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Integration of High-Resolution Well Data to Reservoir Models in a Multiuser E&P Collaboration Environment*

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Abstract

This study is the result of a multidisciplinary workflow across software platforms to improve reservoir modeling for better understanding of reservoir distribution, more accurate reserve estimation, and overall reduced risk and uncertainty in the E&P lifecycle. Efficient two-way data transfer between a shared-wellbore platform and a shared-earth platform promote knowledge sharing and understanding at both the borehole and the reservoir scale.

The potential benefits of cm- or mm-scale geologic observations at the well to complement coarse resolution and wide-area coverage of seismic data are easy for geoscientists to envision. The obstacles are the vast difference in scales and the smooth transfer of relevant information between applications.

A potential sandstone reservoir is initially modeled based on interpretation of the available 3D seismic data, leaving high uncertainty in the distribution of sand bodies and low-resolution definition of channels, and overbank deposits. As the first wells are drilled, higher resolution data such as logs, borehole images, and cores become available, providing hard data on lithofacies and depositional trends that are valuable to constrain stochastic models if provided at a relevant scale.

A new workflow to achieve this has the following main steps: 1) transfer of logs, images, and interpreted facies to the 3D shared-earth platform, 2) picking of well tops and updating of interpreted seismic surfaces, 3) transfer of updated model zones to the shared-wellbore platform, 4) upscaling interpreted data (e.g. dip or paleocurrent trends) to zone-scale, and 5) transfer back to the reservoir modeling platform.

The cross-platform data transfers are seamlessly realized in a new, secure, cloud-based multiuser solution. In this cross-discipline environment, geoscientists and engineers share their work at the folder level, using automation to exchange updates with team members who have opted to

keep those same folders in sync. Alerts and notifications give users awareness of what is happening in the team throughout the project, setting new standards in data sharing efficiency.

Updated reservoir models leveraging the maximum hard data gained from wellbore studies lead to a more representative appraisal and a more geologically sound development plan. The ability to smoothly integrate and collaborate at different scales is key to increasing team productivity and will become the new way of working for operators seeking to maximize certainty of return-on-investment.

Introduction

Lack of collaboration between geoscientists most often results in unused critical pieces of information that could have a big impact on a 3D reservoir model.

The multi-disciplinary workflow described in this paper is designed to enhance collaboration between sedimentologists and geomodelers; it enables geoscientists to efficiently transfer data across platforms and shows how to improve the reservoir model for better understanding of reservoir distribution, more accurate reserves estimation, and overall reduced risks and uncertainty in the E&P lifecycle.

When we talk about Techlog shared-wellbore platform and Petrel shared-earth platform, the challenge to bear in mind is that we seek to smartly combine different sources of data that not only reside in different pieces of software, but also have greatly different scale, scope, and confidence. The high level of resolution from wellbore measurements provides geologists a means to understand reservoir geology with high certainty. In this work, we focus on high-resolution microelectrical images acquired on wireline, such as the example in Figure 1, though this work could apply equally to log, core, or other types of wellbore interpretation. From the figure it is at once apparent that such images contain much of the same visual information as an outcrop or a core (precisely oriented): these types of images, processed in the shared-wellbore platform, can display very fine textural features down to a few millimeters in scale. The images are used by sedimentologists to determine, via direct observation, sedimentary facies, depositional subenvironments, and depositional trend or paleocurrent direction in the subsurface at the wellbore. These interpretations lack the wide-area coverage of seismic data, but are highly complementary in that they are high-resolution, high-certainty data, providing a level of detail that could potentially have a significant impact on the 3D static reservoir model if they are made timely available in a format that the modeling workflow can consume.

We observe that this is normally not the case in the industry today, and so we developed software tools and workflows that would ensure easier and better availability and relevance of hard data from wellbore observations to the 3D facies modeling process. In the following paragraphs, we detail the main workflow steps and tools to make this possible.

Facies Interpretation in the Shared-Wellbore Platform

Various workflows enable users to interpret microelectrical borehole images at the wellbore scale, typically using commercially available software specialized for the processing, display, and interpretation of wellbore data such as logs and core. In this example, a commercial shared-wellbore platform is used to perform interpretation of a dataset representing the first exploration well drilled in a deepwater, lower continental slope environment, with the eventual aim that results will be consumed in the shared-earth platform to improve model accuracy. Borehole image interpretation is well-documented in other works (Cantwell et al., 2015; Kumar et al., 2014; Laronga and Forsyth, 2014). For the purposes of this writing, we summarize the main steps followed:

1. Raw data are loaded in the shared-wellbore platform, and a standard commercial borehole image processing workflow is applied, including depth correction, false-color scaling, color enhancement, and orientation to produce spatially oriented static (absolute) and dynamic (enhanced contrast) interpretation-ready images.
2. All visible surfaces or interfaces are interactively traced with a sinusoidal template to determine dip and dip azimuth (+/-2°). Surfaces are interactively classified based on orientation and observable relationships, e.g., bed boundary, cross/inclined bedding, unconformity, slump, fault, etc.
3. Local curvature axis stereonet technique is applied to determine structural dip and dip azimuth and to subdivide the interval into zones. The resulting structural dip/dip azimuth for each zone is subtracted from all oriented sedimentary features to determine dip and dip azimuth at the time of deposition.
4. Classification representing distinct depositional subenvironments (facies) are visually interpreted based on apparent relative grain size from image resistivity, bed thickness, and planarity, grain size and stacking trends, depositional dip, presence of visible clasts, Bouma sequence elements channel scours or other sedimentary structures (Bouma, 1962). One of the main outputs of the workflow is a set of interactively interpreted facies and of depositional sub-environments on a scale of a few feet to tens of feet. These facies are interpreted using a predefined scheme. To simplify later tasks, the facies-naming scheme should be defined to exactly match the scheme used for facies modeling in the 3D shared-earth platform.

A set of interpreted facies is one of the most valuable pieces of wellbore data when building a 3D static model. These manually interpreted facies are saved inside the shared-wellbore application as a zonation dataset (Figure 2, track 2).

Use of Wellbore Data to Constrain the 3D Reservoir Model

In a multiuser E&P collaboration environment, borehole images, wireline logs, and facies interpretation are transferred from the shared-wellbore platform to the shared-earth platform and are used as hard data to condition and constrain a seismic-based 3D geological model (Figure 3).

Lateral distribution and vertical proportions of facies in a depositional system are key factors to correctly capture reservoir heterogeneity and connectivity when performing a reliable assessment of the reservoir flow performance. Therefore, the high level of detail provided by the facies interpreted in the shared-wellbore platform is an essential element when we want to build 3D geological models that can generate reliable production forecasts.

These are the main steps followed once data are transferred from the shared-wellbore platform:

1. Comparison of the facies already existing in the shared-earth platform, which were modeled based on seismic interpretation, with the facies log transferred from the shared-wellbore platform. High-resolution facies, borehole images, and wireline logs transferred from the shared-wellbore platform complement the standard geophysical workflow to perform time-depth correlation. These data help to perfect the depth of interpreted markers in the shared-earth platform (Figure 4).

