Integration of Surface Seismic and Well Information to Improve Drilling Success for Onshore Carbonate Caves

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SUMMARY

Ordovician carbonate caves have been considered as important reservoirs for a long time and their exploration has rapidly increased in recent years in China (Yang et al, 2010). Accurately locating the target is very critical to improve drilling success for carbonate caves. As carbonate reservoir exploration has moved deeper and deeper (6000-8000 m), wells often either hit the side of the cave or totally miss it. Here we look at the application of a new technology that is particularly suited to cave drilling. It initially builds an accurate baseline earth model; and then, during the process of drilling, it updates the subsurface image in real time by using information acquired while drilling in combination with surface seismic data. In this paper we show how this new technology can be used to help accurately reach deep carbonate caves.
Introduction

Carbonate caves could be buried up to 6000 to 8000 m deep in China and the cost of each wells to reach them have been rising accordingly. Furthermore, the overburden (including near-surface layers) and especially complex volcanic layers cause spatial location uncertainties, sometimes resulting in missing the drilling target entirely.

Therefore an accurate subsurface earth model is the key to drilling success. In current drilling process, surface seismic image is finalized using pre-drill velocity model to identify the reservoir, then the drilling program is designed according to the provided drilling target position. However, in the actual drilling process, the measured data (for example, LWD, VSP, SVWD, etc.) may show a significant difference between the pre-drill earth model and measured one. Rebuilding the earth model with the latest while-drilling information is required to reduce target location uncertainties.

Seismic Guided Drilling (SGD), described in Esmersoy et al. (2011, 2013) and Peng et al, (2013), provides this real-time model building. First a pre-drill baseline model is built using local seismic and all offset well data and geological information available. Then, as the well is being drilled, well data from the new well are used as constraints to rebuild the model, providing a more accurate 3D look-ahead image than any legacy or pre-drill images. The model update has to be performed rapidly “in time” to make to impact drilling decisions such as well trajectory.

In this paper, we apply this new technology and show its value for geoscience and drilling engineering. This is the first time this technology has been used in carbonate cave exploration in China.

Method

Typical process for this technology has three stages: feasibility, baseline model building, and real-time update. There is no fixed workflow, depending on different drilling challenges and objectives, a special fit-for-purpose workflow is designed to address them.

1) Feasibility study (2-3 weeks)
Understand drilling challenges and analyze existing data and relevant information for making plans to implement solutions.

2) Predrill baseline model building (8-12 weeks)
Before drilling, surface seismic (including preprocessing if necessary), geologic, and offset well information are integrated to build an accurate earth model and obtain the best possible depth image. Well location selection and drilling plans are made based on interpretation of the baseline earth model and seismic image. Also data are conditioned for the rapid updates in the next stage.

3) Real-time updating (24 hours turnaround time per update)
Baseline model around the well is updated with real-time logs and checkshots (LWD, SVWD, Wireline) within 24 hours. The results are used by drillers to make adjustments to the well trajectory, casing points, and/or possible sidetrack decisions.

In this paper we show how this new technology was employed in drilling a well in the Tarim basin and how it helped successfully hitting a carbonate cave.

Examples

Deep Onshore Carbonate Caves of Tarim Basin
The well location is in the north of Tarim basin, west China and the target is an Ordovician carbonate cave. Caves in the area are relatively small (100-300 m) compared to their buried depth of about 6000-8000 m. Seismic data was acquired in 2007 and its signal-to-noise ratio is relatively high. Offset well and geological information are abundant in this area, which makes the new technique particularly suitable to this project.

1) Initial Velocity Model Building
A simple practical VTI anisotropic model was created as an initial model. A smoothed velocity model from refraction tomography was used in the shallow part (0 to ~1000 m). In the deeper part (>1000 m), 1D checkshot velocity from one of the offset wells was propagated with geology as a constraint. Based on the regional geology study and checkshot calibration, a 1D model with epsilon (max 5%) and delta (max 2%) was created and propagated into the whole area.

2) Layer Stripping and Global Updating
A layer-stripping strategy is applied to obtain a low-frequency background velocity model as the main layers are relatively flat in this area. Subsurface area (10 km in depth) is divided into 4 different stratigraphic zones. Tomography updates were performed from top to bottom. The cave zone is updated last. The advantage of this strategy is that travel-time errors in the shallow part of the model will not have further impact on the deeper part, especially for the cave zone. After this more details are added to the model by reducing the scale length of the tomography inversion both vertically and horizontally.

3) Mistie Analysis and Model Fine-Tuning
Checkshot and sonic logs are used for calibrating the velocity model in each update. An error map is created from mistie analysis of the interpreted horizons and post-drill well markers. Meanwhile, qualities of cave images (under-migrated or over-migrated diffraction energies) are studied and used as additional information for model fine-tuning to obtain final baseline image. Figure 1 shows the velocity comparisons between seismic and sonic/VSP in well locations. Results show more consistent in the new model than that in the initial one.

4) Baseline Earth Model Results
Representative results are shown in Figures 2, which demonstrate significant improvements in the earth model and seismic image, including better focused caves, with our approach. Comparison between the new baseline image and legacy image are shown in Figure 3, where the volcanic rock and the strata (dashed box) are more reasonable (green arrow) and better reveal the influence of the overlying volcanic rock formation. The cave position at the new well location (A) deviates by >100 m impacting the drilling plans.

![Figure 1](image_url) Sonic (blue) and VSP velocity (rightmost, blue), initial seismic velocity (rightmost, black), and final updated seismic velocity (red).
Figure 2 Initial (A) and new (B) interval velocity model, Seismic image (PSDM) with initial (C) and new (D) velocity models.

Figure 3 Example of legacy seismic image (top) and the new baseline seismic image (bottom).

5) Well A Real-Time Updating
Vertical well A is planned based on the new baseline image interpretation aimed at reaching cave as shown in Figure 3. A VSP survey is acquired during well A drilling and used for real-time update, which is shown in left half of Figure 4. Comparing with baseline, the real-time produces slower velocities in the shallow section and faster velocities in the deep section to be consistent with VSP data. Right half of Figure 4 shows the target cave is about 8-10 meters deeper in the real-time updated compared with baseline model, and it is within 8 m of the actual cave depth encountered. If the well were drilled based on the legacy interpretation it would have missed the cave by about 150 m. Figure 5 shows abnormal conditions while drilling (3 times bit breaks, lots of leakage and overflow) are strong evidences of hitting deep onshore carbonate caves.

Figure 4 left half: VSP velocity (grey) and seismic velocity (blue). Right half: seismic image of baseline and real-time update.
Figure 5 Target carbonate cave with abnormal conditions while drilling (different perspectives).

Conclusions

In this paper, we have described the use of a new technology (SGD\textsuperscript{1}) to improve drilling success of onshore carbonate caves in China by optimally utilizing while-drilling well data from the well being drilled as well as any offset well and geology information. We have described the process and showed how it helped to lead the well to the target cave that would otherwise have been missed.

References


