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Quick 3D Formation Model for Unconventional Carbonate Reservoirs by Resistivity Imaging While Drilling in Horizontal Well*

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Abstract

Resistivity imaging-while-drilling measurement in two horizontal wells was used to construct a quick 3D formation model, which encapsulates both the structural information and the properties of horizontal sections through a thin (approximately 2-m thick) carbonate gas reservoir in a field in China. The true horizontal lengths were about 790 m and 840 m. The high-resolution resistivity images obtained while drilling revealed the geological structure's details as well as the variations of the formation properties in the reservoir, leading to optimal placement of horizontal wells in real time. The carbonate gas reservoir of the target formation consists of two types of sedimentary rocks with special resistivity-image textures and resistivity variations that correspond with the reservoir quality of porosity of 0.27–18.7% and permeability of 0.01–5.6 mD. Structural details become increasingly important in the thin, heterogeneous carbonate reservoir because the well borehole may exit the reservoir upon encountering sharp, local changes in the formation's structural dip or azimuth. These changes could be caused by faults or rapid vertical and lateral variability of depositional lithofacies that are below seismic resolution because of the limited frequency content of surface seismic data.

Resistivity imaging while drilling is ideal for thin heterogeneous carbonate gas reservoirs; this method measures azimuthally focused laterolog resistivity at four depths of investigation: 15 cm, 13 cm, 8 cm, and 4 cm. This provides formation-resistivity data with minimal bed-boundary effects in high-angle and horizontal wells. With the use of 3D modeling techniques, integrating the structure details and formation property variations to a quick 3D formation model constrains the likely stratigraphic distribution of each layer and ensures that the well stays within the thin target layer. Upscaling the resistivity of the reservoir-rock properties to the formation model constrains the likely architecture of reservoirs in the target formation. The resistivity-property model further improves the understanding of thin unconventional carbonate gas reservoir.

The quick 3D formation model from resistivity imaging while drilling can be used in drilling tendency adjustment to properly trace thin target layer and increase reservoir exposure and, hence, production. The technique enables real-time 3D reservoir modeling for subsequent reserves calculations, production simulation, and future well planning.

Geological Settings

The carbonate formation of the unconventional gas reservoir in the case study is from the early Triassic subtidal shallow sediments of the Jia-Ling-Jiang carbonate formation in southwestern China. The sediments are dominantly composed of micritic limestone and crystalline dolomite. The dolomite was modified by diagenesis, which caused well-developed secondary solution intergranular pores. The thin-section photomicrographs in the case study illustrate that the controls on reservoir quality are mainly secondary intergranular porosity in the dolomite, as shown in Figure 1.

The thickness of the gas reservoir in the formation varies from about 0.5–2.5 m, occasionally up to 3.5 m. The main challenges for well placement include thin target layer and lack of structure details in the field. The reverse faults were very developed in the field (Figure 2), which predominately strike NE-SW. The faults make the structure very complex in the field; the structural dip and structural surface trend change too much around the reverse fault drag zones. The real-time geosteering requires a good understanding of the geological structure details. Seismic data enables recognizing large structural features. The structure details, however, are below the resolution of surface seismic data. The surface seismic data shows a very gentle structure around the thin target layer, as shown in Figure 3.

Methodology and Case Study

Developing a quick 3D formation model for the carbonate reservoir requires the structure details and the properties of the thin target layer. High-resolution images while drilling provide detailed geological features related to structure details and azimuthally focused laterolog resistivity at four depths of investigation for the resistivity property of target layer.

The quick 3D formation modeling in the case study includes the main procedures as follows:

- Structural dip interpretation on images
- 3D grid model construction, and structural dips uploading into 3D model
- Structural surface creation
- Formation property propagation into 3D model.

Figure 4 and Figure 5 show the workflow of a quick 3D formation modeling based on high-resolution images while drilling.

The geological structure dips are indicated from the bed boundary on high-resolution images while drilling (Figure 4a), which were derived from surface seismic data and well-to-well log correlations with limited resolution. The 3D structural surface trend from the dips indicates formation changes in thin target layer thickness (Figure 4c).

