

Contents

<i>List of contributors</i>	xi		
<i>Preface</i>	xiii		
<i>Acknowledgements</i>	xvii		
1 Geodynamic controls on glaciation in Earth history	1		
N. EYLES and G.M. YOUNG			
Abstract	1		
Introduction	1		
Late Archean–Paleoproterozoic glaciations	2		
Mesoproterozoic non-glacial epoch	3		
Neoproterozoic glaciations	5		
Overview	5		
Timing and tectonic setting	6		
The importance of extensional rift basins	7		
South Australia/northern Canadian Cordillera	7		
North Atlantic sector	8		
Discussion	9		
Early and Late Paleozoic glaciations	10		
South America	11		
South Africa	14		
Australia	15		
Antarctica	17		
Southeast Asia	17		
Arabian Peninsula	17		
India and Pakistan	17		
Discussion	18		
Mesozoic glaciation	18		
Late Cenozoic glaciations	19		
The role of tectonic uplift	19		
The role of ocean currents	21		
Conclusions	22		
Acknowledgements	22		
References	22		
2 Glacial-marine facies in a continental rift environment: Neoproterozoic rocks of the western United States Cordillera	29		
P.K. LINK, J.M.G. MILLER and N. CHRISTIE-BLICK			
Abstract	29		
Introduction	29		
Evidence for overall glacial origin	31		
Facies associations	31		
Review of stratigraphy	34		
Death Valley region of southeastern California (Kingston Peak Formation)	36		
Central Wasatch Range and Antelope Island, northern Utah (Mineral Fork Formation)	36		
Fremont Island, Little Mountain and Ogden area, northern Utah (formation of Perry Canyon)	37		
Sheeprock Mountains and Deep Creek Range, western Utah (Sheeprock Group and Horse Canyon Formation)	37		
Southeastern Idaho (Pocatello Formation)	38		
Interpretation of facies associations	38		
Massive diamictite facies association: ice-proximal non-reworked deposits	38		
Stratified diamictite and graded sandstone association: sediment gravity flow deposits	39		
Diamictite and laminated sandstone association: ice- proximal deposits with abundant meltwater	39		
Carbonate, shale and sandstone association: non- glacial marine deposits	40		
Cross-bedded sandstone association: fluvial deposits	40		
Discussion: facies distribution, subsidence mechanisms, unconformities and preservation potential in rift settings	40		
Subsidence mechanisms	40		
Relation of facies to tectonic position	41		
Generation of unconformities	41		
Geologic setting of the Rapitan glaciation	42		
Acknowledgements	42		
References	42		
3 The Neoproterozoic Konnarock Formation, southwestern Virginia, USA: glaciolacustrine facies in a continental rift	47		
J.M.G. MILLER			
Abstract	47		
Introduction	47		
Stratigraphic and structural setting	48		
Paleotectonic setting	50		
Facies and facies associations	50		
Argillite	50		
Sandstone	53		
Diamictite	54		
Environmental synthesis	55		
Conclusion	57		
Acknowledgements	57		
References	57		
4 Glaciogenic deposits of the Permo-Carboniferous Dwyka Group in the eastern region of the Karoo Basin, South Africa	60		
V. VON BRUNN			
Abstract	60		

