[EA]Digitally Logging the Virtual Core: Innovative, Cost-Effective and Time-Efficient Workflow*

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Search and Discovery Article #42378 (2019)**
Posted June 24, 2019

*Adapted from extended abstract based on oral presentation given at 2018 International Conference and Exhibition, Cape Town, South Africa, November 4-7, 2018
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Abstract

Attempts have been made with ever-evolving technology to reduce the dependence on full-core for various analysis in to optimize time, cost and operational efficiency. Here, an innovative workflow is being presented that utilizes the large format rotary sidewall cores and borehole images with advanced acoustic, spectroscopy and nuclear magnetic resonance (NMR) measurements on an integrated software platform, thereby digitally logging the virtual core.

The highest resolution borehole images acquired through the logging interval provide the framework and base to capture the geological heterogeneity amidst gross depositional environment interpretation, and representative rock samples are taken in various facies as large format rotary sidewall cores. Advanced acoustic logs are calibrated with the stationery measurements performed on rotary cores for rock mechanical properties. The state-of-the-art spectroscopy logs that acquire information in both inelastic and capture domain provide the highest resolution elemental information that are processed into mineralogical composition. The trimmed ends of sidewall plugs are used for X-Ray diffraction and X-Ray fluorescence for minerals and elemental calibration. The NMR log-derived capillary pressure measurement is also calibrated with sidewall trims for calibration in specific facies identified on image logs. For other analysis like texture, grain-size, porosity, and permeability, all the lab measured values are used to calibrate the log-derived measurement in all the key-facies identified on borehole images.

All these measurements are taken on an advanced software platform where the stationery measurements in specific facies are used to calibrate logs, and prepare the continuous calibrated logs for further analysis. This digital logging of the virtual core, when performed in one well and calibration coefficients acquired for the geological facies, provides control for the next wells in the field, with the coefficients further refined for the field. And, therefore with logs and the correlation coefficients, the dependence on the full core is minimized.

Digital logging of virtual core workflow (Figure 1) is very cost-efficient as it saves on the coring services and associated rig time, and provides fast efficient analysis similar in accuracy to full-core measurements. Studies comparing the results of this workflow against full-core have proved this could be used as a cost-effective and time-efficient alternate.

Introduction to the Concept

With "Digital Oilfield" and "Big Data" being the buzz words today in oil and gas industry, the advances in technology have provided avenues to lean the data acquisition in wells being drilled. Not only has the dependence on full-bore drill-core been reduced with advent of large-format rotary sidewall cores, but also the utilization and integration of all available data on a common digital platform and seamless integration with the field data has made it possible to innovatively optimize the associated costs while providing efficient solutions. Saeed (2014) reported significant saving against full-coring operations in terms of rig-days and the service charges when acquiring large-format rotary sidewall cores while still meeting the objectives of planned coring.

There is an array of applications for core analysis, such as enhancing hydrocarbon recovery strategies, improving exploration campaigns, defining field development plans, refining reservoir description, and assembling key data for ultimate recovery. Conventional coring is an intrinsic part of all these elements owing to the value it brings; however, rotary sidewall coring could offer a time-effective and flexible alternative (Torlov, 2018). Recent advances in sidewall coring has eased the operations and also ensured a larger volume of rocks for most of the analysis performed on the conventional cores. The latest generation of rotary sidewall coring technology lends itself to address various challenges in formation evaluation and beyond - in completion planning and stimulation design. Recent advances in sidewall coring have ensured that most of the analysis performed on conventional core can actually be done with the latest generation of rotary sidewall cores (Shrivastava, 2013).

The advanced measurements of Borehole Images, Nuclear Magnetic Resonance (NMR), Full-wave Array Sonic and Advanced Spectroscopy provide detailed characterization for the sub-surface at very high resolution; and often very little calibration is needed with core. Various core analyses are Routine Core Analysis (RCA), Special Core Analysis (SCAL), and Geomechanical tests can be performed on rotary sidewall plugs if specific volume and size are retrieved. The large-format sidewall cores not only provide the required volume, aspect ratio, and dimensions for most of the lab tests performed on full-core, but also minimize the number of samples needed over legacy rotary cores. Adams (2005) described quantitative methodologies for comparing log-derived porosities, permeabilities and water saturation with their core-based equivalents. The log interpretation, validated with large-format sidewall cores, provides a continuous virtual core along the logged interval where petrophysical properties (porosity, permeability, saturation, etc.) and geological descriptions (texture, lithology, mineralogy, sedimentary features, fractures, etc.) are available at each depth investigated. And, this virtual core on an advanced software platform can be digitally logged to retrieve and analyze any relevant information required.

