EUG XI

Symposium PCM2

Self-Potential (SP) Measurements: Applications and Interpretations

Convenors

Laurence Jouniaux
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PCM2
Self-potential (SP) Measurements: Applications and Interpretations

Tuesday AM Session

PCM2 : TUam02 : G5
New Perspectives of the Self-Potential Probability Tomography

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This paper is an extension of a previous study, in which the principles of the self-potential ground surface tomography including topographic effects were outlined. The new arguments which are here set forth are the proper accounting for the topographic effects and a robust approach to global 3D tomography inversion. The 2D case is initially considered in order to facilitate a full understanding of the new method. To gauge the topographic distortions, the concepts of slope-effect and surface-regularisation are introduced, as suitable means to compute point by point correction factors of the measured self-potential data, prior to the recognition of the tomographic images of the primary and induced electrical sources underground. Then, the tomographic inversion approach is developed by introducing again the concepts of scanning function and of charge occurrence probability function, which were amply dealt with in the previous study. The new approach to 3D global tomography inversion is here meant as the composition of charge occurrence probability functions related to any two orthogonal surface components of the natural electric field, in order to fully account for the total surface component of the self-potential field and hence to elicit the greatest amount of information. Two field examples are presented to show the full effectiveness of the proposed method. They respectively refer to a near surface investigation for archaeological purposes and to a very deep prospecting in an active volcanic area.

PCM2 : TUam03 : G5
Forward and Inverse Modelling of SP Anomalies Caused by Subsurface Fluid Flow: Numerical Experiments

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We propose a novel approach to the forward and inverse modelling of self-potential (SP) data caused by subsurface fluid flow (Sailhac & Marquis, 2000). We use analytic signals and wavelets associated with the electric and fluid flow potentials. We then apply an inversion in the wavelet domain, which is in fact a correlation between Green's functions and the SP anomalies and is equivalent to the probability tomography introduced by Patella (1997).

Our approach includes fluid flow potential functions in the inversion scheme: modelling is not reduced to equivalent electric sources but involves parameters of the velocity field of underground fluid flow causing SP anomalies from electrokinetics. Simplest cases involve stream flow with homogeneous discharge functions directly proportional to the wavelet coefficient of the SP anomaly. We illustrate the results for the simple case of flow around an angular wedge for which an analytic solution exists.

More realistic cases require numerical modelling of the fluid velocity distribution. We present here an example of flow in a confined aquifer with a wedge at its base. The fluid velocities are computed using a finite-element technique. The resulting wavelet-domain SP anomalies are inverted and yield satisfactory estimates of flow geometry and intensity.

Sailhac, P & Marquis, G, *Geophys. Res. Lett. (submitted)*, (2000).
Patella, D, *Geophys. Prosp*, **45**, 653-681, (1997).

PCM2 : TUam04 : G5
Self-Potential Tomographic Techniques for Landslide Monitoring: First Results on Southern Apennine Chain (Italy)

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In past and recent years, the whole Southern Apennine Chain has been affected by many mass movements that have damaged villages, road systems and important engineered buildings in this area. Usually, traditional geophysical prospecting techniques have been applied in the study of landslide areas to delineate the geometry of the landslide zone, to identify the sliding surface and to study the groundwater system (McCann, D.M. and Forster, A., 1990). In the last years, new self-potential tomographic techniques have been proposed to study landslide areas. In this framework, an innovative system for the acquisition, elaboration and inversion in real-time of the self-potential data, based on the inversion algorithm proposed by Patella (1997), has been designed and developed to get tomographic images indicating the probability to locate electrical sources in subsoil. From the analysis both of the spatial and temporal patterns of the electrical source distribution in the subsoil, we obtain information about the geometry of landslide bodies and the main outline of the underground fluid flow. In this work we present the first results regarding the application of the new self-potential tomographic techniques to study the Giarrossa and Varco Izzo landslides, ascribed to a rototranslational slide - earthflow type of ancient genesis, located on Southern Apennine chain, close to Potenza town (Basilicata, Italy). The analysis of self-potential tomographic images, compared and integrated with the results obtained from geological and borehole data, allowed us to characterize the main features of the circulation network of the underground fluid flow and to obtain information about the sliding surface and, consequently, the thickness of the slide body. In conclusion, the new self-potential tomographic technique shows this approach to be a possible powerful tool, with fast data acquisition times and low costs, for investigating landslide areas characterized by very complex geology.

