# Comparison of Damage Zones of the Nojima and the Asano Faults from the Deep Drilling Project: Differences in Meso-to-microscale Deformation Structures related to Fault Activity

Takafumi Nishiwaki

**Contents**



**Summary**

Large inland earthquakes occur repeatedly in mature active faults and leave evidence reflecting seismic slip events in deformed rocks, including fault gouge, fault breccia, cataclasite, and pseudotachylyte. In active fault zones, the structural analysis of deformed rocks provides important information for reconstructing long-term seismic activity and understanding faulting mechanisms. Investigations of the structural characteristics of fault rock can be achieved by drilling into fault/shear zones, as this provides continuous samples unaffected by weathering and alteration that occur near the ground surface.

The $M_w$ 6.9 1995 Hyogo-Ken Nanbu earthquake caused great social and economic damage. Surface ruptures associated with this earthquake appeared along the Nojima fault system. At the Ogura site, north of Awaji Island, surface ruptures occurred along

the Nojima and Asano active faults, which together constitute the Nojima fault system. It is important to compare the deformed structures between the Nojima and Asano faults and to discuss their activity and evolution to understand the evolution of the fault/shear zone, which consists of several fault strands. In this thesis, the deformation structures in these faults are compared and their activity and evolution are discussed.

The main findings of this thesis are the following:

1) Meso- to micro-structural analyses on recovered core samples show that the Nojima fault gouge zone has a thickness of 10–30 cm, perpendicular to the fault plane, and can be divided into 10–20 thin sub-layers based on color and structural differences. Individual gouge layers show a range between 2–3 mm and ~5 cm in thickness, and contain differently colored breccia of fault gouge that are offset or cut by cracks and calcite-filled veinlets. Some of the thin calcite veins are bound by fault planes and network veinlets are well developed at the sub-millimeter scale. These features reveal that the 10–30 cm-thick fault gouge zone records recent repeated paleo-seismic events that occurred in the Nojima fault. In contrast, the 2–14 cm-thick Asano fault gouge zone is characterized by a disturbed structure with no distinct shear foliation and sub-layers, in which the number of seismic events cannot be estimated.
2) The fault damage zone of the Nojima fault can be observed in the drilling core samples under the naked eye and the geophysical survey data. The 20 cm-thick fault gouge zone of the Nojima fault was intersected in the main drilling hole at a depth of 529.3 m, whereas the 14 cm-thick fault gouge zone of the Asano fault was intersected in the main drilling hole at a depth of 460.6 m. The dips of the Nojima and Asano faults were estimated to be 82–72° and 62°respectively, and the width of

the fault damage zone associated with both of faults was inferred to be ~57 m.

3) Meso- to micro-structural analyses of the fault damage zone in core samples show that the damage zone of the Nojima fault preserves deformation structures including cataclastic veins and anastomosing fractures. This fault damage zone coincides with a zone of P-wave velocity, rock density, and electric resistivity anomalies in the geophysical logging data sets. In contrast, the fault damage zone of the Asano fault preserves the mineral veins filling the fractures. The fault damage zone does not coincide with a zone of anomalies in the geophysical logging data sets. These structural features may indicate that the seismic activity along the Nojima fault was more notable than that along the Asano fault during the recent geologic period.

4) The orientations of the fractures and subsidiary faults of the Nojima and Asano faults are concentrated in the range of N50–70°E and N30–60°E, respectively, roughly coinciding with the general trend of the Nojima fault system.

The structural differences between the Nojima and Asano faults at the Ogura site suggest the spatiotemporal evolution of the Nojima fault system. In the Nojima fault, there are many structural features indicating that multiple seismic slips occurred along the fault in the meso- to micro-scale in the drilling core samples. On the other hand, in the Asano fault, there is almost no structure indicating that recent seismic activity occurred along the fault, although older sheared structures were preserved in the fault damage zone with almost the same thickness as the Nojima fault. These structural contrasts among the Nojima and Asano faults at the macro- to micro-scale at the Ogura site, between the fault damage zone and fault core zone, indicates that fault shear deformation in the recent geologic period mainly occurs along the Nojima fault accommodated by passive deformation of the Asano fault. By considering the healed structure of the Asano fault which suggests activity in the older geologic period, it is inferred that fault shear deformation has not been active along the Asano fault in recent geologic periods.

According to previously published results on the fault activity of the Nojima fault system based on topography and underground structure, it is likely that the main seismic activity has occurred along the Nojima fault in recent geologic periods, and has shifted from the Asano fault to the Nojima fault in the Late Quaternary. It is thought that the historical seismic activity along the Nojima fault system has formed deformation structures in the fault rocks and the difference in the deformation structure between the Nojima and Asano faults. This study strongly suggest that fault activity can be inferred from the basement fault-rock core samples. When we consider the fault activity from just the basement fault-rock core samples, the most important thing is to investigate whether crushed or sheared structures, which are not healed or changed by the following fluid-rock interaction, develop over a wide-scale range and both the fault damage zone and the fault core zone. As shown in this thesis, the deep drilling investigation of fault zones can provide important information for understanding the historical evolution and present activity of active fault systems.