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Mineralogy of Faults in the San Andreas System That are Characterized by Creep

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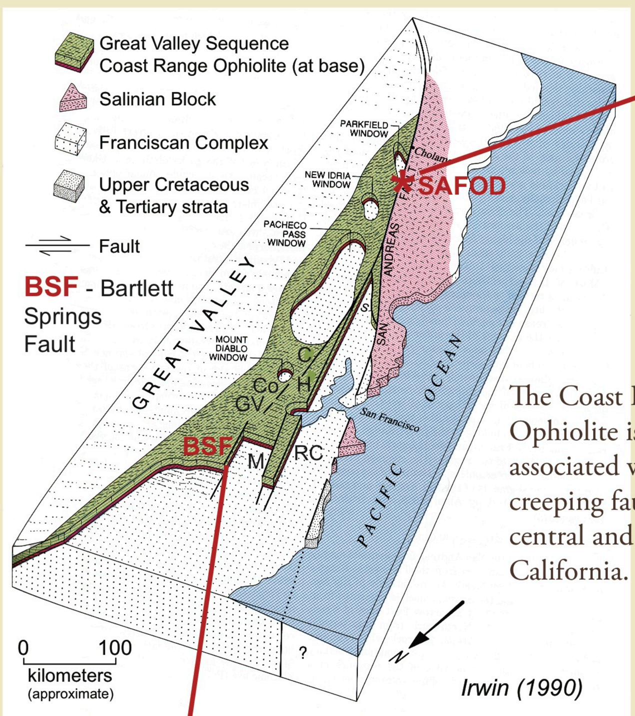
Introduction

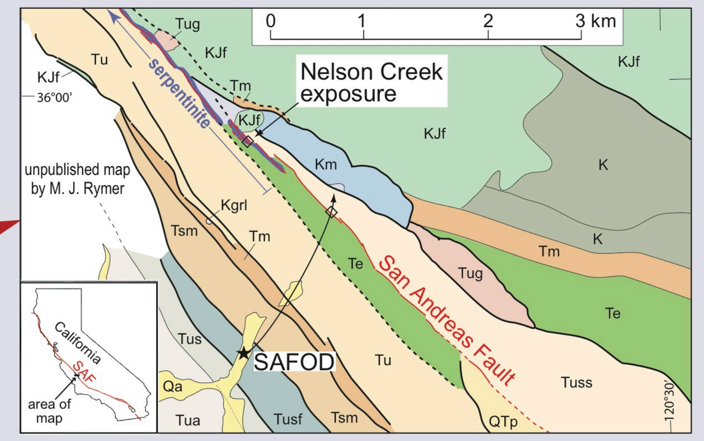
Core recovered from two actively creeping strands of the San Andreas Fault at ~2.7 km depth in the SAFOD borehole is rich in serpentinite and its low-T alteration products, Mg-rich smectite clays. The core supports the long-held view that serpentinite is implicated in the origin of creep. Using the core samples as a guide, similar serpentinite-bearing fault gouge has now been identified in an outcrop near the drill site and, recently, in a creeping strand of the Bartlett Springs Fault (BSF) in northern California. This poster presents a preliminary description of the BSF rocks and compares them to the occurrences of fault gouge in and near SAFOD.



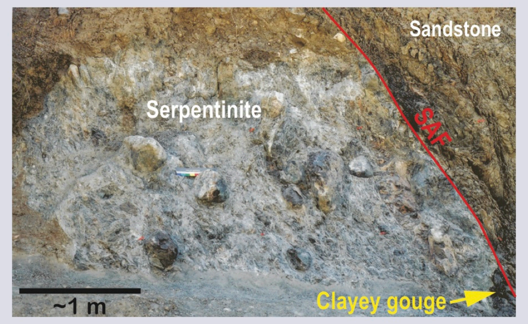
The Coast Range Ophiolite is closely associated with the creeping faults in central and northern California.

San Andreas Fault Observatory at Depth (SAFOD)

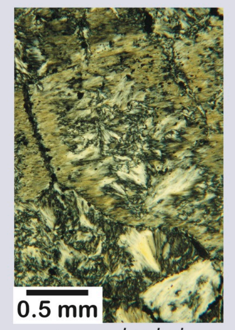
Surface Geology



Geologic map of the area surrounding the SAFOD drill site (black star). The curved black arrow extending NE from the site is the approximate path of the drill hole at depth; the open rectangle marks the fault crossing. Serpentinite occurs as a tectonic smear for at least 2-2.5 km to the NW of the mapped area (extent indicated by purple arrow). An outcrop of the serpentinite at Nelson Creek (photo above, right) features a black, fine-grained zone 0.15 m wide and 0.5 m long at the fault contact, that consists of porphyroclasts of serpentinite and sedimentary rock in a Mg-rich clayey matrix.



