Shared Earth Model to Live Earth Model

Deeper Integration through Understanding the Rocks

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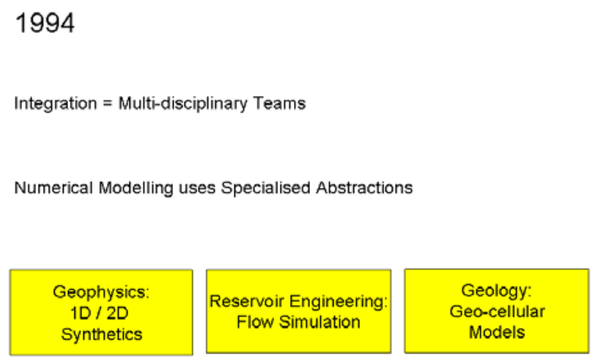


Let me take you back fifteen years, to the start of 1994. At that time, integration was a great buzz-word in exploration and production. There were integrated multi-disciplinary teams in the larger and more progressive oil companies and people were looking into how software technology might be harnessed to push forward this integration.

Prior to this time, for a decade or more, numerical modelling had been growing in scope and influence.

Geophysicists had been making 1D and 2D models of seismic velocity and rock density and calculating synthetic seismic traces and sections in order to understand the geological significance of seismic reflections. Or the seismic response to geological features. This included as a subset AVO modelling which had led to the creation of a geophysical specialization in Lithology and Fluid Prediction (LFP).

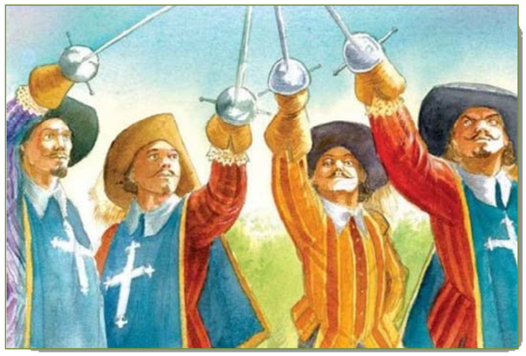
Reservoir simulation engineers had been making 3-dimensional grid models of reservoirs and associated aquifers, with parameters representing the porosity and permeability of reservoir rocks and the fluid saturations and pressure within them. Their purpose was to model the movement of fluids both in inter-well spaces and in the future – or more specifically to predict well performance and oil/gas recovery.

Fairly new at that time was a group of cellular 3D modelling packages with which **geologists** could represent the structural, stratigraphic and sedimentary features of a field. This was a great help in communicating geological concepts between subsurface team members.

Each of these areas of modelling used its own specialised abstraction based on principles appropriate to its own science.

An EU-sponsored project called ARAMIS, running from 1992 to 1995, pioneered a new way of working by bringing together these three disciplines of subsurface modelling, like the Three Musketeers.

The ARAMIS Project introduced the Shared Earth Model



All for One
and
One for All !

Gawith, D.E. & Gutteridge, P.A. 1994 "Closing the Loop: Seismic Validation of Reservoir Simulation using a Shared Earth Model"
Paper presented at EAPG Conference, Vienna 1994
(Also in Petroleum Geoscience, Vol 2. 1996, pp 97-103)

The purpose of ARAMIS was to formalise a key principle underlying cross-disciplinary integration: each discipline uses its own models against which to interpret subsurface data; and the more we can make these into aspects of a common model, the more effective integration will be.

The project set out to use technology to realise this principle and the result was the now well-known Shared Earth Model concept in which the abstractions used computationally by each of the subsurface disciplines would be derived from a shared numerical description of the reservoir.

A series of conference papers and publications helped to make the Shared Earth Model a familiar concept in most corners of the E&P world, and one aspect of its potential was demonstrated by the "Closing the Loop" paper, referenced here. This reported an experimental preview of the sort of integrated 4D modelling workflow which is only now available to general subsurface teams, for example through our RokDoc ChronoSeis software.

Progress since "ARAMIS"

Shared Earth Models are widespread

Structure, Stratigraphy

Geostatistical Properties

Fluid Saturations & Pressure

Seismic Attributes & Response } RokDoc ChronoSeis®

During the last fifteen years a major part of the Shared Earth Model idea has become standard practice: pretty well every reservoir simulation model is now derived from a 3D geological model, with its porosity, permeability and Net/Gross properties dependent on the geology. It is still central to the way in which we discuss our methods – the EAGE/Europec 2007 London conference had a special session on Shared Earth Models and last year's conference in Rome had many sessions and papers on specific cases and general benefits of integrated modelling.

However, the take-up has not been universal and also not complete: basically we model structure, broad stratigraphy and depositional heterogeneity.

