

Springer Theses

Recognizing Outstanding Ph.D. Research

Anna Alexandra Vackiner

Sedimentary Facies Reconstruction and Kinematic Restoration of Tight Gas Fields

Studies from the Upper Permian
in Northwestern Germany

 Springer

Springer Theses

Recognizing Outstanding Ph.D. Research

For further volumes:
<http://www.springer.com/series/8790>

Aims and Scope

The series “Springer Theses” brings together a selection of the very best Ph.D. theses from around the world and across the physical sciences. Nominated and endorsed by two recognized specialists, each published volume has been selected for its scientific excellence and the high impact of its contents for the pertinent field of research. For greater accessibility to non-specialists, the published versions include an extended introduction, as well as a foreword by the student’s supervisor explaining the special relevance of the work for the field. As a whole, the series will provide a valuable resource both for newcomers to the research fields described, and for other scientists seeking detailed background information on special questions. Finally, it provides an accredited documentation of the valuable contributions made by today’s younger generation of scientists.

Theses are accepted into the series by invited nomination only and must fulfill all of the following criteria

- They must be written in good English.
- The topic should fall within the confines of Chemistry, Physics, Earth Sciences, Engineering and related interdisciplinary fields such as Materials, Nanoscience, Chemical Engineering, Complex Systems and Biophysics.
- The work reported in the thesis must represent a significant scientific advance.
- If the thesis includes previously published material, permission to reproduce this must be gained from the respective copyright holder.
- They must have been examined and passed during the 12 months prior to nomination.
- Each thesis should include a foreword by the supervisor outlining the significance of its content.
- The theses should have a clearly defined structure including an introduction accessible to scientists not expert in that particular field.

Anna Alexandra Vackiner

Sedimentary Facies Reconstruction and Kinematic Restoration of Tight Gas Fields

Studies from the Upper Permian
in Northwestern Germany

Doctoral Thesis accepted by
the RWTH Aachen University, Germany

 Springer

Author

Dr. Anna Alexandra Vackiner
Energy and Mineral Resources Group
Geological Institute
RWTH Aachen University
Aachen
Germany

Supervisors

Prof. Dr. Peter A. Kukla
Energy and Mineral Resources Group
Geological Institute
RWTH Aachen University
Aachen
Germany

Prof. Dr. Harald Stollhofen
North Bavarian Center of Earth Sciences
Friedrich-Alexander University
Erlangen–Nürnberg
Germany

ISSN 2190-5053

ISBN 978-3-642-36045-9

DOI 10.1007/978-3-642-36047-3

Springer Heidelberg New York Dordrecht London

ISSN 2190-5061 (electronic)

ISBN 978-3-642-36047-3 (eBook)

Library of Congress Control Number: 2013931748

© Springer-Verlag Berlin Heidelberg 2013

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law. The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Parts of this thesis have been published in the following journal articles:

Anna Alexandra Vackiner, Philipp Antrett, Harald Stollhofen, Stefan Back, Peter Alfred Kukla and Claudia Bärle (2011) Syndepositional Tectonic Controls and Palaeo-Topography of a Permian Tight Gas Reservoir in NW Germany. *Journal of Petroleum Geology*, Vol. 34(4), p. 411–428.

Anna Alexandra Vackiner, Philipp Antrett, Frank Strozyk, Harald Stollhofen, Stefan Back and Peter Alfred Kukla (2012) Reconstructing the Upper Permian sedimentary facies distribution of a tight gas field in Central Europe on the basis of a modern analog field study in the Panamint Valley, western U.S., *Geosphere*, Vol. 8(5), p. 1129–1145.

Anna Alexandra Vackiner, Philipp Antrett, Frank Strozyk, Harald Stollhofen, Peter Kukla, Stefan Back (accepted) Integrating salt kinematics and regional tectonics across a Permian gas field: a case study from East Frisia, NW Germany. *International Journal of Earth Sciences*.

*When you reach the end of your rope, tie a
knot in it and hang on*

—Thomas Jefferson

Supervisor's Foreword

Natural Hydrocarbon Gas is considered to represent the “bridging fuel” until new energies become technically and economically viable. Among hydrocarbon gas, one can classify conventional, unconventional and tight gas resources. The unconventional and tight gas resources have recently received much interest because of the potential very large reserves, which could be produced with suitable technology. Tight gas reservoirs which are found throughout the world and which occur in all common types of reservoir have been produced for many decades, but still pose a major technical challenge owing to their heterogeneous reservoir characteristics and in particular their low permeability and low porosity. Given the global importance of such reservoirs, the understanding of the complexity of tight gas fields therefore requires an integrated approach involving geological, geophysical and petrophysical analysis which very few publications to date have achieved.