2. A refined conceptual 3D geological model of the reservoir representing the depositional environment is created to capture key elements such as facies proportions, facies relationship, and lateral facies distribution (Figure 5).
    - Object-based modeling technique is used to create channels and levees having vertical thickness based on log and image interpretation, and aspect ratios based on literature or analogs.
    - Slumps and lags are then inserted using interactive painting tools based on their observed proportions in the borehole image (Figure 6).

3. The above conceptual model is used as a 3D training image to feed property modeling simulation using the multipoint facies modeling method. The multipoint simulation model is constrained using the upscaled interpreted facies brought in from the shared-wellbore platform (Figure 7).

4. A directional trend map is later added to guide the spatial distribution of facies near the logged wellbore (Figure 8). The trend map is based on the overall canyon trend visible in the seismic data combined with paleocurrent observations at the wellbore (discussed further below).

Dip Analysis in the Shared-Wellbore Platform and Transfer to the Shared-Earth Platform

After the tops have been tuned in the shared-earth platform, they can be transferred to the shared-wellbore platform. The transfer is enabled within the cloud based datacentric environment. The availability of the model zones within the shared-wellbore platform (Figure 9, track 3) can have several uses; in this example, they are used to upscale interpreted paleocurrent orientation data based on the wireline microelectrical borehole images (Laronga and Forsyth, 2014).

Borehole image interpretations typically yield hundreds or thousands of individual dipping events at much higher resolution than what can be practically applied in a reservoir modeling context (Figure 9, track 5). Information contained in the dataset must be filtered for relevance and then upscaled to be useful input to modeling zones that are typically tens to hundreds of feet thick.

Paleocurrent direction is a key input interpreted from borehole images and dips that we would like to have available at a relevant scale for facies modeling. Paleocurrent interpretation techniques are not the main topic of this work, but here we list a few key points to consider when performing such interpretation for purposes of 3D reservoir modeling:

- Stereonet rotation to remove structural dip is mandatory before any interpretation of paleocurrent trend is made, as performed in the commercial image processing workflow described above.
- Often, the majority of dip surfaces interpreted in a borehole do not represent paleocurrent, so it is preferable to isolate those events or groups of events that are in some way indicative of paleocurrent.
- A paleocurrent-related dip event does not always point in the direction of transport. Some sedimentary structures may dip in the opposite direction of flow, whereas others may strike parallel to two equally possible but opposite transport directions.

The first step performed is to first interactively create a new dip dataset representing only those events indicative of paleocurrent. The interpreter specifies the azimuth of each data point as the observed paleocurrent direction based on image and dip evaluation. In the resulting lightweight dataset, each dip azimuth represents one observation of paleocurrent direction within a given facies at a given depth (Figure 9, track 6).

The new paleocurrent dataset is often still too detailed for practical use in modeling. For property modeling purposes, a practical goal is to perform facies modeling with one paleocurrent trend per zone per well. Commercially available dip-upscaling functionality in the shared-wellbore platform readily provides this, given the model zones and the paleocurrent dataset as input. The result is one upscaled dip azimuth per zone in the model, in effect one paleocurrent trend per zone (Figure 9, track 7).

The further workflow in the shared-earth platform relies on reading the upscaled azimuth values off the screen in the shared-wellbore platform and entering them into the facies modeling interface or interactively using them to draw trend maps for each zone that will be input to the facies modeling process (Figure 8).

Multiuser E&P Collaboration Environment Enabling Cross-Discipline Workflows

All the cross-platform data transfers performed in the whole workflow, are seamlessly realized in a new, secure, cloud-based, data-centric, multiuser solution.

The capability to tag data of interest and automatically transfer updates between the shared-wellbore platform and the shared-earth platform is a key feature of the interpretation workflows described in this article. To do this data sharing effectively, several pieces of technology are used, the details of which are described in this section.

Referring to Figure 10, the overall software architecture consists of two high-level systems: 1) a data-aware Job Management System that provides scheduling and execution of transfer jobs that are set up by a data manager and 2) a notification and collaboration system that provides the end user with visibility and control of the data they require (End-User Collaboration Space).

The job management system is a separate set of software from the E&P interpretation platforms, but it needs to be aware of the types of data those systems use and how to transfer data between those platforms. For awareness of what data are available, the system uses a source data index that is defined in terms of common datatypes (e.g., boreholes, logs, etc.) and that is populated by platform-aware adapters that interrogate the different application datastores.

For the workflows demonstrated in this paper, the relevant end-user systems are the shared-wellbore platform and the shared-earth platform. Both of those applications have cloud-resident repositories (shown in Figure 10) that are managed in the multiuser E&P collaboration environment.

Once the data indices for the shared-wellbore platform and the shared-earth platform have been populated, the data manager using the job management system can decide which types of data and which specific instances of that data will be transferred between the two platforms. For example, the data manager can create a job that will transfer logs of interest from certain wells in the shared-wellbore platform into the shared-modeling platform, leaving the bulk of the application data untouched.

After the data transfer jobs are validated and working as expected, the automation engine will continue to manage the synchronizations without further intervention. This frees the end users from having to take any explicit action to force a cross-application update other than saving their work to the native datastore to make it available.

In addition, end users can define further selection criteria for the data they are interested in without changing the underlying data transfer job. This is done by defining filters in the collaboration system. For example, if the automation engine is synchronizing all well logs under a specific folder but the end user is only interested in receiving alerts about updates to gamma ray logs, this rule can be defined as a filter in the collaboration system. Filters are very useful in multi-user scenarios because they allow customizations to the alert criteria on a per-user basis without changing the overall content of the synchronization job (Figure 11).

Conclusions

- Smart combination of different sources of data that not only reside in different pieces of software, but also have greatly different scale, scope, and confidence requires active collaboration among geoscientists.
- Efficient data transfer workflows between a shared-wellbore platform and a shared-earth platform promote the use of wellbore interpretations as hard data to enhance the quality of reservoir models.
- The ability to smoothly integrate and collaborate in a short turnaround at different scales is key to increasing team productivity and will become the new way of working for operators seeking to maximize project success.

The idea of the integration as described in this case leads to what you can see in the two images in Figure 12. The top image displays a patchy, pixelated appearance of sand bodies while the image below looks more geologically sensible. The more accurate we get, not only the channels and overbank deposits look real, but also it leads to the better reserve estimation, more certainty in terms of reservoir distribution, and therefore smarter field development planning, and lesser uncertainty.

