an anomalous response of the georadar cross-hole survey at the depth between -10 and -12 m. We relate that behavior to the presence of residual hydrocarbon trapped in the pore volume below the water table. The Hanai model was used to interpret the electrical permittivity of the emulsion (oil and water) and the bulk electrical permittivity. In order to validate this assumption, a laboratory activity for measuring the electromagnetic parameters of each phase is ongoing. .

Acknowledgements: the study was performed as a part of the SoilCAM project, funded in 7th Framework Programme for the call ENV.2007.3.1.2.2 by the European Community

References

La Brecque, D.J and X. Yang; 2001: Difference inversion of ERT data: a fast inversion method for 3-D in situ monitoring, Journal of Environmental and Engineering Geophysics (JEEG),.6, 83-89.

Rucker, D.F. and Ferré T.P.A.; 2003: Near-surface water content estimation with borehole ground penetrating radar using critically refracted waves, Vadose Zone Journal 2, 247–252.

THE STUDY OF KARSTIC AQUIFERS BY GEODETIC MEASUREMENTS IN CANSIGLIO PLATEAU (NORTH - EASTERN ITALY)

B. Grillo [1], C. Braitenberg [1], R. Devoti [2], D. Zuliani [3], I. Nagy [1], P. Fabris [3]

1 Dipartimento di Geoscienze, Università di Trieste, Italy

2 Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy

3 Centro Ricerche Sismologiche, Ist. Naz. di Oceanografia e di Geofisica Sperimentale - OGS, Udine, Italy

Introduction. We propose an interdisciplinary study of karstic aquifers using tiltmeters and GPS observations. The study region is located in north-eastern Italy, in the seismic area of the Cansiglio Plateau. The Zöllner type Marussi tiltmeters are installed in a natural cavity (Bus de la Genziana) that is part of an interesting karstic area of particular hydro – geologic importance. The Livenza river forms from a number of springs at the foothills of the karstic massif and flows through the Friuli-Veneto plain into the Adriatic Sea. Comparing the tiltmeter signal recorded at the Genziana station with the local pluviometrical series and the hydrometric series of the Livenza river a clear correlation is recognized. Moreover, the data of a permanent GPS station located on the southern slopes of the Cansiglio Massif (CANV) show also a clear correspondence with the water runoff. Here we present the hydrologic induced deformations as observed by tiltmeter and GPS. After heavy rain events we record rapid deformations both by tiltmeters and GPS corresponding to the rainfall duration. In the following days a slow geodetic motion recovers the accumulated deformation with a distinctive pattern both in tilt and GPS data which correlates with the runoff of the karstic aquifer. The purpose of this research is to open a new multidisciplinary frontier between geodetic and karstic systems studies to improve the knowledge of the underground fluid flow circulation in karstic areas. Furthermore a better characterization of the hydrologic effects on GPS and tilt observations will have the benefit that these signals can be corrected when the focus of the study is to recover the tectonic deformation.

The Cansiglio Plateau is a karstic massif situated in the Veneto-Friuli pre-Alpine region in northeast Italy (Fig. 1). It is bordered to the south by the Cansiglio low angle thrust, part of the complex thrust system of the eastern southern Alps. This region was struck by numerous earthquakes with magnitudes up to 6 during historical times. The surface hydrography is reduced to a minimum, as it has been replaced by the underground water flow. The supply of the deep aquifer is given by water infiltration of meteoric precipitation (about 1800 mm/year) in the underground of the Cansiglio Plateau by means of sink-holes, dolines and cavities of prevalent vertical development (Grillo, 2007). In the present work we integrate indirect methodologies with the geologic knowledge of the karstic massif in order to understand better the local hydrogeology. Since December 2005 a couple of tiltmeters are installed on the Cansiglio Plateau in the natural cave of the Bus de la Genziana (Fregona, Treviso) (Fig. 1b). The monitoring station is at 25 m depth and has been set up for the

