Seismic diffraction imaging - a case study from the Southern Aegean Sea

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The active seismic method is a standard tool for studying the Earth's lithosphere. On scales from centimetres to kilometres, academic research is generally interested in highly complex geological targets such as volcanic edifices, crustal faults or salt environments. In order to properly image these structures, large and expensive multichannel acquisitions with a high offset-to-target depth ratio are required. In practice, however, these are often hardly affordable for academic institutions, with the result that reflections often only poorly illuminate laterally variable structures, which in turn compromises imaging and interpretation. As in common practice, most of the processing and interpretational steps are tailored to the reflected wavefield, faint diffracted contributions are typically considered as an unwanted by-product.

In recent works, however, it has been shown that diffractions possess unique properties which bear the potential to overcome the aforementioned limitations. Wave diffraction occurs at geodynamically important features like faults, pinch-outs, erosional surfaces or other small-scale scattering objects and encodes sub-wavelength information on the scattering geometry. Since diffracted waves do not obey Snell's Law, they provide superior illumination compared to reflected waves. Moreover, due to their passive-source like radiation, they encode their full multichannel response in prominent data subsets like the zero-offset section. In order to explore what can be learned from the faint diffracted wavefield, we use academic seismic data from the Santorini-Amorgos Tectonic Zone (SATZ) in the Southern Aegean Sea. This is an area well known for its local complexity, indicated by the occurrence of extended fault systems and volcanic edifices as well as a complex acoustic basement. As the available seismic data in this region were acquired using a relatively short streamer, the SATZ represents a classical example for the need of innovative methods for seismic processing and interpretation.

By means of a robust and computationally efficient scheme for the extraction of diffractions that models and adaptively subtracts the reflected wavefield from the data, we reveal a rich diffracted wavefield from zero-offset data. On the one hand, we use the diffraction-only sections for analysing the small-scale structural complexity and demonstrate that the geological interpretation can benefit from these observations. On the other hand, we use the diffractions to estimate insightful wavefront attributes in the zero-offset domain. Based on these attributes, we perform wavefront tomography to obtain depth-velocity models. Compared to depth-velocity models
derived from the reflected contributions, the diffraction-based velocity model fits the data significantly better. After refining this velocity model, we perform prestack depth migration and obtain highly valuable depth converted seismic sections. Concluding our results, we strongly encourage the incorporation of diffractions in standard processing and interpretational schemes.