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# RELIABILITY ENHANCEMENT OF CRUSTAL DEFORMATION RATES BY JOINT STUDY OF GEODETIC AND GEOLOGIC/GEOMORPHOLOGIC OBSERVATIONS

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A frequent problem in the interpretation of geodetic crustal movement measurements is due to the fact that the observation points are scarce and that the time series are relatively short. The regional representativeness of an observed signal can be problematic, and local effects as topography, local inhomogeneities contribute to distort the regional deformation signal (e.g. Zadro and Braitenberg, 1999). The crustal deformation rate is not necessarily constant in time, being subject to changes on the time period of a few years, which can be averaged only with observation histories of sufficient length. The geologic and geomorphologic observations give information on the crustal movement over a much larger time span, but with a much worse time-resolution. The strain rates that can be derived represent the average movement over the time scale of $10^3$ years upwards. They represent an important source of information on the expected average deformation rate in a geodetic observation site, in which the time series is too short to furnish a reliable average strain rate value.

One example of a geomorphologic study on vertical crustal movements is given by the height of the relative mean sea level along the Italian coastline at the time of the MIS 5.5

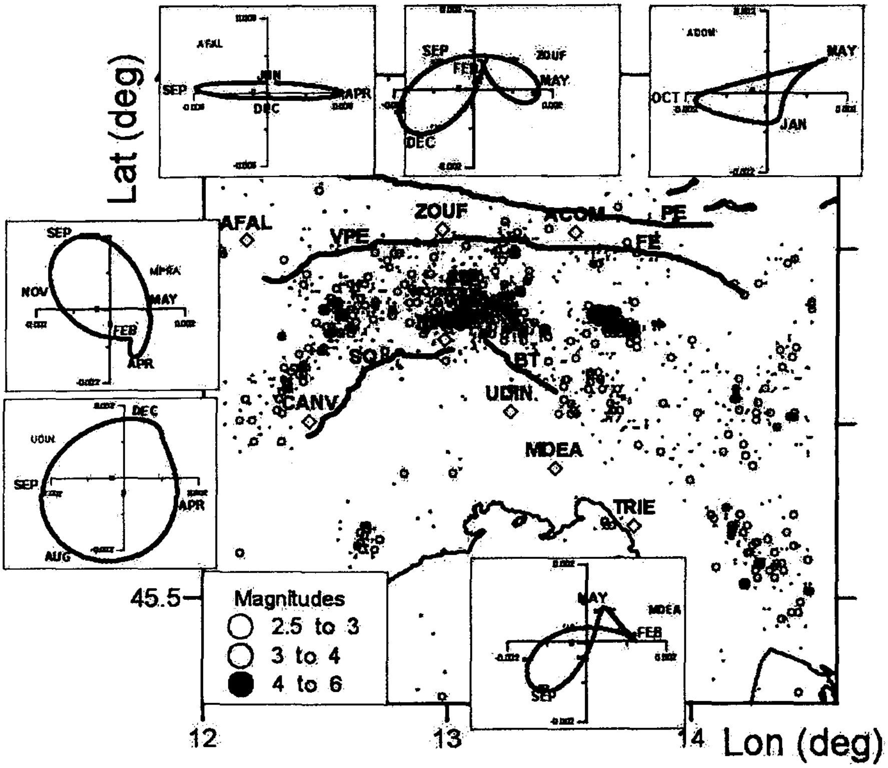


Fig. 1 Graphical representation of the seasonal movements of the FREDNET-GPS monuments in the horizontal plane. The extremal values are labeled with the month of the year. Units: m. Seismicity (CRS-OGS seismologic network) for the years 1977-2004. Fault lines: SQ: Sequals, BT: Buia-Tricesimo, VPE: Val Pesarina, FE: Fella Sava, PE: Periadriatic.

highstand (125 ka; Lambeck et al., 2004). From this work the average vertical movement rate over the last 125 ka can be calculated and compared to the modern observations of vertical crustal movements derived e.g. by GPS, absolute gravity and tide gauges.

The Friuli area and Istria coast give a further good example on the synergy of different types of geodetic and geomorphologic observations. Here the longest geodetic time series is given by the long-base tiltmeters of Grotta Gigante, located in the Trieste Karst, which cover 40 years of observation. Further north, in the Friuli, the observations stem from 25 years of horizontal extensional and tilt measurements. The recently installed FREDNET-GPS network gives the relative horizontal and vertical movements of 3 stations located on the Adria plate and 5 stations located on the Eurasian plate over the time interval of 1-3 years. Moving towards the coast, relative vertical crustal movements can be obtained from the differential values of sea-level change observed by tide-gauges, covering a time interval of at least 45 years. The geodetic observations, both GPS and tilt-extensometric measurements, are influenced by ambient factors, as thermo-elastic deformation and hydrology, which must be corrected in order to extract the tectonic signal. The signal of non-neglectable amplitude is the yearly variation, due to seasonal changes (see Fig. 1). We determine a NW-ward secular tilting of the Grotta Gigante station, which seems to be a regional signal that can be extrapolated to the Karst block into which the cave has been cut (see Fig. 2). The statistical analysis of the three horizontal extensometers of the Villanova station in Friuli reveals that the mean principal strains are oriented roughly NS and EW, with a NS compression-rate and an EW-extension rate. The statistical analysis of seven GPS stations of the FREDNET-network reveal a relative horizontal N-ward movement of the Adria plate with respect to the Eurasian-plate (2-3 mm/yr) and a relative uplift of the pedemountain stations with respect to the Friuli plane and the Trieste station. The two stations on the Friuli plane (UDIN, MDEA) and the Trieste station have nearly no relative horizontal movement. The tide gauges indicate a relative lowering of the Trieste station with respect to the Istria stations, documented by a faster relative sea level rise.

