The Interaction of Reservoir Engineering and Geomechanics (a story)

Brian G D Smart

FREng, FRSE, FIMMM, CEng

Petromall Ltd

Why is the interaction a good thing?

Assertion - *Reservoir Geomechanics enables better Reservoir Engineering-related decisions regarding:-*

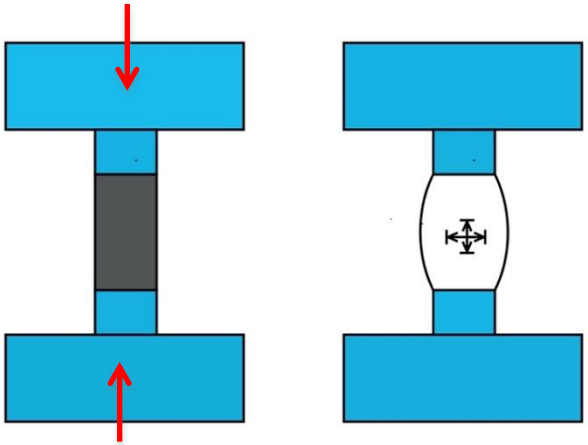
- **Reservoir characterisation including permeability stress sensitivity**
- **Well locations/design**
- **Production strategy (reservoir pressure)**
- **Flood directionality**
- **Compaction drive**
- **4D seismic interpretation**
- **Seal integrity**
- **Changes in compartmentalisation**
- **Subsidence**
- **Production-induced earth tremors**

All impacting recovery factor and costs, i.e. THE BOTTOM LINE (S)

The Story

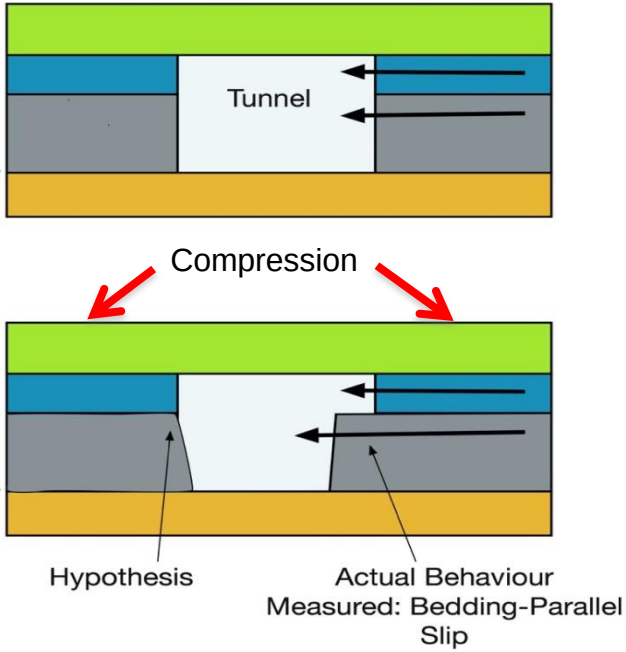
- **1964-1990: BGDS's geomechanics understanding evolved mainly in the world of international coal mining and South African gold mining (Strathclyde, Cardiff, Strathclyde)**
  - **Possible to observe phenomena directly and take both local and remote measurements, and convey recommendations regarding tunnel and coalface support to management – rapid feedback**
- **1982-2003: Migration to petroleum engineering (Strathclyde, Heriot-Watt)**
  - **More difficult to observe and measure phenomena, usually feedback times longer, lab tests involve fluids**
- **From 1982 on, thoughts, actions – *"Can the understanding of the geomechanics of stratified deposits developed in coal mining and gold mining be transferred to petroleum engineering"* (stratified deposits with production-induced in situ stress perturbation)**

The Storyboard 1970-73 Coal: a key understanding



Observation:- Compression testing of rock

In the lab



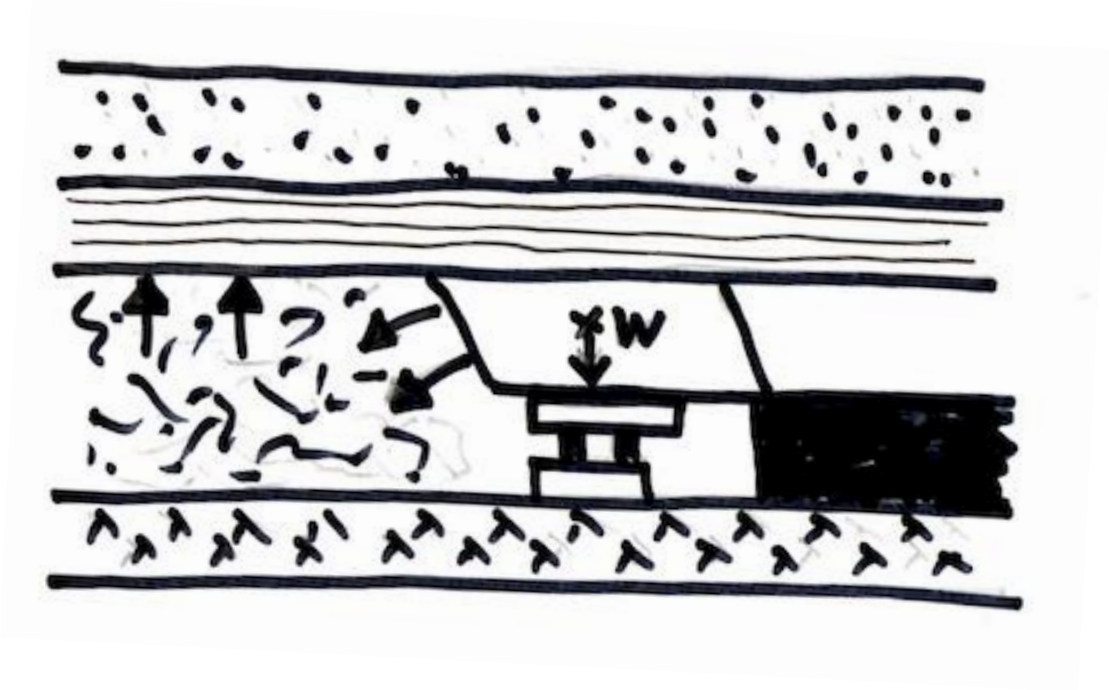
In the mine

Example of a Model Evolution/Use

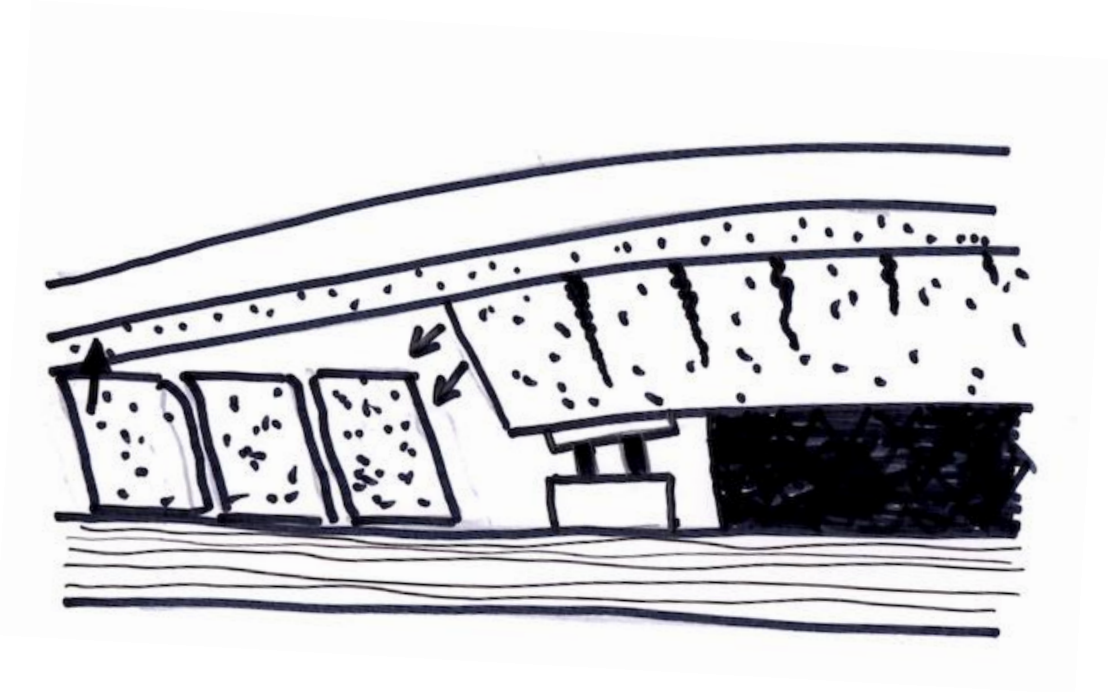
- Load rating of longwall coalface hydraulically-powered supports
- Range 180T to 1000T per unit

