begins with a discussion on the application and limitations of cross-section validation techniques to hydrocarbon exploration and production. Guidelines on how to plan a cross-section validation project, and what datasets to include in such a project, are described. A similar contribution, as a case history, describes a strategy for the restoration of inverted basins.

It is encouraging that many of the contributors in this chapter have paid careful attention to the limitations as well as to the benefits of cross-section validation techniques. One of the main themes running through many of the articles is the intended use of the restored cross-section. The main uses fall into two broad categories, namely, to validate cross-sections by evaluating, and possibly modifying, the structural interpretation and/or to determine and illustrate the (most likely) geometric evolution. The common approach to a section that does not balance would be to change the interpretation and/or restoration algorithm to make the section balance. One point to emerge from this chapter is that in areas of complex geology, or where there is heterogeneous stretching or shear, conventional 2D section restoration may not actually be a suitable technique if the intended use is to modify the structural or seismic interpretation.

The main limitation with conventional cross-section restoration is that restoration is a 2D process that assumes plane strain deformation (that is, there is no movement into or out of the plane of cross-section). This assumption is robust as long as the section is in the direction of material transport and that ductile strain is homogeneous. Examples in Chapter 2 illustrate situations where the 2D plane strain assumption may be invalid (e.g. in areas that have undergone inversion or where there is complex salt tectonics). In such structurally complex areas, the 2D restoration technique may only be useful for identifying grossly invalid interpretations or to determine and illustrate the most likely geometric and kinematic evolution. One conclusion to be drawn from these studies, as pointed out by some of the authors, is that there is an urgent need for 3D restoration techniques in areas of complex structural geometries. Detailed research to characterise and understand the 3D kinematic analysis and evolution of complex areas is required in order to develop 3D restoration techniques. Bearing this in mind, I was a little disappointed to find that there were only three contributions to Chapter 3, *Fault Populations and Kinematic Analyses*. Understanding the 3D kinematic evolution of fault systems is a key part to unravelling the structural evolution of an area. Kinematic analyses can establish whether an individual fault has developed as an isolated structure or has formed by the linkage of segments or by the breaching of relay structures. This chapter provides some excellent examples, based on field observations and seismic interpretations, which underline the importance of understanding the kinematic evolution of fault systems. Unravelling the 3D kinematic evolution of faults depends upon understanding the likely cause(s) of displacement variations on fault surfaces. The authors in this Chapter (and some in Chapter 1) illustrate that displacement analysis techniques is an alternative structural analysis method for testing the validity of 3D fault geometries.

Chapters 4 and 5 deal with analogue and mathematical modelling of geological structures, respectively. The first contribution in Chapter 4 describes the recent advances and limitations of scaled physical models, whilst the second describes sandbox models of thrust tectonics with multiple detachment levels. The mathematical models presented in Chapter 5 range from the finite-element modelling of shear bands to the modelling of localised deformation during crustal extension. Chapter 6, *Regional Analysis and Remote Sensing*, contains two regional studies that demonstrate the added value of integrating techniques to obtain a detailed stratigraphic and structural interpretation of an area.

Finally, a note on the presentation of this volume. I was a little disappointed by the quality of reproduction of some of the diagrams. Detail in some of the seismic cross-sections and contour diagrams is almost totally obscured by an extremely high level of contrast. This is unfortunate not only because the diagrams illustrate key points described in the text but also because the rest of this volume is produced to a very high standard (not withstanding the fact that the publication number on the spine is different to that on the front cover). I understand from the publishers that this volume will be reprinted and that all diagrams will be reproduced. Despite these minor shortcomings, I am certain that this Special Publication will be regarded as a valuable source of techniques for structural interpretation and validation of fault geometries. I can certainly recommend this volume as an essential, and indeed, a worthwhile purchase, for academic and industry structural geologists alike.

*Hundleby, Lincs, U.K.* *P. G. Bretan*

## Something in the basement?

Richard W. Ojakangas, Albert B. Dickas and John C. Green (editors) 1995. *Basement Tectonics 10: Proceedings of the Tenth International Conference on Basement Tectonics held in Duluth, Minnesota, USA, August 1992.* Kluwer Academic Publishers, Netherlands. Price: £135.00 (hardback).

