Framework for the Exploration of Libya: An Illustrated Summary

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General Statement

Recoverable reserves being produced in Libya, from more than 300 fields, exceed 50 billion barrels of oil and 40 trillion cubic feet of gas (Rusk, 2001, 2002). Even so, the Sirte (Sirt), Ghadamis, Murzuq, and Tripolitania basins (Figure 1) are yet to reach full maturity in exploration. Of the 24 giant fields, 20 were discovered prior to 1970. Deep plays are expected to be a large part of upcoming exploration efforts.

Rusk (2001. 2002), in describing the petroleum potential of the centers of Libyan basins, summarized very well the petroleum systems and plays in six basin-center sectors (Figures 1, 2, 3, and 4). This compilation uses the Rusk article as the foundation for presenting several other published maps, cross-sections, and a database, as well as some images in his article; together these should add to the working tool kit for those interested in exploration of Libya.

Maps presented here are in JPEG and PDF formats; for those interested in GIS applications, an expanded version, an atlas, has been prepared for GIS-UDRIL sponsors and other purchasers of AAPG digital products. In the expanded version, approximately 80 georeferenced maps show tectonic features, structural elements and their configuration, thicknesses and facies of key strata and reservoirs, and oil and gas fields, with links to databases and to other images.

The database of giant Libyan fields is from M.K. Horn (2003) in AAPG Memoir 78, Giant Oil and Gas Fields of the Decade 1990-1999. Other information is from various AAPG publications as well as Journal of Petroleum Geology (see Selected Bibliography).

The basin-center sectors in which significant petroleum systems have developed (Rusk, 2001, 2002) are:

Sirte Basin (Figure 2)
- South Ajdabiya Trough
- Maradah Graben
- Southern Zallah Trough – Tumayam Trough

Ghadamis Basin (Figure 3)
Murzuq Basin (Figure 3)
Eastern Tripolitania Basin (Figure 4)

