

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND BULLETIN 1 • 2003

The Jurassic of Denmark and Greenland

Edited by
Jon R. Ineson and Finn Surlyk

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
MINISTRY OF THE ENVIRONMENT

Geological Survey of Denmark and Greenland Bulletin 1

Keywords

Northwest Europe, Denmark, Greenland, Sweden, the Netherlands, Jurassic, chronostratigraphy, biostratigraphy, lithostratigraphy, sequence stratigraphy, structural history, basin evolution, sedimentology, palynostratigraphy, geochemistry, coal petrography/palynology

Cover

Palaeogeography of the Mesozoic rift system in the North Atlantic region in the Middle Jurassic (c. 160–180 Ma), viewed towards the north. Reconstruction by Stefan Sølberg, based on the palaeogeographic maps of Ziegler (1990) and Doré (1992). For references, see Surlyk (2003, this volume).

Chief editor of this series: Peter R. Dawes

Scientific editors: Jon R. Ineson and Finn Surlyk

Copy editors: Jon R. Ineson and Birgit Eriksen

Editorial secretary: Birgit Eriksen

Critical readers: see list on page 6

Illustrations (GEUS): Stefan Sølberg, Gurli E. Hansen Bengaard, Jette Halskov, Eva Melskens, Helle Zetterwall

Photographic work (GEUS): Jacob Lautrup, Benny M. Scharck, Peter K. Warna-Moors

Lay-out and graphic production: Carsten E. Thuesen

Printers: Schultz Grafisk, Albertslund, Denmark

Manuscripts submission/acceptance dates: see individual articles

Printed: 28th October 2003

ISBN 87-7871-116-9

Geological Survey of Denmark and Greenland Bulletin

The series *Geological Survey of Denmark and Greenland Bulletin* replaces *Geology of Denmark Survey Bulletin* and *Geology of Greenland Survey Bulletin*.

Citation of the name of this series

It is recommended that the name of this series is cited in full, viz. *Geological Survey of Denmark and Greenland Bulletin*.

If abbreviation of this volume is necessary the following form is suggested: *Geol. Surv. Den. Green. Bull.* 1, 948 pp.

Available from

Geological Survey of Denmark and Greenland (GEUS)

Øster Voldgade 10, DK-1350 Copenhagen K, Denmark

Phone: +45 38 14 20 00, fax: +45 38 14 20 50, e-mail: geus@geus.dk

or

Geografforlaget ApS

Frøerhøjvej 43, DK-5464 Brenderup, Denmark

Phone: +45 63 44 16 83, fax: +45 63 44 16 97, e-mail: go@geografforlaget.dk

Contents

Dedication	5
Referees	6
Preface	7

The Jurassic of Denmark and Greenland: key elements in the reconstruction of the North Atlantic Jurassic rift system F. Surlyk and J.R. Ineson	9
--	---

Stratigraphy

The Lower Jurassic of Europe: its subdivision and correlation K.N. Page	23
The Middle Jurassic of western and northern Europe: its subdivisions, geochronology and correlations J.H. Callomon	61
The Upper Jurassic of Europe: its subdivision and correlation A. Zeiss	75
The Jurassic dinoflagellate cyst zonation of Subboreal Northwest Europe N.E. Poulsen and J.B. Riding	115

Denmark, southern Sweden and the Netherlands

Jurassic lithostratigraphy and stratigraphic development onshore and offshore Denmark O. Michelsen, L.H. Nielsen, P.N. Johannessen, J. Andsbjerg and F. Surlyk	147
The Jurassic of the Netherlands G.F.W. Herngreen, W.F.P. Kouwe and Th.E. Wong	217