Deformed continental lithosphere is characterised by a broad and diffuse regions in which fault—and shear-zone—bounded blocks partition strains into a series of complex displacements, internal strains and rotations in response to far-field plate tectonic stresses. This behaviour reflects the weakness of continental lithosphere and also important lateral strength variations that occur due to the presence of pre-existing structures in the continental crust such as old faults and shear zones. These long-lived zones of weakness tend repeatedly to reactivate, accommodating successive crustal strains, often in preference to the formation of new zones of displacement. This architecture of inheritance is very long lived since buoyant continental crust is not normally subducted. Basement tectonics is important to a wide range of Earth Scientists because reactivation of pre-existing structures is known to strongly influence the form and location of mountain belts, sedimentary basins, intraplate seismicity, mineralisation sites, fluid/magma migration pathways and shallow groundwater movements.

This book is one of a continuing series of volumes composing papers and abstracts arising from international meetings that are held every few years in the USA and other countries. The conferences aim to bring together Earth Scientists from several disciplines to present work under the general basement theme. In his useful introduction, Patrick Barosh points out that the history of basement tectonics is closely linked to the recognition of 'lineaments'. An appreciation of these linear features arose from the classic work of Hobbs (1901, 1904) who was undoubtedly influenced by earlier studies by Kjerulf, Daubree and, inevitably, Charles Lapworth. As with plate tectonics, the increasing recognition of basement lineaments during the rest of the twentieth century arose from the application of increasingly improved topographic, geological, geophysical and, most recently, satellite mapping methods. Yet many of us still see the whole lineament analysis as unscientific and vague, akin to some kind of glorified reading of the tea-leaves, looking for patterns where none exist. However, our improved understanding of both continental tectonics and the growth of fracture populations in rocks at different scales suggest that these views need changing.

The book is subdivided into four sections: Part I. Rifting—Midcontinent Rifts; Part II. Basement Control on Younger Structures; Part III. Shear Zones; and Part IV. Abstracts. The Contents list 39 papers and 16 abstracts, with topics understandably somewhat biased towards studies in North America given the conference location and list of participants, but work from other regions including Scandinavia, Africa, South America, Asia and Europe is also included. A broad range of geological and geophysical disciplines is represented, including structural geology, stratigraphy, hydrocarbon geology, geochemistry, aeromagnetic studies, seismic profiling and economic geology. It all sounds great, but the end result is a bit of a disappointment. There are two main reasons for this: (i) Too many 'papers' are little more than extended abstracts covering two or three pages without any accompanying diagrams to help locate the reader. (ii) Too many papers are much too focused on their study material, often presenting a rather parochial view. As a result, the general reader will gain less information about basement tectonic processes than they might reasonably expect from such a book. As a newcomer to the region, I found the first part of the volume concerning the North American midcontinent rifts of Proterozoic age to be quite informative and interesting. Elsewhere, there are useful reviews of North American basement tectonic fabrics (Baars *et al.*), together with stimulating papers on recurrent faulting in Montana (Nelson) and reactivated transpressional shear zones in the Superior Province (Hudleston & Bauer). Although the editing is generally satisfactory, I found that some papers could have done with a good deal of pruning. Conversely, some abstracts are tantalisingly interesting—what a pity they never appeared as full papers! Reproduction of diagrams and maps is generally good, but too many papers lack sufficient diagrams.

All in all, then, this volume presents a somewhat unfocused collection of works that will probably only appeal to hard-core aficionados of things in the basement like myself. The utterly outrageous price is likely to put this book well out of the reach of most workers and, in these days of tight library budgets, I cannot recommend immediate purchase. A pity.

**REFERENCES**

Hobbs, W. H. 1901. The river system of Connecticut. *J. Geol.*, **10**, 469–484.

Hobbs, W. H. 1904. Lineaments of the Atlantic border region. *Bull. Geol. Soc. Am.*, **15**, 483–506.

