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High-SNR Staining Algorithm for One-Way Wave Equation-Based Modelling and Imaging

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Abstract. Staining algorithms based on two-way wave equation migration methods have been applied to improve the signal-to-noise ratio (SNR) of poorly illuminated structures such as those in subsalt zones. In regular staining algorithms, when a source wavefield reaches the stained area that is associated with the target structures, a new wavefield called stained wavefield is excited, and this stained wavefield forward extrapolates synchronously with the real source wavefield. The forward-extrapolated stained and real source wavefields are cross-correlated with the backward-extrapolated receiver wavefield, and we obtain the stained and the real reverse time migration (RTM) images. The staining algorithms for RTM can suppress the noise of non-target regions and obtain high SNR images of the target structures. Whereas RTM methods are limited by the low computational efficiency and SNR, by contrast, one-way wave equation migration (OWEM) methods have the advantages of high efficiency and no interference from multiples. Thus, we developed a new staining method based on the generalised screen propagator (GSP) as a case of OWEM methods for subsalt imaging. Furthermore, a new stained wavefield called stained receiver wavefield is proposed here, forming two new staining strategies for seismic imaging, in which forward-propagated source and backward-propagated receiver wavefields can be conveniently selected to be stained at the stained area. Numerical experiments demonstrated that this staining GSP method is more effective in improving the SNR of subsalt structures compared to conventional GSP migration and RTM methods; moreover, these new staining strategies as applied to the OWEM methods can greatly improve the SNR of weakly illuminated structures in subsalt zones, in comparison with regular staining algorithms for one-way methods.

AMS subject classifications: 86-08, 86A15, 86A20, 86A22

Key words: One-way, two-way, modelling, imaging, staining, RTM.

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1 Introduction

Seismic imaging is a technology that returns reflected and diffracted waves to the subsurface where they are generated, allowing images of the underground structures to be obtained. However, weakly illuminated structures exist owing to the limited acquisition geometry, complex overburden structures, and reflector dip angles [59]. Subsalt basins are typical weakly illuminated structures owing to the defocusing by the salt boundaries and by the transmission and reflection losses induced by the strong velocity contrast between the salt and its surrounding sediments when seismic waves pass through the salt bodies [23, 32, 35, 39]. Some approaches have been proposed to improve the illumination of subsalt shadow zones. O'Brien and Gray [40] put forward some proposals to improve the images of the structures below the salt by interpreting poor quality data and building accurate velocity models. Kessinger and Ramaswamy [29] applied mode converted energy to the depth migration for subsalt imaging. Some other studies have focused on compensating the illumination of subsalt regions [43, 63], acquisition aperture correction [4,55,56], and velocity model building [24,33,48]. There are many methods that have been developed for subsalt imaging by using multiples [11, 17, 35], turning waves [18], converted waves [36, 41, 53, 58], or vertical seismic profile data [3, 44]. Moreover, Tang and Biondi [47] presented a strategy based on the target-oriented wavefield tomography using synthesised Born data and obtained improved SNR images of the subsalt structures. Yan et al. [62] presented a hybrid elastic one-way propagator for subsalt imaging. Although these efforts have made great progress in subsalt imaging, there are still problems in enhancing the illumination of the subsalt.

Chen and Jia [6] proposed a staining algorithm derived from the fate mapping technology in developmental biology for improving the SNR of poorly illuminated structures. In fate mapping, embryologists use 'vital dyes' to stain and label an undifferentiated embryonic cell, and then the stained cell goes through differentiation and development and can be seen in the adult organisms [10, 15]. This technique is carried out for tracing the embryonic origin of various tissues in the adult organisms, which establishes a link between a single cell or tissue at a certain stage and adult cells at later stages of development. Corresponding to the fate mapping method, in staining algorithms, we first stain the target-related structures as a stained area, and when the source wavefield reaches the stained area, a new wavefield called stained wavefield is excited. This stained wavefield, which is regarded as a virtual wavefield, propagates synchronously with the real source wavefield. Because the stained wavefield removes information unrelated to the target structures, we can use the stained wavefield for obtaining high SNR images of the target structures. Chen and Jia [5] applied the staining algorithm to broadband seismic illumination and resolution analysis. To overcome the problems of amplitude and waveform distortions, Li and Jia [34] proposed a new amplitude-preserved staining algorithm called generalised staining algorithm for seismic modelling and imaging. In addition, Jia and Yang [26] developed a memory-efficient staining algorithm for 3D seismic modelling and imaging. All the above staining algorithms are based on two-way