A macro- and micro- structural analysis to determine the deformation style of serpentinite gouge, Jade Cove, Monterey County, California

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ABSTRACT

A serpentinite fault zone, in proximity to the Sur-Nacimiento Fault of California, was studied and its shear structures documented. Field evidence supports experiments that show serpentinite shifts from rate strengthening behavior to rate weakening behavior when reaching a critical loading velocity. These two modes of mechanical behavior are characterized by the presence of both brittle and ductile structures in the zone. Macrostructures at the outcrops scale, as well as microstructures and fabrics within the gouge, provide evidence of both seismic and aseismic episodes. Structurally, the zone displays both localized and distributed deformation. Riedel (R1) shears that bend into parallelism with Y shears, overall clast brecciation, and boundary-local serpentinite fractures, suggest local deformation induced by seismic events. However, microstructures such as lattice-preferred orientation, weak s-c fabrics, and an overall flow-like gouge fabric, suggest that portions of the gouge zone distributed deformation aseismically as a result of typical plate rates. In support of experiments previously performed, this study provides field evidence that the abundance of serpentinite within fault zones may allow for two styles of deformation. Therefore, it is the properties of the serpentinite and the subsequent loading velocity in which it was subjected, not necessarily pressure/temperature conditions alone, which cause evidence of both brittle and ductile regimes to coexist.

BACKGROUND

Serpentinite is a common rock within faults and major shear zones (Christensen, 1972; Allen, 1968). Experiments conducted by Reinen et al. (1991), suggest that serpentinite exhibits two modes of mechanical behavior as a function of loading velocity (Fig. 1). Velocities equivalent to average plate rates result in experimental rate strengthening behavior. Such behavior is characterized by distributed deformation analogous to ductile regimes. Conversely, faster loading velocities result in rate weakening behavior, analogous to brittle regimes. Strain characteristics of serpentinite gouge zones should therefore be different than most common quartzo-feldspathic rocks that exhibit only rate weakening tendencies (Tullis and Weeks, 1986; Blanpied, 1987). It is this rate strengthening characteristic of serpentinite which may be responsible for the reduction of seismic activity along these "creeping sections" of the San Andreas, as well as other zones of reduced seismic activity.

TABLE 1. BRITTLE AND DUCTILE CHARACTERISTICS

Deformational regime:	**Brittle**	**Ductile**
Constitutive behavior:	rate weakening	rate strengthening
Types of Structures:	Riedel (R, R1, Y) shears	S-C fabrics
	broken grains	optical continuity
	cataclasite	augen structures
Overall deformation:	localized	distributed
Geologic behavior:	seismic	aseismic
Earthquake risk:	yes	no

(Adapted from Reinen et al., 1991; Chester et al., 1993; Passchier and Trouw, 1996)

