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Calibration of Seismic Fracture Model Using Dynamic Data and Borehole Images: An Example of Fractured Carbonate Reservoir*

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Abstract

The development of a naturally fractured reservoir with a dual permeability system is a challenging task. Placement of wells into fractured zones can help to ramp-up initial hydrocarbon production. However, at the same time it can lead to future problems, especially when fractures are connected to a strong aquifer.

This article describes an example of integrating seismic attributes with static and dynamic data and predicting fracture occurrence in a major Middle East oil field. Proposed workflow is composed of three major steps:
1) Micro-scale fracture characterization by integrating core, logs, and production performance, including PLT and well tests,
2) Large-scale fracture detection using seismic attributes,
3) Validation of seismic discontinuities to log-derived fractures.

The reservoir is a strongly fractured carbonate formation with a natural water-drive support mechanism. Presence of high-permeability fractures, together with strong water support, leads to fast water breakthrough, especially in horizontal wells intersecting several fractures. Major field development challenge is to drill new infill wells avoiding fractured zones.

Fracture Detection from Well Data

Openhole logs, including borehole images often give a reliable indication of major faults or fractures. However, they do not resolve the full complexity of their lateral extension. Fracture detection is most certain when several independent methods confirm their presence. These methods can be divided in two major groups: static and dynamic.

Static Methods

– Openhole Logs

Presence of fractures affects the response of several logging tools. Acoustic logs, based on P and S wave propagation, are least affected by borehole conditions and best suited for fracture identification. Caliper, density, or resistivity log measurements, can also be effective in locating fractured zones.

– Borehole Images

Another useful tool for detecting natural fractures is the formation micro-scanner. This tool provides borehole images based on a large number of micro-resistivity measurements. Such measurements provide detailed information, including: orientation, depth and fractures aperture.

– Core

Core data is the most reliable source of information for fracture identification. Natural fractures can be clearly differentiated from those induced by drilling.

Dynamic Methods

– Drilling Parameters and Mud Losses

Loss of drill mud and the increase in rate of penetration are positive indications of fractured or cavernous formations.

– Production Logs

Analysis of fluid flow and presence of peaks in production profile are good indications of fractures, especially in horizontal wells.

– Well Tests / Pressure Transient Analysis (PTA)

Two types of fracture evidence are known in PTA interpretation: kh (permeability thickness) value and derivative signature. Fractures are expected if ratio of “well test kh” to “log derived kh” is high.

– Production Performance Evaluation

Production performance analysis is based on oil and water production data. Very high productivity index, fast water breakthrough, and rapid change in water-cut are key indicators of active fracture performance.

Figure 1 summarizes the integrated techniques applied in current studies for fracture detection. A fracture evaluation exercise was performed for eighty horizontal boreholes. All wells were classified in two major categories: Fractured and Non-fractured.

Well Evaluation Example

Figure 2 is an example of a fractured well that provides the most complete dataset for confident fracture identification. Borehole image indicates intersection of more than 300 conductive fractures with a mean strike of N86° and a mean dip of 77°. Tectonic fractures are found in the core from vertical pilot hole. About 20,000 bbl of mud loss were encountered during drilling. Well performance analysis confirmed early water breakthrough and high water production related to fracture clusters. Production log analysis supports the condition described by the well performance and is able to pinpoint the exact location of active fractures.

Seismic fracture analysis

Discontinuity detection

Three types of discontinuity attributes were calculated: Variance, Chaos and Curvature. Variance and Chaos attributes are measuring amount of dissimilarity between seismic traces, which could be caused by a presence of fault or artifact. Curvature attribute is a second order derivative representing the rate of change in the seismic signal, consequently very sensitive to noise level.

Establishing the optimum processing parameters for attribute calculation is a key for extracting maximum value from the data. As an example:

- Large processing operator results in more smoothing of original data.
- Smaller operators do the opposite.

Discontinuities (faults or fractures) in developed reservoir are on the edge of or below seismic resolution. Applying any kind of processing operators (including structural smoothing or frequency filtering) leads to a decrease of signal related to discontinuity features. To estimate the influence of computation parameters, multiple realizations were generated using low, mid, and high case settings (Figure 3).

Ant tracking

Ant tracking is a logic-based algorithm that can help to delineate faults and filter artifacts related to non-regular noise. The algorithm is normally applied to discontinuity attributes which have been previously structurally smoothed or frequency filtered. The reservoir presented in this study has a very weak seismic signature from discontinuities. Therefore, to avoid further loss of signal, minimum smoothing was applied to the dataset. However, realizations with structural smoothing were also analyzed. The ant track algorithm has been run in an “aggressive” mode, which is designed for extraction of subtle fault/fracture zones. Series of cross sections are available in Figure 4 and Figure 5.

Fracture Probability Mapping

Ant tracking attributes were calculated based on chaos and variance. The QC of the results of the seismic attribute analysis has been done by converting 3D attributes into fracture probability maps. As can be seen in Figure 6, variance is describing a higher percentage of discontinuities oriented in NE-SW direction and better representing regional stress. Despite different computation techniques, the attributes show similarity in less fractured areas.

