PETROLEUM GEOLOGY OF THE

PERSIAN GULF

Author:

Fereydoun Ghazban
University of Tehran

Technical Advisor:

Homayoun Motiei
NIOC
PREFACE

The intention of this book is to provide a detailed synthesis of the available information published on the petroleum geology of the Persian Gulf. Despite the intensive petroleum exploration which has taken place in the Persian Gulf over the past seventy years, relatively little has been published in the petroleum geology literature. One of the main reasons for this is that many of the studies are undertaken either for or by oil companies, who, for competitive reasons, impose restrictions on publication to maintain confidentiality. This information will aid in estimating oil and gas reserves as well as improving field development technology.

Much work remains to be done regarding the geology of the Persian Gulf. The need for a book on the geology of the Persian Gulf is therefore clear, and it is hoped that it will continue to provide a useful reference manual and resource of ideas for students as well as professionals.

As it is almost always the case with a book of such nature, it is impossible to provide a comprehensive and thorough coverage of geologic and sedimentologic studies in the Persian Gulf. Although this book is not intended to give an impression of the breadth of studies being carried out and the variety of approaches implemented, it should hopefully begin to rectify this, and to provide information on some of the key points.

Progress in the oil and gas producing industry is related closely to the improvement in exploration techniques and increase in discovery rates. Indeed, exploration and production of hydrocarbon resources must be based on reliable scientific information. Considerable amount of geological, geophysical, petrophysical, geochemical, and engineering information has been gathered over more than decades of oil and natural gas exploration and production in the Persian Gulf. The geological history of this economically important region has become increasingly better-investigated in recent years and this trend will undoubtedly continue.

This book takes the reader through the most fundamental description of geological history in the Persian Gulf region. Geoscientific knowledge concerning the Persian Gulf region has been widely scattered in many published works and attempt has been made to survey these materials. The present book also has an important academic purpose. The compilation and editing of this book required the assistance and cooperation of many people. A number of reviewers also dedicated their time to significantly improve the technical merit of each contribution.

It is hoped that the present contribution to the geology of the Persian Gulf will be of interest to stratigraphers and sedimentologists as a general background reference book, to those involved in geophysical exploration, and to environmental geoscientists who are interested in protecting the natural environment of the Persian Gulf as one of the most valuable and magnificent parts of the world.
This book on the Petroleum Geology of the Persian Gulf contains eleven chapters. It provides a broad, but not superficial, introduction to various aspects of the geology of the Persian Gulf.

Chapter one provides a general introduction including a brief historical background on the Persian Gulf and its magnificent history, and also some remarks about the history of oil exploration.

Chapter two is concerned with the physical oceanography of the Persian Gulf including the description of water circulation and hydrological aspects, water chemistry and movements of water. In general the Persian Gulf has been the subject of extraordinary neglect by modern oceanographers, remarkably so in view of the economic and political importance of the area, and the vast amount of marine trade carried on, principally in tanker traffic. This chapter emphasizes the need for better oceanographic knowledge of the Persian Gulf.

Chapter three mainly addresses the stratigraphy of the rock successions in the Persian Gulf region with description of the Precambrian to Recent rocks. The paleogeography, paleontology and facies of the Persian Gulf are also reviewed.

Many stratigraphic columns have been studied by various workers from both subcrops (well logs) and outcrops (measured) sections in various parts of the Zagros Belt and the northern Persian Gulf. Based on this database and available published stratigraphic, sedimentological, and petrographic information, a description for each stratigraphic unit has been presented in this chapter. Such work forms the basis for a synthesis of the uppermost Neoproterozoic through Phanerozoic successions, and provides a framework upon which a scheme for Persian Gulf region geologic evolution can be established.

Chapter four is on the source rocks for hydrocarbons. The petroleum charge system requires source rocks, which must be capable of generating and expelling petroleum, and have a migration pathway into the reservoir unit. Possible source rocks within the Persian Gulf and surrounding region and their potential have been presented in this chapter. In different parts of the Persian Gulf, sediments of quiet different types and age have been suggested as the source rocks, and evidently quite different organic materials are candidates as source. The quantities of organic sediments have been regarded as inadequate for the production of the oil and gas and would probably be seen to be much more inadequate still, if one allowed for the large natural seepage rate of the region observed since ancient times.