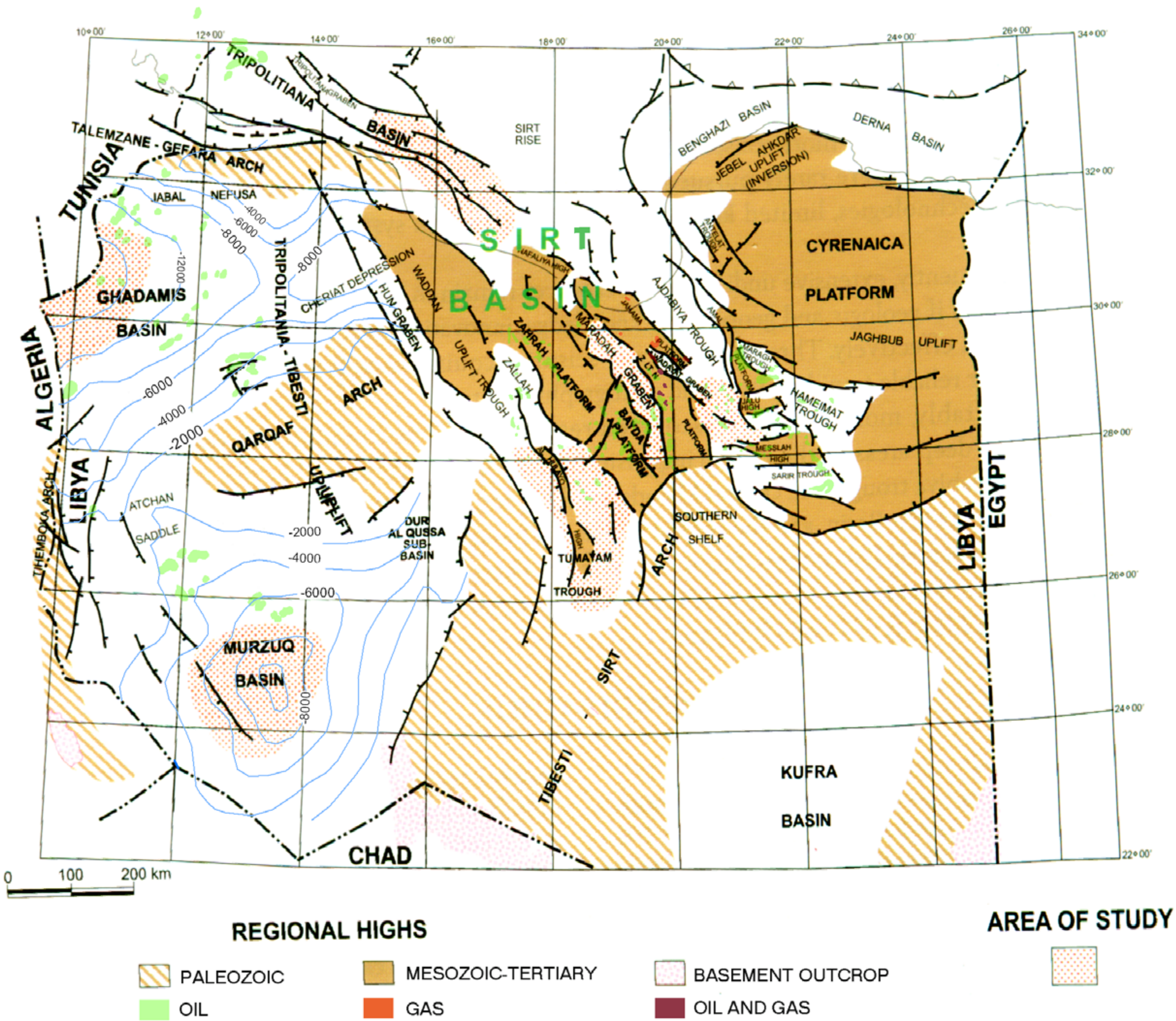

Figure 1. Tectonic elements of Libya, with oil and gas fields, areas of underexplored basin-centers (Rusk's areas of study), and structural contours in the west (modified after Rusk, 2001, 2002).

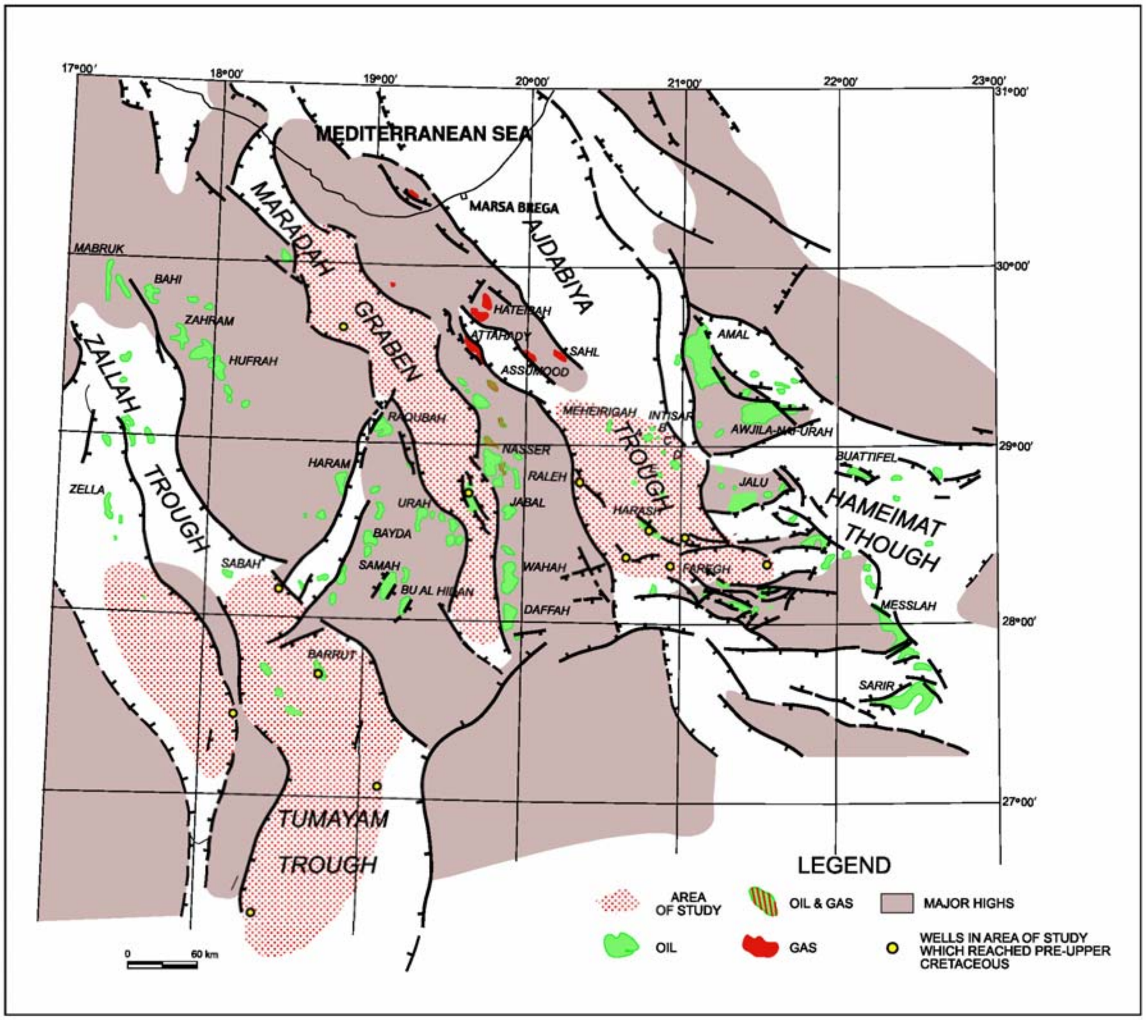

Figure 2. Structural elements of the Sirte Basin, with oil and gas fields, and the three areas of underexplored basin-centers (from Rusk, 2001, 2002).

