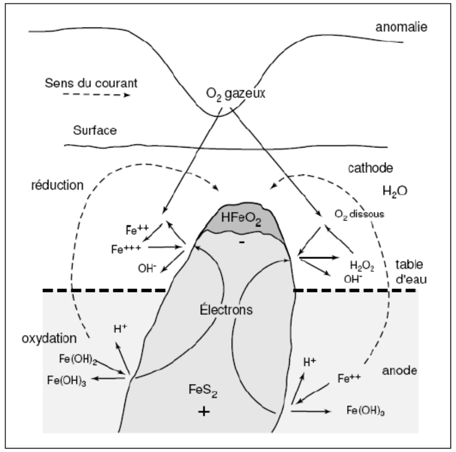
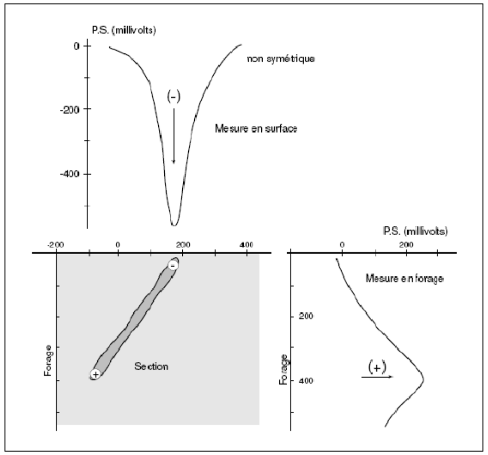
Method principle

- Spontaneous polarization is a passive electrical method which consists in measuring the distribution of the natural electrical potential of the ground, without power injection. The recording of the potential difference between different points of the ground gives a spontaneous potential curve. These measurements can be carried out on the surface or in a drillhole, on an ad hoc basis (production of maps and profiles) or continuously (a few hours to several years). The measurement unit is the millivolt “mV”;
- SP is related to complex polarization phenomena that occur naturally in the soil. They can thus be attached to hydraulic gradients (electrokinetic effect with electrofiltration phenomena) of temperatures (thermoelectric effect) and chemicals (electrochemical effects with electrodiffusion phenomena);
- Electrokinetic phenomena are related to water movement (groundwater flow, variations in piezometric levels, etc.) whereas electrochemical phenomena occur when two formations in contact behave as solutions at different concentrations or when a conductive mass is below the static level. These phenomena, which sometimes give rise to currents inducing differences of potential of several hundred mV, are to be distinguished from terrestrial currents causing disturbances of the measurement. We can also consider other forces generating PS and associated with the presence of organic contaminant (electroredox phenomenon) as well as PS phenomena related to temperature gradients (thermoelectric effect) but these potentials are much lower.



PS in pyrite according to Sato and Mooney (Chouteau)

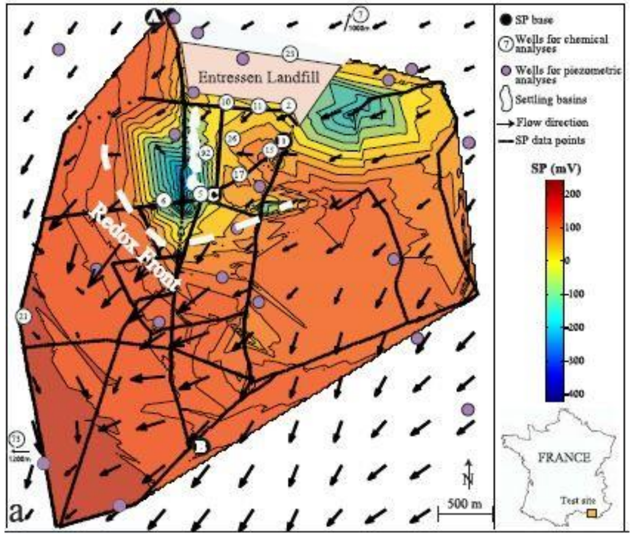


The phenomenon of PS on the surface and in depth profondeur (Chouteau)