Antigorite + magnetite after olivine.

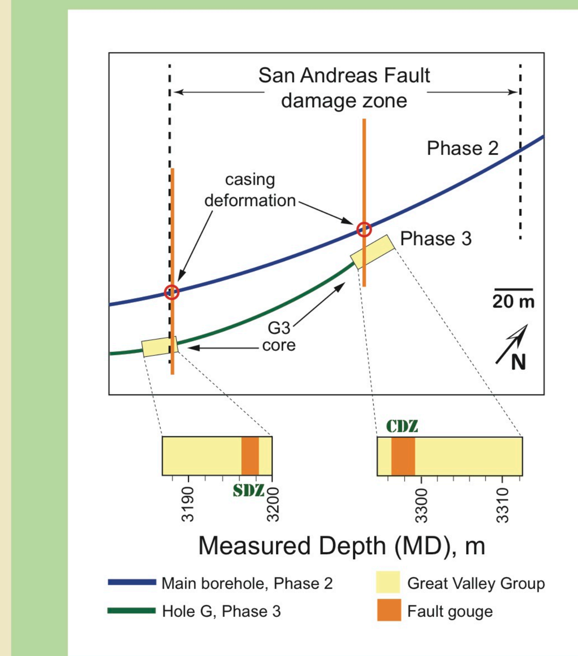


Clayey gouge adjacent to fault trace.

crossed polarizers *thin section scan*

The significance of the clayey gouge became clear after similar fault gouge was recovered at the two depths in the SAFOD core where the fault is creeping.

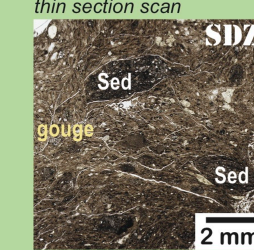
Central Deforming Zone (CDZ) and Southwest Deforming Zone (SDZ)



Phase 3 core was recovered at 2.65-2.7 km vertical depth, at T ~ 112°C. Here, the active trace of the San Andreas Fault lies within North American Plate rocks. The creep rate near SAFOD is 25 mm/yr.

core photo from Phase 3 Core Atlas, www.earthscope.org

Fault creep at SAFOD, evidenced by well-casing deformation, is highly localized to two narrow zones of foliated fault gouge, the central deforming zone (CDZ, 1.6 m wide) and southwest deforming zone (SDZ, 2.6 m wide). Both consist of porphyroclasts of serpentinite (the largest one in the core, shown above, is ~30 cm in diameter) and sedimentary rock dispersed in a foliated matrix rich in Mg-clays.

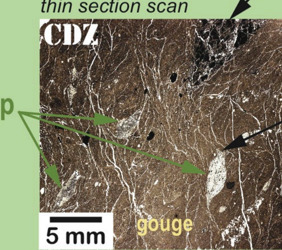


thin section scan

The SDZ is more clast-rich than the CDZ.

thin section scan

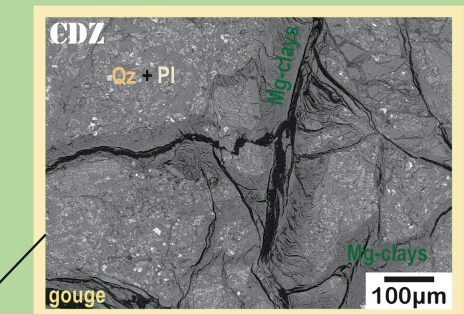
SW boundary of CDZ, faulted against Great Valley rocks.



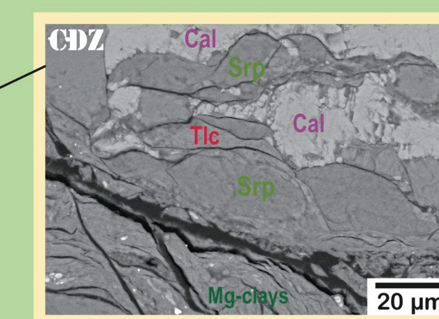
thin section scan

The CDZ takes up the majority of the creep.