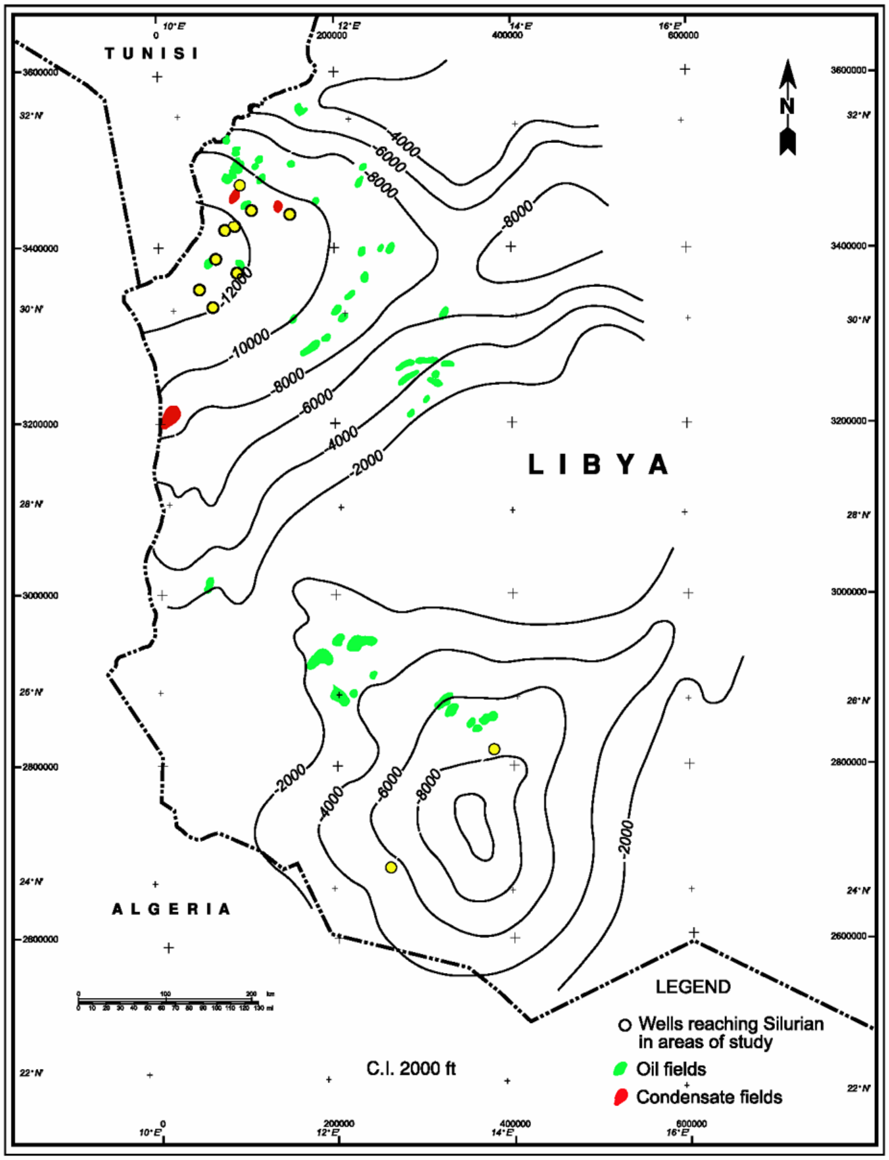

Figure 3. Structural contour map, on top Ordovician, of Ghadamis and Murzuq basins, with oil and gas fields and discoveries (from Rusk, 2001, 2002).

