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Special Section

Subsalt exploration and development — Introduction

Jacques P. Leveille[1], Ian F. Jones[2], Bin Wang[3], and Dimitri Bevc[4]

This special section on subsalt imaging originated from a summer research workshop on the same topic held 26–29 July 2010 in Lake Tahoe, Calif. The title of the workshop, "Subsalt exploration and development: Four years later … what's new in acquisition, imaging and interpretation," describes exactly the variety of topics presented. In some sense, this section attempts to cover most of these topics. Though not all topics or presentations given at the workshop made it into this special section, a great majority of the ideas discussed are represented here. Several papers were also submitted to this special section that were not presented at the workshop.

The section opens with a general review of subsalt imaging meant to be accessible by a wide audience. Leveille et al. address the question of what subsalt imaging is and discuss the physics of the subsalt imaging problem, focusing on the illumination issue. It also provides a review of the main imaging algorithms, the various imaging conditions, and the velocity updating tools.

Six general case history papers follow the review paper. In the first paper, to learn about the accuracy of anisotropic deep-water Gulf of Mexico model building and depth-imaging tools that are used for the processing and imaging of acquired field data, Hoxha et al. create a 3D VTI anisotropic earth model and a 3D seismic data set representing typical subsalt Gulf of Mexico geology called Tempest. The Tempest reverse time migration PSDM is being used to learn about the differences between the exact geological model and the reverse time migration PSDM image, helping in the interpretation of real reverse time migration prestack depth migrated data. Following this, Zhou et al. analyze the challenges they faced when using reverse time migration subsurface angle gathers to update velocity for the Shenzi field. They discuss techniques developed to exploit the full-azimuth coverage of the Shenzi rich-azimuth streamer data to perform TTI reverse time migration 3D angle-gather-based subsalt velocity update. Next, Vigh et al. describe an alternative workflow to enhance the subsalt imaging using a wide-azimuth data set. The elements used — GSMP, FWI, and reverse time migration — on their own are not new, but they argue that the right sequence of these elements provides an uplift over the conventional processing applied in the Gulf of Mexico subsalt imaging, which is demonstrated and supported by examples. In the following case history, Bui et al. attempt to obtain the most lithological information from subsalt imaging. Incorporating prior information from well data and geological information to update the seismic velocity and to scale the relative acoustic impedance volume in the low-frequency model, they show how to improve the subsalt absolute acoustic impedance inversion results significantly, enabling sand/shale identification for subsalt formations. This special approach has been applied successfully in the Gulf of Mexico's subsalt areas, where conventional poststack inversion failed to provide good results. Following this, Swanston et al. describe the uplift achieved in a seismic reimaging project at the prolific subsalt Tahiti Field in the deep-water Gulf of Mexico using wide-azimuth seismic data. Detailed TTI velocity modeling, advanced multiple attenuation, and reverse time migration provide significant imaging enhancements, enabling better well ties and higher confidence mapping of reservoir horizons and faulting. Ma et al. who apply recent technologies to enhance subsalt images, close the case history section. These techniques include orthogonal wide-azimuth acquisition, TTI reverse time migration, and delayed imaging time scanning.

The special section continues with three general theoretical contributions. Zhou and Zhang construct and analyze a new class of highly accurate prefactored compact finite-difference schemes for second-order spatial derivatives with Fourier analysis. These schemes have the advantages of shorter stencils, but with higher resolving power over a wide range of wavenumbers. Chu et al. propose new pure acoustic TTI wave equations and compare them with the conventional coupled pseudoacoustic wave equations. These

Published online 22 November 2011.
[1]ION GX Technology, Houston, Texas. E-mail: jacques.leveille@iongeo.com.
[2]ION GX Technology, U.K. E-mail: ian.jones@iongeo.com.
[3]TGS, Houston, Texas. E-mail: bin.wang@tgsnopec.com.
[4]Chevron. E-mail: dimitri.bevc@chevron.com.

pure acoustic TTI wave equations can be solved using either the finite-difference method or the pseudospectral method to produce pure P-wave responses without S-wave artifacts and instabilities. In the final paper in this subset, Liu and Palacharla present a new approach to Kirchhoff PSDM by using beam methodology. The new method is able to handle multipathing energy correctly and, therefore, provide better quality than that from single-arrival Kirchhoff migration in subsalt and other structurally complex areas.