McCann, D.M. and Forster, A., *Engineering Geology*, **29**, 59-78, (1990).
Patella, D., *Geophys. Prospect.*, **45**, 653-681, (1997).

PCM2 : TUam05 : G5
Modeling SP Anomalies Caused by Rainfall Infiltration

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When acquiring SP data at a high rate (2 s), we have observed large SP anomalies of few hundred mV related to atmospheric phenomena that may mask the usual signals of a few mV caused by surface SP sources of geophysical significance.

In order to qualify the SP anomaly caused by rainfall infiltration, we have first applied a 1-D diffusion model with a saturation-dependent diffusivity following Brooks and Corey (1964). To compute the resulting anomaly measured at a depth of one meter, we have integrated the equivalent electric sources from the surface to a few tens of centimeters. The electric sources are proportional to minus the saturation gradient, i.e. negative above the infiltration front and positive below it. The integration volume used is a cylinder interpreted as the envelope of the relevant fingering pattern.

We applied our scheme to SP data acquired during a 3-day period of stormy weather in July 2000. We found that a good fit can be obtained when using C = 1 V/MPa and a permeability at saturation of 4 mD, a reasonable value for this loess environment. We have also found that the amplitude of the SP anomaly varies with depth and hence electrode depth must be carefully controlled when designing SP monitoring experiments.

Brooks R.H. & Corey A.T., *Hydrology*, **3**, (1964).

PCM2 : TUam06 : G5
Searching for Extreme Events in Self-Potential Time Series Measured in a Seismic Active Area of Southern Italy

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In this work we show the first results of a study regarding the statistical analysis of self-potential signals measured in the Irpinia -Basilicata region (Southern Italy), one of the most seismic active areas of the Mediterranean region characterised by a probability >60% to generate at least one earthquake with M>3.5 in a time span of 3 years (Martinelli and Albarello, 1997). In particular, we analyse the possible correlation between the anomalous events detected in the self-potential time series and the local seismic events jointly measured by means of a new multiparametric station (Balsaco et al., 2000) installed at the Geophysical Laboratory of the Institute of Advanced Methodologies of Environmental Analysis (CNR), that is located close the Tito town (Southern Italy). This station allows us to measure the self-potential across an electrode array by means of a multi-channels continuous monitoring system combining an high sampling rate with a good sensitivity. In this work we present the analysis of data recorded during the last two years (1999-2000). Firstly, we had great attention to identify and remove the time fluctuations connected to climatological cycles, in particular we proposed a quantitative procedure to remove the rainfall influence over the self-potential signals. In a second step, robust statistical methodologies have been applied to search extreme events in self-potential time series (Cuomo et al., 1998), we consider significant anomalous patterns only the events characterised by a very low occurrence probability. Finally, we investigate the possible correlation between the detected anomalies in electrical signals with local seismic activity analysing the implications with the earthquake prediction problem.

Balsaco M, Chianese D, Cuomo V, Di Bello G, Gallipoli MR, Lapenna V & Mucciarelli

PCM2 : TUam09 : G5
Natural Self-Potential Anomalies Jointly Detected with CO_2 Flow Rate Variations in Soos (NW-Bohemia)

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In order to better understand SP signal generation, an array for SP measurements has been set up in the mofettes area of Soos, NW-Bohemia (Czech Republic). The area is affected by relatively strong CO_2 gas emission. During the experimental phase CO_2 flow rate variations as well as meteorological parameter has been measured. A statistical evaluation of the collected data demonstrate that both hystorical series of data are strictly correlated. Laboratory measurements recently carried out show that underground CO_2 flow rate can influence SP data in proximity of the sensors installed in the ground.

