SALT CAVERNS :
AN INSTRUMENT FOR GEOPHYSICAL OBSERVATIONS

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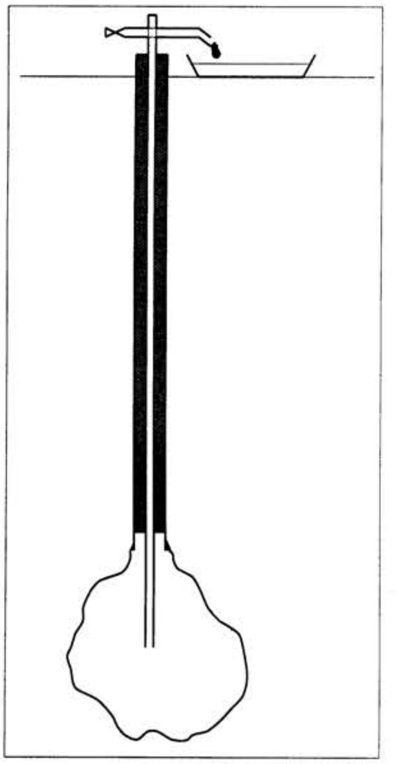
The simplest mechanical test that can be performed in a brine-filled cavern is to open the well head and measure the flow of brine expelled by the cavern (Figure 1). Several tests of this kind have been described in the literature by, among others, Clerc Renaud and Dubois (1980), Crotogino (1981), Boucly (1982), Hugout (1988), You, Maisons, Valette (1994), Berest, Brouard, Durup, Guerber (1996).



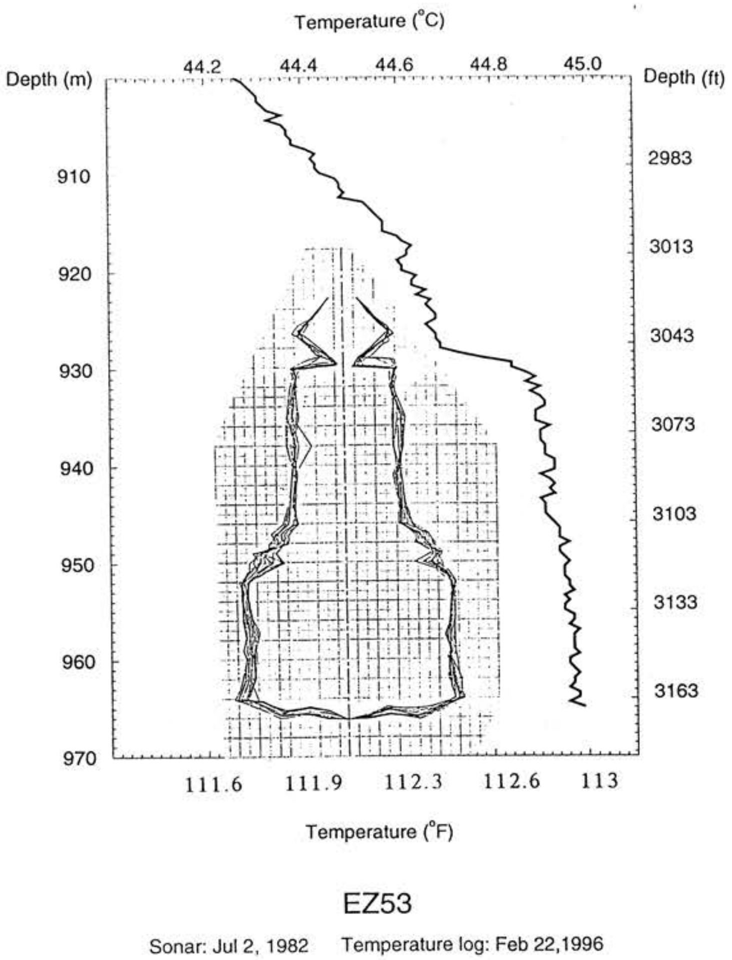


Figure 1. - The simplest mechanical test in a brine-filled cavern (The well head is opened to atmosphere and the brine flow expelled from the cavern is thoroughly measured).