Applications

The main applications of SP measurement are:

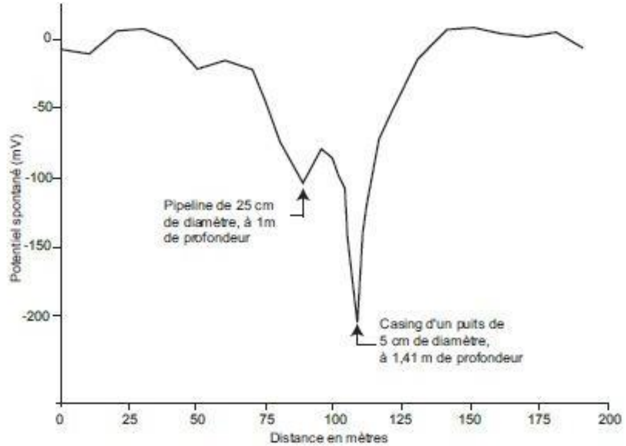
- The location of the extension limits of permeable zones or layers;
- The search for mineral deposits;
- Study of hydrothermal circulation in volcanic buildings for geothermal and volcanology and, more generally, study of underground fluid circulation;
- Looking for a leak in a dam, dyke, or pipe;
- The delimitation of pollution plumes;
- Estimating water resistivity;
- A qualitative indication of the clay content of the formations.



Map obtained from PS measurements (Naudet)

Limitations / Constraints / Prohibitions

- The multiplicity of sources at the origin of PS signals and the low intensity of measured signals are the main limitations of this yet simple method to implement;
- Temporal variations of the earth's magnetic field can disturb the PS measurements by inducing electrical currents in the ground;
- In a metallic body, a temperature variation will generate an electric field at its terminals. If two electrodes are at different temperatures, this may generate a parasitic electric field which will induce sources of additional noise during the PS measurement. To avoid this noise, care must be taken to ensure that all electrodes are exposed to similar temperatures, especially during monitoring on several electrodes. It is therefore necessary to ensure homogeneity of the temperatures between the electrodes or to correct the measurements of the effect associated with the temperature if necessary;
- A bioelectric effect can be observed between wooded and non-wooded areas, where the roots of trees drain groundwater and thus generate electrical potential that can be confused with that of the phenomenon studied. These potentials can reach a few tens of millivolts at the level of the roots. To avoid this noise, measurements close to roots or plants should not be made and the upper part of the grassy soil removed by digging a hole of about ten centimeters in which the measuring electrodes are placed;
- PS prospecting near buried pipelines, railways or in populated areas is difficult. As a matter of fact, the electric currents circulating in the network induce important electric currents in the ground. Similarly, in the case of heavy rains followed by episodes of high evaporation, the measurements may provide results with a very variable quality.



Influence of metal pipes on the PS signal (Naudet)

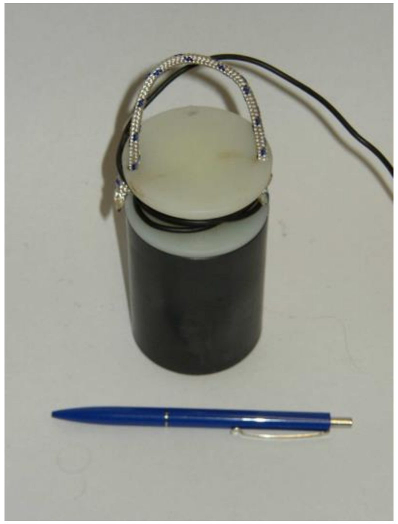
Means necessary for the acquisition

- <u>Equipments</u> :

Measuring spontaneous polarization requires at least a pair of unpolarizable electrodes and a voltmeter or a resistivimeter (Terrameter LS2, Iris Syscal or Lippmann 4Point Light):

