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The effect of effective normal stress on particle breakage, porosity and permeability of sand: Evaluation of faults around methane hydrate reservoirs

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ABSTRACT

To provide evaluation of faults around methane hydrate reservoirs, we used a ring-shear apparatus to examine the perpendicular permeability of silica sand. The effects of effective normal stress and artificial overconsolidation ratios on the permeability were investigated. We obtained measurements under constant effective normal stress ranging from 0.5 MPa to 8.0 MPa and under two overconsolidation ratios (OCR 1.6 and 16.0). Permeability and porosity after ring-shearing substantially decreased with increasing effective normal stress up to an effective normal stress of 2.0 MPa, and became constant for effective normal stress values greater than 2.0 MPa. Stress dependency of both permeability and porosity after large-displacement shearing was clearly observed. Significant changes in permeability after ring-shearing related to the artificial overconsolidation ratio were not observed. To observe the shear zone microstructure and grain crushing, we conducted analyses using field emission scanning electron microscopy and laser diffraction. The stress dependency of permeability reduction after ring-shearing was reflected by the porosity and grain size reduction due to grain crushing in a finite shear zone. The results indicate that fault (shear zone) formed at the moderate effective normal stress may act as a sealing structure in gas production areas.

1. Introduction

Methane hydrates in sediments under the seafloor and in permafrost regions are anticipated to be an unconventional methane resource (Boswell and Collet, 2011; Collet and Kuuskraa, 1998). Methane hydrates in sediments are expected to be developed as a future energy resource and to affect the future development of agriculture, construction, industry and human life. In situ dissociation of natural gas hydrates is necessary for commercial recovery of natural gas from natural gas-hydrate-bearing sediments. The exploitation of methane hydrates and production methods of methane gas from methane hydrate depressurization, thermal stimulation and inhibiter injection have been proposed (e.g. Kawamura et al., 2006; Pooladi-Darvish, 2004; Sakamoto et al., 2007; Sakamoto et al., 2009). For all methods, the gas and water permeability in methane-hydrate-bearing sediments are important factors for estimating the efficiency of methane gas production.

From coring and logging, the existence of a sandy layer containing a large amount of methane hydrate is predicted in the eastern Nankai Trough area, offshore central Japan, where many faults and folds have

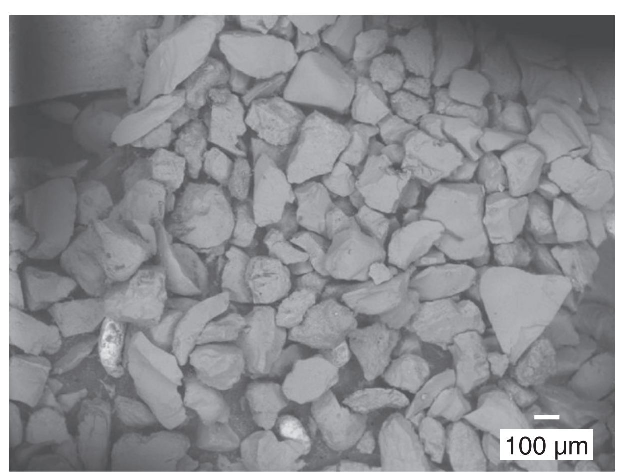

Fig. 1. Field emission scanning electron microscopy image of the microstructure of the sand used in the experiments.

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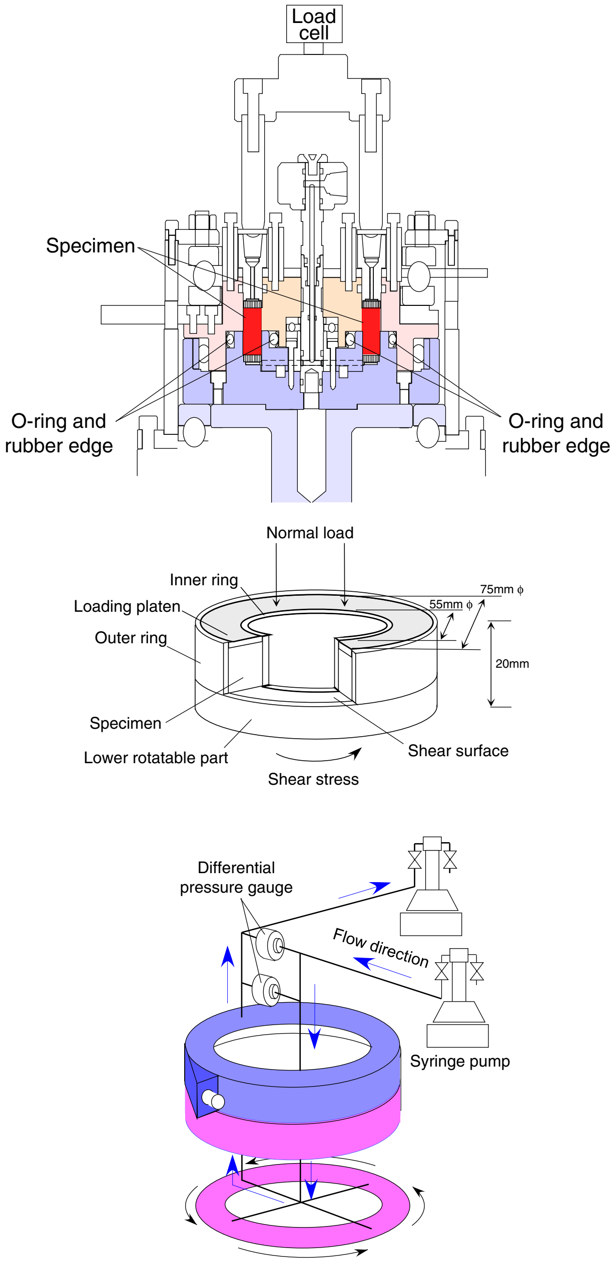

