GEOPHYSICAL INVESTIGATION WITHIN THE ZENNARE BASIN (VENICE)

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Abstract.

A multi-technique geophysical investigation is performed to map the shallow depositional units in the Zennare peat basin nearby the Venetian Lagoon. The detection and resolution capabilities of Earth Resistivity Tomography, Refraction Seismic, and Ground Probing Radar are compared in a small test area within the basin, where also additional stratigraphic point information is available. The results obtained with the different methods prove comparable, and the integration of these distinct geophysical responses allows for a more precise identification of the subsurface structure. The Ground Probing Radar survey, because of its cost-effectiveness, has been extended to the entire basin. Some coherent noise patterns, associated with the frozen ground surface, required a specific processing sequence to enhance the radar record quality. The radar images outline the main shallow discontinuities of the basin related to the different depositional framework, allowing for a detailed reconstruction of peat layers as well as of a series of sand-silty paleo-channels distributed within the area. Borehole and remote sensing data are used to calibrate the geophysical interpretation.

1. *Introduction.*

A geophysical investigation with various techniques was recently carried out in a peatland area of the Zennare Basin in the vicinity of the Venice Lagoon (Fig. 1). This investigation is part of a research project

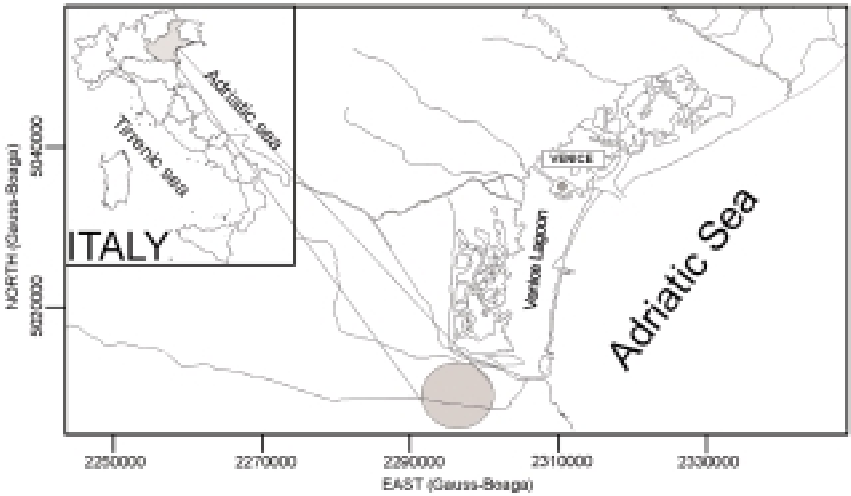

Fig. 1 - Geographical location map of the investigated area.

aimed to model the volume reduction of some shallow organic depositional units due to the aerobic peat oxidation [Nieuwenhuis and Schokking, 1997]. The target of the surveys was to map geometry and stratigraphy of the uppermost sandy and peaty layers [Hanninen, 1992; Saarenketo et al., 1992] and to assess the potentials of a multi-technique geophysical approach that make use of Refraction Seismic, ERT (Earth Resistivity Tomography) and GPR (Ground Probing Radar).

The above techniques are sensitive to variation of acoustic impedance, electrical and electro-magnetical suscettivity, respectively, and are characterized by different degrees of resolution, but all are able to detect the near-surface peaty and sandy bodies. Because of their capability of mapping moisture, mineralogical and textural changes, ERT and GPR were highly successful in detecting the peat-clay or peat-sand interface [Ulriksen, 1982].

On the basis of a field test GPR was selected as the most adequate technique to carry out the entire geophysical investigation. The GPR images clearly outlined the spatial distribution of the peat bodies. The initial data analysis was based on a series of stratigraphic boreholes, and the final interpretation has been controlled by means of aerophotographycal remote sensing [Rizzetto et al., this issue].

2. *General Settings.*

The Zennare Basin is an area of approximately 23 km^2 located south of the Venice Lagoon, about 10 km from the Adriatic Sea. The basin was reclaimed about 70 years ago and presently lies almost entirely below the mean sea level, mostly between -2 and -4 m [Rizzetto et al., this issue]. The land use is completely devoted to agriculture.

