Quantifying fault connectivity drilling hazards through simple flux computations

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Motivation and Research Questions

Faults can enhance production when confined to the reservoir and impede production when connected to a nearby aquifer, such as those that connect the Eagle Ford Shale to the deeper Edwards Limestone. These later faults constitute geohazards and need to be avoided. Many shale resource plays within the United States lie on or near similar carbonate aquifers, some of which are also karstified. While faults provide crucial geologic information that can be critical for reservoir modeling, large surveys may contain hundreds of faults requiring significant interpretation effort.

Our objective is to develop a “quick and dirty” image processing algorithm (in contrast to a more accurate reservoir simulator) that will highlight those faults that may be connected to nearby aquifers. We envision coupling this tool with statistical analysis of water production to identify faults that are safe to complete and those that need to be avoided.

Methods

If we imagine that the 3D volumetric result of an edge detecting attribute such as coherence as representing thermal, electrical or hydraulic conductivity, we can simulate what would be the steady-state solution for flux using two horizons on this conductivity volume with the aquifer to be modeled as the source and the target horizon or well path to be a sink.

We will first calculate the head potential h using the three-dimensional steady-state saturated flow equation (Istok, 2013):

$$\frac{\partial}{\partial x}\left(K_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial h}{\partial z}\right)=0, \qquad (1)$$

where K_x,K_y, and K_z are the conductivities of the media in the x, y and z coordinate directions. Next, we will calculate the flow q using:

$$q_x\hat{\mathbf{x}}+q_y\hat{\mathbf{y}}+q_z\hat{\mathbf{z}}=-K_x\frac{\partial h}{\partial x}\hat{\mathbf{x}}-K_y\frac{\partial h}{\partial y}\hat{\mathbf{y}}-K_x\frac{\partial h}{\partial z}\hat{\mathbf{z}}, \qquad (2)$$

where $\hat{\mathbf{x}}$, $\hat{\mathbf{y}}$ and $\hat{\mathbf{z}}$ are the unit vectors for x, y and z directions respectively. We expect to observe the conductors connecting source and sink with a higher absolute flow value, $|\mathbf{q}|$, compared to the other areas.

Preliminary results

Initial testing results can be observed on **Figure 1** and **Figure 2**. Partially satisfactory, these results can be improved using a higher order finite difference method.

Figure 1 shows the results obtained using a simple synthetic model with vertical faults along with the intermediate step of the algorithm, the calculation of the potential field. The black arrow on the flux results indicates a connected fault which has a high anomalous value as expected. The gray arrows show that the disjoint faults have weaker absolute flux.

Figure 2 shows results obtained testing with real seismic data. The conductivity input volume came from the directional Laplacian of a Gaussian attribute computed from a coherence volume. The conductivity volume presented here is a small section on what is presented by Machado et al. (2016), from a survey over the Great South Basin, New Zealand. The red circles show weakly connected faults between the two horizons. The red arrows in the cross section shows one example of a weak connected fault highlighted by the algorithm.

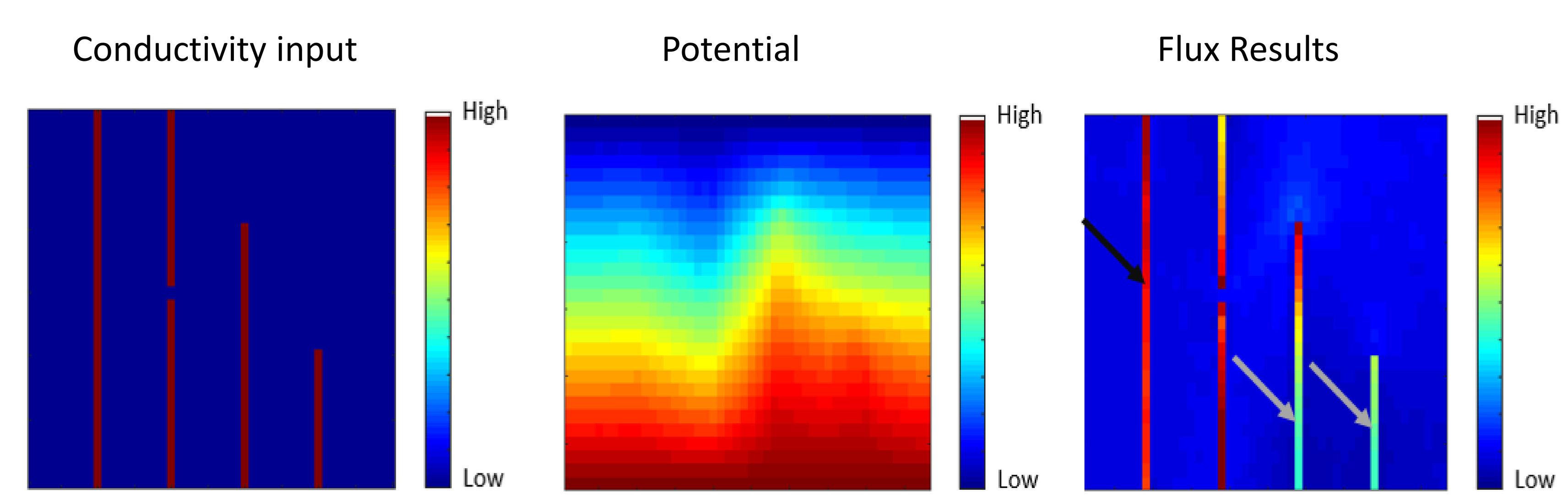

Figure 1: Cross section results using a synthetic model with vertically connected and not connected faults. The black arrow indicates a strongly connected fault which has high absolute flux values as expected. The gray arrows show that the disjoint faults have weaker absolute flux.