Longwall Coalface Hydraulically-Powered Roof Supports

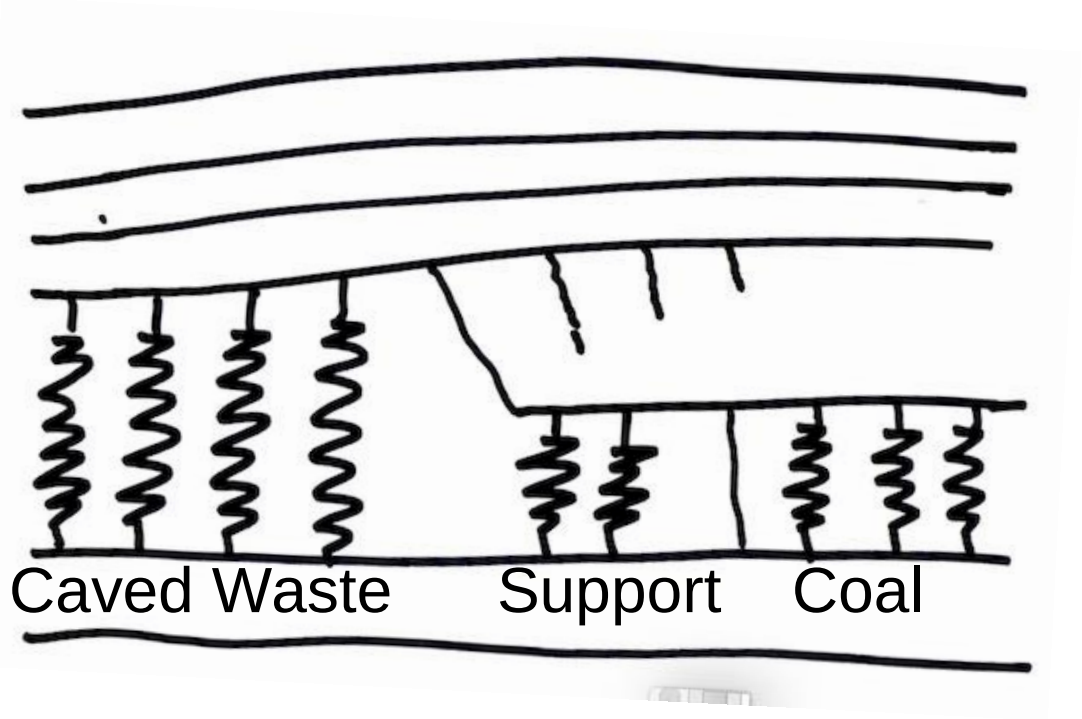
The official UK model : The Detached Block



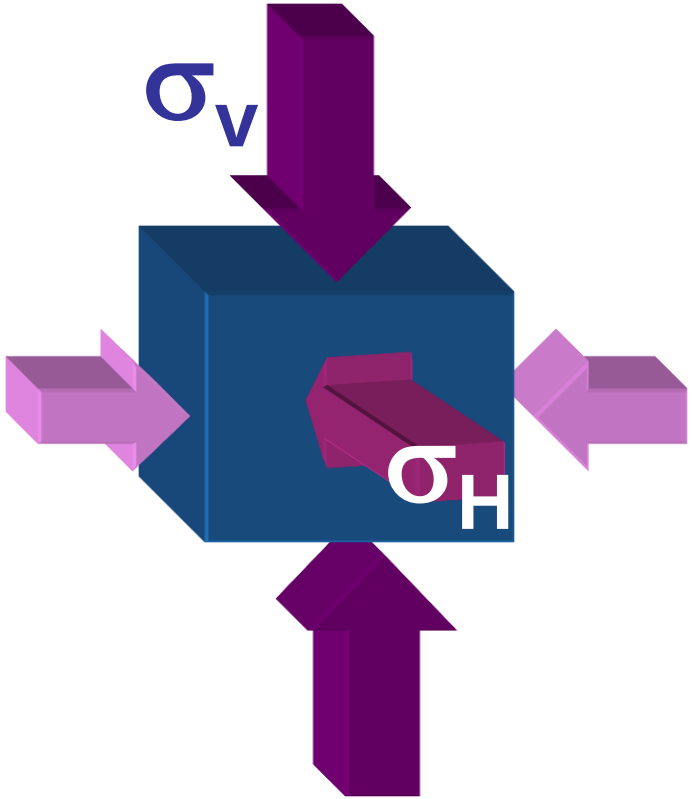
Caving observed in NSW and SA where higher rated supports required than in UK – why, how can they be specified from first principles?



New “3 Foundations” Conceptual Model



The Story Board 1975-80 Coal: The in situ stress state is anisotropic - another key understanding

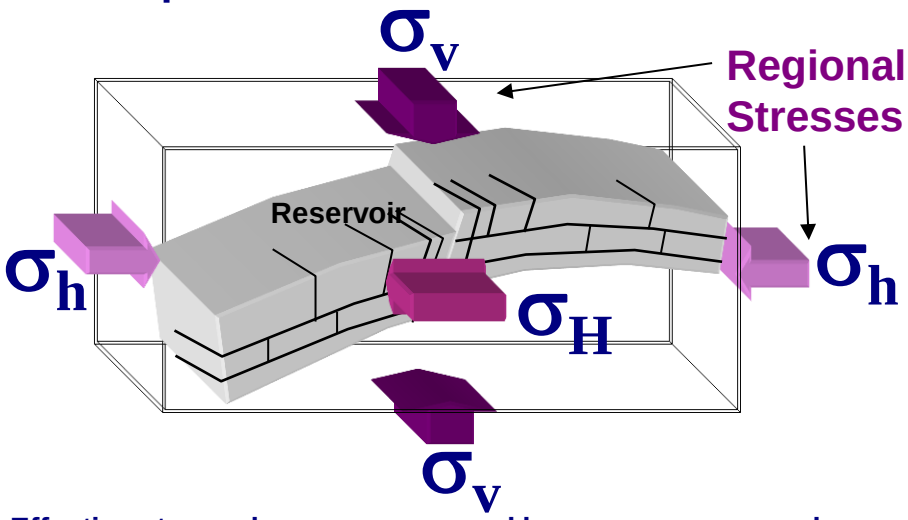


$$\sigma_v > \sigma_H > \sigma_h$$

The Storyboard 1990 Petroleum

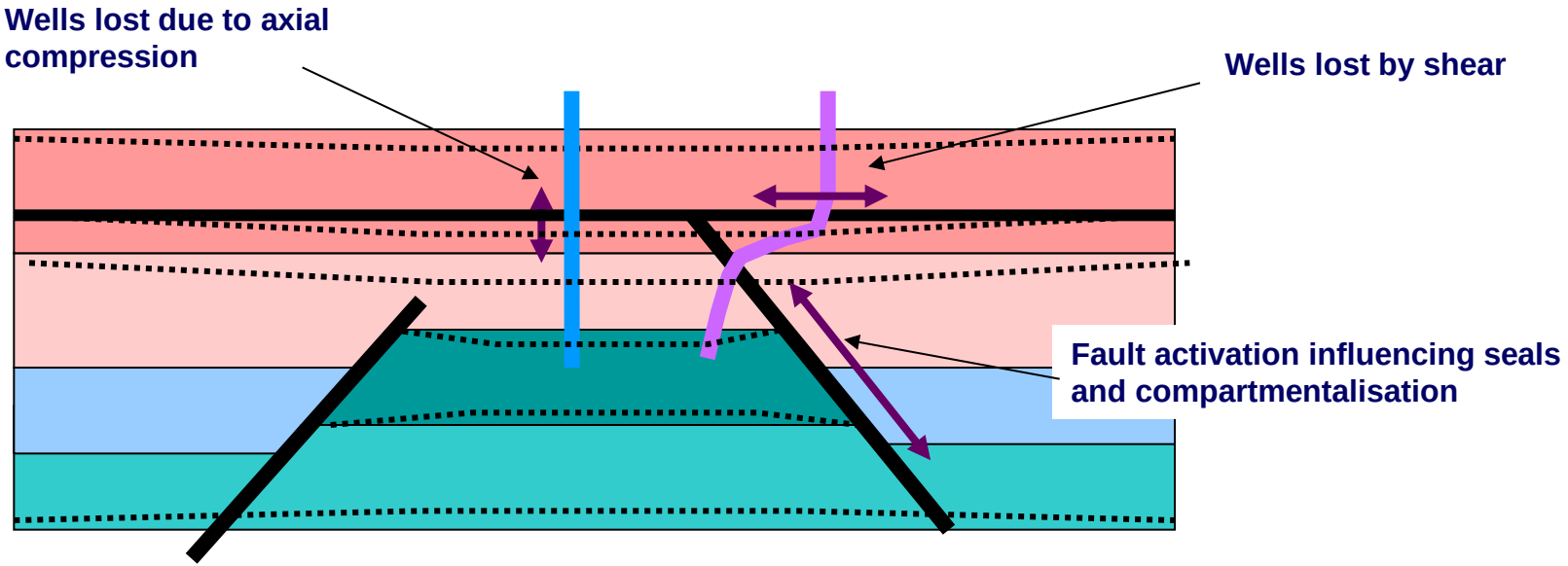
Thin mudstone intervals separating sharp-based turbidite sandstones