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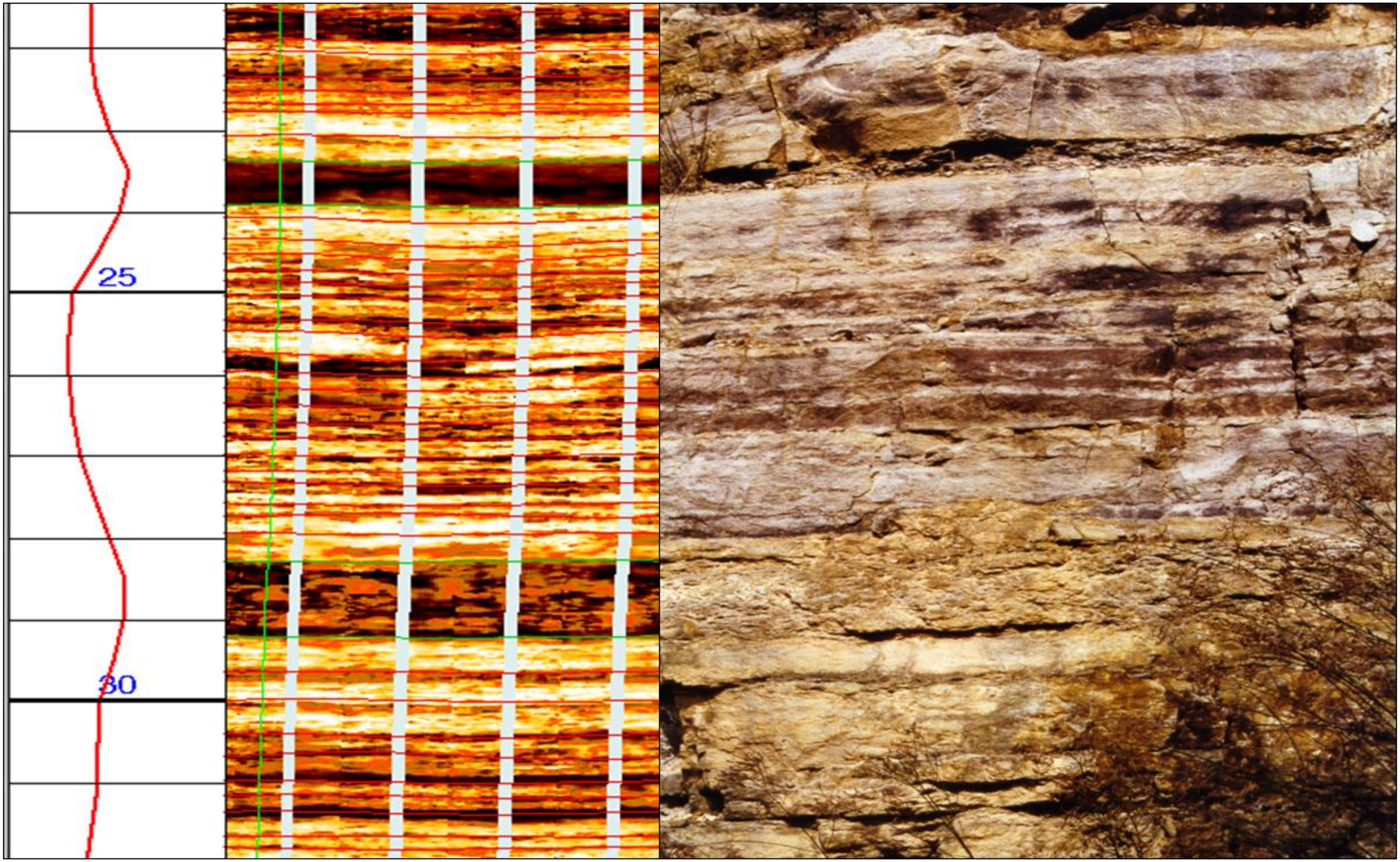


Figure 1. On the left: high-resolution borehole image acquired at Hollywood Quarry, Arkansas. The image was recorded in a research well drilled about 70 ft behind the outcrop displayed to the right. Vertical scale is in feet. (Hansen and Fett, 2000).

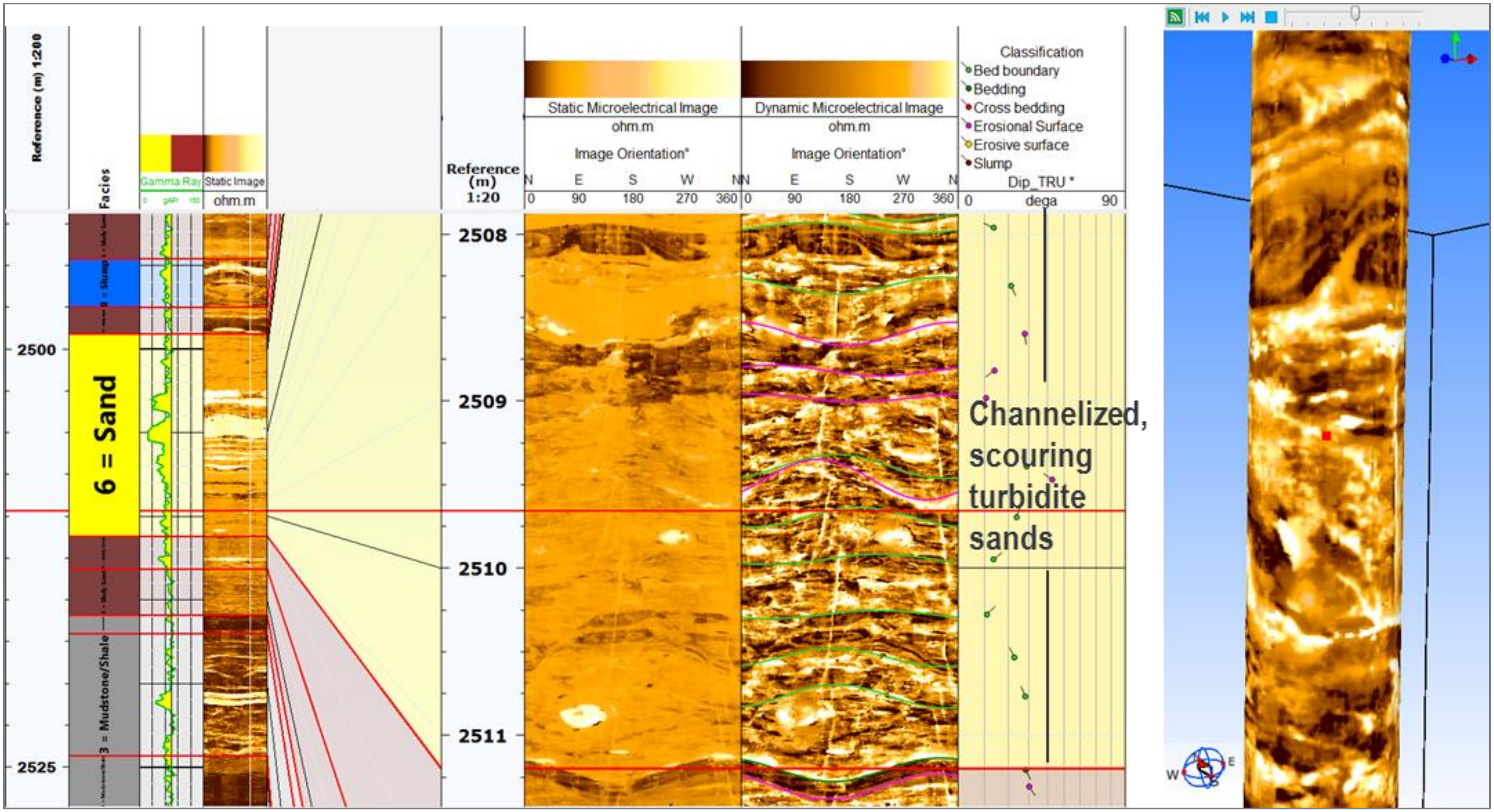


Figure 2. Example facies interpretation layout in the Techlog. From left to right: track 1, depth reference in m (1/250 vertical scale); track 2, facies trends interpreted using interactive zonation; track 3, gamma ray; track 4, static (absolute color scale) microelectrical image; track 5, zoomed (1/25 vertical scale) static image; track 6, zoomed (1/25) dynamic (optimized contrast) microelectrical image. Right, 3D interactive "virtual core" rendering of dynamic image, 1/10 scale.