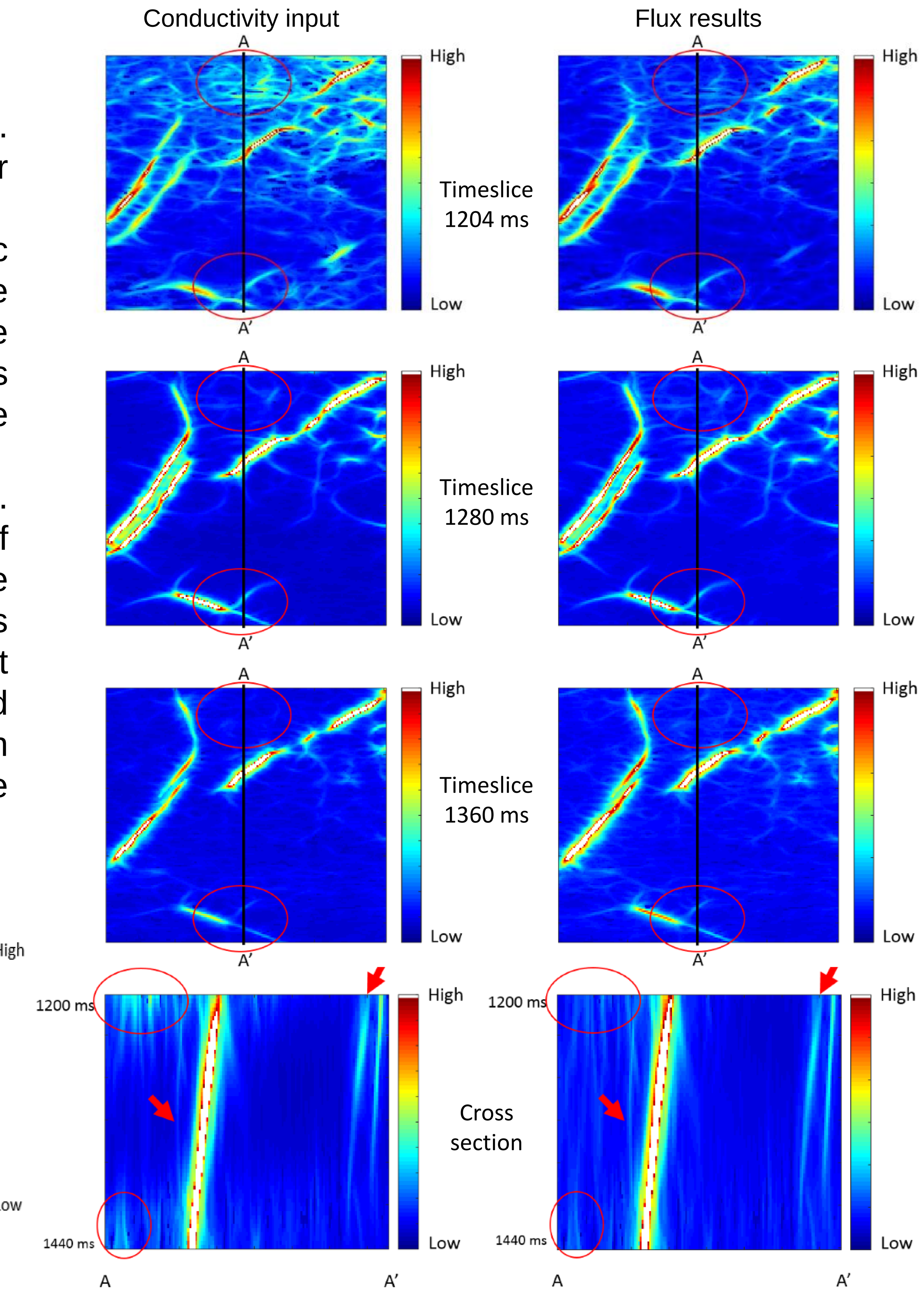

Figure 2: Timeslices and cross section results using the enhanced coherence attribute extracted from a real seismic dataset.

Conclusions and Future work

We have prototyped a very simple flow model that is built on the hypothesis that seismic attributes such as coherence delineate conductive faults. While such a simple flow model cannot replace more carefully (and interpreter intensive!) models such as Eclipse or CMG, it can be used to statistically correlate water production from a suite of horizontal wells to azimuthally limited fault families. Such correlations may help us avoid problematic faults or target those that may enhance production.

References

Istok, J., 2013. Step 2: Derive the Approximating Equations, Groundwater Modeling by the Finite Element Method. American Geophysical Union, pp. 30-79.

Machado, G., Alali, A., Hutchinson, B., Olorunsola, O. and Marfurt, K.J., 2016. Display and enhancement of volumetric fault images. Interpretation, 4(1): SB51-SB61.

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