CONTENTS

PREFACE **15**

ACKNOWLEDGEMENT **17**

ABOUT THE AUTHORS **18**

CHAPTER 1

INTRODUCTION *(Saad Z. Jassim)* **21**

1.1 History of geological investigations in Iraq 21

1.2 Morphology 22

1.3 Surface geology 23

1.4 Outline of the book 24

1.5 Data used 26

CHAPTER 2

LATE PRECAMBRIAN DEVELOPMENT OF THE ARABIAN PLATE *(Saad Z. Jassim)* **27**

2.1 Tectonostratigraphy of the Late Precambrian 27

2.2 Precambrian Terranes 28

2.2.1 Western Terranes 28

2.2.2 Eastern Terranes 28

2.3 The buried Precambrian basement in Iraq 29

2.4 Summary of Precambrian evolution 31

2.4.1 Oceanic accretion and subduction 31

2.4.2 Orogenesis 31

2.4.3 Extension 31

CHAPTER 3

PHANEROZOIC DEVELOPMENT OF THE NORTHERN ARABIAN PLATE *(Saad Z. Jassim and Jeremy C. Goff)* **32**

3.1 Introduction 32

3.2 Late Precambrian-Carboniferous basin formation and inversion 34

3.2.1 Late Precambrian-Early Cambrian Rifting 34

3.2.2 Mid Cambrian-Silurian Intracratonic Subsidence 34

3.2.3 Latest Silurian-Early Late Devonian Uplift 34

3.2.4 Late Devonian-Early Late Carboniferous Intracratonic Subsidence 35

3.2.5 Late Carboniferous "Hercynian" Compression 35

3.3 Extension and passive subsidence associated with the opening of the Neo-Tethys Ocean 37

3.3.1 Early-"Mid" Permian rifting 37

3.3.2 Late Permian-Early Triassic passive margin development 37

3.3.3 Mid Triassic-Norian rifting 37

3.3.4 Norian-Mid Toarcian passive subsidence 38

3.3.5 Late Toarcian-Early Tithonian Differential Subsidence and Rifting 38

3.3.6 Late Tithonian-Cenomanian opening of the Southern Neo-Tethys 39

3.4 Turonian-Eocene foreland basin formation and closure of the Neo-Tethys 41

3.4.1 Turonian-Early Campanian Closure of the Southern Neo-Tethys 41

3.4.2 Late Campanian-Early Maastrichtian Ophiolite Obduction 42

3.4.3 Late Maastrichtian-Danian 42

3.4.4. Palaeocene-Eocene closure of the Neo-Tethys 42

3.5 Oligocene-Recent compression and continental collision 44

CHAPTER 4

TECTONIC FRAMEWORK *(Saad Z. Jassim and Tibor Buday)* **45**

4.1 Bouguer gravity field 45

4.2 Total magnetic field map 45

4.3 Crustal thickness 45
4.4 Precambrian Basement Depth 47
4.5 Fault Systems 48
4.5.1 Nabitah (Idsas) Fault System 49
4.5.2 Najd Fault System 49
4.5.3 Transversal Fault System and transversal blocks 53
4.6 Basic structural units of Iraq and basis of zonation 54
4.7 Longitudinal Zones 55

CHAPTER 5
UNITS OF THE STABLE SHELF *(Saad Z. Jassim and Tibor Buday)* **57**
5.1 Outline of major divisions 57
5.2 The Rutba-Jezira Zone 57
5.2.1 The Rutba Subzone 57
5.2.1.1 Geological and geomorphological characteristics 57
5.2.1.2 Structures 61
5.2.2 The Jezira Subzone 63
5.2.2.1 Geological and geomorphological characteristics 63
5.2.2.2 Structures 63
5.3 Salman Zone 63
5.3.1 Geological and geomorphological characteristics 64
5.3.2 Structures 66
5.4 Mesopotamian Zone 67
5.4.1 Geological and geomorphological characteristics 67
5.4.2 Structures 69
5.4.3 Zubair Subzone 69
5.4.4 Tigris Subzone 70
5.4.5 Euphrates Subzone 70