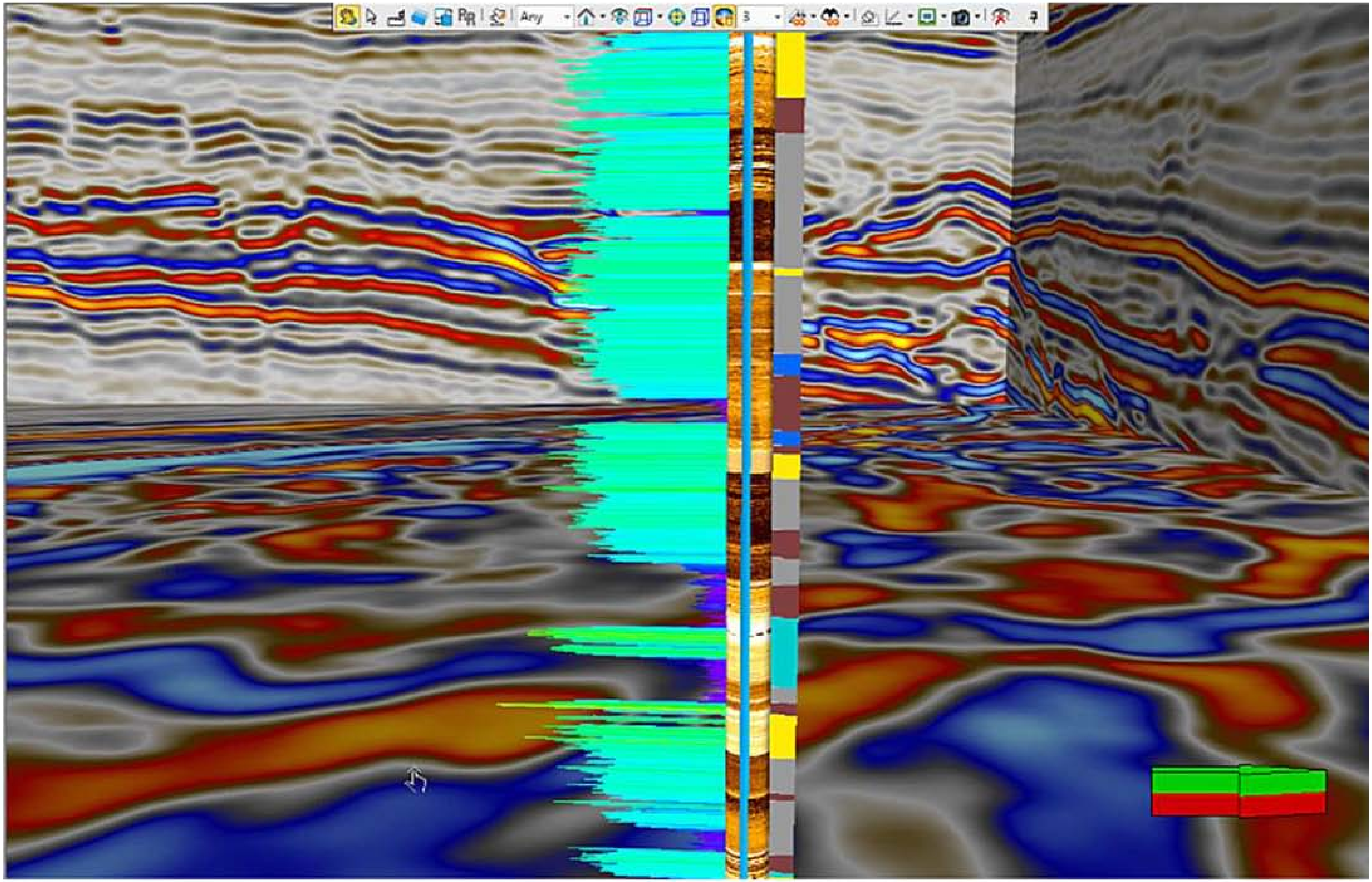


Figure 3. Borehole images, wireline logs, and high-resolution facies are transferred from Techlog to Petrel and are used as hard data to condition and constrain a seismic-based 3D geological model.