Portion of a heavily fractured volcanic (?) porphyroclast (large black clast in the thin-section scan); fractures are lined with Mg-clays.



backscattered electrons



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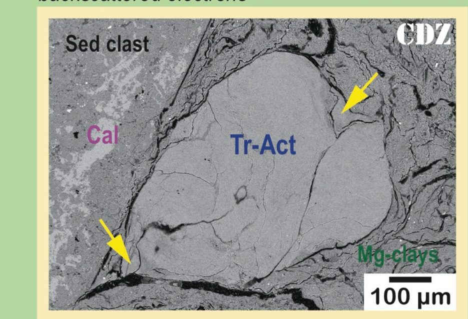

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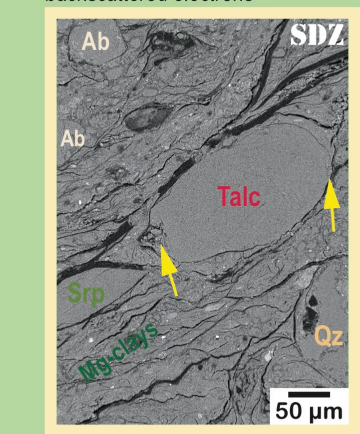
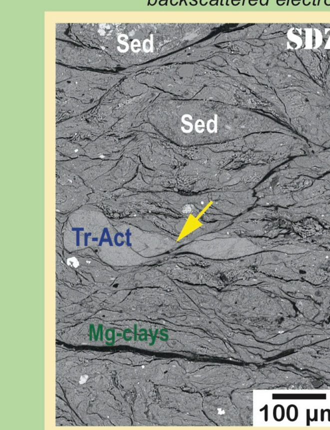


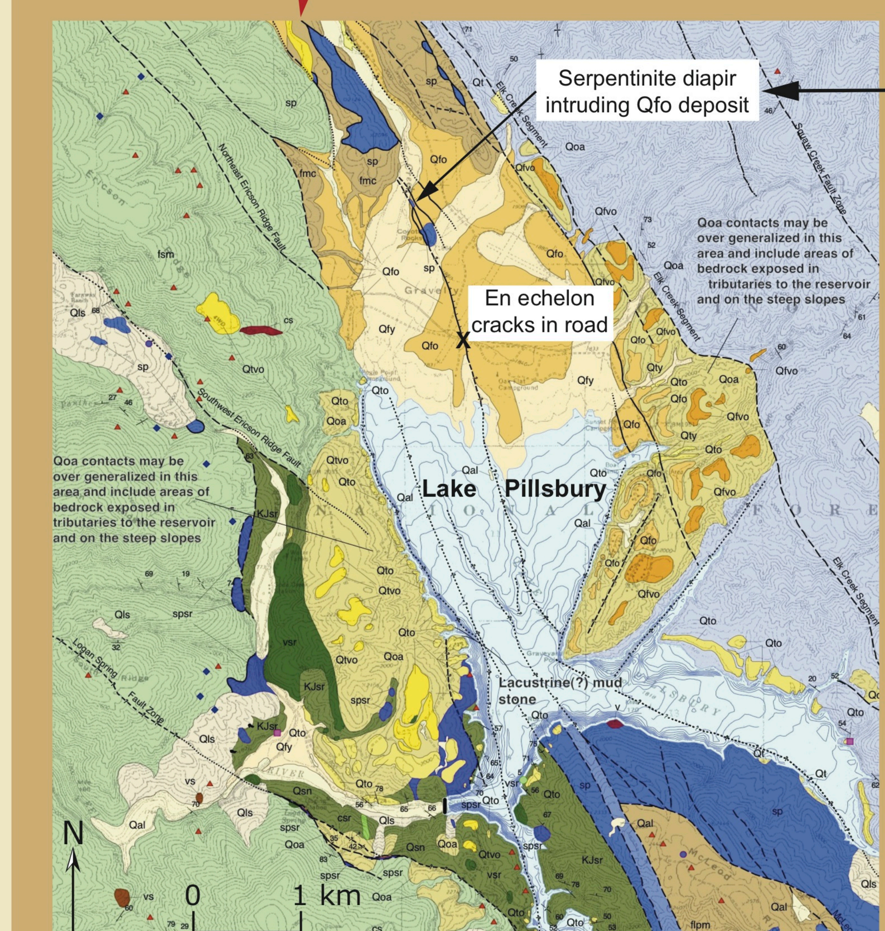
Talc, tremolite-actinolite, and Mg-rich chlorite are minor constituents of the clay-rich CDZ and SDZ. They are found in some of the serpentinite porphyroclasts (e.g., talc in SEM image at lower left), and talc and tremolite also occur as small, monominerali porphyroclasts. These clasts are gradually being broken down into smaller fragments by shear (e.g., the tremolite clasts above and at right) and altered to Mg-rich clays. Some of the altered portions of talc and tremolite clasts are marked by yellow arrows.

