

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

by

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TABLE OF CONTENTS

FIGURES AND TABLES.....	VII
ABSTRACT.....	XI
STATEMENT OF ORIGINALITY.....	XIII
ACKNOWLEDGMENTS.....	XV
ABBREVIATIONS AND SYMBOLS.....	XVII
CHAPTER 1—INTRODUCTION.....	1
1.1 Study rationale.....	1
1.1.1 Greenhouse gases and the greenhouse effect.....	1
1.1.2 Carbon dioxide capture and storage.....	3
1.1.3 Trapping mechanisms and containment.....	3
1.1.4 Carbon dioxide storage options.....	4
1.1.5 Carbon dioxide storage—assessment strategies.....	5
1.2 Research objectives.....	8
1.3 Study area rationale.....	10
1.4 Study workflow.....	14
CHAPTER 2—REGIONAL GEOLOGY.....	17
2.1 Introduction.....	17
2.2 Stratigraphy and bounding unconformities.....	17
2.2.1 Nomenclature.....	17
2.2.2 Strzelecki Group and Otway Unconformity.....	19
2.2.3 Latrobe Group (Emperor Subgroup and Longtom Unconformity).....	20
2.2.4 Latrobe Group (Golden Beach Subgroup and Seahorse Unconformity).....	24
2.2.5 Latrobe Group (Halibut Subgroup, Mackerel and Marlin Unconformities).....	24
2.2.6 Latrobe Group (Cobia Subgroup and Latrobe Unconformity).....	28
2.2.7 Seaspray Group (Marshall Paraconformity and Bullseye Karst).....	29
2.3 Volcanostratigraphy.....	31
2.4 Fault systems.....	32
2.5 Basin phases.....	34
2.6 Petroleum prospectivity.....	39
2.7 Discussion.....	42
2.8 Conclusions.....	44
CHAPTER 3—SEISMIC INTERPRETATION.....	45
3.1 Introduction.....	45
3.2 Study area.....	46
3.3 Datasets.....	47
3.4 Local geology.....	51
3.5 Methodology.....	52
3.6 Results.....	63
3.6.1 Tectonostratigraphic framework.....	63

3.6.2 Unconformity/horizon interpretation	67
3.6.3 Fault interpretation—outline	77
3.6.4 Fault interpretation (Strzelecki and lower Latrobe Groups)	79
3.6.5 Fault interpretation (Latrobe Group)	84
3.6.6 Fault interpretation (Seaspray Group)	93
3.6.7 Fault regimes	94
3.6.8 Basin phases/subphases	97
3.7 Discussion	104
3.7.1 Tuna-Flounder and Marlin Channels	106
3.7.2 Latrobe and Mackerel Unconformities	107
3.7.3 Faults (Latrobe and Seaspray Groups)	109
3.7.4 Fault zones	110
3.7.5 Fault regime and mode (Palaeocene to Early Eocene)	111
3.7.6 Basin phases/subphases	113
3.7.7 Geohistory (Late Eocene to Middle Miocene)	115
3.7.8 Geohistory (Middle Miocene to Pleistocene)	116
3.8 Conclusions	118
CHAPTER 4—DEPTH CONVERSION	121
4.1 Introduction	121
4.2 Methodology and context	122
4.3 Results	122
4.3.1 Software development	122
4.3.2 Seafloor interpretation	123
4.3.3 Interpretation—checkshot data	125
4.3.4 Interpretation—stacking velocity data	125
4.3.5 Time to depth conversion	129
4.3.6 Software runs	129
4.4 Discussion	131
4.4.1 Error of fit—checkshot data	131
4.4.2 Error of fit—stacking velocity data	132
4.5 Conclusions	133
CHAPTER 5—CARBON DIOXIDE STORAGE LEADS	135
5.1 Introduction	135
5.2 Terminology	136
5.3 Methodology	138
5.4 Results	139
5.4.1 Interpretation of reservoir intervals	139
5.4.2 Interpretation of seal intervals	142
5.4.3 Interpretation of CO ₂ SLs	145
5.4.4 Screening of CO ₂ SLs and subleads	163
5.5 Discussion	166
5.5.1 Synthesis—traps	166