Danish Central Graben

Upper Jurassic – Lower Cretaceous of the Danish Central Graben: structural framework and nomenclature P. Japsen, P. Britze and C. Andersen	233
Middle Jurassic – Early Cretaceous rifting of the Danish Central Graben J.J. Møller and E.S. Rasmussen	247
Sequence stratigraphy of the Jurassic of the Danish Central Graben J. Andsbjerg and K. Dybkjær	265
Sedimentology and sequence stratigraphy of the Bryne and Lulu Formations, Middle Jurassic, northern Danish Central Graben J. Andsbjerg	301
The use of spectral natural gamma-ray analysis in reservoir evaluation of siliciclastic sediments: a case study from the Middle Jurassic of the Harald Field, Danish Central Graben I.L. Fabricius, L. Dahlerup Fazladic, A. Steinholm and U. Korsbech	349
Sedimentology and sequence stratigraphy of paralic and shallow marine Upper Jurassic sandstones in the northern Danish Central Graben P.N. Johannessen	367
Volgian–Ryazanian ‘hot shales’ of the Bo Member (Farsund Formation) in the Danish Central Graben, North Sea: stratigraphy, facies and geochemistry J.R. Ineson, J.A. Bojesen-Koefoed, K. Dybkjær and L.H. Nielsen	403

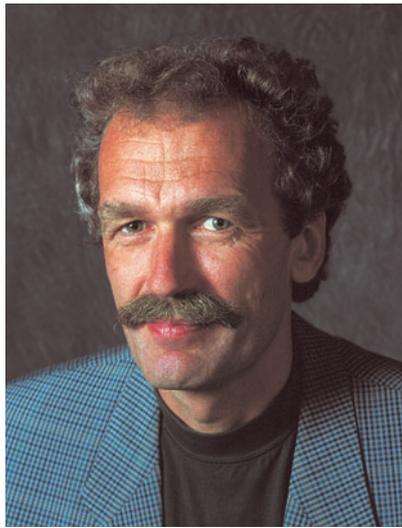
Danish Basin and Fennoscandian Border Zone

- Triassic and Jurassic transtension along part of the Sorgenfrei–Tornquist Zone in the Danish Kattegat**
T.E. Mogensen and J.A. Korstgård 439
- Late Triassic – Jurassic development of the Danish Basin and the Fennoscandian Border Zone, southern Scandinavia**
L.H. Nielsen 459
- The Jurassic of Skåne, southern Sweden**
A. Ahlberg, U. Sivhed and M. Erlström 527
- An offshore transgressive–regressive mudstone-dominated succession from the Sinemurian of Skåne, Sweden**
N. Frandsen and F. Surlyk 543
- Lower Jurassic (Pliensbachian) ammonites from Bornholm, Baltic Sea, Denmark**
D.T. Donovan and F. Surlyk 555
- The Lower–Middle Jurassic of the Anholt borehole: implications for the geological evolution of the eastern margin of the Danish Basin**
O.B. Nielsen, M.-S. Seidenkrantz, N. Abrahamsen, B.J. Schmidt, E.B. Koppelhus, H. Ravn-Sørensen, U. Korsbech and K.G. Nielsen 585
- Burial depth and post-Early Cretaceous uplift of Lower–Middle Jurassic strata in the Fennoscandian Border Zone based on organic maturity**
H.I. Petersen, L.H. Nielsen, T. Bidstrup and E. Thomsen 611
- Early and Middle Jurassic mires of Bornholm and the Fennoscandian Border Zone: a comparison of depositional environments and vegetation**
H.I. Petersen, L.H. Nielsen, E.B. Koppelhus and H.S. Sørensen 631

East Greenland

- The Jurassic of East Greenland: a sedimentary record of thermal subsidence, onset and culmination of rifting**
F. Surlyk 659
- Palynostratigraphy and palaeoenvironments of the Rævekløft, Gule Horn and Ostreaelv Formations (Lower–Middle Jurassic), Neill Klinte Group, Jameson Land, East Greenland**
E.B. Koppelhus and G. Dam 723
- Palynostratigraphy and palaeoenvironment of the Middle Jurassic Sortehat Formation (Neill Klinte Group), Jameson Land, East Greenland**
E.B. Koppelhus and C.F. Hansen 777
- Shallow marine syn-rift sedimentation: Middle Jurassic Pelion Formation, Jameson Land, East Greenland**
M. Engkilde and F. Surlyk 813
- The Jurassic of Kuhn Ø, North-East Greenland**
P.C. Alsgaard, V.L. Felt, H. Vosgerau and F. Surlyk 865
- Stratigraphy and sedimentology of a basement-onlapping shallow marine sandstone succession, the Charcot Bugt Formation, Middle–Upper Jurassic, East Greenland**
M. Larsen, S. Piasecki and F. Surlyk 893
- Shelf-edge delta and slope deposition in the Upper Callovian – Middle Oxfordian Olympen Formation, East Greenland**
M. Larsen and F. Surlyk 931

Dedication



This book is dedicated to the memory of **Ole Winther Christensen** (1951–1998), Director of the Geological Survey of Denmark (DGU) from 1990 to 1995 and the Geological Survey of Denmark and Greenland (GEUS) from 1995 to 1998.

