

Contents

1 The earth in the planetary system	1
1.1 Origin of the earth in the solar system (H. WÄNKE)	1
1.1.1 Introduction	1
1.1.1.1 Definitions	1
1.1.1.2 General remarks	1
1.1.2 Compositional constraints on the accretion history of the earth	2
1.1.2.1 Geophysical constraints	2
1.1.2.2 Geochemical constraints	2
1.1.3 Fractionation of chemical elements prior to accretion.	3
1.1.3.1 Fractionation of elements during condensation from a hot solar nebula	3
1.1.3.2 Fractionation of elements due to evaporation from small objects	4
1.1.4 Time scale of accretion and initial temperature of the earth	4
1.1.5 Protoplanet models for planet formation	4
1.1.6 Planetesimal models of planet formation	5
1.1.6.1 Classical homogeneous accretion model.	5
1.1.6.2 Single stage model	5
1.1.6.3 Two component homogeneous accretion model	6
1.1.6.4 Fast heterogeneous accretion model	6
1.1.6.5 Two component heterogeneous accretion model	7
1.1.7 The earth's early atmosphere	7
1.1.8 References	8
1.2 The motion of the earth (E. GROTEK)	9
1.2.0 Abbreviations, notation and units	9
1.2.1 Introduction	12
1.2.2 Units and definitions	12
1.2.2.1 Time.	12
1.2.2.2 Basic systems of reference	14
1.2.3 Orbital motion of the earth	15
1.2.4 Primary parameters of the earth's rotational motion in space	18
1.2.5 Forced nutation	19
1.2.6 The rotation of the earth	25
1.2.6.1 Polar motion and length of the day variations	25
1.2.6.2 Polar motion	28
1.2.6.3 The length of the day (l.o.d.)	32
1.2.6.3.1 Decade fluctuations	33
1.2.6.3.2 Seasonal variations	34
1.2.6.3.3 Tidal variations.	34
1.2.6.4 Polar wander	36
1.2.6.5 Geophysical discussion	38
1.2.6.5.1 Geodetic aspects	38
1.2.6.5.2 Geophysical aspects	39
1.2.6.5.2.1 Length of the day (l.o.d.)	39
1.2.6.5.2.2 Polar motion	39
1.2.6.5.2.3 Sea tidal and core-mantle-decoupling effects in l.o.d. and polar motion	40
1.2.6.5.2.4 Polar motion and global geophysics	40
1.2.7 Tidal dissipation	41
1.2.8 The Celestial Ephemeris Pole	42
1.2.9 Bibliography	44

2 Properties of the solid earth	47
2.1 Seismicity and the interior of the earth	47
2.1.1 Seismicity (G. SCHNEIDER)	47
2.1.1.0 List of symbols	47
2.1.1.1 Introduction	47
2.1.1.2 Geometric and dynamic source parameters	48
2.1.1.3 Radiation pattern and source mechanisms.	50
2.1.1.4 Seismic source spectrum and magnitude.	50
2.1.1.5 The spatial distribution of earthquake foci.	55
2.1.1.6 Seismic return period and earthquake statistics.	57
2.1.1.7 Macroseismic effects	57
2.1.1.8 Earthquake prediction	59
2.1.1.9 References	59
2.1.2 Seismic waves and free oscillations (G. MÜLLER, W. ZÜRN)	61
2.1.2.0 List of symbols and abbreviations	61
2.1.2.1 Body waves.	62
2.1.2.1.1 Rays and travel times	62
2.1.2.1.2 Amplitudes	64
2.1.2.1.3 Absorption and dispersion	67
2.1.2.1.4 Lateral heterogeneity and scattering	68
2.1.2.1.5 Anisotropy.	69
2.1.2.2 Surface waves	71
2.1.2.2.1 Wave types, dispersion and modes.	71
2.1.2.2.2 Regional dispersion curves	72
2.1.2.2.3 Absorption and anisotropy.	74
2.1.2.2.4 Mantle waves	75
2.1.2.3 Free oscillations	76
2.1.2.3.1 Classification.	76
2.1.2.3.2 Eigenperiods and attenuation.	76
2.1.2.3.3 Eigenfunctions	79
2.1.2.3.4 Multiplet splitting.	80
2.1.2.3.5 Asymptotic properties	81
2.1.2.3.6 Special modes	81
2.1.2.4 References for 2.1.2	82
2.1.3 Structure, elastic and rheological properties and density of the earth's interior, gravity and pressure (A. M. DZIEWONSKI, D. L. ANDERSON)	84
2.1.3.0 List of symbols	84
2.1.3.1 The Gross Earth Data Set.	85
2.1.3.2 The earth model.	85
2.1.3.2.1 Anisotropy.	85
2.1.3.2.2 Discussion	87
2.1.3.2.3 Viscosity of the mantle.	96
2.1.3.3 References for 2.1.3	96
2.1.4 Structure of the earth's crust and upper mantle (C. PRODEHL)	97
2.1.4.1 Introduction	97
2.1.4.2 Procedure of interpretation	97
2.1.4.3 Main features of continental and oceanic crustal structure	100
2.1.4.3.1 Main features of continental crustal structure	100
2.1.4.3.2 Main features of oceanic crustal structure.	109
2.1.4.4 Presentation of individual results.	110
2.1.4.4.1 Europe	115
2.1.4.4.1.1 Fennosarmatia	115
2.1.4.4.1.2 Caledonian Europe	116
2.1.4.4.1.3 Hercynian Europe	117
2.1.4.4.1.4 Alpine Europe and Mediterranean	120
2.1.4.4.2 Africa and the Arabian Peninsula	123
2.1.4.4.3 Asia	125

