

# Contents

<b>Acknowledgements</b>	<b>iii</b>
<b>Abstract</b>	<b>v</b>
<b>Introduction</b>	<b>1</b>
<b>I Seafloor Morphology of the Osbourn Trough and Kermadec Trench</b>	<b>7</b>
<b>1 Morphology and Origin of the Osbourn Trough</b>	<b>9</b>
<b>Abstract</b>	<b>10</b>
1.1 Introduction . . . . .	11
1.2 Observations: Bathymetry, Gravity and Magnetics . . . . .	13
1.3 Analysis of Ship Track Data . . . . .	17
1.4 Discussion . . . . .	21
1.5 Conclusions . . . . .	23
References . . . . .	27
<b>2 Morphology and Strength of the Pacific Plate Within the Kermadec Trench</b>	<b>29</b>
<b>Abstract</b>	<b>30</b>
2.1 Introduction . . . . .	31
2.2 Swath Bathymetry and Gravity Observations . . . . .	33
2.3 Response Function Analysis for Plate Rigidity . . . . .	38
2.4 Discussion and Conclusions . . . . .	44
References . . . . .	49

<b>II</b>	<b>Multiscale Dynamics of Subduction Zones</b>	<b>51</b>
<b>3</b>	<b>A Low Viscosity Wedge in Subduction Zones</b>	<b>53</b>
	<b>Abstract</b>	<b>54</b>
3.1	Introduction . . . . .	55
3.2	Dynamic Models with a Low Viscosity Wedge . . . . .	58
3.2.1	2-D Models . . . . .	60
3.2.2	3-D Models: Tonga-Kermadec Subduction Zone . . . . .	62
3.3	Discussion . . . . .	63
3.3.1	Mineral Physics Constraints on Wedge Viscosity . . . . .	64
3.3.2	Geophysical and Geochemical Implications of a LVW . . . . .	66
3.4	Conclusions . . . . .	67
	References . . . . .	72
<b>4</b>	<b>Multiscale Dynamics of the Tonga-Kermadec Subduction Zone</b>	<b>73</b>
	<b>Abstract</b>	<b>74</b>
4.1	Introduction . . . . .	76
4.2	Dynamic Modeling Constraints on Viscosity . . . . .	77
4.2.1	Long Wavelength Geoid and Topography . . . . .	77
4.2.2	Short Wavelength Topography and Gravity . . . . .	79
4.2.3	Seismological Constraints on Viscosity . . . . .	81
4.3	The Subduction Zone Wedge . . . . .	82
4.3.1	Evidence of a Low Viscosity Wedge . . . . .	83
4.3.2	Sources of Buoyancy in the Wedge . . . . .	85
4.4	Numerical Method . . . . .	86
4.4.1	Model Domain and Boundary Conditions . . . . .	88
4.4.2	Density Structure . . . . .	90
4.4.3	Surface Observables . . . . .	91
4.5	2-D Models of Subduction Zone Dynamics . . . . .	94
4.5.1	Radial and Temperature Dependent Viscosity Models . . . . .	96
4.5.2	Low Viscosity Wedge Models . . . . .	104

4.5.3	Buoyancy in the LVW . . . . .	109
4.5.4	Fault Singularity . . . . .	110
4.5.5	Summary of 2-D Models . . . . .	112
4.6	3-D Models of the Tonga-Kermadec Subduction Zone . . . . .	113
4.6.1	Dynamic Topography . . . . .	115
4.6.2	Multiscale Analysis of the Geoid . . . . .	120
4.7	Discussion and Conclusions . . . . .	128
<b>A</b>	<b>Transformation of Citcom with Faults to Spherical Geometry</b>	<b>134</b>
A.1	Faults in Spherical Coordinates . . . . .	135
<b>B</b>	<b>Dynamic Topography Benchmark</b>	<b>137</b>
B.1	Long Wavelength Topography and Radial Viscosity Structure . . . . .	137
B.2	Short Wavelength Topography and Lateral Viscosity Structure . . . . .	140
<b>C</b>	<b>Geoid and Gravity Calculation</b>	<b>142</b>
C.1	Geoid and Gravity . . . . .	143
C.2	Benchmarks . . . . .	144
<b>D</b>	<b>Slab Buoyancy</b>	<b>146</b>
<b>E</b>	<b>Behavior of a Low Viscosity Region: 2-D Test Cases</b>	<b>149</b>
	References . . . . .	164
<b>5</b>	<b>The Central Aleutian and Tonga-Kermadec Subduction Zones: Stress, Topography and Geoid in Dynamic Flow Models with a Low Viscosity Wedge.</b>	<b>165</b>
	<b>Abstract</b>	<b>166</b>
5.1	Introduction . . . . .	168
5.2	Numerical Method . . . . .	171
5.3	3-D Model Results for the Central Aleutians . . . . .	178
5.4	Discussion and Conclusions . . . . .	182
	References . . . . .	193

