



Petroleum Geology of Libya

Don Hallett

CONTENTS

CONTENTS	3
LIST of FIGURES	7
PREFACE	11
NOTES and DEFINITIONS	13
Chapter 1 HISTORY of LIBYAN OIL EXPLORATION and PRODUCTION	17
<p><i>1.1 Before Independence, p. 17. 1.2 The fledgling Libyan oil industry, p. 17. 1.3 Exploration activity, 1956-1958, p. 19. 1.4 Bonanza, 1959-1961, p. 20. 1.5 Events leading to the Petroleum Law of 1965, p. 22. 1.6 Exploration and production activity, 1962-1965, p. 24. 1.7 New concession awards and Joint Ventures, 1966-1969, p.26. 1.8 Exploration and Production, 1966-1969, p. 29. 1.9 The Revolution and its aftermath, 1969-1974, p. 30. 1.10 The decline in exploration activity, 1969-1974, p. 33. 1.11 EPSA I, 1974, p. 34. 1.12 Consolidation, 1975-1979, p. 35. 1.13 Turmoil. 1979-1986, p. 38. 1.14 EPSA II and new discoveries, 1979-1986, p. 39. 1.15 Sanctions and EPSA III, 1986-1999, p. 40. 1.16 Reserves, p. 43. 1.17 Natural Gas, p. 46. 1.18 Summary, p. 46.</i></p>	
Chapter 2 PLATE TECTONIC HISTORY of LIBYA	48
<p><i>2.1 Introduction, p. 48. 2.2 Rodinia, p. 50. 2.3 The break-up of Rodinia, p. 50. 2.4 The Pan-African orogeny and the assembly of Gondwana, p. 52. 2.5 Gondwana during the Palaeozoic, p. 55. 2.6 Pangaea, p. 59. 2.7 Tethys, p. 61. 2.8 The development of Tethys, p. 62. 2.9 Tethys to Mediterranean, p. 71.</i></p>	
Chapter 3 STRATIGRAPHY: PRECAMBRIAN and PALAEOZOIC	76
<p><i>3.1 The development of Libyan stratigraphy, p. 76. Precambrian, p. 79. 3.2 Archaean and Proterozoic, p. 79. Palaeozoic, p. 82. 3.3 Cambro-Ordovician, p. 82. 3.3.1 Hasawnah Formation, p. 85. 3.3.2 Ash Shabiyat Formation, p. 93. 3.3.3 Hawaz Formation, p. 95. 3.3.4 Melaz Shuqran Formation, p. 97. 3.3.5 Tasghart Formation, p. 99. 3.3.6 Mamuniyat Formation, p. 99. Late Ordovician glaciation, p. 103. 3.4 Silurian, p. 105. 3.4.1 Iyadhar and Bi'r Tlakshin Formations, p. 105. 3.4.2 Tanzuft Formation, p. 106. 3.4.3 Akakus Formation, p. 111. 3.5 Devonian, p. 116. 3.5.1 Tadrart Formation, p. 116. 3.5.2 Wan Kasa Formation, p. 119. 3.5.3 Awaynat Wanin Formation, p. 123. Local stratigraphy of the Awaynat Wanin 'Group', south flank of the Al Qarqaf Arch, p. 125. The Awaynat Wanin</i></p>	

Formation in other areas, p. 127. 3.5.4 Tahara Formation, p. 129. 3.6 Carboniferous, p. 130. 3.6.1 Marar Formation, p. 130. 3.6.2 Assedjefar Formation, p. 133. 3.6.3 Dimbabah Formation, p. 136. 3.6.4 Tiguentourine Formation, p. 138. 3.7 Permian, p. 140. 3.7.1 Al Watyah Formation, p. 142. 3.7.2 Bi'r al Jaja Formation, p. 143.

