

# Contents

<b>1</b>	<b>The Nature and Importance of Aeolian Sand Research</b> .....	1
1.1	Definitions .....	1
1.2	Previous Work .....	3
1.3	Future Research Requirements .....	6
<b>2</b>	<b>The Nature of Airflow</b> .....	9
2.1	Physical Properties of Air and the Earth's Atmosphere .....	9
2.1.1	The Nature of Air as a Gas .....	9
2.1.2	Composition of the Lower Atmosphere .....	10
2.1.3	Vertical Gradient of Temperature and Stability of the Atmosphere .....	11
2.2	Nature and Types of Air Motion .....	13
2.2.1	Horizontal Air Motion .....	13
2.2.2	The Global Atmospheric Circulation .....	15
2.3	Storm Types that Generate Sand-Transporting Winds .....	18
2.3.1	The Energy of Violent Storms .....	18
2.3.2	Atmospheric Stability and Instability in Subtropical Deserts	21
2.3.3	Dust Devils .....	23
2.3.4	Squalls .....	24
2.3.5	Wind Regimes in the World's Deserts .....	26
2.3.6	Coastal Wind Regimes .....	30
2.4	Flow in the Atmospheric Boundary Layer .....	32
2.4.1	Viscosity, Reynolds Number and Their Effect on the Airflow .....	32
2.4.2	Variation of Wind Velocity with Height .....	35
2.4.3	Continuity of Airflow: Bernoulli Equation and Separation of Flow .....	40
2.4.4	The Drag Force .....	43
2.4.5	Airflow over Isolated Hills and Complex Terrain .....	46

<b>3</b>	<b>Characteristics of Windblown Sediments</b> .....	51
3.1	General Properties of Sediment Grains .....	51
3.1.1	Concepts of Grain Size .....	51
3.1.2	Grain Size Scales .....	53
3.1.3	Grain Mass and Density .....	54
3.1.4	Graphical Presentation of Grain Size Data .....	56
3.1.5	Graphical Statistical Parameters .....	58
3.1.6	Moment Parameters .....	60
3.1.7	Bivariate Plots and Statistical Analysis of Grain Size Parameters .....	60
3.1.8	Log-Hyperbolic Parameters .....	61
3.2	Grain Shape .....	65
3.2.1	Grain Form .....	65
3.2.2	Grain Roundness .....	67
3.2.3	Grain Surface Texture .....	68
3.2.4	Two-Dimensional Analysis of Digitized Grain Outlines ....	68
3.2.5	Behavioural Indicators of Grain Shape .....	71
3.2.6	Controls on the Shape of Sand Grains .....	71
3.3	Porosity, Permeability, and Packing of Sands .....	72
3.4	Grain Size Characteristics of Aeolian Sediments .....	74
3.4.1	The Nature of Aeolian Sediments .....	74
3.4.2	Differentiation Between Aeolian Dune and Other Environments .....	77
3.4.3	Grain Size Variations Within Dune Fields and on Individual Dunes .....	80
3.5	Shape Characteristics of Aeolian Dune Sands .....	82
3.6	Surface Textures of Aeolian Sands .....	86
3.7	Porosity and Permeability of Aeolian Sands .....	89
3.8	Sources and Mineral Composition of Aeolian Dune Sand .....	89
3.8.1	Weathering and Erosion of Crustal Rocks .....	90
3.8.2	Formation of Sand-Size Particles in the Near-Surface Environment .....	92
3.8.2.1	Gypsum Sands .....	92
3.8.2.2	Clay Pellets .....	92
3.8.2.3	Volcaniclastic Sands .....	94
3.8.2.4	Carbonate Ooids and Peloids .....	95
3.8.3	Formation of Biogenic Carbonate Sand .....	96
<b>4</b>	<b>Mechanics of Aeolian Sand Transport</b> .....	99
4.1	Particle Entrainment .....	99
4.1.1	Forces Exerted on Static Grains by the Wind .....	99
4.1.2	Threshold of Grain Movement .....	101
4.1.3	Impact Threshold .....	106
4.1.4	Threshold Velocities for Poorly Sorted Sediments .....	108
4.1.5	Effect of Bed Slope on Threshold Velocity .....	109

