PERGAMON

Journal of Structural Geology 21 (1999) 1495–1496

JOURNAL OF STRUCTURAL GEOLOGY

www.elsevier.nl/locate/jstrugeo

Book Review

The study of brittle fault zones and fluid flow in hydrocarbon reservoirs makes it into late childhood!

***Faulting, Fault Sealing, and Fluid Flow in Hydrocarbon Reservoirs*, Jones, G., Fisher, Q.J., and Knipe, R.J. (Eds). Geological Society, London, Special Publication No. 147, 319 pp. List price US$125.**

Fluid flow in brittle fault zones has been a topic of increasing interest over the last two decades and the last several years have witnessed the burgeoning efforts of many researchers in trying to better predict fault-related fluid flow in hydrocarbon, geothermal, and groundwater reservoirs. Special Publication 147 represents a big step from what the editors refer to as the 'infancy' of the study of faults and fluid flow in hydrocarbon reservoirs into late childhood or perhaps adolescence. The book comprises 20 individual papers of generally high quality and is an outgrowth of an international meeting held at the University of Leeds, U.K. in 1996. The meeting was sponsored by the editors at the Rock Deformation Research Group at Leeds in conjunction with the Petroleum and Tectonics Group of the Geological Society of London.

The publication of this book reflects the need for a quantitative and predictive understanding of how fault zones influence the rates and patterns of fluid flow in the Earth's upper crust. Predicting fault-related fluid flow is hampered by our limited ability to view and sample the wide range of fault zones found in the subsurface. It is particularly difficult to measure their in situ properties at meaningful scales, and observe, sample and measure extensive parts of fault zone analogs in outcrop. The specific aim of this collection of papers is to present recent work that addresses some of the fundamental questions pertinent to the oil industry. These concerns include: how fault zones are related to hydrocarbon migration and trapping; how to identify their three-dimensional geometries from seismic data; the range of hydrocarbon column heights they may support; how they may compartmentalize and form complex flow paths in reservoirs; and how to most efficiently plan and facilitate the exploration and production of hydrocarbons from previously untapped sources. For example, many of the papers address how one might go through the steps of fault zone identification in 3D seismic data and then develop and parameterize predictive models for reservoir fluid flow management. Overall the compendium does an excellent job of making significant steps in answering the types of general questions posed and certainly provides a wealth of very interesting reading for a broad audience. Many of the papers can also be viewed as frameworks for developing methodologies to answer specific fault-related fluid flow problems. Although the book focuses on problems involving hydrocarbons, much of the work has significance with regard to the myriad of other fault-related fluid flow problems with respect to groundwater, solute transport, mineral deposition, geothermal energy, faulting and earthquake mechanics and associated hazards.

The papers are loosely divided into topical groups that give readers a view of how different authors approach fault-related fluid flow problems. The book starts with an introductory paper that sets out the major problems at hand, outlines many of the topics to come later in the book, and presents a view of the state of the art. Later sections discuss fault zone mapping, geometry, and evolution; faulting processes and fault seal characterization; experimental and numerical modeling of deformation and fluid flow; and the structure and fault seal analysis of hydrocarbon fields. There is also an important contribution in the introduction that deals with recognition of fault-related damage zones as distinct permeability structures. Damage zones are rather poorly understood in terms of how they form, particularly in a predictive manner, and how they contribute to a fault-related fluid flow field.

In the section on fault zone mapping, geometry, and evolution problems related to imaging fault zones from seismic data are dealt with using both conceptual and practical approaches. For example, several papers discuss how to identify and determine the influence that 'subseismic' fault zones (fault zones that generally have approximately 10–15 m of displacement) might have on reservoir scale flow systems. A thorough exposé on the use and limitations of seismic attribute mapping and possible links between outcrop analog studies and

0191-8141/99/$ - see front matter
PII: S0191-8141(99)00129-7

seismic attribute analyses is presented. This approach helps to constrain conceptual models that might be employed when interpreting seismic data. The results of physical modeling and X-ray tomography of progressive deformation in the models are presented at the end of this section. Tying this unique view of a deformed volume together with interpreted fault zone geometry from seismic data gives a scaled experimental basis for associating the growth of natural faults with resulting geometries.