viii	Contents		
Introduction	60	Poorly stratified diamictite facies	103
Pre-Dwyka highland surface (Northern Region)	60	Bedded diamictite facies	103
Zone of irregular palaeorelief (Intermediate Region)	62	Dropstone-bearing laminated lithofacies	103
Diamictite–mudrock facies association	63	Thin-bedded to banded-laminated siltstone–mudstone facies	104
Sandstone–arenaceous diamictite–conglomerate facies association	63	The Wudaotang Section in Helan County	104
Pre-Dwyka lowland plain (Southern Region)	65	The Tuerkeng Section	105
Sequence of events	66	The Zhengmuguan Section	105
Discussion	67	The Jingdiquan Section	105
Acknowledgements	68	REE geochemical characteristics of the Zhengmuguan Formation	106
References	68	Sedimentary facies and environmental analysis	107
5 Itararé Group: Gondwanan Carboniferous–Permian of the Paraná Basin, Brazil	70	Conclusions	107
A. B. FRANÇA		References	107
Abstract	70	9 Architectural styles of glacially influenced marine deposits on tectonically active and passive margins	109
Introduction	70	M. R. GIPP	
Tectonic setting	70	Abstract	109
Stratigraphy	71	Introduction	109
Lagoa Azul Formation	72	The Gulf of Alaska	109
Campo Mourão Formation	73	The Scotian margin	110
Taciba Formation	75	Models	111
Summary and conclusions	76	Passive margin	111
Acknowledgements	82	Active margin	112
References	82	Similarities	113
6 The interpretation of massive rain-out and debris-flow diamictites from the glacial marine environment	83	Distinguishing features in the models	116
J. N. J. VISSER		Other examples	117
Abstract	83	Summary	119
Introduction	83	Acknowledgements	119
Massive diamictites from the Dwyka Formation	84	References	119
Floriskraal	84	10 Marine to non-marine sequence architecture of an intracratonic glacially related basin. Late Proterozoic of the West African platform in western Mali	121
Elandsvlei	86	J. N. PROUST and M. DEYNOUX	
Kransgat River	87	Abstract	121
Douglas	90	Introduction	121
Discussion	92	Baselevel concept	122
Acknowledgements	94	Geological setting	122
References	94	Definition of the depositional genetic unit from the sediment architecture of a key exposure	124
7 Neoproterozoic tillite and tilloid in the Aksu area, Tarim Basin, Uygur Xinjiang Autonomous Region, Northwest China	95	Facies distribution in architectural elements	127
LU SONGNIAN and GAO ZHENJIA		Landward-stepping unit	127
Abstract	95	Vertical stacking unit	130
Introduction	95	Seaward-stepping unit	132
The Precambrian stratigraphic sequences	95	Discussion	135
Sedimentary features of diamictites in the Qiaoenbulak Group	97	Bimodal facies architecture and time/space distribution of sediments and bounding surfaces within genetic units	135
Features of the diamictite of the Umainak Formation (Wushinanshan Group)	98	Stacking cycle	137
Comparison between diamictites of the Qiaoenbulak Group and the Wushinanshan Group	98	Comparison with genetic units described in the literature	138
Acknowledgements	99	Estimated baselevel cycles duration	139
References	99	Inferred factors controlling sedimentation	139
8 Lithology, sedimentology and genesis of the Zhengmuguan Formation of Ningxia, China	101	Conclusion	141
ZHENG ZHAOCHANG, LI YUZHEN, LU SONGNIAN and LI HUAIKUN		Acknowledgements	141
Abstract	101	References	142
Introduction	101	11 The enigmatic Late Proterozoic glacial climate: an Australian perspective	146
Tectonic and stratigraphic setting of the Zhengmuguan Formation	101	G. E. WILLIAMS	
The sedimentary facies and their associations in the Zhengmuguan Formation	103	Abstract	146
Massive diamictite facies	103	Introduction	146
		Late Proterozoic glacial and periglacial climate	146
		Possible explanations of low-palaeolatitude glaciation	153
		Global refrigeration	153