2.1.4.4.4	North America	128
2.1.4.4.4.1	The Canadian Shield	128
2.1.4.4.4.2	Canadian Arctic	129
2.1.4.4.4.3	Appalachian region and Coastal Plains	129
2.1.4.4.4.4	The Interior Platform	130
2.1.4.4.4.5	The Cordillerean region	131
2.1.4.4.5	Gulf of Mexico and Caribbean Sea	135
2.1.4.4.6	South America	136
2.1.4.4.7	Australasia.	137
2.1.4.4.7.1	Shield areas of western and central Australia.	137
2.1.4.4.7.2	Tasman Orogen of eastern Australia	138
2.1.4.4.7.3	The Island Complexes of Australasia	138
2.1.4.4.8	The West Pacific Margin.	139
2.1.4.4.9	Central Pacific Ocean	141
2.1.4.4.10	Atlantic Ocean	143
2.1.4.4.11	Indian Ocean.	146
2.1.4.4.12	Tables on characteristics of crustal structure	147
2.1.4.5	Main features of the structure of the lower lithosphere and asthenosphere	170
2.1.4.6	Presentation of individual results.	171
2.1.4.6.1	Europe	171
2.1.4.6.2	Asia	175
2.1.4.6.3	Africa	176
2.1.4.6.4	Australia	176
2.1.4.6.5	North America	177
2.1.4.6.6	Oceans	179
2.1.4.6.7	Tables and Figures on velocity-depth models of the subcrustal lithosphere .	180
2.1.4.7	References	194
2.2	Heat flow and temperature distribution in the earth's interior	
2.2.1	Oceanic and continental heat-flow data.	207
2.2.1.1	Oceanic heat flow data (R. von HERZEN)	207
2.2.1.1.1	Introduction	207
2.2.1.1.2	Western and South Pacific	208
2.2.1.1.3	Northeast and Central Pacific	211
2.2.1.1.4	East Pacific	215
2.2.1.1.5	North Atlantic	221
2.2.1.1.6	South Atlantic	228
2.2.1.1.7	Indian Ocean.	230
2.2.1.1.8	Marginal Seas	232
2.2.1.1.9	References for 2.2.1.1	240
2.2.1.2	Continental heat flow data (D.S. CHAPMAN)	See Subvolume V/2b
2.2.2	Radioactive heat production in the continental crust (L. RYBACH)	242
2.2.2.0	List of symbols	242
2.2.2.1	Introduction	242
2.2.2.2	Heat generating natural radioelements	243
2.2.2.3	Variation of heat production with rock type	243
2.2.2.4	Continental heat flow provinces	244
2.2.2.5	Vertical distribution of crustal radioactivity	244
2.2.2.6	Age dependence of crustal heat production	245
2.2.2.7	Heat production estimates for the subcontinental upper mantle.	246
2.2.2.8	References	247
2.2.3	Temperature profiles in the earth's interior (E.A. LUBIMOVA)	See Subvolume V/2b
2.2.4	Heat transport in the earth's interior (F.D. STACEY)	See Subvolume V/2b
2.3	Electrical properties of the earth's interior	
2.3.1	Depth distribution of the electrical conductivity (U. SCHMUCKER)	See Subvolume V/2b
2.3.2	Anomalies of the electrical conductivity in the earth's crust and upper mantle (U. SCHMUCKER)	See Subvolume V/2b