We compare our results with geologic/geomorphologic observations, which give average movements over a much larger time-span. The most direct comparison of relative sea-level changes are made with inferences obtained from the study of tidal notches and the level of roman harbour-monuments (Antonioli et al., 2004). These give the differential vertical movements along the coast averaged over a time-span of 2 ka. Regarding the subsidence of the Friuli plane, geomorphologic evidences exist on the basis of a karstic cave at the depth

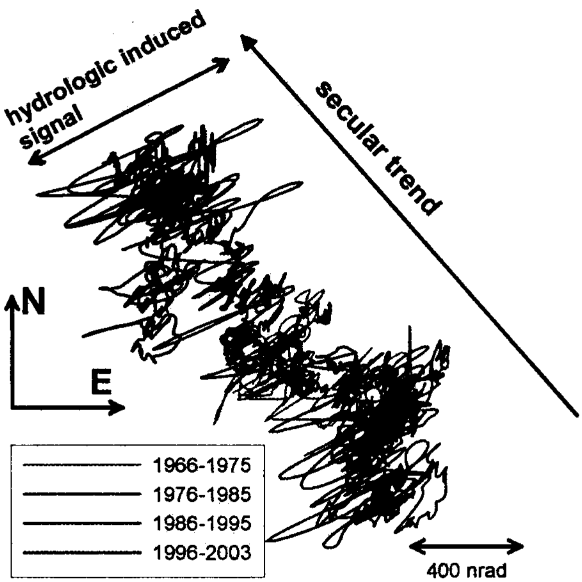


Fig. 2 - Tilt-hodograph, which shows the secular variation of the tilt-vector of the Grotta Gigante long-base tiltmeter. The grey coding refers to different time windows. The original records with daily sampling have been cleaned from the yearly variation.

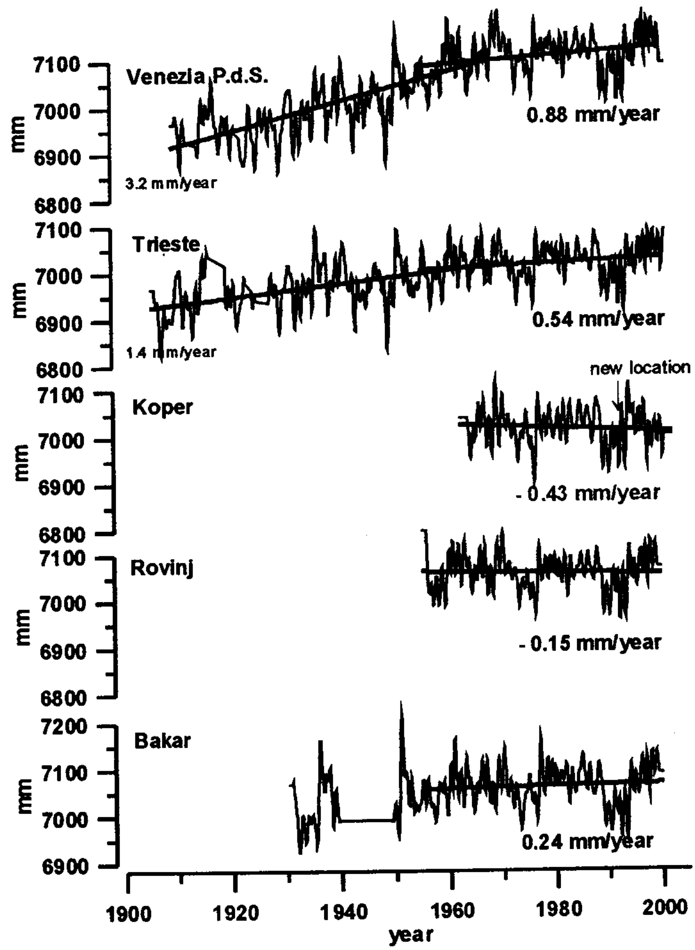


Fig. 3 - Monthly record of tide gauge measurement of sea level in the upper Adriatic, including the locations Venezia Punta della Salute, Trieste, Koper, Rovinj and Bakar. The regression lines are calculated on the common time interval of years 1955-2000. For Trieste and Venice, furthermore the mean sea level rise has also been calculated for the years 1905-1970 and 1907-1970, respectively.

of -180 m, located 30 km northwest of Trieste (Albrecht and Mosetti, 1987). The cave must have formed above sea level, as subsurface water erosion was responsible for its formation. Another observation was that of a sequence of submerged marine terraces in the gulf of Trieste, the uppermost of which at the level of -20 m was attributed (Antonioli et al., 2004) to the MIS 5.5 (marine isotope stage, about 125 ka).

We conclude that the cross-disciplinary comparison and validation of the results stemming from geodesy and geology/geomorphology is auspicable and can be a means to improve our estimation of the seismic risk in the future.