CHAPTER 6
UNITS OF THE UNSTABLE SHELF AND THE ZAGROS SUTURE *(Saad Z. Jassim and Tibor Buday)* **71**
6.1 Units of the Unstable Shelf 71
6.1.1 The Foothill Zone 71
6.1.1.1 Hemrin-Makhul Subzone 73
6.1.1.2 Butmah-Chemchemal Subzone 73
6.1.2 The High Folded Zone 75
6.1.3 The Imbricated Zones 77
6.1.3.1 The Balambo-Tanjero Zone 77
6.1.3.2 The Northern (Ora) Thrust Zone 78
6.2 Units of the Zagros Suture 78
6.2.1 Qulqula-Khwakurk Zone 80
6.2.2 Penjween-Walsh Zone 82
6.2.3 Shalair (Sanandaj-Sirjan) Zone 83

CHAPTER 7
SEISMICITY *(Sahil A. Alsinawi)* **84**
7.1 Seismic monitoring in Iraq 84
7.2 Geodynamic considerations 84
7.3 The crust and Moho 85
7.4 Historical seismicity 86
7.5 Macro and microseismicity 86
7.5.1 Regional seismicity 86
7.5.2 Macroseismicity of Iraq 86
7.5.3 Microseismicity of Iraq 87
7.5.4 Focal mechanism studies 87
7.5.5 Induced seismicity investigations 87
7.6 Seismotectonics of Iraq 88
7.7 Seismic hazards 88
7.7.1. Seismic zoning 88
7.7.2 Seismicity index "ST" 89

7.7.3 Isoacceleration map 89
7.7.4 Probabilistic hazard assessment 89
7.7.5 Seismic wave attenuation 89
7.7.6 Strong motion seismology 90
7.8 Recommendations 90

CHAPTER 8
PALAEOZOIC MEGASEQUENCES (**AP1-AP-5**) *(Saad Z. Jassim)* **91**
8.1 The Vendian-late Late Cambrian Megasequence AP1 (Infracambrian Megasequence) 91
8.1.1 Palaeogeographic considerations and regional distribution 91
8.2 The late early Cambrian-early Ashgill Megasequence AP2 (Cambro-Ordovician Megasequence) 94
8.2.1 Late Early Cambrian-Late Cambrian Sequence 94
8.2.1.1 Salib Formation 94
8.2.1.2 Burj Limestone Formation 94
8.2.1.3 Ajram Formation 95
8.2.2 Late Cambrian-Early Ordovician Sequence 95
8.2.3 Mid-Late Ordovician Sequence 95
8.2.3.1 Khabour Formation 96
8.3 The late Ashgill-Frasnian Megasequence AP3 96
8.3.1 Late Ashgill "Saharan Glaciation" Sequence (445-443 Ma) 96
8.3.2 Silurian Sequence 97
8.3.2.1 Akkas Formation 98
8.3.3 Late Silurian (Pridoli)-early Late Devonian (Frasnian) Sequence 98
8.3.3.1 The "Caledonian" disturbance 98
8.3.3.2 Stratigraphy 99
8.4 The Frasnian-Namurian modified Megasequence AP4 99
8.4.1 Pirispiki Formation (including Chalki Volcanics) 100
8.4.2 Ora Formation (Famennian-L Tournasian) 100
8.4.3 Harur Formation 100
8.5 The Modified Westphalian-Ufimian (Syn-Hercynian) Megasequence AP5 101
8.5.1 Bir El Rah Formation 102
8.5.2 Ga'ara Formation (Early Permian-early Late Permian /Ufimian/) 102