Once the formation resistivity has been propagated into 3D space to create a formation property model (Figure 5b), the formation resistivity at each point along the well trajectory is derived from the property model. It leads to better understand how to improve real-time geosteering while drilling in the thin carbonate reservoirs (Figure 6).

In fact, the formation resistivity's changes result from different sedimentary lithotypes. In the case study, the tight micritic limestone corresponds to higher formation resistivity, and the crystalline dolomite corresponds to lower resistivity, as shown in Figure 7.

Conclusions

The resistivity imaging while drilling provides high-resolution full-borehole-coverage electrical images and laterolog resistivity measurements in conductive mud environments that can be used in real-time horizontal well placement, structure details analysis, and quick-look formation evaluation.
3D modeling techniques help integrate structure details and lithotype resistivity variations into the 3D formation model, which constrains the likely architecture of the thin carbonate reservoirs for real-time well placement and well completion and production design optimization.

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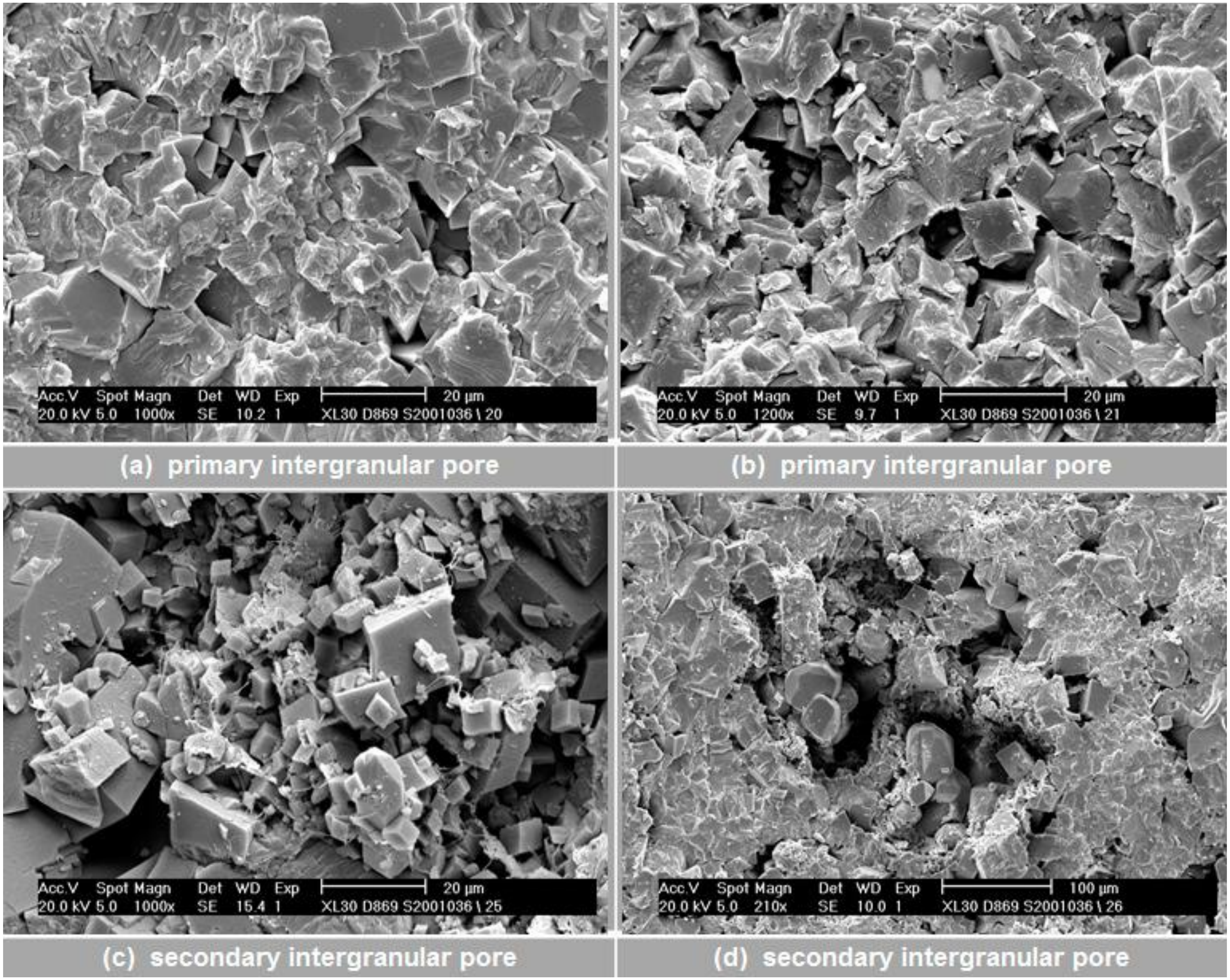

