Possible Evidence for Decarbonation Reactions from Carbonate Clumped-Isotope Analyses of Fault Gouges

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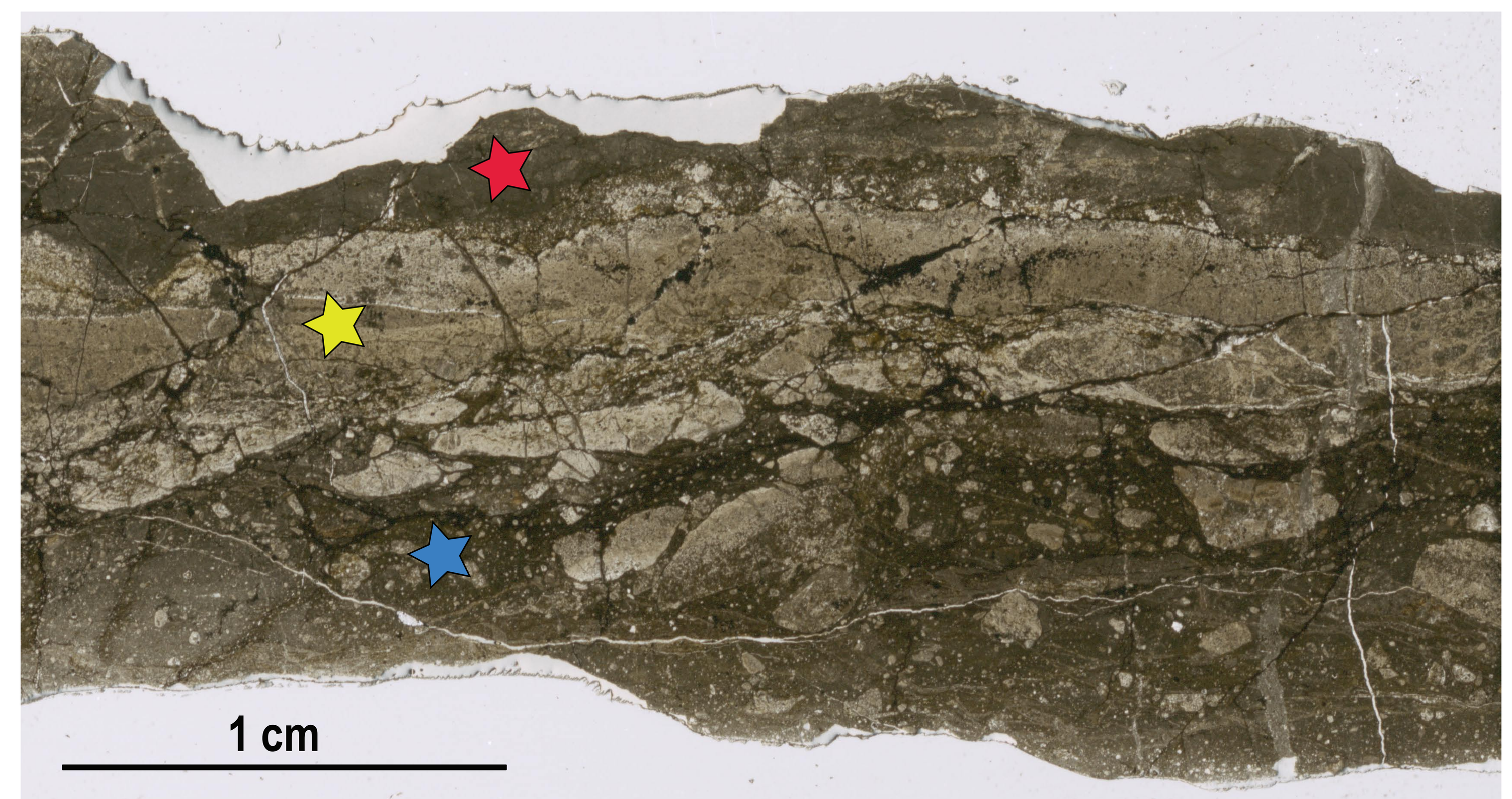
Abstract