CHAPTER 9
LATE PERMIAN-LIASSIC MEGASEQUENCE AP6 *(Saad Z. Jassim, Tibor Buday, Ivan Cicha and Vladimír Prouza)* **104**
9.1 Late Permian-Mid Triassic Sequence 104
9.1.1 Chia Zairi Formation 104
9.1.2 Mirga Mir Formation 107
9.1.3 Beduh Formation 107
9.1.4 Geli Khana Formation 107
9.2 Late Triassic Sequence 108
9.2.1 Carbonate-clastic inner shelf 108
9.2.1.1 Mulussa Formation 108
9.2.1.2 Zor Hauran Formation 110
9.2.2 Carbonate-evaporite inner shelf and restricted lagoons 110
9.2.2.1 Kurra Chine Formation 110
9.2.2.2 Baluti Formation 111
9.3 Liassic Sequence 111
9.3.1 The Clastic-carbonate inner shelf 112
9.3.1.1 Ubaid Formation 112
9.3.1.2 Hussainiyat Formation 113
9.3.1.3 Amij Formation 113
9.3.2 Carbonate-evaporite inner shelf 114
9.3.2.1 Butmah Formation 114
9.3.2.2 Adaiyah Formation 114
9.3.2.3 Mus Formation 115
9.3.2.4 Alan Formation 115

9.3.3 Restricted lagoons 115
9.3.3.1 Sarki Formation 115
9.3.3.2 Sehkaniyan Formation 116

CHAPTER 10
LATE TOARCIAN-EARLY TITHONIAN (MID-LATE JURASSIC) MEGASEQUENCE AP7
(Saad Z. Jassim and Tibor Buday) **117**
10.1 The Mid Jurassic (Late Toarcian-Callovian) Sequence 117
10.1.1 Inner shelf clastic-carbonate platform (Muhaiwir Formation) 118
10.1.2 Restricted outer shelf and basinal (Sargelu Formation) 119
10.2 Late Jurassic Sequence 120
10.2.1 Clastic-carbonate inner shelf (Najmah Formation) 120
10.2.2 Evaporite-carbonate lagoons and sabkha (Gotnia Formation) 121
10.2.2.1 Gotnia Formation 121
10.2.2.2 Saggar Formation 122
10.2.3 Euxinic basin 122
10.2.3.1 Naokelekan Formation 122
10.2.3.2 Barsarin Formation 123

CHAPTER 11
LATE TITHONIAN-EARLY TURONIAN MEGASEQUENCE AP8 *(Saad Z. Jassim and Tibor Buday)* **124**
11.1 Upper Tithonian-Aptian Thamama Group 125
11.1.1. Late Tithonian-Hauterivian Sequence 126
11.1.1.1 Inner shelf and deep inner shelf facies 126
11.1.1.2 Outer shelf and basinal 128
11.1.2 Barremian-Aptian Sequence 129
11.1.2.1 Clastic-carbonate inner shelf 130
11.1.2.2. Outer shelf and Basinal 131
11.2 Albian-Early Turonian Sequence (Wasi'a Group) 131
11.2.1 The Albian Sequence 131
11.2.1.1 Clastic-carbonate inner shelf (Nahr Umr Formation, including Rim Siltstone) 132
11.2.1.2 Carbonate ramp (Mauddud Formation, including U Qamchuqa) 133
11.2.1.3 Inner shelf lagoons 134
11.2.2 The Cenomanian-Early Turonian Sequence 134
11.2.2.1 Clastic-carbonate inner shelf facies 135
11.2.2.2 Deep inner shelf facies (Rumaila Formation) 137
11.2.2.3 Rudist reefs (Mishrif Formation, including Gir Bir) 137
11.2.2.4 Evaporitic inner shelf lagoonal facies (Kifl Formation) 138
11.2.2.5 Restricted deep basin facies (Dokan and Gulneri formations) 139
11.2.2.6 Open marine facies (Upper Balambo Formation) 139