Chapter 4 STRATIGRAPHY: MESOZOIC

144

Mesozoic, p. 144. 4.1 Triassic, p. 144. 4.1.1 Al Guidr (Ouled Chebbi Formation), p. 147. 4.1.2 Kurrush (Ra's Hamia) Formation, p. 147. 4.1.3 Al Aziziyah Formation, p. 149. 4.1.4 Abu Shaybah Formation, p. 150. Triassic continental equivalents, p. 152. 4.1.5 Zarzaitine Formation, p. 152. Permo-Triassic igneous rocks, p. 154. 4.2 Jurassic, p. 154. 4.2.1 Abu Ghaylan Formation, p. 154. 4.2.2 Bi'r al Ghanam Formation, p. 156. 4.2.3 Takbal Formation, p. 157. 4.2.4 Khashm az Zarzur Formation, p. 159. 4.2.5 Shakshuk Formation, p. 159. 4.2.6 Kabaw Formation, p. 161. Jurassic continental equivalents, p. 162. 4.2.7 Taouratine Formation, p. 162. 4.3 Lower Cretaceous, p. 164. Northwest Libya, p. 164. 4.3.1 Kiklah Formation, p. 164. Offshore northwest Libya, p. 165. 4.3.2 Turghat Formation, p. 165. 4.3.3 Masid Formation, p. 165. Lower Cretaceous continental equivalents, p. 168. 4.3.4 Messak Formation, p. 168. 4.3.5 Nubian 'Formation'. p. 169. Northeastern Libya, p. 172. 4.3.6 Qahash 'Formation', p. 172. 4.3.7 Daryanah Formation, p. 172. 4.4 Upper Cretaceous, p. 175. Northwest Libya, p. 175. 4.4.1 Sidi as Sid Formation, p. 175. 4.4.2 Nalut Formation, p. 178. 4.4.3 Qasr Taghrinnah Formation, p. 179. 4.4.4 Mizdah Formation, p. 179. 4.4.5 Al Gharbiyah Formation, p. 184. Northwestern offshore, p. 188. 4.4.6 Alalgah Formation, p. 188. 4.4.7 Makhbaz Formation, p. 189. 4.4.8 Jamil Formation, p. 189. 4.4.9 Abu Isa formation, p. 189. 4.4.10 Al Jurf Formation (lower part), p. 190. Sirt Basin Subsurface, p. 190. 4.4.11 Bahi Formation, p. 190. 4.4.12 Maragh Formation, p. 190. 4.4.13 Lidam Formation, p. 191. 4.4.14 Argub Formation, p. 192. 4.4.15 Etel Formation, p. 192. 4.4.16 Rachmat Formation, p. 193. 4.4.17 Taqrifat Formation, p. 193. 4.4.18 Sirt Formation, p. 194. 4.4.19 Kalash Formation, p. 194. 4.4.20 Samah Formation, p. 195. 4.4.21 Satal Formation (Lower Member), p. 196. 4.4.22 Wahah Formation, p. 196. Northeastern Libya, p. 197. 4.4.23 Qasr al Ahrar Formation, p. 197. 4.4.24 Al Baniyah Formation, p. 197. 4.4.25 Al Majahir Formation, p. 198. 4.4.26 Wadi Dukhan Formation. p. 199. 4.4.27 Al Hilal Formation, p. 199. 4.4.28 Al Athrun Formation, p. 199.

Chapter 5 STRATIGRAPHY: CAINOZOIC

201

5.1 Palaeocene, p. 201. West Libya, p. 203. 5.1.1 Zimam Formation, p. 203. 5.1.2 Shurfah Formation, p. 203. Northwest Libya offshore, p. 205. 5.1.3 Al Jurf Formation (upper part), p. 205. 5.1.4 Ehduz Formation, p. 210. Sirt Basin, p. 210. 5.1.5 Al Hagfah Formation, p. 210. 5.1.6 Dayfah (Defa) Formation, p. 211. 5.1.7 Satal Formation (Upper Member), p. 211. 5.1.8 Sabil Formation (Lower Member), p. 211. 5.1.9 Al Bayda (Beda) Formation, p. 214. 5.1.10 Khalifah Member, p. 216. 5.1.11 Az Zahrah (Dahra) Formation, p. 216. 5.1.12 Sheterat Formation, p. 217. 5.1.13 Zaltan Formation, p. 217. 5.1.14 Sabil Formation (Upper member), p. 218. 5.1.15 Harash Formation, p. 219. 5.1.16 Khayir (Kheir) Formation, p. 219. Northeast Libya, p. 220. 5.1.17 Al 'Uwayliah Formation, p. 220. 5.2 Eocene, p. 220. Western outcrops, p. 221. 5.2.1 Bishimah Formation, p. 221. 5.2.2 Al Jir Formation (sensu IRC), p. 224. 5.2.3 Wadi Thamat Formation, p. 225. Northwest Libya offshore, p. 228. Farwah Group, p. 228. 5.2.4 Bilal Formation, p. 229. 5.2.5 Jdeir Formation, p. 229. 5.2.6 Taljah Formation, p. 232. 5.2.7 Tajoura Formation, p. 232. Tellil Group, p. 232. 5.2.8 Harshah Formation, p. 232. 5.2.9 Dahman Formation, p. 233. 5.2.10 Samdun Formation, p. 233. 5.2.11 Ghalil Formation, p. 233.