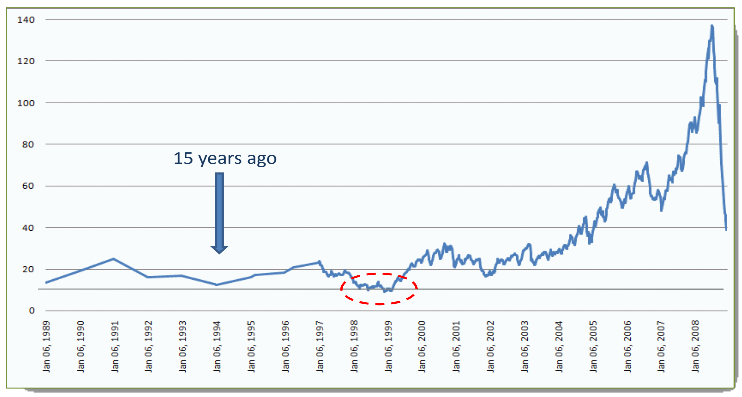
On that point, a very important development, quite early on, was the application of geostatistical techniques in these 3D models to simulate the spatial variability of rock types and properties. These techniques had been taken from mining geoscience and adapted by reservoir engineers to model the heterogeneity which affects fluid flow in reservoirs; their inclusion in geological modelling was a clear sign of growing integration through technology.

Further involvement of geophysics, in the sense of relating acoustic properties to geology and reservoir fluids, to make practical the approach of the "Closing the Loop" paper, effectively had to wait for Rock Models to come along – to which we shall come in a moment.

Before that, Events ...

Let us remind ourselves of what has happened in our industry since 1994. The price of oil was about $15 to $20 and our project economics were conservatively based on$16. Then in 1998/9 the price fell to $10 and the industry panicked. Exploration activity fell off and developments were postponed. Oil companies merged, were taken over and disappeared; thousands of experienced subsurface professionals were laid off and recruiting stopped.

Oil Price, US$ / Bbl (Money of the day) US Government data

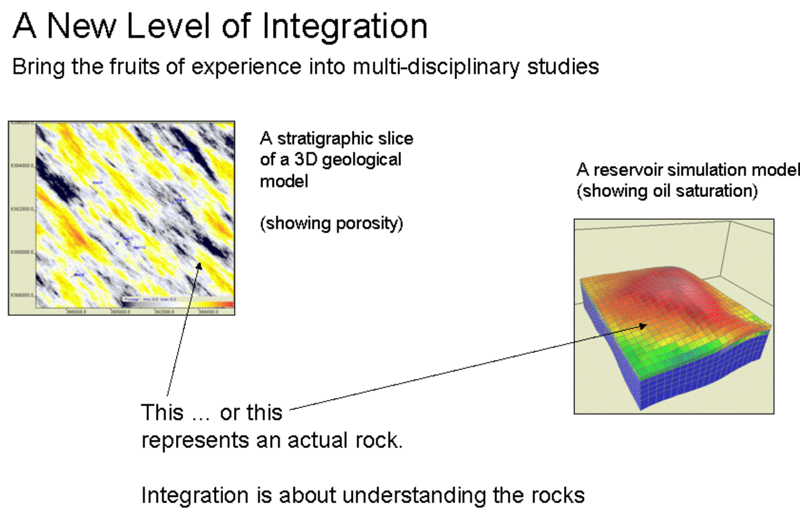


Soon though, the price of oil recovered, and went on recovering. Exploration re-started and developments were found to be economic again. More than that – now smaller fields could be profitable, and previously abandoned fields could be revived.

When things had been improving for a few years, it became apparent that there had been a serious loss of experience and skills in the industry. Small developments take proportionally more subsurface effort than large ones. Oil companies did not have the experienced staff they would need to do the job in traditional ways; the consulting trade could make up some of the shortfall, but much of the accumulated knowledge and experience had moved away, into universities and technology companies, or into retirement.

Now, despite the recent oil-price bubble and its bursting (and the current financial difficulties), most people seem to agree that the economic growth of China and India will ensure that a general upward price trend continues, so we shall be able to make money from small developments and reserves-enhancements. This means we shall have to learn how to handle a lot of relatively small projects without a lot of experienced subsurface professionals.

This brings us back to our subject: integration.

