The Effect of Faults on the 3-D Connectivity of Coal Measure Sandstones: the East Pennine Coalfield, U.K

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Summary

The connectivity of sand bodies has been tested in a deterministic, high resolution, 3-D, geocellular model (15 million cells in a 20km x 20km x ca. 500m volume), derived from the Carboniferous East Pennine Coalfield, UK. Tests were undertaken on unfaulted and variably faulted models to analyse the effects of faults of different sizes on sand body connectivity. Our analysis is restricted to the geometrical effects of faults, and is a necessary prelude to future studies on the effects of fault membrane seals on connectivity.

We show that sedimentary architecture, together with interval net:gross and thickness, have profound effects on whether faulting results in increased or decreased connectivity. Faults are most detrimental to sand body connectivity in thinner, lower net:gross, intervals containing laterally discontinuous bodies. Systems containing only channelised bodies tend to be disconnected by faulting, whilst models containing laterally extensive, tabular sand bodies are typically better connected with the addition of faults. Although our findings demonstrate that generalisations can be made regarding the connectivity of sand bodies as a function of sequence net:gross, the most significant factors are the dimensionality of sand body geometries in relation to faults.

Model Building

Coal mine-plan and borehole data from the East Pennine Coalfield have been used to construct deterministic, high resolution, 3-D, unfaulted and faulted geocellular models. 14 facies identified in 1100 boreholes constrain the sedimentology of the delta-top reservoir analogue, which contains over 1500 post-depositional normal faults with maximum throws between <1m to 140m. Four models were generated, one unfaulted and three faulted, constructed using three different resolutions, namely, fault systems with maximum displacements (a) >1m (N = 1088), (b) >5m (N = 156), and (c) >20m (N = 32).

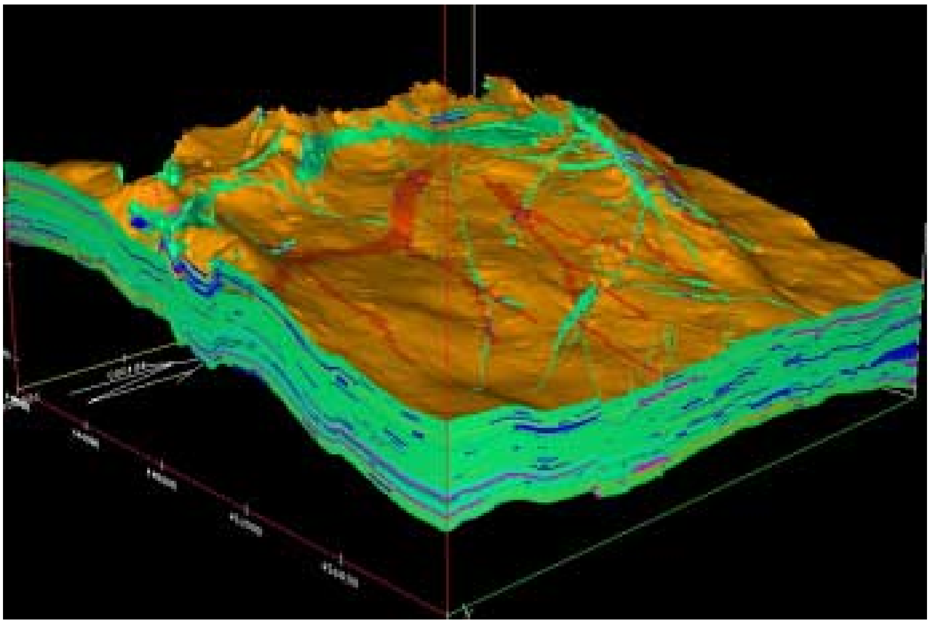

Fig. 1. 20 km x 20 km x ca. 500m faulted stratigraphic geocellular model of the study area. Cells are colour coded for facies. Note the offset of stratigraphy along faults in both map and cross-sectional views. Vertical exaggeration – x5.

