Introduction to this special section: Imaging migration

Biondo Biondi and Dave Nichols, Stanford, California
Paul Sava, Golden, Colorado

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Modern imaging methods are slowly but surely trending toward the solution of an inverse problem, not only for the velocity-estimation phase but also for the migration step. The general direction is toward the conventional imaging two-step process of velocity estimation followed by migration being superseded by the single full-waveform inversion (FWI) process. However, today, advanced imaging workflows are hybrid, and FWI is complemented by more conventional imaging methods.

The gradual transformation of imaging into inversion is made possible not only by significant increases in computing power, facilitating methods that iterate with migrationlike operators, but also by theoretical advances that better exploit information in the acquired data. Moreover, modern acquisition provides data with increasingly long offsets and wide-azimuth coverage, higher signal-to-noise ratio (S/N), and broader bandwidth. Acquisition increasingly makes use of multicomponent sensors that allow sampling of elastic wavefields, which contain additional information that can be used to better characterize the physical properties of the subsurface. This special section aims to explore some of the above-mentioned trends and to highlight methods that build on existing imaging technology while reaching beyond the current state of the art.

Three articles describe the application of least-squares migration, which is an example of linearized waveform inversion. Huang et al. and Zeng et al. demonstrate the improvement in bandwidth, resolution, and S/N achieved by posing the migration problem as an inversion. As computational efficiency keeps improving, the use of inversion in the migration phase of the imaging process is likely to increase, particularly for data sets that suffer from severely irregular data sampling and from poor illumination caused by complex overburden. Wong et al. demonstrate that linearized inversion can go beyond the imaging of primary events, which is the main goal of conventional imaging, to image multiple reflections generated by known multiple generators, such as the seafloor and sea surface. Primary and multiple reflections can be inverted simultaneously to form an image that is superior to those obtained by separately inverting primaries and multiples. Multiples provide additional coverage of the subsurface, thus increasing its illumination and better constraining the geologic structure in complex geologic environments.

Vigh et al. and Ratcliffe et al. discuss other ways in which waveform inversion and migration are increasingly connected and complementary. Both articles show how FWI can be used as a preprocessing step before high-frequency reverse time migration (RTM). Because of computational cost, current applications of FWI do not yet exploit the full bandwidth of acquired seismic data. Thus, images produced by FWI are between long-wavelength models produced with conventional velocity-analysis techniques and high-resolution images obtained by migration. Nevertheless, the improved resolution of velocity models estimated by FWI has a significant positive impact on the final RTM results.

The impact of inversion on seismic imaging is also facilitated by the continuous improvements in seismic data acquisition, particularly by recording low frequencies at longer offsets as well as wider azimuths. This connection between better recording and waveform inversion is explicit in the Vigh et al. article. In contrast, Li et al. present a case history in which the availability of longer-offset data enabled a significant improvement in the subsalt velocity model. Angle gathers computed using longer-offset data provided the necessary velocity resolution to update the velocity model and yield a much improved image of the subsalt structures.

Raknes et al. describe another complementary application of FWI and more conventional imaging algorithms. The authors apply wave-equation migration velocity analysis to estimate the long-wavelength component of the velocity model before FWI, which is notoriously prone to cycle skipping when long wavelengths in the starting model are inaccurate. In this case, the goal of using FWI is to estimate a model that is not only kinematically consistent with the data but is also consistent with data amplitudes when data are modeled using a full elastic wave equation instead of its more commonly used acoustic approximation. By describing a 2D field data application to a time-lapse elastic imaging problem, this article provides a glimpse into future imaging algorithms and the gains that those algorithms might provide for interpretation.

As our algorithms and workflows become more accurate and robust, we will be able to explain the whole of recorded waveforms through more and more accurate physical modeling of all wavefield components (i.e., elastic) as well as all events, including what we used to label as noise and try to attenuate, such as multiples.

At the other end of the spectrum, the article by Bonomi et al. shows that time migration is still a valuable tool when data quality is poor and we cannot build a velocity model that describes the data kinematics because of their poor S/N. In that case, we can still produce interpretable images by maximizing the focusing of the data by applying multiparameter Kirchhoff-like imaging operators described by a well-chosen set of parameters.

Two articles highlight the fact that not all geologic structures require a wavefield-based imaging method but can take advantage of well-established techniques. Luo et al. and Karazincir and Orumwense show that ray-based tomography is still an excellent tool for estimating complex velocity models. The flexibility of ray-based methods, along with the possibility of integrating velocity modeling with interpretation, enables the imaging of complex structures. Karazincir and Orumwense show that a sophisticated processing flow can yield image improvements and better well ties even when complex anisotropy (e.g., tilted orthorhombic) is present in the overburden. TLE

Corresponding author: biondo@sep.stanford.edu