PCM2 : TUam11 : G5
Numerical Simulation of Electrokinetic Potential Induced by Subsurface Fluid Flow in Geothermal and Volcanic Areas

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The flow of a fluid through pores and cracks in a rock may transport electric charge along the flow path by the interaction of the moving pore fluid with the electrical double layer at the pore surface. This process is known as electrokinetic coupling. The total current density is composed of a drag current density caused by charges moved by fluid flow and a conduction current density caused by electric conduction.

In order to evaluate the contribution of electrokinetic effects to the generation of self-potentials in geothermal and volcanic areas, numerical simulations were performed. The present numerical approach ("EKP-postprocessor") simulates electric fields caused by subsurface fluid flow by a two-step process (Ishido and Pritchett, 1999). First, it calculates the distributions of drag current etc. from the underground conditions (pressure, temperature, liquid-phase saturation, salinity, flow rate, etc.) computed by thermohydraulic (geothermal reservoir) simulations. Second, it calculates the distribution of electric potential by solving Poisson's equation, the source term of which is the divergence of drag current density, within a 3-D finite-difference grid. In case to calculate the magnetic field distribution, an additional step is required: the Biot-Savart law is applied to the distributions of drag and conduction currents.

In the first step, electrokinetic coupling coefficients are computed by the EKP-postprocessor using formulations based on experimental work reported by Ishido and Mizutani (1981); the zeta-potential and surface conductance calculated for silicate rock/water systems at temperatures between 20 and 200^{o}C agree well with the newly-obtained experimental data. Then, assuming appropriate mixing laws such as capillary model or Archie's law, the postprocessor calculates the distributions of electrokinetic coupling coefficient and electrical conductivity of fluid/rock composite.

The postprocessor was applied to both numerical modeling of natural self-potential (SP) anomalies in geothermal fields and production-induced SP changes. The essential features of the SP anomalies and SP changes which have actually been observed in real geothermal fields are reasonably well reproduced in these calculations for both single-phase (liquid) and two-phase (vapor/liquid) geothermal reservoirs.

We also applied the postprocessor to a simple two-dimensional model of hydrothermal activity in volcanic island Izu-Oshima, Japan. The low potentials in areas of high elevation are reproduced in the model, and are caused by downflow of meteoric waters. The high potential centered at the summit crater is found to be produced by upflows of volcanic gas and vapor which diminish meteoric water downflow near the volcanic conduit.

Ishido T & Mizutani H, *J. Geophys. Res*, **86**, 1763-1775, (1981).
Ishido T & Pritchett JW, *J. Geophys. Res*, **104**, 15247-15259, (1999).

PCM2 : TUam12 : G5
Temporal Variations of Self-Potential (SP) Anomalies at Piton de la Fournaise (Reunion Island)

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Several spontaneous polarisation (SP) surveys have been made during the nineties around the summit craters of Piton de La Fournaise that are the most active part of the volcano, during or between eruptive periods. This study completes the Malengreau et al. (1994) work, for the 1981-1992 period. Piton de la Fournaise is a basaltic shield volcano and one of the most active volcanoes in the world. The historic volcanic activity occur mostly on the central cone, inside the Enclos Fouqué caldera. The eruptions are preferentially concentrated along two weak zones, the southeast and northeast rift zones. These curved structures join together in the summit area and correspond to a radial fracture system. A second system of concentric fissures exists around the summit craters (the Bory crater in the western part and the Dolomieu crater in the eastern part). In our study (1992-1998 period), SP data were collected along the same profile, 3.75 km long around the summit craters, with a step of 25 m. The comparison of these periodic measurements has shown large relative SP variations with time. Those SP variations indicate changes in the hydrothermal system surrounding the magmatic plumbing system under the summit. They may also partly result from external causes, as seasonal and daily thermal effects (Malengreau et al, 1994). SP reiterations reveal the main structural features of the summit area. Indeed, anomalies of different wavelengths (few metres to several hundred of metres) have been found from the scale of individual fissures to the scale of the main structures, as the rift zones. Results of our interpretations may be divided into two main categories, the permanent features and the variable signals that fluctuate with time and that are clearly related to eruptive episodes. Permanent SP anomalies (up to 1000 mV) give two main aspects. (1) the local maxima of SP anomalies are clearly linked to the concentric fracture network, as previously noted by other authors. Internal fluid circulations appear to be influenced by the cone-sheet fracture system. (2) The main anomaly is located beneath the western part of the Dolomieu crater. If it represents the surface expression of the hydrothermal system associated to the shallow magma reservoir, it means that it is not centered on the summit crater system. Other geophysical data, such as sismicity, are in good agreement with this hypothesis. Temporary signals, related to the eruptive activity, show that some fissure systems are preferentially involved to drain the excess of heat of the convective hydrothermal system.