The Conceptual Model

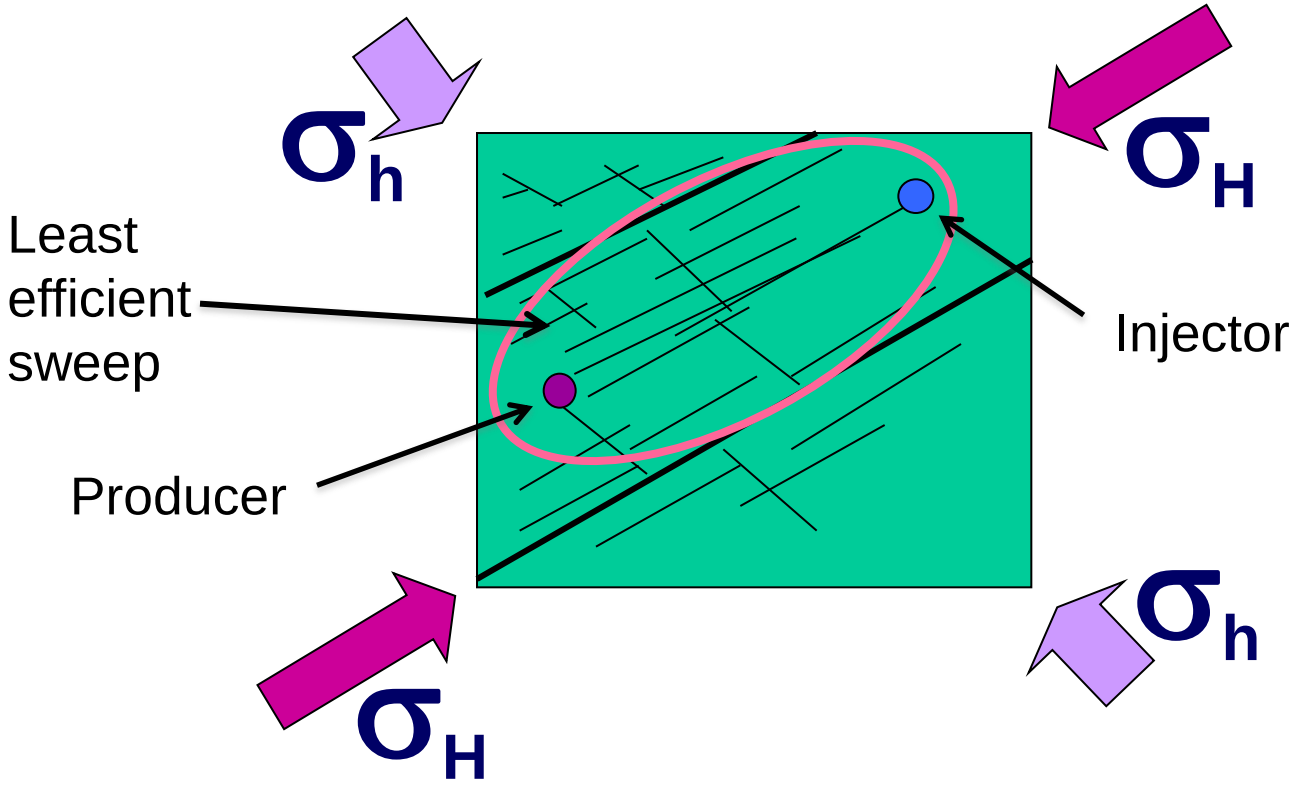


1. Effective stress changes are caused by pore pressure and temperature changes – ground deforms with structural and anisotropic σ controls
2. Permeability and seismic velocities are stress sensitive
3. Input data required
4. Coupled modelling required

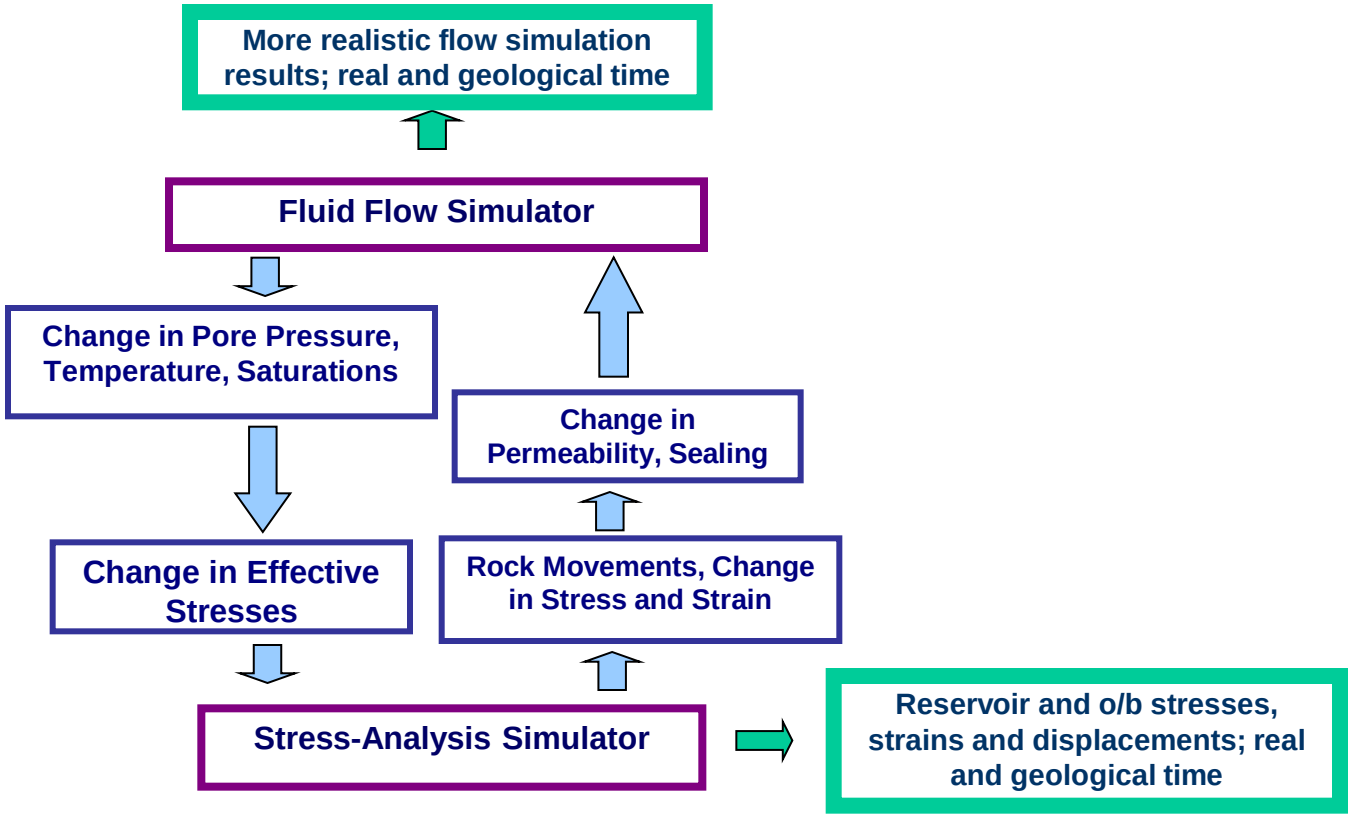
This Conceptual Model predicts, for example, for compacting reservoirs:-