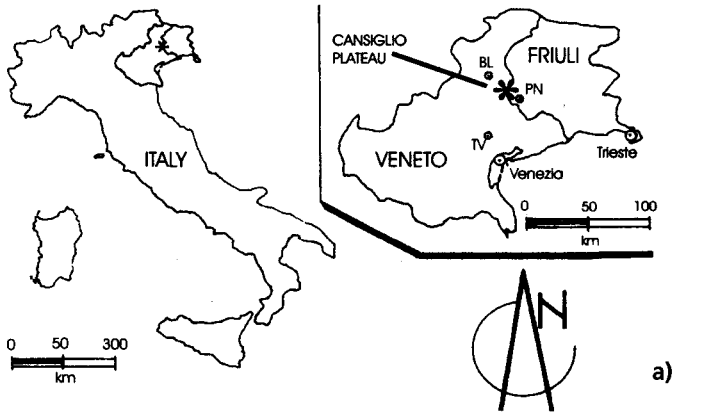

Fig. 1 - a: location of Cansiglio – Cavallo Plateau; b: grey squares represent the positions of the main caves of Plateau Cansiglio and GPS station, black squares the principal springs of Livenza River (Molinetto, Santissima, Gorgazzo).

study of slow crustal movements (Braitenberg et al., 2007). It is part of a network of geodetic stations run by the Department of Geosciences, University of Trieste (Grotta Gigante, Trieste and Grotta Nuova of Villanova, Udine). Considering the evident signal of deformation induced by underground runoff waters, we evaluated the possibility that this deformation could be surveyed with GPS instrumentation. In the area of Cansiglio a unique permanent GPS station (CANV) has been installed by the Centro di Ricerche Sismologiche - Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (CRS-OGS) in 2004 and is part of the monitoring GPS network of the Friuli area (FReDNET) (Zuliani (2003)). The GPS station is situated at about 800 m height in the external Friulian part of the Cansiglio-Cavallo Plateau and at a distance of about 8 km from the Genziana cave tiltmeter. The GPS data have been analyzed with the program Bernese (v.5.0) (Beutler et al., 2007) in the framework of a network solution including about 40 permanent GPS stations in the area of the north-eastern Alps.

Discussion of tiltmeters and GPS observations. The slow movement recorded by the tiltmeters is the sum of a tectonic deformation, a tidal deformation and the effect of environmental factors like temperature, superficial and underground water, and snow. The separation of the different signals is not always univocal. The tidal signal can be accurately modelled, the daily temperature has the exact solar day period, the hydrologic effects can be of all frequencies and can mask the tectonic signal. In general the tilting reflects the actual tectonic situation in northeast Italy, which shows the convergence of the Adriatic and Euroasiatic plates. During heavy rainfalls the tilt records become particularly disturbed and the deriving deformation can be interpreted as a hydrologic effect. Comparing the tiltmeter time series with the pluviometric data of Cansiglio (station Tremedere A.R.P.A. Veneto) and with the hydrometric data of River Livenza (Civil Protection of Friuli Venezia Giulia Net of Hydrometric Monitoring), we noted a very clear causal relationship between the tilting and the runoff of underground rainwaters (Fig. 2).