Chapter five is confined to a selection of representative, relatively well-documented accounts of carbonate and clastic reservoirs in the Persian Gulf and surrounding region. One of the objectives of this chapter is to focus on the geology of a select number of reservoirs and to present geologic case studies. The cases also demonstrate the depositional settings and facies, diageneis and the resulting petrophysical modification of these facies, and the reservoir properties that resulted from all these interrelated factors.
The small number of reservoirs cited in this chapter provided a reasonable representation of known reservoirs in the Persian Gulf, since carbonates are the principal reservoirs in majority of the oil fields. The chapter also focuses on the lithology and depositional settings of the producing formations of the Persian Gulf, and describes the habitat of the hydrocarbons (sources, reservoirs, and seals) for the region. Non-producing formations are also described to give the reader a general sense of local stratigraphy.

Included in this book (i.e., Chapter six), is a chapter on caprocks. Petroleum generation remains the rate-limiting factor in the formation of a petroleum system but competent caprocks are vital for commercial accumulations of petroleum in the sedimentary basin. The characters of efficient seals, including the regionally extensive evaporites and shales, especially in Upper Jurassic, Cretaceous and most importantly Miocene have been described.

Chapter seven is on the structural history of the Persian Gulf. Many authors have noted that the occurrence of petroleum seems to be more closely related to large-scale tectonic features of the crust than the magnitude of organic sedimentary deposits. Within the petrolierous province of the Persian Gulf, it is indeed common to find many different stratigraphic levels that are productive. The tectonic framework and evolution of the Persian Gulf is the focus of this section, with a review of the structural significance of the Zagros zone. The present tectonic picture of the Persian Gulf region is described in this chapter is written by Dr. Shahram Sherkati of the National Iranian Oil Company.

Salt Diapirism is dealt with in chapter eight. The subject of how structures are evolved is very important to understand because they are associated with major hydrocarbon reserves in the Persian Gulf. In this regard salt diapirism plays a very important role. Dr. Abbas Bahroudi is the main author of this part of the book and he has extensive experience in salt tectonic of the Persian Gulf region.

Chapter nine is concerned with some of the oil fields located in mostly Iranian waters of the Persian Gulf. This includes development, exploration and production history of the field and a summary of stratigraphy and reservoir characteristics. In the Persian Gulf, similar to the onshore region surrounding it, a close association of suitable source rocks and high quality reservoirs appears to be the most significant factor in the development of the great productivity of the Persian Gulf region. The main idea for organizing this chapter comes from Mr. Homayoun Motiei.

Chapter ten is a review of the geophysical activities during the past few decades and the initial draft was contributed by Mr. C. Amir Behboodi and Mr. A. Memarzade and revised by Dr. F. Ghazban. The chapter also provides some of the results of 3D seismic interpretation performed by geophysical consultants on some of the oil fields in the Persian Gulf.
Chapter eleven is on the environmental geology of the Persian Gulf. This chapter focuses on, the quaternary geology, environmental aspects, oil and industrial pollutions, and some climatic aspects of the Persian Gulf region.

I am deeply appreciative of the help given by others to make this book a reality. Special thanks to the University of Tehran for publishing the second edition of this book. I am very grateful to Homayoun Motiei who provided some of the background materials used in this book. Mr. Hassan Nazari significantly improved the illustrations appeared in the book. Mr. Arta Sharifi made a respectable cover design.

Special recognition and appreciation is due to my family (Shayan, Farzan and Elham) who provided me with many years of patient, understanding and encouragement while the first edition of this book was in preparation.

For the shortcomings that remain in the book, I alone feel responsible. Preparing this book was a major task and there is a lot of material used, probably too much to be error-free. I welcome all comments, pro and con, as well as suggested revisions. I hope that readers will actually enjoy reading most of this book.

This book is dedicated to all the geoscientists who contributed greatly to the knowledge and our understanding of the geology of southern parts of Iran and the Persian Gulf.

