A New Rig for Measuring Electrical Properties of Fluid Saturated Crustal Rocks: Impedance Spectroscopy, AC Voltammetry & Electro-Kinetic Behaviour

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INTRODUCTION

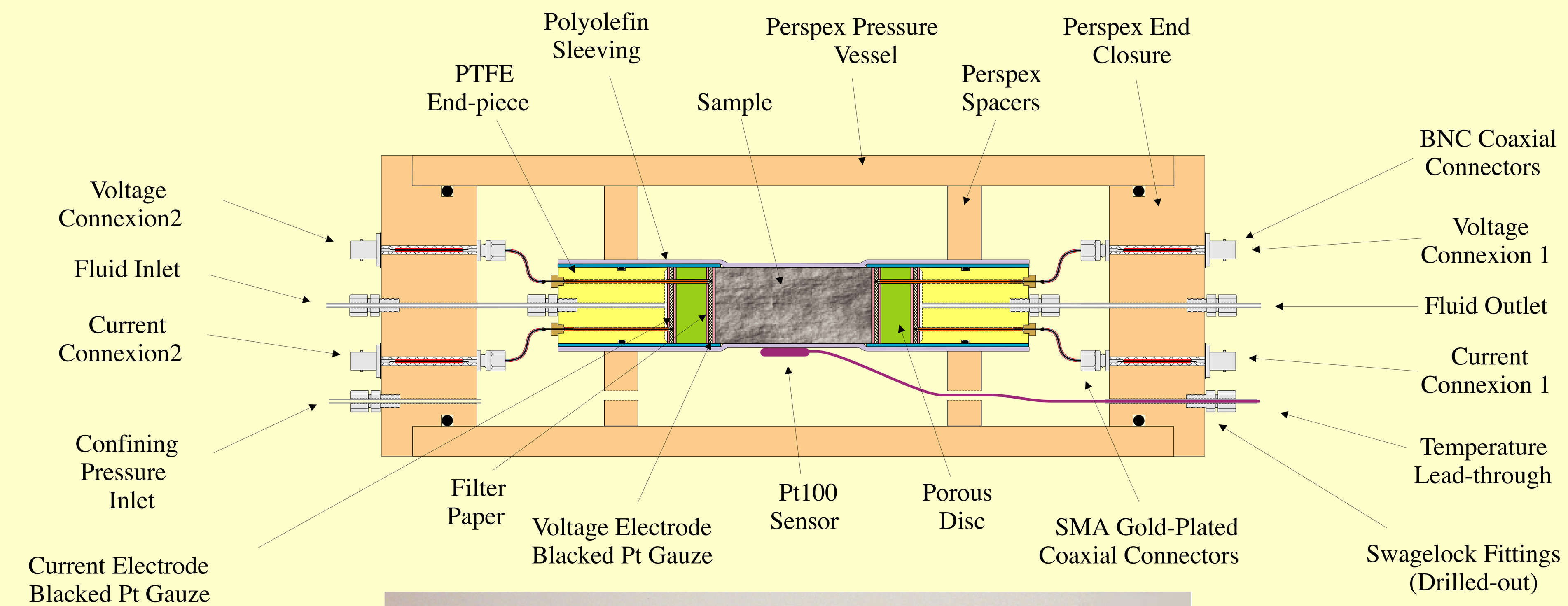
It is known that the bulk and surface properties of rocks saturated with saline pore fluids are extremely sensitive to porosity and the micro-structural distribution of that porosity.

