Seismic interpretation of the eastern Gippsland Basin with application to fault seal analysis in carbon dioxide storage leads

by

Jacques Sayers, M.Sc., B.Sc. Hons

Thesis Submitted in Fulfilment of the Requirements for the Degree of

Doctor of Philosophy

The University of Adelaide

Faculty of Engineering, Computer and Mathematical Sciences

Australian School of Petroleum

May 2011

TABLE OF CONTENTS

FIGURES AND TABLES

ABSTRACT

Geological storage of carbon dioxide (CO_2) is a mitigation option for reducing greenhouse gases. To date, CO_2 storage-related research in the Gippsland Basin, has focussed on detailing how the stratigraphy and facies, but not how the faults may affect CO_2 storage/fluid-flow and fault-trap integrity. This thesis addresses this latter deficiency through a 3-D seismic-based structural interpretation of CO_2 storage leads (CO_2SL) identified in the eastern part of the basin. Further underpinning this study are over 800 tops/markers collated and/or interpreted from 95 wells.

The primary goals of this study are two-fold: first, to ascertain how structural events, basin tectonic phases and associated sedimentary fill, influence fault-trap integrity, and second, how the fault network across fault-block complexes, minor faults, fault tips, branch lines, juxtaposition of reservoir intervals and modelling of shale smear across-fault influence fault-trap integrity.

With respect to CO_2 storage, and based on the structural interpretation undertaken, the basin's rift-drift subphase and the associated Halibut Subgroup sedimentary section, is the best overall storage option. Of the 200 or so faults interpreted, 20% and 67% have fault tips that arrest at the Campanian Seahorse and Early Eocene Mackerel Unconformities, respectively, but fault tips do not arrest at the Oligocene Latrobe Unconformity, as has been previously interpreted. The implication is that the intra-Halibut Subgroup faults are not kinematically and/or hydraulically linked to the minor faults present in the overlying regional seal, thus providing some assurance of fault-trap integrity.

Twelve CO_2SLs are identified and screened; areal closures are 16.9 ± 13 km^2 (excluding outliers), CO_2 flow-path distances are 7.4 ± 4.2 km and, flow-path heights are 0.55 ± 0.14 km. The fault network across the fault-block complexes is interpreted to be reduced, providing some assurance that CO_2 flow-paths are relatively unimpeded.

The high proportion of across-fault sand-on-sand windows and, poorly developed shale smear, precludes any significant amounts of CO_2 from being trapped against any significant length of any of the larger fault planes. It is established that most faults have a moderate to high likelihood of fault reactivation, as most trend subparallel to one of the conjugate planes of shear failure; however, the likelihood can be low across portions of the fault plane where the strike deviates from trend (up to ± 33°). When splay faults are considered, there is an increase in the overall likelihood of fault reactivation for 32% of the branch-line cases considered, a reduction for 26% of cases and, negligible effect for the remaining 42%.

This study conclusively demonstrates that the primary factor affecting fault-trap integrity in the Halibut Subgroup is the high number of across-fault sand-on-sand windows; by comparison, the contribution of fault tips, branched faults and presence of shale smear is secondary. Any breach of containment by CO_2 flow across-fault will adversely affect adjacent fault-block complexes, raising the concern that CO_2 storage in this part of the basin, or similar geological areas in this or other basins, may be difficult to contain geographically. The implications would be profound for other offshore basins that are more poorly ranked than the Gippsland Basin.

STATEMENT OF ORIGINALITY

This work contains no material that has been accepted for the award of any other degree or diploma in any university or other tertiary institution to Jacques Sayers and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to this copy of my thesis, when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968. I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the library catalogue, the Australasian Digital Theses Program (ADTP) and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