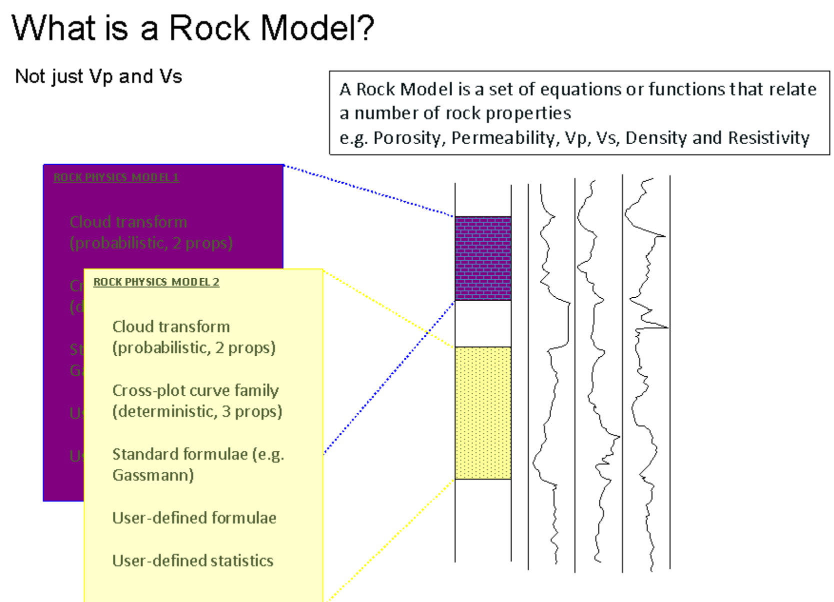


Technology can contribute by helping the subsurface disciplines to reinforce each other through a new phase of Shared Earth Models, and by encapsulating the fruits of experience in the tools that people use.

What this means is that the need for integration has now moved to a deeper level concerning the nature of the rocks we are modelling in our shared earth models

Geophysicists, Petrophysicists and Petroleum Engineers are all interested in rock properties, and these properties are dependent on the geology of the reservoir, but we are not doing enough to take advantage of the fact that these are properties of the same rocks.

Put simply, we treat rock properties in models either as independent quantities (only the position in the model is common) or as being related by transforms; we do not use the interdependencies between properties and so fail to make the best use of the shared model. There are opportunities to synthesize a more accurate and less uncertain picture by the use of Rock Models.



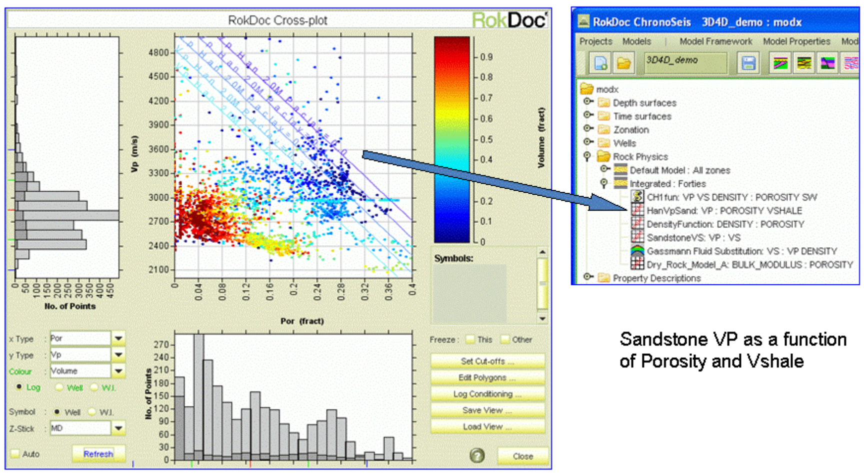
A Rock Model is a set of equations and statistics capturing the relationships between physical properties for a given rock type or formation. They have been around for a long time, but in the background, as obscure rules for specialists.

I believe we are about to see Rock Models as central to a new phase of Integration, bringing Shared Earth Models to life.

In our RokDoc ChronoSeis software they are known as Rock Physics Models. Here are two examples, from RokDoc work-flows, of how empirical relationships between rock properties are translated into rules governing the properties in a 3D reservoir model.

What is Inside a Rock Physics Model?

Example: a Standard Empirical Function calibrated to well data

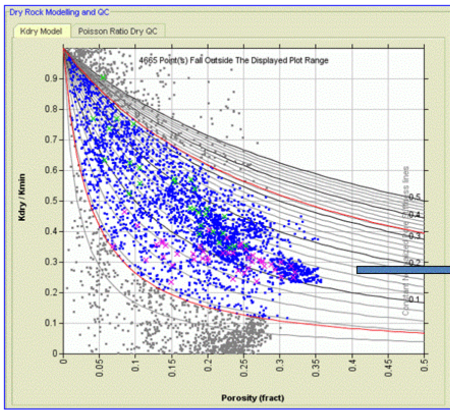


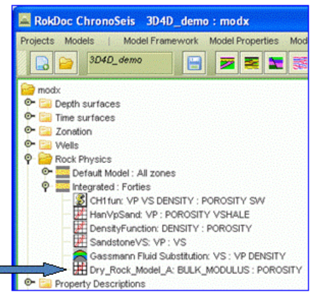
Sandstone VP as a function of Porosity and Vshale

In the first instance we have some well-logs and we cross-plot VP against Porosity, with colour showing Vshale. We are interested in a rule for describing the relationship between these properties for the sands in our target formation away from well control. We find a standard empirical function that overlays the sandstone points on our plot, adjust its coefficients and bring it into a Rock Physics Model for use in 3D.

What is Inside a Rock Physics Model?