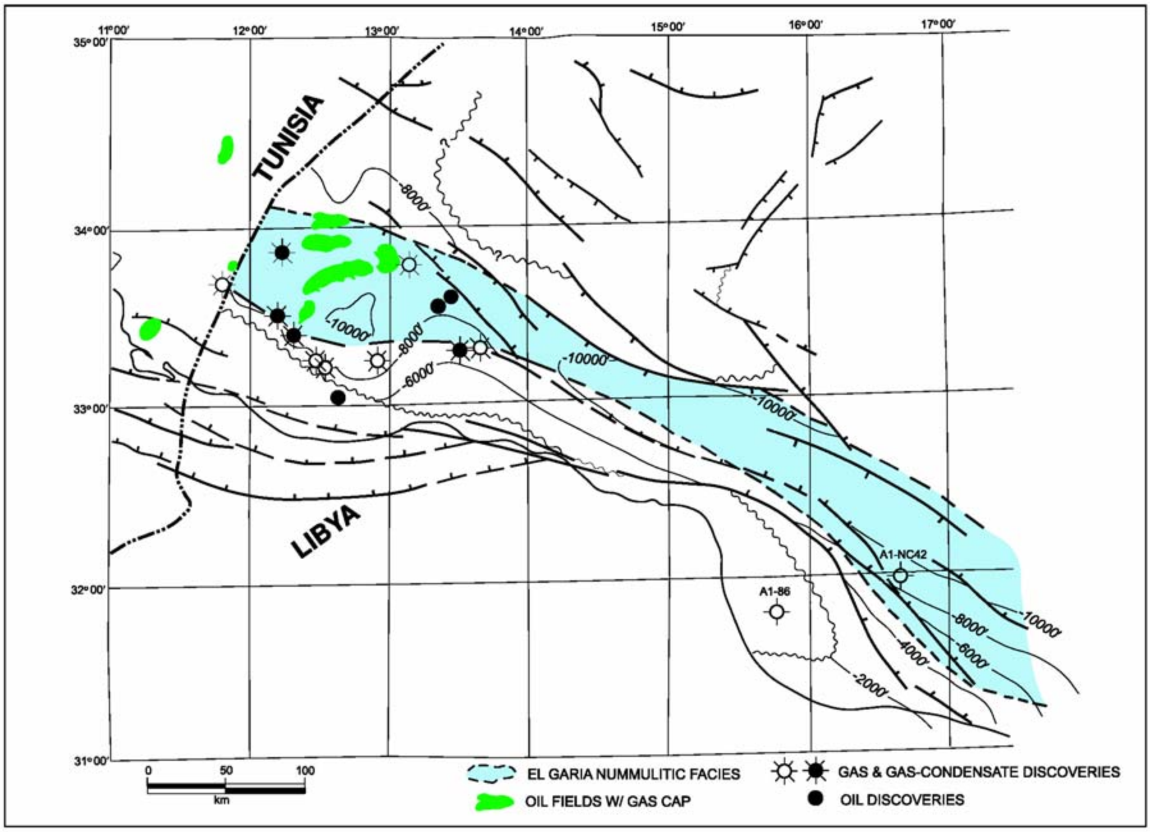

Figure 4. Structural contour map, on top Eocene Metlaoui Group, of the Tripolitania Basin in offshore Libya, showing oil fields and discoveries (from Rusk, 2001, 2002).

Sirte Basin

Common features of the three underexplored elements of the Sirte Basin (Figure 2) are:

- Nearby oil production
- Outstanding source rock (Upper Cretaceous Sirte-Rachmat Shale)
- Large areal extent
- Limited number of tests to pre-Upper Cretaceous units

South Ajdabiya Trough

The underexplored parts of the Ajdabiya Trough cover 8500 km^2. In addition to the Sirte-Rachmat Shale (Campanian-Coniacian in age), the Cenomanian-Turonian Etel Formation is an effective source rock, and the Lower Cretaceous lacustrine to lagoonal shale in the Nubian (Sarir) section probably should be considered a minor source (Figure 5). Reservoirs include the Nubian sandstones and Paleocene Lower and Upper Sabil carbonates.

Maradah Graben

The underexplored part of Maradah Graben is 10,000 km^2 in areal extent. The Sirte-Rachmat Shale and the Etel Formation are the known source rocks in this sector (Figure 5). Important reservoirs are the Nubian sandstones, carbonates of the Zelten Formation (equivalent to the Sabil), and Upper Cretaceous Bahi Sandstone, overlying the Nubian.

Southern Zallah Trough – Tumajam Trough

These troughs in the southern to southwestern part of the Sirte Basin contain 25,000 km^2 that are underexplored. The Sirte-Rachmat Shale is the known source rock of this area (Figure 5). Nubian sandstones and the commonly indistinguishable Bahi Sandstone are important reservoirs, along with Paleocene Defa and Beda and lower Eocene Facha limestones. Also, as potential reservoirs are Upper Cretaceous sandstones in the Sirte-Rachmat interval.

Central Ghadamis Basin

The basin-center sector encompasses more than 20,000 km^2. Two very good source rocks are distributed throughout the entire basin: Lower Silurian Tanezzuft and Middle to Upper Devonian Uennin formations (Figure 6). The main reservoirs are the Upper Silurian Acacus and the Lower Devonian Tadrart and Kasa formations. Three other objectives are the Middle Devonian Uennin Sandstone, Upper Devonian Tahara Formation, and the Triassic Ras Hamia Formation.

Central Murzuq Basin

In this area of more than 30,000 km^2, up to the year 2000 only four wells had been drilled. In the area to the north, where oil reserves are some 1 billion barrels, the reservoirs are the sandstones of the Ordovician Memouniat Formation (Figure 6).

