Sediment Compaction The Achilles' Heel of Basin

From being a tool mainly for the prediction of petroleum maturation, basin modelling has become a fundamental process in almost all aspects of the analysis of petroleum systems.

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Basin modelling is nowadays applied to the study of sedimentary basins at all scales, from the initiation of the basin and its development until thermal and isostatic equilibrium is reached, through the analysis of reservoir and source rock distribution, identification and evaluation of traps, maturation, migration and filling of the reservoir, and finally, to hydrocarbon distribution in the basin. The concepts of basin modelling also frequently provide a background for reservoir evaluation and production planning.

1978: Starting point

The basic principles of basin modelling were established in a famous paper by Dan McKenzie, entitled "Some remarks on the development of sedimentary basins". Published in Earth and Planetary Science Letters in 1978, this paper has become one of the most cited in geosciences of all times. Based on the concepts established by McKenzie, and supported by the explosion in computer capacity and imaging systems, techniques of basin modelling have undergone tremendous developments, leading to the fully integrated four-dimensional modelling of sedimentary basins that is available in the study of petroleum systems today.

This has increased our need to understand profound geological processes even more and also enhanced our ability to quantify such processes, and to translate their dynamics into a mathematical language.

It would appear that these developments have happened not least due to our emerging ability to integrate the many disciplines that are necessary to perform modern basin analysis and modelling. The concept of basin modelling forces geochemists, geophysicists, reservoir engineers, sedimentologists, stratigraphers and structural geologists to work closely together with physicists, mathematicians and modellers within the same projects and scientific framework, and to publish their results together. These are disciplines that have long lived separate lives and always used to publish in separate journals.

Introducing Compaction

However, one important element in the study of basin development may seem to have gained less attention than it deserves. Reading McKenzie's paper, it is obvious that sediment compaction is an important primary factor in understanding the internal geometry of a developing basin, particularly because it changes the physical properties of sediments during burial. This in turn affects the geophysical response of the sediments, and hence influences the geophysical imaging of the compacting beds. Perhaps even more importantly, it influences physical rock properties like mechanical strength and capacity for heat conductivity.

In a study in 1980, Sclater & Christie addressed the problem of compaction by producing porosity-depth trends for several lithologies. Since then, understanding of the processes behind these curves seems to have only marginally improved, even though compaction data is now available from a great number of basins **(Figure 1a).**

Thus it would appear that little has been done to study the details and the relationships between the mechanisms that predominate at different depths and in various lithologies. In particular, compaction processes in mudstones have been little focussed upon.

The compaction processes of sediments are complex, particularly because the relationship between processes alters during burial as a result of changes in differential stress, water pressure and temperature. The interplay between these relations becomes even more complex when burial occurs at changing rates. In many cases, burial may even be interrupted by episodes of uplift. This means that it is important

Modelling

to identify the difference between *mechanical* and *chemical compaction.*

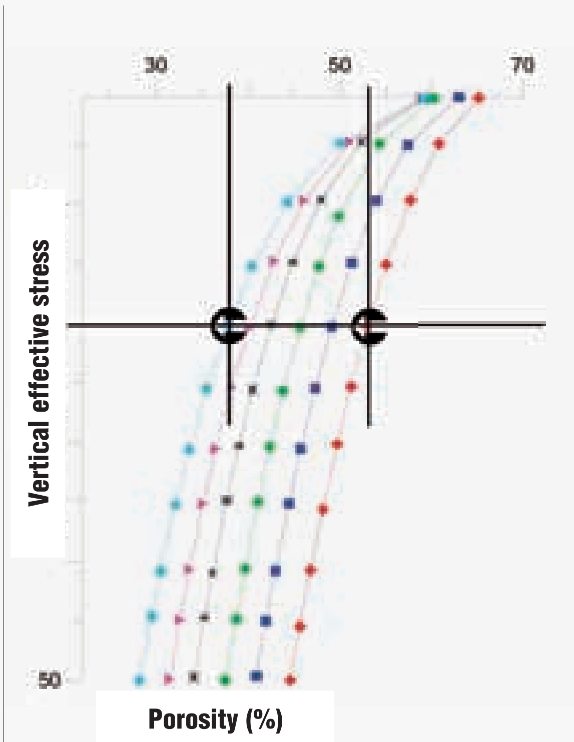
The very nature of the sediments, which can vary from completely unconsolidated to rock with a high shear strength, also demands that principles from both soil mechanics and rock mechanics must be applied in the mechanical analysis.