Fereydoun Ghazban
July, 2008
Tehran University, Iran
ACKNOWLEDGEMENT

The National Iranian Oil Company sponsored the publication of this book. The University of Tehran vice president of research and academic and the chief author of this book Dr. Fereydoun Ghazban would like to thank National Iranian Oil Company for their financial support.

Many people have helped considerably in putting together this book. Homayoun Motiei formerly of the Research and Development Division of the NIOC provided considerable feedback, significant input and encouragement and much needed council during the editing and preparation process. Eng. Abdolhamid Memarzia, the former exploration manager of the Iranian continental offshore company, was a prime source of encouragement throughout the publication of this book and acted as a driving force from the initiation stages of this project. Professor M. A., Ala of the Imperial College in London also provided several key references and his help is greatly appreciated.

Mrs. Arengo of the University of Zurich sincerely provided assistance with locating some of the key references in the library of the Swiss Technical University, geology department. Staff of the library of the exploration division of the NIOC in Tehran was also of considerable help.

The quality of the book was significantly improved by the valuable insights provided by comments from the technical and advisory board and the reviewers. The main text benefited greatly from critical and constructive reviews and suggestions by Homayoun Motiei, Mohammad Reza Kanali, Mahmood Bargrizan, Elham Hajikazemi and Reza Nouri. Mrs. S. Arya of the NIOC Research and Development department also provided much needed encouragement and financial assistance throughout the work. The author also would like to thank Dr. Ali Pourmand (Tulane University) for constructive editing of the manuscript.
CONTENTS

PREFACE .........................................................................................I
Acknowledgement ........................................................................V

CHAPTER-1 ...................................................................................1
INTRODUCTION .................................................................................1
   History of the Persian Gulf .....................................................3
   Oil Discovery in the Persian Gulf Region ...............................5
   Historical Perspective in the Persian Gulf .............................8
   Offshore Oil Discovery in the Persian Gulf .........................8
   Hydrocarbon in the Persian Gulf .........................................10
   Exploration Potential ..........................................................10
   The Persian Gulf Forever .....................................................12
   References ...........................................................................15

CHAPTER-2 ...................................................................................20
OCEANOGRAPHY OF THE PERSIAN GULF ..............................20
   Introduction ..........................................................................20
   Bathymetry and dimensions of Persian Gulf .......................20
   Bathymetric form of the Persian Gulf ....................................21
   Persian Gulf and the Strait of Hormuz .................................23
   Climate ................................................................................24
   Winds ..................................................................................25
   Evaporation ........................................................................27
   Fresh Water Exchange ..........................................................28
   Tides and Currents ...............................................................30
   Mixing Process .....................................................................34
   Residence Times ...................................................................35
   Water Circulation in the Persian Gulf ..................................36
   Dense Water in Persian Gulf .................................................39
   Salinity Distribution .............................................................40
   Bottom Sediments ..................................................................43
   Productivity ...........................................................................45
   Concluding Remarks ...........................................................48
   References ...........................................................................49