The documented source rock is the Tanezzuft Shale, although some oil may have been sourced from the Uennin Shale. The potential reservoirs include the Acacus and Tadrart-Kasa sandstones, as well as the Memouniat.

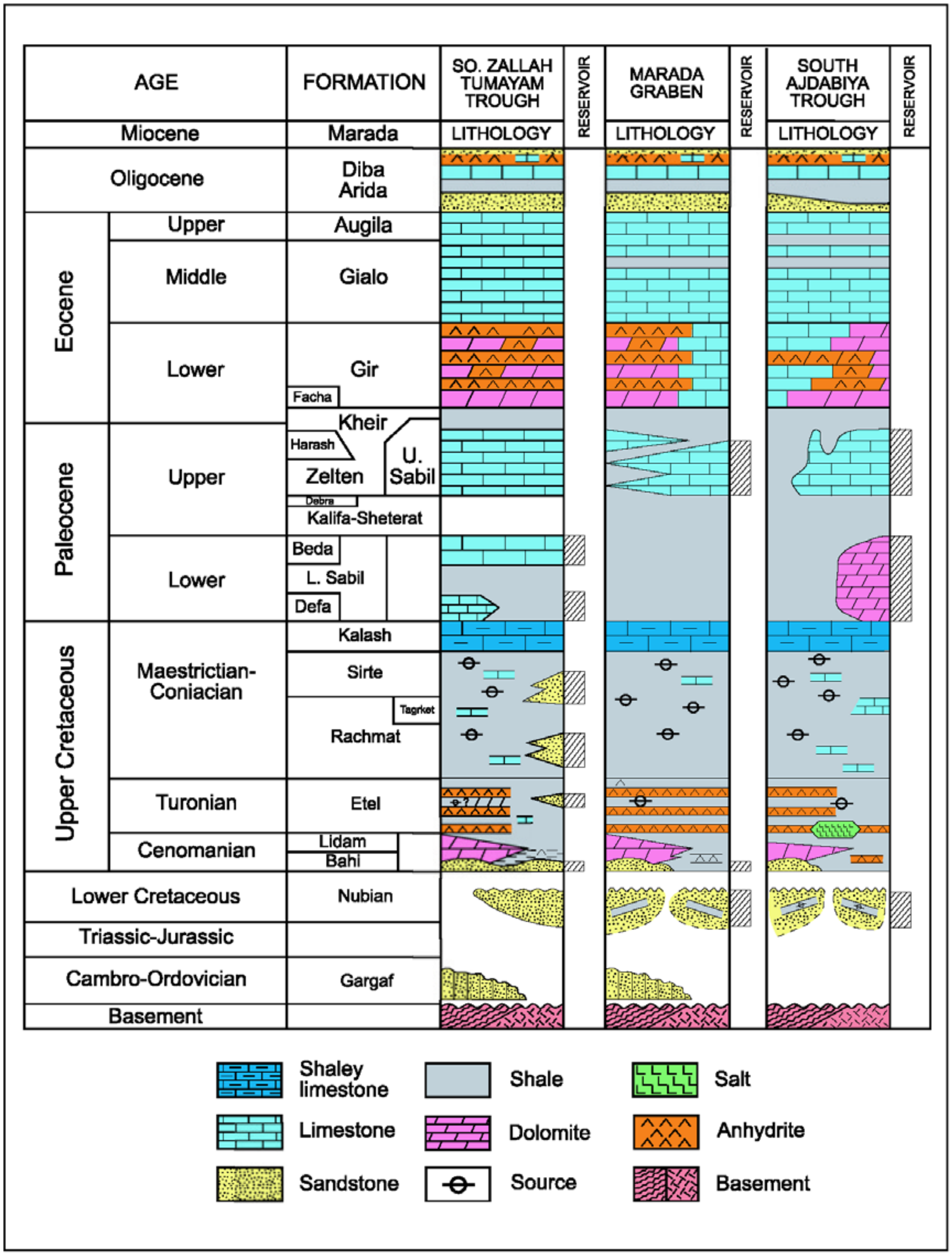

Figure 5. Generalized correlation chart for the underexplored areas of the Sirte Basin, showing lithology, source rock, and reservoir (from Rusk, 2001, 2002).