Figure 1. Examples of thin section microphotographs showing secondary intergranular pore in crystalline dolomite: (a and b) primary intergranular pores, and (c and d) secondary intergranular pores.

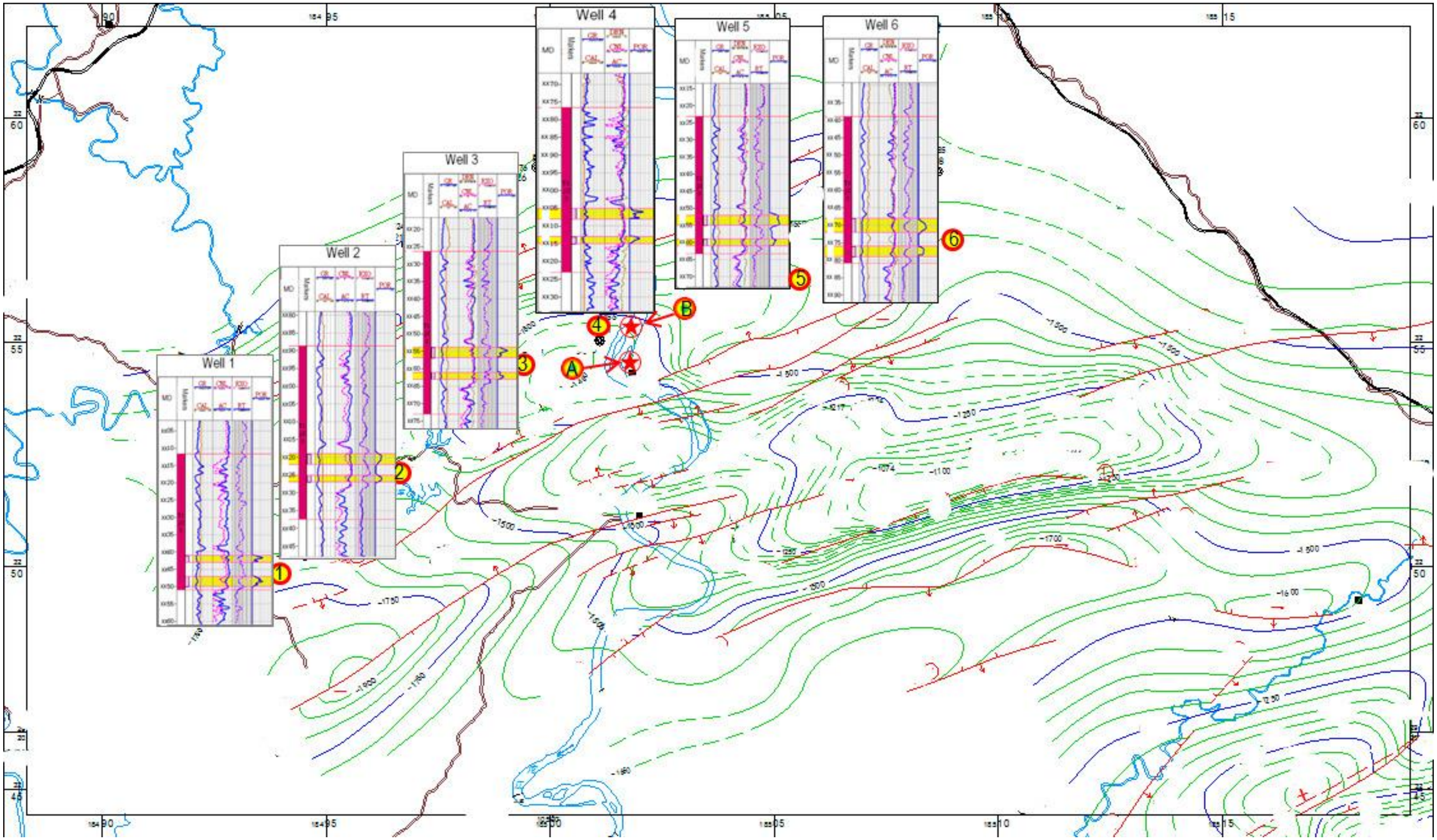

Figure 2. Structure map of the top of early Triassic Formation, including well locations (yellow circles) and target layer well-to-well correlations (yellow parts of log plots).