CHAPTER 12
LATE TURONIAN-DANIAN MEGASEQUENCE AP9 *(Saad Z.. Jassim and Tibor Buday)* **141**
12.1 Introduction 141
12.2 Late Turonian-Early Campanian Sequence 141
12.2.1 Deep inner shelf and lagoons 143
12.2.1.1 Khasib Formation 143
12.2.1.2 Tanuma Formation 144
12.2.1.3 Sa'di Formation 144
12.2.2 Outer shelf and basinal (Kometan Formation) 144
12.3 Upper Campanian-Maastrichtian Sequence 145
12.3.1 Carbonate inner shelf (Hartha and Tayarat formations) 146
12.3.1.1 Hartha Formation 146
12.3.1.2 Tayarat Formation 147
12.3.2 Phosphatic inner and outer shelf (Digma Formation) 148
12.3.3 Carbonate ramp (Bekhme and Aqra Formation) 149
12.3.4 Outer shelf-basinal (Shiranish Formation) 150
12.3.5 Isolated basin of the Balambo-Tanjero Zone (Tanjero Formation) 150
12.3.6 Isolated basin of the Northern Thrust Zone (Hadiena Formation) 151
12.4 Danian sequence 151

12.4.1 Phosphatic outer shelf (Tarfawi Member of Akashat Formation) 151

CHAPTER 13
MIDDLE PALAEOCENE-EOCENE MEGASEQUENCE (AP10) *(Saad Z. Jassim and Tibor Buday)* **155**
13.1 Mid Palaeocene-Early Eocene Sequence 155
13.1.1 Carbonate-Evaporite inner shelf 157
13.1.1.1 Umm Er Radhuma Formation 157
13.1.1.2 Rus (Jil) Formation 157
13.1.2. Phosphatic inner shelf 159
13.1.2.1 Akashat Formation (M-U Palaeocene part only) 159
13.1.2.2 Ratga Formation (Swab Member) 160
13.1.3 Outer shelf-basinal 160
13.1.3.1 Aaliji Formation 160
13.1.3.2 Kolosh Formation 161
13.1.4 Carbonate ramp (Sinjar Formation) 162
13.1.5 Carbonate inner shelf (Khurmala Formation) 162
13.2 Mid-Late Eocene Sequence 163
13.2.1 Carbonate inner shelf lagoons and shoals 164
13.2.1.1 Dammam Formation 164
13.2.1.2 Avanah Formation 165
13.2.1.3 Pila Spi Formation 165
13.2.2 Phosphatic deep inner shelf-inner shelf (Damlouk and Mugur members of Ratga Formation) 166
13.2.3 Outer shelf-basinal (Jaddala Formation) 166
13.2.4 Fluvial and fluviomarine (Gercus Formation) 167

CHAPTER 14
LATEST EOCENE-RECENT MEGASEQUENCE AP11 *(Saad Z. Jassim and Tibor Buday)* **169**
14.1 Latest Eocene-Oligocene Sequence 169
14.1.1 Lower Sequence 171
14.1.1.1 Basinal (Palani and Tarjil formations) 171
14.1.1.2 Reef-backreef and forereef 172
14.1.2 Upper Sequence 172
14.1.2.1 Basinal (Ibrahim Formation) 172
14.1.2.2 Reef, backreef and forereef 173
14.2 Early-Mid Miocene Sequence 174
14.2.1 Early Miocene Sequence 175
14.2.1.1 Clastic inner shelf (Ghar Formation) 175
14.2.1.2 Carbonate inner shelf (Euphrates Formation) 176
14.2.1.3 Basinal (Serikagni Formation) 177
14.2.1.4 Evaporite lagoons (Dhiban Formation) 178
14.2.2 Middle Miocene Sequence 178
14.2.2.1 Carbonate inner shelf and shaols (Jeribe Formation) 178
14.2.2.2 Evaporite lagoons (Fatha /Lower Fars/ Formation) 179
14.3 Late Miocene-Pliocene Sequence 181
14.3.1 Fluvio-lacustrine and karst fill facies (Zahra Formation) 182
14.3.2 Alluvial Fans of the Stable Shelf (Dibdibba Formation) 182
14.3.3 Fluvial system 183
14.3.3.1 Injana (Upper Fars Formation) 183
14.3.3.2 Mukdadiya and Bai Hassan (Lower and Upper Bakhtiari) formations 184