Example: a Dry Rock Model to constrain Gassmann Fluid Substitution

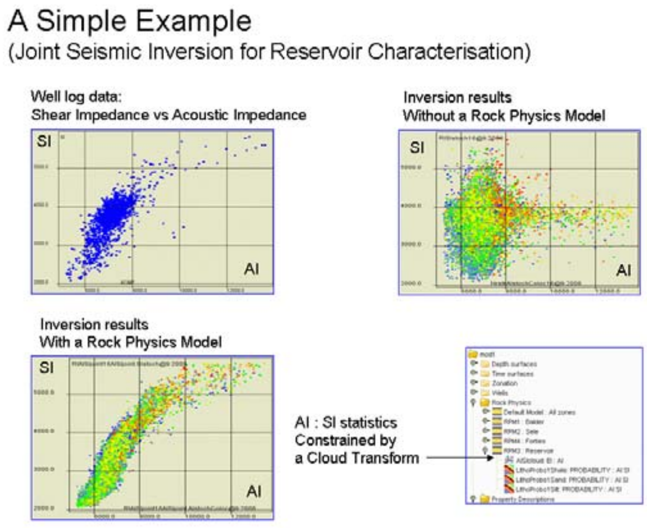




Un-physical property combinations are not permitted to corrupt the results

In the second instance, we are going to use a Gassmann function for fluid substitution in a 4D model, and we know that well-based rock properties are likely to come together in some un-physical combinations, owing to poor log quality. This will, if left alone, produce nonsense in our seismic modelling. Using a cross-plot of well data points and a standard empirical function, we can define an acceptable range of rock matrix stiffness for any value of porosity. This is brought into the Rock Physics Model to provide constraints in 4D.

Rock Physics Models are also very helpful in probabilistic modelling. I'll give you a simple illustration.



Seismic impedances to pressure waves and shear waves (P-wave and S-wave impedance AI and SI) are important acoustic properties which determine the amplitude-v-offset (AVO) character of seismic reflections. We use them in seismic reservoir characterization.

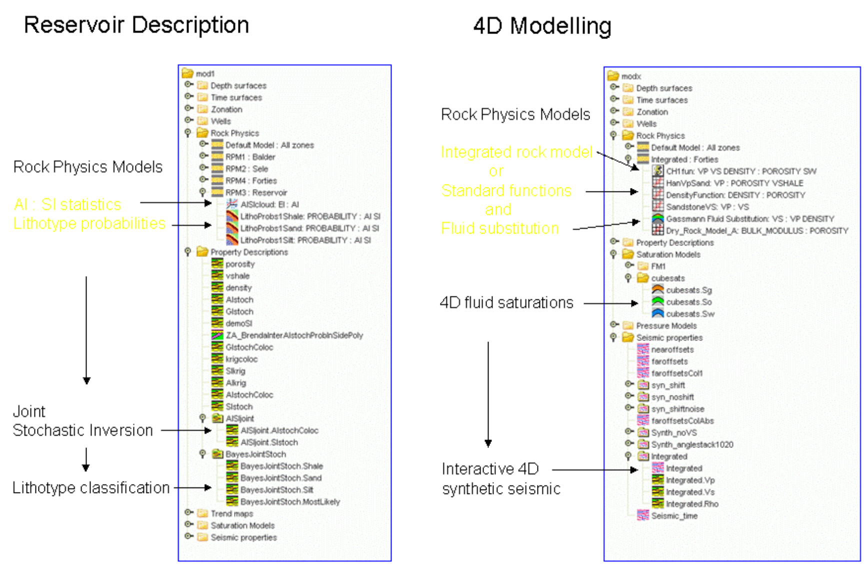
If we measure these quantities with well logs and cross-plot them we get something like the plot at top-left – there is a statistical relationship between AI and SI for the same rocks.

Traditionally we make estimates of AI and SI from seismic data either as independent properties, in which case the resulting values cross-plot like the view at top-right – no apparent relationship – or with a fixed relationship between them. Better estimates of P-wave and S-wave impedance can be achieved through the use of Rock Physics Models.

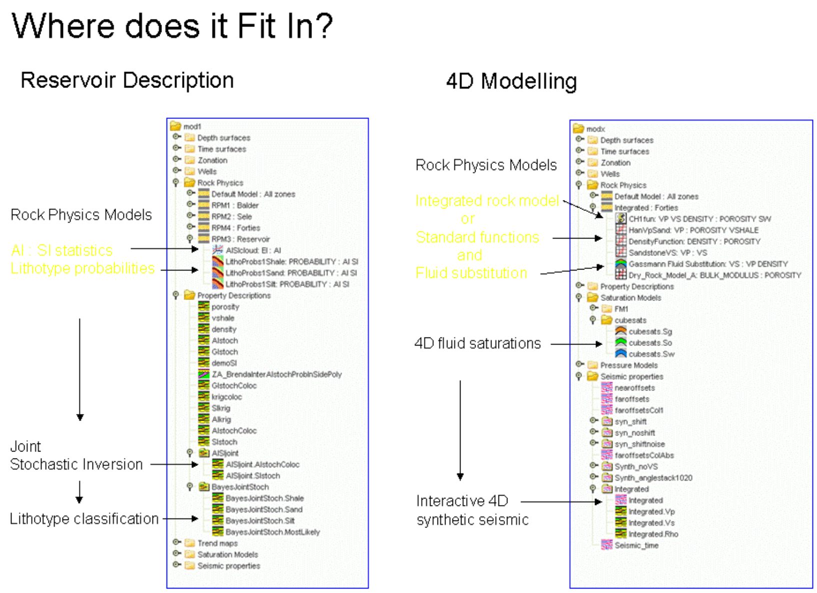
By encapsulating the statistical relationship between AI and SI for major rock-types in the geological model, we can ensure that joint inversion produces results in agreement with Nature, like the plot at lower-left. The modelled AI and SI values are consistent with each other and the reservoir geology, making them more likely to be accurate.