Validation of Fracture Probability Maps with Well Data

Integration of static and dynamic data allowed for classifying wells in two major categories: fractured and non-fractured. Blind tests were performed between well data and fracture maps in order to identify the most appropriate seismic attribute realization (Figure 7 and Figure 8). Overall results of comparisons between wells and seismic attributes are in Table 1Table 1 Seismic attribute predictability (in percentage).. The ant tracking attribute calculated using optimum search parameters (Case 1) provide 77% predictability for fractured areas and 47% for non-fractured. Doing blind test allowed to independently evaluating the quality of fracture probability maps. Generated maps are used for the purpose of fracture model update and optimization of infill drilling locations.

Practical Application

Results of the study have a direct impact on field development. The fracture maps are used as an input to constrain static property distribution and condition permeability multipliers for history matching. Having a calibrated permeability model allows making more accurate prediction of wells performance, especially the timing of water breakthrough. From an operational standpoint, fracture maps are used to optimize infill drilling locations and to avoid fractured areas (Figure 9).

Summary

There are numerous geophysical techniques designed for fault or fracture identification, and seismic attribute analysis is one of the most commonly used. Curvature, Variance, Coherency and Ant Tracking are example of attributes that highlight discontinuities in seismic data and are useful for delineating faults, especially those with minor displacements. Seismic attribute analysis has been performed in two steps. Firstly, multiple realizations of discontinuity attributes were calculated using various computation parameters. Secondly, a logic-based technique (Ant Tracking) was applied to the discontinuity attributes. Application of logic-based operators led to reduction of noise and better discontinuity delineation. Blind test techniques have been applied to validate fracture maps with static and dynamic well data.

Results of the study confirmed the presence of highly fractured zones oriented in a NE-SW direction. The fracture maps helped in constraining static property distribution and conditioning permeability multipliers for history matching. Having a calibrated permeability model allows making more accurate prediction of wells performance, especially the timing of water breakthrough. From an operational standpoint, fracture maps are used to optimize infill drilling locations and to avoid fractured areas.

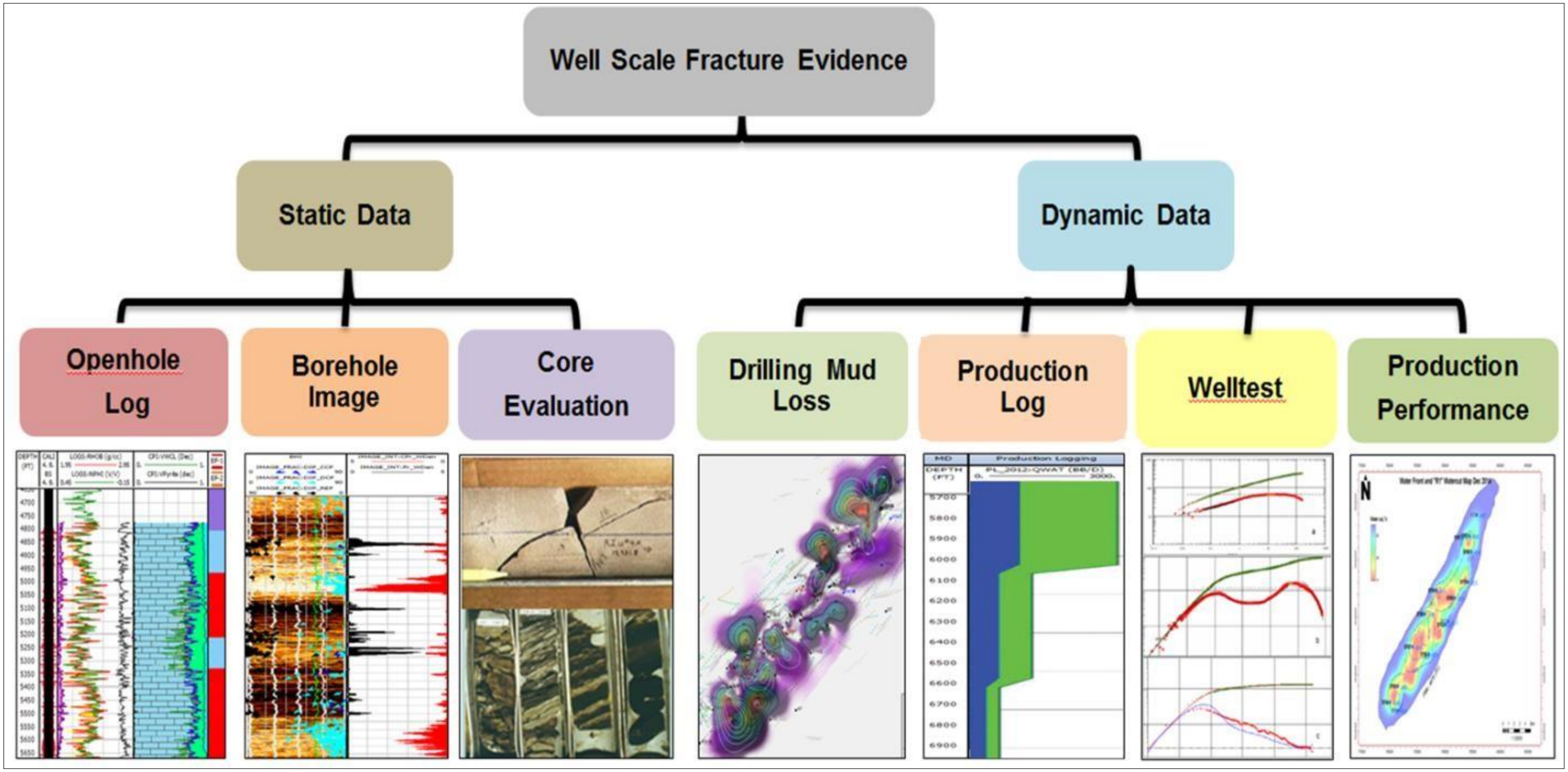

Figure 1 Fracture detection workflow.