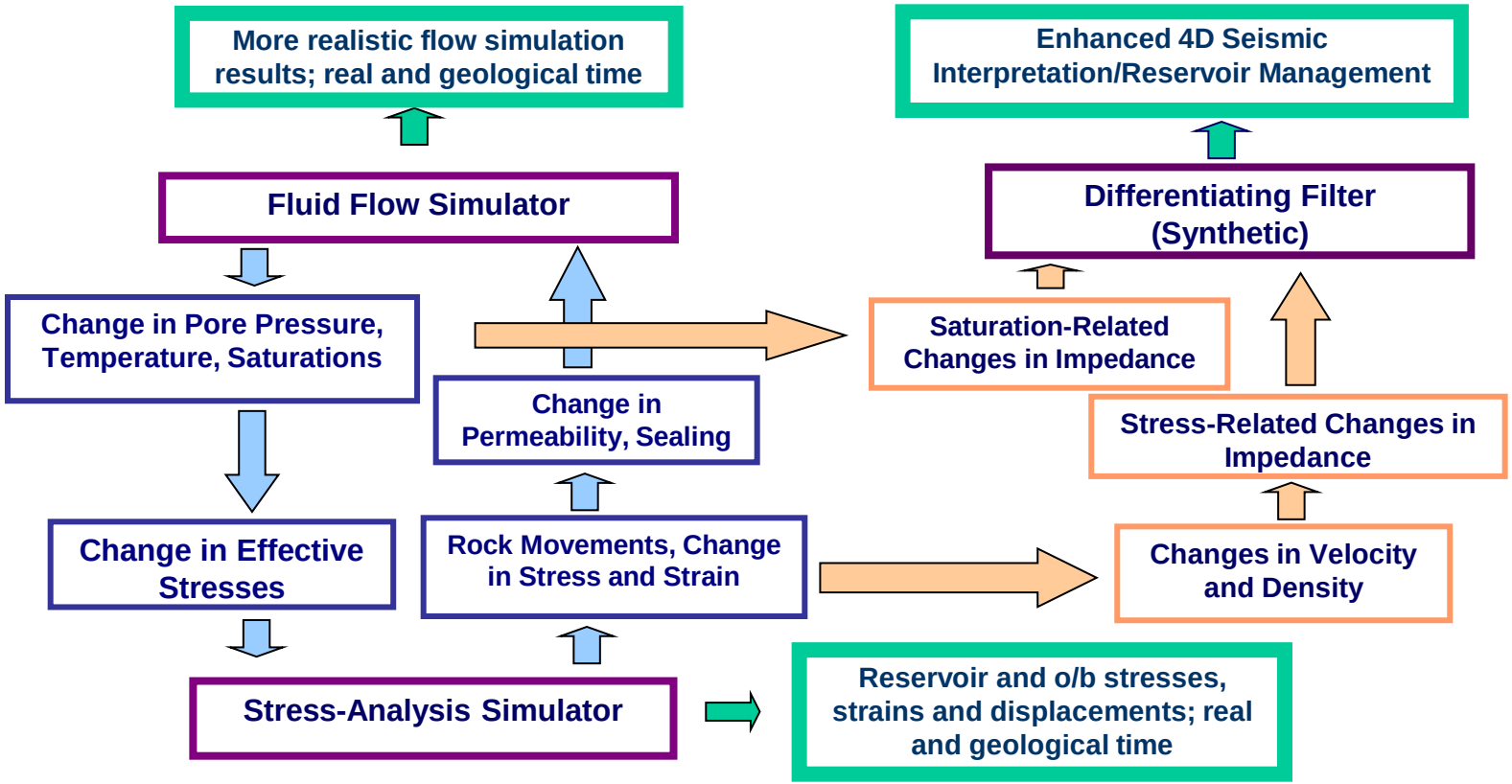
This Conceptual Model predicts, for example, for fractured reservoirs:-



The Storyboard 1988 on – Coupled Modelling



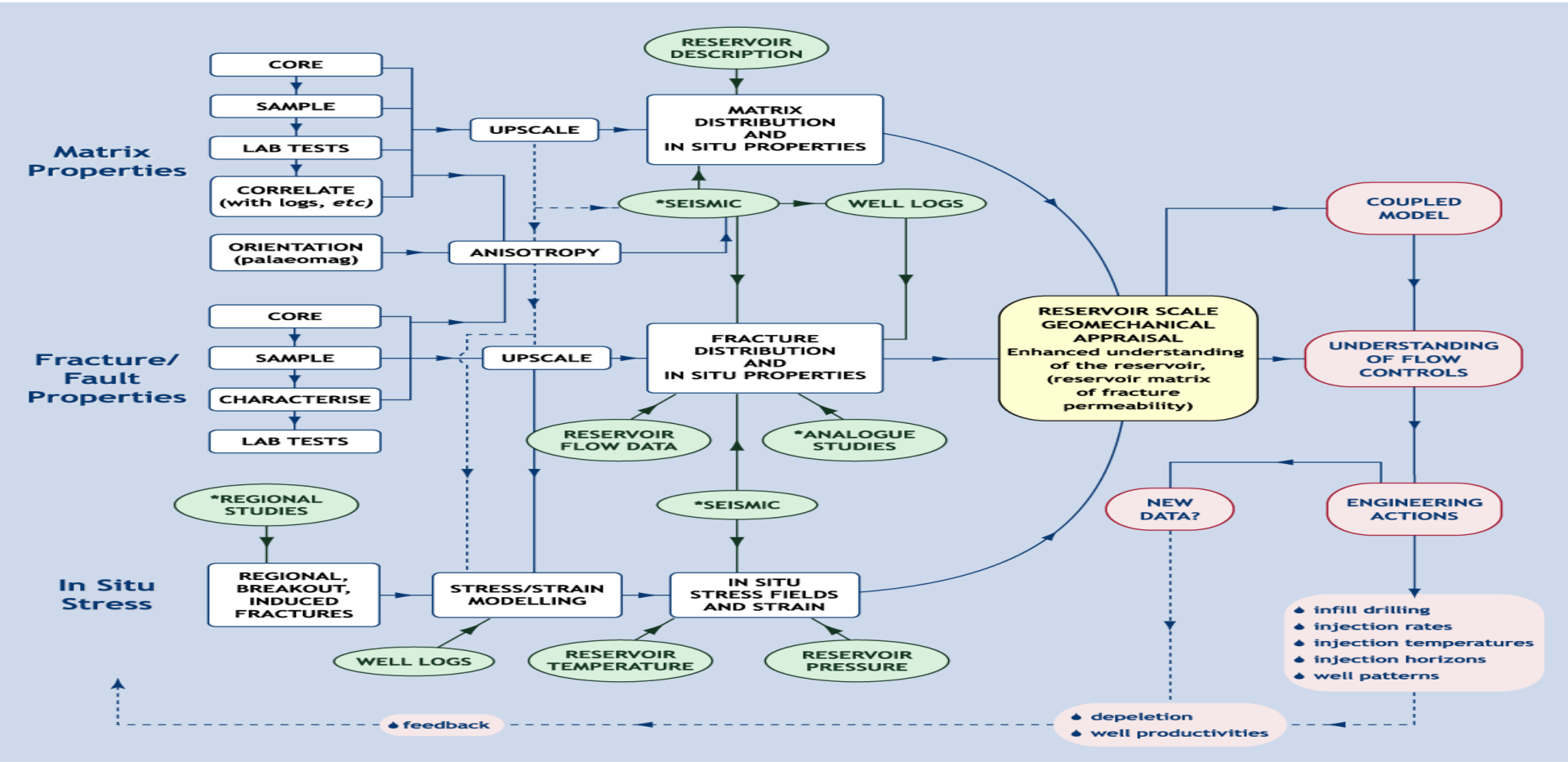
The Storyboard 1990 on – Coupled Modelling



Begin with a Geomechanical Appraisal. Data Set:-

- **Intact rock properties?**
- **Discontinuity (fracture) properties?**
- ***In situ* stress state(s)?**
- **Spreading and upscaling - populating the Geomechanical Model with properties**
- **NB fracture distribution**