Eight papers on various techniques for image enhancements through velocity model building and updating follow. These use tomographic techniques, enhanced gathers, or new directions such as visibility analysis or dirty salt. Menyoli et al. start by demonstrating visibility analysis as a tool for selecting which shot records contribute the most energy on a given subsalt target event. Selectively running reverse time migration on those shot records reduces noise contamination from low energy contributing shots, improves signal continuity, and yields a better trap definition in the target area. Then Al-Saleh et al. argue that migration velocity using the common image cube offers a powerful domain for building and updating the velocity model. This method generates data whose wavefields approximate the ones that would have been generated if the correct velocity model had been used, and that are free from the raw data related problems such as noise and multiples. Zhang and McMechan calculate incident angles for angle-domain common-image angle gathers using wavefield polarization for the incident wavefield direction and a Hilbert transform for the direction normal to the reflector. They successfully apply their method to construct common-image gathers for both PP and PS reflections. Next, Guerra and Biondi develop a modeling technique to synthesize data suitable for migration-velocity analysis, whose size can be up to two orders of magnitude smaller than the conventional data size while keeping the kinematic information necessary for velocity updates. They show, in a North Sea 3D data set example, that using these new data makes migration-velocity analysis by wavefield extrapolation possible in routine production because of improved computational efficiency and increased flexibility in parameterizing the model space. Ji et al. introduce a reflectivity-based dirty salt velocity estimation scheme. This is presented as a new concept for intrasalt inclusion bodies velocity estimation. The method is shown to be practical, stable, and robust due to added constraints. The next three papers cover tomography-based velocity estimation. First, Huang et al. discuss the benefits of reverse time migration 3D angle gathers on wide-azimuth data to retain the localized subsurface information with respect to azimuth and reflection angle and to take care of anisotropy in the migration medium. The authors argue that the experiments presented demonstrate that reverse time migration 3D angle gathers, together with angle-domain tomography, provide the method of choice to estimate velocity in subsalt areas, improving the subsalt image quality. Then Zhou et al., show that TTI model building can be achieved by multiparameter joint tomography. However, ambiguity exists among anisotropy parameters as discussed by the authors. Tang and Biondi close this series of tomographic papers by performing target-oriented wavefield tomography using a new data set designed specifically for velocity analysis. They show that this new data set, synthesized in a target-oriented fashion using generalized Born wavefield modeling, is much smaller than the original surface-recorded data set, but it contains all necessary information for successful velocity updating.

The last two papers in this special section tackle the problem of multiples in subsalt imaging. Liu et al., first propose to modify conventional reverse time migration so that multiples can be used as constructive reflection energy for subsalt imaging. This approach replaces the impulsive source wavelet with the recorded data containing both primaries and multiples and uses predicted multiples as the input data instead of primary reflections. In the reverse time migration process, multiples recorded on the surface are extrapolated backward in time to each depth level, and the observed data with both primaries and multiples are extrapolated forward in time to the same depth levels, followed by a crosscorrelation imaging condition. A numerical test on the Sigsbee2B data set shows that a wider coverage and a more balanced illumination of the subsurface can be achieved by migration of multiples compared with conventional migration of primary reflections. Finally, Wang et al. demonstrate by examples that they have developed a practical technique for predicting and removing multiples in the postmigration depth domain based on wavefield extrapolation and attribute-based subtraction. The new technique can be applied for aiding salt and subsalt interpretation and removing residual multiples in the final migration images.