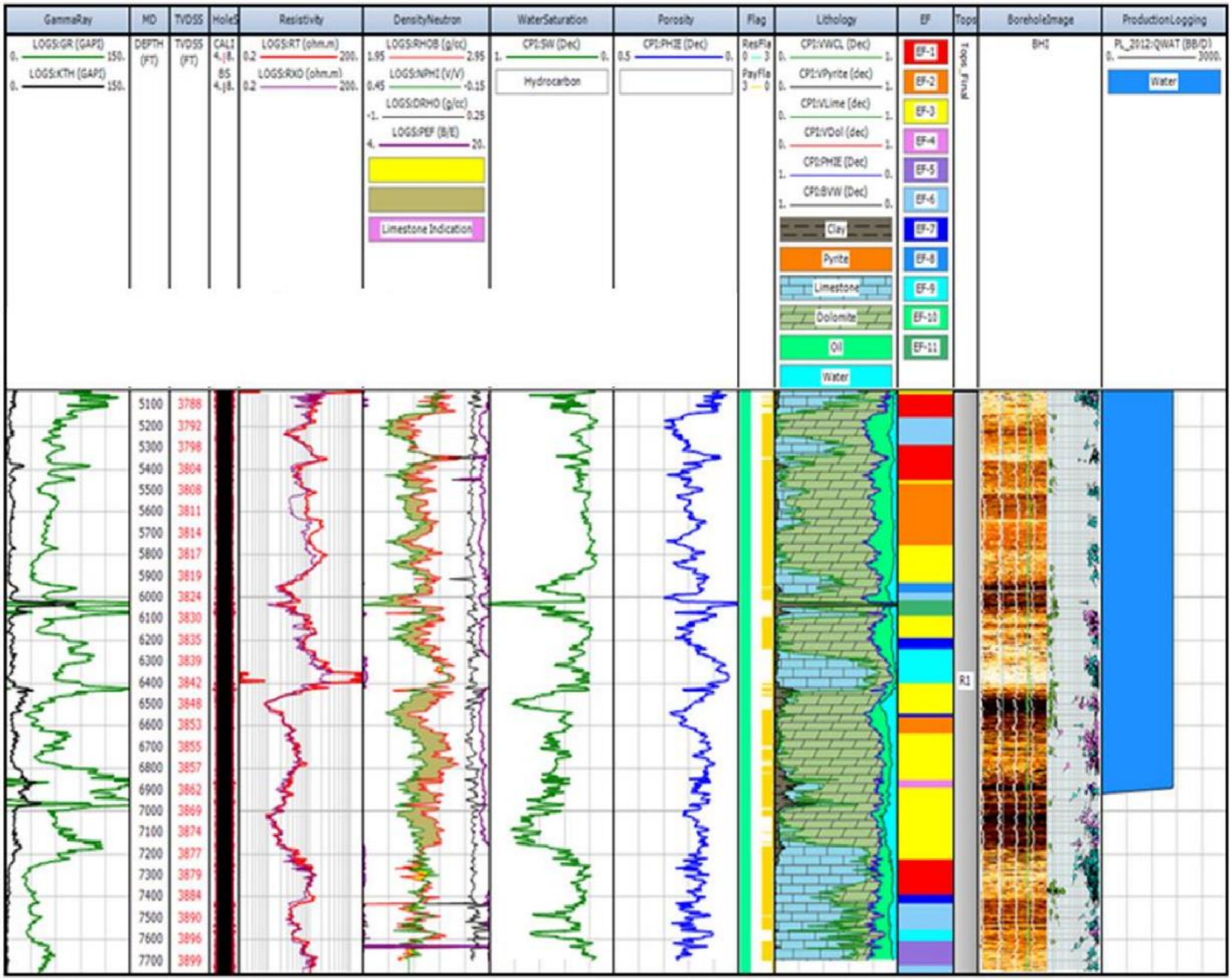

Figure 2 Fracture detection workflow.