The mechanisms of slip for large slip events on low-angle faults have puzzled researchers for decades. Recently, numerous researchers have explored the idea that slip might occur as a result of the reduction of friction via decarbonation reactions in carbonates, and other reactions in silicates. These former reactions release carbon dioxide, which could, under pressure, reduce friction and facilitate slipping at low angles. Experiments suggest that this process can occur in the laboratory, but evidence that it occurs in natural settings is limited. In this study, we test this hypothesis by seeking evidence for high-temperature decarbonation reactions predicted to occur in gouges, from a fault and two large landslides, by comparing temperatures and fluid sources in gouges and their host rocks. Preliminary data from fault gouge along the Mormon Peak detachment in Nevada shows carbonate crystallization temperatures varying by more than 200°C, from 240°C along the slip surface, to 110°C 5 mm above the slip surface, to 40°C 1 cm above the slip surface. Unstrained host rocks near the fault plane generally yield temperatures of 70-80°C, and late recrystallized calcites generally yield temperatures of 30°C. These higher temperatures appear to be the result of significant shear heating along the detachment, which would be necessary for decarbonation reactions to occur. Samples from the 1987 Bualtar landslide in Pakistan, where Hewitt (1988, Science) directly observed evidence for decarbonation reactions, yield gouge temperatures of ~340°C, not significantly different from temperatures measured in host marbles. This may indicate that decarbonation reactions are volumetrically minor, or that the back-reaction of CaO is to a mineral other than calcite. We are currently working to confirm these preliminary results, and analyze gouges from numerous areas, to better understand the role of decarbonation and recarbonation in gouges from faults and landslides.

Preservation of Large Temperature Gradient



Red star	238 ± 12°C 249 ± 20°C
Yellow star	109 ± 5°C 121 ± 6°C
Blue star	39 ± 4°C

This sample from along the Mormon Peak detachment fault in south-western Nevada shows a large variation in carbonate crystallization temperatures over mm lengthscale, as determined by clumped-isotope thermometry. This rock was sampled in 3 discrete layers, with each layer giving the temperatures indicated to the left.