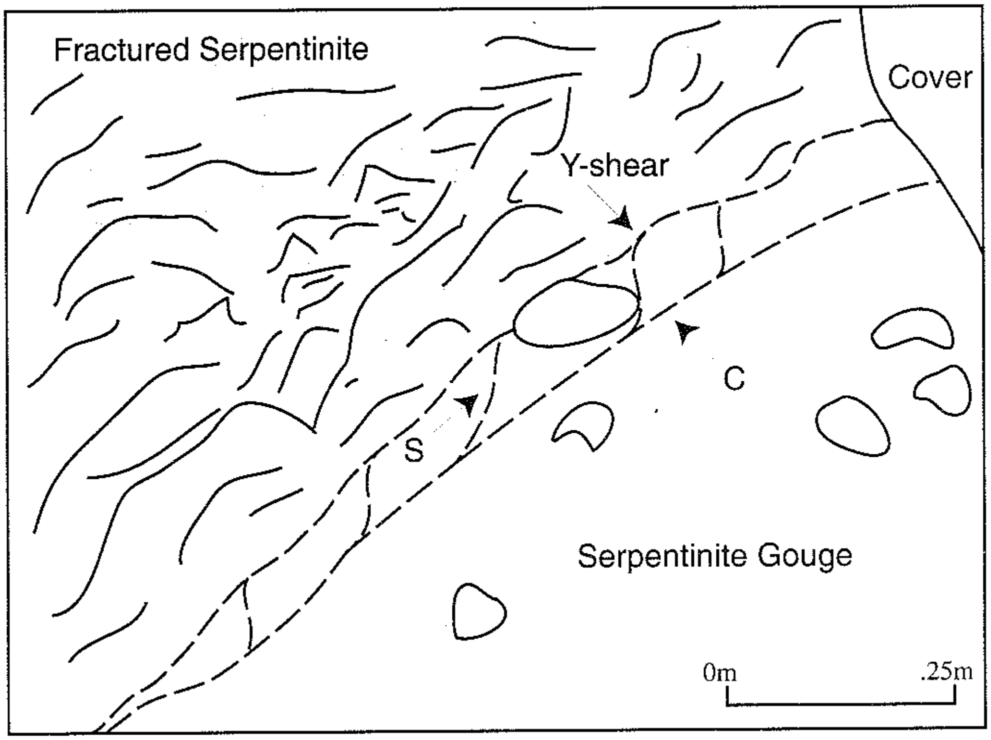

Figure 4. Line drawing of distributed deformation on the outcrop scale. Arrows mark the shear boundary (C) and schistocity (S) within the fabric. Dotted lines indicate all features that are lined with talc.

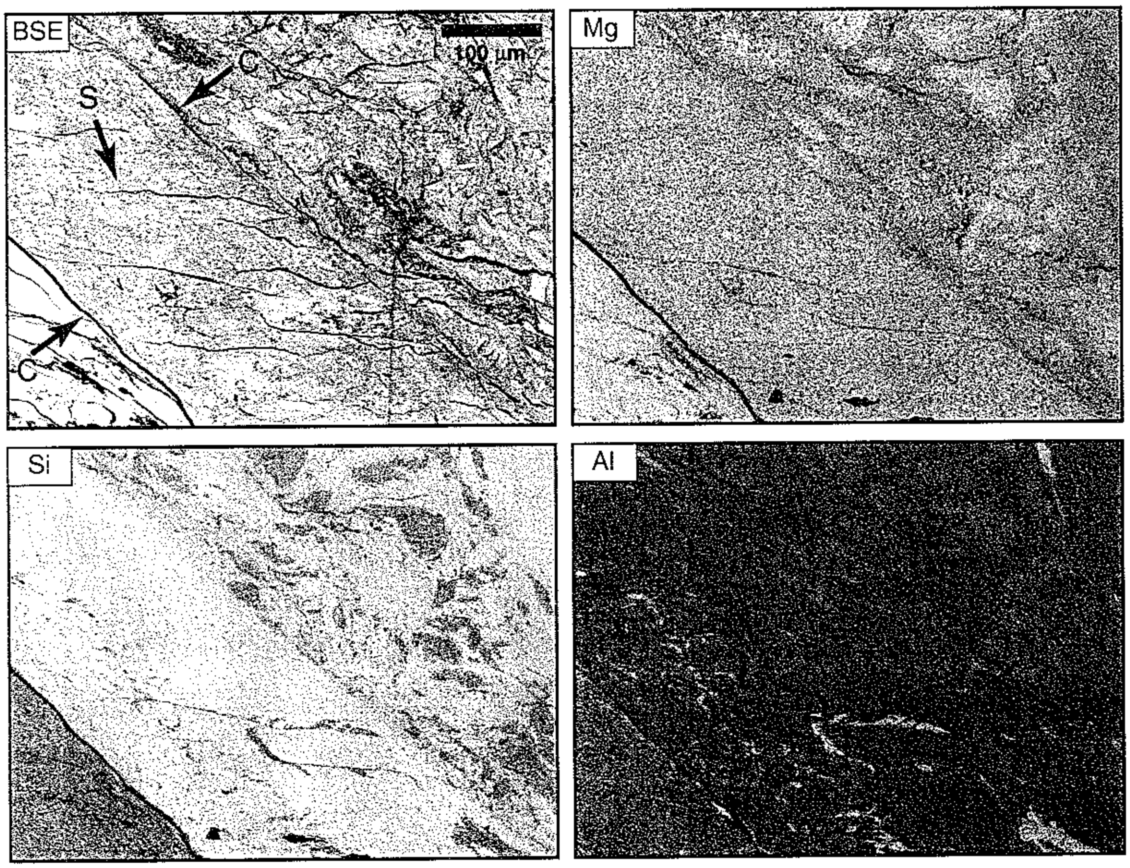

Figure 5. Backscattered electron image and x-ray maps of plastic deformation in the serpentinite gouge. Bright areas have higher concentrations of the elements in the x-ray maps than the dark areas. Arrows indicate S and C foliations. Light material in lower left of BSE is lizardite or antigorite. The foliated, Si-rich material is talc, and the cataclasite in upper right is lizardite/antigorite + talc.

