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 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 ............................................................................................

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 ....................................................................................

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
# Table of contents

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 CO₂ SLs ................................................................................ 145  
5.4.4 Screening of CO₂ SLs and subleads ............................................................... 163  
5.5 Discussion ............................................................................................................ 166  
5.5.1 Synthesis—traps .............................................................................................. 166
6.3 Methodology ..........................................................................................................................206
6.3.1 Framework geomodel.........................................................................................................175
6.3.2 Generating $V_{\text{shale}}$ 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 ..........................................................................................................................................206
6.4.1 $CO_2$ storage leads ...............................................................................................................182
6.4.2 Stratigraphic interpretation ...................................................................................................185
6.4.3 $V_{\text{shale}}$ curves ..................................................................................................................193
6.4.4 $V_{\text{shale}}$ 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
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
8.1 Introduction .....................................................................................................................................247
8.2 Geomechanical concepts ..............................................................................................................248
8.2.1 The stress tensor ..................................................................................................................248
8.2.2 Principal stress .....................................................................................................................248
8.2.3 Effective stress .....................................................................................................................250
8.2.4 Mohr’s circle .......................................................................................................................250
8.2.5 Rock failure criterion and envelope .....................................................................................251
8.3 Methodology ..................................................................................................................................252
8.3.1 Geomechanical input ..........................................................................................................252
8.3.2 Mode-of-failure attributes ....................................................................................................255
8.4 Results ..........................................................................................................................................258
8.4.1 Fault reactivation—stand-alone faults .................................................................................258
8.4.2 Fault reactivation—branched faults .......................................................................................261
8.4.3 Sensitivity analysis ...............................................................................................................264
8.5 Discussion ......................................................................................................................................267
8.5.1 Fault interpretation and model .............................................................................................267
8.5.2 Fault reactivation and fault-trap breach .............................................................................269
8.4 Conclusions ...................................................................................................................................273
9.1 Introduction .....................................................................................................................................274
9.2 Geomechanical concepts ..............................................................................................................275
9.2.1 The stress tensor ..................................................................................................................275
9.2.2 Principal stress .....................................................................................................................275
9.2.3 Effective stress .....................................................................................................................277
9.2.4 Mohr’s circle .......................................................................................................................277
9.2.5 Rock failure criterion and envelope .....................................................................................278
9.3 Methodology ..................................................................................................................................279
9.3.1 Geomechanical input ..........................................................................................................279
9.3.2 Mode-of-failure attributes ....................................................................................................282
9.4 Results ..........................................................................................................................................285
9.4.1 Fault reactivation—stand-alone faults .................................................................................285
9.4.2 Fault reactivation—branched faults .......................................................................................288
9.4.3 Sensitivity analysis ...............................................................................................................291
9.5 Discussion ......................................................................................................................................294
9.5.1 Fault interpretation and model .............................................................................................294
9.5.2 Fault reactivation and fault-trap breach .............................................................................296
9.4 Conclusions ...................................................................................................................................299
Table of contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>PREFACE—APPENDICES 1–3</td>
<td>271</td>
</tr>
<tr>
<td>APPENDIX 1—GEOLOGICAL DATASETS AND INTERPRETATION</td>
<td>273</td>
</tr>
<tr>
<td>A1.1 Well datasets and data distribution</td>
<td>273</td>
</tr>
<tr>
<td>A1.2 Formation tops and hiatus markers</td>
<td>281</td>
</tr>
<tr>
<td>APPENDIX 2—GEOPHYSICAL DATASETS AND INTERPRETATION</td>
<td>367</td>
</tr>
<tr>
<td>A2.1 Seismic acquisition and processing</td>
<td>367</td>
</tr>
<tr>
<td>A2.2 Seismic interpretation</td>
<td>371</td>
</tr>
<tr>
<td>A2.3 Checkshot data</td>
<td>385</td>
</tr>
<tr>
<td>A2.4 Seismic workstation and software</td>
<td>431</td>
</tr>
<tr>
<td>A2.5 Depth conversion of SEGY and ASCII data</td>
<td>431</td>
</tr>
<tr>
<td>APPENDIX 3—GEOMECHANICAL DATASETS AND FAULT SEAL ANALYSIS</td>
<td>447</td>
</tr>
<tr>
<td>APPENDIX 4—PUBLICATIONS</td>
<td>459</td>
</tr>
</tbody>
</table>
FIGURES AND TABLES