Discussion and Workflow

Core-like geological interpretation can be done with the high-resolution borehole images (Figure 2), and advanced well-logs calibrated with sidewall cores (Figure 3) provide further interpretation to develop virtual core. Once the geological description is fed to the virtual core, the petrophysical interpretations are added on the digital platform with all available logs. The mineralogy is fixed with the X-Ray Diffraction and X-Ray Fluorescence (XRF) done on the sidewall core trims within a day, and used to calibrate and compare the spectroscopy logs acquired in capture and inelastic spectrum. The NMR measurements help understand porosity distribution and pore-size/ pore-throat geometry and are calibrated with sidewall-core derived T2 and capillary pressure measurements. Different elastic moduli and stress-values are attained from the rock-testing and integrated with advanced sonic measurements. And, the anisotropy parameters derived with advanced sonic measurements should be used, if need be, for re-processing of seismic in the field to provide an accurate framework for static modeling. Also, formation pressure and fluid composition derived from formation testing logs are integrated with the petrophysical framework. The geological, petrophysical and reservoir properties acquired with logs, validated and calibrated with large format sidewall plugs are integrated to add to the value of the virtual core (Figure 4).

Way Forward

Similar exercises can be done with additional wells, gradually reducing the need of some of the measurements and compensating for that specific measurement with pattern recognition, artificial neuron network or other advanced techniques. Once there is good control on uncertainties associated with propagating the virtual core model over an interpreted seismic section with characteristic seismic attributes (Figure 5), a virtual core can be digitally logged in another well location with even less log data requirement. However, there is a need to acquire an essential suite of advanced logs in quite a few wells to strengthen the virtual core for such purpose. In the next few wells with lesser log data overall, an advanced suite of logs could help with refining the correlation coefficient between logs and sidewall cores to compensate for the heterogeneity within grossly similar or dissimilar facies between wells.

Conclusions

This work presents an innovative workflow for time-efficient and cost-effective ways to digitally log the Virtual Core prepared with the help of well log interpretation, sidewall cores and an advanced interpretation platform with high-end visualization capabilities. The dependence on expensive coring services can be minimized and most of the core-related calibration of petrophysical properties can be done with the large-format sidewall cores. Also, various geomechanical tests can be done on these sidewall cores and then fed into the advanced sonic measurements for continuous profile of mechanical and elastic properties, along with the geological and petrophysical properties. The various applications available on advanced software platforms help integrate these data seamlessly from well to field-scale, thereby providing core-like value in digital space.

Acknowledgements

Author is indebted to various colleagues in the oil and gas industry who have provided valuable feedback to the development of the content of this work. He also acknowledges Schlumberger management for their support to present this work.

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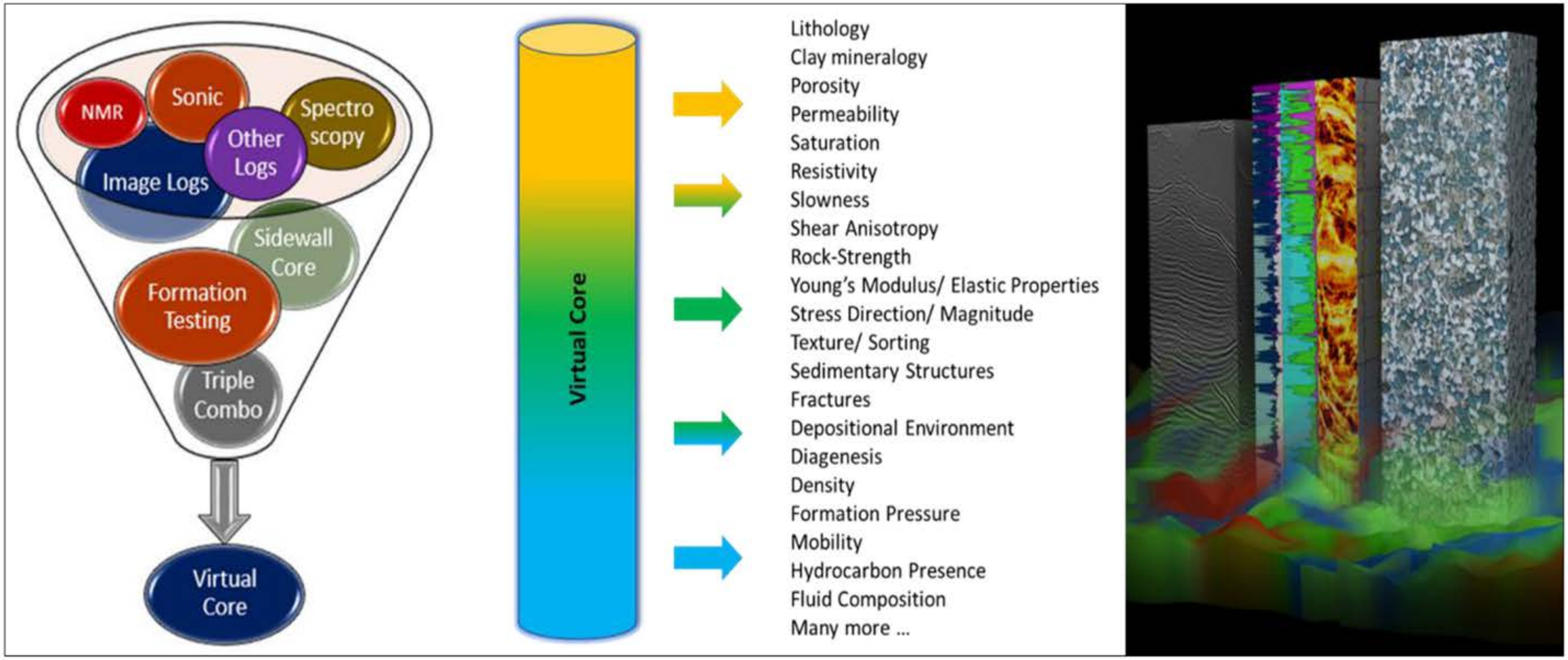