CHAPTER-3 ...................................................................................52
STRATIGRAPHY OF THE PERSIAN GULF .................................52
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>52</td>
</tr>
<tr>
<td>Infracambrian</td>
<td>53</td>
</tr>
<tr>
<td>Introduction</td>
<td>53</td>
</tr>
<tr>
<td>Infra-Cambrian Sedimentary Sequences</td>
<td>54</td>
</tr>
<tr>
<td>Formation of Persian Gulf Salt Basin</td>
<td>56</td>
</tr>
<tr>
<td>Salt Basins</td>
<td>59</td>
</tr>
<tr>
<td>Hormoz Complex</td>
<td>61</td>
</tr>
<tr>
<td>Characteristics of Hormoz Complex</td>
<td>62</td>
</tr>
<tr>
<td>Distribution of Evaporites</td>
<td>65</td>
</tr>
<tr>
<td>Age of the Hormoz Complex</td>
<td>68</td>
</tr>
<tr>
<td>Environment of Evaporite Deposition</td>
<td>69</td>
</tr>
<tr>
<td>Late Precambrian to Early Cambrian</td>
<td>70</td>
</tr>
<tr>
<td>Paleozoic</td>
<td>71</td>
</tr>
<tr>
<td>Introduction</td>
<td>71</td>
</tr>
<tr>
<td>Geologic Setting of Persian Gulf Region</td>
<td>71</td>
</tr>
<tr>
<td>Paleoclimatic Synopsis</td>
<td>74</td>
</tr>
<tr>
<td>Gondwana and Persian Gulf</td>
<td>75</td>
</tr>
<tr>
<td>Cambrian in Northern Persian Gulf</td>
<td>76</td>
</tr>
<tr>
<td>Lalun, Barout and Zaigun Formations</td>
<td>77</td>
</tr>
<tr>
<td>Mila Formation</td>
<td>80</td>
</tr>
<tr>
<td>Ilebeyk Formation</td>
<td>82</td>
</tr>
<tr>
<td>Cambrian in Southern Persian Gulf</td>
<td>83</td>
</tr>
<tr>
<td>Ordovician</td>
<td>84</td>
</tr>
<tr>
<td>Ordovician in Northern Persian Gulf</td>
<td>87</td>
</tr>
<tr>
<td>Zard Kuh Formation</td>
<td>87</td>
</tr>
<tr>
<td>Seyahou Formation</td>
<td>87</td>
</tr>
<tr>
<td>Ordovician in Southern Persian Gulf</td>
<td>88</td>
</tr>
<tr>
<td>Silurian</td>
<td>90</td>
</tr>
<tr>
<td>Silurian in Northern Persian Gulf</td>
<td>92</td>
</tr>
<tr>
<td>Sarchahan Formation</td>
<td>92</td>
</tr>
<tr>
<td>Silurian in Southern Persian Gulf</td>
<td>93</td>
</tr>
<tr>
<td>Devonian</td>
<td>94</td>
</tr>
<tr>
<td>Devonian in Northern Persian Gulf</td>
<td>95</td>
</tr>
<tr>
<td>Zakeen Formation</td>
<td>95</td>
</tr>
<tr>
<td>Devonian of Southern Persian Gulf</td>
<td>97</td>
</tr>
<tr>
<td>Carboniferous</td>
<td>98</td>
</tr>
<tr>
<td>Permian</td>
<td>101</td>
</tr>
<tr>
<td>Permian Paleogeography and Climate</td>
<td>101</td>
</tr>
<tr>
<td>Regional Geologic Setting</td>
<td>104</td>
</tr>
<tr>
<td>Sedimentary Provinces</td>
<td>107</td>
</tr>
</tbody>
</table>
### Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid to Upper Jurassic in Northern Persian Gulf</td>
<td>163</td>
</tr>
<tr>
<td>Surmeh Formation</td>
<td>163</td>
</tr>
<tr>
<td>Surmeh Facies and Lithologic Divisions</td>
<td>164</td>
</tr>
<tr>
<td>Mond Limestone Member</td>
<td>165</td>
</tr>
<tr>
<td>Sargelu Formation</td>
<td>166</td>
</tr>
<tr>
<td>Middle Jurassic in Southern Persian Gulf</td>
<td>167</td>
</tr>
<tr>
<td>Izhara Formation</td>
<td>167</td>
</tr>
<tr>
<td>Araej Formation</td>
<td>168</td>
</tr>
<tr>
<td>Late Jurassic</td>
<td>169</td>
</tr>
<tr>
<td>Najmeh Formation</td>
<td>171</td>
</tr>
<tr>
<td>Gotnia Formation</td>
<td>172</td>
</tr>
<tr>
<td>Arab Formation</td>
<td>173</td>
</tr>
<tr>
<td>Sequence Stratigraphy</td>
<td>178</td>
</tr>
<tr>
<td>Hith Formation</td>
<td>179</td>
</tr>
<tr>
<td>Diyab Formation</td>
<td>181</td>
</tr>
<tr>
<td>Late Jurassic Early Cretaceous Unconformity</td>
<td>181</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>182</td>
</tr>
<tr>
<td>Introduction</td>
<td>182</td>
</tr>
<tr>
<td>Tectonostratigraphic Evolution</td>
<td>183</td>
</tr>
<tr>
<td>Regional Setting</td>
<td>185</td>
</tr>
<tr>
<td>Cretaceous Paleogeography and Paleoclimate</td>
<td>188</td>
</tr>
<tr>
<td>Cretaceous Basins</td>
<td>194</td>
</tr>
<tr>
<td>Cretaceous Sedimentary Breaks</td>
<td>196</td>
</tr>
<tr>
<td>Cretaceous Stratigraphy</td>
<td>198</td>
</tr>
<tr>
<td>Lower Cretaceous in Northern Persian Gulf</td>
<td>201</td>
</tr>
