若手ポスター発表（Poster：MMIJ Students and Young Researchers）

岩盤工学（ Rock Engineering）
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[PY2-73] IMPACT ON PERMEABILITY DUE TO AXIAL STRESS DISTURBANCES FOR CRETACEOUS SANDY SHALE IMPACT ON PERMEABILITY DUE TO AXIAL STRESS DISTURBANCES FOR CRETACEOUS SANDY SHALE

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キーワード：Axial stress disturbances, Enhanced methane gas recovery, Earthquakes, Induced stress, De-routing underground water flow

Seismic waves generated from earthquakes and artificial surface vibration might alter the water level in the wells and oil or gas production. These transient stress disturbances prospectively caused the permeability change due to new pathway occurring or existing pathway being cleared. The permeability change might encourage enhancing gas recovery, inducing small earthquakes preventing future large earthquakes, and de-routing underground water flow for various purposes. The prospective permeability increase by axial stress disturbances of Cretaceous sandy shale may effectively expand the capacity of methane gas recovery of Kushiro Coal Mine. The paper observes the permeability change of intact or triaxially fractured Kushiro Cretaceous sandy shale by axial stress disturbances. It will be shown that increasing and decreasing factors might work together on permeability.

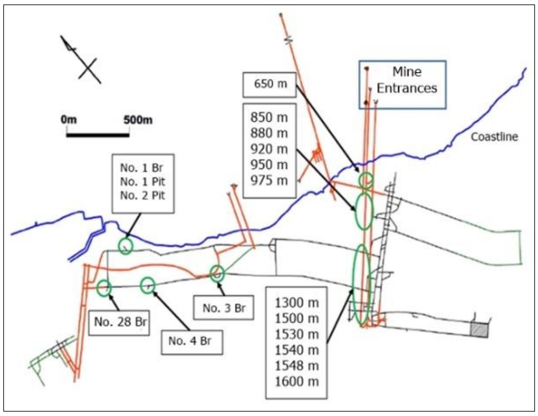
1. Introduction

Seismic waves generated from earthquakes and man-made vibration might alter the water level in the wells and oil or gas production. The result recorded from Manga et al. (2012) and Beresnev & Johnson (1994) both illustrated the water levels and oil or gas production in most cases of the wells had increased, conversely, some wells had decreased the production. Another attention was on the increase of natural gas production of the nearby wells after applying the artificial surface vibration to confuse the source locations of underground nuclear tests from Western countries by Russia during the Cold War (Roegiers, 2016). An alternative man-made explosion of underground nuclear test explosion might prevent the giant earthquakes based on a Russian study. This report claimed no more than M8.3 earthquakes throughout the years of 1950s to 1990s had occurred during the period when the US and the USSR did the underground nuclear explosion tests (Fujii et al., 2017). These phenomena encourage utilization of stress disturbances to enhance gas recovery, inducing small earthquakes preventing future large earthquakes, and de-routing underground water flow for various purposes. The cause of the above phenomena might be permeability change due to the transient stress disturbances. The mechanism of the permeability change would be new pathway occurring or existing pathway being unclogged (Manga et al., 2012). The paper observes the permeability change of intact or triaxially fractured Kushiro Cretaceous sandy shale by axial stress disturbances. The prospective permeability increase by axial stress disturbances of Cretaceous sandy shale may effectively expand the capacity of methane gas recovery of Kushiro Coal Mine.

2. Materials and methods

The cores of Cretaceous sandy shale (Fig. 1a) were provided from Kushiro Coal Mine, located in eastern Hokkaido, along with the Pacific Ocean. The specimens were sampled from borehole No. 72, in the depth of 322.65 to 323.50 m, from the second drilling pit at the inclined shaft 650 m from the entrance (Fig. 1b). Cretaceous sandy shale layer where the methane gas has been extracted is underlying the Paleogene coal bearing formations. A vacuum saturated cylindrical specimen with a diameter of 30 mm and length of 60 mm was attached to the stainless steel endpieces. These endpieces have the central holes to allow water pass through the specimen. The silicon sealant for maintaining the water flow within the specimen was applied to the surface of the specimen. A heat-shrinkable tube was jacketed to the endpiece-attached specimen to prevent direct contact of the confining fluid with the specimen. The specimen was vacuum saturated again and inserted into the triaxial cell (Alam et al., 2014). The pore water pressure (P_p) of 1 MPa was applied at the bottom of the specimen and the upper end was opened to the atmospheric pressure (Fig. 2) after the confining pressure of 3, 10, or 15 MPa was applied. The intact specimen was kept under constant hydrostatic pressure for 24 hours, after then the axial stress disturbance of various