Figure 2.- A vertical cross section of the Ez 53 cavern (The temperature profile was measured in February'96 (i.e., 14 years after the end of leaching). At that time, thermal equilibrium had been reached).

We consider here the case of three tests that have been performed in the Ez 53 cavern, a cavern located in the Gaz de France storage site in Etrez. This is a relatively small cavern (Figure 2) whose volume is 7500 m^3 (8000 m^3 when the sump, and brine trapped in the sump are included) and whose depth is 930 meters below ground level. The leaching process took place from March 19, 1982 to July 6, 1982. This last date is chosen in the following as the origin of time.

During days 3032 to 3068 (i.e., 8-1/2 years after the end of the leaching process), the brine flow has been recorded continuously. The well head was linked by a flexible tube to a central cabin, and a servo-controlled system allowed the brine level to be kept constant in the tube, from which a stepper motor drew off the brine. The withdrawn brine flow is plotted on Figure 3, together with the atmospheric pressure variations.

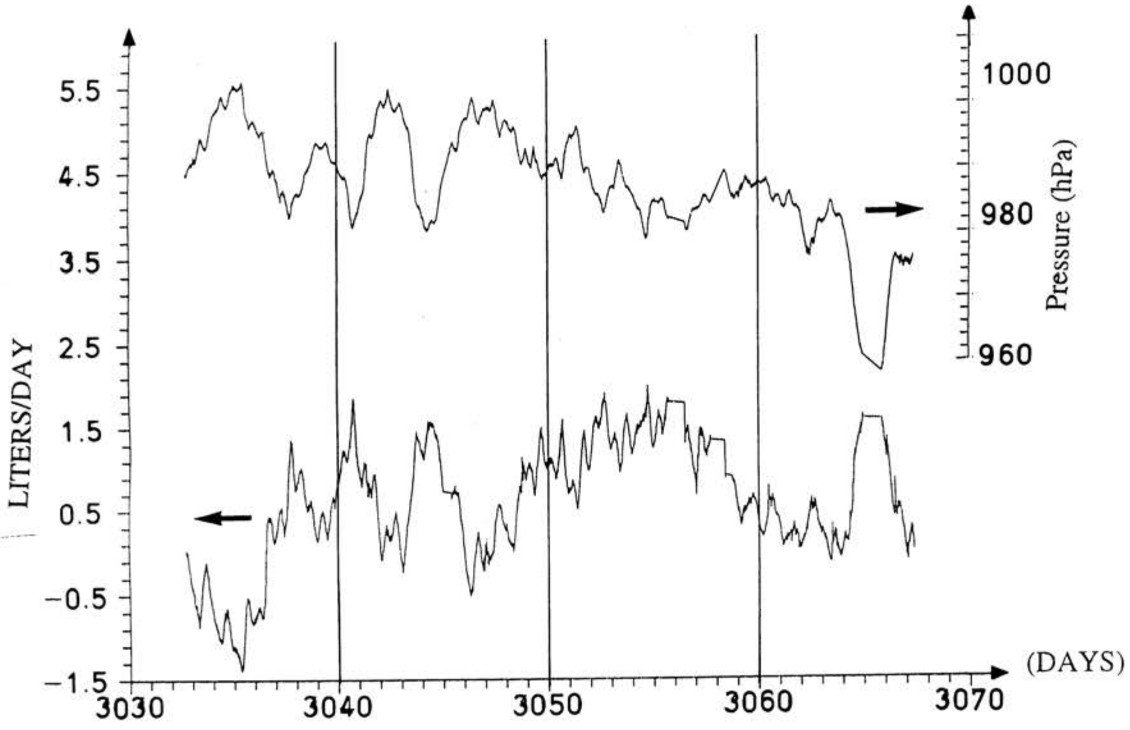


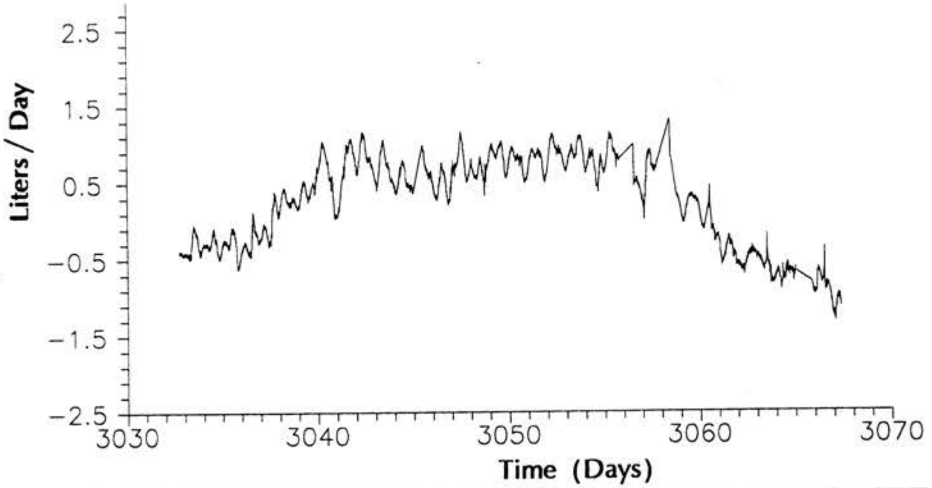
Figure 3.- Brine flow expelled from the Ez 53 cavern and concomitant atmospheric pressure variations

The average expelled brine flow is 5.5 liters per day, or 2.5 10^{-4} per year when the flow is compared to the total cavern volume. This average brine flow must be related to cavern creep. Brine percolation through the rock mass and brine thermal expansion, which, in many cases, are two effective causes of brine volume changes in the cavern, can be disregarded in this case. Brine percolation is negligible, if not nil, when cavern pressure is halmostatic - i.e. equal to the pressure determined by a saturated brine column (see Durup, 1994) ; thermal expansion due to brine heating is a very effective brine-production process immediately after leaching, but it is divided by 4 after a critical time $t_c = V^{2/3}/(4\ k)$, where k is the thermal diffusivity of rock salt and $t_c \simeq$ one year in the case of the Ez 53 cavern. Eight years after the end of leaching, thermal expansion has become extremely small (see, also, Figure 2, which proves that, 14 years after leaching, brine temperature is equal to rock mass temperature).

