J063-016 Room: 302 Time: May 28 9:45-10:00

Development of permeability structure and abnormal geopressure in the focal area of the 1999 Chi-Chi earthquake

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Knowledge of the hydraulic properties of sediments within a sedimentary basin is important to understand the fluid flow processes inside a basin quantitatively. In a laboratory, we can measure the hydraulic parameters of rock samples, such as permeability and storage coefficient, at confined pressure conditions inside a pressure vessel simulating the lithostatically loaded condition of rocks within a basin at depth. If the pore fluid pressure of sediments is hydrostatic throughout the whole region of a basin, we will be able to apply the experimentally determined relationships between the effective pressure (Pe) and the hydraulic parameters of rock samples to the depth condition of the basin simply assuming a constant effective pressure gradient toward the deeper horizons. On the other hand, if there exists regions of abnormal high fluid pressure, we can not apply the experimental results to field, since the gradient of Pe is expected to change downward reflecting the existence of the abnormal fluid pressure regions. In the presented study, we constructed the hydraulic structure of the sedimentary basin in the western foothills in Taiwan from the estimated fluid pressure distribution inside the basin and the experimentally determined hydraulic parameters of the rock samples collected in the outcrop of the basin. The fluid pressure distribution of the basin was estimated by combining the experimental data with a one-dimensional compaction flow model in a sedimentary basin (Bethke and Corbet, 1988).

At the western foothills in Taiwan, we can collect samples in the outcrop with different stratigraphies because sedimentary beds crop out continuously by the strong tectonic deformation. This helps us to estimate the effect of time-dependent compaction on hydraulic constants. The basin is also known as an oil field and observed abnormal fluid pressure at depth by the logging data. We can compare our estimated result of fluid pressure distribution to the real logging data. Moreover in 1999 the earthquake hit the location and large thrusts are observed. Therefore this location is key to reveal the earthquake mechanism.

We measured permeability and porosity as a function of Pe up to 200 MPa using the high-pressure apparatus at Kyoto University. Permeability decreased with increasing Pe and permeability did not fully recover during decompression. Permeability was generally the highest in conglomerate and the lowest in siltstone among conglomerate, sandstone and siltstone, which showed the permeability of 10^-17 ~ 10^-20 m^2, 10^-15 m^2 ~ 10^-18 m^2 and 10^-15 ~ 10^-17 m^2 respectively. Fault rocks showed similar value to siltstone. Sandstones were divided into two groups. Permeability of group 1 did not change so much with increasing Pe. Group 2 decreased with increasing Pe comparatively. Porosity also decreased with increasing Pe and showed hysteresis. Porosities decreased from 4% to 8% at the maximum Pe 200 MPa and we could not identify the difference with rock type. We calculated specific storage using the porosity and pressure sensitivity. Specific storage decreased with effective pressure and the values were from 10^-8 1/Pa at the lower Pe to 10^-10 1/Pa at the highest Pe 200 MPa.

We solved the one-dimensional fluid equation using the permeability and specific storage as a function of Pe measured by experiments. The solution was shown as a relationship between fluid pressure and depth. The result indicated that abnormal fluid pressure was generated from 4000m and the value increased with depth. Abnormal fluid pressure was generated at the depth which permeability was from 10^-17 m^2 to 10^-18 m^2. Moreover our result showed similar trend to the logging data. This suggests that we can estimate the hydraulic constants at the depth using the laboratory data. We also evaluated the permeability/specific storage structure at depth of the western foothills using the fluid pressure distribution.