*Durham, U.K.* *Bob Holdsworth*

## Pinch of salt

Alsop, G. I., Blundell, D. J. and Davison, I. (editors) 1996. *Salt Tectonics*. Geol. Soc. Spec. Publ. **100**, 310 pp. Price: £66 (£22 for members of the Geological Society).

Special Publication No. 100 of the Geological Society of London is devoted to salt tectonics which has received some attention over the past decade, e.g. special volumes in Tectonophysics (v. 228, 1993) and Marine and Petroleum Geology (v. 9, 1992), by the Geological Society of America (Memoir 177, 1990) and by the AAPG (Memoir 65, 1996). The book is a selection of papers presented at a meeting of the Petroleum and Tectonics Group of the Geological Society on 14–15th September 1994. It consists of 5 parts: (1) An introduction to salt tectonics; (2) 7 papers on outcrop, mine and borehole studies; (3) 5 papers on regional case studies; (4) 5 papers on physical modelling; and (5) 3 papers on numerical and geophysical modelling.

Part 1, *Salt tectonics: some aspects of deformation mechanics*, is an introduction to the complex nature of salt tectonics and summarizes highlights of the papers presented in this volume combined with a selection of papers from the literature.

Papers in Part 2, *Outcrop, mine and borehole studies*, give detailed descriptions of the internal structure and kinematics of mobilized salt and surrounding host rocks. Burliga describes the internal structure and kinematics of the Klodawa salt diapir in Central Poland which is characterized by heterogeneous strain distribution and complex folding in alternations of competent (dolomite, anhydrite and shale) and incompetent layers (salt and potash rocks). Davison *et al.* studied salt diapirs and their host rocks in North-West Yemen. They give a detailed description of the uplift and deformation of surrounding sediments, show proof of an ancient namakier (salt glacier) and currently active diapirism. On p. 33 they show a very scenic picture of the village of Jabal al Milh with a large herd of camels and a normal-faulted mosque. Frumkin uses the age and elevation of a cave (stream) channel in the Sedom Diapir located in the Dead Sea Basin, to determine diapiric rise during the Holocene. He found that the average uplift rate is around 3.5 mm per year but with short periods of accelerated uplift of 4 to 18 mm a year. Major, long term changes in uplift rates seem to occur every 1000–1500 years. Hoyos *et al.* describe an interesting mechanism for initiation of evaporite diapirs in two continental Neogene basins in Central Spain. Shallow anhydrite mounds are hydrated to gypsum and this gives an expansion of up to 61% in volume and lowers the density from 2.9 to 2.2. Note, however, that this mechanism of hydration of anhydrite to gypsum for initiating evaporite diapirs can only take place above around 700 meters depth, as below this depth gypsum is unstable. Sans *et al.* studied the deformation in an evaporite detachment horizon in the external part of the Pyrenean fold-and-thrust belt. They give evidence for shear folding in the evaporites and demonstrate that diapiric and compressional folds are absent. Smith gives an analysis of the deformation of mesoscopic structures in the Permian Boulby Halite in Teeside, North-East England. They are mainly formed by lateral movements in the salt caused by differences in confining pressure. Talbot and Alavi predict a future syntaxis (an offset in orogenic belt between tectonic domains), the Quatar incipient syntaxis, in the Zagros mountain chain of the Alpine–Himalayan Orogen in Iran. The localisation is controlled by the presence to the south-east and absence to the north-west of Hormuz salt on Pre-Cambrian basement. Both domains have Miocene salt but the style of folding and diapirism is very different. Their paper illustrates that salt tectonics may not only play an important role on the style of folding, but also on the scale of an orogenic belt. Personally, I would classify this paper in Part 3, *Regional case studies*.

