Coherent diffraction imaging of faults and fractures

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Crustal faults and fracture systems are of significant importance for the structural interpretation of geophysical images. Resulting from acting forces they not only encode past configurations of local stress fields, but also represent primary indicators of man-made or natural hazards or fluid flow in the subsurface. In addition, the delineation of faults also helps to shed light on the mechanical properties of the host material and provides valuable assistance in tracking horizons and spatially linking stratigraphic units in sedimentary regimes. Crystalline-rock environments, which are of special interest for geothermal exploration and production, are known to be brittle and scarred by intricate fracture networks, whose successful identification and characterization has an immediate impact on the desired transition to sustainable energies. Despite their importance, pronounced direct geophysical images of crustal faults, in particular when temporarily inactive, remain largely elusive, owing in large parts to their sub-wavelength structural complexity and the seemingly diffuse and complex wavefields that are typically associated with them.

With a long history in optical imaging, the wave process of diffraction is synonymous with the highest possible resolution achievable in a reconstruction. Large parts of the Earth's crust are known to heavily diffract incoming seismic or electromagnetic radiation. However, exploration and earthquake seismology either rely on transmitted, reflected and converted arrivals or surface waves and often implicitly ignore weaker, seemingly uncorrelated contributions for the direct imaging of the subsurface. Constrained by the interference with other typically stronger reflected or transmitted phases, individual diffractions are often hard to identify on individual records, despite the fact that they represent coherent signal.

Building on recent advances in adaptive processing and weak-wavefield enhancement, we present a simple reproducible strategy for the surgical extraction of these weak yet coherent signatures. In addition, we demonstrate with scale and community-spanning seismic and electromagnetic examples that coherent diffraction imaging not only leads to overall highly-resolved subsurface reconstructions, but also directly and reliably highlights faults and fractures, which are notoriously hard to image conventionally. Concluding this account, we briefly discuss how aside from increased lateral resolution, the diffracted component of the wavefield possesses unique properties, whose systematic exploitation may lead to new, reduced, cost-effective means of acquisition and imaging. These promise to be applicable for controlled as well as uncontrolled coherent sources.