(a)



(b)

Fig. 1 (a) Cores of Cretaceous sandy shale, and (b) location of gas wells for Cretaceous rock mass at Kushiro Coal Mine (Matsumoto et al., 2014).

values (Table 1) with the frequency of 0.5 Hz in the duration of 200 seconds was applied. The specimen was kept once more under constant hydrostatic pressure for 24 hours. The axial compression was conducted at the constant rate of 10^{-5} s^{-1} (0.036 mm/min) until the residual strength state was confirmed, and after that, it was held on under constant hydrostatic pressure for 24 hours. Axial stress disturbance was applied and the constant hydrostatic pressure was carried out again.

Table 1 The confining pressures and axial stress disturbance values for Cretaceous sandy shale experiment

Pc (MPa)	3	10								15	
$\Delta\sigma_A$ (MPa)	1	0	1	3	4	5	7	9	11	1	3

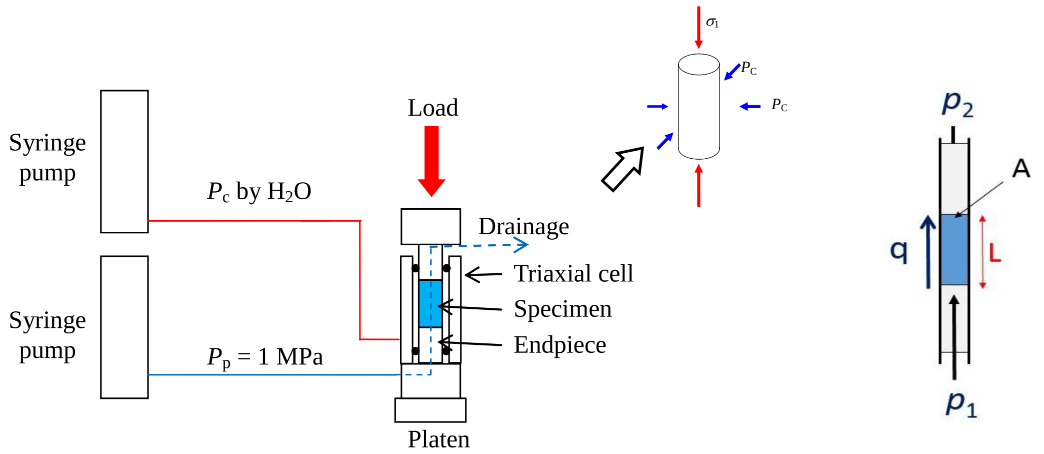


Fig. 2 The schematic diagram of experimental apparatus showing the permeability measurement using the constant flow method.

The permeability was measured for every stage of 24-hour hydrostatic pressure. The permeability of the intact rock was determined as permeability k_1 (Fig. 3a), before the stress disturbance (Fig. 3b), and disturbed rock permeability as k_2 (Fig 3c). After the triaxial compression (Fig. 3d), the permeability of the post-failure rock was measured as k_3 (Fig. 3e). The same stress disturbance was again applied (Fig. 3f) and the permeability k_4 was measured (Fig. 3g).

From constant flow method, the permeability k (m^2) was evaluated by the following this equation.

$$k = \frac{q\mu}{A}\left(\frac{\mathrm{d}p}{\mathrm{d}x}\right)^{-1} \quad \text{(eq. 1)}$$

where q is the flow rate (m^3/s), μ is the fluid viscosity (Pa·s), A is the cross-sectional area (m^2) of the specimen, and dp/dx is the pressure gradient (Pa/m). The viscosity of water (μ) is 9.57 x 10^{-4} (Pa·s) at 295 K.

