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Tectonic implications of damage zone-related fault-fracture networks revealed in drill core through the Nojima fault, Japan

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Abstract

1800 m of drill core through the Nojima fault zone, Japan, reveals subsidiary fault and fracture networks that developed in the fault zone that triggered the 1995 Ms 7.2 Kobe earthquake. The subsidiary fault zones contain a fault gouge of <1 cm bounded by thin zones of foliated cataclasite or breccia. Fractures are filled with calcite veins, calcite-cemented breccias, clay, and iron-oxide and carbonate alternation of the granitic host rock. These features are typical of extensional fractures that form the conduit network for fluid flux close to a major fault zone. The zone of distributed deformation surrounding the main fault is 50 m in width, and the dip of the Nojima fault at >1 km depth is 75°. The fault-fracture networks associated with the Nojima fault zone are coseismic and were filled with carbonate and fine-grained material during repeated seismic-related infiltration of the fault zone by carbonate-bearing subsurface water. This study shows that fault-related fracture networks plays an important role as fluid flow conduits within seismically active faults, and can change in character from zones of high permeability to low permeability due to cementation and/or pore collapse.

Keywords: Nojima fault zone; Drill core; Seismic faulting; Damage zone; Fault-fracture networks

1. Introduction

Long-lived fault zones within the upper crust are generally composed of a fault core containing major slip planes, adjacent damage zones, and surrounding areas of undeformed protolith (e. g. Chester et al., 1993; Caine et al., 1996). The core zone of the active fault accommodates the majority of accumulated fault displacement, and contains major slip planes, fault gouge, cataclasite, foliated cataclasite, and fault breccia (Seront et al., 1998; Caine and Foster, 1999; Lin, 1999, 2001; Wilson et al., 2003). Damage zones, developed on either side of the core zone, are generally characterized by structures subsidiary to the main fault zone, including localized cataclasites, subsidiary faults and fractures linking the core zone and undeformed protolith (Chester and Logan, 1987; Chester et al., 1993). Damage zones record much lower bulk shear strain than the fault core zone (Caine et al., 1996).

The University Project Group of Japan conducted a drilling project through the Nojima fault zone, Awaji Island, Japan (Fig. 1), in order to document the effects of the 1995 M7.2 Kobe earthquake recorded within the

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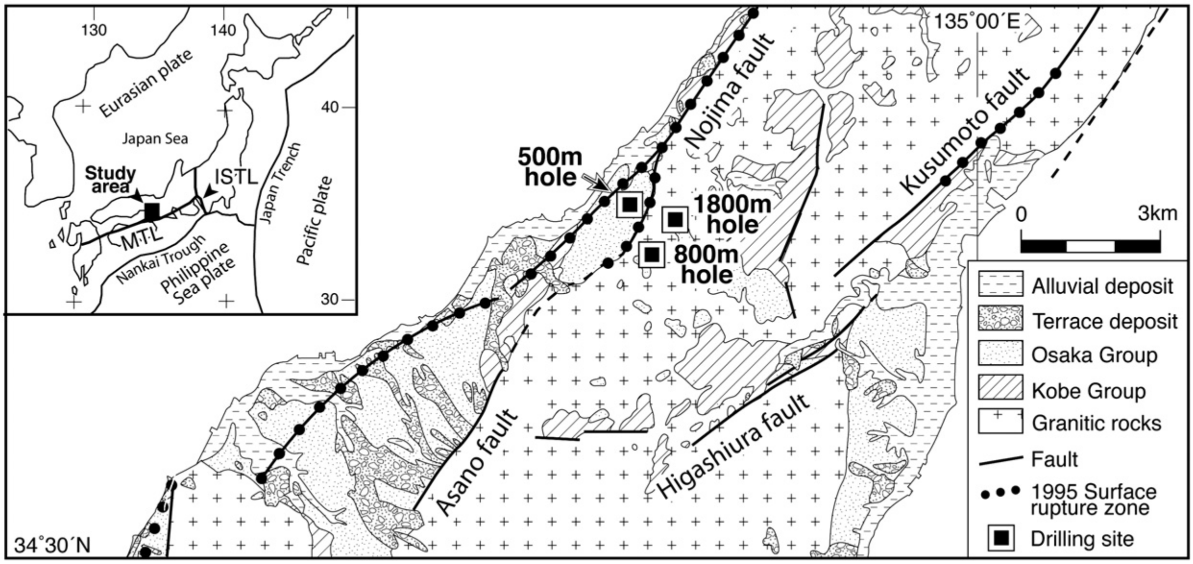