Signed: ……………………………… Date: ………………

ACKNOWLEDGMENTS

I wish to thank my supervisors Prof. Richard Hillis (Australian School of Petroleum) and Dr Peter Boult (Ginkgo ENP GNG) and am indebted to Mr Lynton Spencer (Ophir Exploration Consultants Pty Ltd) for reviewing my Ph.D. I thank Dr Clinton Foster of Geoscience Australia for giving me approval and providing financial support to undertake this Ph.D. I am indebted to the CO2CRC for their financial support. I thank Badley Geoscience Ltd for the use of the fault seal analysis software *TrapTester*™. I thank PESA for sponsoring me to attend Dr R. Nelson's course titled 'Integrated exploration and evaluation of fractured reservoirs' and for awarding me the 2008 PESA federal scholarship for high academic achievement in petroleum geoscience at the postgraduate level. I extend my thanks to Mike Wiltshire, the Director of Occam Technology Pty Ltd, for making 23 suites of well logs available for this study. I am grateful to my partner Kim Deer for her loving support and patience. Lastly, I also acknowledge Elite Editing and Tutoring for carrying out a professional edit of this Ph.D.

Australian School of Petroleum

Dr Ric Daniel (Ph.D. discussion)

Mrs Maxine Drenth (administration)

Ms Eileen Flannery (administration)

Dr Prashant Jadhawar (Ph.D. discussion)

Mr Andy Mitchell (geophysics)

Mrs Maureen Sutton (administration)

Dr Mark Tingay (reviewer)

Mr Ian West (IT)

CO2CRC

Dr Mark Bunch (reviewer)

Dr Peter Cook (Ph.D. approval)

Prof. John Kaldi (Ph.D. approval)

Dr Sandrine Vidal-Gilbert (reviewer)

Department of Primary Industries and Resources of South Australia

Mr Witold Serevyn (depth conversion)

Department of Primary Industries–Victoria

Dr Tom Bernecker (data)

Dr Geoff O'Brien (data)

Mr Terry Smith (data)

Mr Hywel Thomas (data)

Geoscience Australia

Dr John Bradshaw (advisor)

Ms Tamara Buckley (data)

Mr Rick Causebrook (administration)

Ms Paula Cronin (3-D seismic dataset)

Mr Steve LePoidevin (data)

South Australian Research Development Institute

Dr Thomas Banhazi (Ph.D. discussion)

CO2CRC Participants

Supporting Partners: The Global CCS Institute | The University of Queensland | Process Group | Lawrence Berkeley National Laboratory | Government of South Australia

Established & supported under the Australian Government's Cooperative Research Centres Program

ABBREVIATIONS AND SYMBOLS

The abbreviations below are commonly used throughout this thesis.

Abs	absent
CO_2SL	carbon dioxide storage lead
Fm	formation
Gp/Sgp	group/subgroup
KB	kelly bushing
MD	measured depth
MSL	mean sea level
NA	not applicable
SS	subsea depth
TD	total depth
TVD	true vertical depth
TWT	two-way travel time
2-D	two-dimensional seismic data
3-D	three-dimensional seismic data
WCR	well completion report
WD	water depth

The symbols below are commonly used in Chapters 6–7.

C	–	cohesion/cohesive strength
P_P	–	pore pressure (MPa)
S_{Hmax}	–	maximum horizontal stress magnitude/gradient (MPa, MPa/km)
$S_{Hmax\theta}$	–	maximum horizontal stress azimuth (°N)
S_{hmin}	–	minimum horizontal stress magnitude/gradient (MPa, MPa/km)
S_v	–	vertical stress magnitude/gradient (MPa, MPa/km)
S_{Hmax}', S_{Hmin}', S_V'	–	effective maximum, minimum and vertical stress magnitude (MPa)
SGR	–	shale gouge ratio
T	–	tensile strength (MPa)
V_{shale}	–	volume of shale
σ_s, σ_n	–	shear stress, normal stress (MPa)
σ_1, σ_2, σ_3	–	maximum, intermediate and minimum principal stress (MPa)
σ_1', σ_2', σ_3'	–	effective maximum, intermediate and minimum principal stress (MPa)
μ	–	coefficient of internal friction
θ	–	angle between $S_{Hmax\theta}$ and the normal to the plane (°)
Φ	–	angle of internal friction (°)
ΔP	–	maximum sustainable pore pressure increase (determined from fault reactivation modelling, MPa)

The units below are commonly used.

MPa	–	megapascals (1 MPa = 145.03 psi = 10 bar)
Bbbl	–	barrel