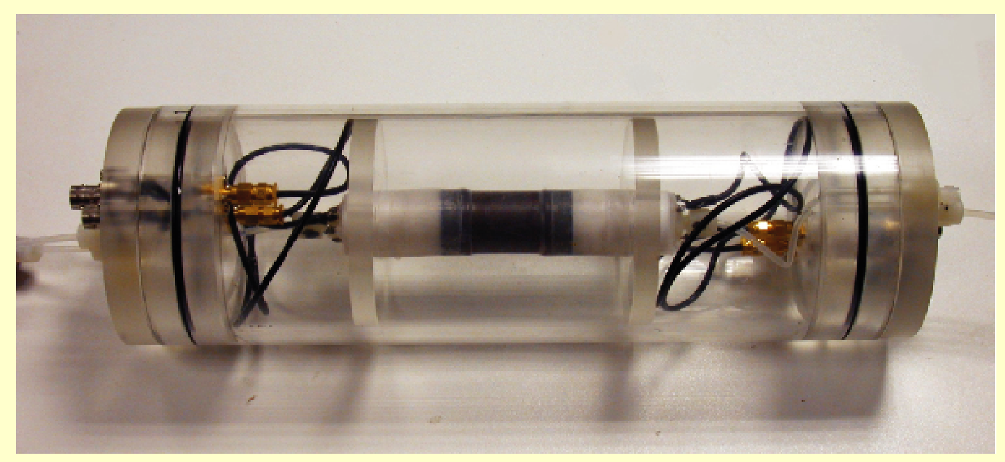
Measurements of the complex electrical properties of rocks as a function of frequency are attibutable directly to the micro-structure of the porosity distribution. However, the detailed theory behind the link is currently still unknown. Recently the theoretical studies (Revil & Glover, 1997; Revil *et al.*, 1998; 1999) have provided the basic theory for the bulk & surface conduction mechanism in a non-frequency dependent form. Generalisation of this theory to take account of frequency dependence is difficult without access to high quality measurements of the complex electrical properties of saturated crustal rocks.

Furthermore, the electrical properties of rocks are fundamentally linked with their hydraulic properties, i.e. there is a relationship between the permeability of a rock and its conductivity. Such a relationship is called an electro-kinetic link, and ensures that fluid flows in a rock when an electric potential is applied OR an electrical current flows when a fluid pressure gradient is applied. The link occurs through the electrical double/triple layer that is developed at the matrix/fluid interface, the same region that gives rise to surface conduction. The electro-kinetic link is implicit in the theory of Revil & Glover, and hence would also be in any frequency-dependent generalisation of it. Again, there is a need for more experimental data to develop the theory, but also to apply our growing need to understand the electrical pre-cursor signals at the sites of earthquakes and volcanoes that may be due to fluid flow (Revil *et al.*, in press).

There are only a few laboratories that are well equipped to carry out high quality impedance spectroscopy, AC voltammetry and electro-kinetic studies on saturated rocks (e.g. Jouniaux *et al.*, 2000; Revil *et al.*, in press). The aim of the developments decribed in this poster is to provide such a facility at the Laboratoire de Tectonophysique, Université Montpellier II.

MEASUREMENT CELL





MEASUREMENT CELL DESCRIPTION

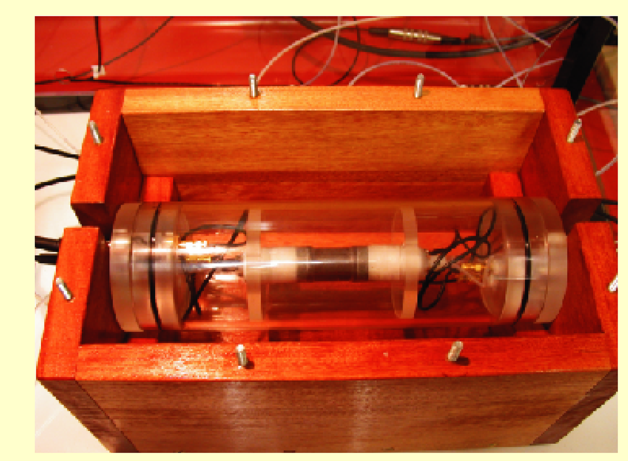
The cell is constructed entirely from non-conducting materials, and is capable of measuring the electrical and electro-kinetic properties of rocks to a high degree of precision using either a 2 or 4 electrode system.

The cell consists of (i) two end-piece assemblies, which are placed at each end of the sample, and which support a choice of two or four electrodes, (ii) a sample sleeve, (iii) a pressure vessel, and (iv) a supporting cage.