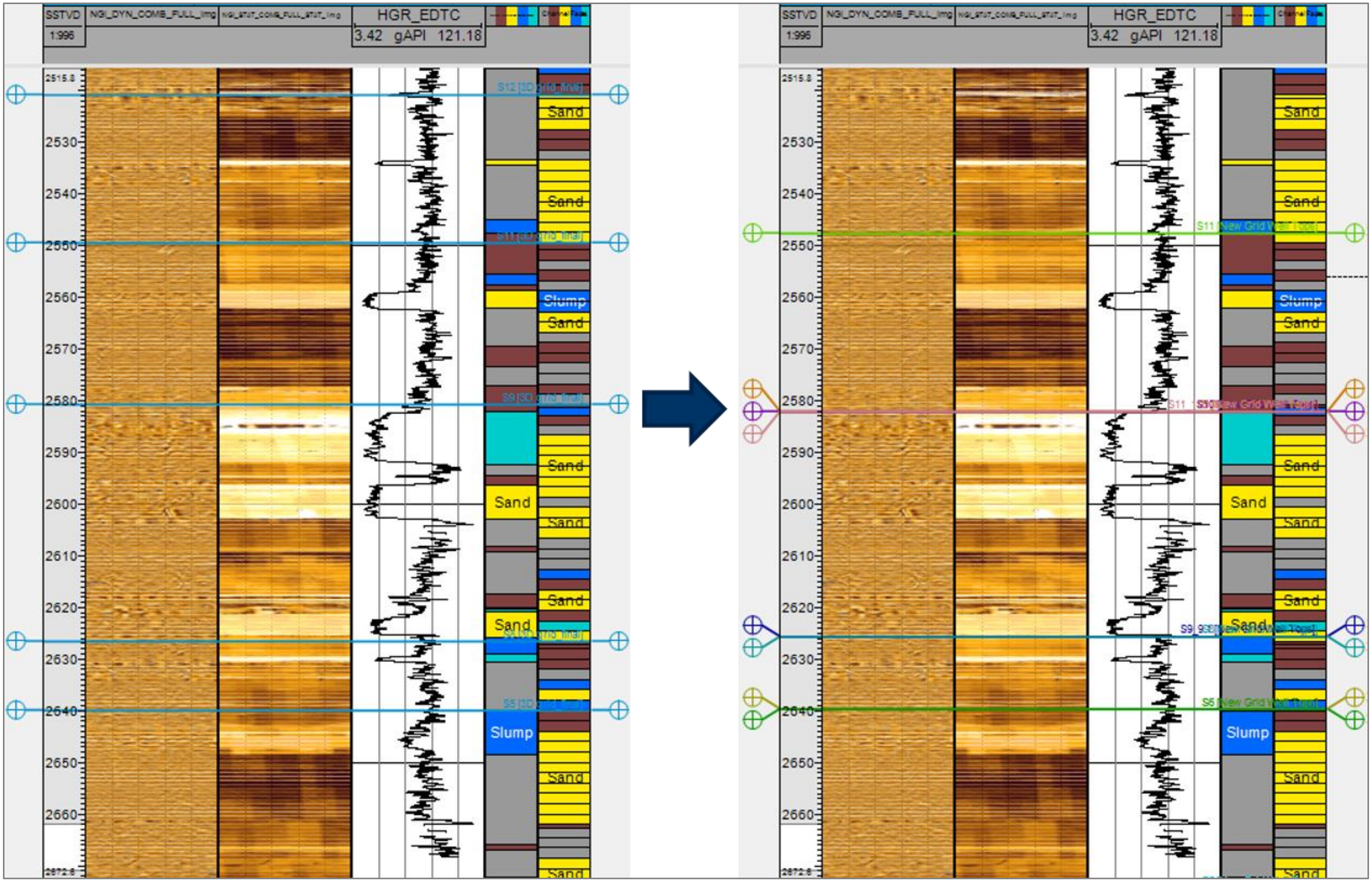


Figure 4. Borehole images, gamma ray, and facies transferred from Techlog and displayed in well section in Petrel. They are used to correct the markers previously interpreted in the original 3D model. The well tops displayed on the image on the left were interpreted in the original model from seismic data and may have small residual depth errors even after time-depth correlation is performed using acoustic log and checkshot data. The image on the right shows the well tops corrected based on the well data transferred from Techlog.

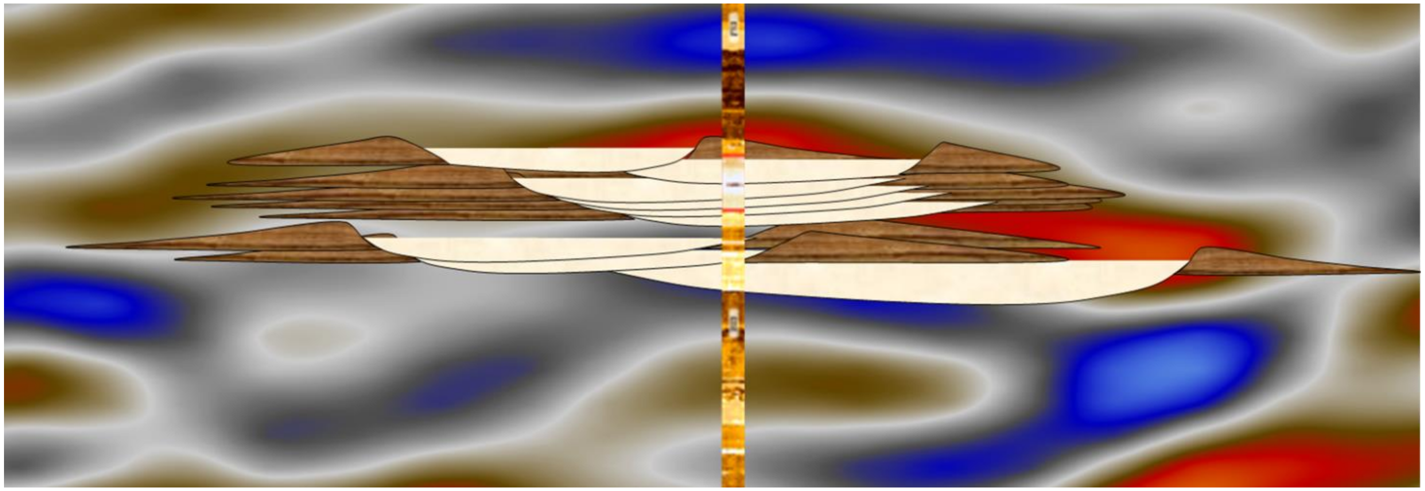


Figure 5. Sketch of the refined conceptual 3D geological model of the reservoir representing the depositional environment.

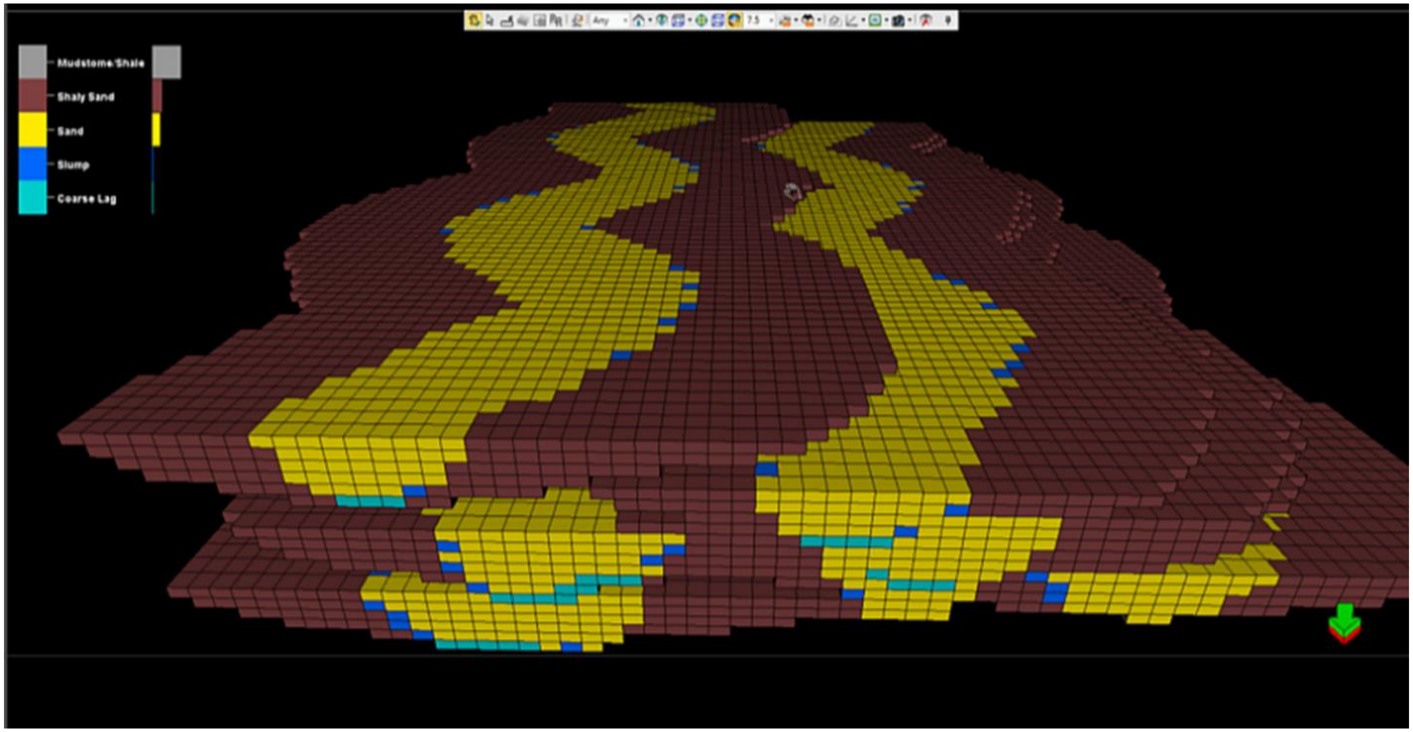


Figure 6. Conceptual 3D geological model created using object-based modeling technique and interactive painting tools.