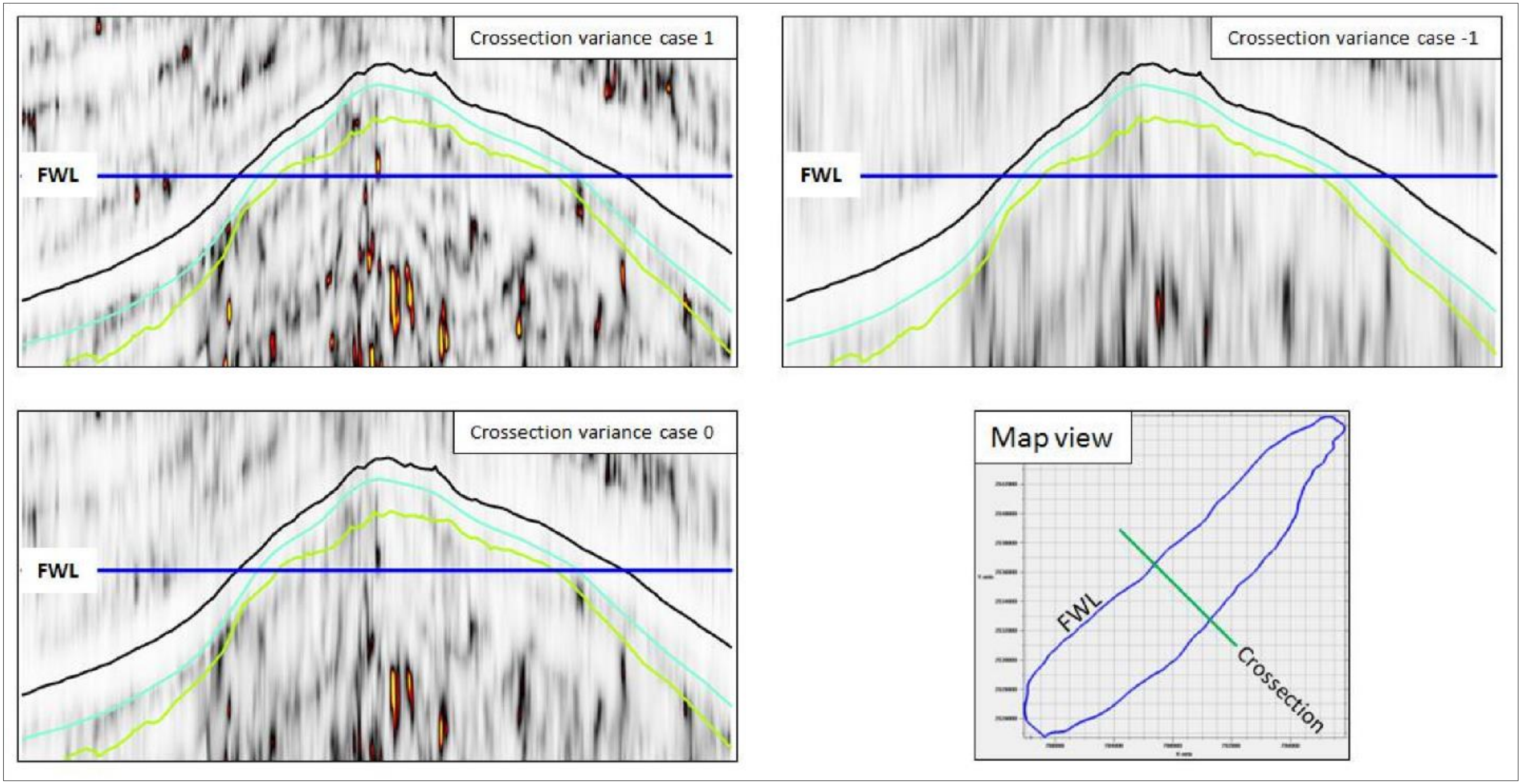

Figure 3 Variance attribute realizations.