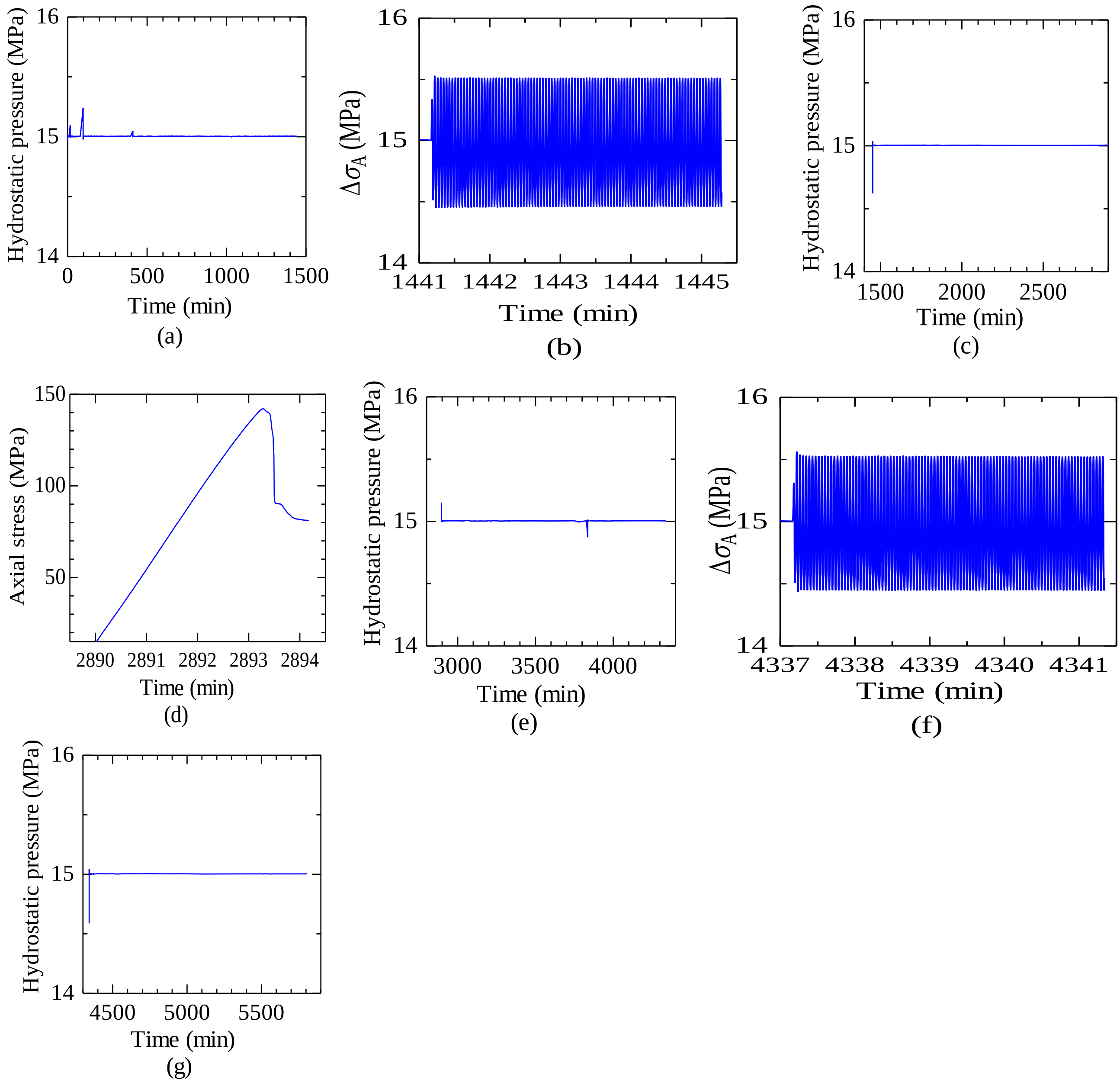


Fig. 3 An example of the applied axial stress (P_c = 15 (MPa) and $\Delta\sigma_A$ = 1 (MPa)) in the experiment, (a) Hydrostatic pressure for 24 hours, (b) stress disturbance with the amplitude of 1 MPa, (c) applied hydrostatic pressure for 24 hours on the disturbed rock, (d) triaxial compression, (e) hydrostatic pressure for 24 hours, (f) stress disturbance, and (g) hydrostatic pressure for 24 hours.