In this paper, we are not as interested in the absolute value of the brine flow as we are in the flow fluctuations. Figure 3 shows a nice (inverse) correlation between flow fluctuations and atmospheric pressure variations. The reason for this is the pushing of atmospheric pressure on both the brine/air interface in the well and the Earth's surface, resulting in a cavern volume change. The empirical correlation coefficient is typically $\beta = 1.25\ 10^{-10}\ Pa^{-1}$. (A one-hecto Pascal pressure variation generates a 0.1 liter flow fluctuation). The daily changes of ground level temperature can also be of some influence : for instance, a temperature increase leads to an expansion of the brine contained in the aerial part of the system (mainly the tube between the well head and the measurement shack) and, therefore, some lightening of the brine column. The two effects combine to produce an additional flow. When both atmospheric-pressure and temperature-variations effects are substracted from the measured flow, a corrected brine flow can be drawn (see Figures 4 and 5). A clear similarity with the local gravity acceleration variations due to Earth tides can be observed. A shift between the two signals can be expected, as surface deformations due to tidal activity can be expressed as a combination of the various derivatives of the gravity-force potential.

In order to obtain better results than previously obtained, some improvements in the measurement system have been introduced during the 1994 test (performed 12 years after the end of leaching). First, the well head, the connecting flexible tube and the measurement shack were better insulated, resulting in much smaller thermal fluctuations. Second, the brine is withdrawn by a pump driven by a stepper motor that measures atmospheric pressure instead of the relative pressure measured in the initial system. In Figure 6, the signal appears much less noisy than during previous tests. The maximum flow variation is 1.4 liters per day, or approximately 2×10^{-7} liters per day when the flow is compared to the cavern volume, and the period is 745 minutes.