backscattered electrons

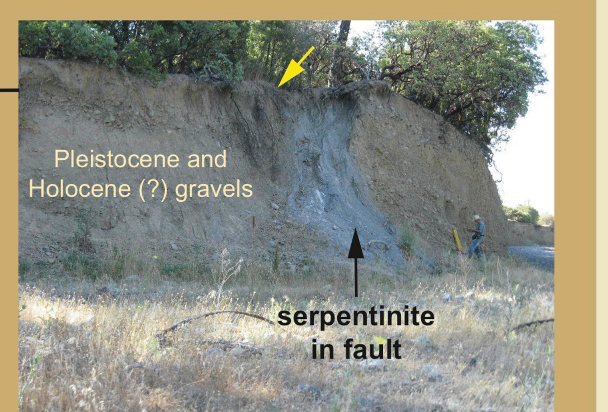


Bartlett Springs Fault

Geologic Setting



Ohlin, McLaughlin, Moring, and Sawyer, 2010, USGS Open File Report 2010-1301



An exposure of the BSF along a scarp face ~1.6 km northwest of Lake Pillsbury consists of sheared serpentinite that has risen buoyantly during right-lateral shear through Late Pleistocene to Holocene (?) fluvial deposits. Some serpentinite has extruded onto the ground surface (yellow arrow).

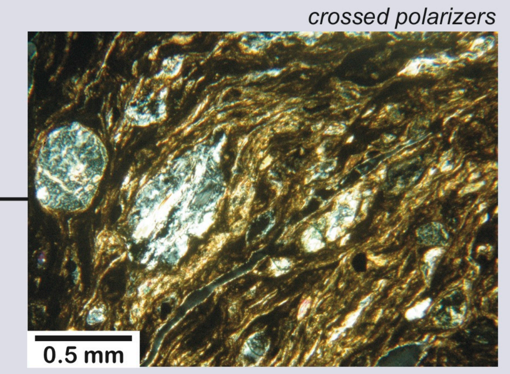
The Bartlett Springs Fault (BSF) is an active, right-lateral strike-slip fault, about 170 km in length, that is part of the San Andreas Fault system north of San Francisco, California. Its slip rate is currently estimated to be 6 +/-2 mm/yr, and along a segment that crosses Lake Pillsbury half the slip rate is taken up by creep. En echelon cracks with orientations that are consistent with right-lateral shear have formed in an asphalt road where it crosses the fault.

The serpentinite-rich mass contains a large concentration of porphyroclasts distributed in a sheared and foliated, fine-grained matrix that varies from light greenish- to dark bluish-gray in color. The darker and lighter zones were sampled separately for petrographic study.

Lighter-Colored Zones

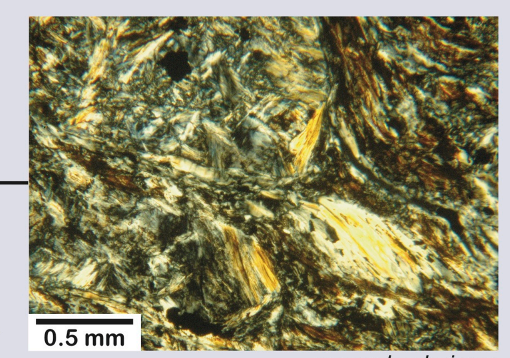
The lighter-colored zones are dominated by antigorite serpentinite, that shows some retrograde crystallization of chrysotile and lizardite. Incipient low temperature alteration accompanying shear has produced Mg-rich clays, with local development of a foliated, clay-rich gouge containing clasts of the other rock types.

Pale green portion of thin section scan is serpentinite, brown area is gouge.



crossed polarizers

Foliated gouge rich in porphyroclasts of serpentinite. Matrix clays are largely trioctahedral, Mg-rich smectite clays; compositions are shown at far right.