5.5.2 Synthesis—CO ₂ SLs	170
5.6 Conclusions	171
CHAPTER 6—JUXTAPOSITION ANALYSIS AND MODELLING SHALE SMEAR	173
6.1 Introduction.....	173
6.2 Datasets.....	173
6.3 Methodology	175
6.3.1 Framework geomodel.....	175
6.3.2 Generating V _{shale} curves.....	177
6.3.3 Juxtaposition analysis and modelling shale smear	179
6.3.4 Estimating retention capacity/CO ₂ column heights.....	181
6.4 Results.....	182
6.4.1 CO ₂ storage leads.....	182
6.4.2 Stratigraphic interpretation.....	185
6.4.3 V _{shale} curves	193
6.4.4 V _{shale} and SGR attribute mapping.....	198
6.4.5 Sensitivity analysis	200
6.4.6 Retention capacity—CO ₂ column heights	205
6.5 Discussion	206
6.5.1 Fault traps and sealing across-fault.....	206
6.5.2 Modelling shale smear.....	208
6.6 Conclusions	213
CHAPTER 7—FAULT REACTIVATION MODELLING	215
7.1 Introduction.....	215
7.2 Geomechanical concepts	216
7.2.1 The stress tensor	216
7.2.2 Principal stress	216
7.2.3 Effective stress	218
7.2.4 Mohr's circle	218
7.2.5 Rock failure criterion and envelope	219
7.3 Methodology	221
7.3.1 Geomechanical input.....	221
7.3.2 Mode-of-failure attributes.....	224
7.4 Results.....	226
7.4.1 Fault reactivation—stand-alone faults	226
7.4.2 Fault reactivation—branched faults	229
7.4.3 Sensitivity analysis	237
7.5 Discussion	240
7.5.1 Fault interpretation and model	240
7.5.2 Fault reactivation and fault-trap breach	242
7.4 Conclusions	244
CHAPTER 8—CONCLUSIONS	247
REFERENCES	255

PREFACE—APPENDICES 1–3	271
APPENDIX 1—GEOLOGICAL DATASETS AND INTERPRETATION	273
A1.1 Well datasets and data distribution	273
A1.2 Formation tops and hiatus markers.....	281
APPENDIX 2—GEOPHYSICAL DATASETS AND INTERPRETATION	367
A2.1 Seismic acquisition and processing.....	367
A2.2 Seismic interpretation	371
A2.3 Checkshot data.....	385
A2.4 Seismic workstation and software.....	431
A2.5 Depth conversion of SEG Y and ASCII data.....	431
APPENDIX 3—GEOMECHANICAL DATASETS AND FAULT SEAL ANALYSIS	447
APPENDIX 4—PUBLICATIONS	459

FIGURES AND TABLES

Figure 1.1. Geotechnical workflow for assessing CO ₂ storage—sequence stratigraphic–depositional-based approach. ...6	6
Figure 1.2. Conceptual representation of key structural–stratigraphic factors critical to the fault/trap integrity in CO ₂ SLs.11	11
Figure 1.3. Geotechnical workflow for assessing CO ₂ storage sites in this study—structure-based approach.16	16
Figure 2.1. Structural elements and depth-to-basement map—Gippsland Basin.....18	18
Figure 2.2. Events chart of the Gippsland Basin—stratigraphy, basin phases and petroleum system elements.21	21
Figure 2.3. Seismic line-profiles showing the sequence stratigraphy of the Seaspray Group.23	23
Figure 2.4. TWT thickness maps, (a) Strzelecki Gp, (b) Emperor Sgp, (c) Golden Beach Sgp, (d) lower Halibut Sgp.25	25
Figure 2.5. TWT thickness map of the Seaspray Group—post-Oligocene structures superimposed.....35	35
Figure 2.6. Wells, petroleum tenements, infrastructure and CO ₂ concentrations—offshore Gippsland Basin.40	40
Figure 2.7. Generic cross-section showing petroleum-bearing traps—offshore Gippsland Basin.42	42
Figure 3.1. Location map of the study area—wells, bathymetric image and key physiographic features.....48	48
Figure 3.2. Northern Fields 3-D seismic survey area—offshore Gippsland Basin.49	49
Figure 3.3. Interpretation workflow—(a–b) age-depth plot and, (b–g) seismic data.55	55
Figure 3.4. Seismic sequence/interval, horizon, formation top, hiatus marker and fault nomenclature.58	58
Figure 3.5. Seismic resolution—application to fault detectability, (a) vertical and, (b) horizontal resolution.59	59
Figure 3.6. Merged unconformities of the study area—application to improving on well-tie control.64	64
Figure 3.7. Subcrop maps of the (a) ILHalS, (b) LHalSS and (c) IUHalS horizons, (d–e) representative sections.65	65
Figure 3.8. Age-space diagrams (a) Seaspray Gp, (c) Halibut–Cobia Sgps; age-depth plots (b) Flounder-5, (d) Tuna-4. 71	71
Figure 3.9. Depth structure—Mackerel Unconformity (MackMS horizon).....74	74
Figure 3.10. Depth structure—Latrobe Unconformity (LatrSS horizon).75	75
Figure 3.12. Subprovinces, fault families, fault zones, fault arrays and stand-alone faults—study area.81	81
Figure 3.13. Seismic interpretation of the Rosedale Fault System.83	83
Figure 3.14. Seismic interpretation of extensional and flower (strike-slip) structures—Flounder Field.84	84
Figure 3.15. Fault zones associated with the east and west Tuna fault families.86	86
Figure 3.16. Seismic interpretation of an inversion structure—Tuna Field.87	87
Figure 3.17. Seismic interpretation of an inversion structure—Flounder Field.88	88
Figure 3.18. Seismic interpretation of Early Eocene normal faults.90	90
Figure 3.19. Fault trace interpretation, (a) near-base and, (b) below the Tuna-Flounder Channel.91	91
Figure 3.20. Minor faults in the CongSS–SworSS intervals, (a) seismic section and, (b) slice (variance attribute).95	95
Figure 3.21. Seismic interpretation of an inversion structure—Longtom Field.96	96
Figure 3.22. Seismic interpretation of inversion structures—Tuna, Flounder and Pilotfish Fields.97	97
Figure 3.23. Events chart—Latrobe and Seaspray Groups99	99
Figure 3.24. Isopach map—combined UHalSS3–CobiSS intervals.....103	103
Figure 3.25. Time thickness map—combined CongSS to UWhiSS intervals.105	105
Figure 4.1. Generic cross-section showing the methodology adopted for depth conversion of SEG Y and ASCII data. ..123	123
Figure 4.2. Map showing distribution of checkshot and stacking velocity data—application to depth conversion.....124	124
Figure 4.3. Depth-conversion methodology for ASCII data.127	127
Figure 4.4. Depth-conversion methodology—example using checkshot data for Scallop-1.....128	128
Figure 4.5. Depth-conversion results, (a) seismic TWT profile and, (b) seismic depth profile.130	130
Figure 4.6. Bar graph showing depth-conversion errors—depth error plotted against checkshot count.133	133
Figure 5.1. Conceptual representation of a CO ₂ SL—portrayal of the criteria used to screen CO ₂ SLs.....137	137