Figure 1.1. Geotechnical workflow for assessing CO₂ storage—sequence stratigraphic–depositional-based approach. ...6
Figure 1.2. Conceptual representation of key structural–stratigraphic factors critical to the fault/trap integrity in CO₂-SLs. .................................................................11
Figure 1.3. Geotechnical workflow for assessing CO₂ storage sites in this study—structure-based approach. ...............16
Figure 2.1. Structural elements and depth-to-basement map—Gippsland Basin. ............................................................18
Figure 2.2. Events chart of the Gippsland Basin—stratigraphy, basin phases and petroleum system elements. ........21
Figure 2.3. Seismic line-profiles showing the sequence stratigraphy of the Seaspray Group. .....................................23
Figure 2.4. TWT thickness maps, (a) Strzelecki Gp, (b) Emperor Gp, (c) Golden Beach Gp, (d) lower Halibut Gp. ....25
Figure 2.5. TWT thickness map of the Seaspray Group—post-Oligocene structures superimposed ................35
Figure 2.6. Wells, petroleum tenements, infrastructure and CO₂ concentrations—offshore Gippsland Basin. .........40
Figure 2.7. Generic cross-section showing petroleum-bearing traps—offshore Gippsland Basin .......................42
Figure 3.1. Location map of the study area—wells, bathymetric image and key physiographic features. .................48
Figure 3.2. Northern Fields 3-D seismic survey area—offshore Gippsland Basin. ....................................................49
Figure 3.3. Interpretation workflow—(a–b) age-depth plot and, (b–g) seismic data ..........................................................55
Figure 3.4. Seismic sequence/interval, horizon, formation top, hiatus marker and fault nomenclature. .......................58
Figure 3.5. Seismic resolution—application to fault detectability, (a) vertical and, (b) horizontal resolution .............59
Figure 3.6. Merged unconformities of the study area—application to improving on well-tie control .........................64
Figure 3.7. Subcrop maps of the (a) ILHalS, (b) LHalSS and (c) IUHalS horizons, (d–e) representative sections. ....65
Figure 3.8. Age-space diagrams (a) Seaspray Gp, (c) Halibut–Cobia Gps; age-depth plots (b) Flounder-5, (d) Tuna-4. 71
Figure 3.9. Depth structure—Mackerel Unconformity (MackMS horizon) .................................................................74
Figure 3.10. Depth structure—Latrobe Unconformity (LatrSS horizon) .................................................................75
Figure 3.11. Seismic interpretation of the Rosedale Fault System .................................................................81
Figure 3.12. Subprovinces, fault families, fault zones, fault arrays and stand-alone faults—study area. ..................83
Figure 3.13. Seismic interpretation of an inversion structure—Flounder Field .......................................................84
Figure 3.14. Seismic interpretation of extensional and flower (strike-slip) structures—Flounder Field .................86
Figure 3.15. Fault zones associated with the east and west Tuna fault families .....................................................87
Figure 3.16. Seismic interpretation of an inversion structure—Tuna Field ............................................................88
Figure 3.17. Seismic interpretation of an inversion structure—Flounder Field .....................................................89
Figure 3.18. Seismic interpretation of Early Eocene normal faults .................................................................90
Figure 3.19. Fault trace interpretation, (a) near-base and, (b) below the Tuna-Flounder Channel.........................91
Figure 3.20. Minor faults in the CongSS–SwoRSS intervals, (a) seismic section and, (b) slice (variance attribute). 95
Figure 3.21. Seismic interpretation of an inversion structure—Longtom Field .....................................................96
Figure 3.22. Seismic interpretation of inversion structures—Tuna, Flounder and Pilotfish Fields ........................97
Figure 3.23. Events chart—Latrobe and Seaspray Groups.................................................................99
Figure 3.24. Isopach map—combined UHalSS–CobiSS intervals .................................................................103
Figure 3.25. Time thickness map—combined CongSS to UWhiSS intervals .....................................................105
Figure 4.1. Generic cross-section showing the methodology adopted for depth conversion of SEGY and ASCII data. 123
Figure 4.2. Map showing distribution of checkshot and stacking velocity data—application to depth conversion ....124
Figure 4.3. Depth-conversion methodology for ASCII data .................................................................127
Figure 4.4. Depth-conversion methodology—example using checkshot data for Scallop-1 .................................128
Figure 4.5. Depth-conversion results, (a) seismic TWT profile and, (b) seismic depth profile ..............................130
Figure 4.6. Bar graph showing depth-conversion errors—depth error plotted against checkshot count ............133
Figure 5.1. Conceptual representation of a CO₂-SL—portrayal of the criteria used to screen CO₂-SLs ..................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. CO2SLs at the Seahorse Unconformity—depth-structure map of the SeahSS horizon .............................. 146
Figure 5.6. CO2SLs at the intra-lower Halibut unconformity—depth structure map of the ILHalS horizon ............... 147
Figure 5.7. CO2SLs at the lower Halibut unconformity—depth structure map of the LHalS horizon ................................. 148
Figure 5.8. CO2SLs at the intra-upper Halibut unconformity—depth structure map of the IUHalS horizon .......... 149
Figure 5.9. CO2SLs at the Mackerel Unconformity—depth structure map of the MackMS horizon ............................. 150
Figure 5.10. CO2SLs at the Latrobe Unconformity—depth structure map of the LatrSS horizon ............................... 151
Figure 5.11. CO2SL-12—isopach map of the Flounder Formation and Cobia Subgroup (seal intervals) ...................... 152
Figure 5.12. Location of CO2SLs—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. CO2SL-1 to -3 (study subarea)—depth structure and faults ....................................................... 174
Figure 6.2. Structural terminology used in fault seal analysis .................................................................................. 175
Figure 6.3. Log-interpreted lithologies, sand lines and shale lines—application to generating Vshale curves ............ 176
Figure 6.4. Fault strike, dip and throw summary—study subarea ........................................................................ 178
Figure 6.5. Representative fluid-flow paths for CO2SL-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 UHalS1 interval (3 API bins) ............. 194
Figure 6.9. Stratigraphic cross-section showing GR logs and GR-generated Vshale curves—study subarea ............. 195
Figure 6.10. Comparison between natural and Thorium GR-generated Vshale curves—error analysis .......... 198
Figure 6.11. Comparison of transmissivity cut-offs for the volume of shale (Vshale) and shale gouge ratio (SGR) .... 199
Figure 6.12. Comparison of volume of shale (Vshale) 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 Vshale curves .... 203
Figure 6.15. 3-D representation of a fault trap (fault F18) at the ILHalS horizon—CO2SL-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. Location of CO2SLs—structural elements and fault strike ............................................................. 153
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–IUHalS 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 Smax from 139 to 149°N .......... 238
Figure 7.12. Sensitivity of the fracture stability (ΔP) attribute when varying the fault regime with depth .............. 240
Figures and tables

