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# Spatial variations in damage zone width along strike-slip faults: An example from active faults in southwest Japan

Aiming Lin [a,*], Kazuhiko Yamashita [b]

[a] Department of Geophysics, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan
[b] Graduate School of Science and Technology, Shizuoka University, Shizuoka 422-8529, Japan

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ABSTRACT

Field investigations reveal spatial variations in fault zone width along strike-slip active faults of the Arima–Takatsuki Tectonic Line (ATTL) and the Rokko–Awaji Fault Zone (RAFZ) of southwest Japan, which together form a left-stepping geometric pattern. The fault zones are composed of damage zones dominated by fractured host rocks, non-foliated and foliated cataclasites, and a fault core zone that consists of cataclastic rocks including fault gouge and fault breccia. The fault damage zones of the ATTL are characterized by subsidiary faults and fractures that are asymmetrically developed on each side of the main fault. The width of the damage zone varies along faults developed within granitic rocks of the ATTL and RAFZ, from ∼50 to ∼1000 m. In contrast, the width of the damage zone within rhyolitic tuff on the northwestern side of the ATTL varies from ∼30 to ∼100 m. The fault core zone is generally concentrated in a narrow zone of ∼0.5–∼5 m in width, consisting mainly of pulverized cataclastic rocks that lack the primary cohesion of the host rocks, including a narrow zone of fault gouge (<0.5 m) and fault-breccia zones either side of the fault. The present results indicate that spatial variations in the width of damage zone and the asymmetric distribution of damage zones across the studied strike-slip faults are mainly caused by local concentrations in compressive stress within an overstep area between left-stepping strike-slip faults of the ATTL and RAFZ. The findings demonstrate that fault zone structures and the spatial distribution in the width of damage zone are strongly affected by the geometric patterns of strike-slip faults.



## 1. Introduction

Active faults and related fault-zone structures that form at shallow depths within the upper crust are closely related to the long-term seismic faulting history of seismogenic faults (e.g., Lin, 1999, 2008; Sibson, 2003; Lin et al., 2010). Accordingly, the analysis of deformation structures along active fault zones provides important information in reconstructing the long-term seismic faulting behavior of active faults and in understanding the tectonic environment and history of such faults.

Active fault zones are generally characterized by damage zones developed on either side of the fault, and an intervening fault core zone that contains the main slip surfaces (Fig. 1) (e.g., Bruhn et al., 1994; Kim et al., 2004; Gudmundsson et al., 2010; Takagi et al., 2012). The damage zones, which comprise deformed wall rocks that bound the fault core zone, result from the accumulated seismic slip along faults. These zones typically contain fractured host rocks, and foliated and non-foliated cataclasites that retain the primary cohesion of the host rocks. In the case of a mature fault, the width of the damage zone varies from decameters to kilometers (Fig. 1) (e.g., Cowie and Scholz, 1992; McGrath and Davison, 1995; Lin et al., 2007; Takagi et al., 2012).

In contrast, the core zone consists of cataclastic rocks that have lost the primary cohesion of the host rocks, including fault breccia and fault gouge in zones that accommodate the majority of the accumulated seismic slip, which is commonly concentrated in a narrow zone (<10 m wide) along the main fault plane (e.g., Sibson, 1977, 2003; Lin, 1999, 2001; Kim et al., 2004; Mitchell et al., 2011). In a mature fault zone, the damage zone commonly contains subsidiary faults with narrow core zones that include thin zones of fault breccia and fault gouge layers with widths of millimeter to meters.

This study presents a case study on the structures of strike-slip fault zones of the Arima–Takatsuki Tectonic Line (ATTL) and Rokko–Awaji Fault Zone (RAFZ), which consist of multiple right-lateral strike-slip active faults in southwest Japan. Previous

* Corresponding author. Tel./fax: +81 75 753 3941.
*E-mail addresses:* slin@kugi.kyoto-u.ac.jp, aiming777@hotmail.com (A. Lin).

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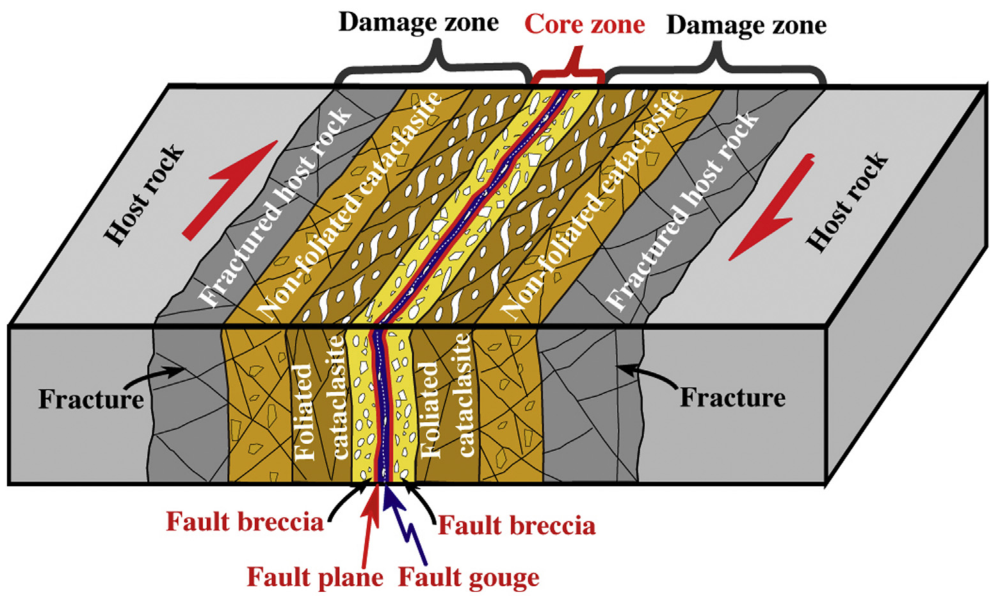