Figure 1. Concept of the Virtual Core with various logging data, and digital logging of the virtual core.

Figure 2. Borehole images showing the core-features, (a) cross-bedded sands, (b) diagenetic nodules, with fractures, vugs, and stylolites in right hand side of the snapshot.

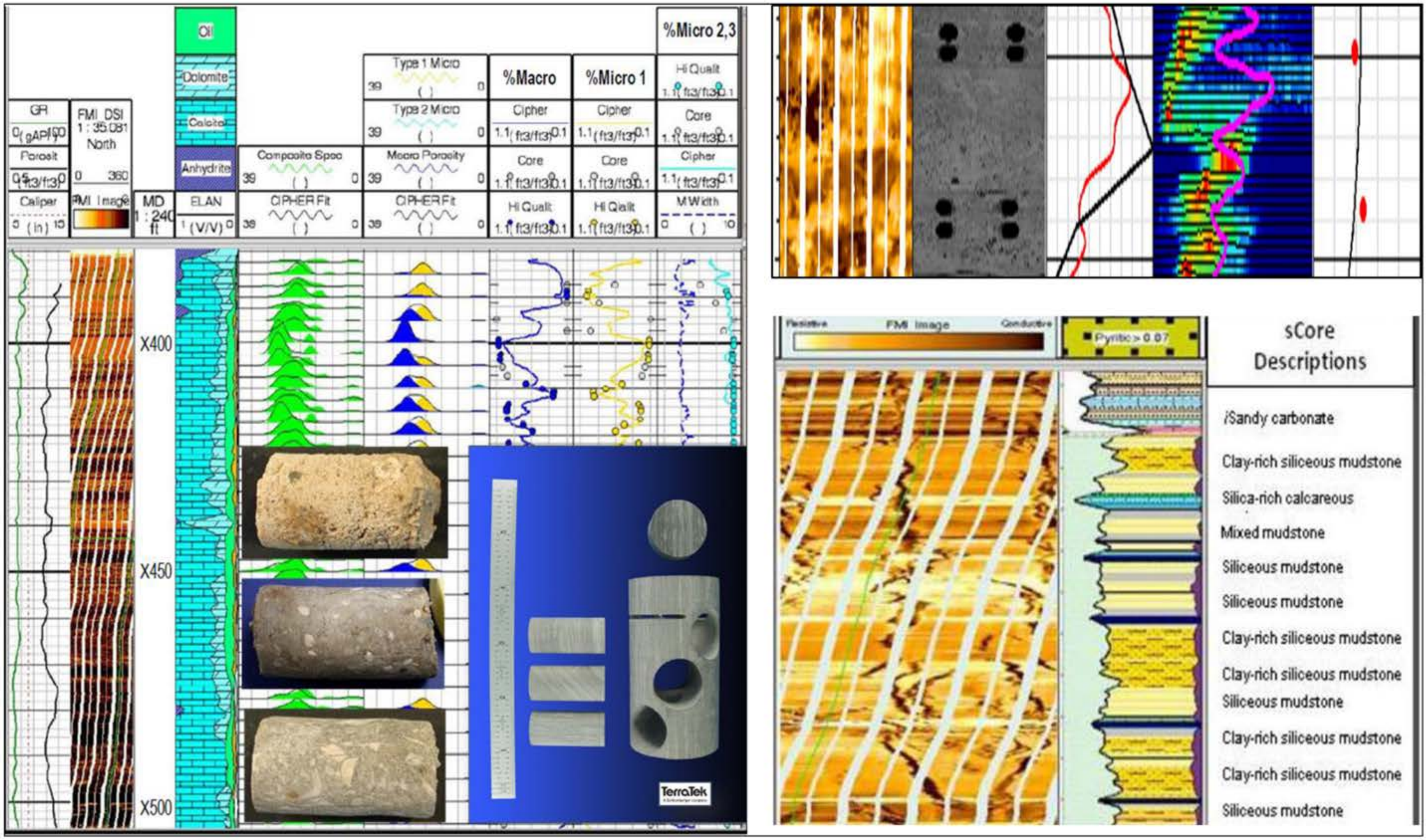

Figure 3. Borehole images, large-format sidewall cores, NMR. Spectroscopy data incorporated towards developing Virtual Core.