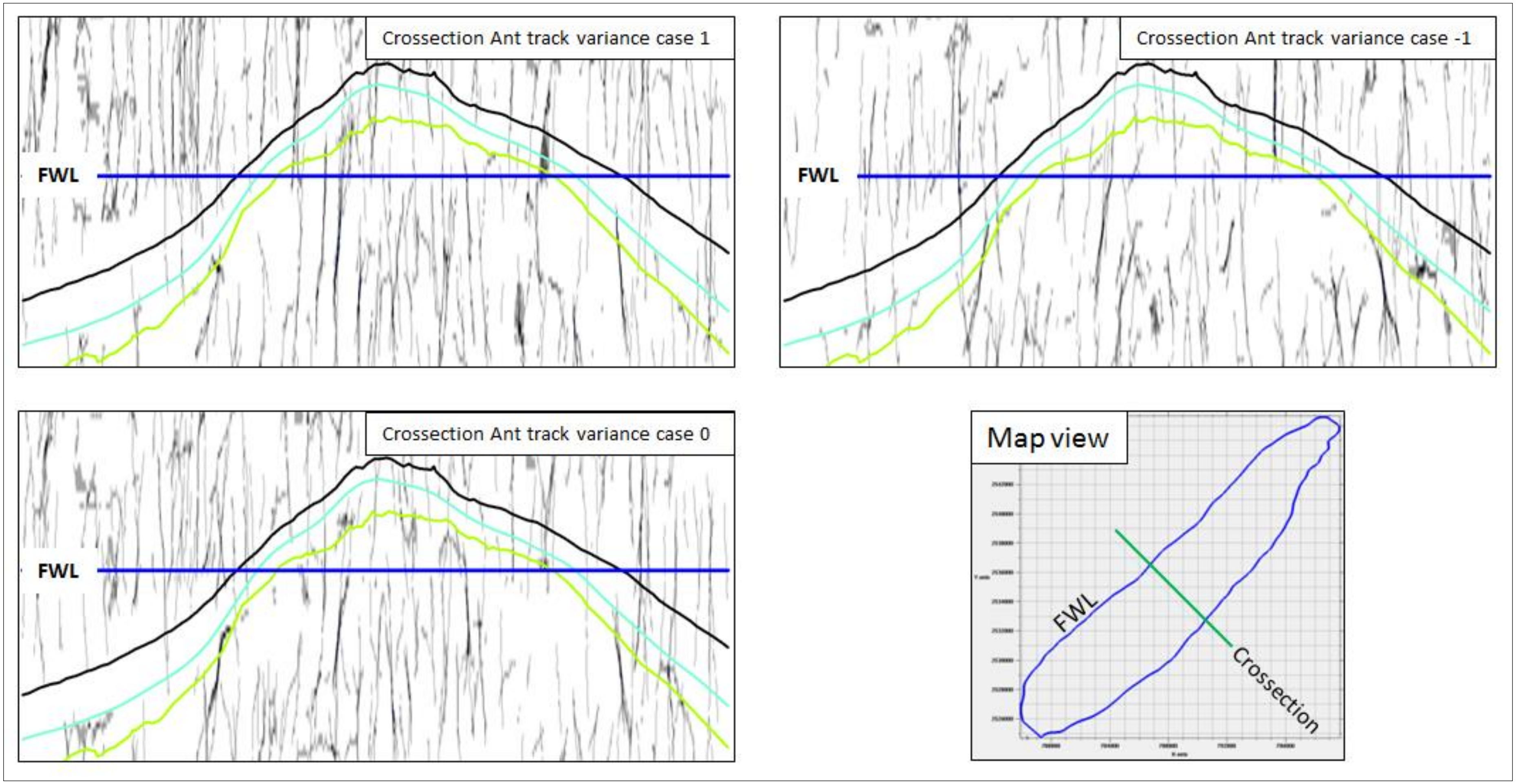

Figure 4 Ant tracking attribute realizations, calculated via variance.

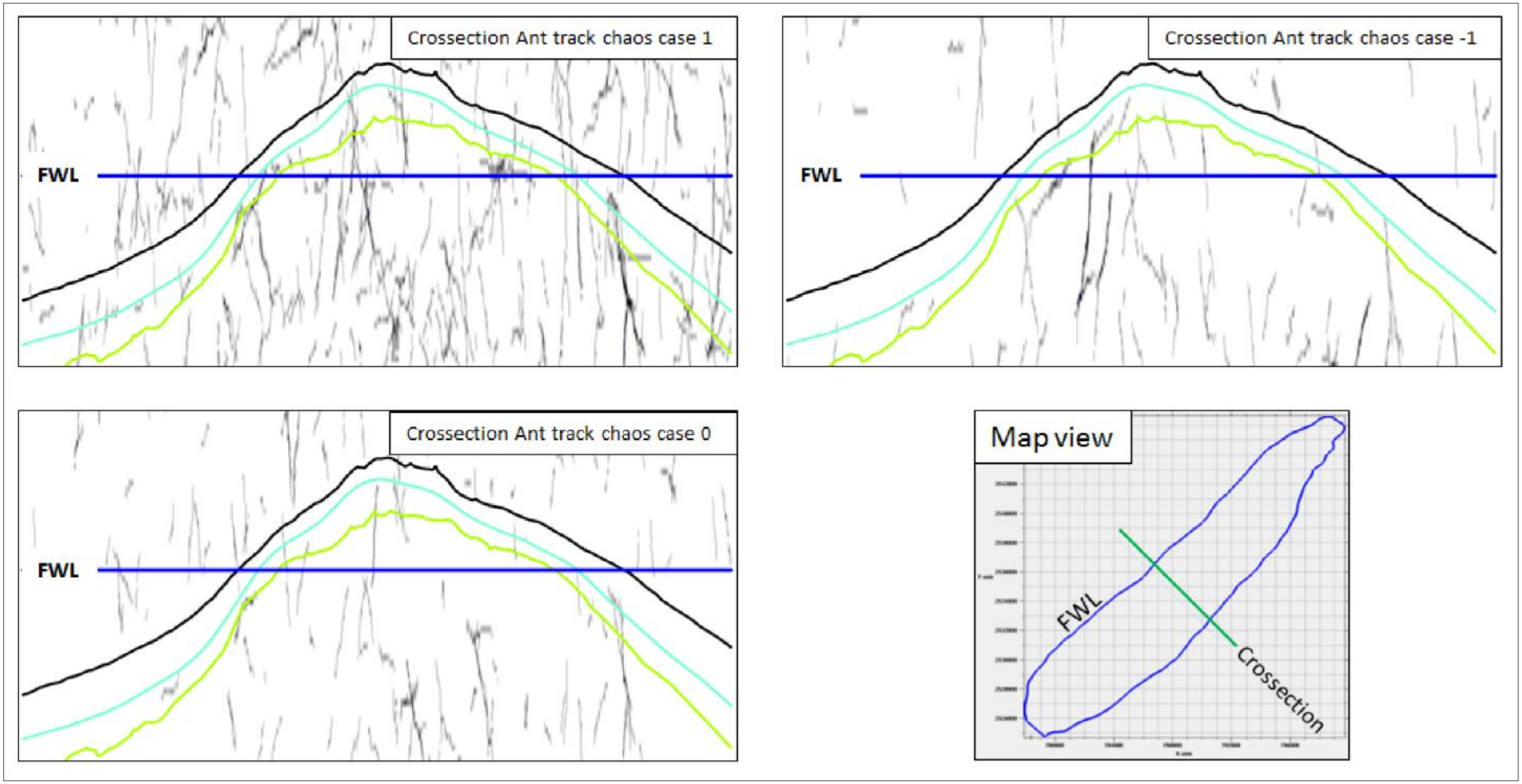

Figure 5 Ant tracking attribute realizations, calculated via chaos.

