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Carbon ordering in an aseismic shear zone: implications for crustal weakening and Raman spectroscopy

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Multi-layered stratigraphic sequences present ample opportunity for the study of strain localization and its complexities. By constraining mechanisms of crustal weakening, it is possible to gain a sounder understanding of the dynamic evolution of the Earth's crust, especially when applied to realistic, field-based scenarios. One such mechanism is that of strain-related carbon ordering. This is the process whereby the amorphous nanostructure of fossilized organic matter contained within the rock is progressively organized towards a more sheet-like structure, similar to that of graphite. One common method of studying this process is through Raman spectroscopy. This is a non-destructive tool which makes use of the relative positions and intensities of two key spectral peaks, where one peak represents graphitic carbon and the other disordered (or amorphous) carbon. The intensity ratio between these two peaks suggests the degree to which the carbon has progressed from its original kerogen-like structure towards that of graphite. This progression can be due to increasing temperature or increasing strain, and until now, these two contributory factors have been difficult to separate, particularly in field examples.

Previous field-based studies have focused on carbon ordering on fault planes, while experimental studies have monitored the effects of strain-related ordering in organic carbon on both fault surfaces and more distributed shear zones. These studies confirmed the occurrence of strain-related ordering at seismic rates, particularly in the form of graphitization of carbon. However, these experiments showed the effects of strain-related ordering at aseismic rates to be limited when distributed shear zones were considered, in part due to the geological timescales required to emulate true conditions.

In this study, Raman spectroscopy is used to compare the relative nanostructural order of organic carbon within a recumbent isoclinal fold formed of interbedded limestones and marls. The central, overturned fold limb forms a 170m wide, 1km long aseismic shear zone, with evidence of increased strain recorded in calcite grains relative to the upper and lower limbs. Raman spectroscopy intensity ratios (I[d]/I[g]) are compared across the fold, showing a marked 23% decrease in the overturned limb. Such a decrease in I[d]/I[g] suggests increased carbon ordering within the overturned limb, which in combination with evidence for increased strain in calcite, suggests that the carbon ordering here is derived directly from strain-related ordering. This has important implications. We infer, from previous studies, that strain-related carbon ordering encourages further strain partitioning in carbonaceous material, and may enhance zones of

weakness in the rock. This ordering in aseismic shear zones has so far been unreported in nature, and so our field-based results are significant in supporting previous experimental evidence for this phenomenon. Our results also have implications for understanding dynamic crustal evolution, and will play an important role in the development of Raman thermobarometry, especially since current methods do not distinguish between strain-related and temperature-related ordering.