Establishing Trends

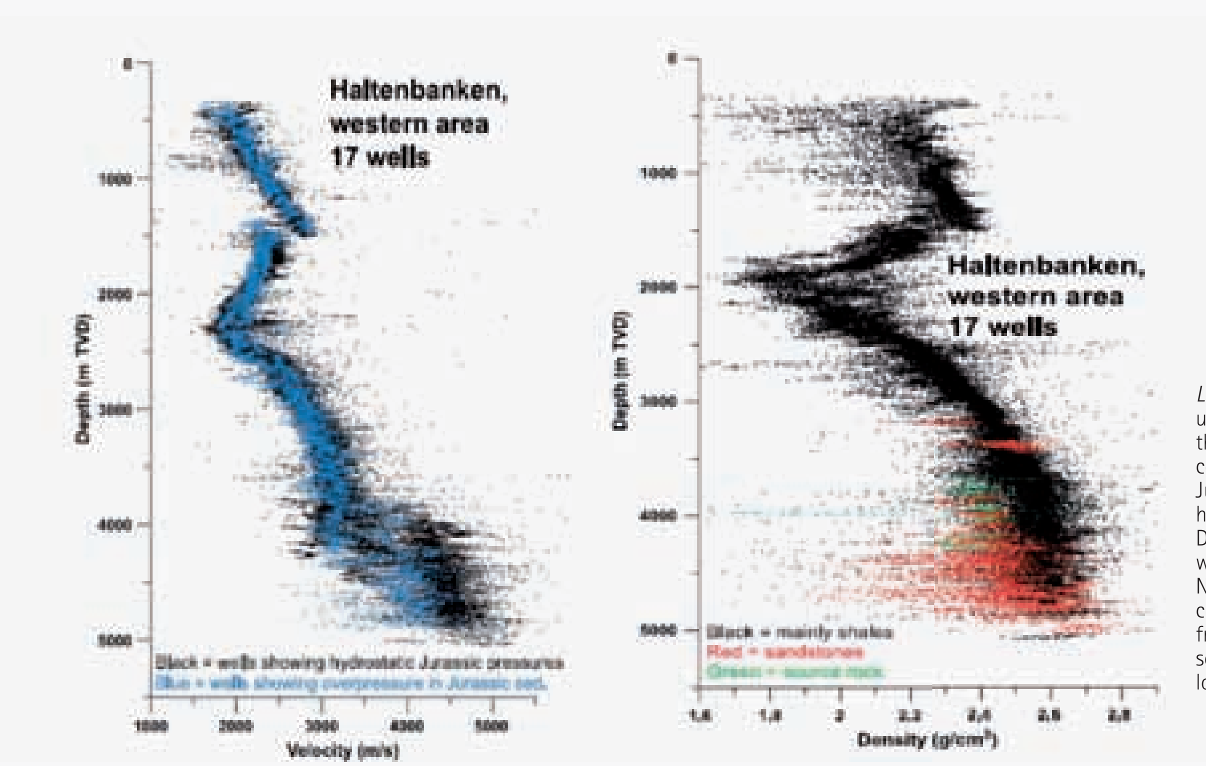
The problems of sediment compaction have recently been tackled by a research group lead by professor Knut Bjørlykke at the University of Oslo. Combining data from the Norwegian Continental Shelf with experimental results, and focussing particularly on the effects of burial in clays and mudstones, their results have recently been published or are in press in AAPG Bulletin and Petroleum Geoscience.

These results demonstrate that the physical properties of very fine-grained sediments as a function of depth of burial deviate a great deal from the smooth curves that are commonly used as prompts in basin modelling tools, reflecting the interplay between mechanical and chemical compaction. Bulk physical rock properties like porosity, permeability, density and seismic velocity vary depending on the clay content, dominant diagentic processes at different depths and clay mineralogy. Interestingly, but not surprisingly, the difference in grain size between coarser-grained sand, fine-grained sediment and silt cause great variance in the compaction pattern.

In basins of normal geothermal gradients, mechanical compaction (grain crushing) dominates down to depths of 2 – 2.5 km, whereas chemical compaction takes over at greater depths.



Experiments demonstrating the effects of clay mineral composition on mechanical compaction.