Papers in Part 3, *Regional case studies*, highlight the large influence of salt on the style of deformation. Buchanan *et al.* use a balanced section restoration technique to unravel the geometric and kinematic evolution of salt structures and their sedimentary host rocks in the North Sea. They demonstrate the presence of three structural provinces: (1) Central Graben with thick-skinned extensional basement faults with large offsets, salt swells and high-amplitude diapirs; (2) Eastern Platform with low amplitude salt swells and no cover rock faults; and (3) Western Platform with low-amplitude salt swells and thin-skinned faults in the cover rocks. Edgell's paper is a summary of salt structures in the entire Persian Gulf Region, e.g. salt walls are localized along basement faults and domes at interacting basement faults. In some cases, the association of salt structues with oil fields is inferred from negative Bouguer gravity anomalies. He reports that 60% of proven recoverable oil reserves in the Persian Gulf Basin are related to salt structures and as the common theme in the paper is hydrocarbon accumulation near salt structures, I miss information on oil source rocks, migration and trapping. For example, the slow rise of diapiric structures and increased thermal anomalies are very important for generating (suitable oil window) and migrating oil. Spathopoulos shows an example of raft tectonics due to thin-skinned extension above a salt layer in the Angola Basin. In the sloping basin, there is extension with listric faults up-dip, but folding with salt diapirs (and possibly also allochtonous salt) down-dip. Raft tectonics is only active in those parts of the basin with a convex upward basement. Stewart *et al.* demonstrate the influence of the thickness of salt layers on cover faulting during thick-skinned extensional faulting in the North Sea. Salt diapirs are initiated at basement faults, and salt controls cover fault reactivation during inversion by regional compression, as the presence of salt prevents reactivated reverse basement faults from propagating through the cover rocks. Zirngast gives a detailed analysis of the development of the Gorleben salt dome in North-West Germany, presently being used for nuclear waste disposal. He uses the increase of sedimentary volume in rim synclines caused by withdrawal of salt to calculate the rise of the diapir. Growth rates show a large variation, the highest during the Late Cretaceous (0.14 mm per year) and much less during the Miocene and Quaternary (minimum of 0.03 mm per year).

Part 4, *Physical modelling*, has three papers on scale models. Alsop models overburden faults formed by diapirism due to down-building. Faults and fracture patterns characteristic for diapirism are formed in the sedimentary host rocks. Koyi analyses the origin of the salt sheets of the Gulf of Mexico using the following models: (1) tabular salt and tabular overburden; (2) tabular salt and wedge-shaped overburden; and (3) wedge-shaped salt and wedge-shaped overburden. His third model confirms that salt sheets are mobilized by differential loading formed by prograding sedimentary wedges. Szatmari *et al.* modelled a large scale extensional structure from the Santos Basin, offshore Brasil.

Part 5, *Numerical modelling*, has three papers on computer models. Cohen and Hardy calculated the effect of differential loading by prograding sedimentary wedges. They found that density inversion is not required but that with viscosity contrast, sufficient thickness of salt and slope could be responsible for the salt movement. Petersen and Lerche show the importance of thermal anomalies around salt structures for hydrocarbon generation. Poliakov *et al.* are the first to model simultaneous brittle faults and viscous flow in the overburden.

In their concluding remarks on p. 9, the Editors indicate that "there are a great deal of unknown aspects of salt tectonics". I agree with this statement and this is also visible in the book as it covers a rather limited scope. The reader will not find an overview of salt tectonics but papers dealing with some aspects of and new ideas on salt tectonics, illustrating the complex interaction of buoyancy, regional tectonics, faulting, sedimentation, etc., controlled by the high viscosity contrast between evaporites and host rocks. Most striking is the relation between extensional/basement faults and localization of diapirs and how salt controls the style of extensional faulting in the cover rocks. I also agree with the Editors that advances can be made in future research using 3D seimics, more realistic modelling materials, viscous/brittle deformation in numerical models (see the paper by Poliakov *et al.*) and detailed outcrop studies.

The book is well organized, has a large number of high quality photographs and illustrations, very few typos (e.g. bouyant on p. 136 instead of buoyant; numbering out of sequence on p. 172). It has a good mix of papers on field studies, regional studies, physical and numerical modelling, but is mainly suited for specialists readers and not for non-specialists. It does not give a complete overview but deals