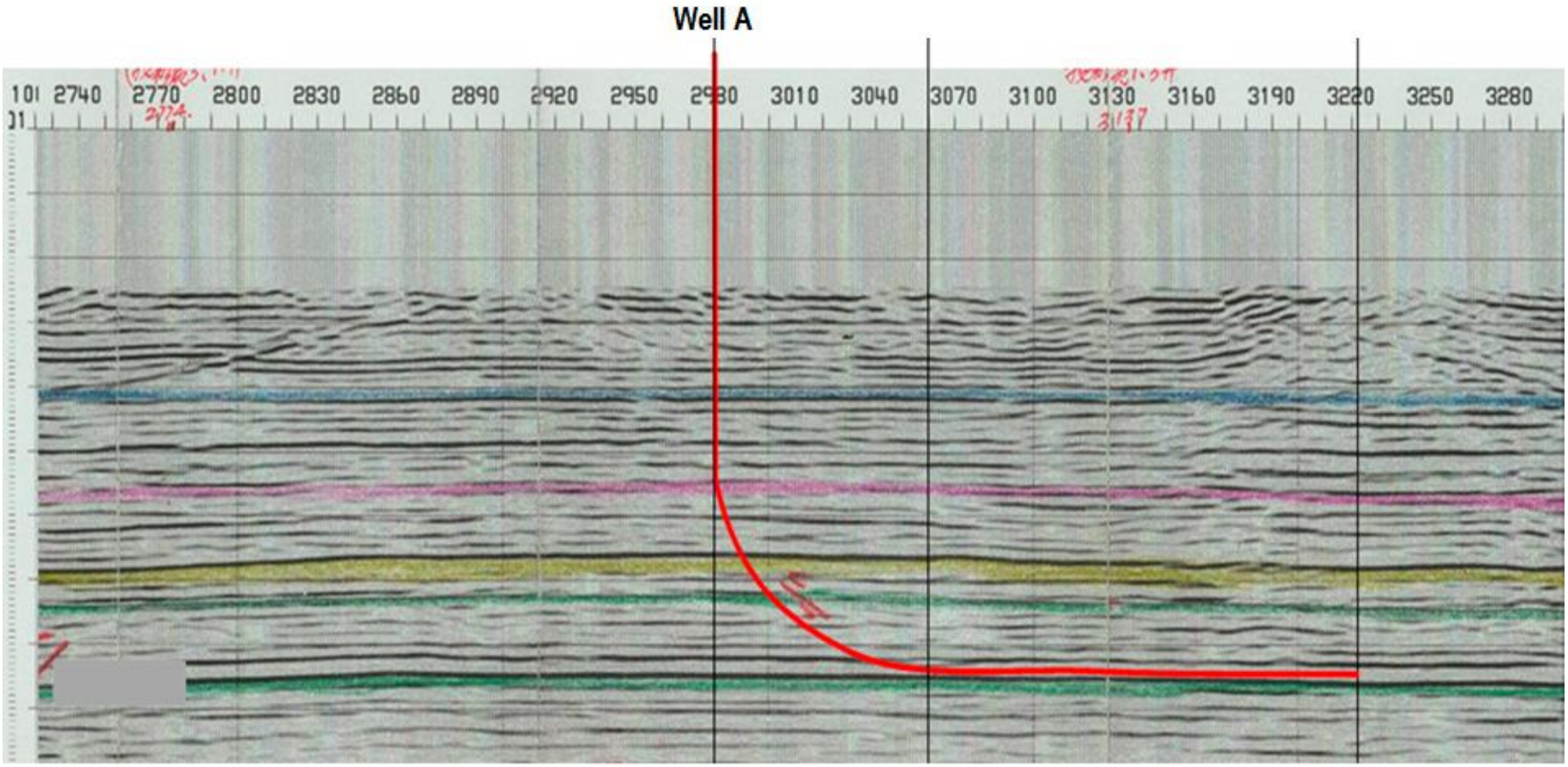

Figure 3. Limited structure information around the thin target layer from surface seismic data.