<tr>
<td>Fahliyan Formation</td>
<td>203</td>
</tr>
<tr>
<td>Garau Formation</td>
<td>205</td>
</tr>
<tr>
<td>Gadvan Formation</td>
<td>206</td>
</tr>
<tr>
<td>Khalij Member</td>
<td>208</td>
</tr>
<tr>
<td>Dariyan Formation</td>
<td>208</td>
</tr>
<tr>
<td>Lower Cretaceous in Southern Persian Gulf</td>
<td>211</td>
</tr>
<tr>
<td>Division of The Early Cretaceous</td>
<td>212</td>
</tr>
<tr>
<td>Aptian in Southern Persian Gulf</td>
<td>213</td>
</tr>
<tr>
<td>Sulaiy Formation</td>
<td>215</td>
</tr>
<tr>
<td>Yamama Formation</td>
<td>216</td>
</tr>
<tr>
<td>Facies and Depositional Setting During Early Cretaceous</td>
<td>217</td>
</tr>
<tr>
<td>Sedimentary Facies</td>
<td>218</td>
</tr>
<tr>
<td>Middle Cretaceous of Persian Gulf</td>
<td>218</td>
</tr>
<tr>
<td>Kazhdumi Formation</td>
<td>222</td>
</tr>
<tr>
<td>Burgan Formation</td>
<td>225</td>
</tr>
</tbody>
</table>
Safaniya Sandstone ................................................................. 226
Upper Middle Cretaceous of the Persian Gulf .................. 227
Wasia Group in Persian Gulf ........................................... 228
The Sarvak Formation ....................................................... 231
Lower Sarvak Formation (=Mauddud Member) .................. 236
Khatiyah Formation .......................................................... 237
Upper Sarvak Formation (= Mishrif Member) .................... 238
Mid-Cretaceous Sea Level Changes ................................. 240
Upper-Middle Cretaceous Boundary ................................. 241
Upper Cretaceous of the Northern Persian Gulf .............. 242
Laffan Formation .............................................................. 244
Ilam Formation ................................................................. 246
Gurpi Formation ............................................................... 247
Tarbur Formation ............................................................. 249
Upper Cretaceous of the Southern Persian Gulf .............. 250
The Significance of Cretaceous Rudists ......................... 252
Mesozoic Closure ............................................................. 253
Cenozoic of the Persian Gulf .............................................. 255
Introduction ........................................................................ 255
Development History ........................................................ 255
Persian Gulf Geologic Setting during Tertiary ............... 257
Foreland Basin ................................................................. 259
Paleocene- Eocene Sedimentary Environment of Persian Gulf 261
Pabdeh Formation ............................................................. 266
Sachun, Kashkan and Shahbazan Formations .................... 269
Paleocene-Eocene in Southern Persian Gulf ..................... 270
Umm Er Radhuma Formation ........................................... 271
Rus Formation ................................................................. 272
Dammam Formation .......................................................... 273
Eocene of Oman ............................................................... 273
Jahrum Formation (Paleocene-Late Eocene) ..................... 274
Oligocene ........................................................................... 276
Asmari Formation (Oligo-Miocene) ................................. 278
Age of the Asmari Formation ............................................ 283
Ahwaz Member of Asmari Formation ............................. 284
Asmari Depositional Environment .................................... 286
Neogene (Miocene-Pliocene) ............................................. 287
Miocene ............................................................................. 288
Early to Middle Miocene in Persian Gulf ....................... 290
Gachsaran Formation ......................................................... 292
TABLE OF CONTENT