The thesis of Alexandra presents such a multidisciplinary approach towards the analysis of complex tight gas reservoirs using the example of the Permian in the Northwest European Basin. Despite a long exploration and production history in this basin, previous work in Germany has mainly concentrated on the overall basin evolution based on seismic and wireline borehole data and the diagenesis of the reservoirs based on core data. Very little work on the other hand has been undertaken to discern the multiple reactivations of structural elements within the basin and to separate syntectonic versus post-tectonic deformation patterns and styles. The methods used in this work therefore include geological and geophysical analyses, remote sensing, 2D retro-deformation modelling and log- and core analysis.

In a first step, a detailed and high-resolution facies analysis of fluvio-eolian sediments of the Upper Rotliegend II sequences was undertaken. A separation of different dune types and interdune deposits was achieved and supported by a comparison with modern reservoirs in Panamint Valley, western USA leading to a palaeo-sedimentary and palaeo-geomorphologic model through time. A sequential retro-deformation of the study area aimed at a differentiation between salt rise mechanisms, their timing and their relation to regional tectonic events. It involves

sedimentation, decompaction, fault-related deformation, salt movement, thermal subsidence and isostasy. Results suggest that reactive diapirism started with lateral salt movement and local injection of salt into the overburden during the Lower Triassic Buntsandstein deposition. During the Upper Buntsandstein, rafts developed and small diapirs first breached through the sediment surface. Active diapirism during the Upper Triassic (Lower Keuper) was accompanied by salt piercement of the overburden. For the Jurassic, hydrothermal fluid circulation along active faults in an extensional regime is postulated. In the Lower Cretaceous, the salt rise mechanism changed to passive diapirism, which is still continuous until today. The downbuilding phase was accompanied by the development of large salt rim synclines leading to local development of faults. The structural analysis further shows multiple reactivations which demonstrate that syn- and post-sedimentary tectonics exert a strong control on facies' architecture in the basins. The importance of fault tip geometries and pull-apart structures for sedimentation and fluid flow could further be established.

Alexandras's research formed part of the Tight Gas Initiative (TGI) between RWTH Aachen University and Wintershall Holding GmbH which supported this study. She has presented her work in several international publications and at international conferences. Her thesis is a well-documented piece of work which presents for the first time an integrated model in which the influence of regional tectonics, salt tectonics, sedimentation, compaction, thermal subsidence and isostasy on tight gas reservoir evolution and distribution can be discerned. It therefore represents a major step forward in the understanding of this complex reservoir type.

Aachen, September 2012

Prof. Dr. Peter A. Kukla

Acknowledgments

My sincerest thanks go to my advisors Prof. Peter Kukla Ph.D. and Prof. Dr. Harald Stollhofen. I thank Peter Kukla for his supervision and for protecting and defending me when scientific disagreements occurred. I thank Prof. Dr. Harald Stollhofen for sharing his enormous knowledge about sedimentology and for the time he invested for detailed internal reviews of my manuscripts. I am grateful to my colleagues, co-authors and friends Philipp Antrett, Dr. Frank Strozyk, Dr. Stefan Back and Dr. Chris Hilgers for long discussions, logistic support and high spirits. Special thanks to Frank, who invested a lot of time in cross-reading my manuscripts. To my additional co-authors, Vanessa Havenith, Dr. Claudia Bärle, Dr. Sven Sindern, Prof. Dr. Michael Meyer and Dr. Ina Blumenstein-Weingartz, I am deeply grateful.

This doctoral thesis is part of the Wintershall and RWTH Aachen University Tight-Gas Initiative. I thank the Wintershall Holding GmbH and the GDF Suez E&P Deutschland GmbH for providing the seismic data and the core material and for financing the project. The thesis benefitted from fruitful discussions with the industrial partners during several meetings. In particular Dr. Claudia Bärle, Dr. Harald Karg, Bernhard Siethoff, Dr. Wolfram Unverhaun, Petra Unverhaun, Michael Blum, Dr. Wolf-Dieter Karnin, Dr. Ina Blumenstein-Weingartz, Dr. Dirk Adelman, Jan Himmerkus and Dr. Dieter Kaufmann (all from Wintershall Holding GmbH), Dr. Robert Bussert and Dr. Anton Irmen (GDF Suez E&P Deutschland GmbH) shared their knowledge and experience.