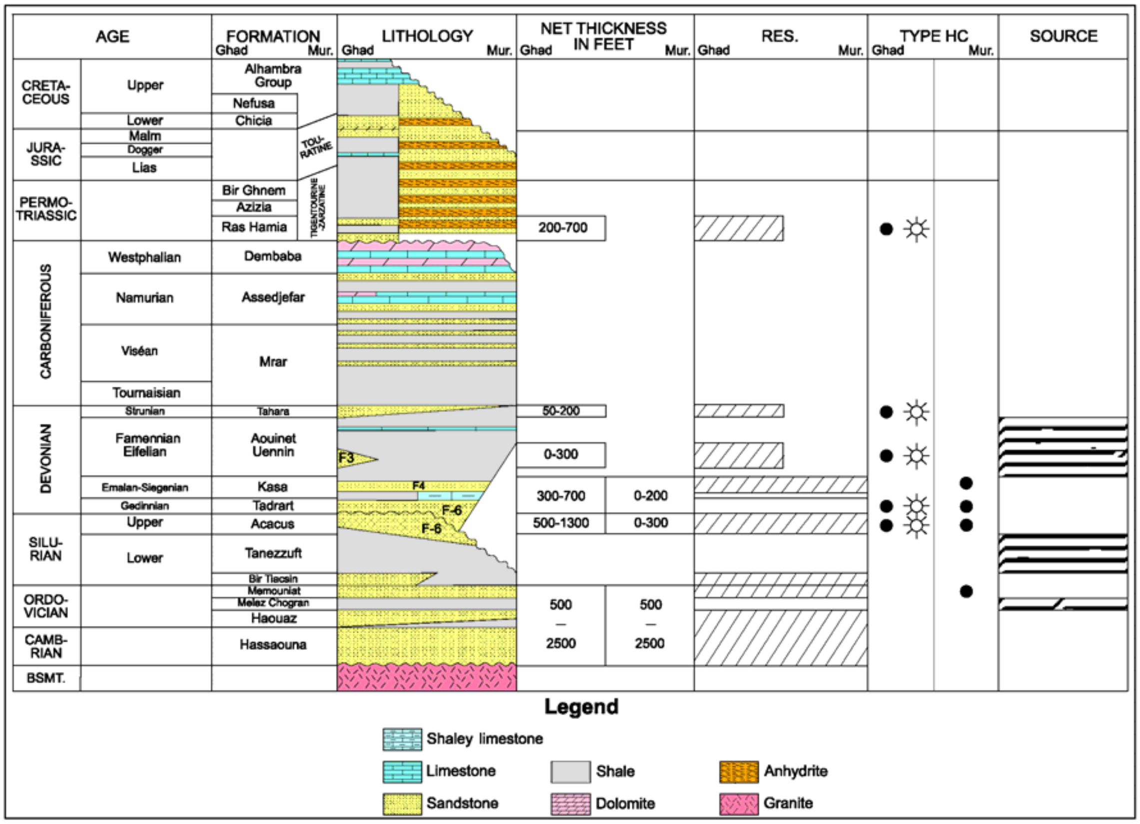

Figure 6. Generalized correlation chart for the Ghadamis and Murzuq basins, showing lithology, source rock, and reservoir (from Rusk, 2001, 2002).

Eastern Tripolitania Basin

This offshore basin, which is a highly faulted, deep trough, extends from the Gulf of Gabes to the northwestern margin of the Sirte Basin. The eastern sector is some 20,000 km^2 in extent and is essentially unexplored, with only one dry hole (up to the year 2000); known accumulations are 100-150 km west of the area.

Source rocks include the Turonian Bahloul limestone, Necomian-Cenomanian Sidi Kralif – Fahdene shales, Silurian Tanezzuft Shale (in the southwesternmost part), and lower Eocene Chouabine Limestone (in the western part) (Figure 7). Potential reservoirs are (1) limestone comprising the lower Eocene El Garia Formation (of the Metlaoui Group), the main pay in the basin, (2) the Jirani and Bilal carbonates, the equivalent of, or underlying, the El Garia, (3) carbonates of the Alagah and Makhabaz formations (or Lidam-Argub) (Cenomanian-Turonian), and (4) marine sandstones and rudist carbonates of the Lower Cretaceous Turghat-Kiklah sequence.