3. Results and discussions

The permeability of intact rock (k_1), disturbed rock (k_2), post-failure rock (k_3), and disturbed post-failure rock (k_4) was calculated based on the change in water volume in the syringe pump as illustrated in Fig. 4(a-d) respectively. The permeability tended to decrease from k_1 to k_2, and from k_3 to k_4 due to the axial stress disturbances but increase from k_2 to k_3 due to rock failure (Figs. 5 and 6). The decreased amount for k_1 to k_2 increased with confining pressure (Fig. 7a) but slightly decreased with stress disturbance amplitudes (Fig. 7d). This could mean that the permeability decreased with time due to creep deformation by plastic and viscous deformation, but increased by the stress disturbances for intact rock. On the other hand, effects of confining pressure or stress disturbance amplitudes on the permeability decrease from k_3 to k_4 were not apparent for post-failure rock (Fig. 7c or f). This may suggest that permeability decreased with time but did not increase by the axial stress disturbances for the post-failure rock specimens. The amount of permeability increase from k_2 to k_3 by rock failure (Fig. 5) decreased with confining pressure (Fig. 7b). Similar results can be seen in the research of Alam et al. (2014).

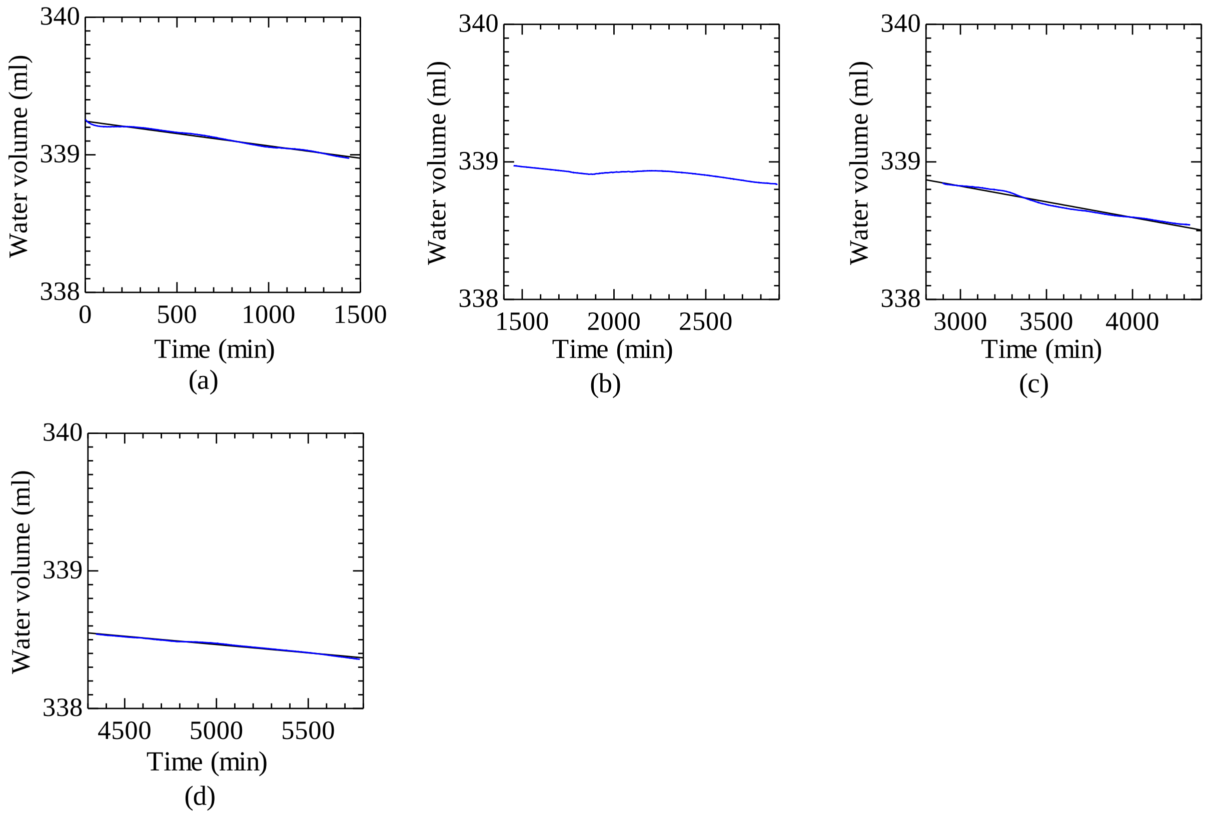


Fig. 4 Example of water volume change in syringe pump for (a) intact rock, (b) disturbed rock, (c) post-failure rock, (d) disturbed post-failure rock (P_c = 15 (MPa) and $\Delta\sigma_A$ = 1 (MPa)).