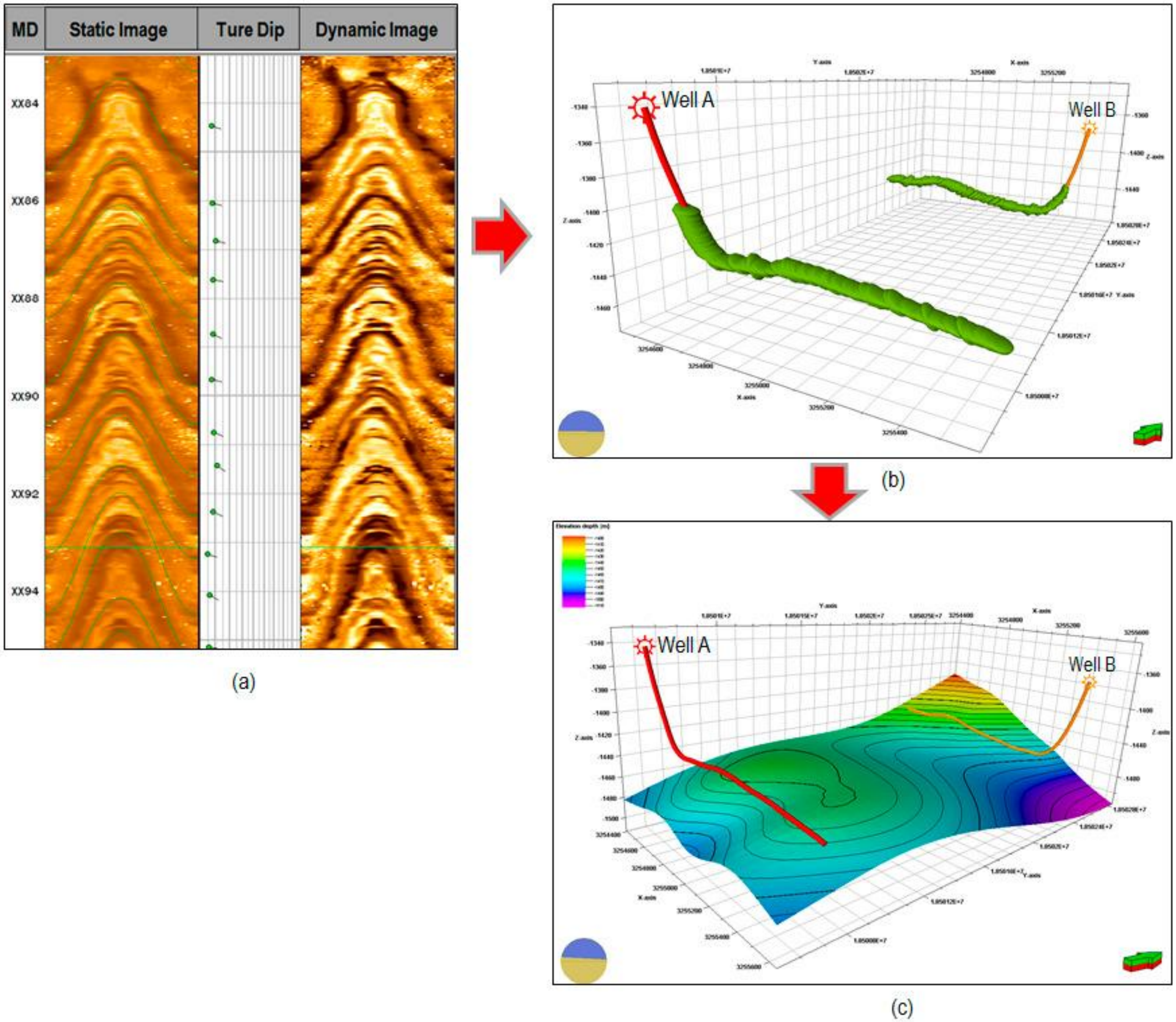

Figure 4. Workflow of structural surface creation from high-resolution resistivity images while drilling: (a) structural dip interpretation on the images while drilling, (b) display of the structural dips in 3D grid model, and (c) 3D structural surface trend modeling based on the structure dips of Wells A and B.