Sirt Basin, p. 236. **5.2.12 Al Jir (Gir) Formation** (*sensu Barr and Weegar*), p. 236. **5.2.13 Jalu (Gialo) Formation**, p. 237. **5.2.14 Gedari Formation**, p. 237. **5.2.15 Awjilah (Augila) Formation**, p. 238. *Northeast Libya*, p. 238. **5.2.16 Apollonia Formation**, p. 238. **5.2.17 Darnah Formation**, p. 239. **5.3 Oligocene**, p. 240. *Western outcrops*, p. 240. **5.3.1 Ma'zul Ninah Formation**, p. 244. **5.3.2 Umm ad Dahiy Formation**, p. 244. **5.3.3 Bu Hashish Formation**, p. 245. *Northwest Libya offshore*, p. 245. **5.3.4 Dirbal Formation**, p. 245. **5.3.5 Ra's Abd Jalil Formation**, p. 245. *Sirt Basin*, p. 246. **5.3.6 Arida Formation**, p. 246. **5.3.7 Diba Formation**, p. 246. *Northeast Libya*, p. 247. **5.3.8 Al Bayda Formation**, p. 247. **5.3.9 Al Abraaq Formation**, p. 248. **5.4 Miocene**, p. 248. *Coastal Plain*, p. 249. **5.4.1 Maradah Formation**, p. 249. **5.4.2 Al Khums Formation**, p. 254. **5.4.3 Sahabi Formation**, p. 256. *Northwest Libya offshore*, p. 258. **5.4.4 Al Mayah Formation**, p. 258. **5.4.5 Sidi Bannour Formation**, p. 258. **5.4.6 Bi'r Sharuf Formation**, p. 258. **5.4.7 Tubtah Formation**, p. 258. **5.4.8 Marsa Zouaghah Formation**, p. 259. *Sirt Basin*, p. 260. *Cyrenaica*, p. 261. **5.4.9 Al Faydiyah Formation**, p. 261. **5.4.10 Ar Rajmah Formation**, p. 262. **5.4.11 Al Jaghbub Formation**, p. 262. **5.5 Pliocene and Quaternary**, p. 263.

Chapter 6 STRUCTURE

265

6.1 Southern Libya, p. 266. **6.1.1 Basement**, p. 266. *Southern Libya evolution*, p. 266. **6.1.2 Al Kufrah Basin**, p. 268. *Al Kufrah Basin evolution*, p. 270. **6.2 Western Libya**, p. 271. **6.2.1 Murzuq Basin**, p. 271. *Tihemboka Arch*, p. 271. *Al Awaynat Trough*, p. 271. *Tirirene High*, p. 273. *Awbari Trough*, p. 273. *Idhan Depression*, p. 274. *Brak-Bin Ghanimah Uplift*, p. 274. *Dur al Qussah Trough*, p. 274. *Murzuq Basin evolution*, p. 274. **6.2.2 Al Qarqaf Arch**, p. 276. **6.2.3 Ghadamis Basin**, p. 277. *Ghadamis Basin evolution*, p. 277. **6.2.4 Nafusah Uplift**, p. 281. **6.2.5 Jifarah Basin**, p. 282. **6.3 Sirt Basin**, p. 283. **6.3.1 Sirt Basin evolution**, p. 286. **6.3.2 Structural components of the Sirt Basin**, p. 290. *Hun Graben*, p. 290. *Waddan Platform*, p. 290. *Zallah Trough*, p. 291. *Dur al Abd Trough*, p. 292. *Abu Tumayam Trough*, p. 292. *Az Zahrah-Al Hufrah Platform*, p. 293. *Al Bayda Platform*, p. 294. *Maradah Trough*, p. 295. *Zaltan and Al Jahamah Platforms*, p. 296. *Ajdabiya Trough*, p. 297. *Eastern Sirt Embayment*, p. 298. **6.4 Cyrenaica**, p. 299. **6.4.1 Structural evolution of Cyrenaica**, p. 300. **6.4.2 Structural components of Cyrenaica**, p. 304. *Cyrenaica Platform*, p. 304. *Jabal al Akhdar Uplift*, p. 304. *Marmarica Basin*, p. 305. *Northern coastal margin*, p. 305. *Al Jaghbub High*, p. 306. *Maragh Graben*, p. 306. *Amal/Nafusah Nose*, p. 306. *Ash Shulaydimah Trough*, p. 307. **6.5 Offshore**, p. 307. **6.5.1 Pelagian Block**, p. 310. *Sabratah Basin*, p. 311. *Jarrafa Arch*, p. 312. *Melita-Medina Plateau*, p. 313. *Misratah Basin*, p. 313. **6.5.2 Sirt Embayment**, p. 313. **6.5.3 Northern Cyrenaican offshore**, p. 315. **6.6 Structural synthesis**, p. 316. *Palaeozoic*, p. 316. *Mesozoic*, p. 317. *Cainozoic*, p. 318. **6.7 Summary**, p. 320.