From its conception in the early 1990s, the ‘Jurassic book’ has benefited from the progressive integration of Danish geological institutions. This began in 1995 with the amalgamation of DGU with the Geological Survey of Greenland (GGU) to form GEUS and culminated in 2002 with the opening of the Geocenter Copenhagen, a conglomeration of GEUS, the Danish Lithosphere Centre (DLC), the Geological Museum and the Geological and Geographical Institutes of the University of Copenhagen. Ole Winther Christensen played a key role in both these positive developments in Danish geology. Sadly, he was not to experience the full realisation of the Geocenter Copenhagen concept due to his untimely death in 1998.

Referees

The editors are indebted to the following referees, whose conscientious and incisive reviews have been invaluable in the production of this book – your efforts are greatly appreciated.

- J. Alexander, *University of East Anglia, UK*
J. Andsbjerg, *Geological Survey of Denmark and Greenland, Denmark*
D.J. Batten, *University of Wales, UK*
D.G. Benson, *Texas, USA*
J.H. Callomon, *University College London, UK*
J. Cartwright, *Cardiff University, UK*
B.M. Cox, *British Geological Survey, UK*
R.J. Davey, *Simon Petroleum Technology Ltd, UK*
R.J. Davies, *Mobil North Sea Ltd, UK*
G. Dietl, *Staatliches Museum für Naturkunde, Germany*
D.T. Donovan, *University College London, UK*
T. Dreyer, *Norsk Hydro Research Centre, Norway*
K. Dybkjær, *Geological Survey of Denmark and Greenland, Denmark*
C.J. Fielding, *University of Queensland, Australia*
M.J. Fisher, *Helensburgh, UK*
J. Gjelberg, *Norsk Hydro Research Centre, Norway*
M.B. Gowers, *DONG Norge AS, Norway*
F. Gramann, *Niedersächsisches Landesamt für Bodenforschung, Germany*
D. Guy-Ohlsen, *Swedish Museum of Natural History, Sweden*
A. Hallam, *Birmingham University, UK*
S.D. Harker, *Totalfinaelf Exploration, UK*
G.F.W. Hengreen, *TNO-NITG, The Netherlands*
S.P. Hesselbo, *University of Oxford, UK*
S. Holloway, *British Geological Survey, UK*
A. Hurst, *University of Aberdeen, UK*
L.N. Jensen, *Statoil Norge AS, Norway*
J.A. Korstgård, *University of Aarhus, Denmark*
D.A. Leckie, *Geological Survey of Canada, Canada*
H.B. Lindgreen, *Geological Survey of Denmark and Greenland, Denmark*
C. Mangold, *Université Claude Bernard Lyon I, France*
J.E.A. Marshall, *University of Southampton, UK*
L.H. Nielsen, *Geological Survey of Denmark and Greenland, Denmark*
A. Nøttvedt, *Norsk Hydro Canada, Canada*
S. Olaussen, *Norsk Agip AS, Norway*
T. Olsen, *Statoil Norge AS, Norway*
K.N. Page, *University of Plymouth, UK*
N. Parkinson, *Western Atlas Logging Services, UK*
G.K. Pedersen, *University of Copenhagen, Denmark*
R.M. Pegrum, *Statoil Norge AS, Norway*
S. Piasecki, *Geological Survey of Denmark and Greenland, Denmark*
K.T. Pickering, *University College London, UK*
D. Pirrie, *University of Exeter, UK*
A.G. Plint, *University of Western Ontario, Canada*
J.B. Riding, *British Geological Survey, UK*
A. Ryseth, *Norsk Hydro Research Centre, Norway*
B.W. Sellwood, *Reading University, UK*
R.J. Steel, *University of Wyoming, USA*
G.M. Sykes, *Helix RDS Ltd, UK*
N.H. Trewin, *University of Aberdeen, UK*
R.V. Tyson, *University of Newcastle, UK*
G. Warrington, *British Geological Survey, UK*
O.V. Vejbæk, *Geological Survey of Denmark and Greenland, Denmark*
A.G. Whitham, *CASP, UK*
A. Wierzbowski, *Warsaw University, Poland*
P.B. Wignall, *Leeds University, UK*