  - The voltmeter must have an input impedance strong enough (greater than 200MOhm) so that the current coming from the earth during the measurement is negligible;
  - The electrodes used must be unpolarizable to avoid the accumulation of charges on the surface of the metal electrode (parasitic potentials which may have an order of magnitude similar to the values to be measured). They must also have a fairly low temperature coefficient (200 uV/°C) to maintain certain stability during temperature variations. It will consist of a metal immersed in a solution saturated with its own salt (Cu in SO4Cu, Zn in SO4Zn), contained in a porous pot that allows the solution to diffuse slowly and ensure contact with the ground.

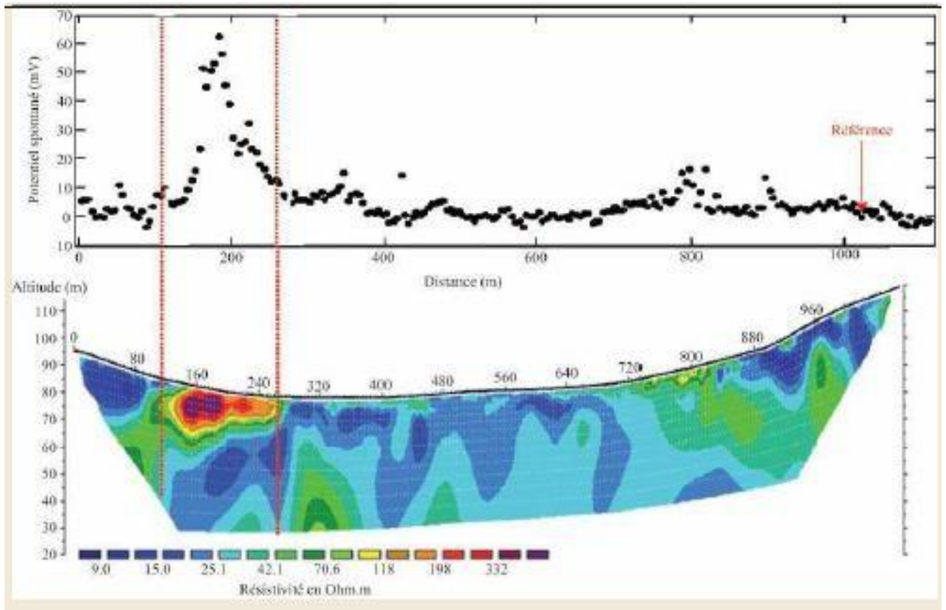
- <u>Positioning</u>: equipment for tracking profiles, markers, tape measure, GPS.
- <u>Vehicles</u>: 1 light transport vehicle (van, station wagon), preferably all-terrain/all-road, allowing the transport of personnel and equipment. Measurements are then made on foot.
- <u>Personnel and skills</u>: 1 operator qualified for implementation, 1 geophysicist qualified for interpretation (including a Head of Mission), ~1 unqualified helper.