Each flat end of the cylindrical sample is in direct contact with an end-piece assembly, which are available in two core plug diameters (2.54 mm & 3.81mm). They consist of a PTFE cylinder housing a drilled-out1/8" swagelock-1/4" tapered NPT polymer fitting with a hole to enable fluids to pass through the sample. The other end is machined with radial grooves to facilitate the flow of fluids.

The PTFE also houses connections for two miniature 50 Ω coaxial leads. Insulated electrical leads pass through the PTFE cylinder and terminate at each of the electrode assemblies, which consist of a filter paper-electrode-filter paper sandwich. For a four electrode arrangement, the two electrode assemblies are separated by a disc of porous ceramic 5 mm thick.

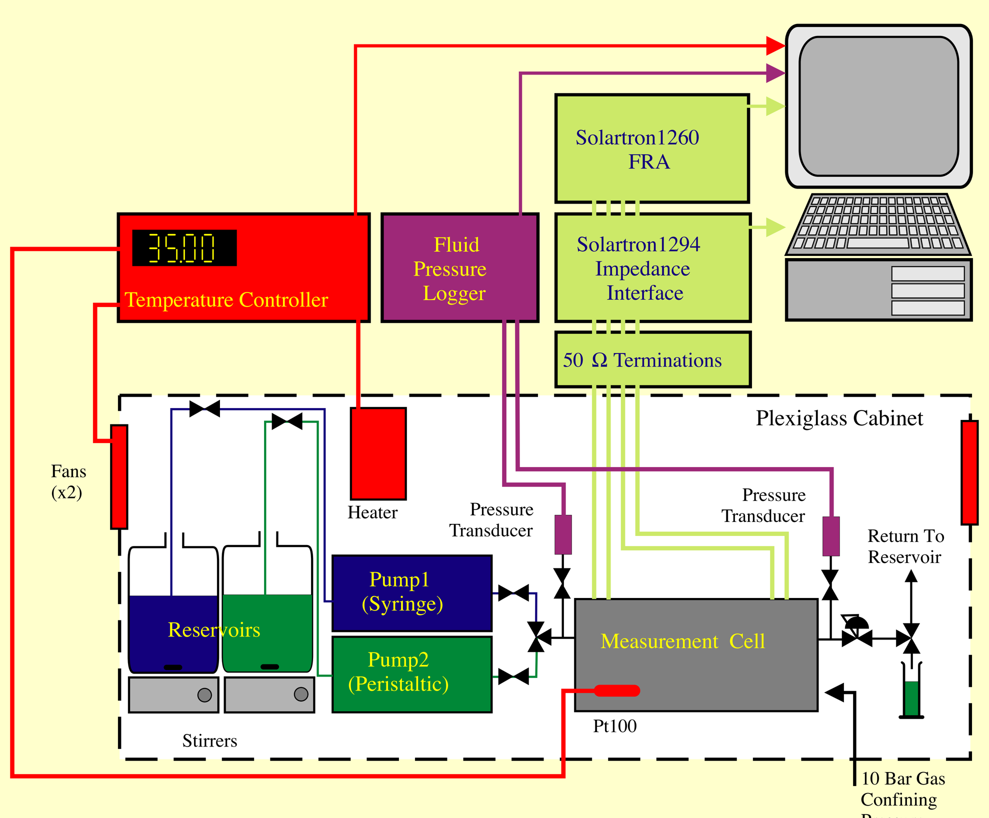
The electrodes themselves are discs of platinum gauze (99.995 % purity, 52 mesh, 0.1 mm wire thickness from Johnson Matthey) cut from a larger sheet and stabilised by spot-welding. Each platinum disc was coated with a very high surface area layer of amorphous black platinum by electro-deposition from Hydrogen Hexachloroplatinate solution at approximately100mA/cm^3 DC.



The sample and end-pieces are sleeved in transparent polyethylene heat shrinkable sleeving.

A strong, electrically insulating and water repellant supporting cage made from varnished recycled mahogany holds the endcaps of the pressure vessel securely removing the need for large screw-threads in the polymer.