Malengreau B, Lénat JF & Bonneville A, *Bull. Soc. Géol. France*, **165**, 221-232, (1994).

PCM2 : TUam13 : G5
Detection of Magma Movements Based on Transient Streaming Potential

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Volcanic eruptions are generally preceded by magma intrusion. Volcanic forecast is sure to make considerable progress if we have a practical means of detecting magma movement. Electric potential variations have been observed since April 1999 at the Miyake Island, a volcanic island in Japan. The measurement has been conducted by a special long vertical antenna and by a short dipole. There occurred the largest eruption on 18 August in the present activity. At the time and some half a day before the largest eruption anomalous electric field changes were detected on the whole three bands of DC, ULF and ELF/VLF. Before about a day of each stage of the volcanic event, longer period fluctuations of about a few hours are also seen. Those longer signals were generally superimposed by the ULF signals. Higher frequency ULF band variation of the electric field suggests that there are a strong confined water pressure fluctuation in the process of interactions between hydrothermal circulation and the intruded magma through the electro-kinetic effect. The trend-like changes are suggested to reflect quasi-stationary changes of hydrothermal circulation and stream potential coefficient distribution. The transient self-potential measurements underground have been proved to be an efficient window for looking into complex volcanic activity by detecting magma intrusion, and to be useful means for forecasting volcanic eruption.

PCM2 : TUam14 : G5
Electric and Magnetic Fields Generated Through the Electrokinetic Coupling in an Active Volcano

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Transient electric and magnetic field variations correlated with volcanic activity have been observed at the ground surface of active volcanoes. We propose here that this phenomenon is due to a hydroelectric coupling of electrokinetic nature. Indeed, free convection of pore fluids inside a confined porous aquifer or through a network of fractures produces a magnetic field due to the drag of the excess of ions (generally cations) occurring in the vicinity of the pore water/mineral interface in the so-called electrical double (triple) layer at the molecular scale. This drag of an excess of electrical charge by the pore fluid flow generates a convective electrical current density, hence a magnetic field. In this paper, we investigate the intensity of the this phenomenon. Laboratory experiments have been performed to investigate the electrokinetic properties of volcanic altered materials. These experiments combined with the theoretical investigations performed here at various scales allow to compute a magnetic field intensity on the order of 1-10 nT, which is the range of values reported for the so-called volcano-magnetic effect at the ground surface of active volcanoes. Therefore, electrokinetic effects related to free convection of the pore fluid inside confined aquifers located in the flanks of active volcanoes and especially just around the central caldeira could provide a possible explanation for the so-called volcano-magnetic effect.

Tuesday PO Session

PCM2 : TUpo01 : PO
Streaming Potential Collection & Data Processing Techniques

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Recently, there has been a renewed interest in self-potential measurements in both the field and the laboratory. When preparing to make laboratory measurements of streaming potential coupling coefficients it is important to know which measurement technique and data-processing scheme is best suited to a specific application. In recent years, there have been advances in the acquisition and processing of streaming potential data, but there has not been any comprehensive comparison of the different methods.

In this presentation, time varying streaming potential and DC streaming potential data collection and processing techniques are presented and compared. The time varying streaming potential techniques include sinusoidal and transient streaming potentials. The collection techniques include DC streaming potential at various pressures, time varying streaming potentials at varying pressures, streaming potential versus frequency, and transient streaming potentials. The processing techniques for DC streaming potentials include DC filtering. The processing techniques for time varying streaming potentials include RMS, cross correlation, spectral analysis, and the plotting of raw time varying streaming potential versus raw pressure data. The results show that all processing methods achieve the same coupling coefficient within 3%. The analysis also shows that if there is a good signal to noise ratio, all processing methods perform satisfactory. If the signal to noise ratio is poor, then the spectral analysis outperforms the other processing methods. The data collection methods are all adequate but individual applications may make one method superior over another.