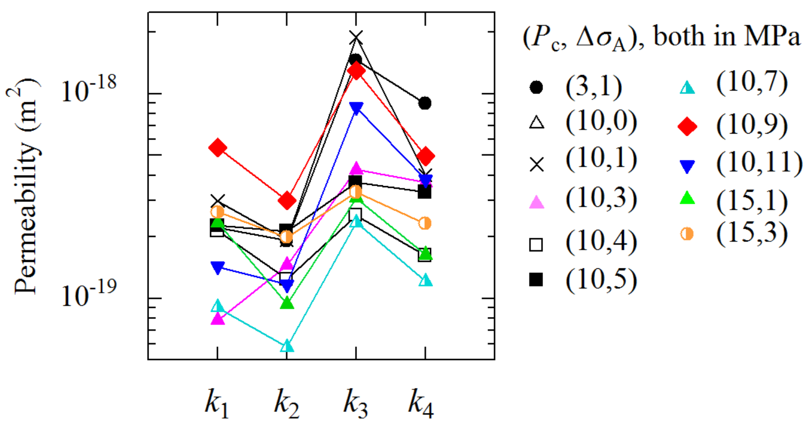


Fig. 5 Change in permeability due to stress disturbances and triaxial compression. The confining pressures and axial stress disturbances were represented by coordination with exact values and symbols with colors.

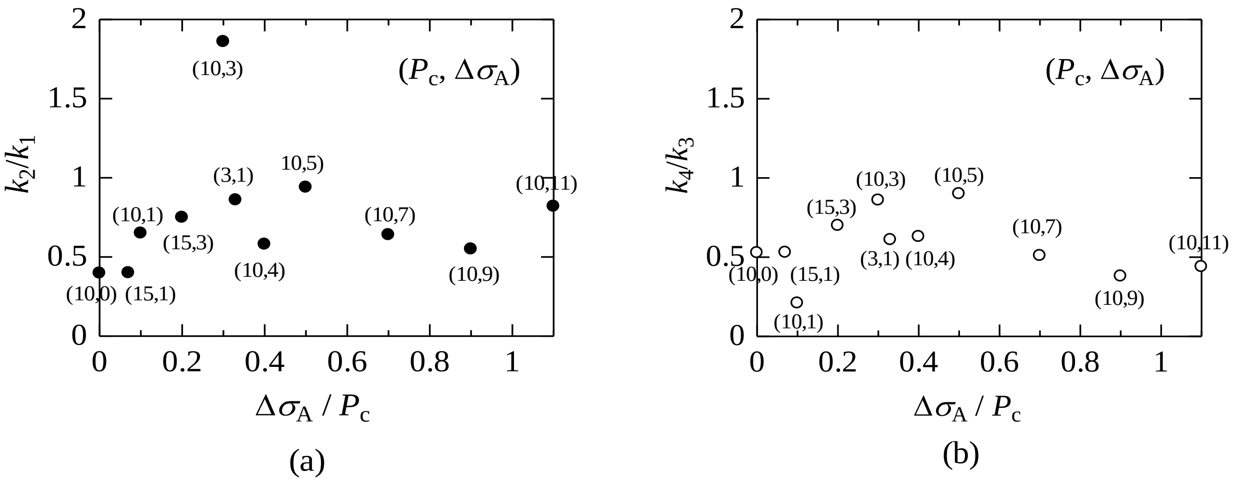


Fig. 6 (a) Permeability change in pre-failure, and (b) permeability change in post-failure as a function of $\Delta\sigma_A/P_C$.