The Geomechanics Work Flow

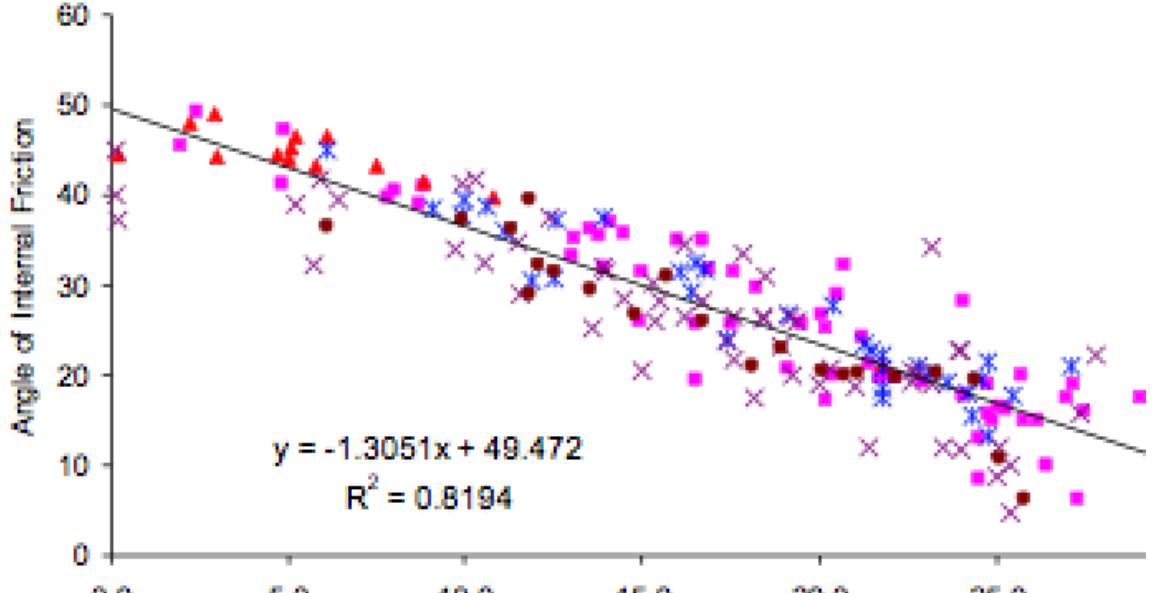


Matrix Properties with good porosity correlations

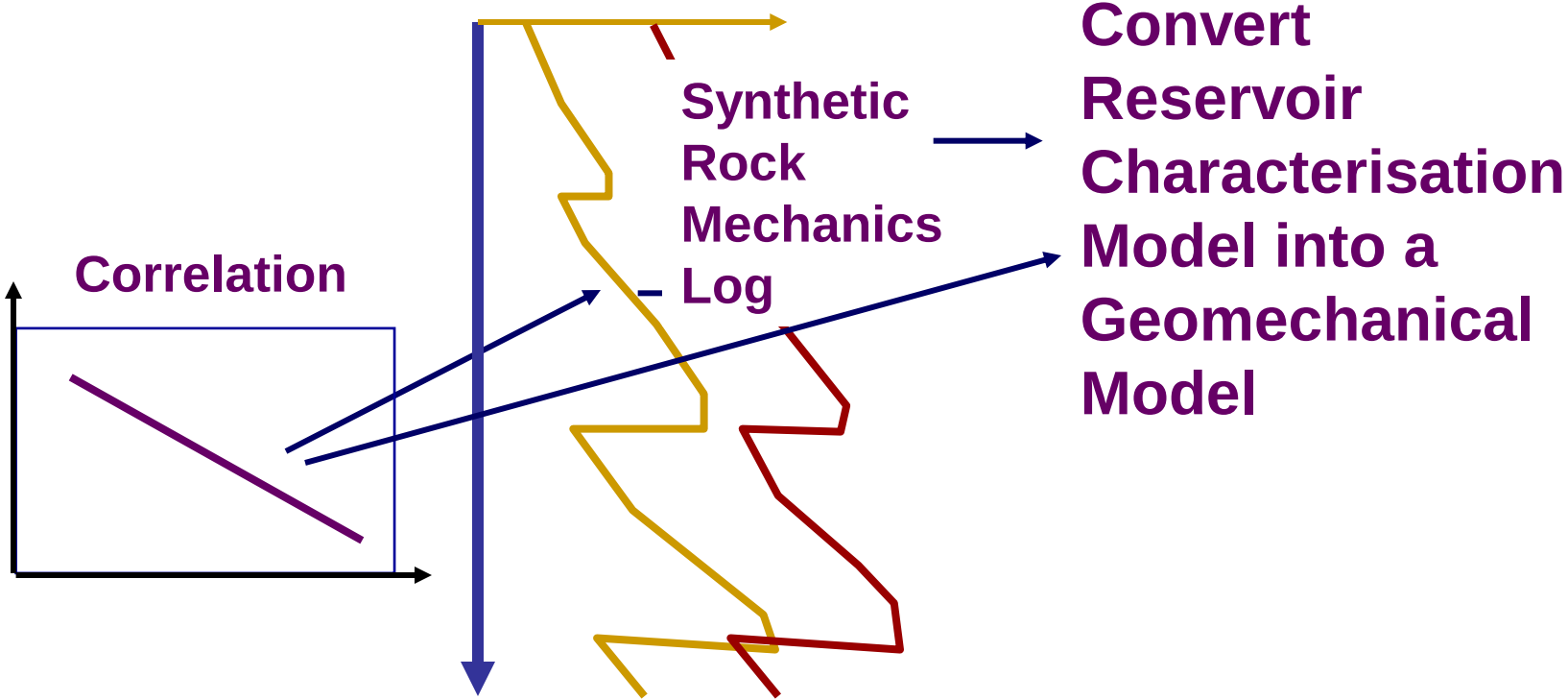
(stress-sensitive values where appropriate)

- Elastic constants E and v
- Biot's coefficient
- Failure (Fracture) Criteria
- Vp and Vs velocities
- Permeability at reservoir stress conditions