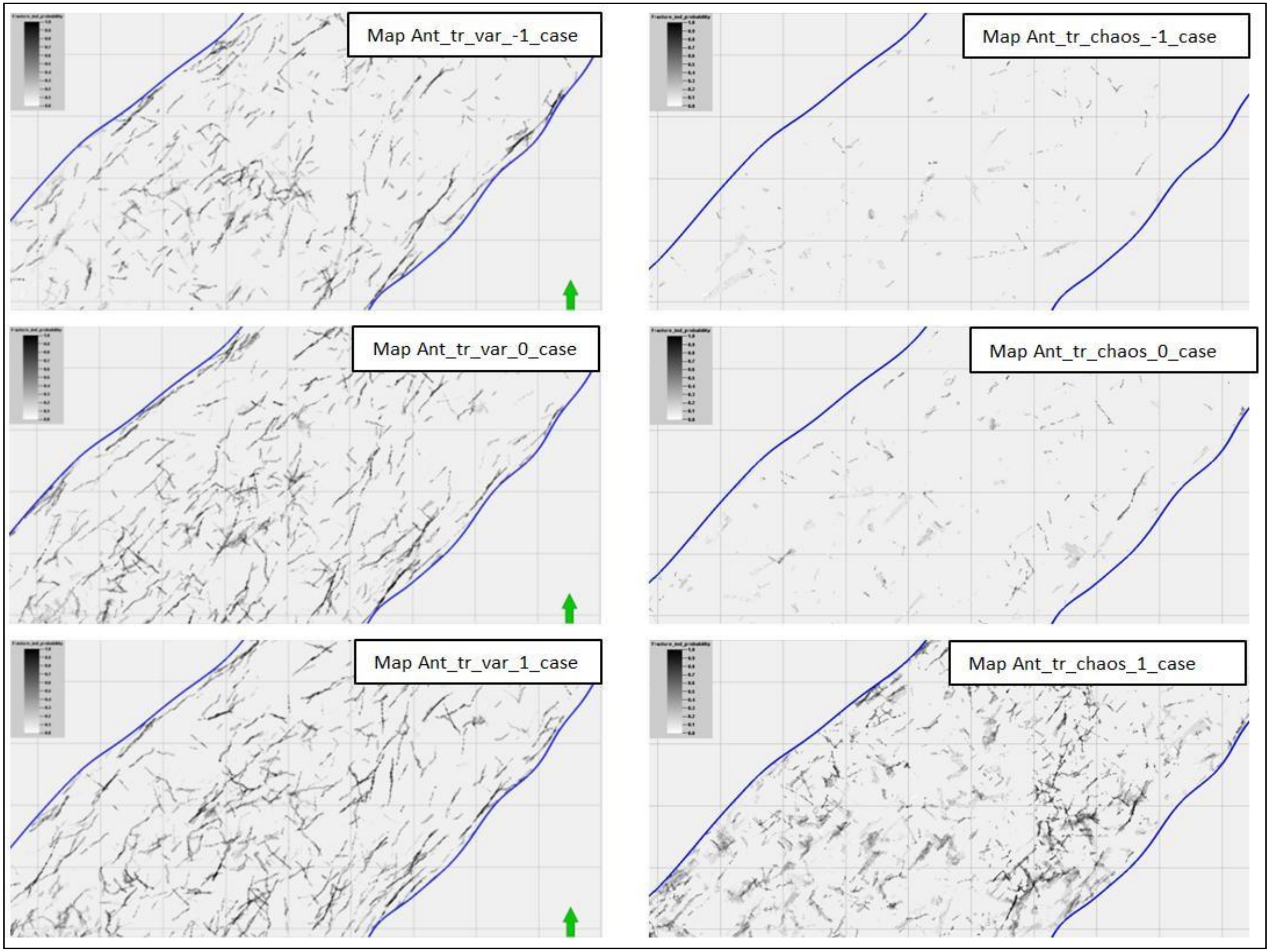

Figure 6 Fracture probability maps calculated from variance and chaos attributes.