So how do Rock Physics Models come into our 3D and 4D work? Lots of different ways; I'll describe two scenarios.

Where does it Fit In?



In reservoir description, or characterisation, a Rock Physics Model for one formation may contain: a statistical function relating AI and SI, which is used to constrain joint inversion of seismic data; and a set of probability functions for rock types mapped in AI:SI space for Bayesian classification. This will give probabilistic estimates of rock-type throughout the 3D model, based on a combination of acoustic properties which are forced to be consistent.



In 4D seismic modelling, for planning or interpreting time-lapse surveys, a Rock Physics Model, again for one formation, might contain a single integrated rock-model function. This would encapsulate an experience-based model of the acoustic properties of the formation and how they vary with fluid saturation and pressure changes.

Alternatively the Rock Physics Model might contain a set of empirical functions for Vp, Vs and Density and a fluid substitution function, typically Gassmann, constrained by a Dry Rock Model.

Normally our integrated reservoir model will contain a Rock Physics Model for each of its stratigraphic zones, and each one will contain a number of functions whose job is to keep the geology, reservoir properties and acoustic properties consistent.

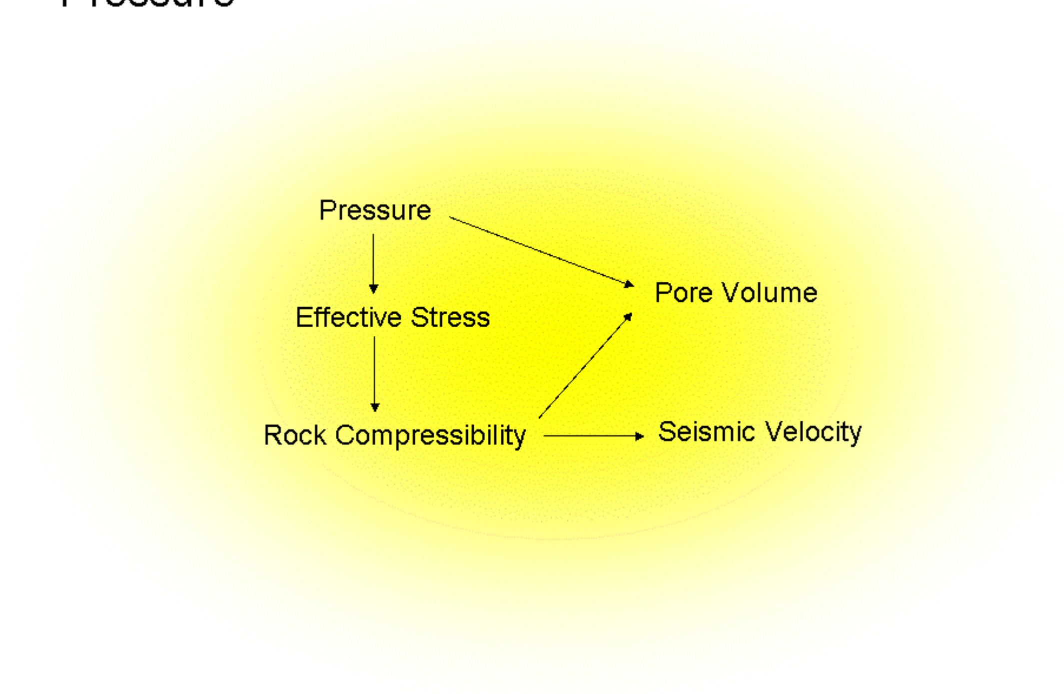
Going Beyond Seismic

Rock Models can tie together

previously independent parameters

But the idea can be expanded beyond seismic geophysics. Here are some other areas where Rock Models can tie together the different model parameters previously determined independently in each subsurface discipline.