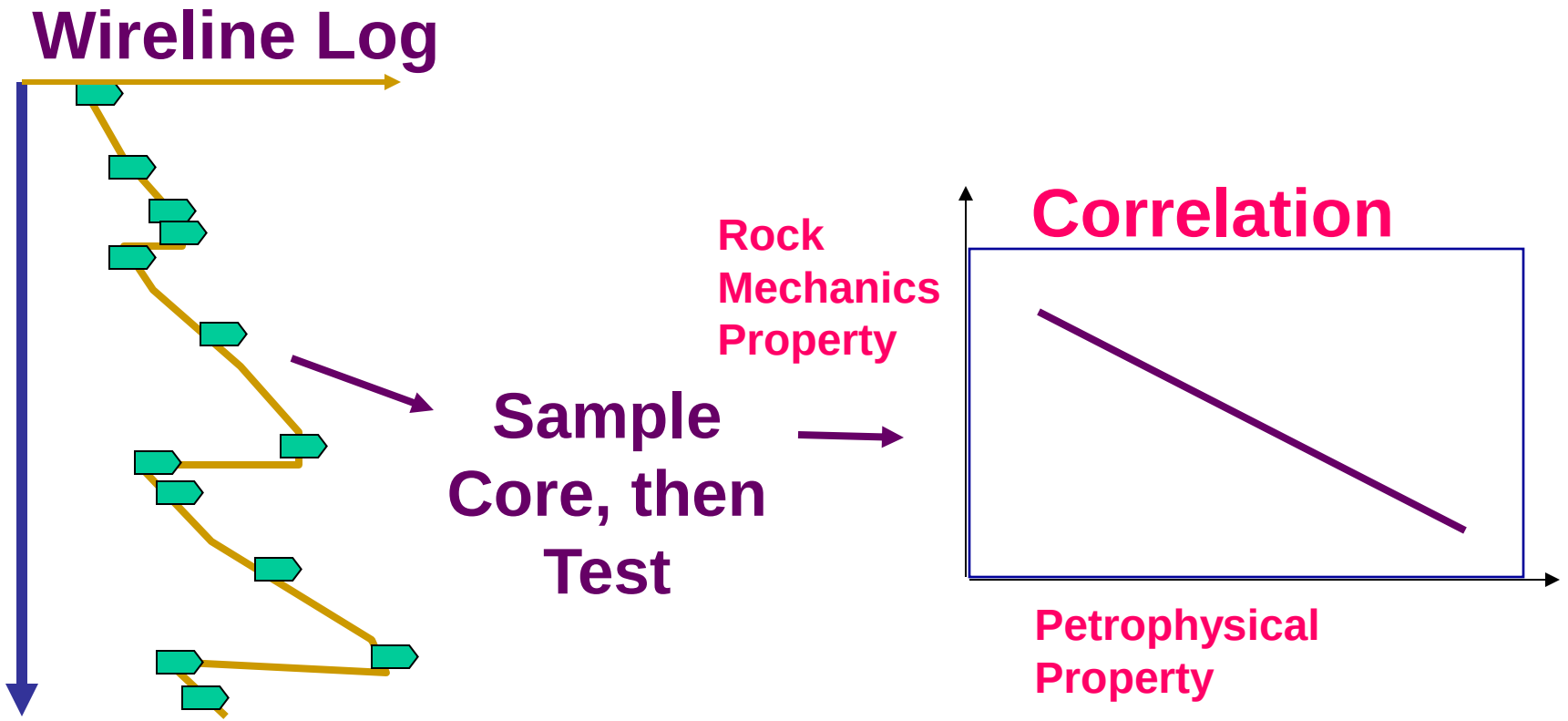
Rock Properties - Property Correlations



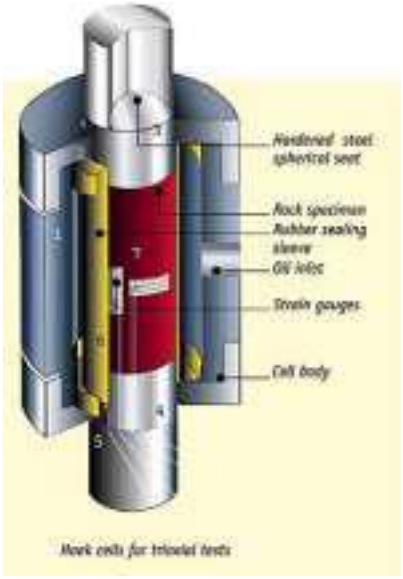
Populating Model - Intact Rock



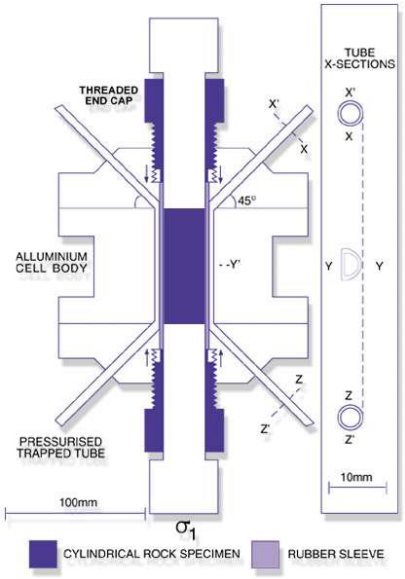
Sampling Rationale - Matrix

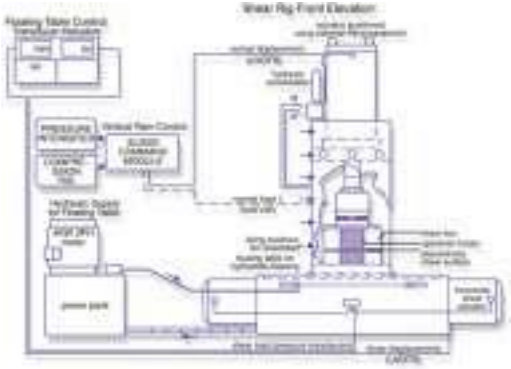


HWU Innovative Rock Testing Equipment:-discontinuities?



Hoek cells for triaxial tests





Understanding and Tools Developed/Developig: Progress?

- Measure using “Reservoir Geomechanics” publications listed in OnePetro
- Compare with other Reservoir Engineering topics

Topic Publications Referenced in OnePetro

Periods with Number of Publications

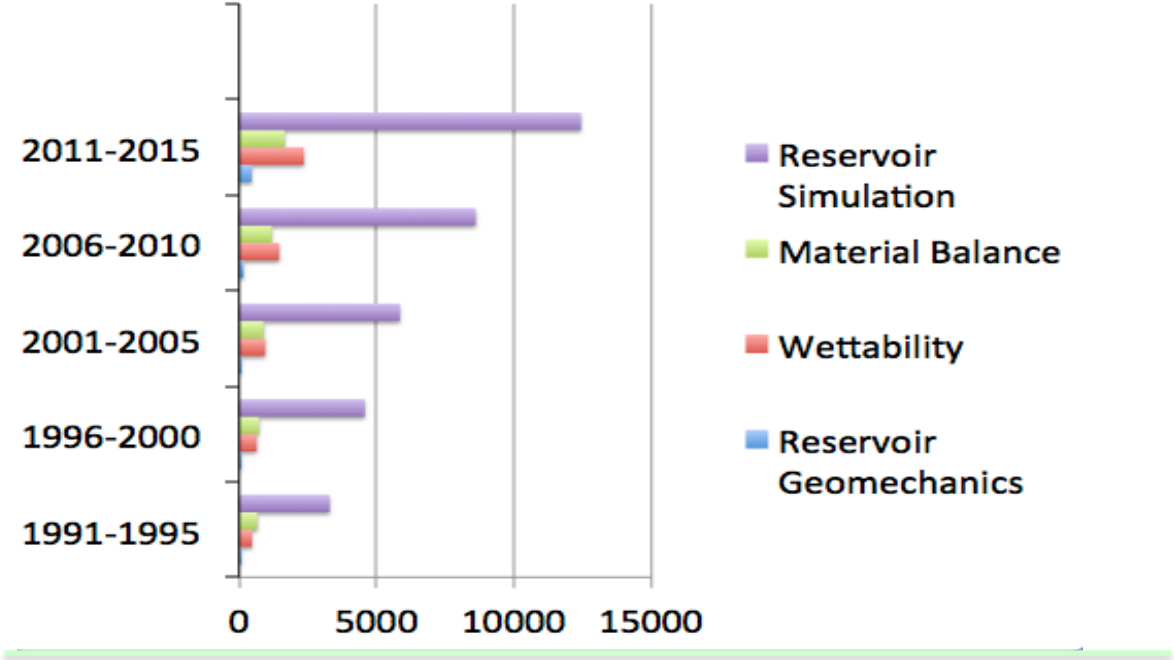
	Reservoir Geomechanics	Wettability	Material Balance	Reservoir Simulation
1991-1995	3	468	657	3289
1996-2000	19	634	716	4569
2001-2005	85	947	887	5846
2006-2010	165	1458	1179	8602
2011-2015	455	2355	1656	12433

% Growth Period on Period

	Reservoir Geomechanics	Wettability	Material Balance	Reservoir Simulation
1996-2000	533	35	9	39
2001-2005	347	49	24	28
2006-2010	94	54	33	47
2011-2015	176	62	40	45