NEW EXPERIMENTAL APPARATUS

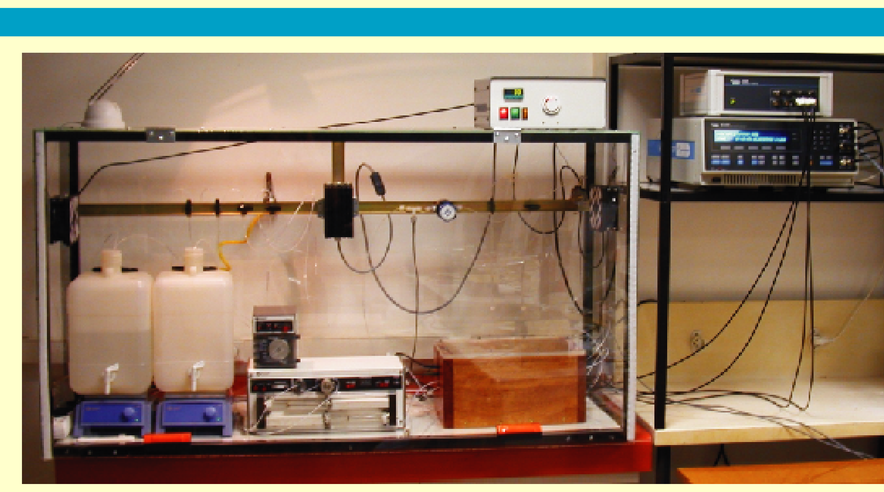


The entire fluid flow system is housed in a temperature controlled enclosure whose temperature is stabilised by a system of fans and heaters controlled by a specially constructed control box which houses a PID controller, a fan controller and associated electronics.

Electrical measurements are made for both real and imaginary parts of the signal from 10 μHz to 32 MHz using a Solartron 1260 Frequency Response Analyser and a Solartron 1294 Impedance Interface with the required terminations.

Fluid pressure measurements are made with two matched pressure transducers, which are logged every second by a dedicated logger connected to a PC.

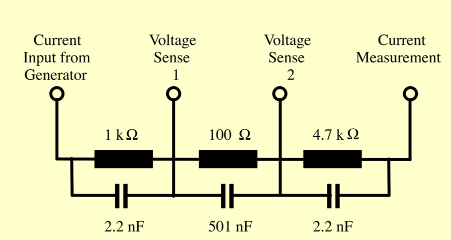
PHOTOGRAPH OF THE RIG

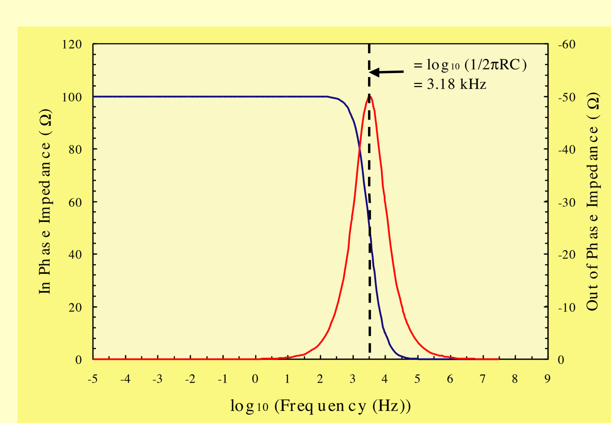


The experimental rig is attached to a logging PC (not shown in the photo above).

DUMMY TEST MEASUREMENTS

The electrical measurement arrangement has been tested with a range of dummy cells such as that shown below from 10 μHz to 32 MHz to ensure that the measuring devices are operating correctly, and to ensure that electrical noise from the fans and heater elements are negligible.



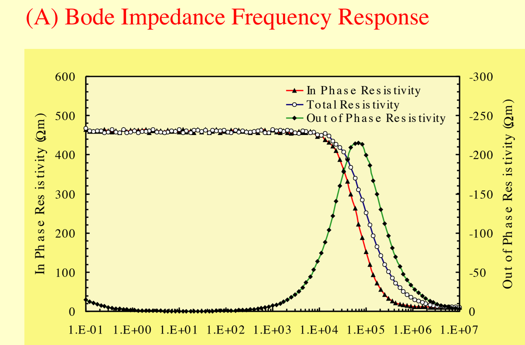


The results of these tests (example given to the right) shows that high quality noise-free measurements can be made.