4.1.6	Effect of Moisture Content and Cementing Agents on Threshold Velocity .....	110
4.1.7	Effects of Non-Erodible Roughness Elements and Vegetation on Particle Entrainment .....	113
4.2	Transport of Particles by the Wind .....	113
4.2.1	Aeolian Transport Modes .....	113
4.2.2	Suspension .....	116
4.2.3	Saltation .....	116
4.2.4	Wind Velocity Profile During Saltation .....	124
4.2.5	Contact Load (Surface Creep) .....	127
4.2.6	Sand Transport Rate .....	128
4.2.7	Avalanching of Sand on Dune Slip Faces .....	136
<b>5</b>	<b>The Formation of Sand Seas and Dune Fields .....</b>	<b>141</b>
5.1	Definition of Sand Seas and Dune Fields .....	141
5.2	Global Distribution of Sand Seas .....	141
5.3	Factors Controlling the Distribution and Magnitude of Sand Seas .....	147
5.3.1	Sand Sources and Dune Field Development .....	147
5.3.2	Relationship Between Sand Deposits and Climate .....	153
5.3.3	Time Required for the Development of Ergs and Dune Fields .....	155
5.4	Development of Sand Seas in Relation to Topography .....	156
5.5	Wind Regime and Regional Sand Flow Paths .....	159
5.6	Evolution of Ergs in Response to Climatic Changes .....	168
5.7	Effect of Sea-Level Changes on Coastal Dune Fields .....	170
5.8	Effect of Sea-Level Changes on Continental Dune Fields .....	172
<b>6</b>	<b>Aeolian Bed Forms .....</b>	<b>175</b>
6.1	Types of Aeolian Sand Accumulation and Bed Form Terminology ..	175
6.2	Ripples .....	176
6.2.1	The General Nature of Sand Ripples .....	176
6.2.2	Effect of Wind Velocity and Grain Size on Aeolian Ripple Development .....	178
6.2.3	Models of Ripple Formation .....	180
6.2.4	Adhesion Ripples .....	184
6.3	Sand Dunes .....	185
6.3.1	Classification of Sand Dunes and Other Aeolian Sand Accumulations .....	185
6.3.2	Dune Accumulation Influenced by Topographic Obstacles ..	190
6.3.2.1	Lee Dunes .....	190
6.3.2.2	Echo Dunes .....	192
6.3.2.3	Cliff-Top Dunes .....	195
6.3.3	Formation of Self-Accumulated Dunes .....	195
6.3.3.1	Dune Initiation .....	195

6.3.3.2	Development of a Steady-State Dune Profile . . . . .	197
6.3.3.3	Flow Separation and the Development of a Dune Slip-Face . . . . .	200
6.3.4	Simple Barchans and Transverse Barchanoid Ridges . . . . .	201
6.3.5	Linear Dunes . . . . .	206
6.3.5.1	Development of Seif Dunes . . . . .	209
6.3.5.2	Oblique Dunes . . . . .	216
6.3.6	Star Dunes . . . . .	219
6.3.7	Dome Dunes . . . . .	223
6.4	Vegetated Dunes . . . . .	224
6.4.1	Hummock Dunes . . . . .	225
6.4.2	Parabolic and Elongate Parabolic Dunes . . . . .	229
6.4.3	Precipitation Ridges . . . . .	237
6.4.4	Lunette Dunes . . . . .	238
6.4.5	Vegetated Linear Dunes . . . . .	239
6.5	Sand Sheets . . . . .	245
6.5.1	Warm Climate Sand Sheets . . . . .	245
6.5.2	Zibar . . . . .	247
6.5.3	Cold Climate Sand Sheets . . . . .	248
6.6	Summary of Factors Determining the Morphology of Aeolian Sand Accumulations . . . . .	251
<b>7</b>	<b>Internal Sedimentary Structures of Aeolian Sand Deposits . . . . .</b>	<b>255</b>
7.1	Introduction . . . . .	255
7.2	Internal Structures of Sand Dunes . . . . .	258
7.2.1	Primary Structural Features Common to Most Dune Types . . . . .	258
7.2.2	Internal Structure of Barchans . . . . .	262
7.2.3	Internal Structure of Transverse Dunes . . . . .	266
7.2.4	Internal Structure of Seif Dunes . . . . .	266
7.2.5	Internal Structure of Unvegetated Dome Dunes . . . . .	270
7.2.6	Internal Structure of Reversing Dunes and Star Dunes . . . . .	270
7.2.7	Internal Structures of Shadow Dunes . . . . .	273
7.2.8	Internal Structures of Vegetated Coastal Dunes . . . . .	275
7.2.9	Internal Structure of Parabolic Dunes . . . . .	275
7.2.10	Nature and Origin of Bounding Surfaces . . . . .	277
7.3	Secondary Sedimentary Structures in Dunes . . . . .	280
7.4	Sedimentary Structures of Inter-dune Areas and Sand Sheets . . . . .	284
7.4.1	Inter-dune Areas . . . . .	284
7.4.2	Extra-Dune Sand Sheets . . . . .	289
7.5	Niveo-Aeolian Deposits and Cryogenic Structures in Cold-Climate Dunes . . . . .	290