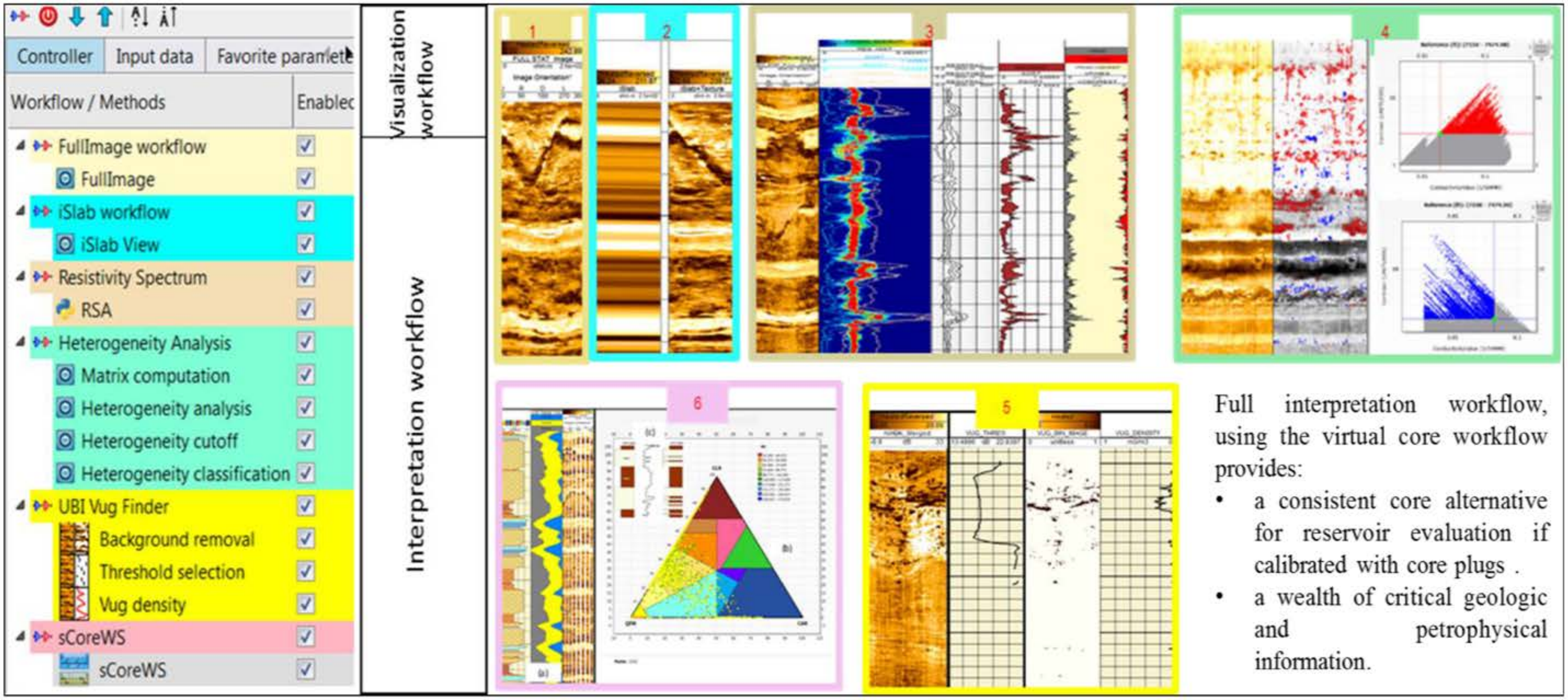

Figure 4. The detailed geological description from borehole images and other logs being used to extract digital logs for texture, heterogeneity, fractures, etc., providing the geological framework for the virtual core; further integrated with petrophysical parameters. Modified after Bize (2014).