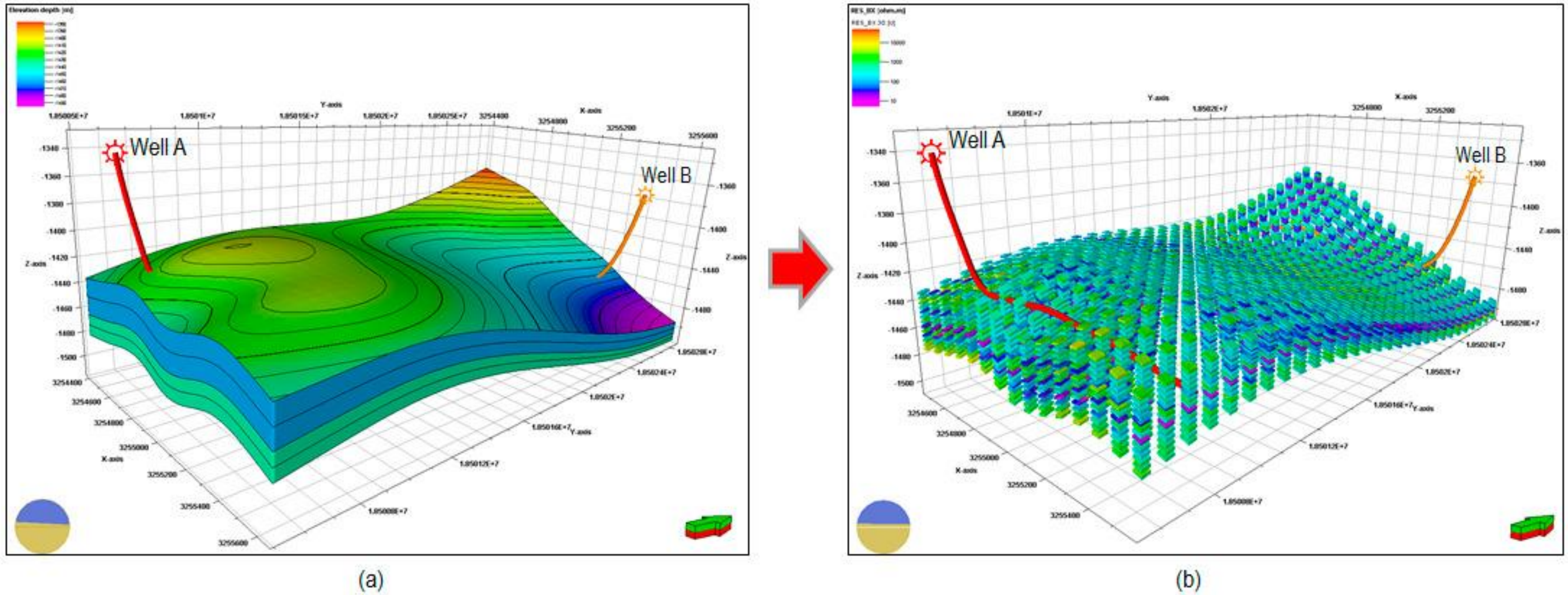

Figure 5. 3D modeling based on the resistivity images in the wells A and B. (a) 3D formation modeling based on structural surface trend and true stratigraphic thickness (TST), and (b) 3D property modeling by integrating the azimuthally focused laterolog resistivity from resistivity images while drilling.