<b>8</b>	<b>Post-Depositional Modification of Dune Sands</b> .....	293
8.1	Introduction .....	293
8.2	Denudation by Rain Splash, Surface Wash, Soil Creep, and Gullyng .....	294
8.3	Near-Surface Compaction .....	295
8.4	Addition of Allochthonous Components .....	295
8.5	Weathering and Pedogenesis of Siliceous Dune Sands .....	297
8.5.1	Leaching of Soluble Salts and Carbonates .....	297
8.5.2	Chemical Weathering of Silicates and Oxides .....	297
8.5.3	Heavy Minerals .....	298
8.5.3.1	Feldspars .....	298
8.5.3.2	Quartz .....	299
8.5.4	Physical Weathering Processes .....	301
8.5.5	Chemical Weathering and Reddening of Siliciclastic Dune Sands .....	301
8.5.6	Silica Coatings and Cementation .....	307
8.5.7	Formation of Soil Profiles in Dune Sands .....	309
8.5.8	Podsolization and Humate Cementation .....	309
8.6	Formation of Carbonate Aeolianites .....	316
8.6.1	Definition and Occurrence of Aeolianites .....	316
8.6.2	Controls on Carbonate Cementation in Aeolianites .....	318
8.6.2.1	Effects of Carbonate Mineralogy .....	318
8.6.2.2	Effects of Rainfall and Evaporation .....	322
8.6.2.3	Effects of Vegetation .....	324
8.6.3	Calcrete Horizons in Carbonate Dune Sands .....	325
8.6.4	Karstification of Aeolianites .....	327
8.6.5	Relationship Between Aeolianites and Red Soils .....	327
8.6.6	Regressive Diagenesis of Aeolianites .....	328
8.7	Early Diagenetic Cementation by Evaporite Minerals .....	328
<b>9</b>	<b>Management and Human Use of Sand Dune Environments</b> .....	329
9.1	Thermal Properties of Sand, Moisture Regime, and Vegetation Growth .....	329
9.1.1	Thermal Properties .....	329
9.1.2	Sand Moisture Regime .....	331
9.1.3	Other Factors Which Influence Dune Vegetation .....	336
9.2	Water Courses in Dune Areas .....	338
9.3	Control of Windblown Sand .....	340
9.3.1	Reduction of Sand Supply .....	340
9.3.1.1	Surface Stabilization by Mulches .....	341
9.3.1.2	Physical Barriers to Airflow .....	342
9.3.1.3	Restriction of Human Activity in Potential Sand Source Areas .....	342
9.3.2	Enhancement of Sand Transport .....	343
9.3.3	Diversion of Moving Sand .....	344

9.3.4	Enhancement of Sand Deposition . . . . .	344
9.3.4.1	Sand Fences . . . . .	344
9.3.4.2	Sand Ditches . . . . .	349
9.3.4.3	Vegetation Planting . . . . .	349
9.3.4.4	Combined Stabilization Methods . . . . .	354
9.3.5	Control of Moving Dunes . . . . .	355
9.4	Human Use of Sand Dune Areas . . . . .	355
9.4.1	Cultivation on Desert Sand . . . . .	356
9.4.2	Cultivation and Grazing on Coastal Dunes . . . . .	358
9.4.3	Urban Development and Recreational Activities . . . . .	360
9.4.4	Sand Mining . . . . .	361
9.4.5	Dunes and Water Supply . . . . .	362
9.4.6	Coastal Dunes as Natural Sea Defences . . . . .	364
<b>10</b>	<b>Aeolian Research Techniques . . . . .</b>	<b>369</b>
10.1	Wind Tunnel Studies . . . . .	369
10.2	Measurement of Sand Movement Using Sand Traps . . . . .	374
10.2.1	Horizontal Sand Traps . . . . .	375
10.2.2	Vertical Sand Traps . . . . .	376
10.2.3	Surface Creep Traps . . . . .	381
10.3	Sand Tracer Techniques . . . . .	381
10.4	Methods of Sample Collection for Grain Size and Mineralogical Analysis . . . . .	385
10.5	Methods of Determining the Grain Size of Sands . . . . .	388
10.5.1	Sieving . . . . .	388
10.5.1.1	Sample Pretreatment . . . . .	388
10.5.1.2	Dry Sieving . . . . .	389
10.5.1.3	Wet Sieving . . . . .	390
10.5.2	Settling Tube Analysis . . . . .	391
10.5.3	Electro-Optical Methods of Size Analysis . . . . .	391
10.5.4	Direct Measurement of Grain Size by Image Analysis . . . . .	392
10.6	Characterization of Airflow . . . . .	392
10.6.1	Wind Velocity Measurements . . . . .	392
10.6.2	Flow Visualization . . . . .	393
10.7	Methods of Monitoring Changes in Sand Dune Terrain . . . . .	393
10.7.1	Field Surveys . . . . .	393
10.7.2	Remote Sensing . . . . .	394
10.7.3	Sand Dating Methods . . . . .	394
	<b>Appendix: SI units and c.g.s. equivalents . . . . .</b>	<b>397</b>
	<b>References . . . . .</b>	<b>399</b>
	<b>Index . . . . .</b>	<b>453</b>