CHAPTER 15
QUATERNARY DEPOSITS *(Adnan A. M. Aqrawi, Jaroslav Domas and Saad Z. Jassim)* **185**
15.1. Quaternary sediments of the Rutba-Jezira and Salman zones 185
15.2 Quaternary sediments of the Mesopotamian Zone 187
15.2.1 Plio-Pleistocene (Mahmudiya Formation) 187
15.2.2 Pleistocene 188
15.2.2.1 River terraces 188
15.2.2.2 Alluvial fans 188
15.2.3 Holocene 189
15.2.3.1 Sedimentary environments 190

15.2.3.2 Fauna ... 194
15.2.3.3 Palaeogeographic history of the Mesopotamian Plain ... 195
15.3 Quaternary sediments of the Foothill and High Folded zones ... 197
15.3.1. Polygenetic synclinal fill and depression fill of the Unstable Shelf ... 197

CHAPTER 16
TECTONOSTRATIGRAPHY OF THE ZAGROS SUTURE *(Saad Z. Jassim, Tibor Buday, Ivan Cicha and Mojmír Opletal)* ... **199**
16.1 Tectonostratigraphy of the Red Beds Basin ... 199
16.1.1. Red Beds Series ... 199
16.1.1.1 Marine and continental foredeep (Suwais Red Beds Group) ... 199
16.1.1.2 Marine-continental marginal basin (Govanda Limestone) ... 201
16.1.1.3 Intermontane molasse basin (Merga Red Beds Group) ... 202
16.2 Tectonostratigraphy of the Qulqula-Khwakurk Zone ... 202
16.2.1 Biyarah Limestone ... 202
16.2.2 Avroman Limestone ... 203
16.2.3 Jurassic imbricates ... 204
16.2.4 Qulqula Group ... 204
16.2.4.1 Shallow water carbonate sequence (Tithonian-Berriasian) ... 204
16.2.4.2 Carbonate-chert sequence (Valanginian-Lower Aptian) ... 204
16.2.4.3 Offshore Southern Neo-Tethys radiolarian chert (Aptian-Albian) ... 205
16.2.4.4 Qulqula Conglomerate Formation (Cenomanian-Lower Senonian?) ... 205
16.2.5 Chert, volcanic and ultramafic rocks of the Southern Neo-Tethys (Khwakurk Series) ... 206
16.3 Tectonostratigraphy of the Central Neo-Tethys Penjween-Walash Zone ... 206
16.3.1 Pre-Tertiary Qandil Metamorphic Series ... 206
16.3.1.1 Mawat Volcanic Group ... 206
16.3.1.2 Gimo Calcareous Group ... 206
16.3.1.3 Sirginil Phyllite Group ... 207
16.3.2 Non metamorphosed Tertiary volcanosedimentary units ... 208
16.3.2.1 Walash (Volcanic) Group ... 208
16.3.2.2 Naopurdan (shaly) Group ... 208
16.4 Tectonostratigraphy of the Shalair Zone ... 209
16.4.1 Mishav Complex ... 210
16.4.2 Darokhan Limestone ... 210
16.4.3 Shalair Group ... 210
16.4.4 Central volcanic arc (Katar Rash Group) ... 211
16.4.5 Carbonate shelf of the Sanandaj-Sirjan Zone (Piran Limestone) ... 211

CHAPTER 17
MAGMATISM AND METAMORPHISM IN THE ZAGROS SUTURE *(Saad Z. Jassim, Miloš Suk and Jarmila Waldhausrová)* ... **212**
17.1 Magmatism ... 213
17.1.1 Magmatism of the Southern Neo-Tethys (Qulqula-Khwakurk Zone) ... 213
17.1.2 Cretaceous Magmatism of the Central Neo-Tethys (Penjween-Walash Zone) ... 213
17.1.2.1 Penjween ophiolites ... 213
17.1.2.2 Mawat ... 214
17.1.2.3 Bulfat ... 215
17.1.2.4 Pushtashan ... 216
17.1.3 Tertiary volcanic arc of the Neo-Tethys (Penjween-Walash Zone) ... 216
17.1.4 Upper Cretaceous volcanic arc of the Shalair Zone (Sanandaj-Sirjan Zone) ... 217
17.1.5 Origin of the Iraqi Ophiolites ... 217
17.2 Metamorphism of the Zagros Suture units ... 219
17.2.1 Serpentinite imbricates ... 219
17.2.2 Regional metamorphism ... 220
17.2.2.1 Metamorphism of the Shalair and Katar Rash groups ... 220
17.2.2.2 Metamorphism of the Gimo Group ... 220
17.2.2.3 Metamorphism of the Mawat Group ... 221
17.2.2.4 Metamorphism of the Bulfat area (Gimo and Sirginil groups) ... 221
17.2.3 Contact Metamorphism ... 221

