Poroelastic waves distortion related to the damage of an unsaturated fractured-porous carbonate rock by high pressure fluid injections.

Benoit Derode[1], Frédéric Cappa[1], Yves Guglielmi[2], Stéphane Gaffet[1-3] and Tony Monfret[1]

[1] Géoazur (UMR6526), UNS-CNRS-IRD-OCA, Sophia-Antipolis, France

[2] GSRC, University of Aix-Marseille 1, Marseille, France

[3] LSBB, UNS/CNRS/OCA, Rustrel, France

Abstract :

Interactions between fluid pressure, deformation and seismic wave propagation were analyzed in-situ in an unsaturated fractured porous carbonate block 3m x 3m x 3m imbedded in a gallery at 250 m depth within the Low Noise Underground Laboratory (LSBB, France). The block was subjected to a series of 3 high pressure pulse injections measured with a fluid fiber optic pressuremeter located in the injection chamber, and coupled to a three-component MEM accelerometer located at the block boundary. Typically, from the pulse beginning to the pulse peak, high frequency pressure variations of 10 to 250 Hz are measured. During the pulse decreasing, pressure signals display a very low frequency response of 0 to 1 Hz related to fluid hydraulic diffusion in the block. Block hydraulic transmissivity increased from 1 to 3x10-3 m2.s-1 respectively from pulse 1 to 3. An evolution of the frequency contents of both the seismic signals induced by the pulse and the pressure signals was evidenced: respectively seismic wave frequency content and magnitudes increased while the same attributes decreased on the pressure signals. This was clearly correlated to rock damage related to pre-existing fractures inelastic opening around the injection that favored fluid flow and modified solid block resonant frequencies.

Keywords: poroelastic waves, damaging, fluid pressure-ground acceleration coupling, seismic permeability

1. INTRODUCTION

A better understanding of the coupling between hydromechanical characteristics and the seismo-acoustic signatures of fractured-porous rocks is a key issue in reservoir monitoring, and fault instability studies [1]. To improve the understanding of these complex relationships, an in-situ experiment has been realized in a 3m x 3m x 3m block volume embedded inside one of the Low Noise Underground Laboratory gallery (France) at the depth of 273 meters below the ground surface. We show some preliminary simultaneous measurements of fluid pore pressures and ground acceleration of the solid medium that were conducted for a series of 3 pulse tests imposed at the block center.

2. EXPERIMENTAL SETTING

The experiment block is made of carbonate rocks with a 10-15% porosity cut by fractures with lengths exceeding the block dimensions (Figure 1). Several horizontal boreholes were drilled perpendicular to the fracture planes. In one borehole, an injection chamber of 2x10-3m3 was set between two inflatable packers. In the chamber a high accuracy fiber optic (Fabry-Perot type) sensor was set to allow pressure measurements with a sensitivity of 10^2 to 10^6 Pa and a 10^3 Hz sampling rate. 1m from the injection chamber, a niche was drilled in the gallery wall to install a three-dimensional MEM accelerometer (Colibrys@ SF3000L model) with a sensitivity of 1.5 V/g and a [0 – 1 kHz] frequency range. A series of 3 pressure pulses was imposed in the chamber with magnitudes of 5 to $6x10^5$ Pa. During the experiments, cracking noises and water outflows from the shaft wall were observed that proved that the block was damaged by the tests.

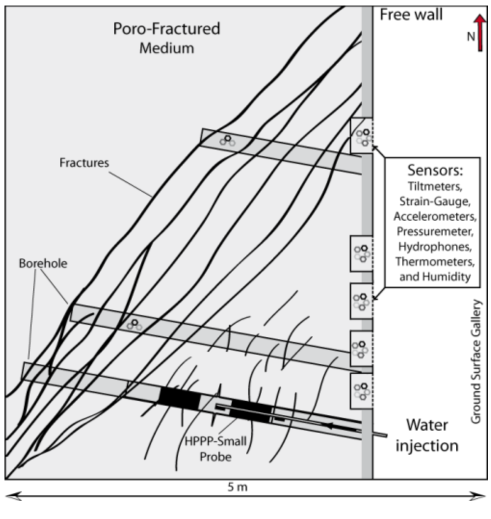

Figure 1: Geology of the Block Experiments.

3. RESULTS

Pressure versus time curves were analyzed using the classical Cooper approximation ([2]). Curves display a changing shape related to an increase in the block transmissivity from pulse 1 to 3, with values respectively of 1 to 3x10-3 m2.s-1 (Figure 2a). This transmissivity increase is correlated to the decrease of the arrival time of the seismic wave registered at the accelerometer (Figure 2b). Indeed, water outflow was observed to occur faster at the gallery wall respectively after pulses 1 to 3.

