Improving the fidelity of seismic imaging in deep Earth exploration

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The geologic interpretability of seismic images relies on their fidelity, which defines the truthfulness of the imaged targets in terms of their resolution, position accuracy and artifact. It is particularly challenging to improve the fidelity of seismic images in deep Earth exploration due to the decrease of data quality with depth and lack of direct validations beyond the drilling limit. Both the inversion and modeling approaches that are used in most geophysical studies seek those solution models whose predictions best match the observations in data space. However, selection of the output models in the data space rather than the output space has exacerbated the nonuniqueness problem for inversion and modeling in deep Earth exploration. In most seismic imaging studies of deep Earth so far, we have not been able to apply geologic constraints directly in the imaging process.

How to assess and improve the fidelity of seismic imaging in deep Earth exploration? We may learn much from exploration geophysics where the practice has long established a two-fold approach of seismic imaging: Using velocity model building to establish the long-wavelength reference velocity models, and using seismic migration to map the short-wavelength reflectivity structures. Of these two complementing efforts, velocity model building aims at improving the accuracy of image positions, and seismic migration aims at improving the resolution. Interestingly, advanced depth migration methods such as reverse time migration (RTM) map the data into an output space called imaging space, where the output reflection images of the subsurface are formed based on an imaging condition. The RTM method seeks the reflectivity image as the best fit in the image space between the extrapolation of time-reversed waveform data and the prediction based on estimated velocity model and source parameters. It will be effective to apply geologic constraints in the image space during the RTM process.

The complex undertaking of deep Earth exploration requires a high standard for the fidelity of seismic imaging and a broad understanding about the limitations and artifacts of seismic images by interdisciplinary researchers. The use of advanced seismic migration and velocity model building methods will be necessary in the planning and execution of future deep Earth exploration studies, as well as in re-processing of previous lithosphere-scale profiles. We will illustrate the benefits and challenges of RTM and other advanced seismic imaging and tomographic model building methods in deep Earth exploration using examples from resource exploration and crustal and mantle seismic studies.