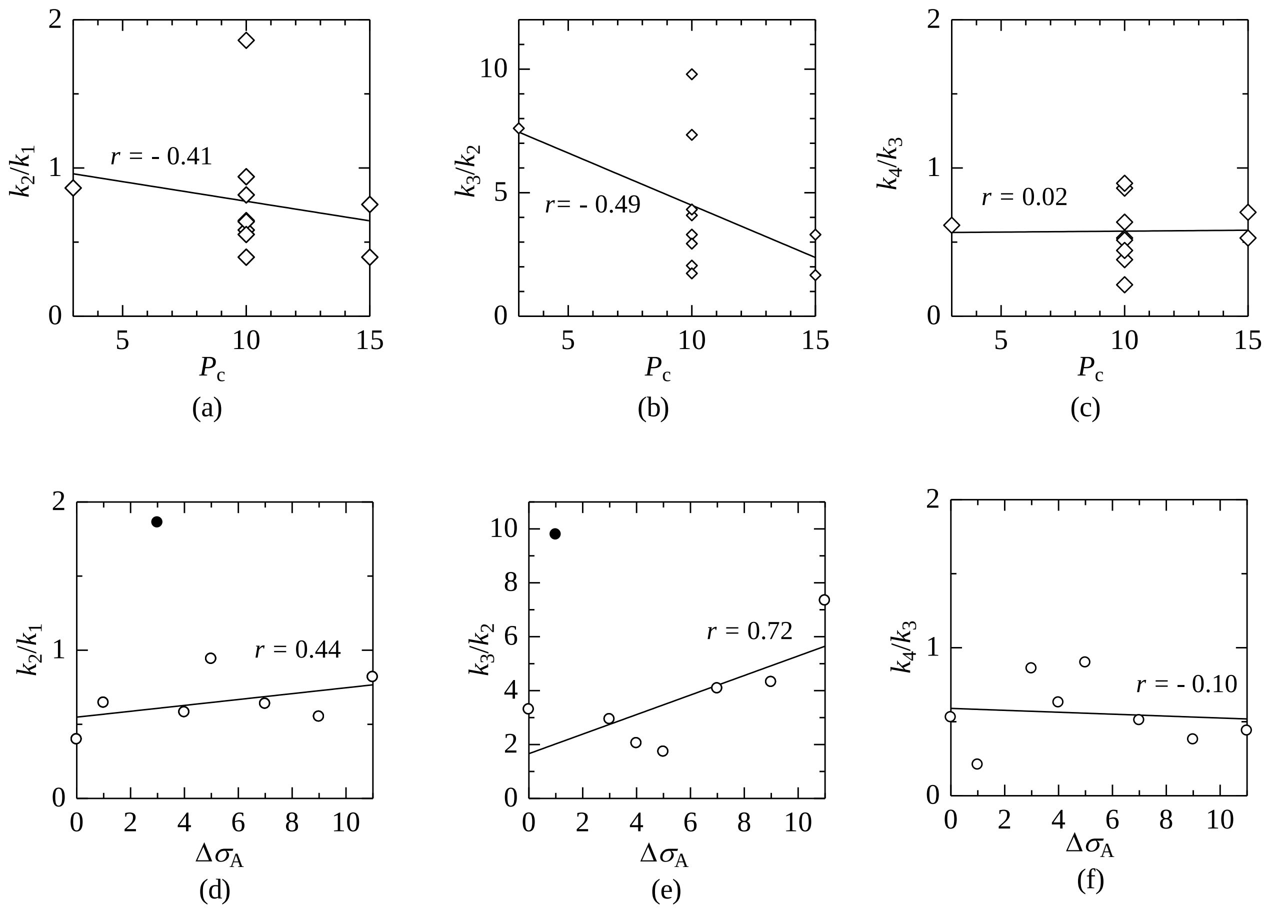


Fig. 7 (a, b, c) Change in permeability vs. confining pressure of pre-failure, failure, and post-failure stages respectively, and (d, e, f) change in permeability vs. axial stress disturbances of pre-failure, failure, and post-failure stages respectively for P_C =10 (MPa). The outlier data shown as solid circles in (d) and (e) are ignored.

4. Concluding remarks

Kushiro Cretaceous sandy shale specimens were triaxially compressed under confining pressures of 3, 5, or 10 MPa, and various stress disturbance amplitudes were applied. The permeability of pre-failure rock before (k_1) and (k_2) after and post failure rocks before (k_3) and (k_4) after the disturbances were measured. The permeability decreased from k_1 to k_2, increased from k_2 to k_3, and again decreased from k_3 to k_4. The decreased amount in permeability increased with confining pressure for pre-failure rock and no effect was observed for post-failure rock. The decreased amount in permeability of pre-failure rock decreased with the axial stress disturbance amplitudes; however, there was no apparent effect of stress disturbances on the decrease of post-failure rock. Therefore, it was estimated that the permeability of pre-failure Cretaceous sandy shale decreased with time and increased by the axial stress disturbances. The data accumulation is required to validate the estimation.

Acknowledgement

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