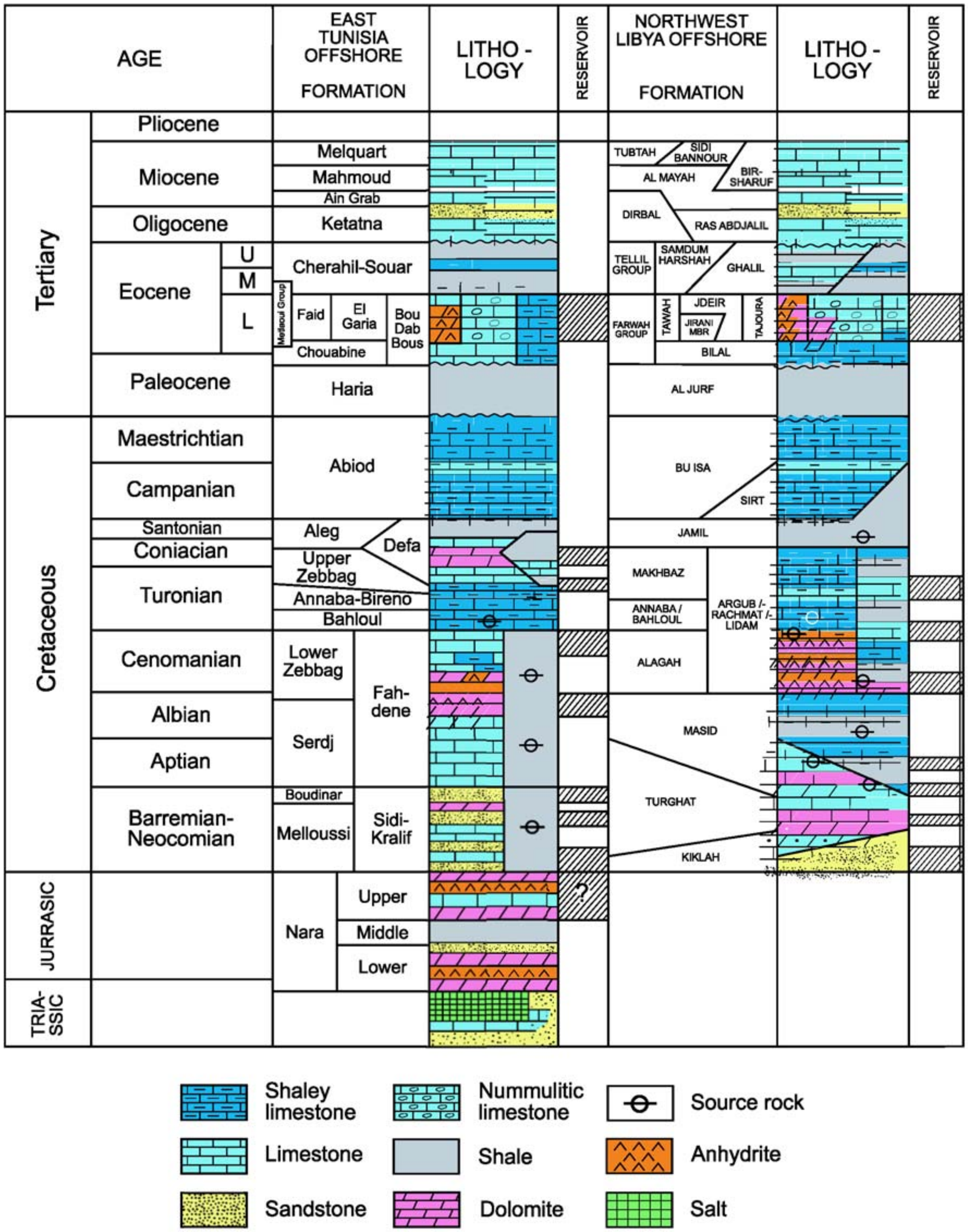

Figure 7. Generalized correlation chart for the Tripolitania Basin, showing lithology, source rock, and reservoir (from Rusk, 2001, 2002).

Giant Fields

The giant fields in Libya (Horn, 2003) are listed below according to basin; the database of selected features of these fields, prepared by M.K. Horn (2003), is presented in Table 1.

Sirte Basin
- Augila-Nafoora
- Bahi
- Beda
- Bu Attifel
- Dahra East
- Defa
- Gialo
- Intisar A
- Intisar D
- Mabril
- Masrab
- Messlah
- Nasser (Zelten)
- Samah
- Sarir C
- Sarir L
- Waha

Ghadamis Basin
- Al Wafa

Murzuk Basin
- Elephant

Tripolitania Basin
- Bouri

Selected Sirte Basin Fields

Producing reservoirs in the giant fields of the Sirte Basin range from Precambrian basement (igneous rocks) to Oligocene sands. Fracture porosity is important not only in the basement rocks but also in Cambro-Ordovician sandstone at Amal field. Pre-Upper Cretaceous sandstones are important reservoirs in the Sarir, Messlah, Bu Attifel, and Masrab fields. Paleocene and Upper Cretaceous carbonates are the main reservoirs in the other Sirte Basin giant fields.

The primary trap in the giant fields ranges from anticline (the most common type), nose, and fault block, to reef and wedge-out/truncation (Horn, 2003). Together, they reflect the tectonic history of the basin, with Mesozoic pre-graben arching, pre-Late Cretaceous faulting and nonmarine sedimentation, Late Cretaceous graben development, represented by several arms, and, to a less extent, Eocene-Neogene sag (Harding, 1984) (Figure 8).