2.4	Composition of the earth's interior (I. JACKSON)	248
2.4.1	List of symbols and abbreviations	248
2.4.2	Introduction	248
2.4.3	The crust	248
2.4.4	The upper mantle	250
2.4.5	The transition zone	252
2.4.6	The lower mantle	254
2.4.7	The core	256
2.4.8	References	257
2.5	Tides of the earth	259
2.5.0	List of symbols and abbreviations for 2.5.1 and 2.5.2	259
2.5.1	Tidal forcing field (H. WILHELM, W. ZÜRN)	261
2.5.1.1	Introduction	261
2.5.1.2	Expansion in spherical harmonics	262
2.5.1.3	Equatorial and ecliptical coordinates	265
2.5.1.4	Components	266
2.5.1.5	Astronomical variables. Time	267
2.5.1.6	Harmonic development	268
2.5.1.7	References for 2.5.1.1-2.5.1.6	279
2.5.2	Tides of the solid earth (W. ZÜRN, H. WILHELM)	280
2.5.2.1	Introduction	280
2.5.2.2	Body tides	280
2.5.2.3	Observations	283
2.5.2.4	Load tides	285
2.5.2.5	Systematic effects	291
2.5.2.5.1	Rotation and ellipticity of the earth	291
2.5.2.5.2	Liquid core resonance	295
2.5.2.5.3	Anelasticity and tidal friction	295
2.5.2.5.4	Relativistic effects	296
2.5.2.5.5	Nonlinearities	296
2.5.2.6	Local elastic inhomogeneities	296
2.5.2.7	Meteorological effects	297
2.5.2.8	References for 2.5.2.1-2.5.2.7	298
2.5.3	Tidal friction and dynamics of the earth-moon-system (P. BROSCHE, J. SÜNDERMANN)	299
2.5.3.0	List of symbols and abbreviations	299
2.5.3.1	The principle	300
2.5.3.2	Observations	300
2.5.3.2.1	Observable quantities	300
2.5.3.2.2	Artificial satellites	301
2.5.3.2.3	Lunar Laser Ranging (LLR)	301
2.5.3.2.4	Telescopic observations	301
2.5.3.2.5	Antique solar eclipses	301
2.5.3.2.6	Growth rhythms	302
2.5.3.2.7	Synopsis	302
2.5.3.3	Balances of energy and angular momentum	304
2.5.3.3.1	Basis features	304
2.5.3.3.2	The influence of the atmosphere and the solid Earth	306
2.5.3.3.3	Balances for the oceans	306
2.5.3.3.4	Paleotides	308
2.5.3.4	Long time integration	308
2.5.3.5	Bibliography	310
3	Gravity field and figure of the earth (H.-G. KAHLE)	311
3.1	Gravity potential of the earth	311
3.1.0	List of symbols, numerical values and abbreviations	311
3.1.1	Gravitational law and gravitational potential	314
3.1.2	Centrifugal potential	315
3.1.3	Earth's gravity potential W =geopotential	315

3.2	Fundamental notions of gravimetry	315
3.2.1	Equipotential surfaces, plumb lines and gravity acceleration	315
3.2.2	Gravity gradient tensor and curvature of equipotential surfaces	316
3.3	Gravimetric measuring techniques	317
3.3.1	Absolute gravity measurements	317
3.3.1.1	Pendulum methods	317
3.3.1.3	Free-fall and symmetrical free-motion methods.	319
3.3.2	Relative gravity measurements	322
3.3.2.1	Principle of spring gravimeters.	322
3.3.2.2	Mechanical sensitivity and astatization	323
3.3.2.3	New techniques of relative gravity measurements	325
3.3.3	Gravity reductions	325
3.3.3.1	Principles.	325
3.3.3.2	Normal gravity	326
3.3.3.3	Effect of topography g_{top} (terrain effect)	326
3.3.3.4	Effect of elevation of station (free-air effect), g_{Free}	328
3.3.3.5	Earth-tide reductions, g_{tide}	328
3.3.4	Marine gravity	328
3.3.4.1	Techniques and discussion of measuring errors	328
3.3.4.2	References and sources of gravity anomaly maps over the world's oceans after [Wat75]	
3.4	Reference ellipsoid and geoid	332
3.4.1	Geodetic reference system 1980 [80Mor2]	332
3.4.1.1	Definition	332
3.4.1.2	Computational formulas	333
3.4.1.2.1	Geometric constants.	333
3.4.1.2.2	Physical constants	334
3.4.1.2.3	The formulas of normal gravity	334
3.4.1.3	Numerical values [80Mor2] of the geodetic reference system 1980	336
3.4.1.4	Origin and orientation of the reference system	337
3.4.2	The geoid and telluroid	337
3.4.2.1	Definition	337
3.4.2.2	Height systems	338
3.4.2.3	Curvilinear coordinate systems	338
3.5	Satellite geodesy and the earth's gravitational potential V	339
3.5.1	Potential, gravity anomalies and geoidal undulations expressed as series of spherical harmonics	339
3.6	References	351