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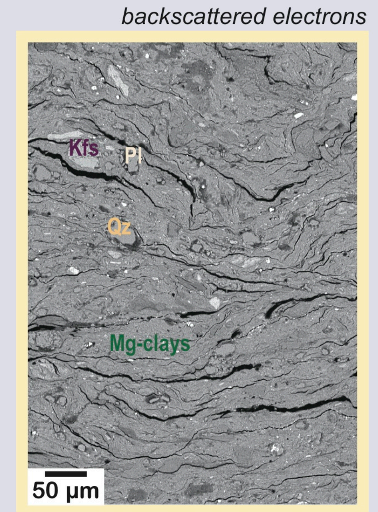
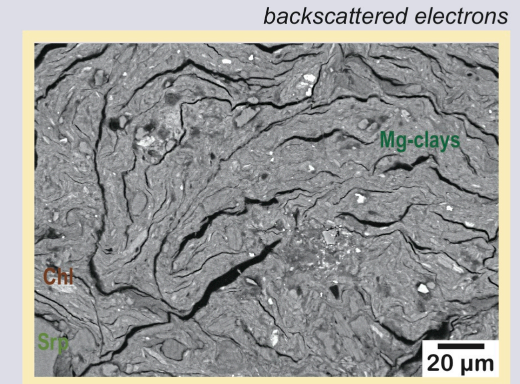
Bladed, interlocking texture of serpentine minerals is suggestive of antigorite crystallization. Antigorite, lizardite, and chrysotile were all identified in powder XRD patterns of the serpentinite.



backscattered electrons



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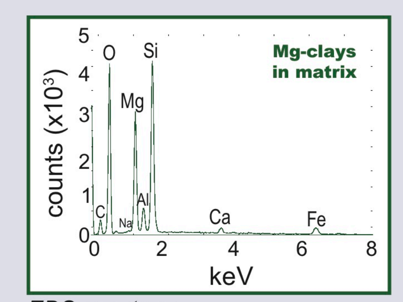
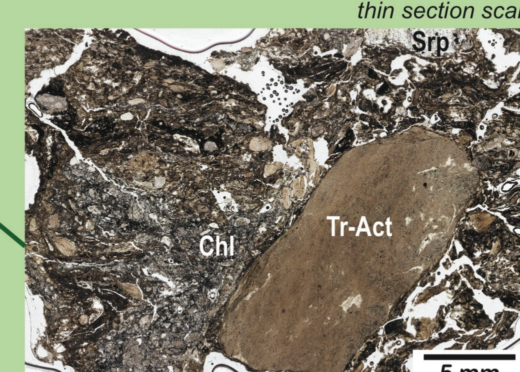
The fine-grained matrix of the gouge consists of small fragments of other rock types dispersed in foliated Mg-rich clays.



EDS spectrum

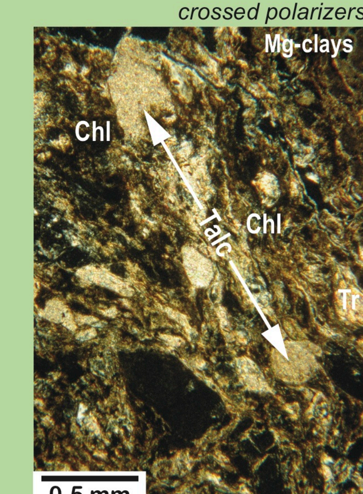
Darker-Colored Zones



thin section scan

The mineral assemblage of the darker areas is characteristic of metasomatic reaction zones formed between ultramafic and crustal rocks at greenschist to subgreenschist facies conditions. The abundance of sphene in the chlorite- and amphibole-rich porphyroclasts suggests a crustal origin for their protoliths. Much of the talc probably represents Si-metasomatism of the serpentinite.

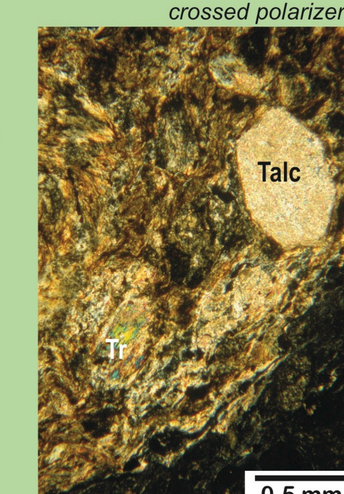
The darker zones are rich in porphyroclasts containing talc, chlorite, and/or tremolite-actinolite in a sheared matrix of the same minerals.



crossed polarizers

Smears of talc and chlorite in matrix.