PCM2 : TUpo02 : PO
Interpretation of Anomalous Piezoelectric Effects, Obtained in the Experiments on Rock Samples

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There is a large evidence of transient electric polarization occurring in many kinds of rocks, subjected to abrupt change of mechanical load (anomalous piezoelectricity). In first approximation, the generation of electrical signal is proportional to first time-derivative of the mechanical load. The details of electrical response to increase and decrease of load may differ and generally the extent of polarization, measured as the signal voltage, is different in various rocks and differs even between individual samples of the same material. The shape of the signal curve undergoes considerable variation, too. The signal simulation should involve summation of several components (which have different time properties), if outcoming plot is to be similar to the experimental one. Therefore, both the generation and relaxation of the signal are probably ruled by complex mechanisms.

PCM2 : TUpo03 : PO
The Role of Seismotectonic Setting in the Study of Anomalous Patterns in Electrical Earthquake Precursors Measured in Seismic Active Areas: Observational Evidences in Southern Italy and Crete Island (Greece)

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In this work we analyse anomalous patterns in self-potential time series instrumentally recorded in seismic active areas in the Mediterranean region: Southern Italy (Giuliano station) and Crete island (Heraklion station). The geoelectrical data cover the period from January 1996 to December 1998, with data missing less than 10%. In a first step, we investigated the time dynamics of geoelectrical time series and applied robust statistical methodologies to pick out anomalous patterns from background fluctuations (Colangelo et al., 2000; Cuomo et al., 2000). In a second step, we approached the very controversial and fascinating problem of the possible correlation between electrical anomalies and locals seismic activities. To this aim, the comparison between the temporal map of self-potential anomalies and the sequences of earthquakes, observed by Nationals Seismometric Networks in the investigated areas, is deeply analysed and discussed. In particular, we focused our attention to the criteria adopted to select the earthquakes that, in principle, could be responsible for strain effects in the investigated areas. Many authors approached this problem using the Dobrovolsky rule (r=100.43M), where r is the radius of the area in which the effects of the earthquake are in principle detectable and M is the magnitude (Dobrovolsky et al., 1989). In this work we enhance the weak points of this approach, taking into account the geological and seismological settings of the investigated areas. In this way, we better described the appearance of anomalous sequences in electrical signals that seem to be correlate with seismic events associated to the Giuliano strike-slip fault (Ekstrom, 1994) and the Heraklion normal fault. In conclusion, our findings suggest us to better consider the role of geological and seismological setting in the study of temporal and spatial patterns in electrical signals detected in seismic active areas.

Ekstrom G, *Annali di Geofisica*, **37**, 1591-1599 (1994).
Colangelo G, Lapenna V, Vallianatos F & Nomikos C *Annali di Geofisica*, **43**, 391-408, (2000).
Cuomo V, Di Bello G, Lapenna V, Piscitelli S, Telesca L, Macchiato M & Serio C, *Natural Hazard*, **21**, 247-261, (2000).
Dobrovolsky IP, Gersherzon NI & Gokhberg MB, *Physics of the Earth and Planetary Interiors*, **57**, 144-156, (1989).

PCM2 : TUpo04 : PO
A Physical Model of ULF Electromagnetic Earthquake Precursors due to a SOC System