17.2.3.1 Contact metamorphism of pelitic rocks of Bulfat 223
17.2.3.2 Contact metamorphism of calcareous and basic rocks of Bulfat 224
17.2.4 The development of the metamorphism of the Zagros Suture 224
17.2.5 History of metamorphic events 224

CHAPTER 18
HYDROCARBONS *(Saad Z. Jassim and Mohammad Al-Gailani)* **232**
18.1 Introduction 232
18.2 Oil and gas reserves 232
18.3 Oil Production 233
18.4 Oil Production System 233
18.5 Oil Pipelines and Export Facilities 235
18.6 Gas processing and Transportation 236
18.7 Petroleum Systems 236
18.7.1 Introduction 236
18.7.1.1 Thermal gradient and heat flow 237
18.7.1.2 Maturity of organic matter 237
18.7.2 Hydrocarbon seepages 238
18.7.3 Palaeozoic petroleum system 240
18.7.3.1 Source rocks 240
18.7.3.2 Ordovician 240
18.7.3.3 Silurian 241
18.7.3.4 Lower Carboniferous 241
18.7.3.5 Upper Permian 241
18.7.3.6 Reservoirs and seals 242
18.7.4 Triassic petroleum system 242
18.7.4.1 Source rocks 242
18.7.4.2 Reservoirs and seals 242
18.7.5 Jurassic petroleum system 243
18.7.5.1 Source rocks 243
18.7.5.2 Reservoirs and seals 243
18.7.6 Cretaceous petroleum system 244
18.7.6.1 Source rocks 244
18.7.6.2 Reservoirs and seals 245
18.7.7 Tertiary system 247
18.7.7.1 Source rocks 247
18.7.7.2 Reservoirs and seals 247
18.7.8 Hydrocarbon budget and exploration potential 249

CHAPTER 19
HYDROGEOLOGY *(Jiří Krásný, Saad Alsam and Saad Z. Jassim)* **251**
19.1 Introduction 251
19.2 Available data, methodology of treatment of hydrogeological data 251
19.3 Natural conditions influencing hydrogeological conditions 252
19.3.1 Geological conditions 252
19.3.2 Climatic conditions 252
19.3.3 Morphological and hypsometric conditions 253
19.3.4 Hydrography 253
19.4 General features of hydrogeological conditions in Iraq 254
19.4.1 Main aquifers 254
19.4.2 Regional groundwater flow and level 255
19.4.3 Chemical composition and salinity 256
19.5 Hydrogeological provinces of Iraq 258
19.5.1 Aquifer System of the Western and Southern Deserts 259
19.5.1.1 Fractured Cretaceous-Tertiary limestone of the Rutbah, Digma, Tayarat Akashat and Ratga formations (Aquifer Group 1) 259
19.5.1.2 Sandstones of Permocarboniferous Ga'ara and Bir El-Rah formations (Ga'ara Aquifer, Group 2) 259
19.5.1.3 Fractured limestones and sandstones of Triassic-Cretaceous age (Aquifer Group 3) 259