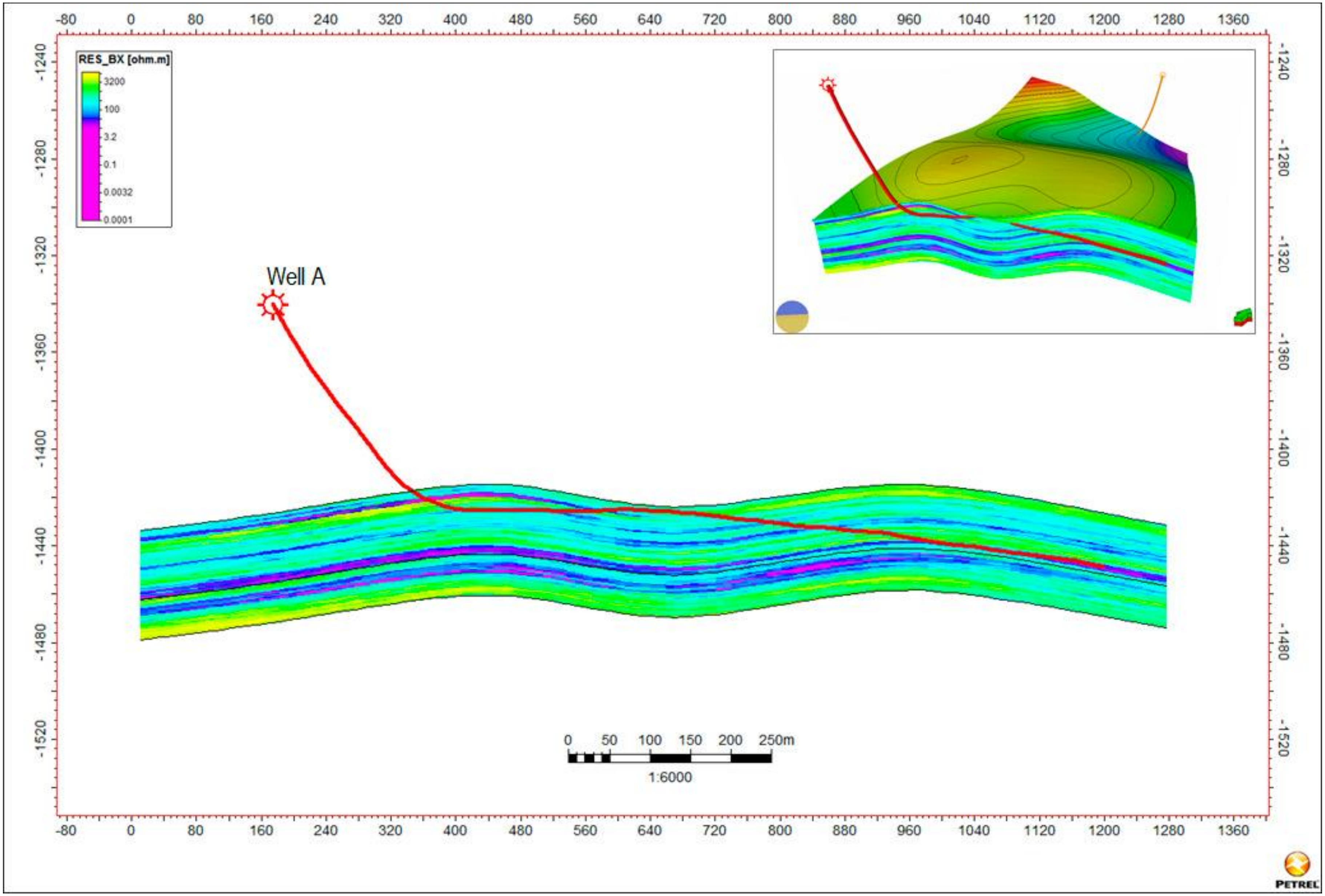

Figure 6. Display of an intersection of 3D formation resistivity model showing the structure details and formation resistivity variations along the well trajectory.

