Fracture characteristics obtained from core observations and image logs in a borehole drilled through an active fault zone

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ABSTRACT: Fracture characteristics in and around active fault zones are required for understanding hydrogeological characteristics along fault zones. To examine the fracture characteristics, we used core samples and geophysical log data collected from the Futagawa fault drilling project. Fracture density and angle of dip were quantitatively measured using core samples. As a result, the closed fractures with semiconsolidated brown clays were revealed dominant along the Fault 461 damage zone ruptured during 2016 Kumamoto earthquake mainshock, and the fracture density were higher in volcanic rocks than that in sedimentary rocks, and fractures were mainly oblique fractures with respect to the strike of the active fault. Kumamoto earthquake occurred at Fault 461 damage zone characterized by closed fractures, it suggests that the fault may have ruptured at the low permeability zone.

Keywords: fracture density, active fault, core, image log, 2016 Kumamoto earthquake.

1 INTRODUCTION

Fracture characteristics and distributional parameters in rock masses are required for understanding permeability and mechanical properties in and around fault zones. Observation of rock cores and analysis of fracture orientation from image logs in drilling are considered to be useful to determine the fracture characteristics and distributional parameters. The Futagawa fault drilling project (hereafter called FFDP) including one mostly vertical main borehole (FDB borehole) penetrating the Futagawa fault zone ruptured during the 2016 Mw 7.0 Kumamoto earthquake mainshock was conducted by Kyoto University (2018). The FDB borehole is located west-southwest of Aso volcano ~10 km away from the edge of the caldera (Figure 1). Here, we report fracture characteristics in sedimentary rocks and volcanic rocks in and around an active fault zone in the FDB borehole determined from core observations and borehole televiewer (BHTV) images.

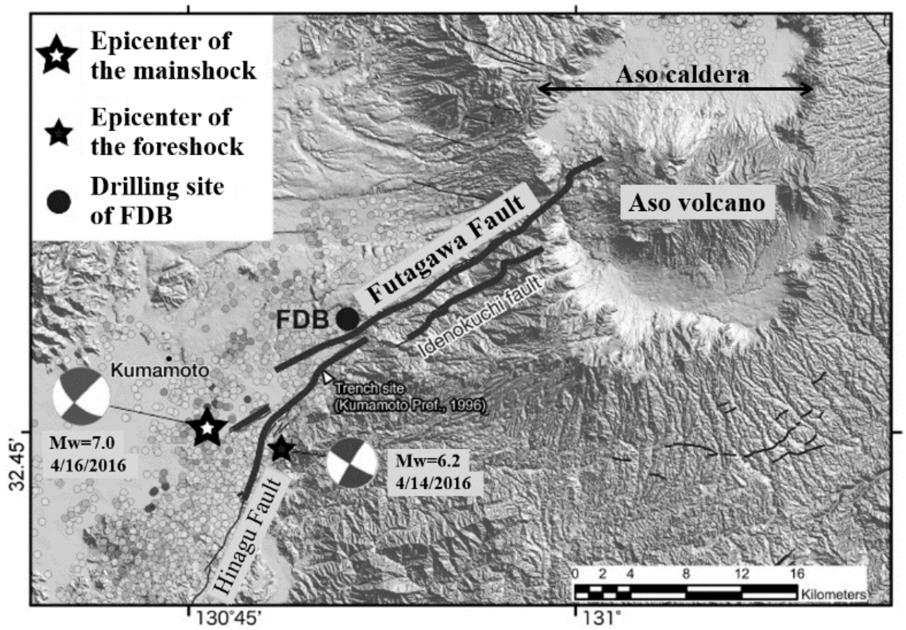

Figure 1. Locations of drilling site of the FDB borehole and Futagawa fault (modified from Toda et al. 2016).

2 CORE SAMPLES AND IMAGE LOG DATA

We used core samples and geophysical log data obtained from the FFDP conducted in southwestern Japan (Kyoto University 2018). Fracture density in the FDB borehole was determined by Shibutani et al. (2022). To reveal the fracture characteristics in the damage zone of the active fault more clearly, we only report the core observations and BHTV images for fracture analysis in this congress full paper.