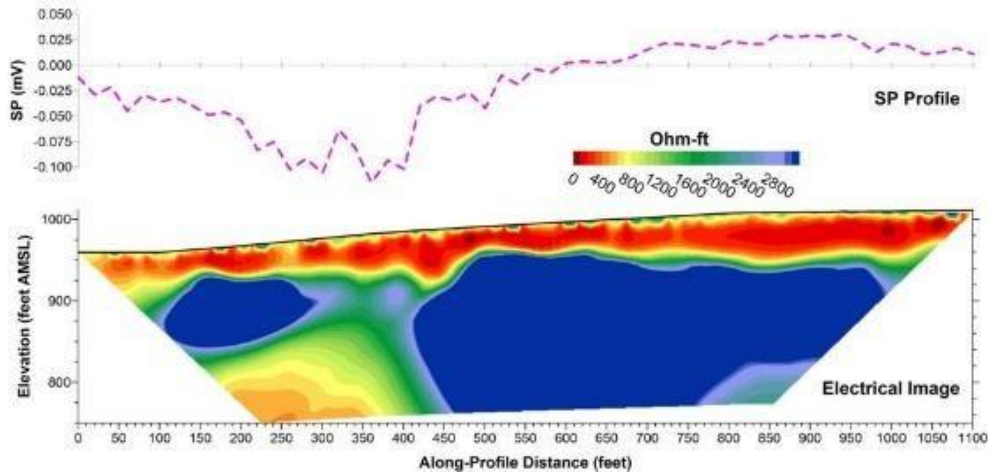
Example of equipment used to measure PS

Field Implementation

- Before the mission starts, the difference in potential within the electrode pairs should be noted once they are placed in a bin filled with unsaturated salt water. The difference must be less than 2 mV and the pairs thus formed must be carefully labelled to keep them together throughout the study. If this value is too high, you can try to improve it by replacing one of the electrodes.
- Before the start of the mission and at the end of each acquisition day, the electrode pairs are connected to each other by the same electrical wire and then placed in a container filled with unsaturated salt water to avoid reducing the porosity of the ceramics that make contact with the electrode base.
- The measurement profiles should be, as far as possible, perpendicular to the direction of the anomalies sought, with a distance between measurement points from 3 to 30 m.
- Two types of devices can be used, the “Fixed-Based” technique and the “Gradient” technique:
    - « Fixed-Based »: A first fixed electrode, located in a quiet place and representative of the study, will serve as the base. A second electrode is moved along the profile to measure the electrical potential distribution. The measurements being made with the same base, the potential reading is direct in regards to a fixed point and this makes the errors related to the potential difference between electrodes negligible. The disadvantage of this technique is the length of the profiles, limited by the length of the cables. This technique is therefore most often used for relatively small areas (< 1 km²);
    - « Gradient »: The 2 electrodes are simultaneously moved along the profile, maintaining a constant interval between them. This amounts to measuring the difference in potential along a dipole consisting of two fixed electrodes. This technique is used to map large areas (> 1 km²). By adding the successive measured values, we obtain a potential profile comparable to that obtained with the first device, but nevertheless running the risk of also adding zero errors as the progress is made.
- For both devices, measurements must be made following a program that will include a regular reoccupation of a reference station to better correct drift and reduce errors by zero.
- When measuring on each new station, there is often a fluctuation in the potential difference, forcing the operator to record an average value. The measurement is considered stable if a difference of less than 0.1 mV is observed between two consecutive values.
- When measurements become unstable, the operator can shorten the profile length by changing the base.
- PS monitoring of water infiltration can also be done by placing electrodes at different depths.
- In addition, to avoid inducing additional drift during each acquisition program, we must try to keep a fairly similar temperature between the reference electrode and the mobile electrode, avoiding, for example, heating up the mobile electrode by holding it too long in its hand and avoiding touching the entire device during the measure.



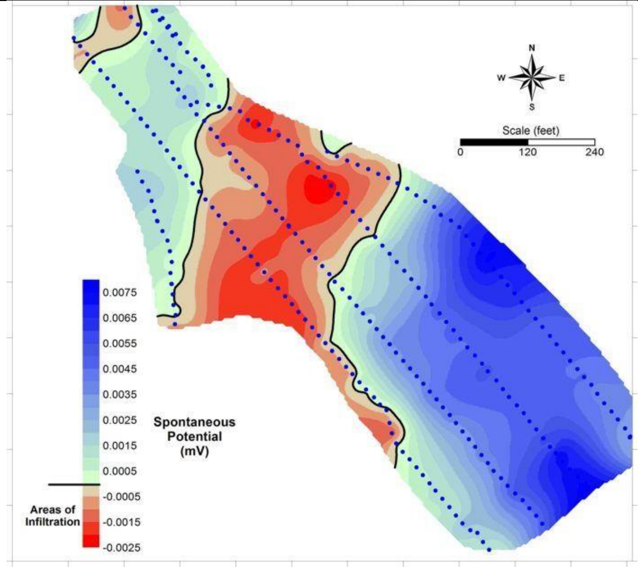
PS and ERT measurements performed on the Roujan–Hérault watershed (Fugro)



