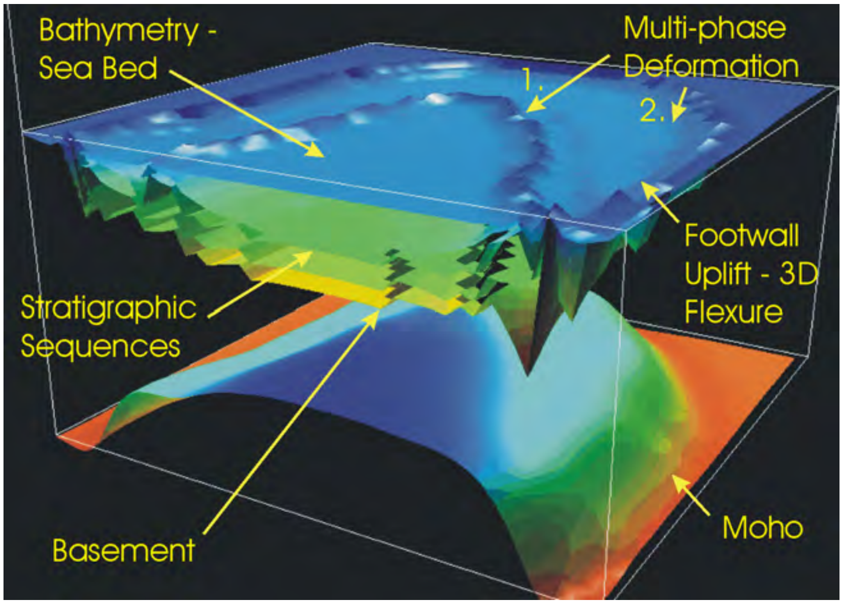
**AAPG Annual Meeting**
**March 10-13, 2002**
**Houston, Texas**

# 4-Dimensional Modelling of Structural Geology: Implications for Hydrocarbon Migration and Accumulation

Graham Williams, Stuart Clarke, Andrew Richards, David Meredith, Stuart Egan, Basin Dynamics Research Group, Keele University, Keele, ST5 5BG, United Kingdom; Stuart Burley, BG Group, 100 Thames Valley Park Drive, Reading, RG6 1PT, United Kingdom

Dynamic computer modelling of structural geology in three dimensions provides analytical tools that can be applied to petroleum systems present in extensional, compressional, wrench and inversion tectonic settings. The fundamental basis for basin-scale modelling is structural retro-deformation by sequential movement on faults with associated hanging-wall and footwall deformation. This procedure coupled with flexural isostatic and decompaction-related compensation provides 'snapshots' of well constrained structural and stratigraphic geometries through time.

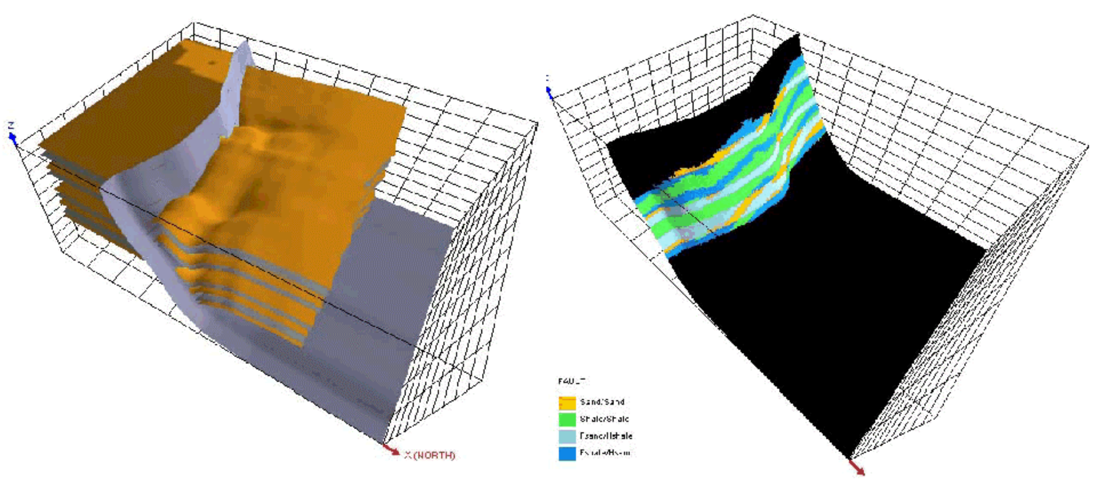



*Lithosphere scale geodynamic modelling simulates three dimensional profiles of basin stratigraphy, basement and moho. Cross section and well data can be extracted from the models.The models simulate multiple phases of rifting and/or inversion and can replicate the varying styles of extensional/compressional deformation often encountered* *throughout a basin's evolution, (e.g. discontinuous depth dependent stretching and migration of the rift locus through time).*