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We present a model of electrification involving the motion of charged edge dislocation arrays during microfracturing, and demonstrate the relationship between current density and strain rate. We demonstrate the feasibility of intermediate - long-distance signals by simulating the propagation of the ULF electromagnetic fields generated by a fractal set of emitters in a simulated fault zone. The motion of dislocations parallel to the applied shear stress allows for the generation of a dipole electric field, parallel to the slip vector of the moving dislocations, hence quasi-parallel to the slip vector of shear cracks and by the self-similarity of faulting processes, to the slip vector of the upcoming earthquake. In a next step, we simulate the evolution of crack populations using a simple generic feedback system and an ad hoc kinetic theory based on Maxwell-Boltzman statistics. Our results indicate that crack propagation evolves according to a limited class of time functions with characteristic bay and bell-like shapes. This allows for the generation of a limited class of ULF seismic precursors with analogous shape and duration varying from a few tens of seconds to a few hours. We investigate the effects of the self-similar geometry of brittle failure on the expected signal. These assume the form of a self-similar scaling law which is constructed from first principles and relates the observed amplitude of the electric (E) or magnetic (B) field, through the size of the electrified rock volume to the magnitude of the earthquake with an expression of the form logF=CsF+bM, b0.35, F=E or B, and CsF dependent on source properties and source-receiver path. The slope is universal under the conditions for which it has been derived, but the intercept source-and-observer specific. The magnetic field turns out to be mainly vertical and observable only if the seismogenic process generates a source with polarisation rate perpendicular to the vertical plane through the source and the receiver. Assuming that the evolution of the polarisation process in a self-similar ensemble of sources exhibits a spectrum of relaxation times expressed by an Arrhenius law with distributed energies, we show that the macroscopic ULF magnetic field resulting from the superposition of such an ensemble of sources has power spectrum distributed according to an inverse power-law and we discuss the conditions under which, such a power spectrum evolves towards an 1/f behaviour. A comparison of theoretical results with field observations from Greece and Japan is finally given.

PCM2 : TUpo05 : PO
Identification of Sources of Self-Potential with the Continuous Wavelet Transform

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Self-potential data carry unique information concerning fluid flows underground, geothermal and electro-chemical phenomena. Despite this kind of data is acquired since several decades, only a few studies concern their inversion, and most studies use a forward approach and numerical modeling. In the same spirit, recent studies concerning hydrological applications fit the data through hydrodynamical models which ensure the physical coherence of the current sources responsible for the observed self potential. Although very promising, this approach remains cumbersome and it might be useful to dispose of a less-specialized (i.e. not assuming an hydrological origin for the sources) method to perform a rapid analysis of the data in order to obtain general informations (e.g. number of sources, depth range, multipolar nature, etc.) concerning the sources. In recent studies, we presented a theoretical framework, based on the continuous wavelet transform, which allows a rapid analysis of potential field data (Moreau et al., 1997, 1999). When adapted to potential field theory, the wavelet analysis of potential data (e.g. gravity, magnetic, etc.) enables to identify, localize and characterize the main singular (i.e. mono-pole, dipole, etc.) sources causing the observed anomalies. Indeed the continuation property of the wavelet transform has been generalized, and a particular class of analysing wavelets has been found such that the wavelet transform of a potential field satisfying the Poisson equation may be used to detect, localize and characterize homogeneous singularities eventually present in the causative source distribution. This method is applied to a self-potential profile crossing a shallow fault zone. The area is a mineralized diorite dike which has been industrially exploited and extensively studied, thus the geological structure is well-known, with a linear 4 km-long fault. The self-potential datas has been measured perpendicularly the the fault and display a bipolar anomaly in the vicinity of the fault zone. The continuous wavelet transform allows to localize and characterize the main source causing by this anomaly.

Moreau F, Gibert D, Holschneider M, Saracco G, *Inverse Problems*, **13**, 165-178, (1997).
Moreau F, Gibert D, Holschneider M, Saracco G, *J. Geophys. Res*, **104**, 5003-5013, (1999).

PCM2 : TUpo06 : PO
Streaming Potential of a Sand in Partial Saturation

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The partial saturation conditions are expected to enhance the streaming potential and are therefore of great interest for the interpretation of spontaneous potential observations. We built a device wich allows us to quantify the streaming potential at various humidity rates. We use a sand column of one meter height and 8 cm of diameter. Pressure gradient and streaming potential are measured along the fluid flow by 10 pressure sensors and 10 electrodes. The electrodes are thrusted into permanent saturated porous ceramics. So that electrical signals in non-saturated conditions can be properly measured. Different gases as argon, nitrogen, and carbon dioxide are injected into the sand to decrease its water saturation. The fluid is made to flow by the injection of gas. We monitor humidity of the sand with a capacitive sensor.

