Examining Cross-Cutting Relationships of Veining/Brecciation Episodes in the Miocene Point Arena Formation using Cathodoluminescence, EDX, and EBSD

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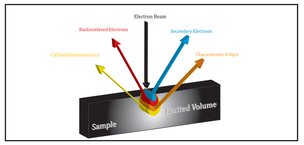
Abstract

The Point Arena area is located approximately 165km north of San Francisco and consists of a Mesozoic Salinian block granitic basement overlain predominantly by marine shales and mudstones, which are bounded on the east by the San Andreas Fault (SAF). Of particular interest for this study, the Miocene, Point Arena Formation, a Monterey Formation equivalent, has been extensively folded and faulted owing to its proximity to the SAF in this area.

Within the relatively localized area of Moat Creek Beach, ca. 3 km south of Point Arena, the Point Arena Fm. is folded by a NW-SE trending, shallowly plunging fold forming at the tip of a blind thrust, subparallel to the SAF. Within this exposure of calcite-rich, asphaltic mudstone, the Point Arena Fm. records multiple episodes of veining and brecciation. Samples exhibiting high densities of vein material collected from these outcrops were analyzed under cathodoluminescence (CL), electron dispersive spectrometry (EDS), and electron backscatter diffraction (EBSD). The results of these analyses indicate that at least three different episodes of fracturing and mineral precipitation can be documented in this area manifesting in two cross-cutting sets of calcite veins and one set of quartz veins.

The use of CL expedited mapping of the gross geometries of the veins structure and identifying particular areas of interest with respect to evaluating cross-cutting relationships. Additionally, the chemical mapping performed via EDS was particularly useful at mapping the thin (5-30 micron) quartz veins. Because the grain size of many of the calcite veins is so small, individual grains were difficult to distinguish via EBSD and produced low hit rates. Regardless, EBSD was the most useful technique for determining cross-cutting relationships for these samples. We were able to use the variable hit rate of the EBSD analysis along with the band contrast image to differentiate subtle variations in grain size of the vein material, which aided in the determination of cross-cutting relationships. A combination of these three analytical tools was valuable in documenting the off-fault fracturing history adjacent to the SAF.

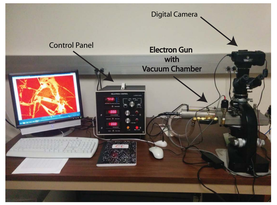
Cathodoluminescence Explained



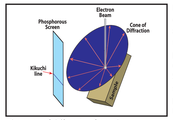
Cathodoluminescence (CL) is an electromagnetic phenomenon where electrons strike a luminescent material and cause the emission of photons. This occurs when a high energy electron beam transmitted to a sample causes the promotion of valence shell electrons to the conduction shell, leaving a vacancy in the valence shell. When an electron fills this vacancy a photon can be emitted. The energy and color of the photon emitted is determined by the sample composition.

Cathodoluminescence Instrument

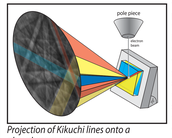
We customize a petrographic microscope by mounted a cathodoluminescence (CL) electron gun and vacuum chamber to the stage. We also modified a digital camera such that we could take low light images. High resolution CL detectors are available for scanning electron microscopes, and while those sytems have there advantages, the optical CL is low cost, easy to use, and has the ability to display plane polarized and cross-polarized light, and structural features through an eyepiece.



EBSD Explained



The cone of diffraction from the electron beam.

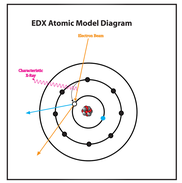


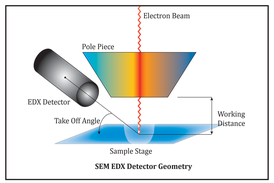
Projection of Kikuchi lines onto a phosphorous screen.

Electron backscater Diffraction (EBSD) is conducted by a detector that works as an add-on to the Scanning Electron scattered electrons to index crystallographic preferred orientations (CPOs). These electrons, which are produced by the SEM, intersect a nucleus within the sample to create a which intersect the phosphorous screen and luminesce to form "Kikuchi bands" (Figure 13). This series of bands are unique to a particular crystal lattice, and make it possible to crystallographic axes orientations. Samples are tilted at a high angle (generally ~70° from horizontal) to ensure shallow penetration of electrons so that electrons will interact only with the nuclei of interest and generate Sample preparation for EBSD analysis was facilitated with the usage of an automated grinder/polisher (Ecomet/Automet 250) and vibratory polisher (Vibromet 2). Four thin sections were prepared for each sample. Every thin section was etched thin sections for each sample (ac section) was then prepared for EBSD analysis. These thin sections were then placed in the vibratory polisher with colloidal silica to increase EBSD quality.