Division of Gachsaran .................................................. 295
Sandy Silty Facies (Razak Formation of ashfi) ............ 295
Gypsum-Anhydrite Facies (Namaki Formation). .......... 297
Massive Salty Facies (Qeshm Formation) .................. 297
Sedimentary Environment ........................................... 297
Late Miocene ............................................................ 299
Mishan Formation .................................................... 299
Miocene in the Southern Persian Gulf .................... 301
Hadrukh Formation .................................................. 302
Dam Formation ....................................................... 303
Agha Jari Formation ................................................ 303
Lahbari (Upper Miocene to Pliocene) ....................... 304
Age of Agha Jari Formation ...................................... 305
Hofuf Formation (Equivalent to Agha Jari) ............... 305
Dibdibba Formation ................................................ 306
Bakhtiari Formation ................................................. 306
Kharg Formation .................................................... 308
Summary of the Cenozoic Stratigraphy ..................... 309
References .............................................................. 309

CHAPTER-4 .................................................................. 335
SOURCE ROCKS IN PERSIAN GULF ................................. 335
Introduction ............................................................... 335
Source Rocks Depositional Environment in Persian Gulf 336
Maturation ............................................................... 338
Paleozoic Source Rocks of Persian Gulf ................. 339
Silurian Source Rocks ............................................... 340
Organic Geochemistry of Silurian Shales ................. 343
Maturation, Generation, and Expulsion ................... 345
Sarchahan Formation ................................................. 349
Permian Source Rocks .............................................. 351
Maturity of Kangan Formation ................................. 351
The Mesozoic Source Rocks ...................................... 352
Triassic Source Rocks ............................................... 354
Jurassic Source Rocks .............................................. 354
Jurassic Source Rock in Northern Persian Gulf ......... 357
Sargelu Source Rock ................................................. 357
Maturation, Generation, and Expulsion ................. 358
Surmeh Source Rock ............................................... 360
Jurassic Source Rock in Southern Persian Gulf ......... 362
TABLE OF CONTENT

Triassic ................................................................. 418
Jurassic ................................................................. 419
Middle Jurassic Reservoir ......................................... 419
Upper Jurassic Reservoirs .......................................... 420
Surmeh and Arab Reservoirs .................................... 422
Cretaceous Reservoirs in the Persian Gulf .................. 425
Lower Cretaceous ..................................................... 426
Fahlīyan Reservoir .................................................. 429
Dariyan Reservoir ................................................... 430
Bangestan Reservoirs .............................................. 433
Azadegan Sand Member ............................................ 434
Burgan Sandstone .................................................. 436
Sarvak Reservoir .................................................... 437
Lower Sarvak Reservoir .......................................... 438
Upper Sarvak Reservoir .......................................... 440
Khafji and Safaniya Reservoirs .................................. 444
Ilam (Halul) and Mansouri (Simsima) ......................... 444
Rudist-Bearing Reservoirs in Persian Gulf ................... 446
Cenozoic Reservoirs ............................................... 448
Asmari Reservoir .................................................. 448
Ahwaz Sandstone Member ....................................... 451
Other Reservoirs .................................................... 453
Concluding Remarks .............................................. 453
References ........................................................... 454

CHAPTER-6 ............................................................. 461
CAP ROCKS AND SEALS IN PERSIAN GULF ................. 461
   Introduction ...................................................... 461
   Cap Rock Properties ........................................... 462
   Capillary Properties ......................................... 463
   Diffusion Losses Through Seals ................................ 463
   Lithology .......................................................... 464
   Ductility .......................................................... 464
   Thickness .......................................................... 465
   Seal Retention .................................................... 466
   Significance of Regional Seals ............................... 469
   Cap Rocks Depositional Setting of Persian Gulf .......... 470
   Seals and Traps in the Persian Gulf Region ............... 471
   Cap Rocks for Paleozoic Reservoirs ......................... 472
   Cap Rocks for Permian Reservoirs ........................... 473
TABLE OF CONTENT