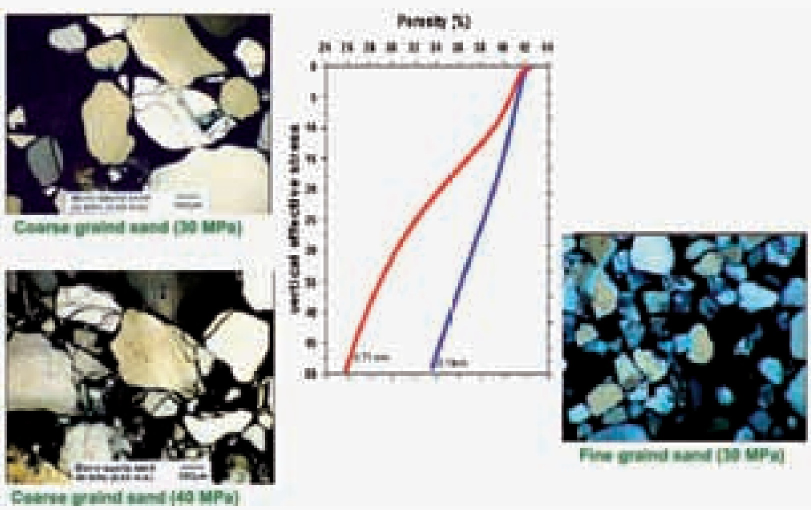


Left: Velocity-depth measurements for 17 wells in the Norwegian Sea. Wells containing overpressured Jurassic sediments are highlighted in blue. *Right:* Density measurements with depths from the Norwegian Sea. Different colours separate shales from sandstones and the source rock in this geological province.

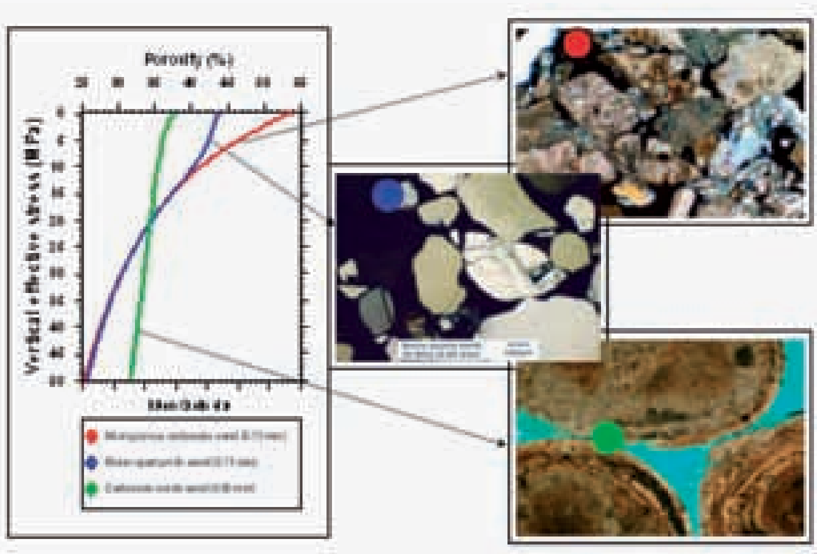
This shift in compaction mechanisms at depth is due to diagenetic stabilisation (precipitation of quartz cement) so that continued volume reduction depends on the interplay between dissolution and precipitation of diagenetic minerals. This implies that for silica-rich sediments, chemical stability, which is temperature-dependent, is more important for changes in physical rock properties than diffe rential stress at such depths.

The research group in Oslo and its partners from the Universities of Stanford and Bergen, Colorado School of Mines and the Norwegian Geotechnical Institute have recently won support from the Norwegian Research Council to continue and broaden their studies. Having started their compaction experiments with the study of loose sand, they now also include experimental studies of carbonate compaction. They will continue the integration of several disciplines of research and will focus even more strongly on establishing a better rock physics database to be correlated with geophysical parameters. The rock physics anisotropy database will be utilised to derive rock properties from geophysical data, to enhance confidence in P and S wave analysis methods and to improve seismic imaging.

Porosity loss in sands due to experimental mechanical compaction. Coarse-grained sand is more easily compacted than fine-grained sand.



Experimental compaction of quartz sand, ooids and skeletal carbonate sand. Quartz grains compact by grain fracturing while ooids are less compressible because they are less likely to fracture. From Chuhan et al and Bjørlykke et al.response in in sediments will be mostly mechanical compaction. Gravitational stress may however be important. From Bjørlykke 2006



A Useful Tool

Several very interesting aspects can be foreseen in the continuation of these studies.

In exploration, the inclusion of better models for sediment compaction in basin modelling will improve reconstructions of the geometry of basin development. This may influence models for basin floor geometry and gradients within basins. Hence, sand (reservoir) distributions, hydrocarbon maturation studies and the evaluation of migration histories should be able to be determined in a more realistic way.

When it comes to reservoir studies, more exact predictions of physical rock parameters (particularly permeability and porosity) may be of help in reservoir characterisation and in the development of drilling and production strategies.

Finally, better correlation between depth of burial, physical rock parameters like density and seismic velocity, seismic wave analysis and seismic imaging will be useful in exploration, reservoir characterisation and production.

We will follow future reports from this compaction and rock physics study at the University of Oslo with great interest.

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