Topic Publications Referenced in OnePetro

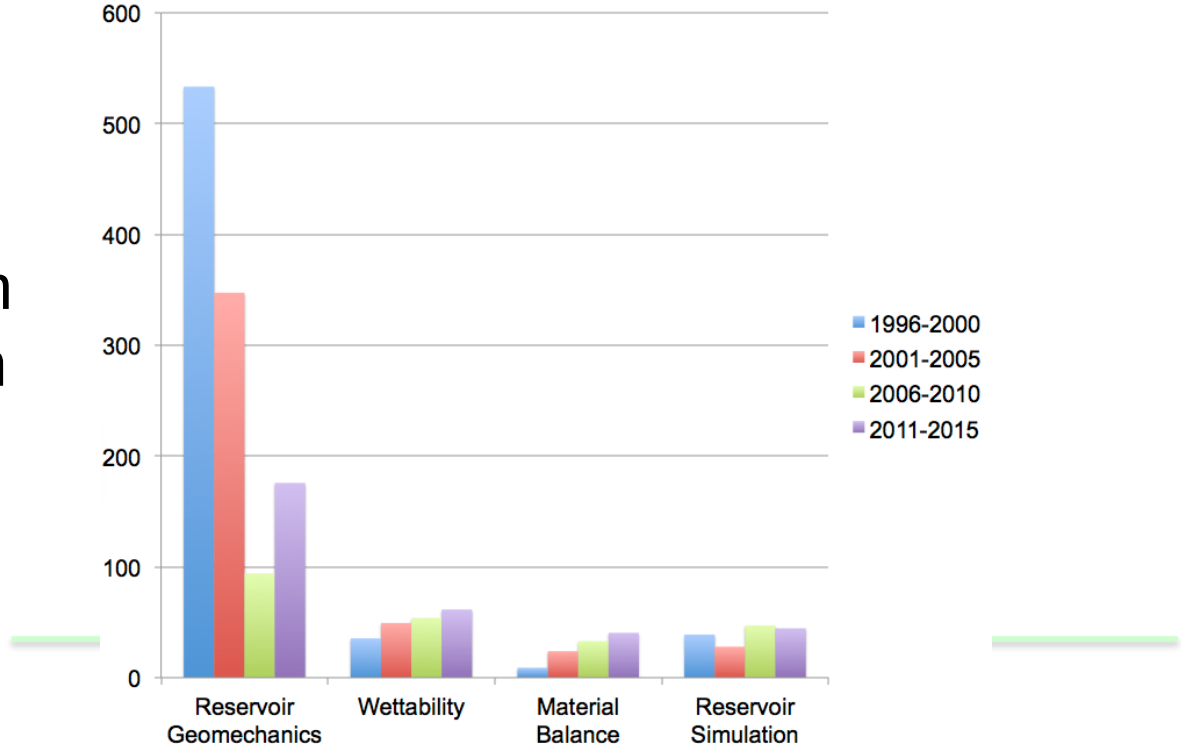
Period Published



Number of Publications

Topic Publications Referenced in OnePetro

% Growth Period on Period



Topics

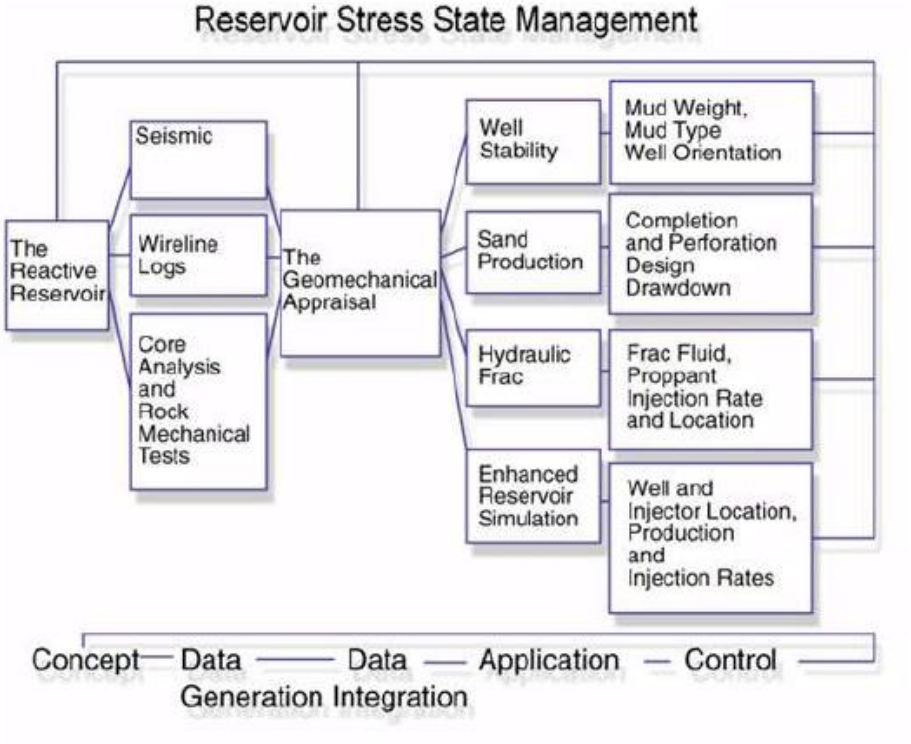
The Story Board 2018

- **The simple OnePetro survey suggests that reservoir geomechanics, while still a niche topic, is growing in activity as understanding and the tools required develop**
- **The growing petroleum reservoir engineering geomechanics fraternity comprises some majors, at least one national oil company, universities, service companies and an growing number of consulting companies**
- **The occurrence of reservoir "geomechanical action" has become obvious in the "extremes" e.g. in subsidence, well-loss, the management of fractured reservoirs. What about the more subtle reservoir scale effects? The challenge with this topic is the time between initiation and results.**
- **Pressure depletion in NS reservoirs approaching decommissioning will initiate geomechanical phenomena – at what scale and can they be used? What risks might they create?**
- **Reservoir geomechanics is a multi-disciplinary topic, and a shared conceptual model could accelerate its application**

ACKNOWLEDGEMENTS

- **Jim Somerville and Colleagues in the Rock Mechanics Group, Heriot-Watt University.**
- **Former colleagues at Strathclyde University and University College Cardiff**
- **Support provided from the Mining and Petroleum industries**

The Original Mission



The Tools Required:-

- **An appropriate geomechanical conceptual model for the reservoir and surrounds**
- **A geomechanical appraisal of the reservoir to populate the model with data (largely the same as for well stability)**
- **Coupled modelling software to realise model**

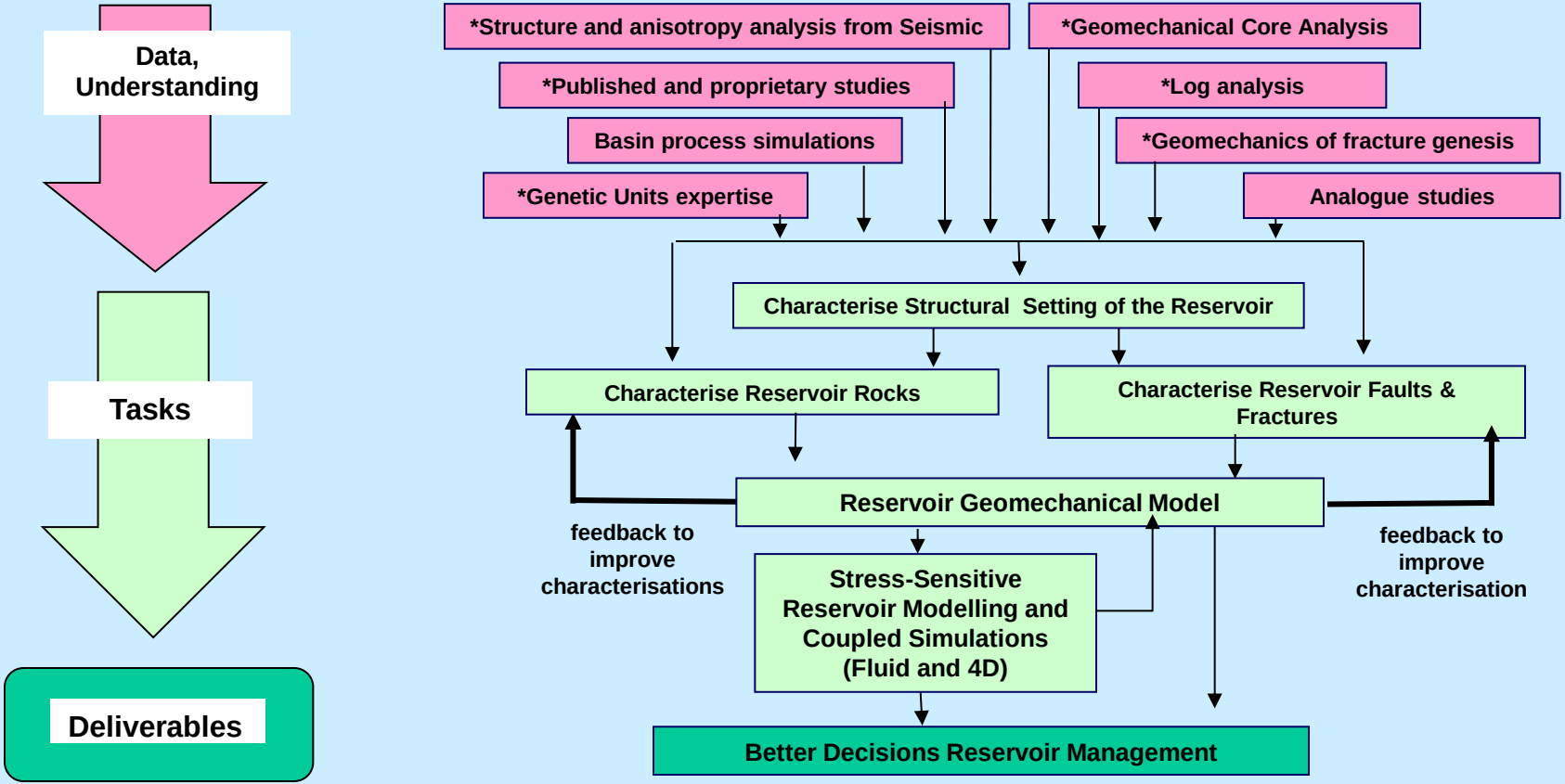
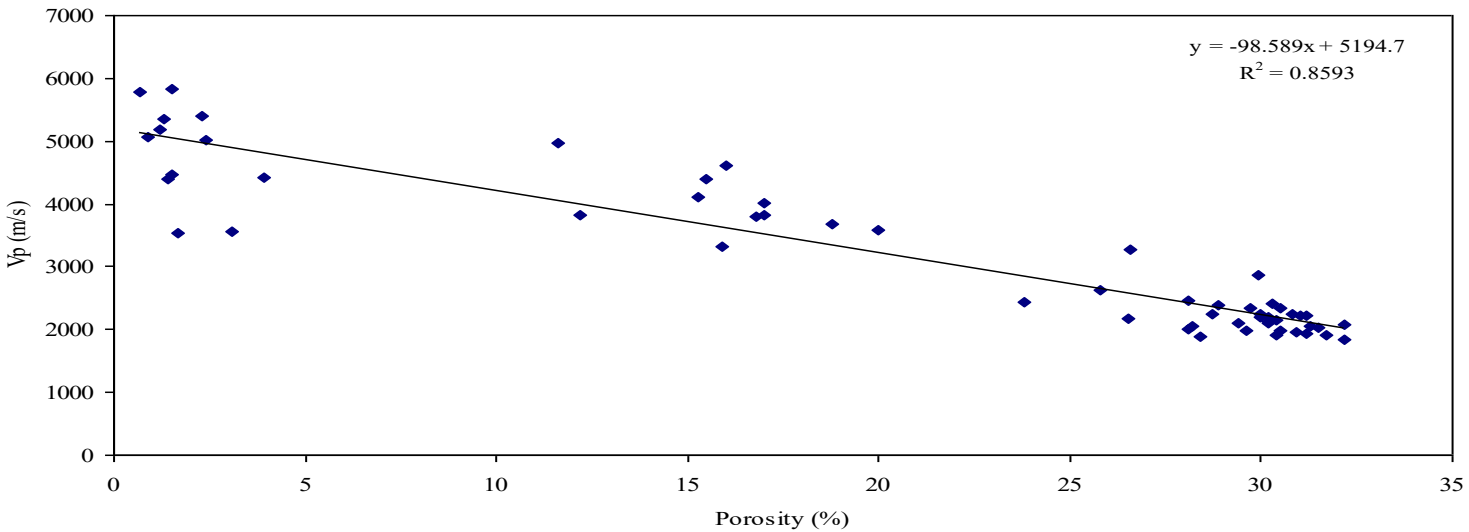