GEOLOGIC SETTING

Jade Cove is located in the Coast Ranges of Western California. The Coast Ranges are composed of three primary rock units: the Franciscan Complex, the Salinian Basement, and the Great Valley Sequence. The geologic histories of each unit are very complex, and have subsequently been heavily debated (Harms and Jayko, 1992; Powell and Weldon, 1992).

CONCLUSIONS

Two distinct styles of deformation were observed from the fault zone located at Jade Cove, Monterey, California. Both brittle and ductile features were present in the fault zone (Fig. 1). Such features represent both rate weakening and rate strengthening episodes within the history of the zone.

Brittle Behavior. At the outcrop scale, the fault zone appeared entirely brittle in origin, with very local deformation. Shears and fractures were very abundant. The boundary rocks in proximity to the damage core were heavily fractured, while the gouge itself was highly brecciated, unconsolidated, and abundant with clasts. Also, both a Y-shear, and a network of R1 Riedel shears were easily visible within the fault zone.

Ductile Behavior. The zone exhibited ductile behavior as well. Preferred crystallographic orientations, weak s-c fabrics, ultra fine-grained talc-serpentinite gouge, as well as overall flow-like gouge fabric, were found in thin section samples. Such structures are indicative of distributed deformation. Portions of the gouge also showed a fabric development at the SEM level.

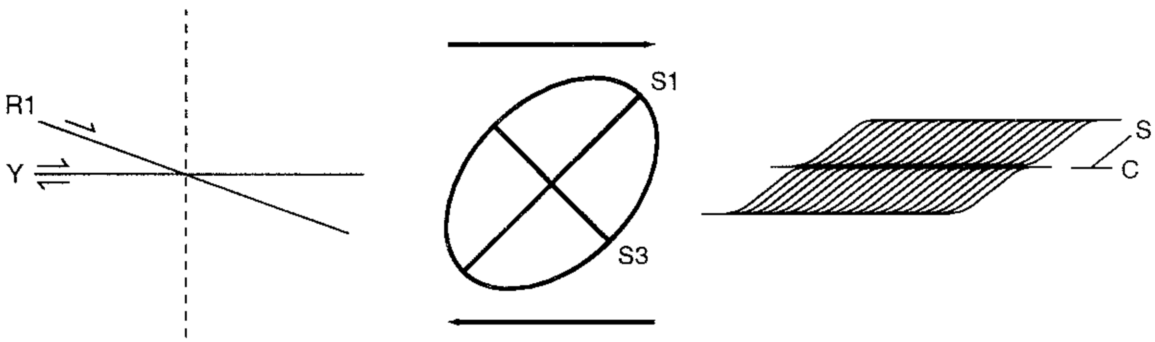

Figure 1. Compilation diagram showing typical structures within Jade Cove fault zone in relation to shear sense. R1 and Y; R1 Riedel shear and Y shear, S1 and S3; long and short axis of finite strain ellipse, S and C; planes of s-c fabric. (Adapted from Hancock, 1985; Petit, 1987, Simpson and Schmid, 1983)

It is very likely that the two separate styles of deformational features found at Jade Cove formed under variable loading velocities. Typical plate rates allowed for ductile deformation, while faster loading velocities accounted for brittle features. This dual deformational behavior can be attributed to the constitutive behavior of serpentinite. At slow loading velocities, the fault behaves in the rate strengthening regime. Conversely, at faster velocities, the fault exhibits a rate weakening behavior.

In conclusion, the fault zone located at Jade Cove, Monterey, California, has experienced both seismic and aseismic episodes. The brittle structures observed were indicative of localized, rate weakening behavior which is evidence of seismicity. Conversely, ductile structures within the fault zone which displayed distributed deformation, recorded aseismic episodes under rate strengthening behavior. In conclusion, the two distinct deformation styles observed at Jade Cove, were directly a result of variable loading velocities acting upon a serpentinite-abundant fault.

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