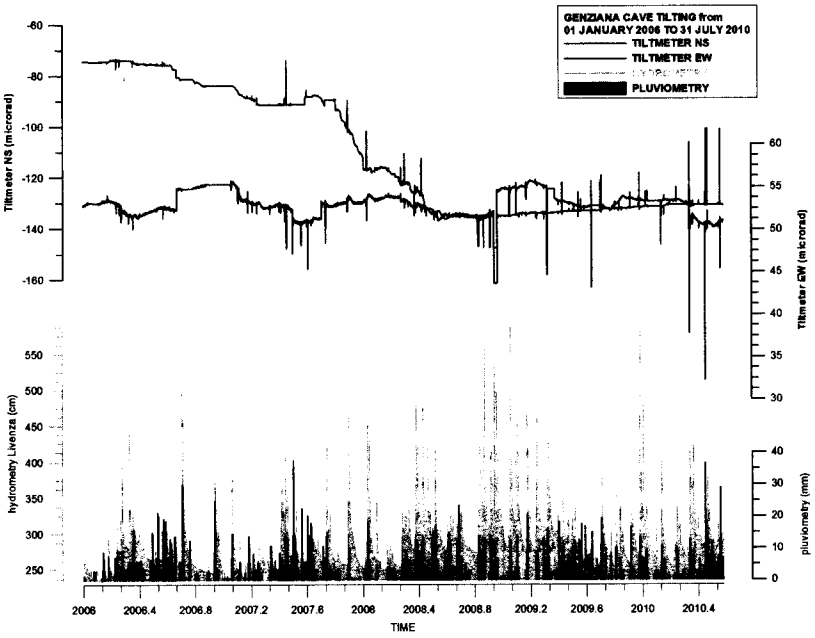

Fig. 2 - The tilting signal of the two components compared with the hydrometry of Livenza and the rainfall of Cansiglio from 01 January 2006 to 31 December 2009. We note a periodical variation in the component EW and a southward drift in the component NS, which could be of tectonic origin, due to the fact that the hydrology does not show an analogous drift. The hydrologic signal manifests itself as spikes and "loops" corresponding to rain events, and also as slow drift in correlation with the runoff curves of the aquifer.

The geodetic station located in Bus de la Genziana is situated in a strategic logistic position from a geophysical and hydrogeologic point of view, as the Cansiglio - Cavallo Plateau represents one of the most interesting karstic areas of northeast Italy. It has been verified that the cave deforms continuously and is particularly sensible to the meteorological variations; the tectonic tilting is directed towards south with semicircles which occur in correspondence of heavy rain events. The response of tiltmeters to a rain event is first immediate (a few hours) and then slow (a few days) in time, following the runoff curves of the aquifer. The recordings are extremely sensible to the atmospheric precipitations, and especially in the NS component, they cause a huge tilt amplitude. For example

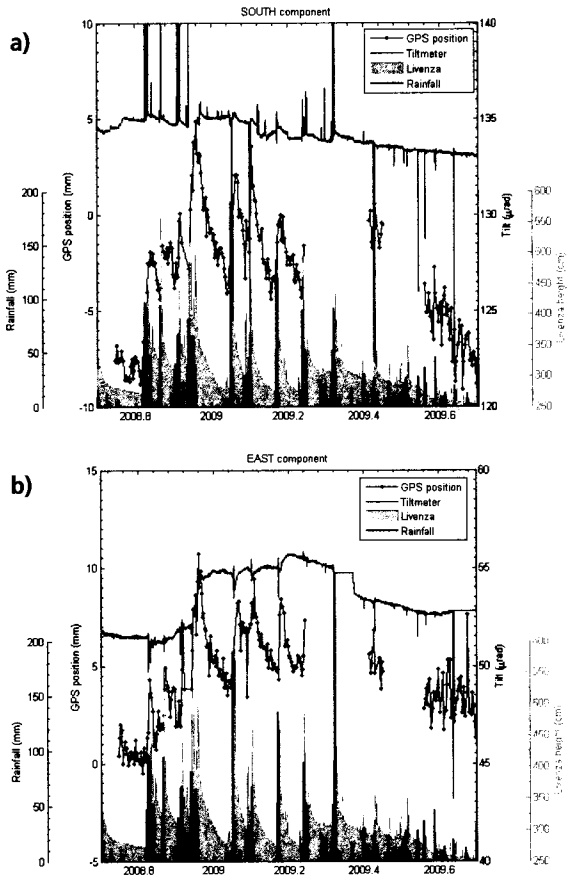

Fig. 3 - a, b. Comparison between the horizontal components NS (a) and EW (b) of the GPS station Caneva, the tilting signal of station Genziana, pluviometrical recordings of Cansiglio and hydrometric signal of River Livenza from 19 October 2008 to 2 April 2009. The tilting signal is violet. The satellite signal is red. Both of them register simultaneously the rainy event.

when the rainfall is 18 mm/hour, the EW impulsive signal is about 3.25 μrad, the NS tiltmeter signal is 14.54 μrad. The observed tiltmeter signal can be explained in terms of loading caused by runoff water flow in underground channels (Longuevergne et al., 2009). The tilting signal permits to give information on the characteristics and location of the underground runoff of rainwater. In case of Cansiglio a rapid runoff has been ascertained which normally passes to the north from the Genziana station, in direction from west to east, which loads a basin situated east of the station. The runoff occurs mainly vertically and/or towards east, otherwise a N-S tilting signal should have been observed. The comparison between tiltmeter and GPS data shows the contemporaneous recording of atmospheric events (Fig. 3). Both instruments record slow deformations after rain events in connection with the hydrometry of the karstic aquifers (curves of Livenza's runoff); the GPS station displaces in a horizontal plane and then turns back to the original position without particular signals in the vertical component.