Fig. 2. Schematics of the ring-shear apparatus, a specimen in the ring-shear apparatus and of permeability measurement.

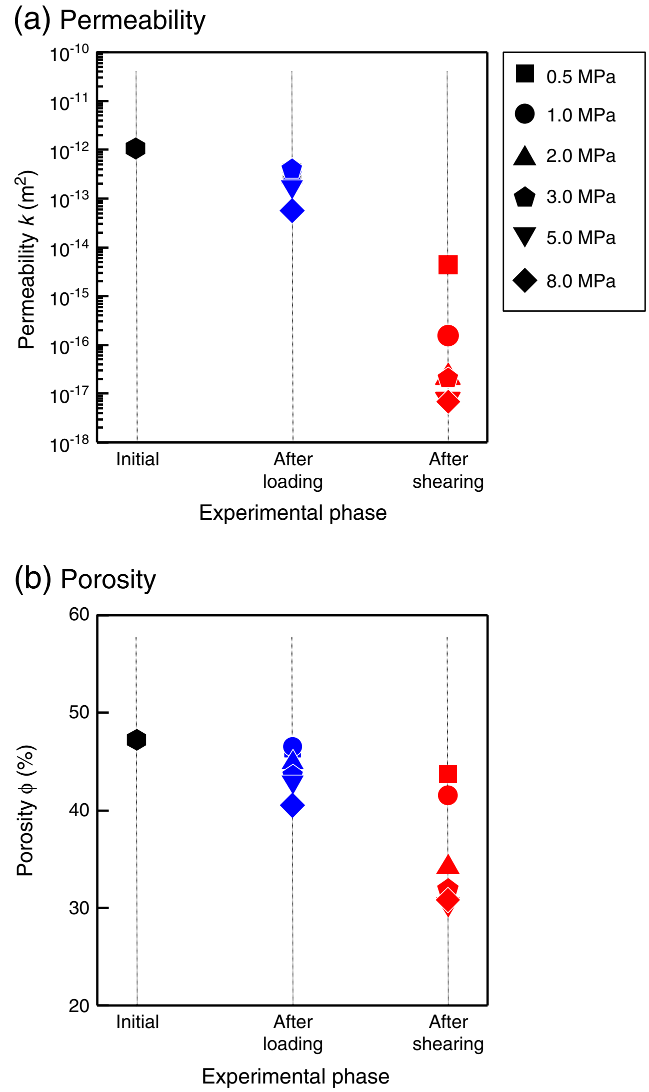

Fig. 3. Changes in permeability and porosity after normal loading and ring-shearing.

been observed (Nagakubo et al., 2009). It is necessary to consider the production methods as well as the permeability around faults to estimate methane gas production from the methane hydrate reservoir, because shearing caused by fault slip may produce drastic changes in the texture of materials. Porosity reduction is usually associated with grain size reduction and with fault slip due to reorientation of particles (Beeler et al., 1996; Biegel et al., 1989; Marone and Scholz, 1989; Morrow and Byerlee, 1989; Tobari et al., 2007).

Several studies have reported grain breakage and porosity reduction under confining stress in artificial fault gouge or natural fault rocks. These studies found that permeability change is related to porosity

Table 1
Permeability and porosity in normally consolidated condition.

Effective normal stress during shearing (MPa)	Permeability (m^2)			Porosity (%)		
	Initial	After loading	After shearing	Initial	After loading	After shearing
σ'_n	k_i	k_{al}	k_{as}	ϕ_i	ϕ_{al}	ϕ_{as}
0.5		3.51×10^{-13}	4.38×10^{-15}		46.2	43.7
1.0		3.88×10^{-13}	1.56×10^{-16}		46.5	41.5
2.0	1.08×10^{-12}	2.83×10^{-13}	2.13×10^{-17}	47.2	44.8	34.1
3.0		4.10×10^{-13}	2.02×10^{-17}		43.5	31.8
5.0		1.82×10^{-13}	7.73×10^{-18}		42.9	30.4
8.0		5.71×10^{-14}	6.89×10^{-18}		40.5	30.8