When sand is saturated with water we measure a coupling coefficient of -1140 mV/MPa with water electrical conductivity of 2.10^{-2} S/m, and water pH=7.3. The coupling coefficient normalized by the coupling coefficient of the totally saturated state is compared with theoretical forcast for various water saturations. Model of Revil et al. (1999) forsees that the increase of the coupling coefficient is favoured by large electrical conductivities of the pore fluid respect to the electrical surface conductivity of the medium, and by a small formation factor. The formation factor of our sand is around 20 and the ratio ξ of the electrical surface conductivity by the electrical conductivity of the pore fluid is around 10^{-2}. Our measurements agree with the model, although no great enhancement of the streaming potential is observed. The normalized coupling coefficient reaches the maximum value of around 1.5 for a water saturation ranges from 40 to 60%. Model forsees that the coupling coefficient is multiplied by around 30 when $\xi=10^{-4}$ in non-saturated conditions; however the coupling coefficient in saturated conditions is small when $\xi=10^{-4}$. For example even if the electrical surface is as low as 10^{-4} S/m and ζ-potential is -30 mV, the coupling coefficient is expected to be around -20 mV/MPa. So that the increase connected to partial saturation would lead to a coupling coefficient of -600 mV/MPa, which is still as small signal despite the enhancement of a factor 30. Therefore in natural conditions (meaning realistic value of ξ) the increase of streaming potential associated to partial saturation conditions will not be so crucial for the interpretation of the observations.

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PCM2 : TUpo07 : PO
Self-Potential (SP) Method Applied to Hydrogeological Prospecting in the Context of a Young Volcanic Area (Chaine des Puys, France)

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In the last years self-potential (SP) anomalies received a growing attention among applied geophysical methods. In particular, SP method appears to be a very sensitive method in the field to map subsurface fluid flows. SP measurements have been applied to a specific hydrogeological context, on a young volcanic area in the French Massif Central, the Chaine des Puys. Jackson and Kauahikaua (1987) showed that, in volcanic area, there is a linear correlation between negative SP anomalies and the thickness of the unsaturated zone, under two conditions (Aubert et al., 1996): (1) high ration between the resistivity of the unsaturated zone and the resistivities of the substratum and the water-saturated zone, and (2) homogeneity of the unsaturated zone. Assuming that these two conditions are satisfied in our case study, we used the concept of a geophysical surface, called the SPS surface. This equipotential surface represents the interface between the unsaturated zone and the lower medium (impermeable substratum and saturated zone). The equation of the SPS surface depends on several parameters, that are very well constrained in our case study by borehole measurements. The Chaine des Puys is a young volcanic area (less than 100.000 years), formed by about one hundred isolated eruptive centres and their associated lava flows or pyroclastic deposits. It lies above a granitic hercynian substratum, that forms a topographic high surrounded by large depressions, several hundred meters below. The topography is characterised by a huge plateau that culminates at 1030 m. It is cutted by deep valleys on its flanks. It implies that the lava-flows have filled the paleo-valleys and have largely covered the summit plateau. Groundwater flow paths are preferentially controlled by the paleo-topography of the substratum. It is the reason why the SP method represents, in this case, a very valuable application for the hydrogeological study of the sector The investigated area has been extensively covered by SP prospecting during the last fifteen years. Combination of geophysical data (SP, electric soundings) and boreholes data within a Geographic Information System (GIS) let us to calculate the SPS surface under the volcanic area. The results presented here give for the first time a global view of the non permeable substratum under the volcanic pile and of the inferred hydrologic network.