A very interesting point is that the signal shown in Figure 6 is very clearly perturbed by still smaller fluctuations, the period of which is approximately 12 or 13 minutes, and the relative amplitude of which is 6×10^{-9}. The origin of these fluctuations remains unclear. It is not due to the period of the shack's thermal regulation system, whose period is erratic, nor to brine thermal convection in the well, which is triggered by nocturnal temperature drop and which can be sometimes observed in brine-filled caverns. An appealing, but still tentative hypothesis, links these fluctuations to an eigen-mode of the Earth's elastic vibrations.



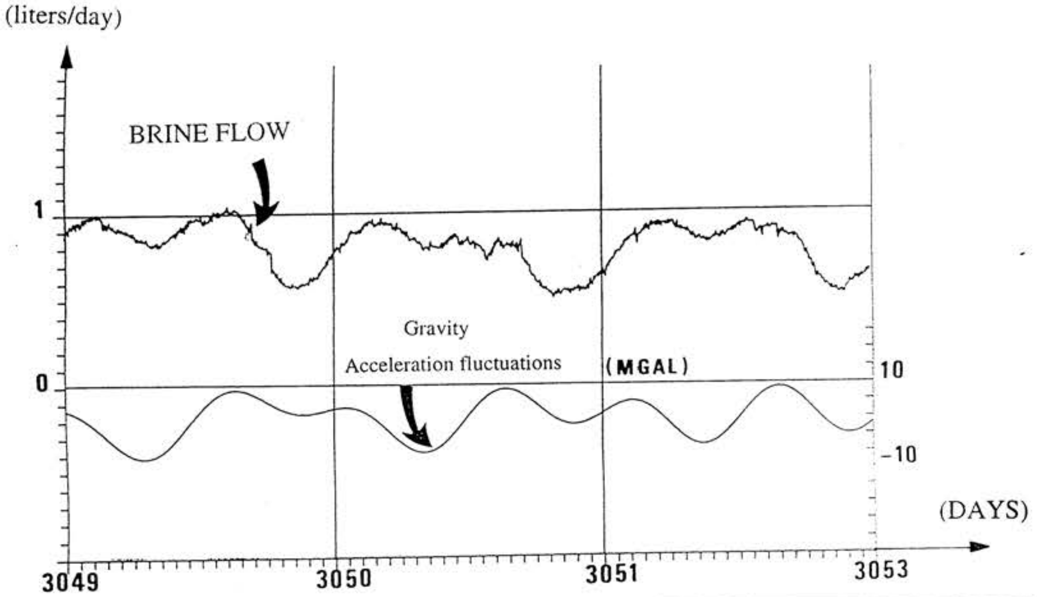
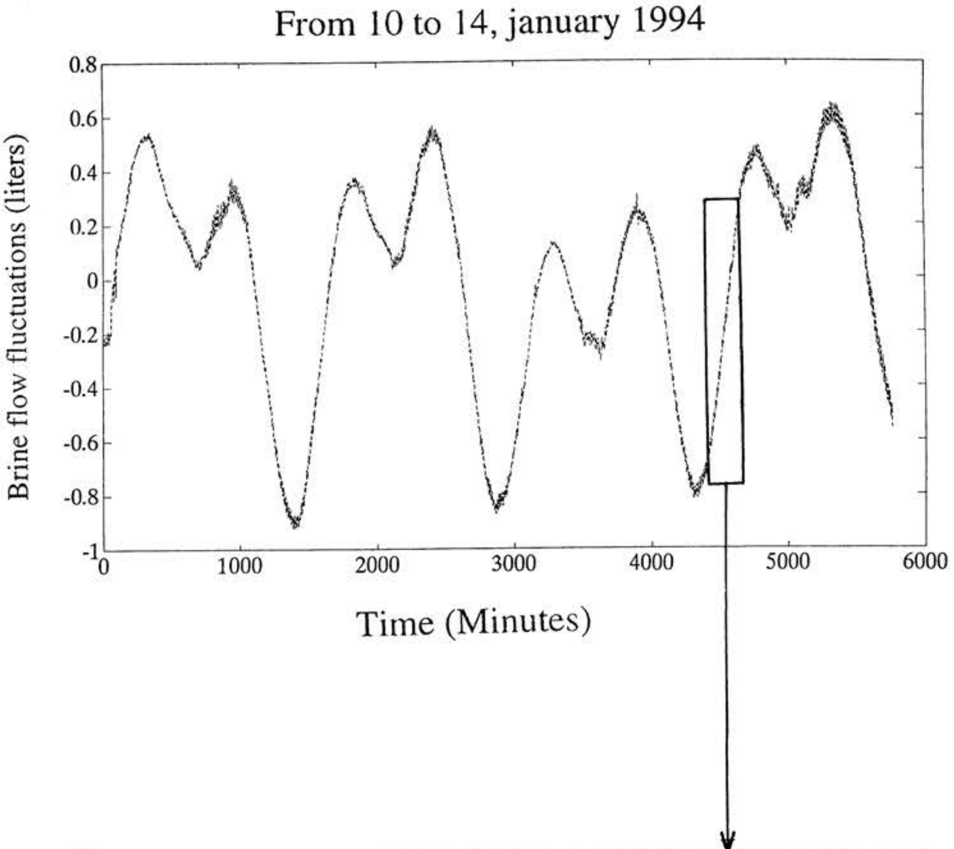