Preface

The Jurassic sedimentary successions of Denmark and East Greenland accumulated on opposite sides of a complex rifted seaway between present-day Greenland and Northwest Europe. The Mesozoic–Cenozoic sedimentary basins created along this seaway are of major importance both scientifically, as they preserve a record of the early evolution of the North Atlantic region, and economically as one of the rift arms contains the North Sea petroleum province. The Jurassic System, in particular, has been the focus of intensive study in Northwest Europe and Greenland. Not only has this system, since the days of William Smith, been at the forefront of stratigraphic research but it also forms a critical component of the North Sea hydrocarbon province, yielding both the most important source rocks and a wide range of sandstone reservoirs.

Although the stratigraphic development of the Jurassic in Denmark and East Greenland can be compared at a number of levels, the nature of the occurrences in the two regions is very different. The Jurassic of East Greenland is one of the world's best-exposed ancient rift basins and is widely regarded as a classic 'field laboratory'. The Jurassic strata are exposed in spectacular cliff sections that provide unique opportunities for detailed research into process sedimentology, genetic stratigraphy and 3D sedimentary architecture. The Danish Jurassic strata, in contrast, have limited outcrop but are well known from the subsurface, both on land and beneath the waters of the North Sea. The papers collected in this volume reflect this contrast – the stratigraphic evolution of East Greenland has been deciphered primarily on the basis of detailed outcrop geological studies whereas the corresponding stratigraphic analyses of the Danish Basin and the Danish sector of the Central Graben are largely dependent on 'remote' subsurface data. Jurassic stratigraphic research in Denmark over the last two decades has benefited immensely from the interaction between these two contrasting yet complementary approaches.

The origins of this book go back to the early 1990s when the idea was mooted for a book on the 'Jurassic of Denmark and adjacent areas', initially with a view to publication of the main results of Ph.D. studies that were underway at the Geological Survey of Denmark (DGU) at that time. In 1995, with the amalgamation of

DGU with the Geological Survey of Greenland (GGU) to form the Geological Survey of Denmark and Greenland (GEUS), the conceptual framework of the book expanded to include the Jurassic of East Greenland, a research area that was under sharp focus both at GGU and at the University of Copenhagen. As the editing of the book entered the final phase, the Geological Survey relocated to the new Geocenter Copenhagen – a centralised amalgam of the Survey (including the Danish Lithosphere Centre) and the Geological and Geographical Institutes and the Geological Museum of the University of Copenhagen. From conception to publication, therefore, the book charts the changing structure of some of the central geological research bodies in Denmark, and its completion coincided with the inception of a new integrated natural science research centre.

The central aim of the book is to present the results of an intense period of research activity in Denmark on the Jurassic System over the last fifteen years – and, where relevant, to present these results at a comprehensive level that is almost impossible in modern scientific journals. Although covering a range of subjects, the common thread that runs through the book is the detailed documentation of the history of the Jurassic rift system as recorded in the sedimentary basins of Greenland and Denmark. Particular areas of focus include: (1) the sedimentary and stratigraphic signatures of syn-rift successions, whether revealed by detailed outcrop study or on the basis of integrated reflection seismic, petrophysical and core data; and (2) testing and application of sequence stratigraphic models and concepts at a variety of scales and in different structural settings.

Although focussing on broad geoscientific topics of general relevance, the book also provides data of specific value to the hydrocarbon industry. The Danish Basin and, in particular, the Danish Central Graben are prospective basins with exploration histories stretching back nearly fifty years. A number of Jurassic fields are under development and production in the Danish Central Graben, and exploration interest remains high. The structural, sedimentological and stratigraphic papers in this volume thus represent a direct source of essential data for the hydrocarbon industry. The onshore East Greenland basins, in contrast, are not prospective *per*

se, yet the detailed sedimentological and stratigraphic analyses included here will be of particular interest to petroleum geologists both as direct stratigraphic analogues of the succession on the conjugate margin (mid-Norway shelf) and as reservoir analogues or case studies applicable particularly to the North Sea region but also valid elsewhere.