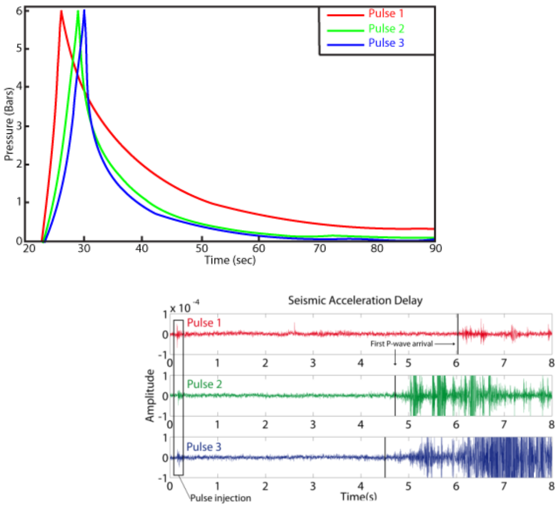

Figure 2: Time signals comparisons of pressure (a) and seismic horizontal acceleration (b) of pulses 1, 2 and 3.

Frequency content of a pulse pressure signal show a high [10 – 250 Hz] pressure frequency content during the rising part of the pulse followed by a drop to low frequencies of [0 – 10Hz] related to fluid flow into the rock. A Fast Fourier Transform analysis (FFT) of the diffusive part of each pressure signal (pressure drop) clearly shows a decreasing variation in the frequency content with the successive pulse tests (Figure 3a). In parallel, frequency content of the accelerometer data display an increase in the frequency band response of the solid rock, centered around 100 Hz (Figure 3b).

These multiple observations show that with the rock hydraulic properties that are changing with the rock damage induced by the injection, the frequency content of the fluid pressure is varying in an opposite way compared to the frequency content of the compressionnal waves that are travelling through the solid rock increases. This phenomenon can be discussed if we consider that the modification of the hydraulic properties is coupled to changes in the mechanical properties. Decreasing of the high frequency content of the pressure signal could show that water flow is easier through wider less rough fractures. Increasing in the high frequency content of the solid acceleration could be be related in changes in the fractures resonant modes because of the breaking of small bridges and some crack generation. Furthermore, these changes in frequency content with cumulative pulses exhibit the increase in the amount of different scales of fractures compared to the initial network geometry. This change in mechanicals behavior by new fractures opening creates new preferential way for the fluid flow, and then increase the flow (and the hydraulic permeability).

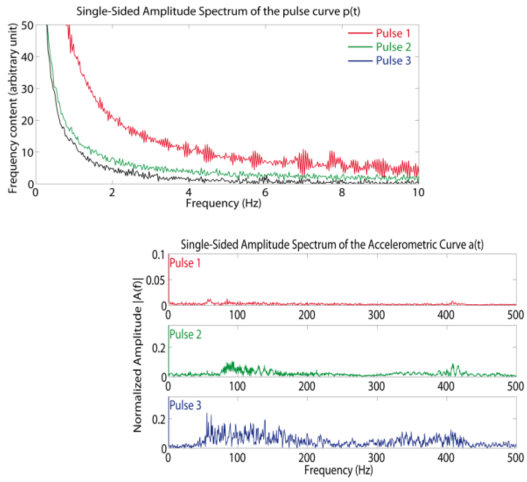

Figure 3: Comparison of pressure (a) and accelerometer (b) frequency contents of the pulses 1, 2 and 3.

4. CONCLUSIONS

Our preliminary in-situ poro-elastic investigations of a fractured porous block in a LSBB shaft illustrate the central role of the fluid flow and hydromechanical effects on seismicity and acoustic waves generation in reservoirs. Thanks to the high quality and accuracy of the measurements and the ultra low ambient noise of the LSBB site, multiple fluid-seismic complex relashionships were identified. In particular, rock damage effects on hydraulic and seismic properties were observed through a time and frequency analysis of the acoustic waves induced by brutal fluid over-pressure on the one hand, and secondly by the fluid diffusion into the opening fracture network.

Acknowledgments:

This work is financed by the ANR «Captage de CO_2» through the HPPP-CO_2 project, by the PACA county through the Petro-Pro project, and by the ANR "RiskNat" through the SLAMS project.

5. REFERENCES

[1] Tsang, C.-F. (1999), Linking thermal, hydrological, and mechanical processes fractured rocks. Annu. Rev. Earth Planet. Sci., 27, 359–384.

[2] Cooper H.H.J., Bredehoeft J.D., Papadopoulos I.S (1967), Response of a finite-diameter well to an instantaneous charge of water. Water Resources Research 3(1), 263-269