The core samples and image log data were retrieved in depths from ~300 m to ~700 m in the FDB borehole at the location (32°48′22.3″N, 130°51′36.4″E) during FFDP. The core samples were obtained by full coring through the Futagawa fault. The image logs were performed twice for different depth intervals from ~300 m to ~700 m in the open borehole. However, the image log data was not available for a depth interval of 383–399 m within ~300–700 m due to borehole wall collapse (Kyoto University 2018 and Shibutani et al. 2022).

3 METHOD

We quantitatively measured fracture density and fracture angle of dip in the core samples retrieved from depths of ~300–700 m in the drilled borehole. The fracture characteristics observed include fracture-filling materials. The fracture density was calculated as the number of fractures per meter by counting all fractures in the core samples. Natural fractures were counted, and their fracture density was calculated, but secondary fractures created by drilling in the core samples were excluded from our fracture counting. Fracture angles of dip were recorded and categorized as “L”, meaning <30° from the horizontal plane, “M” for angles ≥30° and <60° and “H” for angles ≥60° (Figure 2). The fracture orientation (strike and dip) was obtained from the BHTV images (Figure 3), and angles of dip were compared with the those confirmed by core observations. The sine curves on Amplitude panel in Figure 3 are the records of fracture picking to count fracture numbers and to determine fracture’s dip azimuth and angle of dip. Solid and dashed curves denote categories of the fracture certainty; i.e. clear fractures and slightly unclear fractures.

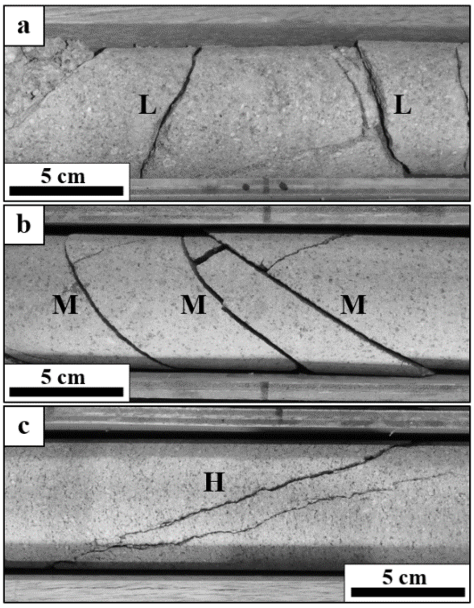

Figure 2. Categories of facture angles of dip. Core photos (a), (b), and (c) show fractures in the L, M, and H categories, respectively.

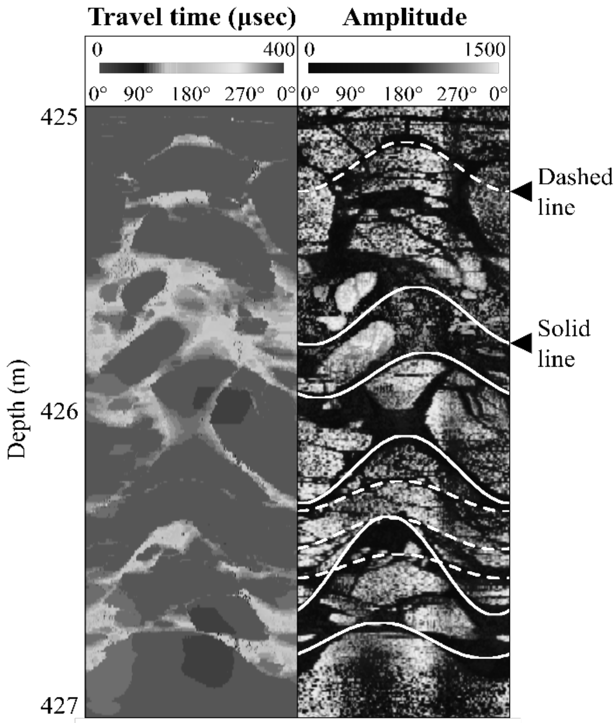

Figure 3. BHTV images of the FDB borehole (modified from Kyoto University 2018 and Shibutani et al. 2022). Two images are arrival time (travel time) and intensity (amplitude value), respectively.