Chapter 7 PETROLEUM GEOCHEMISTRY

322

7.1 Introduction, p. 322. **7.2 Al Kufrah Basin**, p. 325. **7.3 Murzuq Basin**, p. 326. **7.4 Ghadamis Basin**, p. 331. **7.5 Sirt Basin**, p. 336. **7.6 Cyrenaica**, p. 345. **7.7 Offshore**, p. 349.

Chapter 8 PETROLEUM SYSTEMS

355

8.1 Introduction, p. 355. **8.2 Murzuq Basin**, p. 359. **8.2.1 Tanzuft-Mamuniyat petroleum system**, p. 359. **8.2.2 Other reservoirs and source rocks**, p. 364. **8.3 Ghadamis Basin**, p. 365. **8.3.1 Tanzuft-Mamuniyat petroleum system**, p. 365. **8.3.2 Tanzuft-Akakus-Tadrart petroleum system**, p. 366. **8.3.3 Middle/Upper Devonian-Awaynat Wanin petroleum system**, p. 371. **8.3.4 Other reservoirs and source rocks**, p. 372.

8.4 Sirt Basin, p. 372. **Western Sirt Basin**, p. 374. **8.4.1 Zallah Trough**, Sirt Shale-Palaeocene-Eocene petroleum system, p. 376. **8.4.2 Western Sirt Basin**, other reservoirs and source rocks, p. 378. **Central Sirt Basin**, p. 379. **8.4.3 Maradah Trough**, Sirt Shale-Palaeocene petroleum system, p. 379. **8.4.4 Central Sirt Basin**, other reservoirs and source rocks, p. 385. **Ajdabiya Trough**, p. 387. **Western Ajdabiya Trough**, p. 387. **8.4.5 Sirt Shale-Upper Cretaceous petroleum system**, p. 387. **8.4.6 Sirt Shale-Palaeocene petroleum system**, p. 390. **8.4.7 Sirt Shale-Eocene/Oligocene petroleum system**, p. 392. **8.4.8 Other reservoirs**, p. 393. **Eastern Ajdabiya Trough**, p. 393. **8.4.9 Sirt Shale-Nubian petroleum system**, p. 393. **8.4.10 Sirt Shale-Palaeocene petroleum system**, p. 396. **8.4.11 Sirt Shale-Eocene petroleum system**, p. 397. **Eastern Sirt Embayment**, p. 399. **8.4.12 Upper Cretaceous-Nubian petroleum system**, p. 399. **8.4.13 Hameimat Trough**, Upper Cretaceous-Eocene/Oligocene petroleum system, p. 404. **8.4.14 Maragh Graben**, Triassic-Amal petroleum system, p. 404. **8.4.15 Hybrid petroleum systems**, p. 406. **8.5 Offshore**, p. 407. **8.5.1 Eocene-Farwah petroleum system**, p. 407. **8.5.2 Other reservoirs and source rocks**, p. 412. **8.5.3 Sirt Embayment and eastern offshore**, p. 415.

Chapter 9	POSTSCRIPT:	
	WHERE ARE THE REMAINING UNDISCOVERED RESERVES?	417
	<i>9.1 Introduction</i> , p. 417. <i>9.2 Yet-to-find oil</i> , p. 417. <i>9.3 Al Kufrah Basin</i> , p. 421. <i>9.4 Murzuq Basin</i> , p. 421. <i>9.5 Ghadamis Basin</i> , p. 421. <i>9.6 Western Sirt Basin</i> , p. 422. <i>9.7 Maradah Trough</i> , p. 423. <i>9.8 Western Ajdabiya Trough</i> , p. 423. <i>9.9 Eastern Ajdabiya Trough</i> , p. 424. <i>9.10 Eastern Sirt Embayment</i> , p. 425. <i>9.11 Cyrenaica</i> , p. 425. <i>9.12 Offshore</i> , p. 426.	
NOTES		428
REFERENCES		449
Appendix: GLOSSARY of GEOGRAPHIC NAMES		484
INDEX		488