



# Earthquake related fluid migrations: Mechanism, historical records and lessons learnt

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## Introduction

In the image of public, earthquake is regarded as a potential cause of rapid or catastrophic seepage of stored CO<sub>2</sub> in sequestration sites. In fact, there are some cases of earthquake related fluid migration to the surface, but there is no report of human causality. Here, some of such cases are described, and possible mechanisms of them are discussed. Such knowledge is useful for the site selection of CCS program.

## Mechanism and historical record of fluid motion/fluid pressure change due to earthquakes

### Direct relation of gas migration and seismic fault motion

Fluid pressure increase causes the reduction of effective stress. In the condition of high shear stress, this process works as the reduction of frictions and cause the subsequent shear failure. In the seismic active zone, the stress condition is “critical” in which small stress change easily cause the failure. On the other hand, fault motion (both opening and shear displacement) changes, basically increasing, permeability, and can create or enhance fluid flow path. Also, large and rapid deformation of the formation can cause pore pressure surge because pressure diffusion in low permeable rock is a slow process than earthquake.

A well-known case of the interaction of fluid and earthquake happened in Rocky Mountain Arsenal near Denver Co. when wasted fluid was injected in deep well [Evans 1966]. For the geophysical researches, similar process was intentionally caused by water injection to faults in Rangely oil field (CO, USA), Matsushiro (Nagano, Japan), and Nojima fault (Hyogo, Japan). This process, Micro Seismic, is also used for the monitoring of injected fluid motion for the monitoring of EOR (Enhanced Oil Recovery) operation.

Miller et al.[2004] reported a case of relatively big aftershocks following the main shock in Apennine Mts, Italy in 1997. They found that the focal points of the aftershocks correspond to the migration of CO<sub>2</sub> in major faults.

In the above cases, no fluid release to the surface was observed. In Matsushiro, however, vast volume of CO<sub>2</sub> dissolved water appeared on surface during the Matsushiro earthquake swarm (1965-1967) [Nakamura 1971].

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### **Stress change due to earthquake**

Earthquake is a process of stress release from the critical state. However, redistribution of the stress can make stress concentration and pore pressure change at some places due to the heterogeneity of the earth crust (Fig.1). In fact, change of ground water level, spring water production rate and noble gas concentration in the ground water in pre- and post-seismic periods have been studied for the earthquake prediction purpose.

### **Seismic wave induced pore pressure**

According to the theory of dynamic poroelasticity by Biot [1956], P-wave contains the pore-pressure component. When displacement is large, also S-wave can cause pore pressure through dilatancy mechanism (Fig.2). Pore pressure measurement in some underground oil storage sites and a mine showed co-seismic pore pressure change [Sasaki et al. 1999, Hasegawa et al. 1999]. The level of the pore pressure change is not great, but not negligible level when the stress condition is critical.