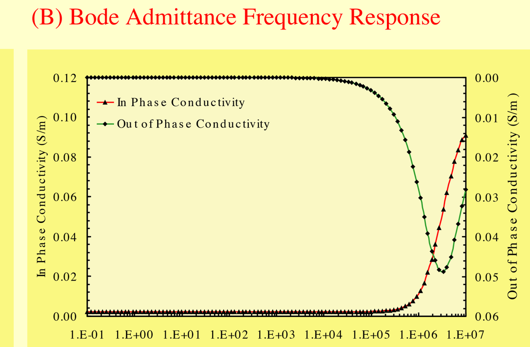
INITIAL ROCK MEASUREMENTS

Initial tests were carried out on a well indurated sample of feldspathic sandstone with a porosity of 9% and a permeability of 5.7 mD that was saturated with 0.001M NaCl solution.

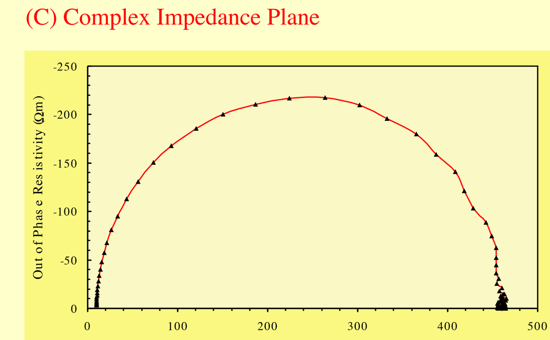
(A) Bode Impedance Frequency Response



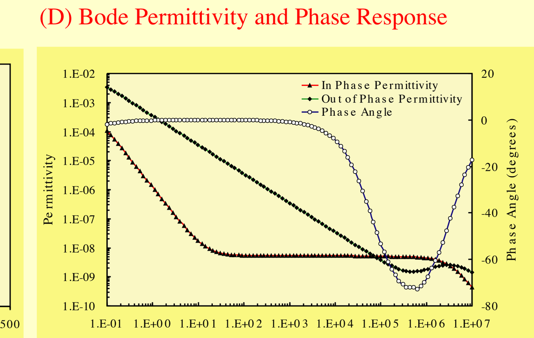
(B) Bode Admittance Frequency Response



(C) Complex Impedance Plane



(D) Bode Permittivity and Phase Response



The data shows a distributed dispersion curve, centred at 69 kHz and containing dispersion mechanisms covering the range 45 kHz to 106 kHz. There is negligible electrode polarisation that is confined to frequencies below 1 Hz, exemplified by the values of the out of phase resistivity which are -14.452, -1.458 and -0.230 Ωm at 0.1, 1.0 and 10 Hz, respectively, compared to that at the peak dispersion (about 216 Ωm). Hence the measurement is of good quality. Curve-fitting provides a resistivity of the rock of 460 Ωm(of which 450 Ωm is dispersive), and a mean capacitance of 50 nF.

FURTHER DEVELOPMENTS

The new rig has the capability to make the following MEASUREMENTS and to provide data for APPLICATION to the following scientific problems.

MEASUREMENTS

Complex electrical conductivity/admittance
Complex electrical resistivity/impedance
Complex electrical permittivity

Surface Conduction
Bulk Conduction
Streaming Potential & Zeta Potential
Electro-kinetic coupling coefficients

All at multiple frequencies from 10 μHz to 32 MHz
Fluid saturation from pure water to 2M NaCl equiv. Variable pH.
Temperature 20∞C to 60∞C
Confining Pressure, 1MPa
Fluid Pressure +/-1 kPa

APPLICA TIONS

- Fundamental theory of bulk and surface conduction in saturated porous media.
- The generalisation of this theory to multi-frequency space.
- Improvement of interpretation and analysis of MT data.
- Understanding of electrical precursor signals associated with earthquakes.
- Understanding of varying electrical signals associated with volcanic activity.
- Fluid flow mapping in the crust using remote electrical tomography.
- Improved borehole and remote tools for the oil and water industries.
- Characterisation of sites for nuclear waste storage.

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