The near surface stratigraphy in this area is mainly made of peat, silt, and sand. The peat deposits are located in the central and southern portion of the basin, while silt and sand terrains outcrop in the northern area [Rizzetto et al., this issue]. A number of paleo-channels with width ranging from some meters to few tens of meters cross the silt and peat deposits.

The depth of the water table is approximately 0.5-1 m, varying only slightly with the ground elevation and seasonal changes, and is controlled by pumping stations. The shallow aquifers of the central and northern parts of the basin are generally characterized by a salt contamination due to sea water intrusion from the nearby lagoon and the Adriatic Sea. The contamination is increased by the sea water that, flowing into the watercourse mouths up to 10 km landward, is dispersed from the river beds frequently laying at a level higher than the surrounding land.

The transition zone between the fresh and the brackish water is located about 4 - 8 m below the ground surface. In the southern part of the Zennare Basin, where the main bog is located, a thick and almost continuous clay layer is present below the outcropping peat unit, precluding the organic soil to be contaminated (personal communication of the Scientific Coordinators of the ISES Project).

3. *Data acquisition and processing.*

ERT survey was carried out using two different spreads: a 155-m "Wenner" profile and a 45-m "Dipole-Dipole" profile. The first profile (5-m electrode spacing) targeted the deeper layers while the second one (3-m electrode spacing) was aimed to obtain an accurate map of the near surface formations. The resistivity pseudosections were inverted to true resistivity sections using an iterative algorithm.

Refraction Seismic was used to achieve a deeper understanding of the shallow stratigraphy. Two 12-channel profiles with 3 m geophone spacing were spread in the field. GRM (Generalized Reciprocal Method) analysis was used to process the data and obtain a near-surface velocity section.

Both the ERT and the seismic profiles were acquired in the southern part of the Zennare Basin where the peat layers are thicker (Fig. 2).

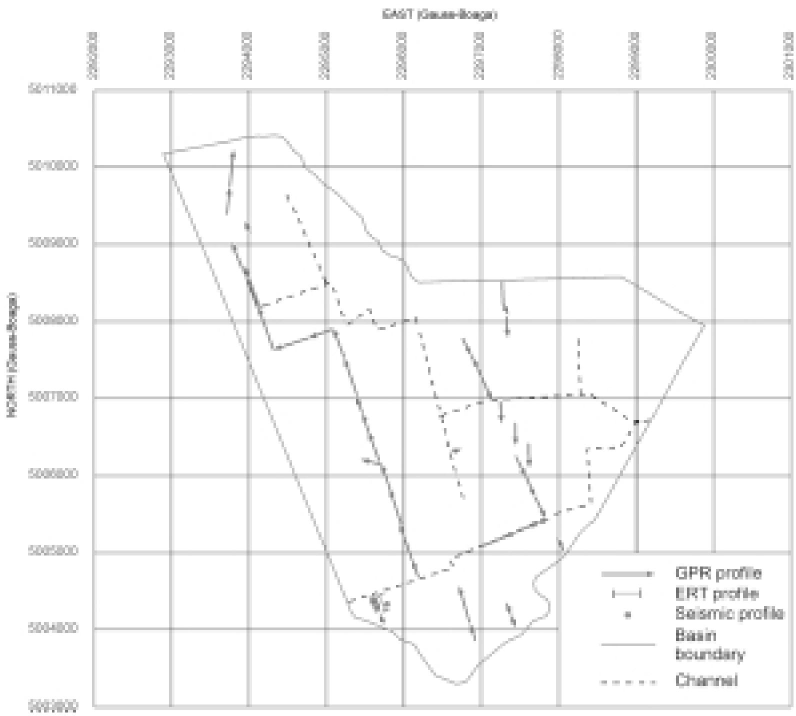

Fig. 2 - Field layout of the geophysical profiles.

The GPR survey was extended to the entire Zennare Basin because of its cost-effectiveness and resolution capabilities. The investigation was carried out with a GSSI SIR-2 system in bi-static configuration, with a constant offset of 0.4 m, using two 500-MHz antennas. The basin was explored with two N-S 2-km long profiles and a series of short E-W sections (Fig. 2).