**Fig. 1.** Schematic model of a fault core zone and damage zone within a strike-slip fault zone. The fault core zone consists of fault breccia and fault gouge that have lost the primary cohesion of the host rocks. The damage zone is composed of foliated and non-foliated cataclasites and fractured host rocks that retain the primary cohesion of the host rocks. Red arrows indicate the sense of strike-slip displacement on the fault. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

studies have shown that the ATTL and RAFZ are dextral strike-slip active faults (Maruyama and Lin, 2000, 2002, 2004), along which the pulverized fault rocks with numerous ultracataclastic veins are developed (Lin et al., 2001, 2007, 2013; Mitchell et al., 2011). In this study, we focus on the spatial variations in damage zone width and fault zone structures along the ATTL and RAFZ based on field investigations, and discuss the formation mechanisms of damage zone of strike-slip active faults and their tectonic implications.

## 2. Geological setting

The study region is located in the marginal zone of the Eurasia plate, and is bounded by the Median Tectonic Line in southwest Japan (Fig. 2a). The study region contains two major strike-slip active fault zones: the ENE–WSW-striking ATTL and the NE–SW-striking RAFZ, which together form a left-stepping geometric pattern (Figs. 2b and 3) (Huzita and Kasama, 1982; Research Group for Active Faults of Japan, 1980; Maruyama and Lin, 2002; Lin et al., 2007). The ATTL is dominated by the Kiyoshikojin, Rokko, and Ibayama faults, which show mainly dextral strike-slip movement. These faults occur along the northern margin of the Osaka Basin, extending for about 60 km (Figs. 2b and 3). The average slip rate along the ATTL is 1–3 mm/year horizontally, with a vertical component of ~0.3 mm/year (Maruyama and Lin, 2002). Based on trench investigations, it is inferred that the youngest seismic faulting event along the fault zone was the M 7.25–7.50 Keicho–Fushimi earthquake of 1596 (Sangawa, 1997; Maruyama and Lin, 2002).

The RAFZ contains the Gosukebashi, Otsuki, Koyo, Suwayama, and Nojima faults, which extend for more than 70 km from the northeastern part of Awaji Island through the Akashi Strait (where the 1995 $M_w$ 7.2 Kobe earthquake occurred; Lin and Uda, 1996), finally meeting the ATTL to the northeast at an oblique angle (Figs. 2b and 3). Co-seismic surface ruptures produced by the 1995 Kobe earthquake occur mainly along the southern segment of the RAFZ, upon the pre-existing Nojima Fault on Awaji Island (Fig. 2b) (Lin and Uda, 1996). Based on geological structures and analyses of topographical features, it is inferred that (i) the total displacement of the ATTL is around 17 km, and (ii) the ATTL and ARFZ formed after mid-Miocene and is presently active, with an average dextral slip rate of 1–3 mm/year and a vertical component of ~0.3–0.4 mm/year (Maruyama and Lin, 2000, 2002). The penultimate seismic event (i.e., prior to the 1995 Kobe earthquake) upon this fault was the 1596 Keicho–Fushimi earthquake (M 7.25–7.50), as also found along the ATTL (Lin et al., 1998).

The basement rocks in the study region are composed mainly of Cretaceous granitic rocks (Rokko granitic rocks), welded rhyolitic tuff (Arima Group), Oligocene–Eocene sedimentary rocks (Kobe Group), and mid-Pleistocene sedimentary rocks (Osaka Group) (Fig. 3). The Rokko granitic rocks occur mainly on the southwest side of the ATTL, whereas the Arima Group occurs mainly on the northern side. The Kobe Group is dominated by mudstone, sandstone, and conglomerate, and occurs mainly on the northwest side of the ATTL. The Osaka Group comprises weakly consolidated to unconsolidated alternating beds of silt, clay, and gravel, mainly in the southeast part of the study region. Quaternary alluvial deposits are largely restricted to lowland areas in the southeastern part of the study region, on which terrace risers are widely developed (Fig. 3).

## 3. Fracture density and occurrence of fault zones

### 3.1. Measurements of fracture density and width of the damage zone

Damage zones generally consist of weakly deformed host rocks within which fault-related fractures and fault rocks are developed in deformation zones of variable width along the fault. To qualitatively assess the spatial distribution and width of the damage zones and related deformation structures, we first performed field measurements of the fracture density along profiles oriented across fault zones of the ATTL and RAFZ, and then observed the meso- and microstructures of fault rocks developed within the zones. We selected the sides where the basement rocks are well exposed due