4 Magnetic field of the earth

4.1	Sources of the geomagnetic field	
4.1.1	External part of the earth's magnetic field (U. SCHMUCKER)	See Subvolume V/2b
4.1.2	Internal part of the earth's magnetic field (U. SCHMUCKER)	See Subvolume V/2b
4.2	Magnetic field on the surface and the interior of the earth	
4.2.1	Crustal anomalies and their cause (W. BOSUM, H. RÖSER, R. PUCHER).	See Subvolume V/2b
4.2.2	Magnetic and electric fields due to electromagnetic induction by external sources (U. SCHMUCKER)	See Subvolume V/2b
4.2.3	Observation and description of the main geomagnetic field and its secular variation (D. VOPPEL)	See Subvolume V/2b
4.2.4	Material properties entering the theory of the main geomagnetic field (F. H. BUSSE)	See Subvolume V/2b
4.3	Palaeomagnetism and Archaeomagnetism (H. SOFFEL)	See Subvolume V/2b

5 Transport of masses in the earth's interior

5.1	Relief of the earth's surface and of the sea floor	See Subvolume V/2b
5.1.1	The relief of the earth's surface (H. HAGEDORN)	See Subvolume V/2b
5.1.2	Relief of the sea floor (H.G. GIERLOFF-EMDEN)	See Subvolume V/2b

5.2	Recent crustal movements (H. MÄLZER)	357
5.2.0	List of symbols	357
5.2.1	Introduction	358
5.2.2	Measurements of deformation within plate interiors and near active plate boundaries	358
5.2.2.1	Ground techniques.	358
5.2.2.1.1	Horizontal displacement	359
5.2.2.1.2	Vertical displacement and gravity changes	360
5.2.2.2	Recent regional crustal movements observed by geodetic techniques	369
5.2.2.2.1	Vertical and horizontal long-term motions	361
5.2.2.2.2	Coseismic (sudden) displacements (ground motions)	365
5.2.2.2.3	Gravity changes in connection with recent crustal movements	367
5.2.3	Measurements on a global scale	368
5.2.3.1	Space techniques	368
5.2.3.1.1	Satellite laser ranging (SLR) and lunar laser ranging (LLR)	368
5.2.3.1.2	Very long baseline interferometry (VLBI)	370
5.2.3.2	Observation by space techniques	372
5.2.4	References	374
5.3	Theories and hypotheses of global tectonics (W.R. JACOBY)	See Subvolume V/2b
5.4	Motions in the earth's core and core-mantle coupling (F. H. BUSSE)	377
5.4.0	List of symbols	377
5.4.1	Origins of motions in the core	377
5.4.2	Core-mantle coupling	378
5.4.3	References	378
6	Planetology of terrestrial planets (R. MEISSNER, P. JANLE)	379
6.0	List of symbols and abbreviations	779
6.1	Introduction	380
6.2	Short description of the terrestrial planetary bodies	380
6.2.1	Mercury	382
6.2.2	Venus	382
6.2.3	Moon	382
6.2.4	Mars	383
6.3	Absolute age determinations	383
6.3.1	Meteorite ages	383
6.3.2	Lunar ages	385
6.3.3	Age of the earth	385
6.4	Relative age determination	385
6.4.1	Lunar age determination	387
6.4.2	Ages for Mercury	388
6.4.3	Ages for Mars	388
6.4.4	Ages for satellites of Mars	388
6.5	Geological – geophysical interpretation of surface structures	389
6.5.1	Heavily cratered terrain versus less cratered area	389
6.5.2	Topography	390
6.5.3	Planetary elevations and the center-of-figure center-of-mass offset	390
6.5.4	Surface properties as determined by lunar soft-landing space probes	391
6.5.5	Surface properties as determined by soft landing space probes on Mars	391
6.5.6	Surface properties as determined by soft landing space probes on Venus	392
6.6	Gravity studies from orbiters and density models of lithospheres	392
6.6.1	Description of method	392
6.6.2	Large scale properties derived from gravity data	392
6.6.3	Lunar gravity studies	395
6.6.4	Gravity studies of Mars	397
6.6.5	Gravity studies of Venus	398
6.7	Additional studies from orbiter, fly-by, and descend missions	399
6.7.1	Lunar γ - and X-ray studies	399

6.7.2	Martian studies	400
6.7.3	Venusian studies	400
6.8	Lunar seismology	400
6.8.1	Station description and characteristics of the seismograms.	400
6.8.2	Lunar seismicity, deep and shallow moonquakes	401
8.2.1	Deep moonquakes	403
8.2.2	Shallow moonquakes	404
6.8.3	Structure of the moon from active and passive seismic experiments	405
6.9	Planetary magnetic fields and remanent magnetization	407
6.9.1	The magnetic field of the moon	407
6.9.2	The magnetic field of Mercury	408
6.9.3	The magnetic fields of Venus and Mars	408
6.10	Electrical conductivity, heat flow and estimates on the lunar temperature	408
6.11	Physical conditions of the interior of planets	409
6.11.1	Density and the sizes of metallic cores	410
6.11.2	Pressures and gravity	410
6.11.3	Temperature models of the planets.	411
	The evolution of terrestrial planets.	412
6.12	References	413