Pressure

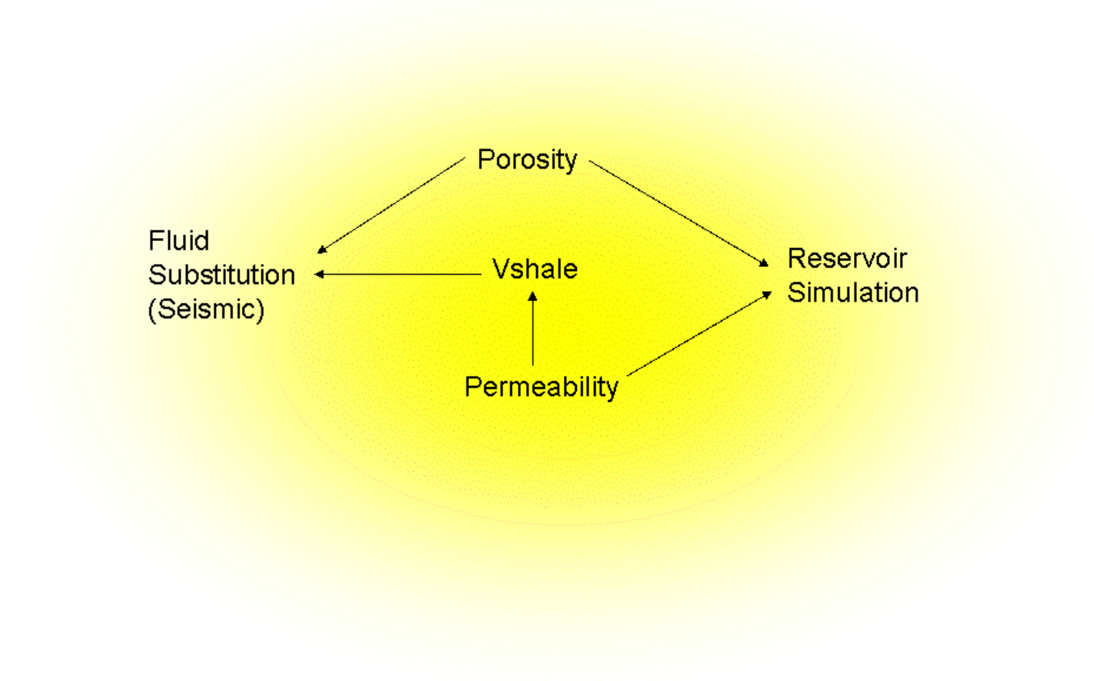


Pressure:

Changing pressure in the reservoir affects pore volume in the reservoir model through the engineering parameter of rock compressibility. This is related to the degree of rock matrix stiffness, which is affected by changing effective stress, due to changing reservoir pressure. Rock matrix stiffness in turn affects the seismic modelling parameters Vp & Vs.

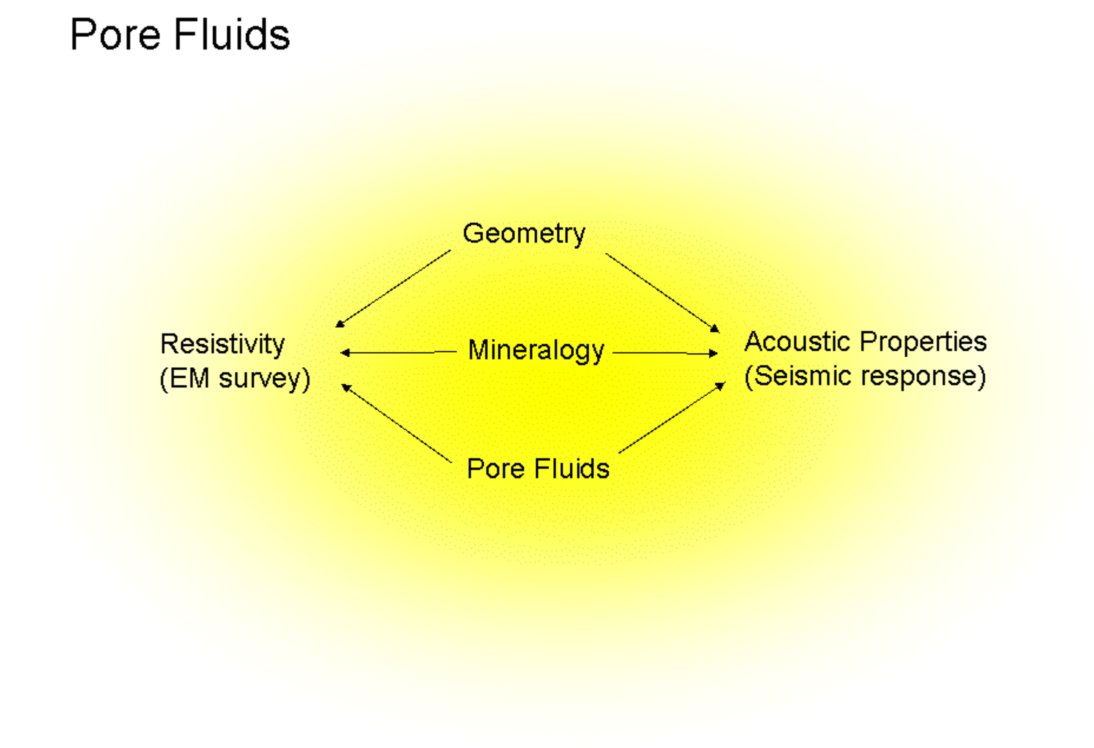
We would like to make the response to pressure changes consistent between models.