Data, Understanding
Tasks
Deliverables
*Structure and anisotropy analysis from Seismic
*Geomechanical Core Analysis
*Published and proprietary studies
*Log analysis
Basin process simulations
*Geomechanics of fracture genesis
*Genetic Units expertise
Analogue studies
Characterise Structural Setting of the Reservoir
Characterise Reservoir Rocks
Characterise Reservoir Faults & Fractures
Reservoir Geomechanical Model
feedback to improve characterisations
feedback to improve characterisation
Stress-Sensitive Reservoir Modelling and Coupled Simulations (Fluid and 4D)
Better Decisions Reservoir Management

Figure 4.1.1 P Wave Velocity versus Porosity



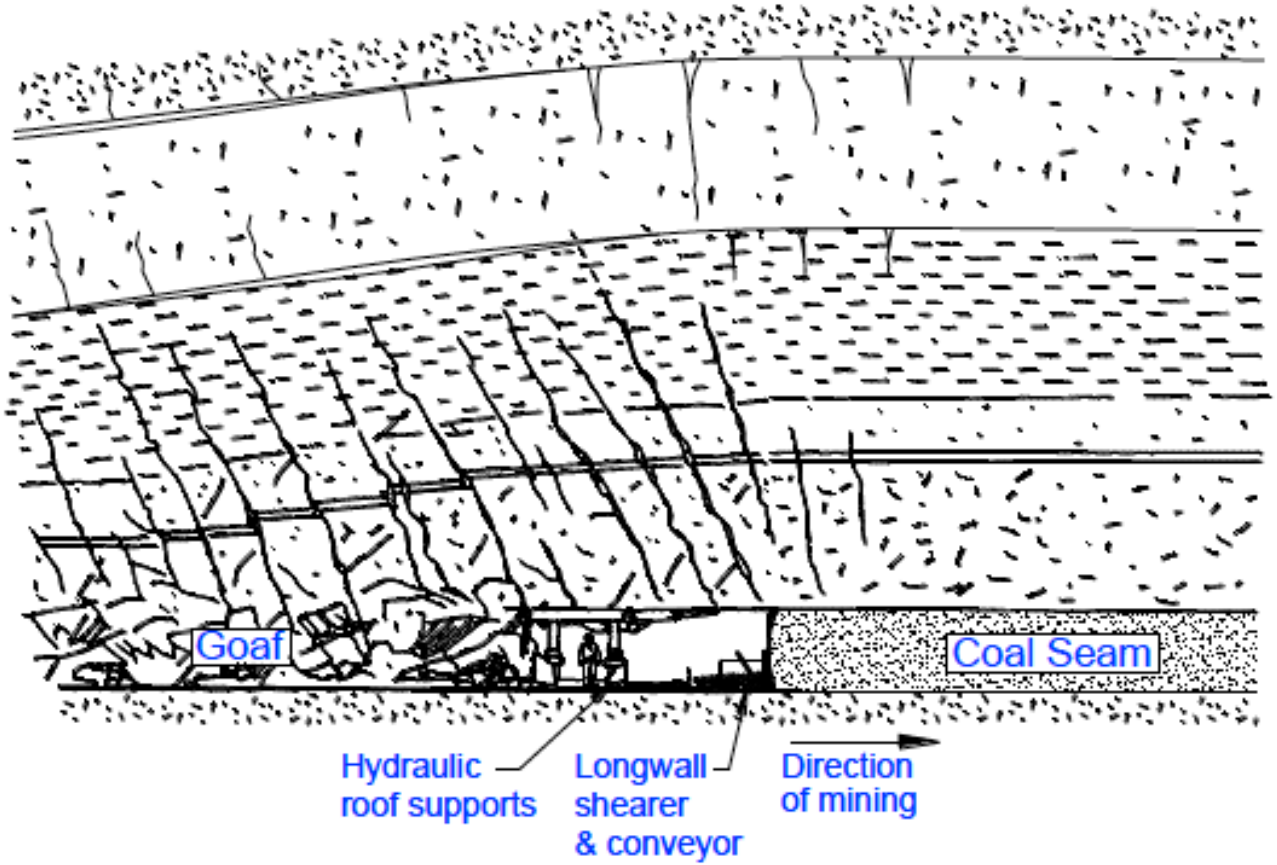
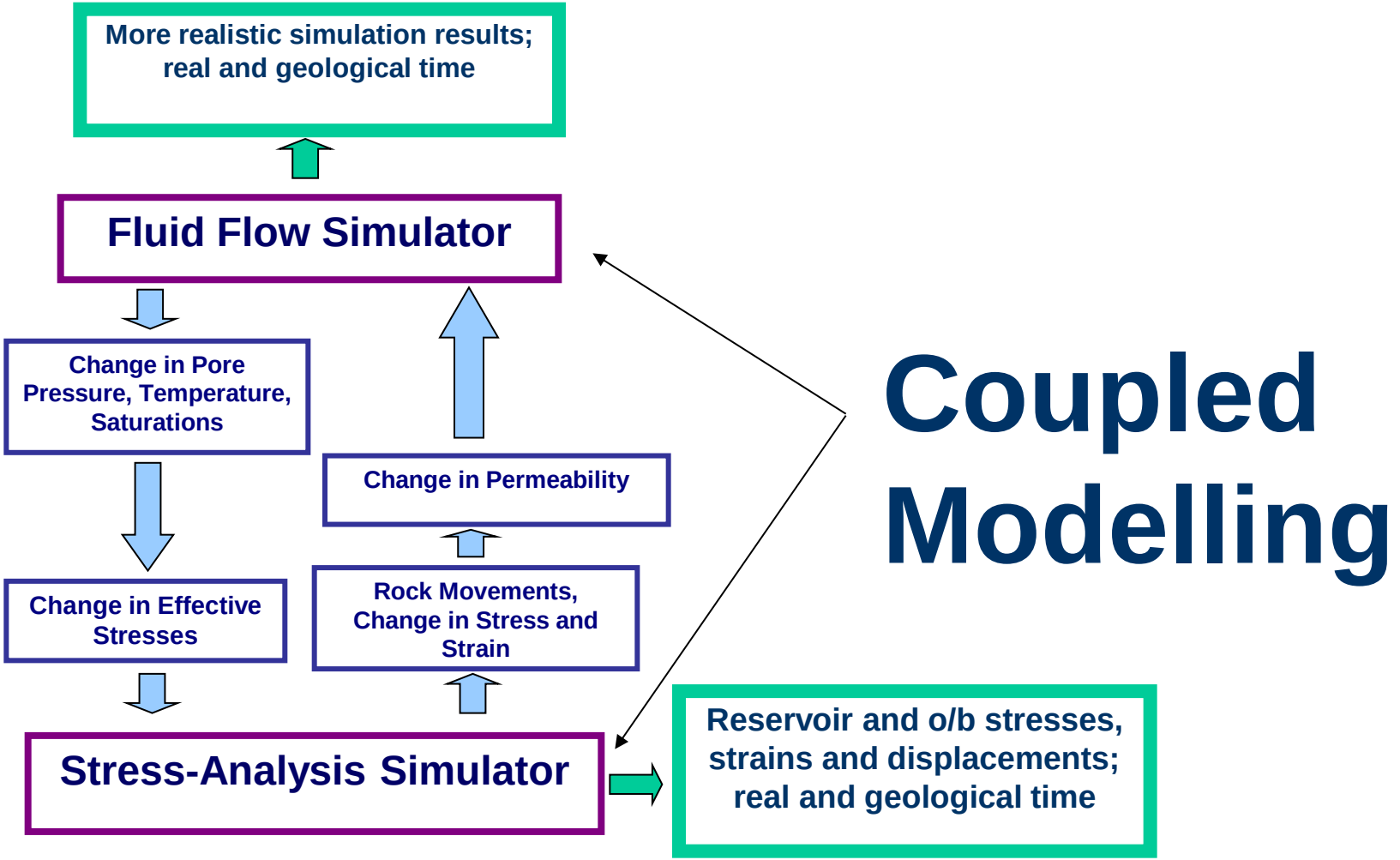


Figure 5 Cross section along the length of a typical longwall at the coal face (© Copyright, MSEC 2007).


More realistic simulation results; real and geological time
Fluid Flow Simulator
Change in Pore Pressure, Temperature, Saturations
Change in Effective Stresses
Change in Permeability
Rock Movements, Change in Stress and Strain
Stress-Analysis Simulator
Reservoir and o/b stresses, strains and displacements; real and geological time
Coupled Modelling