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b-VALUE, ASEISMIC DEFORMATION AND BRITTLE FAILURE WITHIN AN ISOLATED GEOLOGICAL OBJECT : EVIDENCES FROM A DOME STRUCTURE LOADED BY FLUID EXTRACTION

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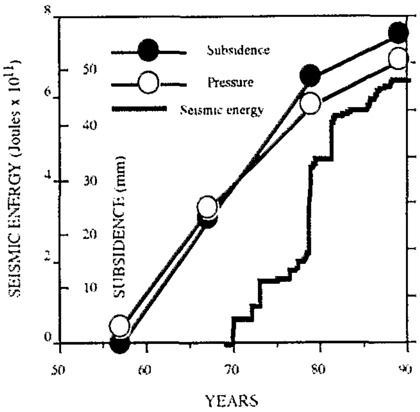
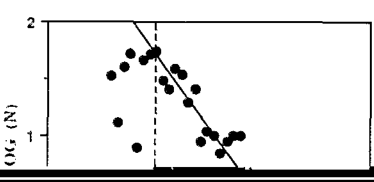


Fig. 1 : Temporal evolution of seismic energy, subsidence and gas pressure drop, since the beginning of gas extraction (1957). Subsidence is the maximum displacement measured at the top of the subsidence bowl. Gas pressure drop is averaged over several wells with a standard deviation ≤ 1 MPa.

1983, deep events have occurred below the reservoir and are more organized on large preexisting faults, defining several clusters (Figure 2b) [see also Guyoton *et al.*, 1992].

The forces applied at the boundaries of such a system are (1) tectonic forces and (2) gas reservoir pressure. Over a time scale of tens of years, we consider that tectonic forces are constant and that possible earthquake after-effects of regional seismicity are short-period phenomena [Grasso *et al.*, 1992]. Thus, the main perturbation of the medium over the 30-year time period of this study has been induced by the pore pressure decrease of the gas reservoir.

Stress changes in the overburden, as well as within the bed below the reservoir, were modeled using pororelastic stressing by Segall and Grasso [1991]. The basic result is that stress changes outside the reservoir (where seismic instabilities occur) are proportional to the pore pressure drop within the gas reservoir itself, despite the fact that there is no direct fluid connection between the reservoir and the overburden. The same critical stress threshold is necessary to explain both the rupture above and below the reservoir, except that due to the free surface a time delay to reach this threshold is two times smaller above the reservoir than below it. The calculated change in shear stress, which triggered shallow seismic activity in 1969 and deeper activity in 1983, is in both cases less than 1 MPa. Even if such stress changes are small, they are of the same order of magnitude as those recognized to drive seismic instabilities in the neighbourhood of artificial water reservoir [Roeloffs, 1988].



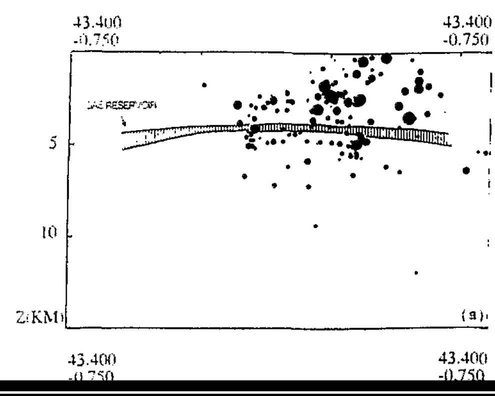
Study of the magnitude frequency relationship

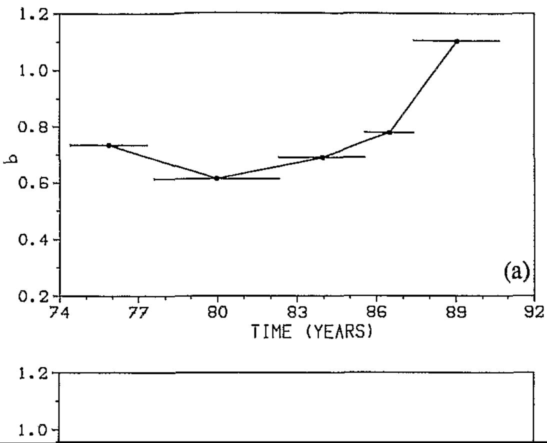
Since 1974, when a local network was installed, we have observed induced seismic activity and computed b-values in order to understand its physical meaning at a scale intermediate between (1) laboratory measurements on rock core samples, where each parameter is controlled, and (2) a large tectonic area where boundary conditions are difficult to isolate. The Lacq local network has operated continuously with only one interruption between July 1979 and December 1979. Starting in 1974, 4 stations were installed and 5 more stations were added between 1974 and 1979. Between 1974 and 1990, about 1000 induced events were detected with a local magnitude ranging from 1.0 to 4.2. Seismicity during the period 1974-1979, in numbers of both low and high magnitude earthquakes, was higher (while the network was smallest), than since 1979 (complete network). We can thus assume that during the first period no significant events were missed. The cutoff magnitude determined by the log-linear portion of the discrete frequency magnitude plot is 1.7 (Figure 3). About 500 events are selected according to this criteria.

As we have a magnitude range spanning less than 2 units, we used the general maximum likelihood estimation of b, where b'=b/log10 [e.g., Page, 1968] :

$$b = \log_{10}e\left[\bar{m}_l - \frac{m_{l\min} - m_{l\max}e^{-b'(m_{l\max} - m_{l\min})}}{1 - e^{-b'(m_{l\max} - m_{l\min})}}\right]^{-1}$$

We calculated the b-value using windows of N events. Windows of N events was preferred to windows of N months in which the difference in the number of events would give heterogeneous results because the seismic activity was not steady. We computed variations in b-values using several windows (between 60 and 100 events) and different increments (between 1 and the window value). Despite some high frequency variations, the general trend is the same. The smoothest variations in b-values were obtained with a window of 87 events. As we are interested in long term b-value variations, we chose this value for the study. Two distinct stages in the behaviour b-value are observed (Figure 4a and





km). The differences between each data set are not significant. The observed b-value variations of the two data subset and that observed from the whole data set are the same. Thus, the contrast in geomechanical properties of rock matrices located above and below the reservoir, within which seismic fractures occur, does not affect the b-value. This is in contradiction to studies on rock samples [e.g. Mogi 1962, 1985], as well as Talwani's [1981] interpretation of b-values from earthquakes around an artificial reservoir, based on differences in rock properties.

Thus, given the first 3 observations, neither the increase of effective stress nor the rock mechanical properties can explain the temporal change in b-value behaviour.

The space-time evolution of the distribution of hypocenters exhibits two patterns (observation 4). During the first period (1974-1982), the seismicity is diffuse with neither aftershocks nor clustering, although the more energy is released during correlation between b-value variations and occurrences of large earthquakes is not always observed. b-value interpretations for earthquake processes using results of rock sample analyses remain ambiguous if only stress interpretation is used, except of specific cases [e.g., Wyss, 1973]. In

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Jin, A. and K. Aki, Spatial and temporal correlation between coda Q-1 and seismicity and its physical mechanism, *J.*