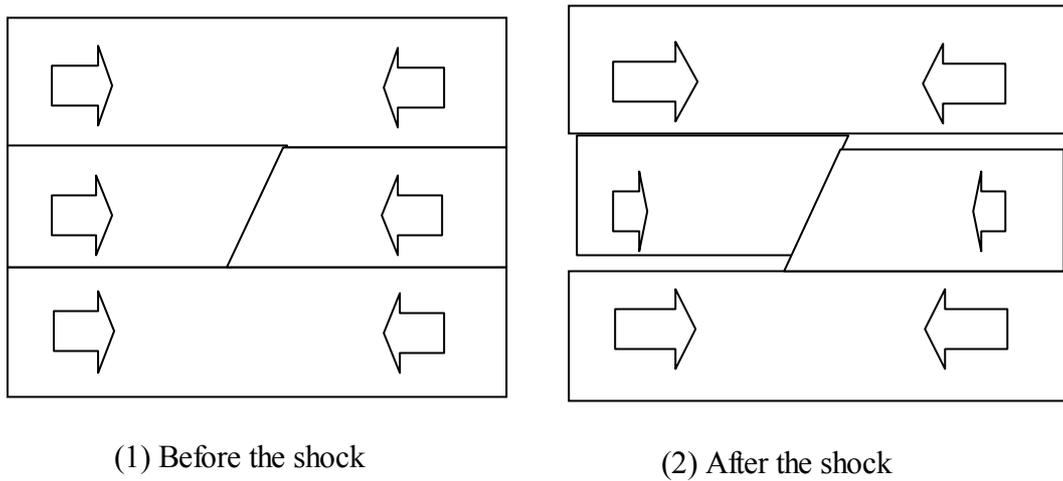
### **Surface deformation**

Deformation of earth crust by earthquake is largest at the surface because of the amplification of free surface. In fact, damage of underground structures caused by major earthquakes is less significant than surface structures. When the stored gas is in shallow depth, surface deformation and failure such as creation of cracks, land slide, liquefaction etc. lead the local failure of seal mechanism. In Chitose, Hokkaido, Japan, natural gas erupted at several places just after the M8.0 Tokachi-oki earthquake in 2003, although the epicentre is 220km far from this place. The area is known as high gas flux region, and gas flow is observed in many places in the regular condition [Kanoko and Inokari, 2005]. The origin of the gas is deep underground, but some volume of gas is usually stored in shallow formation and move to surface gradually. After the earthquake both surface condition and stress state change in this area cause the rapid release of natural gas.

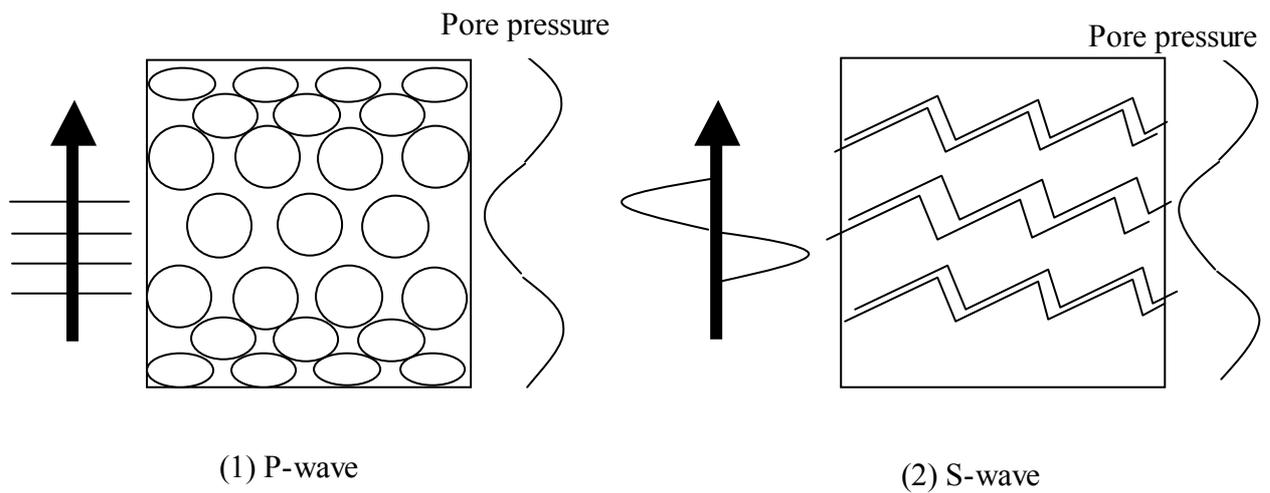
### **Lessons learnt**

Earthquakes surely affect the stability of the stored CO<sub>2</sub>. However, their risk depends on the mechanical condition of the storage site, and is not common. Only when the stress and pore pressure has been already critical, the failure of the seal mechanism occurs, and the earthquakes work as triggers. Also the observation of natural phenomena suggest that the CO<sub>2</sub> discharge is a temporal phenomena, and the fluid flow is decreasing to the normal level, because excess pore pressure is released, and fluid flow usually reduce the fault permeability by the fine particle migration and other mechanisms. Therefore, catastrophic seepage by the earthquake is not likely.

For the safety CO<sub>2</sub> storage, information of faults and natural fractures is important. Also the stress state is how close to the critical condition is the key knowledge of safety assessment. The microseismic survey during injection stage can give useful information about this.



**Fig.1 Stress re-distribution after an earthquake**



**Fig.2 Wave motion and induced pore pressure**

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