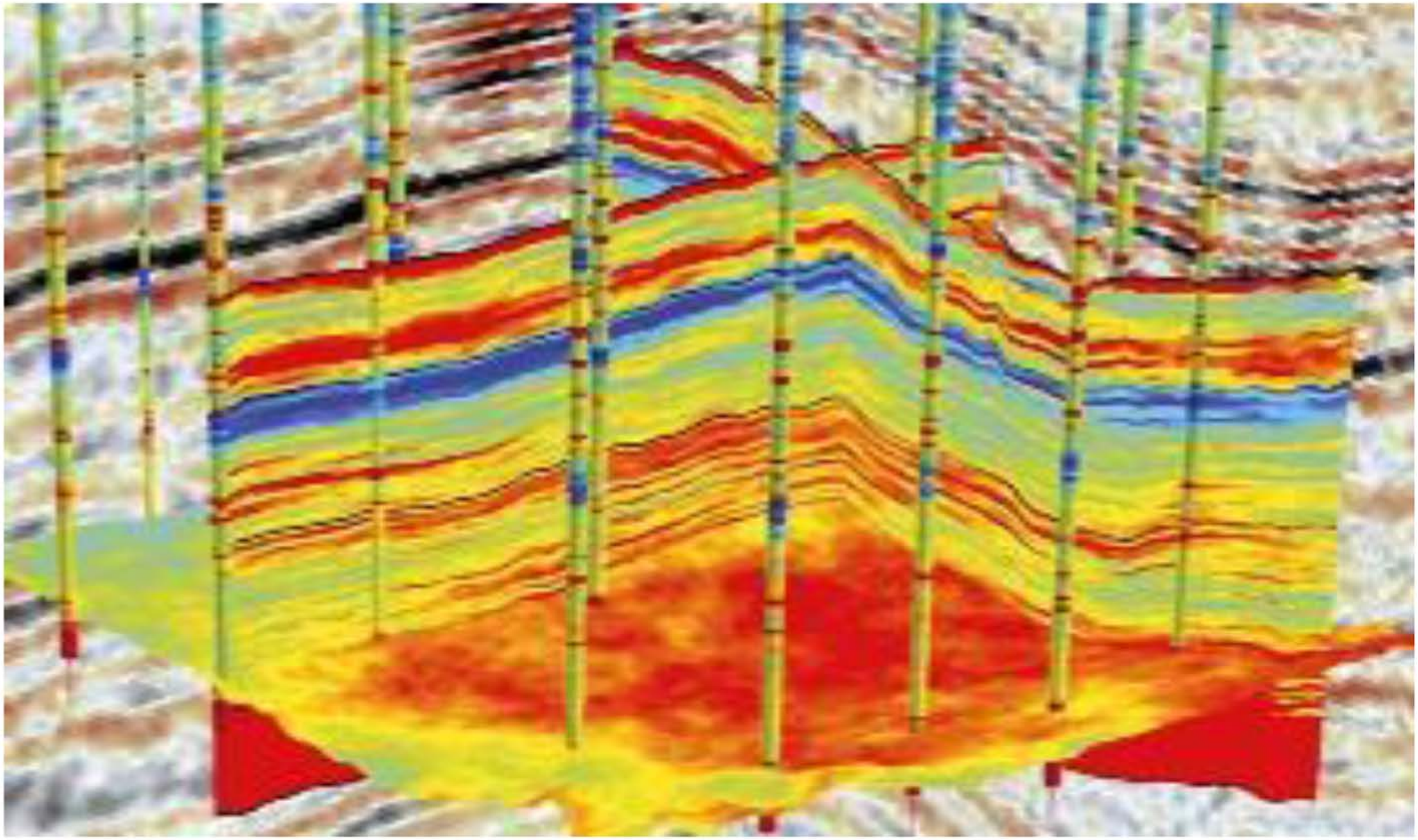

Figure 5. Can I digitally log a Virtual Core in one of these wells, over an interpreted seismic volume?