Conclusion. Both geodetic stations, tiltmeters in Genziana Cave and GPS in Caneva, record the hydraulic loading at the same times, reflecting the fluid flow in the underground conduits during the phase of full load. The slow (weeks) long term response is a deformation which could be the runoff of water from the rock matrix towards the conduits in the phase of normal water flow. The variation in direction of the tilt impulses could be derived from the non homogeneous hydrology of the karstic system. This deformation is probably not of tectonic origin, because also the Livenza River shows these signals. To measure the extent and the style of the deformation a small network of geodetic markers need to be set up on the entire Cansiglio - Cavallo Massif. Surveying the marker points with a few GPS receivers could help to assess the limits of the deformation area and the behaviour of the ongoing deformation.

References

A.R.P.A. F.V.G., 2006 – Rilevamento dello stato dei corpi idrici sotterranei della Regione Friuli Venezia Giulia, (Survey on the state of underground hydrologic units of the Friuli Venezia Giulia Region), Final Report, 68-71, Regione Autonoma Friuli Venezia Giulia.

Battaglia M., Zuliani, D., Pascutti, D., Michelini, A., Marson, I., Murray, M.H. and Burgmann R., 2003 - Network Assesses Earthquake Potential in Italy's Southern Alps. EOS 84 (28), 262-264, 15 July 2003.

Beutler et al., 2007 – Bernese GPS software. In: Dach R., Hugentobler U., Fridez P., Meindl M. (Eds.), Astronomical Institute, University of Bern (January 2007).

Braitenberg C., Grillo B., Nagy I., Zidarich S., Piccin A., 2007 - La stazione geodetico - geofisica ipogea del Bus de la Genziana (1000VTV) - Pian Cansiglio. Atti e Memorie della C.G.E.B., S.A.G. CAI, Trieste, Italia, Vol. 41: pp 105-120.

Grillo B., 2007 - Contributo alle conoscenze idrogeologiche dell'Altopiano del Cansiglio. Atti e Memorie della C.G.E.B.", S.A.G. CAI, Trieste, Italia, Vol. 41: pp 5-15.

Longuevergne L., Florsch N., Boudin F., Oudin L., Camerlynck C., 2009 - Tilt and strain deformation induced by hydrologically active natural fractures: application to the tiltmeters installed in Sainte-Croix-aux-Mines observatory (France). Geophys. J. Int. (2009) 178: pp 667–677.

Zuliani D., 2003 - FREDNET: rete di ricevitori GPS per la valutazione del potenziale sismico nelle Alpi sudorientali italiane. GNGTS, Atti del 22° Convegno Nazionale, Roma 18-20 November 2003.

Zuliani D., Priolo E., Palmieri F., Fabris P., 2009 - Progetto GPS - RTK: una rete GPS per il posizionamento in tempo reale nel Friuli Venezia Giulia, dimensione GEOMETRA 2009 12, 30-36pp.

3D ERT SURVEY TO RECONSTRUCT ARCHAEOLOGICAL FEATURES IN THE SUBSOIL OF THE "SPIRITO SANTO" CHURCH RUINS AT THE SITE OF OCCHIOLÀ (SICILY REGION, ITALY)

F. Greco [1], G. Leucci [2]

1 Istituto Nazionale di Geofisica e Vulcanologia, Catania, , Italy

2 IBAM – CNR- Lecce, Italy

Three-dimensional Electric Resistivity Tomography (ERT) was undertaken at the archaeological site of Occhiolà (Sicily, Italy) a medieval village, located on the north western part of a hill named "Terravecchia" at 491 m above sea level. The survey was carried out inside the ruins of