PS and ERT Profiles (Enviroscan)

Data processing and interpretation

- This method makes it possible to obtain profiles and maps of equipotentials that lead to highlight positive and negative anomalies, potentially associated with water transfers or mineralization. The amplitude of electrical signals measured at the surface of the ground varies from a few mV to a few V in absolute value.
- Although the origin of the PS signals results from numerous and various mechanisms, it is possible, when the PS measurements are associated with other electrical measurements, to carry out inversions of these data especially in the case of PS sources of electrokinetic origin.

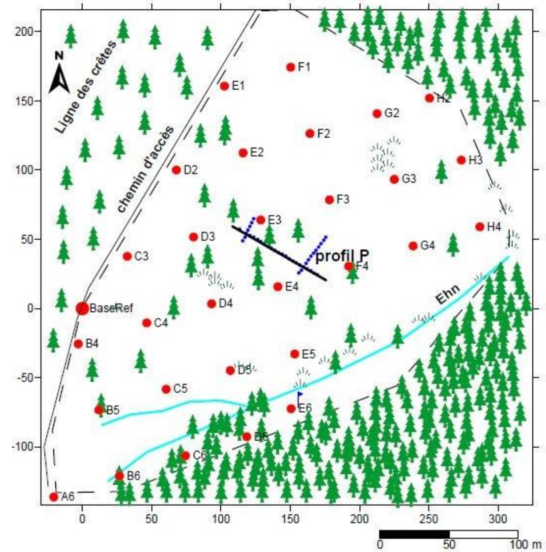


Equipotential PS mapping (Enviroscan)

Results and Deliverables

The study report will include:

- Detailed geological context to properly interpret geophysical survey results.
- On-site intervention conditions (electromagnetic disturbances, clearing, etc.).
- A geo-referenced location map.
- Raw results.
- Results interpreted with resulting maps or profiles and comments on highlighting new structures.
- Interpretive map of all geophysical survey results and proposed location of reconnaissance boreholes for instance.
- Location of points in X, Y coordinates.



Measures position plan (P. Sailhac)

Contractor/service provider dialogue

- At the client's responsibility
  - detailed specifications with clear objectives
  - plans and documents relating to the work, and the area to be explored
  - information about site access and security, and administrative permissions
  - documents relating to any previous investigations
- At the responsibility of the service provider
  - explicit proposal: justification of the proposed method, adaptation to the objective, description of benefits and limitations, influencing and/or uncontrollable factors, accuracy of measurements and realistic final results.
  - professional quality study report: Review of objectives, applied methodologies, discussion of results, conclusions and practical recommendations.

For further information

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- **1974,** Elford W.M, Geldart L.P., Sheriff R.E., Keys D.A., Prospection géophysique, tome 2, Polarisation spontanée
- **2003**, Milsom.J., Field Geophysics, Third Edition
- **2004,** Maineult A, Application de la méthode du potentiel spontané à l'hydrogéologie : expérimentation sur modèle réduit d'aquifère
- **2004**, Naudet F., Les méthodes de résistivité électrique et de potentiel spontané appliquées aux sites contaminés
- **2005**, Chouteau M & Giroux B., Méthodes électriques
- **2007,** Ogilvy & al (1979) *in* Pascal Sailhac
- **2009,** Avancées Thème Détection – Géophysique, Fugro
- **2012,** Genelle F.**,** Les méthodes géophysiques pour la caractérisation des couvertures d'installation de stockage de déchet

Links

- www.georeva.eu
- http://www.iris-instruments.com/
- http://www.sdec-france.com (électrodes impolarisables)
- www.nonpolarizingelectrode.com (électrodes impolarisables)