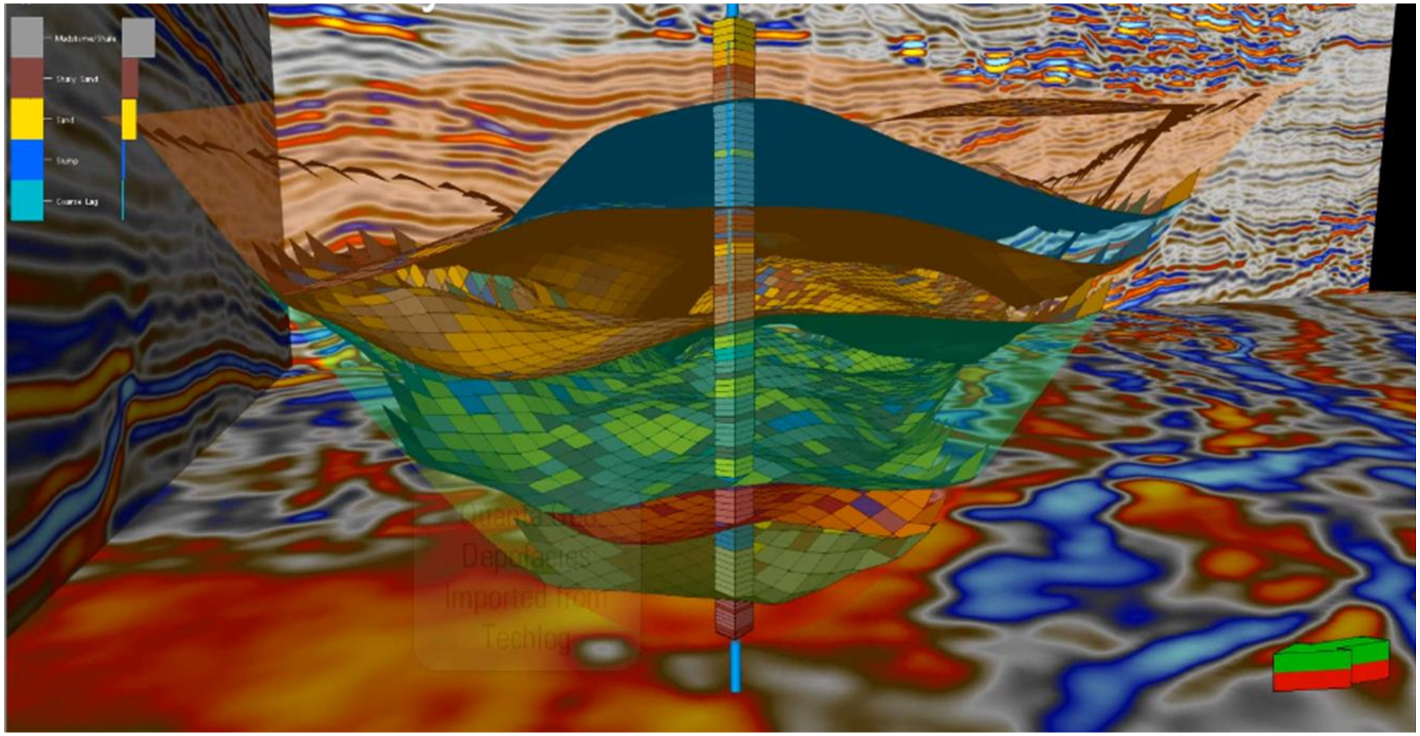


Figure 7. Upscaled interpreted facies transferred from Techlog shown along the wellbore together with the new re-defined zone.