The tremolite-rich porphyroclasts typically are the largest in the darker-blue zones. Talc clasts usually are monomineralic and relatively small; they commonly occur in bands parallel to the foliation, suggesting that they have been smeared-out by shear. Chlorite-rich smears are also common. Matrix chlorite and talc are partly altered to saponitic clays.



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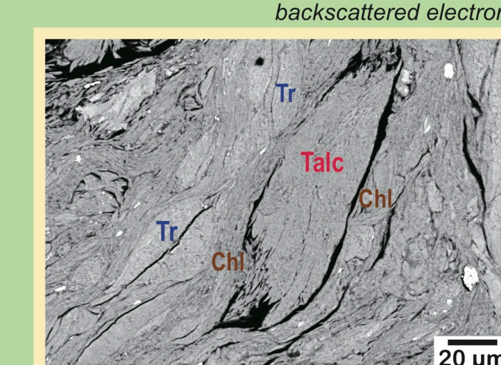
Clast-rich, dark-blue matrix.



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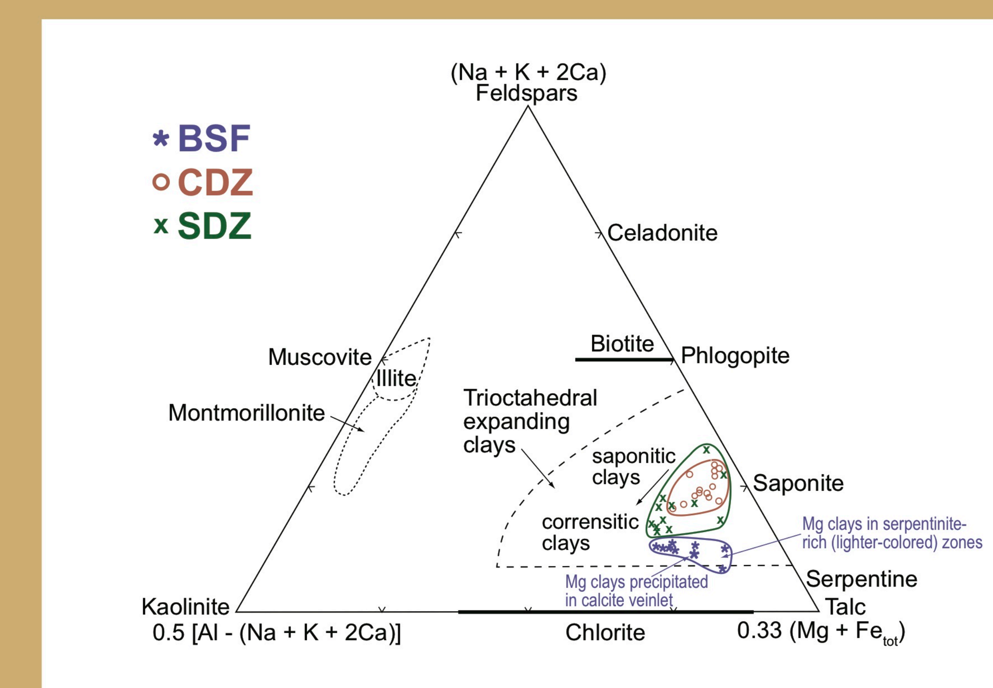
The fine-grained matrix also consists largely of chlorite, talc, and tremolite-actinolite, with only local development of foliated, clay-rich gouge.

Clay-Mineral Chemistry



Gouge-matrix clays in each occurrence are Mg-rich, trioctahedral smectitic clay minerals in the saponite-corrensite-chlorite series, with MgO contents generally between 22 and 25 wt% and Mg/(Mg + Fe) = 0.8-0.9.

Conclusions

Textures and mineral assemblages of the gouge in the exposure of the BSF near Lake Pillsbury are very similar to those observed at SAFOD, both in the SDZ and CDZ and at the surface. The main difference is that the low-temperature, clay-forming reactions have progressed to a substantially greater degree in the SAFOD gouge zones. The BSF outcrop therefore warrants more detailed study as a possible analogue of the early stages in the development of the creeping strands of the San Andreas Fault at SAFOD.