Inferred Blind Hormuz Salt Structures ........................................... 538
Active Salt Extrusions ................................................................. 538
Salt Glacier or Namakier ............................................................... 539
Inactive Salt Extrusions ................................................................. 541
Gachsaran Salt in the Zagros Basin ................................................. 542
Salt Diapirism and Hydrocarbon .................................................... 544
Conclusions ..................................................................................... 548
Acknowledgments ............................................................................ 549
References ....................................................................................... 549

CHAPTER-9 ..................................................................................... 559

HYDROCARBON FIELDS OF PERSIAN GULF ........................................ 559

Introduction .................................................................................... 559
Crude Oil Reserves of Continental Shelf in Persian Gulf ..................... 560
Oil and Gas Reserves, Production, Capacity ..................................... 561
Offshore Persian Gulf ..................................................................... 562
Oil Development ............................................................................ 562
Natural Gas Development ............................................................... 563
Natural Gas ..................................................................................... 564
Introduction to Oil Fields in the Persian Gulf ................................ 564
Pool Size Distribution in the Persian Gulf ....................................... 564
Persian Gulf Oil Fields ..................................................................... 565
Abouzar (Formerly Ardeshir) ............................................................ 566
Alvand- Alpha-1 (IMINOCO) ............................................................... 567
Baneh, Former Beta-1 (IMINOCO) or Behrooz .................................. 568
Bahman (IPAC, B-1) ....................................................................... 568
Binalud (BA-1 Bushco, BA-1) ............................................................. 568
Bahregansar .................................................................................... 568
Balal (Formerly Bahram or 3W-Structure) ........................................ 570
Binalud-B (Former Bushco-B or Bb) ................................................ 571
Binalud-C (Former Bc-1 Bushco, or BC) .......................................... 571
Doroud (Formerly Kharg-Darius) ..................................................... 572
Im-D-1 IMINICO ............................................................................. 573
Esfandiyar ....................................................................................... 573
Farzad-A (Former Farsi A or Fa) ....................................................... 575
Farzad-B (Former Farsi-B-1 or Fb-1) ................................................ 575
Farsi-C-1 (FC-1) .............................................................................. 576
Fateh Field ..................................................................................... 576
Ferdowsi Heavy Oilfield (Formerly F) .............................................. 577
Forooyan (Formerly Fereydoun) ...................................................... 577
Yoush (Former Pegopco “U” Structure) ........................................... 609
‘Im-V’ Structure (Iminoco) .................................................. 610
‘X’ Structure ............................................................................ 610
‘Y’ Structure (Iminoco) .......................................................... 611
Yaldas (Former Lapco-‘3 Y’ Structure) ................................. 611
Hydrocarbon Migration to the Oil Fields of Persian Gulf .......... 611
Concluding Remarks .............................................................. 613
Acknowledgment ................................................................. 615
References .............................................................................. 615