Data acquisition faced a major inconvenient because of the frozen surface during the field operations. In some area the electro-magnetic energy propagated into the ground was trapped in the frozen layer and generated ringing and reverberative patterns in the radargrams.

Radar data have been processed using the CWP-SU rel.3.4. software package running under a SPARC architecture. Two different processing sequences (according to the geographical position of the profiles) were devised to increase the radar signal quality [Annan, 1996]. The sequence for the sand and silt deposit was quite straightforward: raw data were converted from GSSI SIR-2 into the CWP-SU internal format. Furthermore, major processing steps were zero-offset correction, DC component removal, band pass filtering, horizontal filtering, and amplitude recovery. A running average filter (Daniels, 1996) was applied to the data to correct for DC component. The band pass gate was centered on the antenna natural frequency. A statistical analysis of signal-free traces permitted the estimation of the amplitude decay function that allowed a time-dependent amplitude recovery gain. The low-reflectivity peat deposits required further processing steps to enhance the weak response from the bottom of the peat layer. A velocity filter and a predictive deconvolution were both applied to the data to remove some coherent noise patterns and sharpen the boundary response.

The time section was transposed into depth using a relative dielectric constant equal to 40 in the peat layers and 10 in the sand-silty layers. These values were obtained from averaged field data obtained at borehole locations.

4. *Results and discussion.*

The Wenner resistivity profile shows a fairly conductive and discontinuous top layer with a thickness ranging from 3 to 4 m and a resistivity of 10÷20 ohm·m. Many lateral and vertical variations in resistivity are visible in the section. The clayey deeper layers are even more conductive. The dipole-dipole profile shows a more detailed spatial distribution of the underground resistivity (Fig. 3).

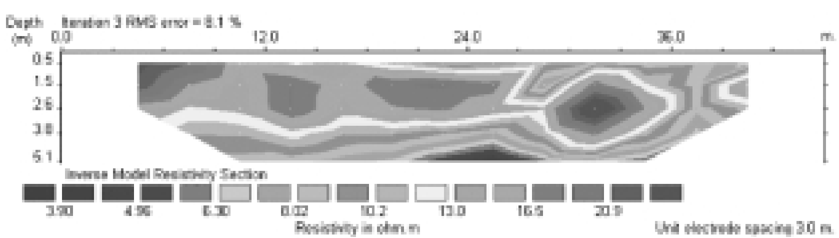

Fig. 3 - ERT inverted resistivity profile.

In particular, the top peaty layer 1.5 m thick exhibits resistivity values ranging from 7.0 to 10.0 ohm·m in the central and left portions of the profile. Resistivity values are higher in the shallower unsaturated zone (above the water table) and lower in the deeper zone (fresh water saturated area). The highly conductive layer (less than 8.0 ohm·m) at the bottom of the ERT “Dipole-Dipole” profile is the response of a clayey horizon. A sand-filled paleo-channel, 6.0 m wide, with resistivity values ranging from 12.0 to 30.0 ohm·m is clearly visible in the right portion of the profile.

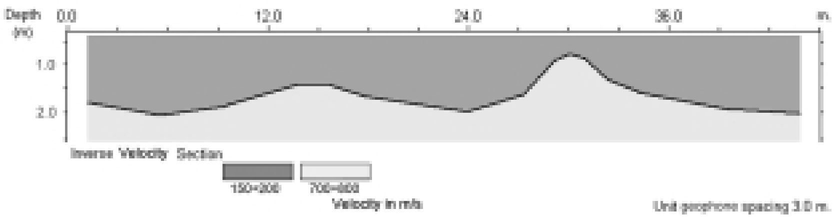

Fig. 4 - Refraction seismic profile.

The seismic section (Fig. 4) was laid out practically coincident with the ERT “Dipole-Dipole” profile. The results evidenced a 200 m/s low velocity layer with a thickness ranging from 1 to 2 m. A deeper layer characterized by a strong increase of P-wave velocity, up to 700-800 m/s, is probably related to a sudden change in lithology. This variation marks the transition to inorganic deposits.