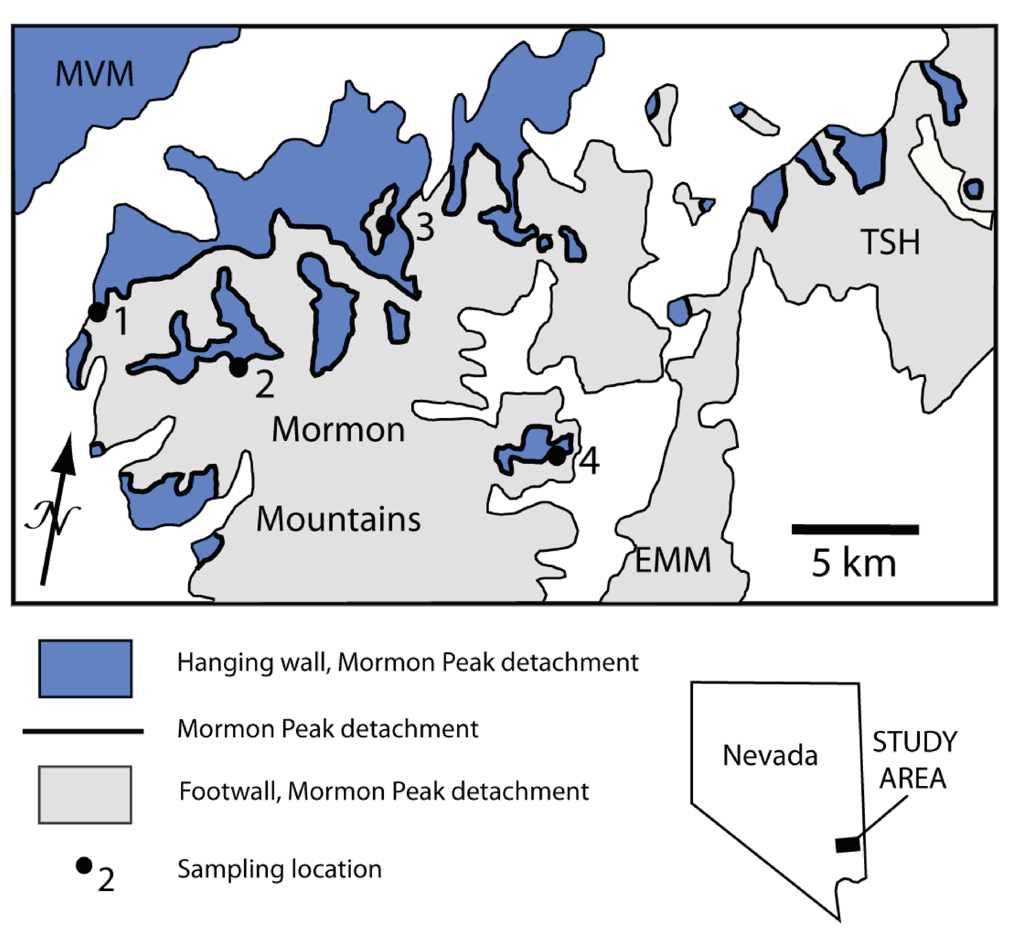
Measurements of Decarbonation Product

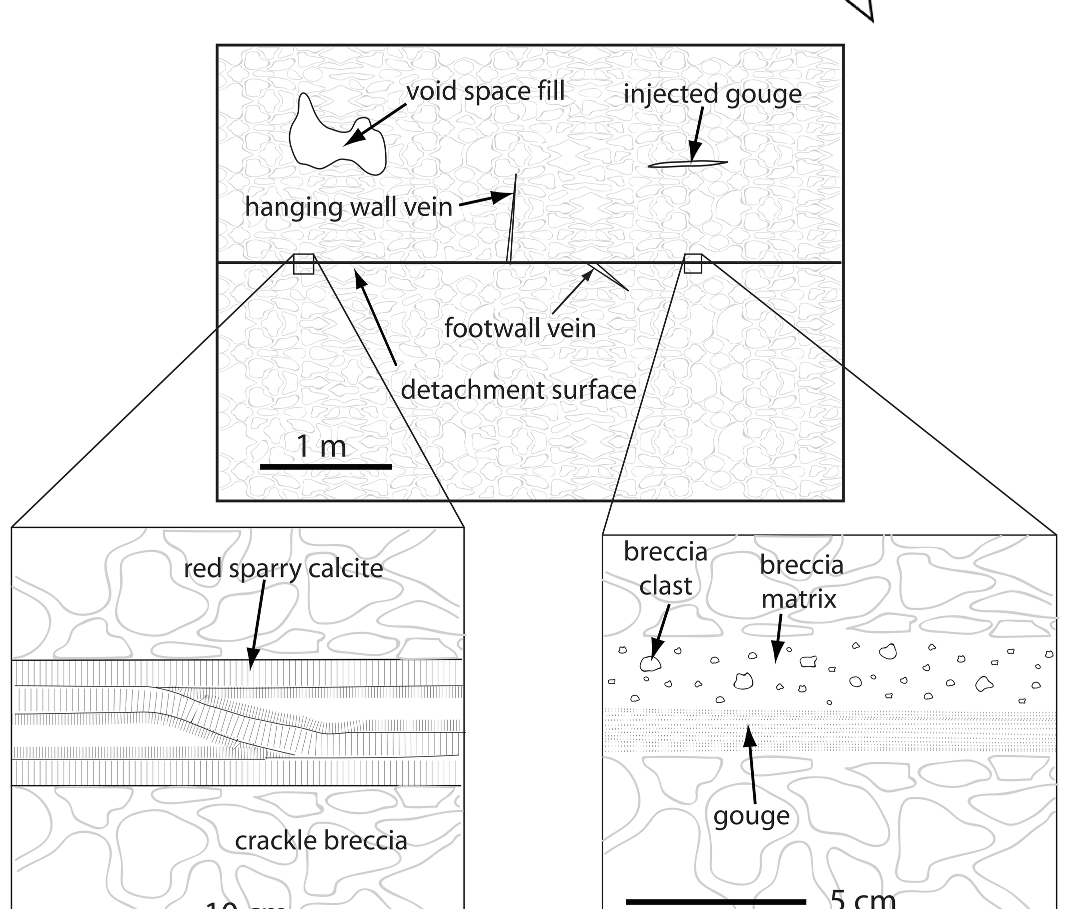
At Bualtar landslide:

Sample type	Temp (°C)	δ13C	δ18O
gouge	203.4 ± 24	1.72	18.96
clast	193.2 ± 24	1.48	18.68