CHAPTER-10 ................................................................. 617
GEOPHYSICAL SURVEY OF THE PERSIAN GULF ............... 617
Introduction ........................................................................... 617
Brief Review of Geophysical Survey in the Persian Gulf .......... 617
Generalities and Data Interpretation ........................................ 621
Abouzar ................................................................................. 621
Resalat and Reshadat Fields ................................................. 622
Sirri Field .............................................................................. 623
Hengam ................................................................................. 624
Seismic Data Quality: Signal and Noise ............................... 625
Velocity Distribution .............................................................. 627
Northern Persian Gulf (Abouzar Field) .................................. 628
Aghajari-Mishan-Top Gachsaran .......................................... 628
Top Upper Ahwaz Sand Member .......................................... 629
Top Lower Asmari/ Near Base Ahwaz Sand Member .............. 629
Lower Pabdeh ........................................................................ 630
Upper Gurpi ........................................................................... 630
Turonian Unconformity ......................................................... 630
Kazhdumi .............................................................................. 631
Top Dariyan ........................................................................... 631
Gadvan ............................................................................... 631
Near Hith ............................................................................... 632
Central Part of the Persian Gulf ............................................. 632
Top Asmari Seismic Event ...................................................... 632
Upper Jahlam Seismic Event ................................................. 633
Top Ilam Seismic Event .......................................................... 633
Top Laffan Seismic Event (Resalat, Reshadat, Sirri C and D) .... 633
Upper Sarvak Reservoir ......................................................... 634
Top Kazhdumi, Top Dariyan Seismic Events ......................... 634
Top and Near Top Hith .......................................................... 635
Kangan-Dalan .......................................................... 635
Eastern Persian Gulf (Hengam) .................................. 635
Miocene Unconformity ............................................... 636
Top Cretaceous and Top Gurpi Shale ......................... 636
Ilam-Sarvak Reservoir ............................................. 637
Kazhdumi and Dariyan Formations .............................. 638
Main Seismic Event ................................................. 638
Structural Aspects .................................................. 638
Salt Diapirism ....................................................... 639
Fault and Fold Development ...................................... 639
Stratigraphy .......................................................... 642
Reefs .................................................................. 642
Facies Changes ....................................................... 643
Reservoir Characterization ....................................... 643
Conclusions ........................................................... 644

CHAPTER-11 ................................................................ 646
PERSIAN GULF ENVIRONMENTAL GEOLOGY ............. 646
Introduction ........................................................... 646
The Persian Gulf Environment .................................. 646
Climate ................................................................. 646
Winds .................................................................. 648
Hydrography ........................................................... 649
Persian Gulf Coastal Morphology .............................. 651
Northern Shore ...................................................... 651
Southern Shore ...................................................... 654
Mesopotamia Plain ................................................ 656
Islands Morphology ................................................ 658
Persian Gulf Marine Habitats .................................... 660
Coral Reefs ............................................................ 661
Mangroves ............................................................. 663
Seagrass Beds ......................................................... 665
Mudflats and Salt Marshes ....................................... 665
Sandy Coastlines and Tidal Flats ............................... 666
Sabkhas ................................................................. 667
Dolomitization ........................................................ 670
Sediments of the Persian Gulf .................................. 671
Nature of the Sediments ......................................... 671
Major Alluvial Accumulation ................................... 674
Fluvial Sediments .................................................. 675
<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleistocene Sedimentology</td>
<td>676</td>
</tr>
<tr>
<td>Eolian Sedimentation</td>
<td>676</td>
</tr>
<tr>
<td>Carbonate Eolianites</td>
<td>677</td>
</tr>
<tr>
<td>Neogene Sediments in the Persian Gulf</td>
<td>678</td>
</tr>
<tr>
<td>Sedimentation Rate</td>
<td>679</td>
</tr>
<tr>
<td>Uplift in the Persian Gulf Region</td>
<td>679</td>
</tr>
<tr>
<td>The Persian Gulf Sea Level Fluctuation</td>
<td>680</td>
</tr>
<tr>
<td>Recent Sea-Level Changes and its Impact</td>
<td>684</td>
</tr>
<tr>
<td>Persian Gulf Paleoclimatic Conditions</td>
<td>685</td>
</tr>
<tr>
<td>Climate and Human Civilization</td>
<td>687</td>
</tr>
<tr>
<td>Environmental Pollution in Persian Gulf</td>
<td>688</td>
</tr>
<tr>
<td>Effects of Regional Conflicts</td>
<td>689</td>
</tr>
<tr>
<td>Faith of Oil in Persian Gulf</td>
<td>692</td>
</tr>
<tr>
<td>Effects of Oil Pollution</td>
<td>692</td>
</tr>
<tr>
<td>Industrial Pollution</td>
<td>694</td>
</tr>
<tr>
<td>Types of Pollutants in the Persian Gulf</td>
<td>695</td>
</tr>
<tr>
<td>Persian Gulf Shoreline Sensitivities</td>
<td>697</td>
</tr>
<tr>
<td>Protection of the Persian Gulf Environment</td>
<td>697</td>
</tr>
<tr>
<td>References</td>
<td>699</td>
</tr>
</tbody>
</table>