Figure 5.2. Palaeoenvironment maps and sand-to-shale ratios—Latrobe Group (reservoir intervals).....	140
Figure 5.3. Palaeoenvironment maps and sand-to-shale ratios—Halibut and Cobia Sgps (reservoir–seal intervals).	141
Figure 5.4. Isopach map—SworSS interval.....	144
Figure 5.5. CO ₂ SLs at the Seahorse Unconformity—depth-structure map of the SeahSS horizon.....	146
Figure 5.6. CO ₂ SLs at the intra-lower Halibut unconformity—depth structure map of the ILSHalS horizon.	147
Figure 5.7. CO ₂ SLs at the lower Halibut unconformity—depth structure map of the LLSHalS horizon.	148
Figure 5.8. CO ₂ SLs at the intra-upper Halibut unconformity—depth structure map of the IUSHalS horizon.	149
Figure 5.9. CO ₂ SLs at the Mackerel Unconformity—depth structure map of the MackMS horizon.	150
Figure 5.10. CO ₂ SLs at the Latrobe Unconformity—depth structure map of the LatrSS horizon.	151
Figure 5.11. CO ₂ SL-12—isopach map of the Flounder Formation and Cobia Subgroup (seal intervals).....	152
Figure 5.12. Location of CO ₂ SLs—structural elements and fault strike.	153
Figure 5.13. Flow-path distances pertaining to subleads in the study area—horizons SeahSS–LatrSS.	159
Figure 5.14. Flow-path heights pertaining to subleads in the study area—horizons SeahSS–LatrSS.....	160
Figure 5.15. Average sweep areas pertaining to subleads in the study area—horizons SeahSS–LatrSS.	161
Figure 6.1. CO ₂ SL-1 to -3 (study subarea)—depth structure and faults.	174
Figure 6.2. Structural terminology used in fault seal analysis.....	176
Figure 6.3. Log-interpreted lithologies, sand lines and shale lines—application to generating V_{shale} curves.	178
Figure 6.4. Fault strike, dip and throw summary—study subarea.	183
Figure 6.5. Representative fluid-flow paths for CO ₂ SL-1 to -3—depth structure, faults and areas of trap breach.....	184
Figure 6.6. Stratigraphic cross-section showing interpreted unconformities across the Latrobe Group—study subarea.	190
Figure 6.7. Stratigraphic cross-section showing GR logs, lithology (cuttings), shows and porosity—study subarea.	191
Figure 6.8. Representative histogram of the GR log-curve response for the ULSHalS1 interval (3 API bins).	194
Figure 6.9. Stratigraphic cross-section showing GR logs and GR-generated V_{shale} curves—study subarea.....	195
Figure 6.10. Comparison between natural and Thorium GR-generated V_{shale} curves—error analysis.	198
Figure 6.11. Comparison of transmissivity cut-offs for the volume of shale (V_{shale}) and shale gouge ratio (SGR).....	199
Figure 6.12. Comparison of volume of shale (V_{shale}) profiles—sensitivity analysis.	201
Figure 6.13. Comparison of shale gouge ratio (SGR) profiles—sensitivity analysis.	202
Figure 6.14. Sensitivity analysis (shale index, sand and shale lines)—application when generating V_{shale} curves.	203
Figure 6.15. 3-D representation of a fault trap (fault F18) at the ILSHalS horizon—CO ₂ SL-1g and h.	206
Figure 6.16. Calculating the shale gouge ratio (SGR)—understanding the contribution of coal.	211
Figure 7.1. Conjugate planes of shear failure in differing fault regimes—classification after Anderson (1951).....	217
Figure 7.2. Effect of pore pressure at a reservoir depth of 2.5 km—study subarea.	218
Figure 7.3. Mohr's circle and failure envelopes.	219
Figure 7.4. Plot of cohesion versus coefficient of static friction—study subarea.	223
Figure 7.5. Mode-of-failure attributes: (a) dilation and (b) slip tendency and, (c) slip and (d) fracture stability.	225
Figure 7.6. Likelihood of fault reactivation estimated from mode-of-failure attributes (dilation, slip, fracture stability).	228
Figure 7.7. Fault reactivation modelling (ΔP)—study subarea, (a) cohesionless case and, (b) intact/healed case.	232
Figure 7.8. ΔP magnitudes at branch lines and at critical parts of stand-alone faults, (a) map and, (b–f) fault planes.	233
Figure 7.9. Comparison of ΔP at horizons LongSS–IUSHalS for (a) stand-alone faults and, (b) fault F18.	235
Figure 7.10. Fault reactivation estimations—differences in strike and ΔP for branched faults (master, splays).	236
Figure 7.11. Sensitivity of the fracture stability (ΔP) attribute to a +10° rotation of $S_{Hmax\theta}$ (from 139 to 149°N).....	238
Figure 7.12. Sensitivity of the fracture stability (ΔP) attribute when varying the fault regime with depth.	240