4 RESULTS

We counted a total of 1095 fractures, including 910 natural fractures and 185 secondary fractures by core observation (Figure 4b). The fractures were clearly concentrated in andesite of volcanic rocks. The depth interval with fracture density of greater than 5 fractures/m was repeatedly identified in depth interval of ~385–515 m within the deformation zone. The natural fracture numbers of categories L, M and H were 245, 396 and 269, respectively. The fractures of category L were concentrated in the upper and lower parts of andesitic massive lava. These fractures were mainly associated with dark brown or black secondary minerals, which are thought to be related to chemical weathering. The fractures of categories M and H were widely existing. In the depth range of 423–434 m, the fracture density showed high values of 5–15 fractures/m, and their attitudes had predominantly medium to high angles. These fractures include fractures without secondary minerals, which are considered to be newly formed were dominant within the andesite.

The fractures with semiconsolidated brown clays were dominant in the Fault 461 damage zone, and fracture density of greater than 5 fractures/m in depths around 461 m, 470 m and 500 m (Figure 4c). Strike-slip slickenlines in approximately horizontal directions on fracture surfaces, within semiconsolidated brown clays were confirmed. This clay is mainly homogenous with no structure of fault. Our observations suggest that closed fractures with semiconsolidated brown clays might be old fractures which experienced strike-slip fault movement after the fracture apertures were filled by clays.