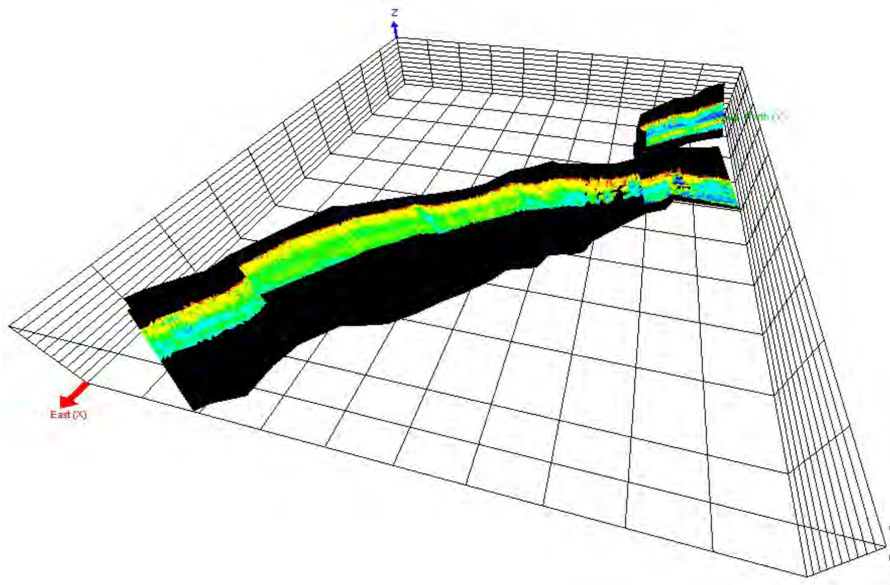
Individual retro-deformation ‘snapshots’ are used in forward modelling from the undeformed state of the rock volume to its present-day architecture. Sequential stages in the forward models provide the foundation for a four-dimensional petroleum system modelling capability that incorporates hydrocarbon maturation, migration and trapping.

Faults are key controlling elements in fluid flow systems in sedimentary basins. As faults undergo displacement, they change their fluid transmissivity properties by juxtaposing varying lithologies across the fault, by pumping or valving diagenetic and other fluids, by smearing semi-permeable or impermeable clays and shales within

fault zones and via cataclasis in sand-rich sequences. In 3-D structural models, the evolution of cross-fault relationships is dynamically calculated and forward modelling enables prediction of the distribution of fault zone smears, gouges and cataclastic rocks. By combining analyses of juxtaposition and fault zone products, the transmissivity of each fault zone is calculated.

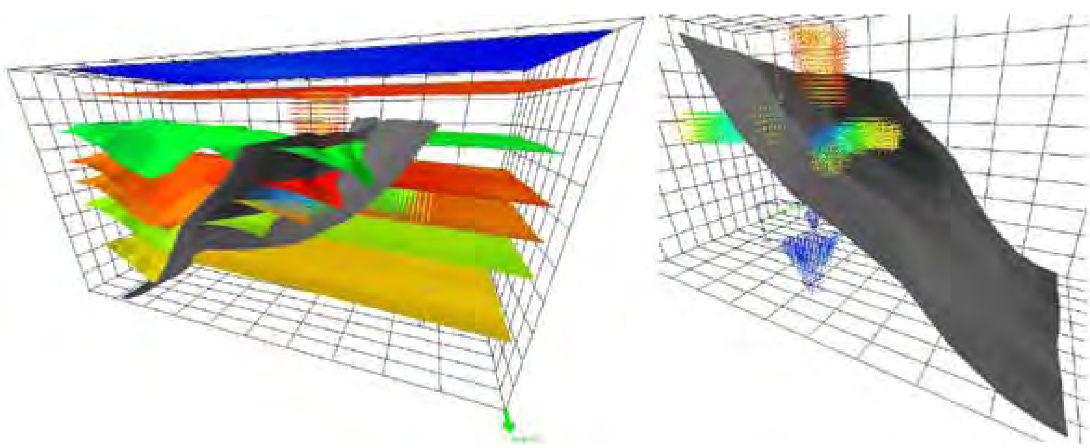



*Three dimensional earth model Based on a simple earth model containing nine interbedded sand and shale units that have been faulted with variable dip slip displacement. Allan diagramshowing juxtaposition relationships from footwall to hanging-wall across the fault (black).*




*Three dimensional shale gouge ratio (3DSGR) for the Moab Fault (present day) This model indicates an SGR cut-off between seal nd non seal of ~17%. This represents a positive improvement over 1D models (Foxford et al., 1998 ~20%) as less SGR is required to seal and 3DSGR shows*
*the distribution of fault rock shale over the extent of the fault surface (not possible for 1D models)*

Fault-parallel and cross-fault fluid flow pathways and hydrocarbon accumulations are predicted using the Invasion Percolation algorithm in three dimensions at each stage of the forward modelling process. Volumetric calculations of all accumulations are performed as a final stage of the modeling.



*Hydrocarbon migration pathways through faulted earth model from NW source. Surface colours indicate permeability (red = high blue = low, log scale), volume node colours indicate stage of fill (red =late stage blue = early stage). Migration pathways can be traced vertically through the faulted structure from source by repeated cross fault migration between high permeable juxtaposed fault-blocks and up-dip flow (Allan 1989).*

*Hydrocarbons accumulate in the highly permeable regions of the hangingwall, small fault block and the post rift strata. The fault is assumed closed to fault parallel migration and their are no fault-rocks. Second figure is based on the first without stratal surfaces.*