Concerning the fieldwork, I thank Dr. Norbert Klitzsch of the Applied Geophysics and Geothermal Energy Department of the E.ON Energy Research Center, who gave Philipp Antrett and me the opportunity to conduct ground resistivity measurements in the Panamint Valley, and Rebecca Möller, who took care of the bedevilled shipping of the ground resistivity equipment from Germany to the US and back. Without Rebecca, the US or the German customs could still call a complete ground-resistivity equipment their own. Furthermore, I would like to thank the United States National Park Services, especially Richard Friese, for issuing a Research and Collecting Permit for the Death Valley National Park. He also gave me the opportunity to ship a potential dinosaur egg to Germany, which, unfortunately, turned out to be a huge pebble. I thank Dr. Marco Möller for taking care of our suitable lodging during fieldwork with lending one of the Hilleberg

tents of the glacial research group of the Geographical Department. It stood strong desert winds and a devastating sandstorm, during which several other tents collapsed.

Further, I thank the volume editor of the Journal of Petroleum Geology Christopher Tiratsoo and the reviewer Prof. Dr. Nigel Mountney for their constructive support, which greatly improved the first of my scientific papers (largely embedded in this thesis; [Chap. 4](#)).

Finally, I would like to thank my friends and family, especially Susan Giffin and Beke Rosleff-Sørensen, for being the best circuit training and athletics companions I ever had, Philipp Antrett for his geological and mental support and for his love, and my parents, Gerhard and Christa Vackiner, for the emotional support, their love and care.

Contents

1	Introduction	1
1.1	Rationale	1
1.2	Objectives.	2
1.3	Thesis Outline.	4
	References	5
2	Geological Setting	7
2.1	Regional Geological Setting	7
2.2	Geology of the Study Area	10
	References	11
3	Data and Methods	13
3.1	Data and Methods	13
3.2	Methods: Sedimentary Facies Analysis from Core Material	16
3.2.1	Pond/Lake	17
3.2.2	Pond/Lake Margin.	18
3.2.3	Aeolian Mudflat	19
3.2.4	Wet to Damp Sandflat.	21
3.2.5	Dry Sandflat.	22
3.2.6	Aeolian Dune (base)	23
3.2.7	Low Energetic Meandering Fluvial Deposits	24
3.2.8	High Energetic Braided Stream Fluvial Deposits	26
	References	29
4	Syn depositional Tectonic Controls and Palaeo-Topography of a Permian Tight Gas Reservoir in NW Germany	31
4.1	Introduction	31
4.1.1	Geological Framework.	32
4.2	Data and Interpretation Methodology.	34
4.3	Structural Subdivision of the Study Area	35
4.4	Palaeo-Relief Analysis from Seismic Data	38
4.5	Palaeo-Relief Analysis from Core and Log Data.	42
4.6	Palaeo-Relief Uncertainty During Zechstein	43

4.7	Discussion	45
4.8	Conclusions	49
	References	51
5	The Panamint Valley, Western US: A Field Analogue for the Sedimentary Facies Distribution of a Permian Tight Gas Field in Central Europe	55
5.1	Introduction	55
5.2	Setting	58
	5.2.1 Geological Setting of Panamint Valley	58
	5.2.2 Subsurface Area Germany	59
5.3	Data and Methods	60
5.4	Results	61
	5.4.1 Panamint Valley	61
	5.4.2 Subsurface Study Area Germany.	66
5.5	Discussion	69
5.6	Conclusions	71
	References	72
6	Integrating Salt Kinematics and Diagenesis in a Tight Gas Field: A Case Study from the Upper Rotliegend in East Frisia	75
6.1	Introduction	75
6.2	Data and Methods	76
	6.2.1 3D Isopach Data	79
	6.2.2 2D Retro-Deformation	81
6.3	Results	86
	6.3.1 3D Isopach Analysis and Lithologies.	87
	6.3.2 2D Retro-Deformation	90
	6.3.3 Core Data (Sandstone Petrography, Fluid Inclusions)	91
6.4	Interpretation	92
6.5	Conclusions	97
	References	98
7	Facies Analysis from Well Cores, Northern Central Germany: Comparison to NW German Well Cores.	103
7.1	Introduction	103
7.2	Core Analysis Results	108
	7.2.1 Well I	108
	7.2.2 Well II.	108
	7.2.3 Well III	109
	7.2.4 Well IV	111
7.3	Interpretation	111
7.4	Comparison to North–Western German Study Area.	113
	References	115

8	Conclusions, Synopsis and Perspectives	117
8.1	Conclusions	117
8.2	Synopsis	121
8.3	Perspectives	121
	References	122