EDX Explained

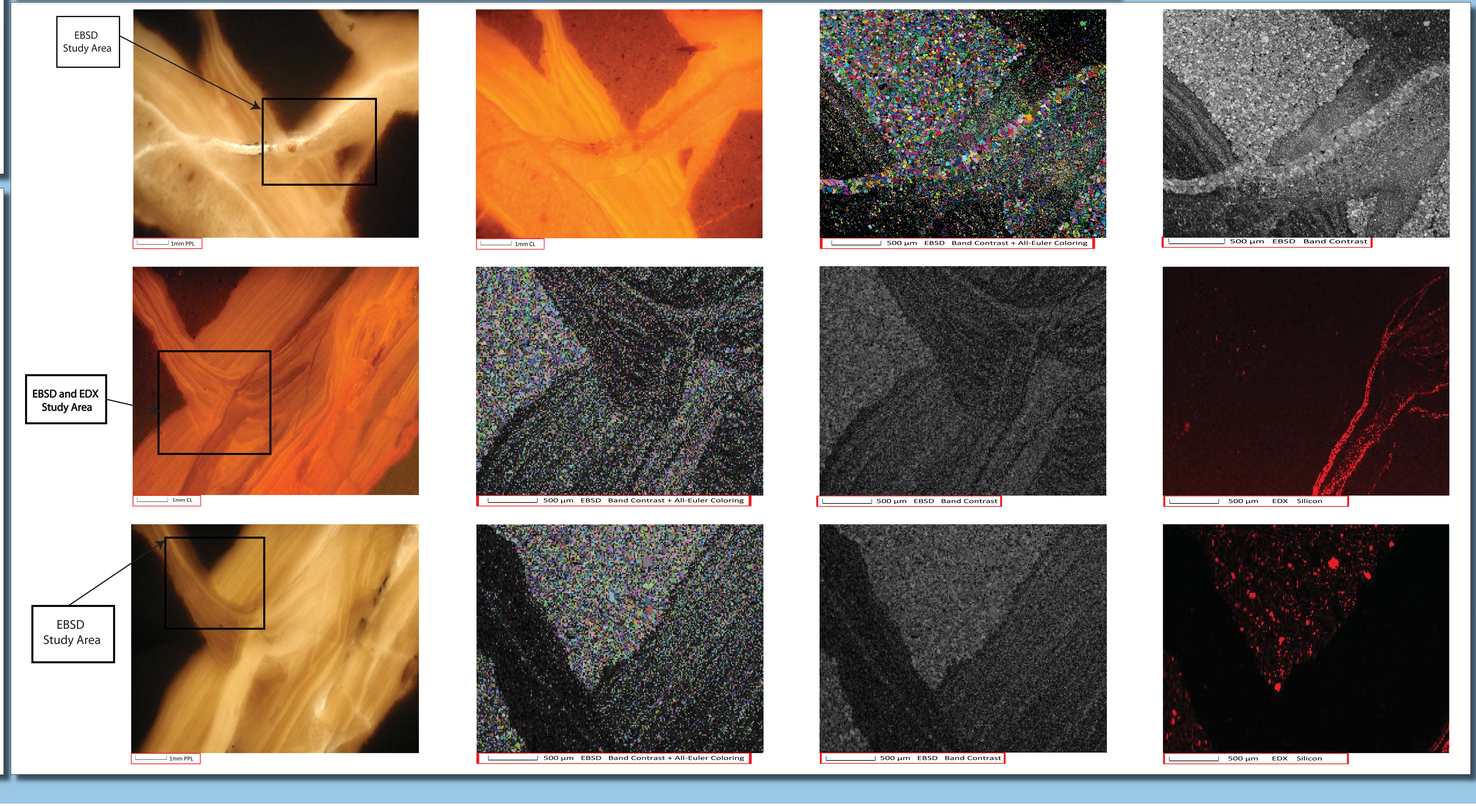
Energy-dispersive X-ray spectroscopy (EDX) is an analytical technique used for the analysis or chemical characterization of a sample involving the interaction of X-ray excitation and the sample. Chemical characterization using EDX relies on emissions within the X-ray spectrum that are unique to each element. The releases of these X-rays are stimulated by a high energy electron beam, which causes the excitation and release of an electron within an atom. The X-rays are generated when an electron in a higher level valence shell moves to replace the released electron in a lower valence shell causing a discharge of energy. The quantity and energy of this release is characteristic of the atomic structure of the element and is measured by the EDX detector.



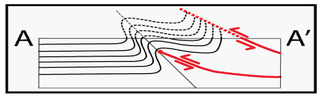


Moat Creek Study Area

Aerial photographs from the California Coastal Records Project (www.californiacoastline.org) of the Moat Creek field area.

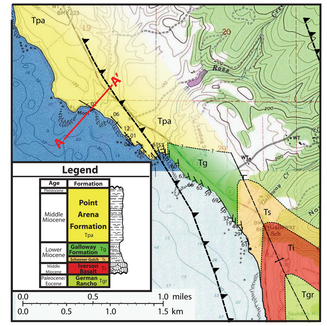


Cross Section of A to A'



Geologic Cross Section(partially modified from Wentworth et al., 1998)

Location Map



Geological map of the field area (Chicchetto, 2009, partially modified from Wentworth et al., 1998) with mean bedding orientations and fold axes measurements.

Conclusions

- The use of cathodoluminescence expedited mapping the gross geometries of the vein/fracture structure and identifying particular areas of interest with respect to evaluating cross-cutting relationships.
- EBSD was the most useful technique for determining cross-cutting relationships for these samples.
- Variable hit rate of the EBSD analysis along with the band contrast image significantly aided in the determination of cross-cutting relationships.
- These analyses indicate that at least three different episodes of fracturing and mineral precipitation can be documented in this area manifesting in two cross-cutting sets of calcite veins and one set of quartz veins
- Further analysis of oriented samples is necessary to characterize distinct deformational episodes.

References

Cicchetto, Daniel and Mookerjee, Matty. 2009. Characterizing Deformation of Neogene Rocks Near Point Arena, California. Geological Society of America, Abstracts with Programs, 41/7, 51.

Wentworth, C. M., D. L. Jones, and E. E. Brabb. 1998. Geology and regional correlation of the Cretaceous and Paleogene rocks of the Gualala Block, California, in Geology and Tectonics of the Gualala Block, Northern California, Book 84, edited by W. P. Elder, pp.3–26, Pac. Sect., Soc. for Sediment. Geol., Walnut Creek, Calif.