Test theory

The connectivity of various 'reservoir' units was tested in unfaulted and faulted models. The emphasis of the analysis is to establish quantitative measures of the connectivity changes arising from the addition of faults of different sizes. Across-fault juxtapositions can either disconnect reservoir bodies, or connect previously isolated bodies. Tests have been undertaken on the whole model volume (ca 500m thick) and on six thinner stratigraphic subdivisions (between 40m and 200m thick). Two different sets of facies were used as net reservoir: (1) only clean channel sands and (2) all channel and overbank sands and heteroliths. The resulting intervals have relatively low net:gross ratios (between 3% and 27%). Connected bodies were sampled using a regularly-spaced (2km) array of 81 wells. Numerical output comprises the number and size of connected bodies per well.

Test Results

Our test results allow subdivision of the models into three main types depending on the impact of faulting on connectivity.

(a) Intervals that are better connected (Fig. 2a).

(b) Intervals that are disconnected (Fig. 2b).

(c) Intervals that are disconnected by large faults (>20m maximum throw) and are partly reconnected by smaller faults (1-5m maximum throw).

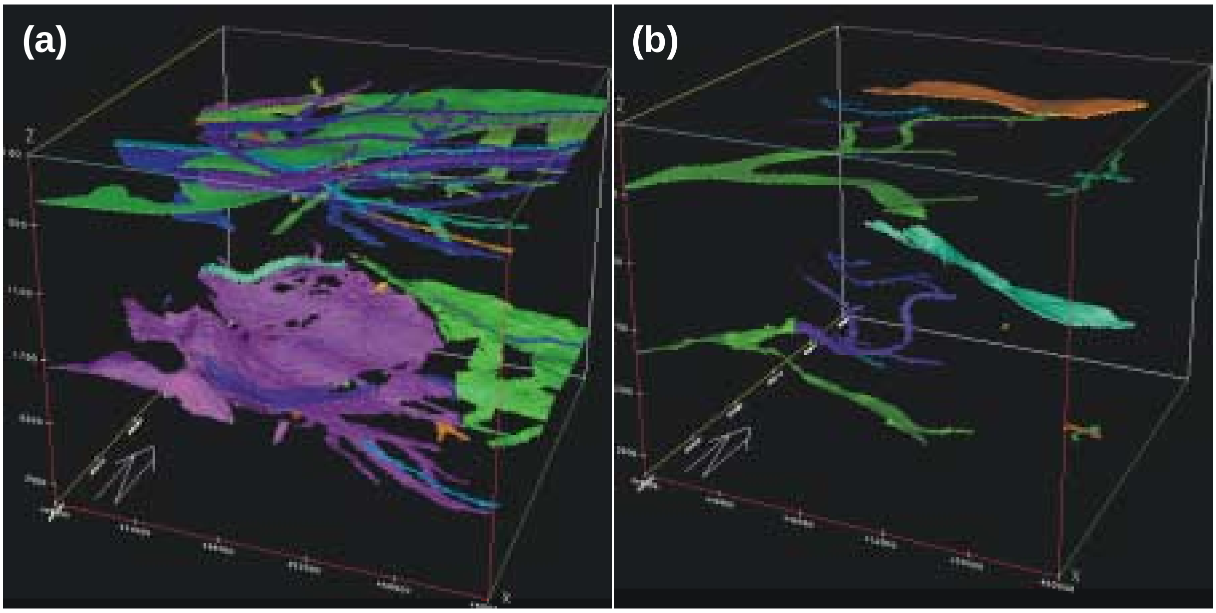

Fig. 2. Two examples of systems in which the connectivity of the unfaulted stratigraphy (top) is compared to that after the addition of 5m maximum throw faults (bottom). Note that colour identifies connected bodies. The model in (a) shows an increase in overall connectivity with the addition of faults, whilst the model in (b) is disconnected by faulting.