The third section of the book deals with fault zone permeability structures, particularly with regard to fault zones as barriers to flow (fault seals), and the geological processes that form them. The types of fault seals are defined and organized into a series of convenient tables and descriptions that are linked directly or indirectly with permeability characteristics, how they might be expressed in various types of borehole images and logs, and what their lithologic characteristics are from outcrop, to borehole, to thin section scales. An important contribution is also found in this section regarding fault zones in carbonate rocks and the role that pressure solution seams have in the overall permeability structure of carbonate hosted fault zones. In general, much attention has been paid to brittle fault zones in siliciclastic rocks while other rock types, and the kinds of fault-related permeability structures that form in them, have been neglected. Other important contributions are made in this section regarding fault zone sealing processes other than the 'smearing' of clay. The fault sealing agents of comminution, fluid interaction, and precipitation of siliciclastic materials are addressed. One drawback of this section, and the book as a whole, is that the role of fault zones as conduits is only touched on, and more importantly that fault zones are often combined conduit-barriers, is largely ignored. Two experimental papers address the efficacy of clays acting as membrane seals and the range of measured permeability anisotropy in natural, clay-rich fault gouge. As well, important contributions in the third section include experimental results of multiphase fluid and gas flow in fault rocks at confining pressures and the impact of tectonic stresses on permeability and sonic velocities. Numerical modeling papers do an excellent job of going from outcrop to simulation in attempting to characterize the impacts of open and closed fracture networks from the well scale to the reservoir scale. Other modeling papers look at the growth of brittle fault zones and the perturbed stress fields around them, the impact of fault zones on fluid flow and heat transport at the basin scale, the impact of deformation-related compaction on scaling laws for fault permeability, and the mathematical treatment of determining hydraulic conductivity in rocks where only limited data are available. Again, the papers in this section offer an important reality check and various parameter constraints in terms of developing geologically realistic, predictive conceptual and numerical models for faulted and fractured reservoirs in the subsurface.

The final section of the book deals with practical issues related to integrating different types of data and developing better predictive reservoir scale models. This section also highlights the importance of scales of observation, measurement, and sampling of different types of data when constructing predictive models. The final papers are excellent examples of the integrated use of multiple types of data such as borehole logs, results from juxtaposition modeling, lithological analyses of recovered core, fracture network data, and production data to construct and calibrate reservoir models at specific, structurally complex field sites. These papers highlight the need for this type of approach because of the highly variable nature and scale of the in situ properties of fault zones.

The book is very good value for money with a high quality hard cover, generally excellent figures, many in color, and an index. It would certainly be an appropriate addition to any library, academic department or other institution. The book reads well and provides fertile ground for new ideas for those engaged in the technical and practical pursuits of finding and producing hydrocarbons as the individual papers show various tactics for dealing with fault zones from borehole and field data to reservoir simulation. The book is also an excellent learning tool for upper division undergraduate and graduate studies in petroleum geology, advanced structural geology, and seminars that deal with fluid flow in the upper crust. Some of the papers in the book are, however, somewhat limited in their scope as a resource for additional references. Many of the papers do not draw upon the rather large body of fault-related fluid flow literature that is marginal to the hydrocarbon context but bears heavily upon the general problem. The papers also tend to focus on normal fault zones. While this is logical in one sense, it highlights the need for continued work in other types of brittle fault zones, in different rock types with various geological histories where learnings from one environment might likely be applied to others in the future. All told, the book holds something for everyone interested fault-related fluid flow in hydrocarbon reservoirs and represents a single volume that may act as a spring board into the next generation of solutions to a set of interesting and challenging problems.

Jonathan Saul Caine
Salt Lake City, Utah USA