The radar images proved to be very sensitive to small lithological changes. Particularly sand and silt deposits exhibit peculiar electromagnetic responses. Data recorded in the southern part of the basin (Fig. 5) indicates at least three different reflectors. The deepest reflector, visible at about 1.5 m depth, was interpreted as the bottom of the peat layer lying on the clayey-silt deposits. A second reflector occurs within the peat layer at about 1.0 m depth. The uppermost reflector, located about 0.5-0.7 m deep, is the image of the water table. Small variations in the water table depths are probably related to ground surface irregularities.

Some profiles performed in the central part of the basin exhibit the response of the infilling sequences of major sandy paleo-channels. The radar scan of a paleo-channel structure is clearly visible in Fig. 6. The bottom of the channel is evidenced by a series of diffraction patterns due to textural and lithological changes at the contact between the infilling sand deposits and the underlying silt layers. Some east prograding clino-forms are reco-

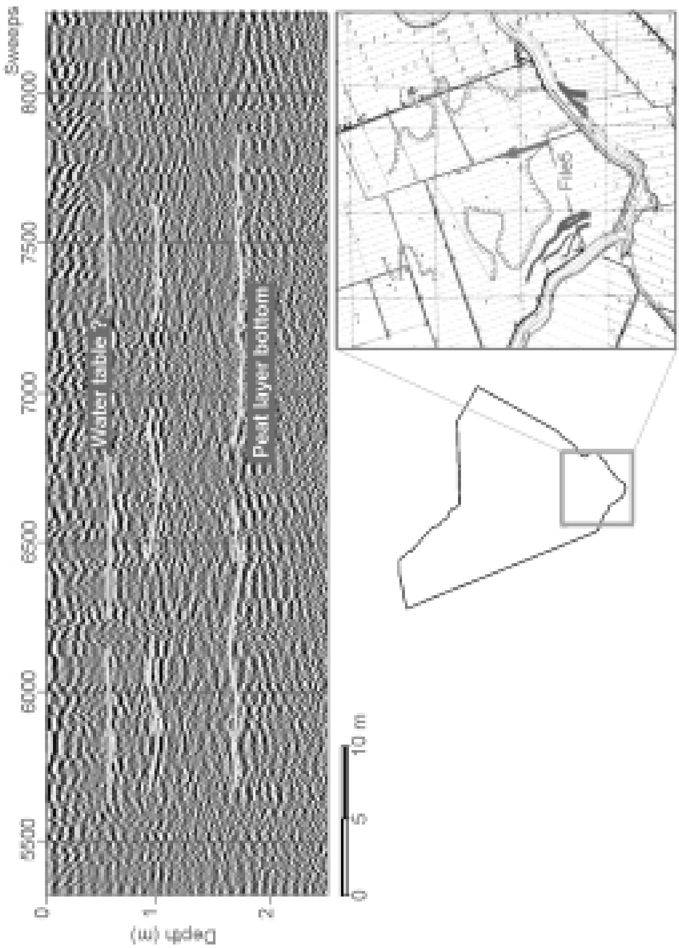

Fig. 5 - Example of the GPR profile in the southern part of the Zennare Basin.

gnizable within the channel infilling sequence. The geomorphological map of the area (in the right side of the figure) supports this interpretation.

An initial analysis of the raw data collected in the northern part of the basin indicates the presence of narrow channel structures (Fig. 7) within the first two meters of depth. The geomorphological map of the area evidences some small channels nearby the radar profile. These sharp shallow patterns are interpreted as ancient canals related to the reclamation started in the 19th century.