Fig. 1. Simplified geological map of the northern Awaji Island, Japan (modified from Mizuno et al., 1990; Lin and Uda, 1995, 1996). ISTL: Itoigawa-Shizuoka Tectonic Line; MTL: Median Tectonic Line.

fault zone (Lin et al., 1995; Lin and Uda, 1996). Three boreholes, of depths 500 m, 800 m, and 1800 m, were drilled into or near the fault zone by the Disaster Prevention Research Institute, Kyoto University (Ando, 2001). The fault rocks within the fault core zone have been studied in detail from both field outcrops (e.g. Lin, 1999; Shigetomi and Lin, 1999; Lin, 2001) and drill core (e.g. Tanaka et al., 1998; Kobayashi et al., 2001; Lin et al., 2001; Uda et al., 2001). It is revealed that fault rocks are composed of cataclastic rocks including foliated cataclasite, cataclasite, fault breccia, pseudotachylyte, and fault gouge, which are distributed in a ~50-m-wide deformation zone in granitic rock on the hanging wall of the Nojima fault (Lin, 1999, 2001; Lin et al., 2001). A fault core zone characterized by a 150-cm-thick fault zone was found in both the 500-m drill core (Tanaka et al., 1998; Lin et al., 2001) and the field outcrops (Shigetomi and Lin, 1999; Lin et al., 2001). The structural and chemical analyses of the drill cores show that there are a lot of crack-filling clay and calcite veins which were formed by the flow of surface water down to the deep fractured zone of the Nojima fault zone during seismic faulting (Uda et al., 2001; Lin et al., 2003a,b).

This study focuses on the tectonic implications of subsidiary fault and fracture networks within the damage zones of host granitic rocks recorded in the 1800-m drill core. Detailed structural analysis of the fault-fracture networks developed in the seismic fault zone will help to develop predictive solutions to problems involving seismic hazards, brittle deformation mechanisms within and near the main fault zone.

2. Geologic setting

The northern Awaji Island, southwestern Japan, is cut by a number of active faults, including the Nojima, Asano, Kusumoto, and Higashiura faults (Fig. 1). The Nojima and Asano faults, which record co-seismic rupture associated with the M7.2 1995 Kobe earthquake, pass close to the drill site (Fig. 1, Lin et al., 1995; Lin and Uda, 1996; Lin, 1997), and form a right-stepping en echelon geometry. The jog area between these two faults is thought to represent a seismic barrier where the aftershocks of the Kobe earthquake were concentrated (Lin and Uda, 1995). Both the Nojima and Asano faults strike northeast, dips 75°–85° southeast, and border the western margin of the mountains on the northwestern coast of the northern Awaji Island (Fig. 1). Based on the analytic results of fault structures and S–C fabrics of foliated cataclastic rocks, it is inferred that the Nojima fault zone is a right-lateral strike–slip fault with a thrust component, and the ratio of horizontal to vertical displacement is about 3:1 (Lin et al., 2001). Total vertical displacements recorded on the Nojima and Asano faults are estimated to be 490–540 m and 260–310 m respectively (Murata et al., 2001). The Nojima fault displaces late Quaternary alluvial fans and terraces up to a few tens of meters both horizontally and vertically (Mizuno et al., 1990; Lin et al., 1995). The fault rocks within the <50–