Figure 4.- The brine flow fluctuations have been corrected from ground level temperature and atmospheric pressure variations. (The periodic character of the corrected fluctuations appear clearly.)

Figure 5.- From Figure 4, days 3049 to 3051. (The gravity acceleration fluctuations due to tides are plotted on the same figure.)

Conclusion

Salt caverns play a fundamental economical role, both as a source of brine for the chemical industry and as a remarkable tool for storing natural gas, oil, compressed air, liquified petroleum gas. They can also be a unique instrument for geophysical observations, for they are sensitive even to tiny quivering of the Earth, and then a source of knowledge on Earth composition and deformations.



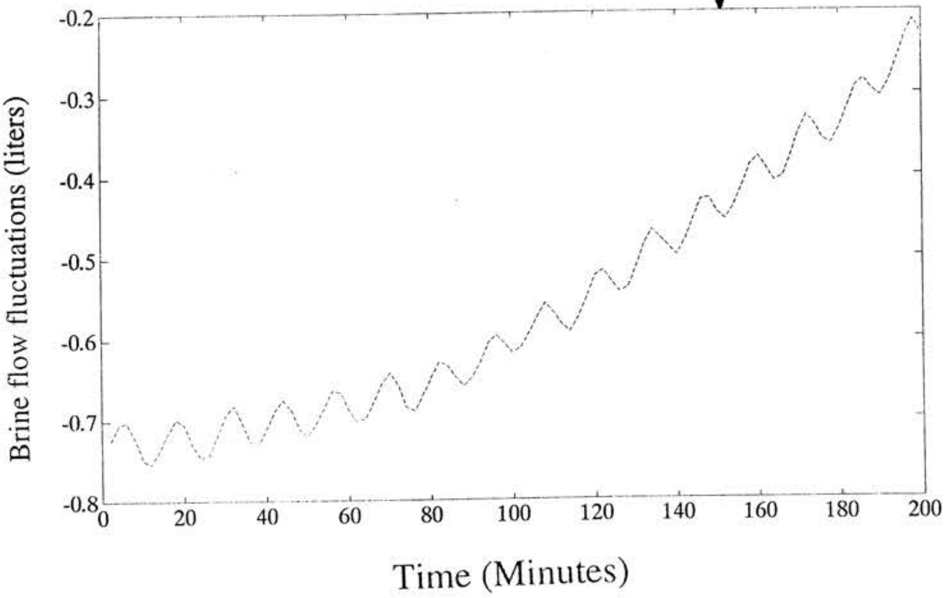


Figure 6.- Brine flow fluctuations observed during four days.

Figure 7.- A magnified section of figure 6, giving evidence of smaller fluctuations (50 milliliters, or $6x10^{-9}$ when compared to cavern volume) whose periods are 13 to 14 minutes.

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