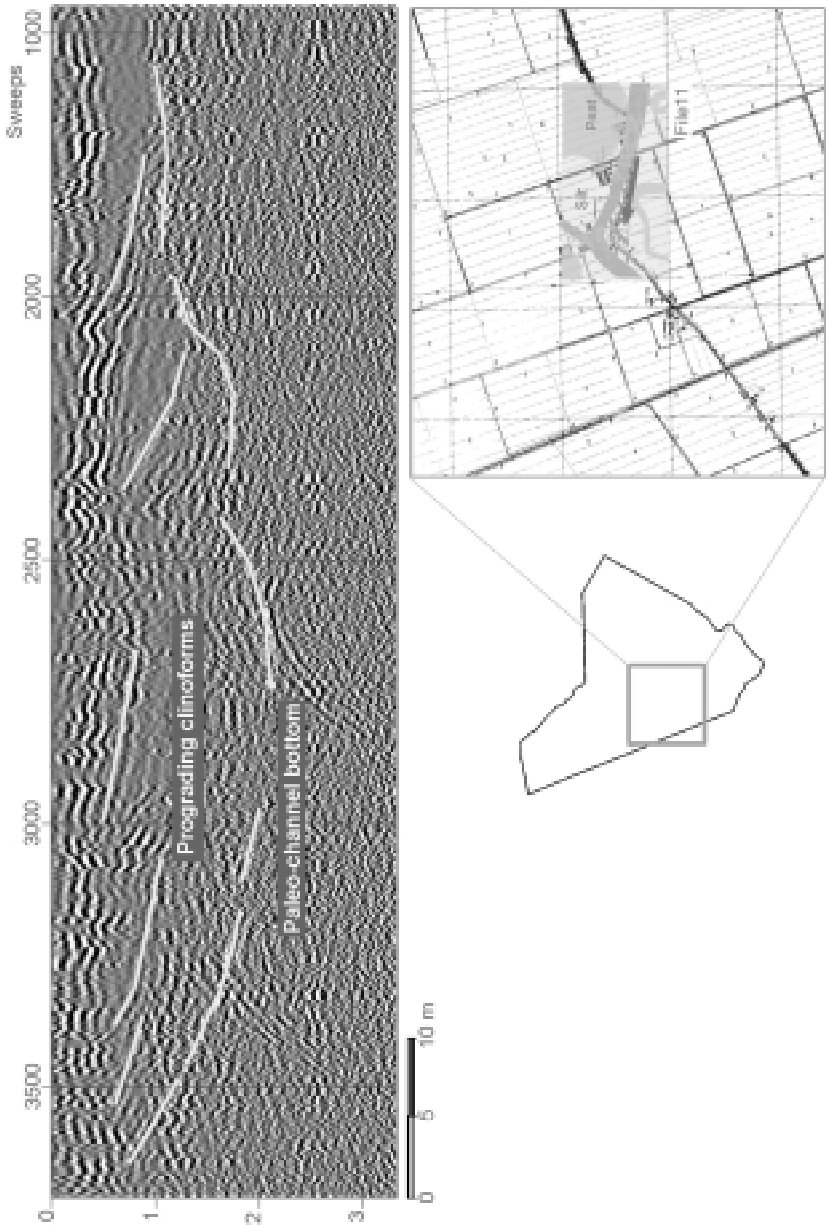

Fig. 6 - Example of the GPR profile in the central part of the Zennare Basin.