Introductory chronostratigraphic reviews of the Lower, Middle and Upper Jurassic were planned from the outset, and contributions were solicited from three international authorities in this field, together with a paper on the Jurassic of southern Sweden. Furthermore, a review of the Jurassic of the Netherlands was invited from the Geological Survey of the Netherlands (RGD) for comparative purposes, building on previous close stratigraphic co-operation between DGU and RGD in the late 1980s.

The aim has been to produce a book that is as balanced and consistent as possible, in terms of content, terminology and appearance. Given the range of subjects covered, however, a certain degree of heterogeneity is inevitable and full consistency in terminology cannot be achieved. The Gradstein *et al.* (1994) time-scale is used in most cases but the Haq *et al.* (1988) and Harland *et al.* (1990) time-scales are employed by some authors; in all cases, the origin of the time-scale used is clearly indicated. Several forms of chronostratigraphic terminology are in common use, all being inherently logical and fully acceptable; particularly prevalent are the 'Standard Zone' nomenclature (Callomon & Donovan 1974) and the 'chronozone' terminology, as laid down in the International Stratigraphic Guide (Salvador 1994). Editorial flexibility has been exercised here, although consistency within individual articles was required. To enhance uniformity, a common graphical style has been imposed wherever possible; detailed sedimentary logs are somewhat variable, however, being dictated by different individual styles and demands.

In an enterprise of this type, undertaken over a number of years, there are clearly many people both in Denmark and abroad who have helped us towards publication. The research projects that formed the initial stimulus behind the book were supported both by state funding – the Danish Energy Agency (Energy Research Program, EFP), the Danish Natural Science Research Council (SNF), the Danish Research Academy and the Norwegian Petroleum Directorate (NPD) – and by the private sector, including Amerada Hess, Amoco, British Petroleum, the Carlsberg Foundation, Conoco,

Mærsk Olie og Gas, Norsk Hydro, Saga Petroleum and Statoil. The long-term support of Danish geological research by these funding bodies and companies is gratefully acknowledged. We are also indebted to a long list of international referees; their contribution is acknowledged elsewhere but their importance in upholding the international standard of the papers bears repetition. During the scientific and technical editing phase, we have leaned heavily on three key personnel: Hanne B. Sørensen, who converted editorial hieroglyphics into ordered manuscripts; Birgit Eriksen, who meticulously checked final manuscripts and proof copies; and Stefan Sølberg whose skilled graphical imprint is engraved on almost every illustration in the book. On editorial matters, we have also benefited greatly from close co-operation with Peter R. Dawes and Esben W. Glendal in the editorial office at GEUS. In the latter stages we have been increasingly reliant on the professional layout work by Carsten E. Thuesen.

To all the above, we offer our heartfelt thanks.

Jon R. Ineson

Finn Surlyk

On behalf of the 'Jurassic book' convening group: Jon R. Ineson, Finn Surlyk, Karen Dybkjær, Lars. H. Nielsen, Niels E. Poulsen.

References

- Callomon, J.H. & Donovan, D.T. 1974: A code of Mesozoic stratigraphic nomenclature. In: Colloque du Jurassique à Luxembourg 1967. Mémoire du Bureau de Recherches Géologiques et Minières **75**, 75–81.
- Gradstein, F.M., Agterberg, F.P., Ogg, J.G., Hardenbol, J., van Veen, P., Thierry, J. & Huang, Z. 1994: A Mesozoic time scale. *Journal of Geophysical Research* **99**, 24051–24074.
- Haq, B.U., Hardenbol, J. & Vail, P. 1988: Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. In: Wilgus, C.K. *et al.* (eds): Sea-level changes – an integrated approach. Society of Economic Paleontologists and Mineralogists Special Publication **42**, 71–108.
- Harland, W.B., Armstrong, R.L., Cox, A.V., Craig, L.E., Smith, A.G. & Smith, D.G. 1990: A geologic time scale 1989, 263 pp. Cambridge: Cambridge University Press.
- Salvador, A. (ed.) 1994: International stratigraphic guide. A guide to stratigraphic classification, terminology, and procedure, 2nd edition, 214 pp. Boulder, Colorado: International Union of Geological Sciences and Geological Society of America, Inc.