Table 3.1. Fault sets depicting the upper tip-line bound—application to differentiating faulting events.....	92
Table 5.1. Qualitatively-based screening of CO ₂ SLs and subleads.	168
Table 6.1. Thickness (m, %) of key lithologies—GBeaSS to SworSS intervals.....	186
Table 6.2. Estimation of CO ₂ column height and percentage of fault-trap fill at the ILHalS horizon—CO ₂ SL-1 to -3.....	205
Table 6.3. Smear continuity contrasted against fault throw.	208
Table 6.4. Top seal capacity of regional, local and intraformational seals—study area.	212
Table 7.1. Estimates of principal <i>in situ</i> stresses and pore pressure—Gippsland Basin.	222
Table 7.2. Estimates of principal <i>in situ</i> stresses at depth based on linear and power functions.	238

ABSTRACT

Geological storage of carbon dioxide (CO₂) is a mitigation option for reducing greenhouse gases. To date, CO₂ storage-related research in the Gippsland Basin, has focussed on detailing how the stratigraphy and facies, but not how the faults may affect CO₂ storage/fluid-flow and fault-trap integrity. This thesis addresses this latter deficiency through a 3-D seismic-based structural interpretation of CO₂ storage leads (CO₂SL) 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 CO₂ 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 CO₂SLs are identified and screened; areal closures are 16.9 ± 13 km² (excluding outliers), CO₂ 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 CO₂ 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 CO₂ 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 $\pm 33^\circ$). 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 CO₂ flow across-fault will adversely affect adjacent fault-block complexes, raising the concern that CO₂ 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.

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ABBREVIATIONS AND SYMBOLS

The abbreviations below are commonly used throughout this thesis.

Abs	absent	SS	subsea depth
CO₂SL	carbon dioxide storage lead	TD	total depth
Fm	formation	TVD	true vertical depth
Gp/Sgp	group/subgroup	TWT	two-way travel time
KB	kelly bushing	2-D	two-dimensional seismic data
MD	measured depth	3-D	three-dimensional seismic data
MSL	mean sea level	WCR	well completion report
NA	not applicable	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_{Hmaxθ}	–	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)
σ₁ , σ₂ , σ₃	–	maximum, intermediate and minimum principal stress (MPa)
σ₁' , σ₂' , σ₃'	–	effective maximum, intermediate and minimum principal stress (MPa)
μ	–	coefficient of internal friction
θ	–	angle between S _{Hmaxθ} 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