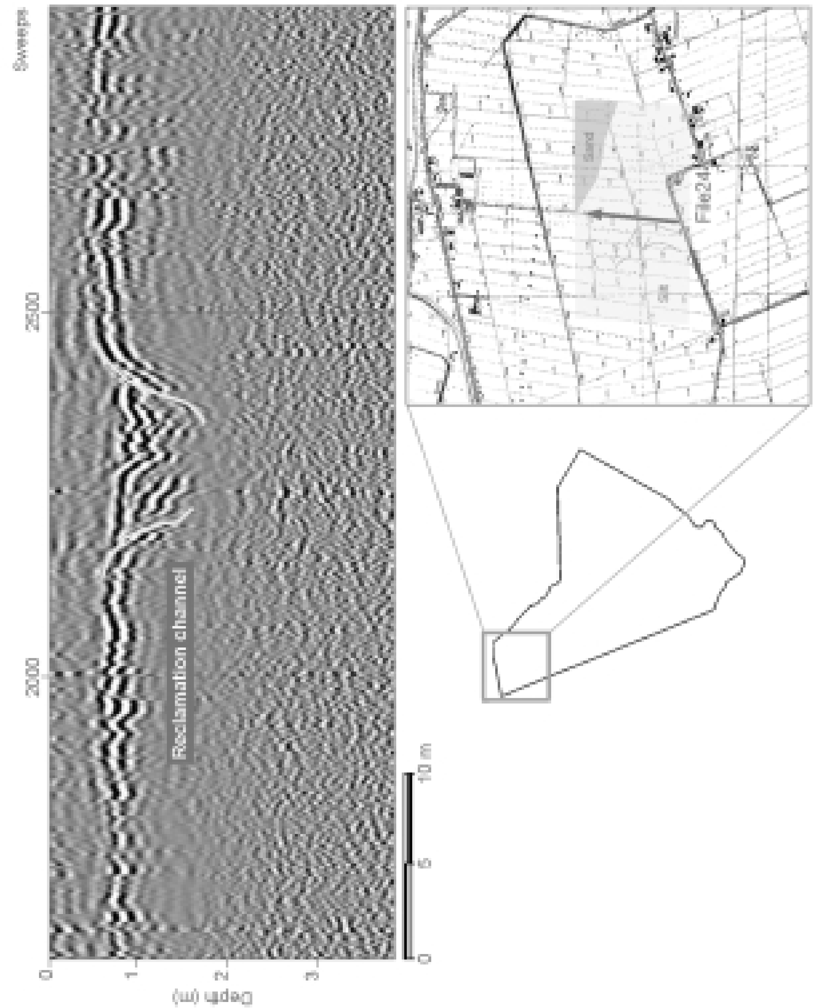

Fig. 7 - Example of the GPR profile in the northern part of the Zennare Basin.

5. *Conclusions.*

A high-resolution geophysical investigation successfully imaged the distribution and thickness of the peat in the uppermost depositional layers within the Zennare Basin. The different physico-chemical and textural properties of sand, silt, clay, and peat lithologies generated distinct geophysical responses.

Three different techniques were tested in the field before carrying out the exploration survey. ERT and refraction seismic provided comparable results in terms of lithology detection and mapping capability.

The GPR provided a much higher resolution with a reduced logistical effort. Because of these accomplishments the radar technique was extended for the survey of the entire basin. Specific processing sequences were tested to enhance the radar images. A multi-step routine was used to enhance the quality of the data degraded by the low reflectivity of the peat deposits.

Analysis and interpretation of the radar images allowed a detailed reconstruction of the fresh water table, peat layer boundaries, and sand and silt filled paleo-channels. The initial interpretation of the geophysical response was supported by remote sensing analysis and borehole data collected in various locations within the peaty basin. The ringing character of some radar profiles due to the frozen surface made their interpretation somewhat difficult when nearby borehole calibration was not available.

The integrated interpretation of the field data measured in the test area proved to be the most efficient approach to outline the framework of the near-surface stratigraphy within these depositional contexts.

Acknowledgments.

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References.

Annan A.P., 1996. Trasmission dispersion and GPR. J. Environ. Eng. Geophys 0, 125-136.

Daniels D.,J., 1996. Surface Penetrating Radar. Institution of Electrical Engineers (IEE), London, UK, 300 pp.

Rizzetto F., et al., this issue. Geomorphological evolution of the southern catchment of the Venice Lagoon (Italy): the Zennare Basin.

Hanninen P., 1992. Application of Ground Penetrating Radar techniques to peatland investigations. In: Fourth Int. Conf. on Ground Penetrating Radar, Rovaniemi, Finlan, Geol. Survey of Finland, Special Paper 16, 217-221.

Nieuwenhuis H.S., Schokking, F., 1997. Land subsidence in drained peat areas of the Province of Friseland, The Netherlands. Q. J. Eng. Geol. 30, 37-48.

Ulriksen P., 1982. Application of impulse radar to civil engineering. Doctoral Thesis, Lund University of Technology, Lund, 175 p.

Saarenketo T., Hietala, K., Salmi, T., 1992. GPR application in geotechnical investigations of peat for road survey purposes. In: Fourth Int. Conf. on Ground Penetrating Radar, Rovaniemi, Finlan, Geol. Survey of Finland, Special Paper 16, 293.