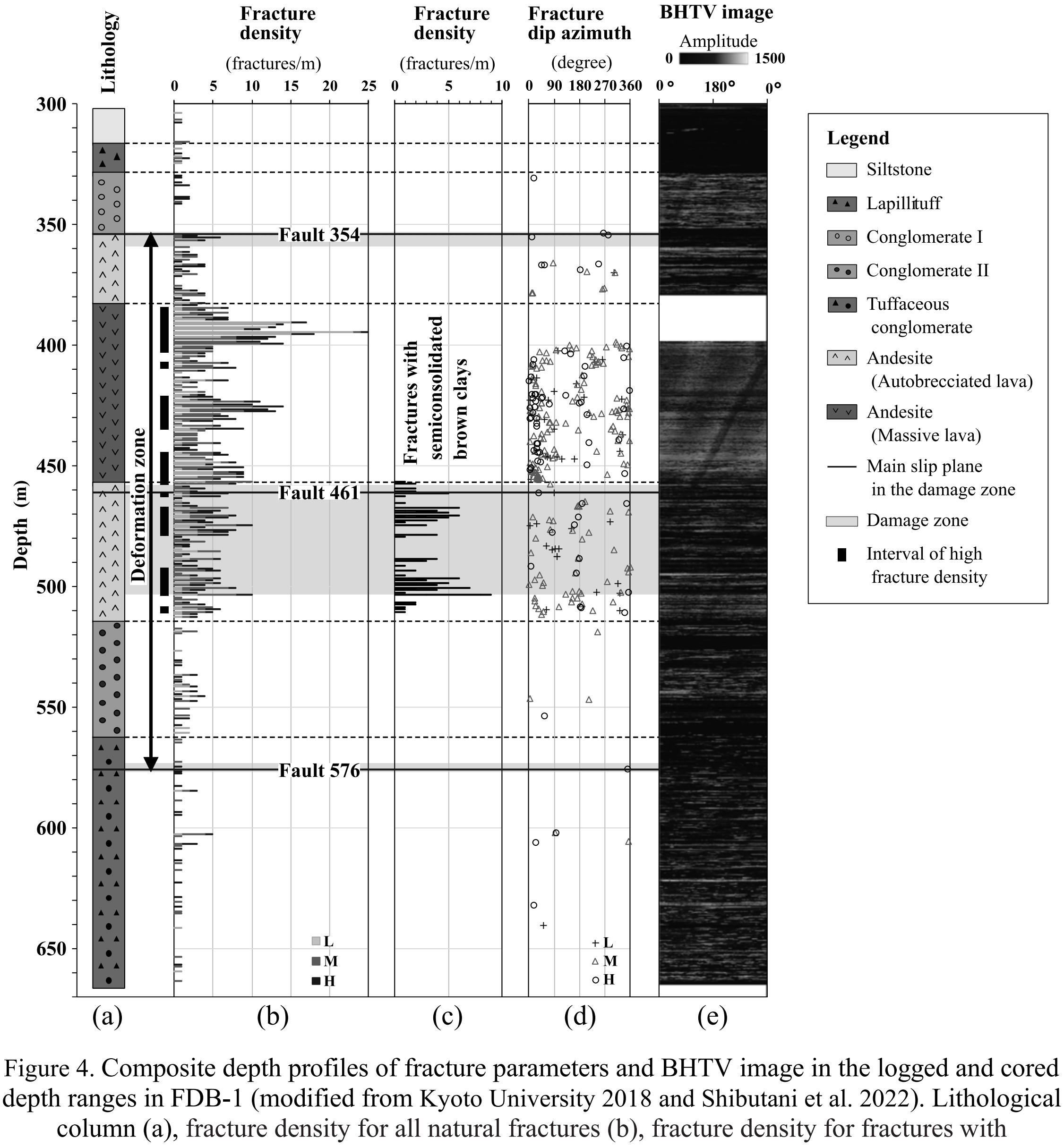

Figure 4. Composite depth profiles of fracture parameters and BHTV image in the logged and cored depth ranges in FDB-1 (modified from Kyoto University 2018 and Shibutani et al. 2022). Lithological column (a), fracture density for all natural fractures (b), fracture density for fractures with semiconsolidated brown clays (c), fracture dip azimuth (d), and a BHTV amplitude image (e).

We obtained fracture orientations of 288 fractures, including 38 clear fractures and 250 slightly unclear fractures, and measured the fracture angles of dip and their dip azimuths by using the BHTV images (Figure 4d and 4e). The fracture numbers of categories L, M and H were 40, 176 and 72, respectively. The dip azimuths of the M and H fractures were dominant from northwest to northeast (approximately 315–45°). Therefore, fracture strikes indicate range of northeast-southwest (NE-SW) to northwest-southeast (NW-SE) directions. This observation revealed that the M and H fractures were mainly oblique fractures, which the fracture strikes ranged widely from subparallel to orthogonal to approximately NE-SW with respect to the surface rupture of the Futagawa fault.

5 SUMMARY

Knowledge of the fracture characteristics in and around active fault zones is necessary for hydrogeological problems, for an example, for understanding the permeability structure of active fault zones. To reveal fracture characteristics along an active fault zone, we qualitatively observed fracture characteristics and quantitatively measured fracture density in the core samples retrieved from depths of ~300–700 m in the drilled borehole (Shibutani et al. 2022); but showed the fracture characteristics focused on the relationship between the filling materials and the fracture angle of dip in this congress full paper simply. The closed fractures with semiconsolidated brown clays were revealed dominant along the Fault 461 damage zone. This result suggests that the Fault 461 damage zone is considered to work as low permeability structure. Considering the results that the rupture of the Kumamoto earthquake occurred at Fault 461 damage zone (Shibutani et al. 2022), it indicates that the fault may have ruptured at the low permeability zone. The fracture strikes in the deformation zone did not concentrate in a coherent direction. This result indicate that may facilitate network connectivity of permeability fractures along the fault zone and increase high permeability zone. In addition, fractures were dominant in volcanic rocks that are harder than sedimentary rocks, which may reflect differences such as Young's modulus of mechanical properties.

ACKNOWLEDGEMENTS

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