Fractured Reservoirs

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Fractured Reservoirs

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Preface

Fractured reservoirs contain an important and ever increasing proportion of the world's hydrocarbon reserves. This is largely because of the huge volume of remaining reserves concentrated in the Middle East, including reservoirs dominated by fracture flow. The current increasing global gas demand has meant that fractured reservoirs have found an increasingly significant role as a global energy source outwith the Middle East, in tight gas basins of North and South America and areas of emerging gas production in North Africa. Many fractured reservoirs have relatively low recovery factors, typically around 20% or lower (compared with ~50% for sandstone reservoirs in the North Sea for example). Thus, even a small improvement in recovery factor would result in a large increase in oil and gas production.

Fractured reservoirs are generally considered to be reservoirs in which fractures provide permeability and the rock matrix tends to provide the main storage capacity and/or those in which fractures significantly enhance the permeability of a reservoir that already has good matrix porosity and permeability. In parts of some fields, or more rarely even entire fields (such as those in crystalline rocks), fractures can provide both the essential storage and permeability where the matrix has little porosity and permeability. In general fractured reservoirs are rarely of one simple type and may exhibit a range of behaviours within different layers or different geographic sectors of the same field.

The characterization and modelling of fractured reservoirs is widely recognized as challenging to geoscientists and engineers alike. A key issue in these reservoirs is the transfer mechanism of the hydrocarbons from the rock matrix to the fracture. This mechanism is often poorly constrained and requires careful choice of simulation methods to capture the range of flow physics in the complex system. The geological problem most often cited in the context of the development and exploitation of fractured reservoirs is the difficulty in defining the geometry of the fractures that impact the flow, especially when a significant component of the fractured network is beneath the imaging resolution of standard three-dimensional reflection seismic techniques. Fractured reservoirs have a wide range of production characteristics. Generally rates of production from wells vary across the field, with many wells experiencing rapid decline following initially high flow rates. In such situations only a few wells dominate production and many production wells may experience early water breakthrough. In these cases the early recognition and prediction of the role of fractures is important. Some clues may come from drilling (such as mud loss events and gas kicks), flow data (such as pressure build-up tests, spinner logs) and well data (such as image logs and core). A major aim in fractured reservoirs is to find ways of recognizing fractures at the appraisal stage and some success has been obtained from analysis of seismic attributes based on amplitude, velocity and shear wave birefringence, which display a strong directional response.

Another major characteristic of fractured reservoirs is their unpredictable and often extreme behaviour. Management of these fields requires clear and careful definition of the full range of uncertainties. It is important to quantify the uncertainties associated with a development plan, and base the economics on this range, rather than to have one "predictive" model that might immediately be disproved by the next well that is drilled. Defining and quantifying the uncertainty associated with fractured reservoir management is an area of much current interest within industry that will continue to grow in importance and sophistication. A number of the case studies in the final section of this volume address ways of assessing uncertainty associated with fracture geometry and connectivity, and how that uncertainty can be incorporated into reservoir simulations of the field. The solution to challenges we briefly mention here must involve the close interaction of subsurface geoscientists and engineers and the integration of their diverse datasets and technologies.

This volume arose from a Petroleum Group meeting of the same title held at the Geological Society, London in November 2004, where the intention of the convenors was to provide a forum at which the range of views and experiences of geoscientists and engineers who manage fractured reservoirs and/or work on fractured rock could be presented and discussed. Two of the recurring themes of the conference were, firstly, the necessity to get the best understanding possible of the fracture network and its impact on the fluid flow in fractured reservoirs using a range of data types, covering all scales available (e.g. seismic, well-logs, image logs, core, outcrop analogues, drilling and production data) and, secondly, the integration of technologies and work flows across the geoscience and engineering disciplines. The 17 papers that comprise this volume mainly focus on addressing the first of these themes. However the second theme features in a number of the reservoir case studies presented in the final section of the volume where production and drilling data are integrated into reservoir models and reservoir management issues are discussed.