## List of Tables

4.1	Model Parameters . . . . .	88
5.1	Model Parameters . . . . .	173

## List of Figures

1.1	Satellite Gravity Image of Osbourn Trough Study Region . . . . .	11
1.2	Swath Bathymetry Map and Gravity Across the Osbourn Trough . . .	13
1.3	Data Profiles and Gravity Model Across Osbourn Trough . . . . .	14
1.4	Magnetic Anomaly Models for the Osbourn Trough . . . . .	16
1.5	Echo Sounder Profiles Across the Osbourn Trough . . . . .	17
1.6	Tectonic Interpretation for the Osbourn Trough . . . . .	22
2.1	Satellite Gravity Image and Shiptrack Location . . . . .	34
2.2	Bathymetry and Gravity Data Profiles for the Kermadec Trench and Pacific Plate . . . . .	35
2.3	3-D Color Image os Seabeam Data within Kermadec Trench . . . . .	36
2.4	Contour Color Image of Seabeam Data within Kermadec Trench . . .	37
2.5	Isostatic Flexural Response within the Kermadec Trench: single ping.	40
2.6	Isostatic Flexural Response within the Kermadec Trench: 80 pings. .	41
2.7	Isostatic Flexural Response for normal Pacific seafloor. . . . .	42
2.8	Isostatic Flexural Response for Seafloor 100 km Seaward of the Ker- madec Trench. . . . .	42
2.9	Schematic for Lithospheric Weakening Length Scale . . . . .	45
3.1	Comparison of Observed and Predicted Gravity, Geoid and Topogra- phy for the Tonga-Kermadec Subduction Zone . . . . .	56
3.2	Effect of LVW Shape and Depth on Topography . . . . .	59
3.3	Pressure and Velocity of Tonga-Kermadec Models With and Without a LVW . . . . .	61
4.1	Map of Observed Geoid in the Tonga-Kermadec Region . . . . .	77
4.2	Map of Observed Bathymetry in Tonga-Kermadec Region . . . . .	80
4.3	A 3-D View of the Mesh and Model Domain . . . . .	89
4.4	Age of the Seafloor in the Tonga-Kermadec Region . . . . .	92

4.5	Basin Depth Dependence on $\eta_{slab}$ and $\eta_{lith}$ for Models 1a–11c. . . . .	97
4.6	Topography and Flow Dependence on Upper Plate Age . . . . .	98
4.6	Caption for Figure 4.6 . . . . .	99
4.7	Effect of Slab Viscosity on Flow . . . . .	100
4.8	Stress Directions Within the Slab for Models With and Without a LVW103	
4.9	Geometry of the Low Viscosity Wedge. . . . .	105
4.10	Effect of Positive Buoyancy in the LVW on Flow . . . . .	111
4.11	Cross Sections of Topography for Tonga 3-D Models . . . . .	116
4.12	Maps of Predicted Topography for 3-D Models. . . . .	118
4.13	Maps of Predicted Geoid for Tonga 3-D Models 1–8. . . . .	119
4.14	Localized R.M.S. Amplitude for the Observed Geoid at 28°S . . . . .	120
4.15	Geoid Localization for Tonga Model 1. . . . .	123
4.16	Geoid Localization for Tonga Model 3. . . . .	124
4.17	Geoid Localization for Tonga Model 7. . . . .	125
4.18	Geoid Localization for Tonga Model 8. . . . .	127
B.1	Topography Benchmark for Columnar Viscosity . . . . .	141
C.1	Geoid anomaly benchmark for a buried point source . . . . .	145
D.1	Corner Flow Velocity and Input Slab Bouyancy . . . . .	148
E.1	Geometry of Simple LVZ Models . . . . .	149
E.2	Pressure and Flow for Model Types 1–4 without a LVZ . . . . .	151
E.3	Topography Profiles for Simple LVZ Models . . . . .	152
E.4	Pressure and Flow for Model Types 1–4 with Cylinder in Position A .	153
E.5	Pressure and Flow for Model Types 1–4 with Cylinder in Position B .	154
E.6	Pressure and Flow for Model Types 1–4 with Cylinder in Position C .	155
5.1	Observed Bathymetry and Geoid for the Central Aleutians . . . . .	169
5.2	Age of the Seafloor in the Central Aleutians . . . . .	174
5.3	Comparison of Observed and Predicted Topography: Central Aleutian Models . . . . .	177
5.4	Maps of Predicted Geoid and Dynamic Topography for Central Aleutians.	178

5.5	Geoid Localization for Central Aleutian Models . . . . .	180
5.6	Comparison of Central Aleutians and Tonga-Kermadec Models. . . . .	183
5.6	Caption for Figure 5.6 . . . . .	184