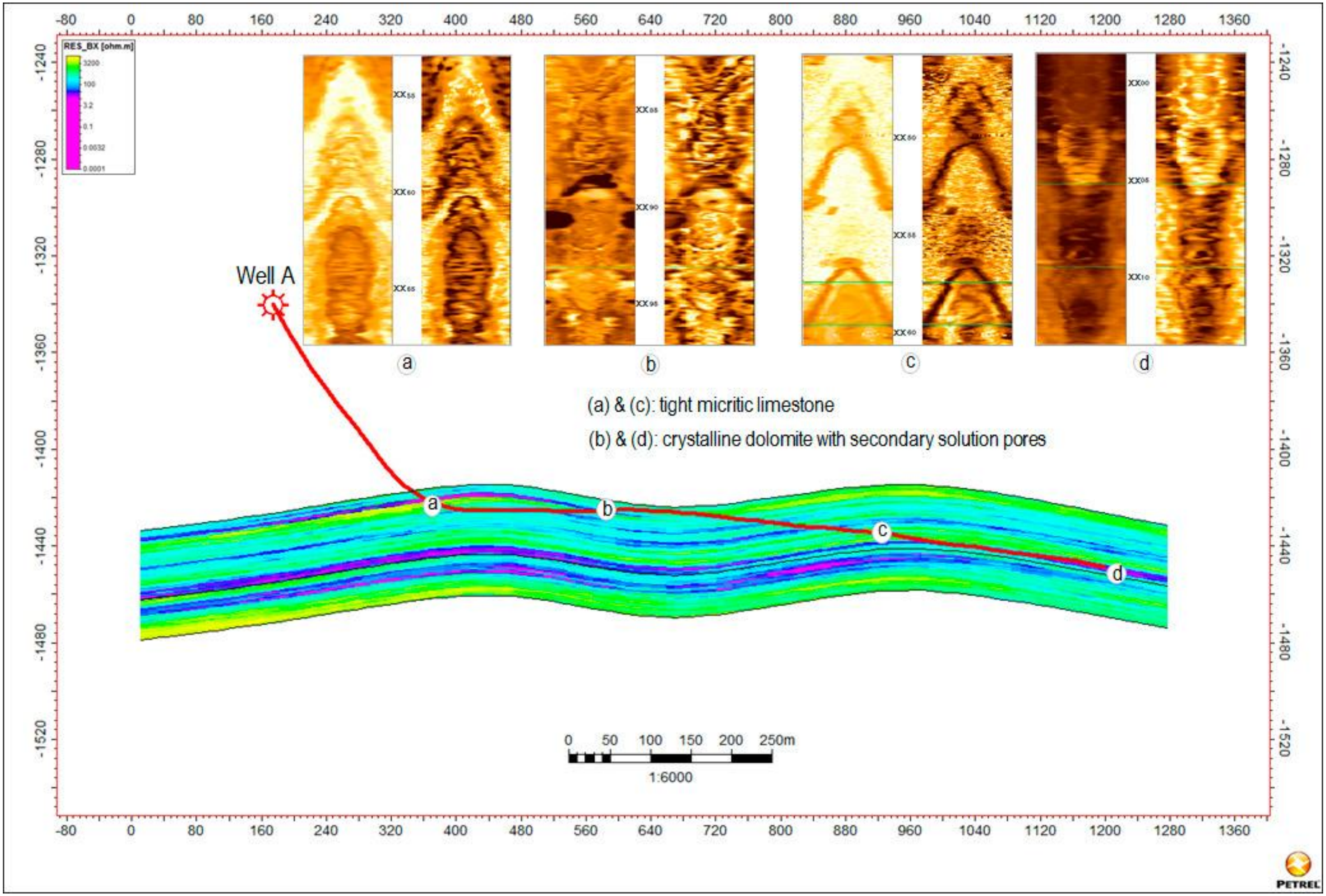

Figure 7. Example of the formation resistivity variations associated with lithotypes along the trajectory.