Any precipitation that percolates into the karst therefore forms springs at the contact between the karstified marble and the less permeable greenschist (a very nice example is the Pyrgos-spring on the road between Ioulis and Aghios Dimitrios); the translational landslide, west of Spathi Bay, originates exactly at such a contact. Different types of mass-movements are observed in regolith. These include: (a) translational landslide (southern valley near Aghios Georgios, west of Spathi Bay) and (b) rotational landslides (west of the marble plateau at Paouras). The end-member types of mass-movements found in solid rocks are: (a) rotational rockslides (NE cliff of the marble plateau at Paouras and below the road east of Kastrianis monastery), (b) toppling, (c) block slides, (d) rock falls and (e) block rotation (b-e occur at and in the vicinity of the marble plateau at Paouras). Some rock-fall blocks at Paouras are predated by Neolithic objects in the underlying soil. We conclude that a striking diversity of mass-movement mechanisms are observable in northern Kea. The main controlling factors for their initiation are (i) the lithological and structural situation resulting from ductile deformation ("hard on soft"), (ii) existence and orientation of steep brittle faults, (iii) precipitation occurring mainly in heavy but brief pulses, (iv) ground water and springs at the contact between karstified marble and greenschist, (v) undercutting of hill slopes by wave action and perhaps (v) seismicity related to active tectonics in the Aegean region.