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PCM2 : TUpo08 : PO
Relationships between Self-Potential Anomalies and CO_2 Degassing on an Active Volcano: Example of Stromboli (Aeolian Islands, Italy)

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The study of fluids circulation of the Stromboli island is addressed using a dense coverage of self-potential (SP) and soil CO_2 data. SP values and CO_2 concentration were measured simultaneously every 20 m along 6 radial profiles extending from the summit to the sea. SP and CO_2 concentration maps show that a marked difference exists between the northern flank and the other flanks of the island. The northern flank exhibits (1) a typical negative SP/altitude gradient not observed on the other flanks, and (2) higher levels of CO_2. The general SP pattern suggests that the northern flank is composed of porous layers through which vadose water flows down to a basal water table, in contrast with the other flanks where impermeable layers impede the vertical flow of vadose water. In the Sciara del Fuoco and Rina Grande-Le Schicciole landslide complexes, shallow gliding planes may constitute such impermeable layers. This general model of the flanks also explains the main CO_2 patterns: concentration of CO_2 at the surface is high on the porous north flank and lower on the other flanks where impermeable layers can block the upward CO_2 flux. In the active upper part of the island, SP and CO_2 profiles allow us to outline a hydrothermal system bounded by short-wavelength negative SP anomalies and high peaks of CO_2. These boundaries coincide with faults limiting ancient collapses of calderas, craters and flank landslides. The association between SP lows and CO_2 peaks above these discontinuities can be explained if the faults zones have a high permeability, enabling gravitational descent of liquid fluids and gas fluids rise. The inner zone of the hydrothermal system is characterised by positive SP anomalies, indicating upward movements of fluids, and by very low values of CO_2 emanation. This pattern suggests that the hydrothermal zone becomes self-sealed at depth, thus creating a barrier to the CO_2 flux. In this hypothesis, the observed hydrothermal system is a shallow one and involves mostly convection of infiltrated meteoric water above the sealed zone. Our experience demonstrates that the combined analysis of SP anomalies and of CO_2 soil concentration is a powerful tool for studying a complex fluid system. A similar approach would probably be efficient on many volcanic sites.

PCM2 : TUpo09 : PO
First Results of Self-Potential Method Application at Archaeological Sites in Israel

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The territory of Israel, in spite of comparatively small dimensions, contains many thousands of archaeological sites of different age and origin. Geophysical investigations at archaeological sites and in their vicinity include, as a rule, sole or integrated applying detailed magnetic investigations and ground penetration radar measurements. However, complicated structure of many archaeological sites and the ambiguity of interpretation of geophysical observations call for an integration of different geophysical methods and their integration with geochemical and geological ones. Self-potential (SP) method was earlier used in Israel for solving some engineering-geological problems, but its application was very limited - it was caused by an assumption that physical-environmental conditions in country are not favourable for this method performing. During the summer of 2000 experimental SP investigations have been carried out at several Israeli archaeological sites. These measurements were integrated with the detailed magnetic investigations and partially with geochemical analyses. SP measurements were performed using microVoltmeter with high input impedance and special non-polarized electrodes (Cu in $CuSo_4$ solution). The potential-array scheme (with a base point electrode) was applied; the depth of electrodes grounding was about of 25-50 cm. The SP measurements were performed at: site of Banias (the Golan Heights) - for localization of the ancient Roman aqueduct remains (total number of observation points No = 150, observation grid G = 1 x 1.5 m), site of Sha'ar-Ha-Golan (the Golan Heights) - for tracing the Prehistoric construction remains (No = 500, G = 1 x 1.2 m), site of Halutza (20 km SW of Be'er-Sheva) - for contouring the ancient walls of the Early Bronze period (No = 220, G = 1 x 1 m) and site of Evrona (5 km north of Eilat) - for recognition of construction of the ancient well and its modern water level (No = 180, G = 1 x 1 m). Revealed essential similarities between the magnetic and self-potential fields make it possible to apply to SP method: (a) correlation procedure for eliminating the terrain relief influence and (b) improved modifications of the inverse problem solution (characteristic points, tangents and square procedures) developed for magnetic prospecting (Khesin, Alexeyev and Eppelbaum, 1996). These procedures are applicable to conditions of inclined relief, arbitrary magnetization (polarization), and an unknown level of the normal field. Results of the quantitative interpretation of SP anomalies performed using above-mentioned procedures are in line with the available archaeological data and contain also new useful information about the buried ancient remains. Thus, we can conclude that the prompt, economic and non-invasive SP method may be effectively used for localization of archaeological remains in Israel (natural limitations of this method performing are the hydrogeological environments and grounding conditions). Support for this study was provided by the Tel Aviv University foundation, grant No. 03430261.

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