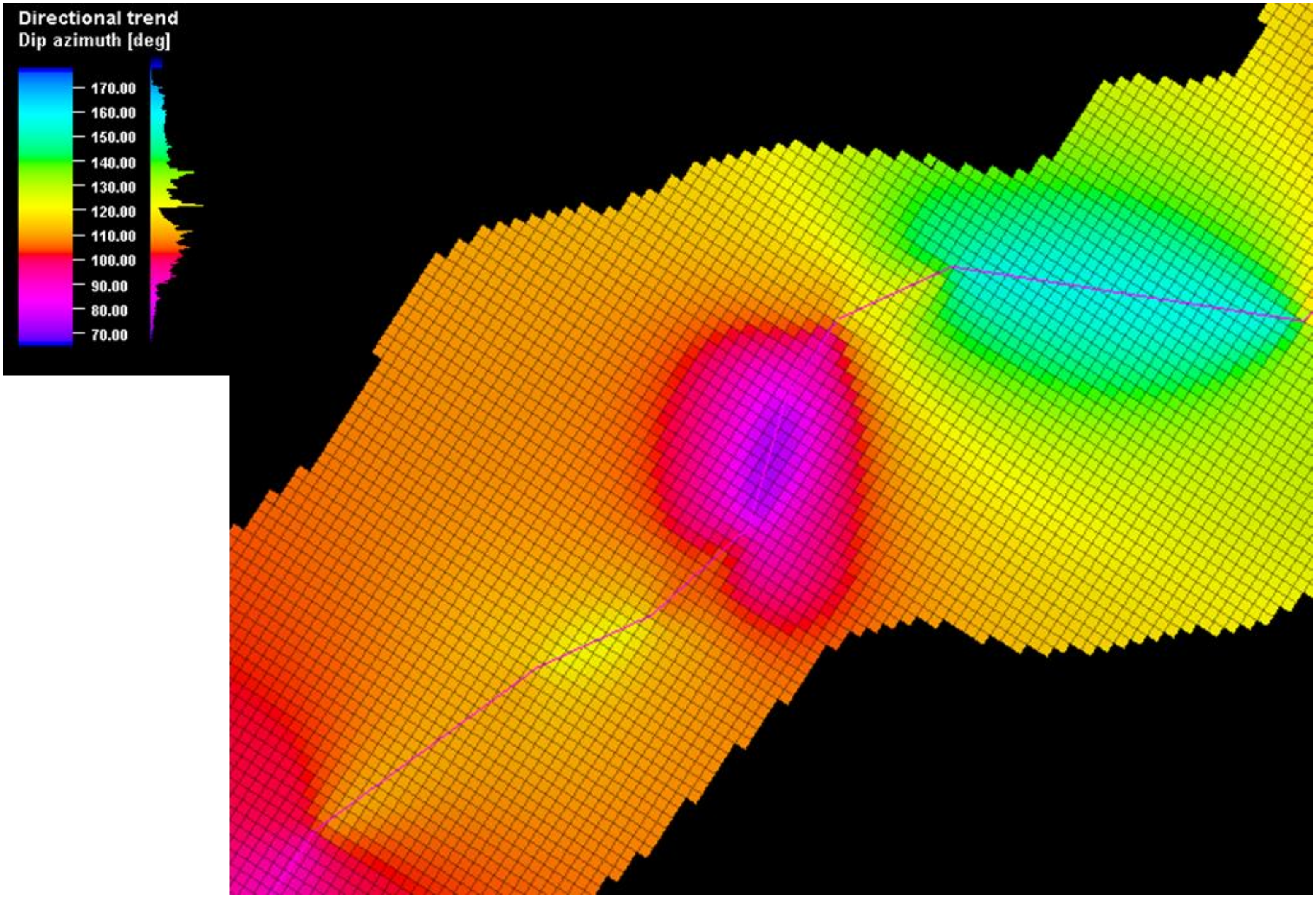
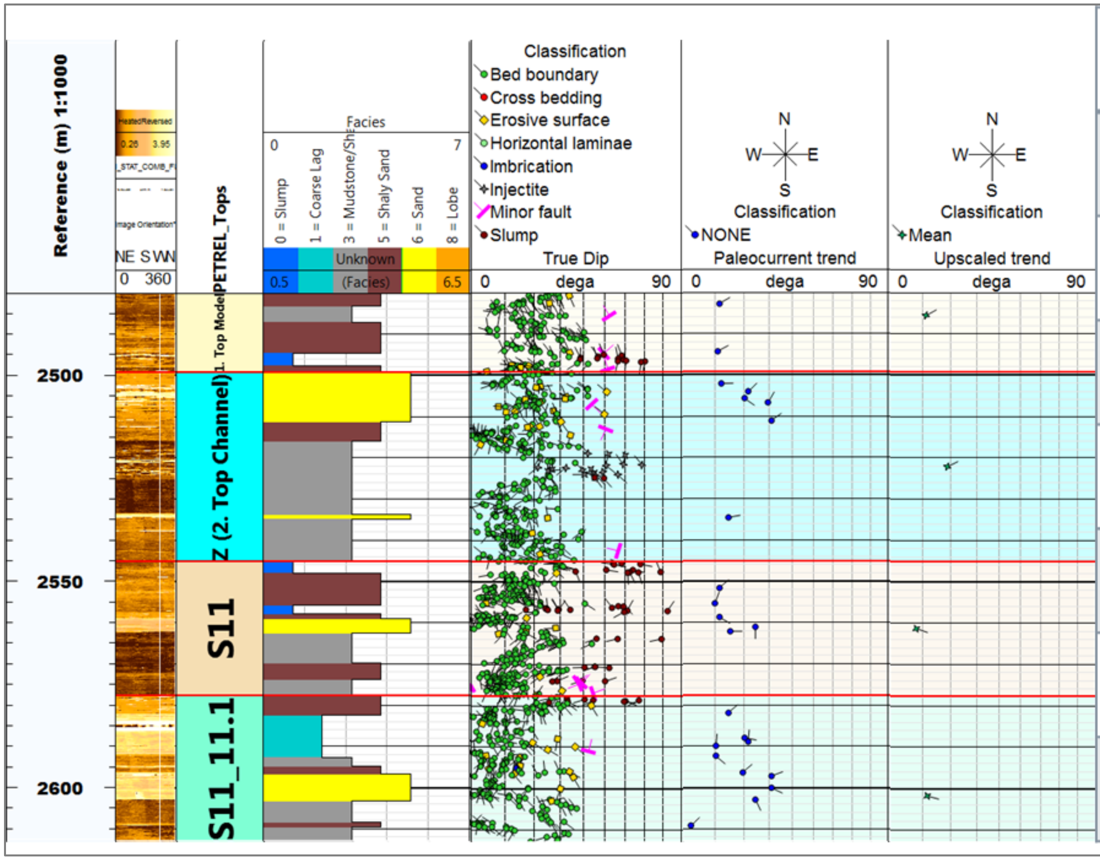


Figure 8. Directional trend map created to guide the spatial distribution of facies near the logged wellbore.



Sedimentary structure imaged	Interpreted transport direction
Channel base/ scour surface	Perpendicular to dip azimuth (2 equally possible opposites)
Drape/ accretionary dip pattern (fill)	Perpendicular to dip azimuth (2 equally possible opposites)
Thin beds-distal levee	~80 degrees to dip azimuth (2 equally possible opposites)
Current ripples	Dip azimuth
Ripple sets	Opposite of dip azimuth
Imbrication plane (cobbles/boulders)	Opposite of dip azimuth
Flame structure/ convolute lamination	Azimuth of observed drag at top of folds

Figure 9. Markers transferred from Petrel display as a zonation dataset in Techlog. They are used to create a single downsampled dip azimuth per 3D model zone as input to the 3D property model. From left to right: track 1, depth reference in m (1/1000 vertical scale); track 2: static microelectrical image; track 3, markers exported from the 3D shared-earth platform and displaying as a zonation dataset; track 4, facies trends interpreted using interactive zonation and displayed as a discrete blocked curve; track 5, individual dipping events interpreted based on borehole images. Track 6, dip dataset that captures only events indicative of paleocurrent directions; track 7, one upscaled dip azimuth per zone in the model (one paleocurrent trend per zone).