Outcrop studies of appropriate reservoir analogues provide important insights into the distribution and role of fractures in reservoirs. The four papers in the first section focus on studies of this type, two of which are related directly to important subsurface Iranian reservoirs and document the fracture systems that formed in carbonates during the development of thrust-related folds in the Zagros Mountains (**Wennberg *et al.* & Stephenson *et al.***). Both of these papers highlight the importance of 'mechanical' stratigraphy in controlling the development of the fracture systems described. A paper in the final section of the volume (**de Keijzer *et al.***) demonstrates how detailed outcrop data can be used to constrain the fracture model developed for a subsurface reservoir in the same formation, in this case the lower Cretaceous Natih Formation limestone reservoir of Oman. The other two papers in this section provide detailed studies of fracturing related to normal faulting (**Rotevatn *et al.***) and the impact of flow on a single fault zone (**Woodcock *et al.***).

The papers in the second section present geophysical techniques that aid in fracture detection and imaging in the subsurface. **Worthington & Lubbe** report a variety of field and laboratory estimates of fracture compliance, the parameter that controls the seismic visibility of fractures (including faults). **Emsley *et al.*** present a case-study of a fractured carbonate reservoir where VSP processing techniques were used to bridge the scale-gap between image log data and variable quality reflection seismic data. The final paper in this section (**Pettitt & King**) describes a set of experiments that measured acoustic emissions during fracturing in a polyaxial test system, that allowed the distribution, orientation and type of fracturing to be calculated during crack growth in the low-permeability sandstones used for the test.

The next section comprises papers on numerical and analogue modelling techniques. The first of these by **Olson *et al.*** describes the modification of flow within modelled fracture networks when diagenesis (e.g. quartz cementation) is incorporated into the geomechanical models. When smaller aperture fracture segments are preferentially cemented, flow connectivity is significantly reduced in the network. **Leckenby *et al.*** report the results of a series of numerical experiments that investigated the effect of anisotropic fracture geometries on transient pressure derivatives (simulating well test data) for single phase flow. They conclude that to detect anisotropic fracture geometries from well-test data long draw-down/build-up times are required. **Dee *et al.*** use geomechanical modelling based on elastic dislocation theory to predict the distribution of small-scale faults from a knowledge of the geometry and slip distribution on large faults imaged in three-dimensional reflection seismic datasets. They apply their methodology to two reservoirs in extensional fault blocks (North Sea and Tunisia) and a reservoir in a thrust anticline in Venezuela. The last paper in this section by **Bazalgette & Petit** discusses the use of analogue models to evaluate fracture development during the growth of multi-layer folds.

The final section comprises six reservoir case studies drawn from a variety of geographic locations, including the Middle East, the North Sea and North America. **Casabianca *et al.*** describe the data and uncertainty assessments used by the team developing the Machar oil field (a fractured chalk reservoir above a salt diapir in the UK North Sea) to review their development and field management plans when reservoir performance was unexpectedly affected by a fast rise in water production. **Rogers *et al.*** investigate the uncertainties in the controls and location of the main flow conduits in the Valhall chalk field in the Norwegian North Sea for a planned water flood project, by conducting a series of simulations of a range of possible conceptual fracture models with a discrete fracture network model calibrated to well tests. **Barr *et al.*** describe the facture analysis and modelling used in preparation for the initial development phase (early 2005) of the Clair oil field in a fractured sandstone reservoir on the UK continental shelf, West of Shetland. The study incorporated outcrop data, fracture data from wells and seismic data (including azimuthal velocity information from a four component three-dimensional seismic survey) to build a series of fracture-matrix flow modes used in the reservoir simulator. The next study, of a Palaeozoic clastic reservoir in Oman by **Ozkaya & Minton** shows how borehole image data, open-hole logs and dynamic data can be used to define a water breakthrough risk map where individual fluid-conductive faults or large fractures cannot be identified with certainty. The final paper in this section (**Rawnsley *et al.***) investigated the extremely variable well performance in the Waterton carbonate gas reservoirs in anticline structures within an imbricate thrust stack, in the Canadian Rocky Mountain foothills. Geophysical, structural, stress, matrix and dynamic datasets were reinterpreted and used to build flow simulations of sectors of the West Carbondale field. Aside from one zone of enhanced flow attributed to a major seismic-scale fault, the fracture system was not found to contribute significantly to the observed flow in the wells.

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