Table 3.1. Fault sets depicting the upper tip-line bound—application to differentiating faulting events.................................92
Table 5.1. Qualitatively-based screening of CO₂ SLs and subleads ........................................................................................168
Table 6.1. Thickness (m, %) of key lithologies—GBeaSS to SworSS intervals ...........................................................................186
Table 6.2. Estimation of CO₂ column height and percentage of fault-trap fill at the ILHalS horizon—CO₂ 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 in situ stresses and pore pressure—Gippsland Basin ...............................................................222
Table 7.2. Estimates of principal in situ 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 ± 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 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.

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abs</td>
<td>absent</td>
</tr>
<tr>
<td>CO₂SL</td>
<td>carbon dioxide storage lead</td>
</tr>
<tr>
<td>Fm</td>
<td>formation</td>
</tr>
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<td>subsea depth</td>
</tr>
<tr>
<td>TD</td>
<td>total depth</td>
</tr>
<tr>
<td>TVD</td>
<td>true vertical depth</td>
</tr>
<tr>
<td>TWT</td>
<td>two-way travel time</td>
</tr>
<tr>
<td>2-D</td>
<td>two-dimensional seismic data</td>
</tr>
<tr>
<td>3-D</td>
<td>three-dimensional seismic data</td>
</tr>
<tr>
<td>WCR</td>
<td>well completion report</td>
</tr>
<tr>
<td>WD</td>
<td>water depth</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>cohesion/cohesive strength</td>
</tr>
<tr>
<td>P_p</td>
<td>pore pressure (MPa)</td>
</tr>
<tr>
<td>S_Hmax</td>
<td>maximum horizontal stress</td>
</tr>
<tr>
<td>S_Hmaxθ</td>
<td>azimuth (°N)</td>
</tr>
<tr>
<td>S_Hmin</td>
<td>minimum horizontal stress</td>
</tr>
<tr>
<td>S_v</td>
<td>vertical stress</td>
</tr>
<tr>
<td>S_Hmax', S_Hmin', S_v'</td>
<td>effective maximum, minimum and vertical stress magnitude (MPa)</td>
</tr>
<tr>
<td>SGR</td>
<td>shale gouge ratio</td>
</tr>
<tr>
<td>T</td>
<td>tensile strength (MPa)</td>
</tr>
<tr>
<td>V_shale</td>
<td>volume of shale</td>
</tr>
<tr>
<td>σ_s, σ_n</td>
<td>shear stress, normal stress (MPa)</td>
</tr>
<tr>
<td>σ_1, σ_2, σ_3</td>
<td>maximum, intermediate and minimum principal stress (MPa)</td>
</tr>
<tr>
<td>σ_1', σ_2', σ_3'</td>
<td>effective maximum, intermediate and minimum principal stress (MPa)</td>
</tr>
<tr>
<td>μ</td>
<td>coefficient of internal friction</td>
</tr>
<tr>
<td>θ</td>
<td>angle between S_Hmaxθ and the normal to the plane (°)</td>
</tr>
<tr>
<td>Φ</td>
<td>angle of internal friction (°)</td>
</tr>
<tr>
<td>ΔP</td>
<td>maximum sustainable pore pressure increase (determined from fault reactivation modelling, MPa)</td>
</tr>
</tbody>
</table>

The units below are commonly used.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPa</td>
<td>megapascals (1 MPa = 145.03 psi = 10 bar)</td>
</tr>
<tr>
<td>Bbbl</td>
<td>barrel</td>
</tr>
</tbody>
</table>