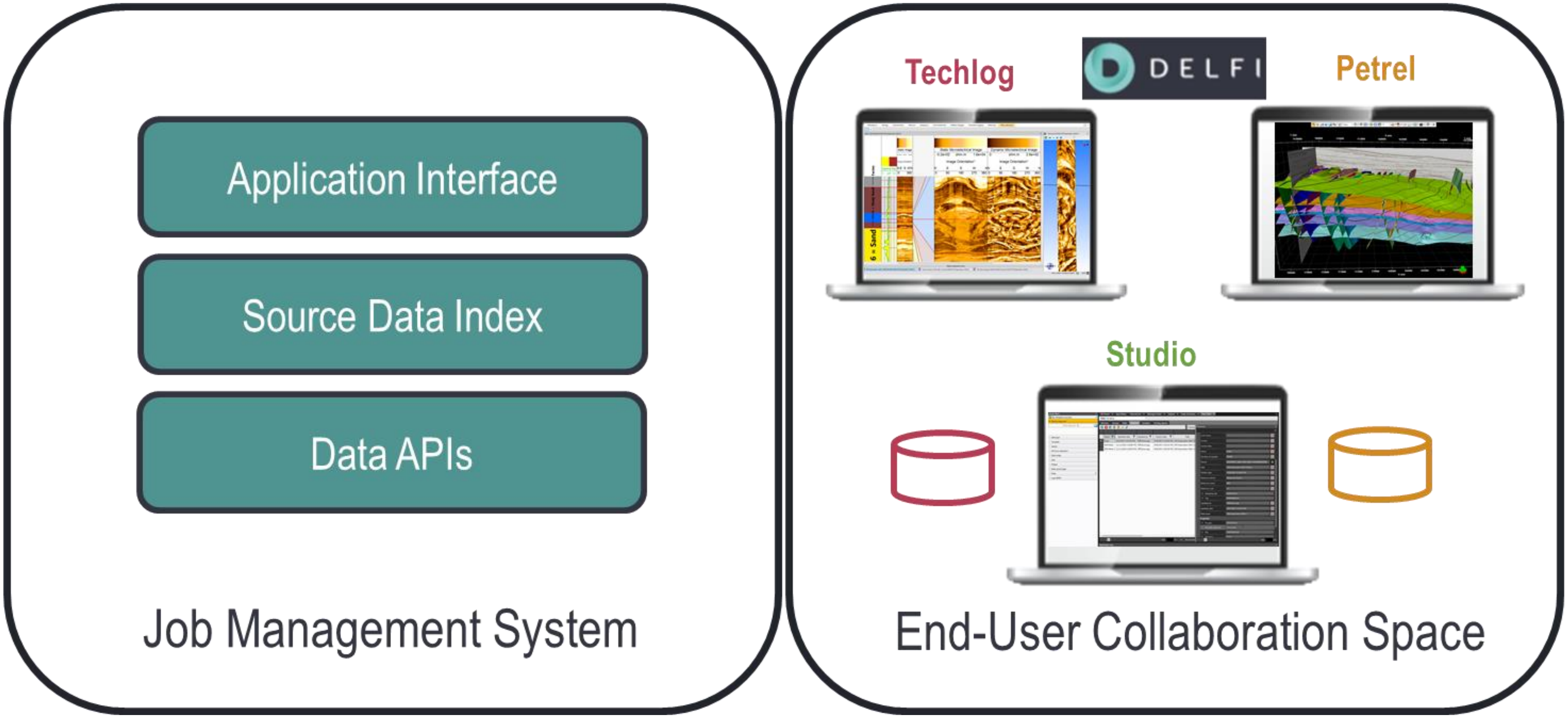


Figure 10. On the left is a high-level diagram of the automation engine that manages the definition of end-user data items to keep synchronized, whereas the right side is the high-level view of the end-user space that includes the shared-earth and the shared-wellbore platforms and their cloud-based datastores. The automation components work directly with the data stored in the DELFI cloud based datacentric environment.

Figure 11. When a data item is updated in the shared-earth platform (left, red cylinder), it will be automatically copied to the shared-wellbore platform datastore (orange cylinder) by the job management system based on the job rules. After the item is in the target system (here the shared-wellbore platform), the end user can choose to be notified of the update based on filter rules configured by the collaboration system.

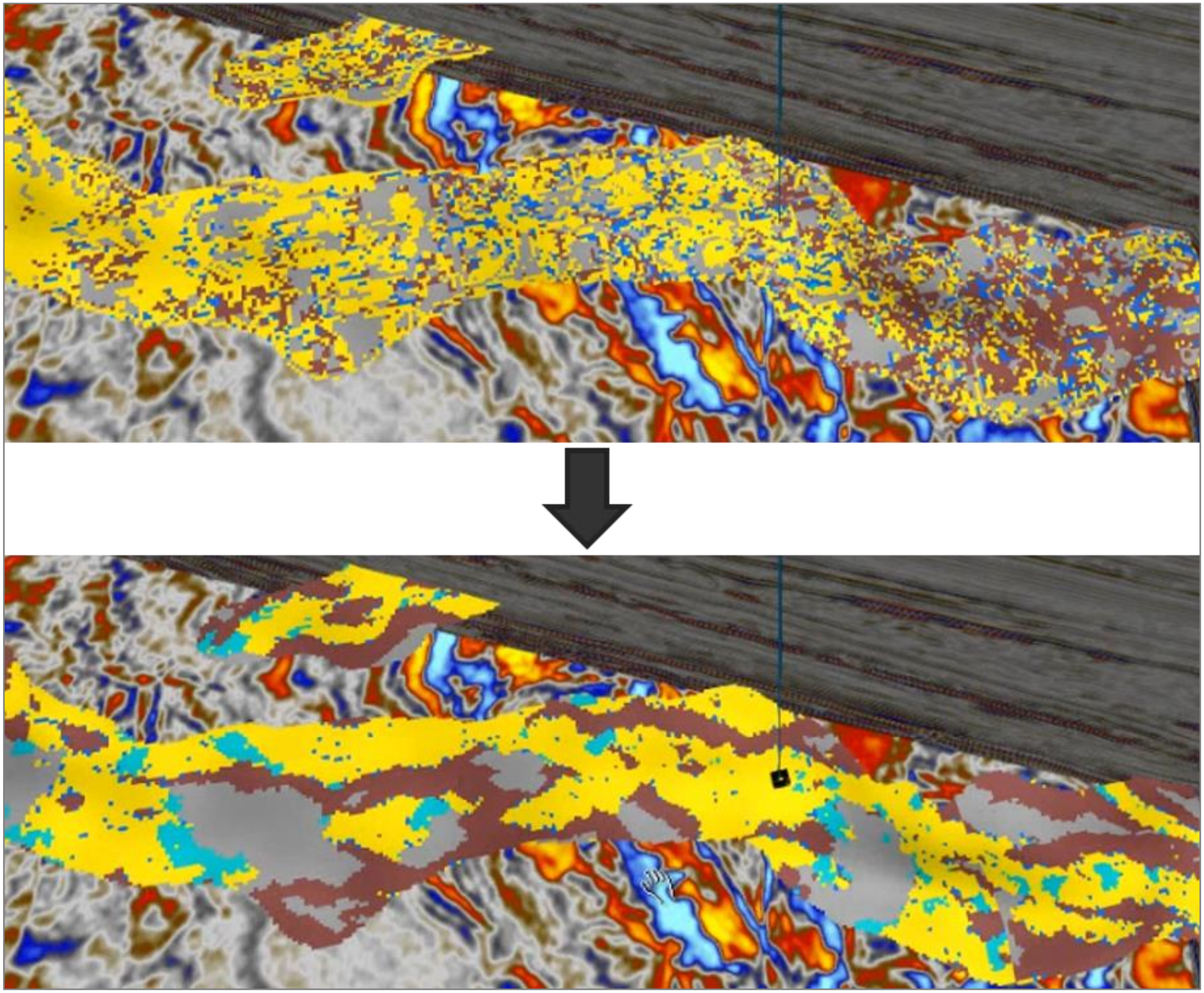


Figure 12. Data sharing between the shared-wellbore platform and 3D shared-earth platform could have a big impact on the quality of static reservoir models. Top image: initial model based on interpretation of the available 3D seismic data. Bottom image: updated reservoir model after completion of the multiscale collaboration workflow.

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