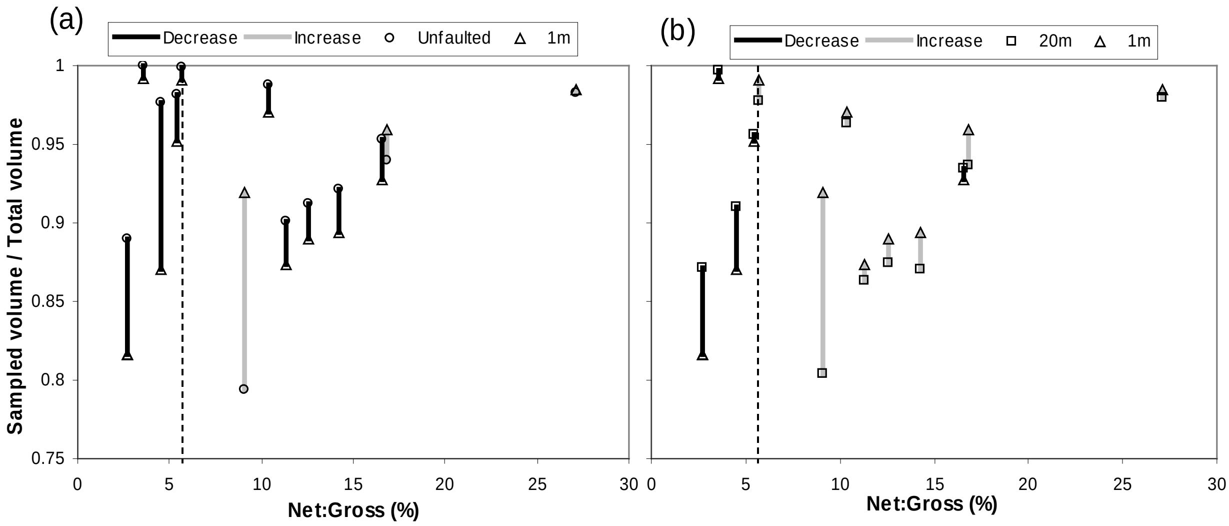

Fig. 3. Comparison of the change in connectivity with the addition of faults (a) and the addition of more smaller faults (b) in various models. Those lines that are grey in both plots are better connected with the addition of faults and progressively better connected with the addition of more smaller faults; significantly, these include models that contain laterally extensive, overbank bodies. Black lines show those models that are disconnected by faults (a) and progressively disconnected with the addition of more smaller faults (b); these models are typically low net:gross (< 5.5% - dotted line). Grey lines show those models that are better connected with the incorporation of faults and with the addition of more smaller faults. Note that some black lines in (a) are grey in (b), which indicates an overall reduction in connectivity with the addition of faults, but the addition of more smaller faults reconnects parts of the system.

A summary of the test results is shown in Figure 3, which displays the change in system connectivity as a function of net:gross. In general, the higher net:gross models (> ca. 6%) are better connected by the addition of faults and with the incorporation of more smaller faults. Lower net:gross models (< ca. 6%), on the other hand, are typically disconnected by faults. On their own, these results would suggest that net:gross is the over-riding control on the connectivity of faulted reservoir units. This is not in fact the case. For example, the existence of laterally extensive, sheet overbank deposits, even within low net:gross sequences, has the effect of connecting vertically and geographically disparate reservoir units within faulted models. The broad equivalence between net:gross and connectivity therefore reflects a weak association between high net:gross sequences and the presence of laterally extensive sand bodies.

Conclusions

These results demonstrate that although net:gross has an effect on whether a system is better connected or not by faulting, the dimensionality of the unfaulted stratigraphy is critical in these relatively low net:gross Coal Measure sequences (3-27%). Channelised bodies, which can be considered as 1-D geometrical elements, have a high probability of being disconnected by faults because of their linearity. Conversely, laterally extensive tabular bodies, which can be generalised as 2-D elements, have a high probability of being juxtaposed against vertically disposed units along faults with laterally variable displacements. In detail, of course, the effect of individual faults varies with the relative size of sedimentary bodies to fault throw: small faults will have little effect on thicker bodies.

The results presented for the East Pennine Coalfield succession are not routinely applicable to other types of reservoir, but provide valuable insights into the likely geometrical impact of faults on sedimentary bodies. For example, the effects of faults on channelised bodies in other types of fluvial deposits will vary with the relationship between the channel width-thickness ratios and the lateral displacement gradients. Disconnection of channelised bodies is best achieved when the lateral displacement gradients are lower than the channel width:thickness ratio and conversely juxtaposition can be optimised if channel width:thickness ratios are large in relation to displacement gradients. Channelised intervals with high net:gross ratios may not be detrimentally affected by faulting and may show an increase in connected and drainable volumes. Whatever the combination of circumstances relating to a particular succession, we conclude however that the dimensionality of the contained sedimentary bodies is a crucial factor in determining the impact of faulting.

Acknowledgments

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