Contents

ix

Equatorial ice-ring system	154	Whitehill Formation	198
Geomagnetic field non-axial	154	Palaeoclimatic reconstruction	198
Obliquity of the ecliptic > 54°	155	Depositional model for the mudrocks	200
Other evidence for Late Proterozoic obliquity	156	Conclusions	201
Discussion	159	Acknowledgements	202
Conclusions	161	References	202
Acknowledgements	161	15 A palaeoenvironmental study of black mudrock in the	204
References	161	glacigenic Dwyka Group from the Boshof–Hertzogville	
12 Isotopic signatures of carbonates associated with	165	region, northern part of the Karoo Basin, South Africa	
Sturtian (Neoproterozoic) glacial facies, central Flinders		D.I. COLE and A.D.M. CHRISTIE	
Ranges, South Australia		Abstract	204
A.R. CROSSING and V.A. GOSTIN		Introduction	204
Abstract	165	Geology	204
Introduction	165	Depositional environment of the Dwyka Group	205
Regional stratigraphy	165	Black mudrock	208
Methods	167	Description	208
Isotopic and geochemical analysis	167	Total organic carbon and organic composition	210
Palaeoenvironmental and diagenetic interpretation	169	Palaeoenvironment	210
Interpretation of ancient dolomites	170	Conclusions and regional analysis	212
Comparison with other Neoproterozoic dolomites	170	Acknowledgements	213
The overlying isotopic signal	173	References	213
Geochemistry and the carbon signal	174	16 Late Paleozoic post-glacial inland sea filled by fine-	215
Conclusions	174	grained turbidites: Mackellar Formation, Central	
Acknowledgements	174	Transantarctic Mountains	
References	174	M.F. MILLER and J.W. COLLINSON	
13 Reactive carbonate in glacial systems: a preliminary	176	Abstract	215
synthesis of its creation, dissolution and reincarnation		Introduction	215
I.J. FAIRCHILD, L. BRADBY and B. SPIRO		Stratigraphic setting	215
Abstract	176	Facies	217
Introduction	176	Shale facies	217
Creation of fine detrital carbonate	178	Interbedded sandstone and shale facies	217
Chemical controls on dissolution and precipitation	179	Massive sandstone facies	220
Weathering reactions	179	Burrowed sandstone facies	220
Equilibrium thermodynamics	180	Diamictite facies	221
Kinetics factors	181	Large-scale cross-stratified sandstone facies	222
Mechanisms of precipitation	182	Large-scale channels	223
Ripening	182	Facies associations and depositional environments	223
Warming	183	Facies associations	223
Freezing	183	Depositional environments	224
Common ion effect	183	Paleocurrents	226
Changes in CO ₂ and alkalinity	184	Paleosalinity	226
Evaporation and transpiration	184	Biogenic structures	226
Skeletal biomineralization	184	Carbon:sulfur ratios	226
Recent examples	184	Comparison with Upper Paleozoic post-glacial	
Carbonate saturations of proglacial waters	184	marine sequences	226
Processes in the ice-marginal meltout zone	186	Summary	227
Crusts on clasts: regelation versus vadose zone		Water depth	227
phenomena	188	Paleogeography	227
Post-glacial transformations	189	Model for filling of the Mackellar post-glacial inland	
Application to glacial sedimentary sections	190	sea	228
Crusts on clasts	190	Basinal processes and environments	228
Diamict matrix and muds	190	Shoreline processes and environments	230
Sorted sands and gravels	190	Model	230
Acknowledgements	190	Conclusions	230
References	190	Appendix. Outcrop locations	231
14 A Permian argillaceous syn- to post-glacial foreland	193	Acknowledgements	231
sequence in the Karoo Basin, South Africa		References	231
J.N.J. VISSER		17 Ice scouring structures in Late Paleozoic rhythmites,	234
Abstract	193	Paraná Basin, Brazil	
Introduction	193	A.C. ROCHA-CAMPOS, P.R. DOS SANTOS and J.R.	
Spatial and age relationships of the Prince Albert and		CANUTO	
Whitehill Formations	193	Abstract	234
Lithology	196	Introduction	234
Prince Albert/Pietermaritzburg Formations	196	Stratigraphic setting	234

Ice scour structures	236	Icebergs and glacimarine sediments in East Greenland	249
Discussion	237	Origin of massive diamicton and ice keel turbate	249
Acknowledgements	239	Criteria for distinguishing glacimarine diamictons and related facies	252
References	239	Discussion	253
18 Soft-sediment striated surfaces and massive diamicton facies produced by floating ice	241	Summary and conclusions	256
C.M.T. WOODWORTH-LYNAS and J.A. DOWDESWELL		Acknowledgements	256
Abstract	241	References	256
Introduction	241	19 Environmental evolution during the early phase of Late Proterozoic glaciation, Hunan, China	260
Origins of soft-sediment striated surfaces	242	QI RUI ZHANG	
Subglacial flutes	242	Abstract	260
Ice sheet grounding line striations	242	Introduction	260
Surfaces formed by free-floating ice masses	242	Geological setting	260
Scour by free-floating ice masses: ice keel scour mark morphology and identification criteria	243	Sedimentology of the Xieshuihe Formation	260
Examples of ice keel scour marks and soft-sediment striated surfaces in ancient glacial sediments	243	Features of the upper contact of the Xieshuihe Formation	264
Background	243	Discussion	266
Examples	244	Acknowledgement	266
Iceberg scouring and massive diamicton formation in the modern glacimarine environment of East Greenland	249	References	266