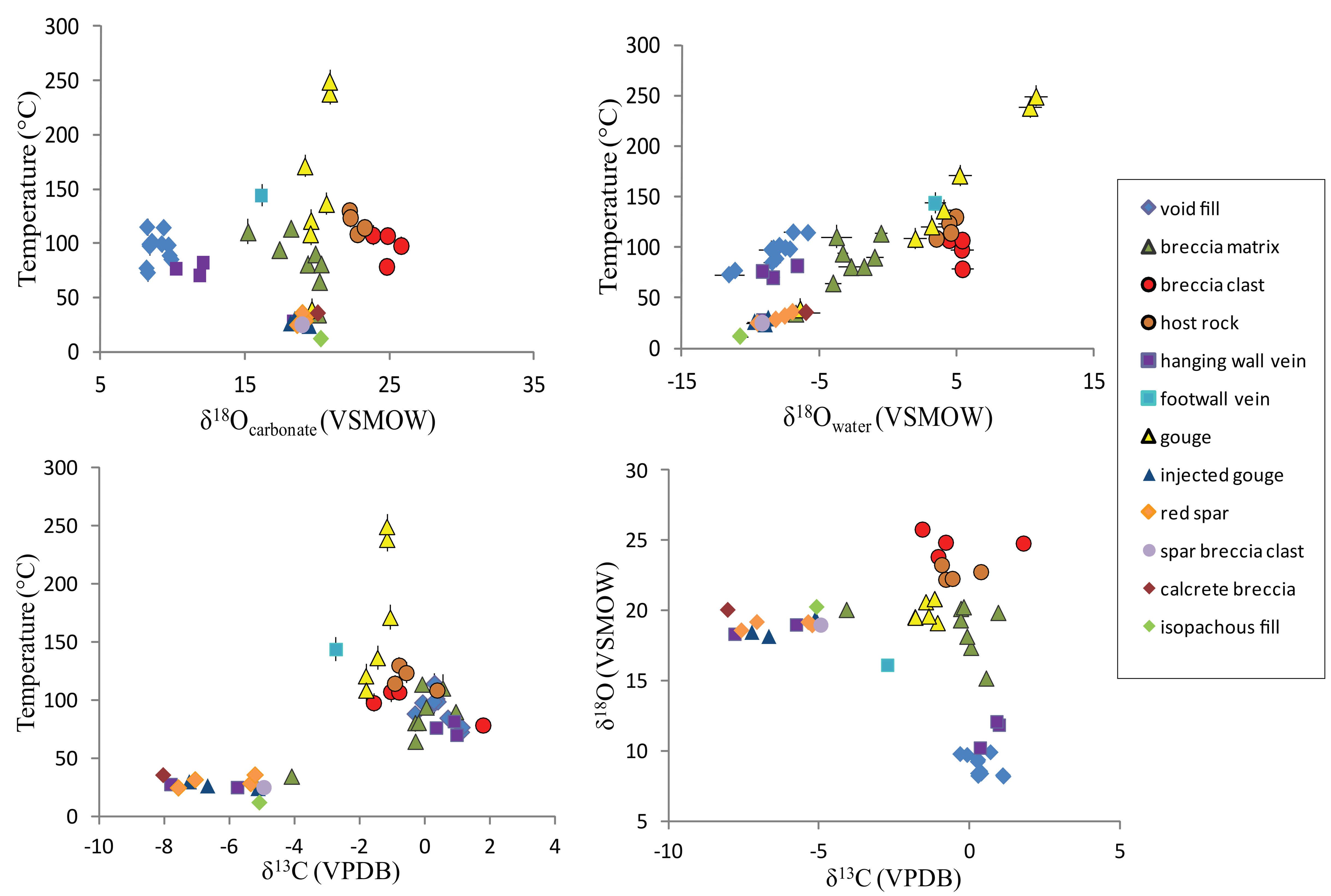
This sample is from the Bualtar landslide in Pakistan, sampled by Ken Hewitt in 1987, within a year of the landslide. This landslide produced powder that chemically burned his hands and killed off lichen within 0.5 km, from the creation of CaO during sliding. Clumped-isotope analyses of slide materials indicate that both the finest size fraction (presumeably the gouge that is most likely to contain the products of decarbonation reactions), and the intact clasts of host rock, are the same within error. In addition, XRD analyses were unable to detect any CaO in the gouge material. This indicates that the amount of product preserved from decarbonation reactions are either volumetrically minor or have back-reacted since the slide.

Mormon Peak Detachment Sampling





Mormon Peak Detachment Clumped-Isotope Results



Discussion

One thing to note for these data is the spread in temperatures, but not oxygen or carbon isotopic ratios, for the gouge samples. Another thing to note is that the temperatures of fault rocks indicate two distinct phases of calcite precipitation from meteoric water infiltration. The warmer phase is unexpectedly warm for depths of 2 kilometers (the thickness of the hanging wall), suggesting potential warm fluid migration up the fault. The cooler phase displays a variety of textures, mostly undeformed, suggesting it formed late in the evolution of slip. Also, the clasts within the breccias preserve the chemical signature of the host rock, indicating that brecciation does not reset the clumped isotopic values for cm-scale clasts.

The evidence for decarbonation reactions based on clumped-isotope thermometry is suggestive, but not conclusive. The close spatial proximity of high- and low-temperatures of crystallization might be a result of high-temperature reactions resulted from shear heating on the slip surface. The interpretation that this temperature variation in gouges on the fault plane is due to recrystallization in the presence of warm fluids is not preferred, both because of the close proximity of warm samples to cool ones (mm scale), and because of the uniformity of carbon and oxygen isotopic ratios. This could be the result of recrystallization in a closed, rock-buffered system, but the source of heat for such a fluid might still be shear heating.

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