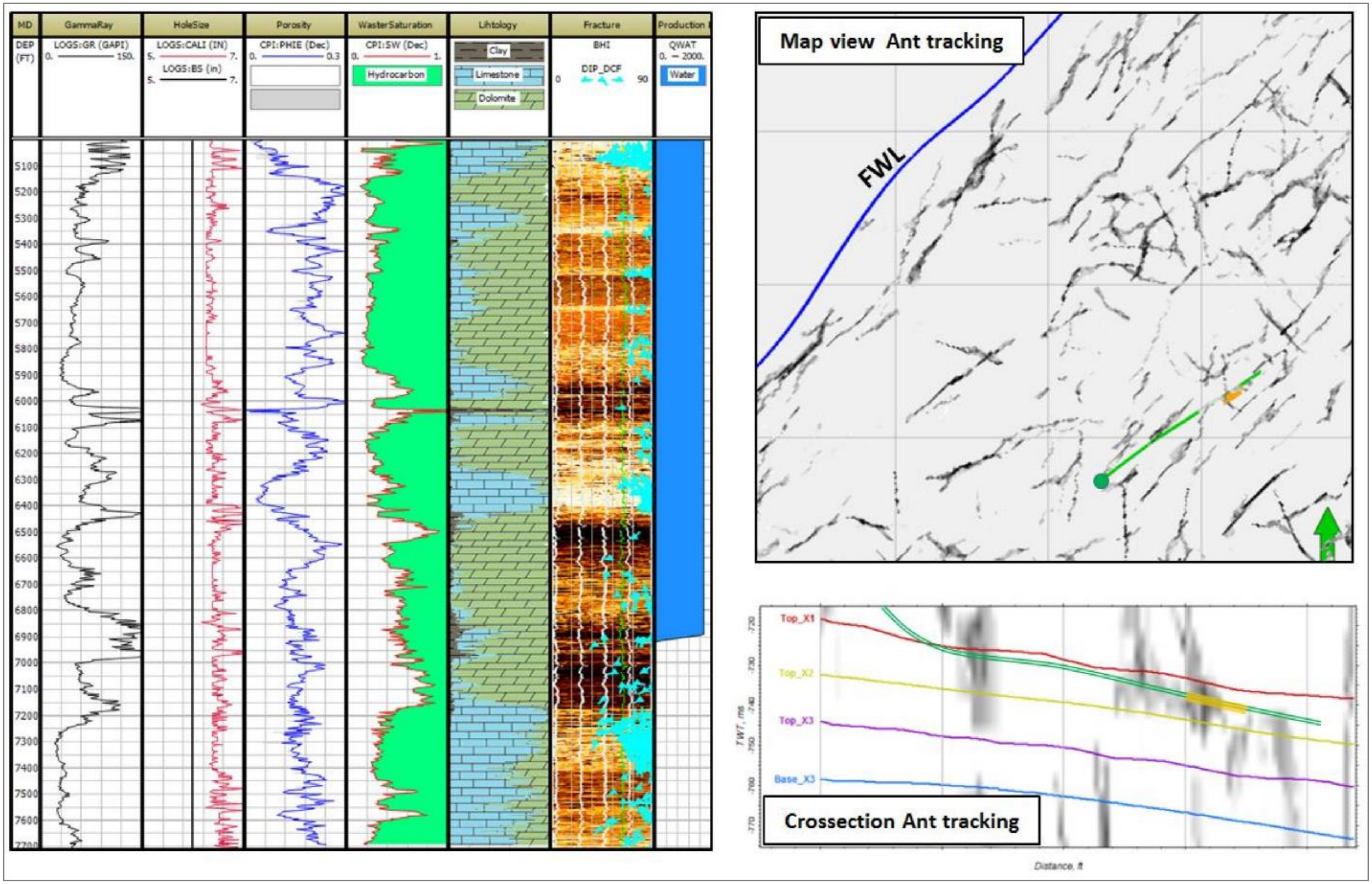

Figure 7 Example of fractured well, logs (left) and seismic attribute (right).