Permeability



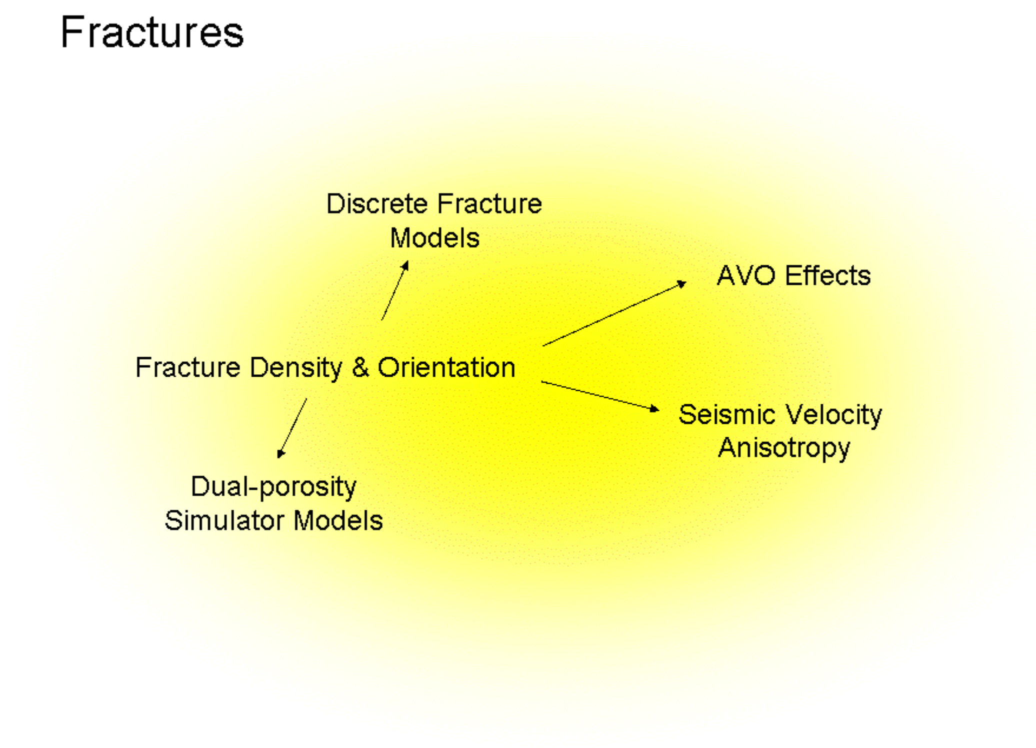
Permeability:

Reservoir permeability and porosity are central to flow simulation; porosity and mineralogy (vshale) are key parameters in seismic modelling with fluid changes; vshale strongly affects permeability. Clearly these properties should be physically consistent in an integrated model.



Pore fluids and Resistivity:

In seismic reservoir characterization there is often an ambiguity between hydrocarbon-bearing reservoir rocks and acoustically similar non-reservoir rocks. Integrating EM techniques brings a chance to resolve this ambiguity, with Rock Models governing the relationships between geology, pore fluids, resistivity and acoustic properties.



Fractured Reservoirs:

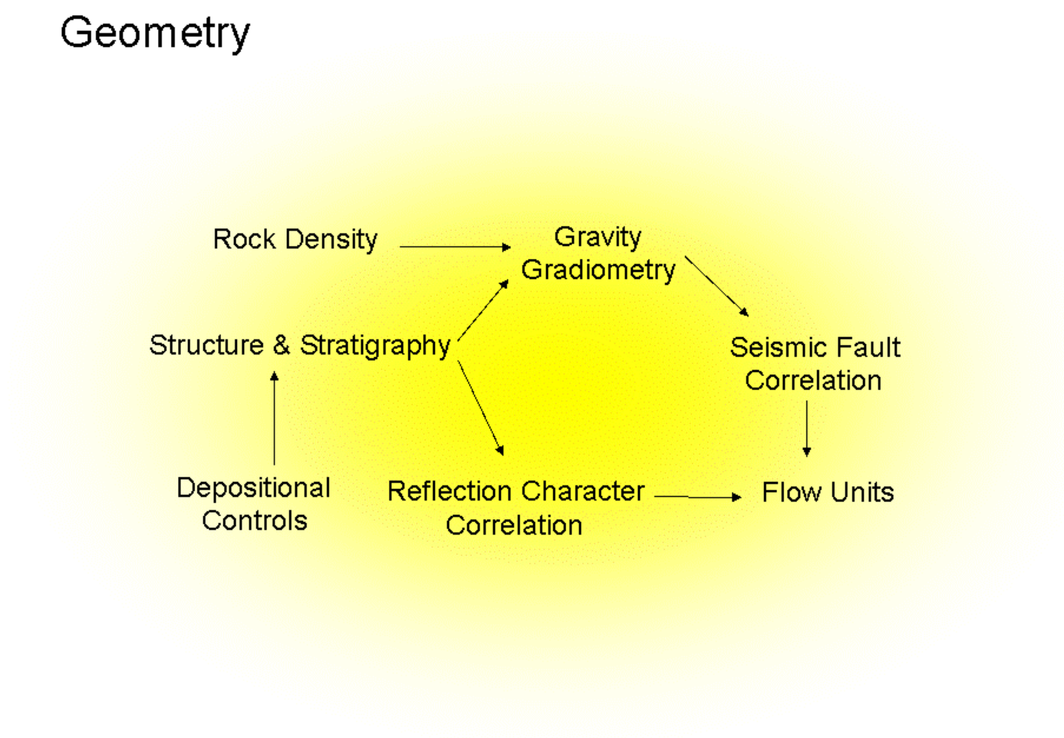
What we know about fractured reservoirs tends to be divided up into quite separate areas of expertise:

reservoir engineers use abstract models with parameters based on an ideal fractured rock;

structural geologists know about stress tensors associated with tectonic regimes (they and rock mechanics specialists can make realistic 3D models of fracture systems);

geophysicists understand empirically the effects of fracturing on seismic velocities and velocity isotropy, but cannot model them very well.

This is an area of great importance for the future, where integration through understanding the rocks should pay large dividends.

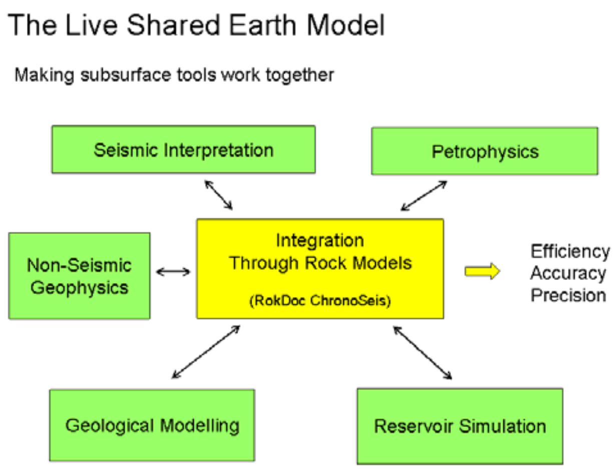


Geometry: often the biggest source of uncertainty

Even with 3D seismic data it is often difficult to delineate complicated fault systems. There is ambiguity between seismic reflection correlation (the stratigraphy of the model) and fault correlation (the structure of the model). One situation in which this can be important is where understanding the fault system is the key to locating depositional sweet-spots in a reservoir formation (where the best NTG is found).

This is where gravity gradiometry may come in. Once the principal faults have been located and a good geological model framework built, we should be able to optimize the model details by integrating sedimentology, structural geology, rock density and acoustic properties (seismic response). This will lead to modelling realistic flow units in more accurate reservoir models.

What does all this mean?



The central point here is that a consistent set of model properties is more likely to be accurate than an unconstrained set, and that the constraints of each subsurface discipline can and should inform the interpretation of data in other disciplines. Rock Models provide the internal connections in a new generation of Shared Earth Models, so that different model properties at the same position in the model are consistent. They are properties of the same piece of rock, not just representative values for that type of rock.

Technology:

I am not proposing a whole new generation of subsurface technology – oil companies and contractors alike have invested heavily in working with existing tools. No, the geological model may continue to live in your favourite geological modelling package; seismic interpretation belongs in an interpretation system, and reservoir simulation models are used in reservoir simulators. Integration – the new deeper integration that defines the new generation of Shared Earth Models – can be mediated by rock-physics-aware software that connects between these familiar tools.

Better integration means supplementing established software tools, not replacing them.

Result:

If our integrated reservoir model is alive – if it will only express physically sensible combinations of properties, then the observations and interpretations of different sciences/disciplines can be integrated to ever better effect. The model can bring into a subsurface study the benefits of experience gained elsewhere: Efficiency; Accuracy; Precision.

Shared Earth Model to Live Earth Model

Integration through Understanding Rocks
can
Multiply the Strength of Subsurface Teams

Final remarks

We are moving from Shared Earth Models to Live Earth Models.

There is a shortage of experienced cross-disciplinary people in our industry.

Subsurface Integration through rock models can bring the Shared Earth Model to life and multiply the strength of subsurface teams, helping to make the best use of scarce resources - which is what our industry needs in volatile times.

It is the job of technology companies, like Ikon Science, to make this happen.

DEG Jan 2009