19.5.1.4 Limestone of the Euphrates Formation (Aquifer Group 4) 260
19.5.1.5 Karstified and fractured limestones of Palaeocene-Eocene of the Southern Desert (Aquifer Group 5) 260
19.5.1.6 Miocene sandstones and Pleistocene conglomerate of the Nukhaib Graben (Aquifer Group 6) 261
19.5.1.7 Sandstones of Miocene-Pliocene Dibdibba Formation (Aquifer Group 7) 261
19.5.1.8 Alluvial fan of Wadi Al-Batin (Aquifer Group 8) 262
19.5.2 Jezira Hydrogeological Region (Aquifer Group 9) 262
19.5.3 Aquifer System of the Mesopotamian Plain (Mesopotamian Aquifer System-Aquifer Group 10) 263
19.5.3.1 Extension and general features 263
19.5.3.2 Geological setting, spatial distribution of hydrogeological bodies 263
19.5.3.3 Transmissivity and permeability of the deposits and conclusions 264
19.5.3.4 Groundwater flow 266
19.5.3.5 Groundwater quality 269
19.5.3.6 Present-day groundwater use and possibilities of future groundwater supply 271
19.5.4 Aquifer systems of alluvial fans (Mandali-Badra-Tib region) 272
19.5.4.1 Extension of the system and its general features 272
19.5.4.2 Geological setting, spatial distribution of hydrogeological bodies, transmissivity and permeability of rocks 272
19.5.4.3 Groundwater flow (extension, depth, recharge, throughflow, discharge) 272
19.5.4.4 Groundwater quality 273
19.5.4.5 Groundwater use 273
19.5.5 Aquifer system of the Foothill zone (Foothill Aquifer System) 274
19.5.5.1 Extension and general features 274
19.5.5.2 Geological setting, spatial distribution of hydro-geological bodies, transmissivity and permeability of rocks 275
19.5.5.3 Groundwater flow (recharge, throughflow, extension, depth, discharge) of the sub-systems of the Foothill Zone 275
19.5.5.4 Groundwater quality 277
19.5.5.5 Present-day groundwater use, possibilities of future groundwater supply 279
19.5.6 Taurus-Zagros Groundwater Province 279
19.5.6.1 Extent and general features 279
19.5.6.2 Geological setting, spatial distribution of hydrogeological bodies, transmissivity and permeability of rocks 280
19.5.6.3 Groundwater flow (extension, depth, recharge, throughflow, discharge) 281
19.5.6.4 Groundwater quality 283
19.5.6.5 Present-day water use, possibilities of future groundwater supply 283
19.6 Estimation of groundwater resources 284
19.6.1 Explotational Resources and Groundwater Use 284
19.7 Environmnetal issues 285

CHAPTER 20
METALLIC AND INDUSTRIAL ROCKS AND MINERALS *(Khaldoun S. Al-Bassam and Jaroslav Hak)* **288**
20.1 Introduction 288
20.2 Minerogenic zonation 288
20.3 Metallic Mineral deposits 290
20.3.1 The principal minerogenic features of the Zagros-Taurus sutures 290
20.3.2 Mineralization of the Northern Thrust Zone 290
20.3.2.1 Serguza lead-zinc deposit and its origin 291
20.3.3 Mineralisations of the Zagros Suture 293
20.3.3.1 The Marapasta base metal deposit and its origin 295
20.3.3.2 Comments on the ore genesis 295
20.4 Non-metallic mineral and industrial rocks 297
20.4.1 Non-metallic minerogenic stratigraphy 297
20.4.2 Deposits 297
20.4.2.1 Kaolinitic claystone 297
20.4.2.2 Montmorillonite and Palygorskite 297
20.4.2.3 Bentonite 298
20.4.2.4 Phosphorite 298

20.4.2.5 Porcelanites 299
20.4.2.6 Native Sulphur 299
20.4.2.7 Gypsum 299
20.4.2.8 Halite 299
20.4.2.9 Thenardite and Glauberite 300
20.4.2.10 Barite 300
20.4.2.11 Celestite 300
20.4.2.12 Ironstone 300
20.4.2.13 Karst Bauxite 300
20.4.2.14 Quartz sand 301
20.4.2.15 Heavy mineral bearing sandstone 301
20.4.2.16 Feldspathic sands 301
20.4.2.17 Limestone 301
20.4.2.18 Dolomite 302
20.4.2.19 Marble 302
20.4.2.20 Industrial igneous rocks 302

REFERENCES **303**

APPENDICES **319**

LITHOSTRATIGRAPHIC UNIS INDEX **337**