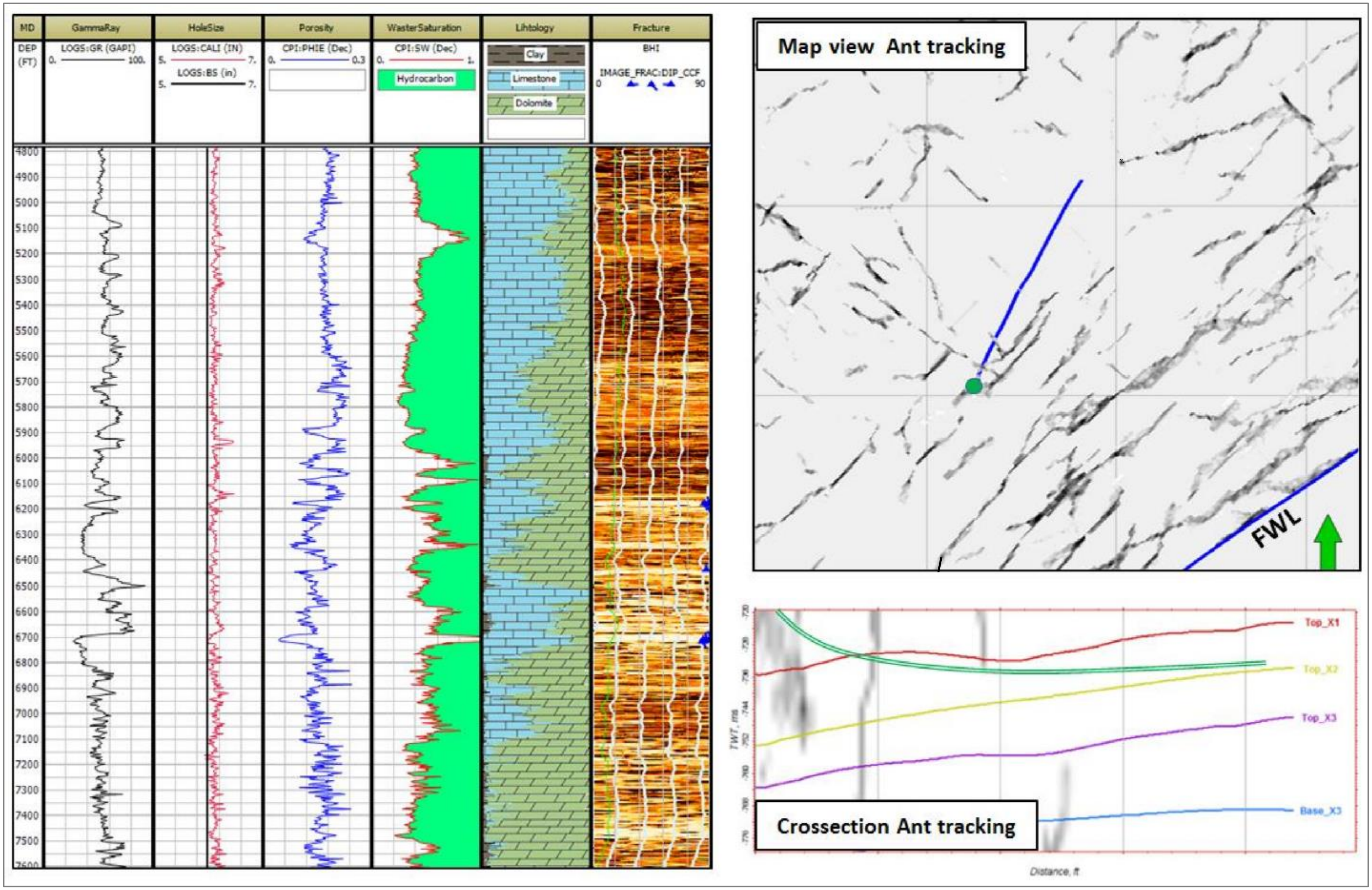

Figure 8 Example of non-fractured well, logs (left) and seismic attribute (right).

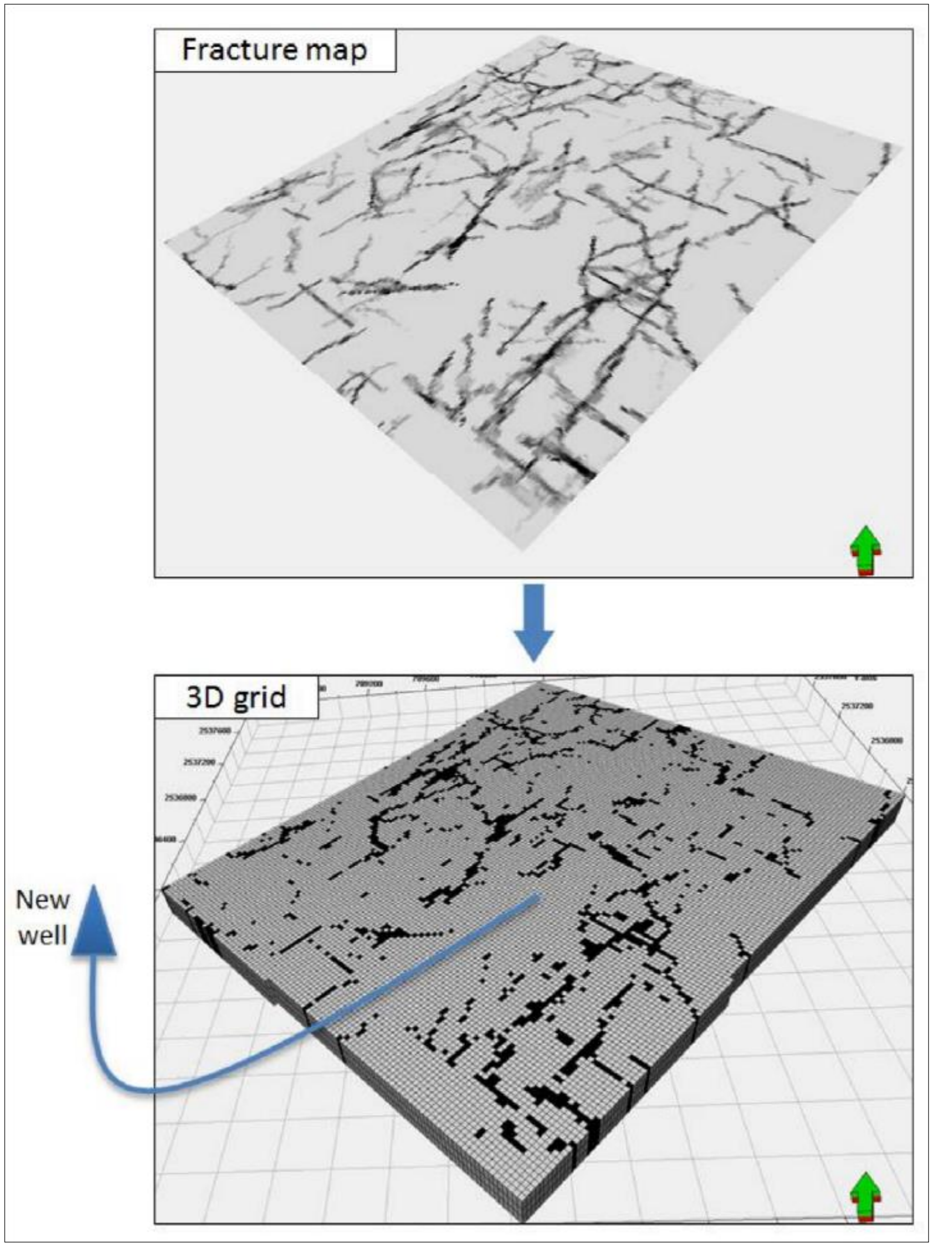

Figure 9 Fracture map to 3D grid.

	Ant tracking, %			Curvature, %
	Case 1	Case 2	Case 3	
Fractured wells	77	83	63	69
Non-fractured wells	47	33	40	40
Total	68	68	56	60

Table 1 Seismic attribute predictability (in percentage).