Country	Field Name	Oil or Gas	Class	ULTIMATE RECOVERY OIL, MMBO	ULTIMATE RECOVERY GAS, TCF	ULTIMATE RECOVERY CONDENSATE, MMBO	ULTIMATE RECOVERY EQUIVALENT, MMBOE	KLETT'S ANNUAL FIELD GROWTH	KLETT CORRECTED ULTIMATE RECOVERY OIL, MMBO	KLETT CORRECTED ULTIMATE RECOVERY GAS, TCF	KLETT CORRECTED ULTIMATE RECOVERY CONDENSATE, MMBO	KLETT CORRECTED ULTIMATE RECOVERY EQUIVALENT, MMBOE
Libya	Al Wafa	g	Giant	135	2.7		590		135	2.7	0	590
Libya	Amal (Libya)	g	Giant	3,322	3.5		3,906		3,322	3.5	0	3,906
Libya	Attahadi	g	Giant		10.0	200	1,867		0	10.0	200	1,867
Libya	Augila-Nafoora	o	Giant	834	1.5		1,084	1.4%	908	1.6	0	1,181
Libya	Bahi	o	Giant	600			600	-1.1%	561	0.0	0	561
Libya	Beda	o	Giant	703	0.2		732	7.7%	1,096	0.3	0	1,141
Libya	Bouri (NC041-B)	o	Giant	533			533	0.6%	553	0.0	0	553
Libya	Bu Attifel (A-100)	o	Giant	1,444	4.4	127	2,311	1.8%	1,612	5.0	142	2,580
Libya	Dahra East-Hofra	o	Giant	621			621	0.0%	621	0.0	0	621
Libya	Defa	o	Giant	1,097			1,097	0.0%	1,097	0.0	0	1,097
Libya	Elephant	o	Giant	700	0.4		758		700	0.4	0	758
Libya	Gialo	o	Giant	1,087	0.3		1,135	0.0%	1,088	0.3	0	1,136
Libya	Hateiba	g	Giant		4.8		795		0	4.8	0	795
Libya	Intisar "A"	o	Giant	1,200			1,200	1.7%	1,325	0.0	0	1,325
Libya	Intisar "D"	o	Giant	1,500			1,500	-1.4%	1,382	0.0	0	1,382
Libya	Mabruk	o	Giant	500			500		500	0.0	0	500
Libya	Masrab	o	Giant	706	0.5		783		706	0.5	0	783
Libya	Messla	o	Giant	1,004	0.5		1,094	1.6%	1,107	0.6	0	1,205
Libya	Nasser (Zelten)	o	Giant	515	0.7	0	632	3.9%	647	0.9	0	794
Libya	Raguba	o	Giant	1,000			1,000	0.0%	1,000	0.0	0	1,000
Libya	Samah	o	Giant	500			500		500	0.0	0	500
Libya	Sarir C	o	Giant	2,922	0.6		3,015	-4.6%	2,203	0.4	0	2,272
Libya	Sarir L (L-65)	o	Giant	1,200			1,200		1,200	0.0	0	1,200
Libya	Waha	o	Giant	1,400			1,400	2.7%	1,639	0.0	0	1,639

Field Name	HL=10 REMAINING RECOVERABLE ESTIMATE. EQUIVALENT MMBOE	HL=50 REMAINING RECOVERABLE ESTIMATE. EQUIVALENT MMBOE	HL=90 REMAINING RECOVERABLE ESTIMATE. EQUIVALENT MMBOE	LAT deg.decimal	LONG deg.decimal	D.Y.	BALLY	KLEMME	MANN	ST. JOHN (MODIFIED) PROVINCE Sedimentary Provinces of the World, compiled by Bill St. John. Published by AAPG. Also found in AAPG Utility Data Set 1. Modified in this study to expand Gulf of Mexico and Arabian Provinces.
Al Wafa	389	543	563	28.85	10.00	1991	121	I	A	Illizi-Berkine (316)
Amal (Libya)	281	2,307	2,915	29.45	21.16	1959	1211	IIIA	A	Sirte (354)
Attahadi	190	1,181	1,448	29.75	19.83	1964	1211	IIIA	A	Sirte (354)
Augila-Nafoora	69	669	861	29.24	21.55	1956	1211	IIIA	A	Sirte (354)
Bahi	38	327	416	29.87	17.58	1958	1211	IIIA	A	Sirte (354)
Beda	82	674	852	28.36	19.00	1959	221	IICa	A	Sirte (354)
Bouri (NC041-B)	138	419	474	33.90	12.51	1977	1141	IICa	A	Pelagian (347)
Bu Attifel (A-100)	346	1,726	2,063	28.85	22.12	1968	1211	IIIA	A	Sirte (354)
Dahra East-Hofra	42	362	460	29.39	17.97	1958	1211	IIIA	A	Sirte (354)
Defa	84	657	825	28.08	19.92	1960	1211	IIIA	A	Sirte (354)
Elephant	758	758	758	26.00	11.58	1997	121	I	A	Murzuk (339)
Gialo	94	690	861	28.69	21.40	1961	1211	IIIA	A	Sirte (354)
Hateiba	75	496	612	29.72	19.68	1963	1211	IIIA	A	Sirte (354)
Intisar "A"	166	874	1,052	29.03	20.77	1967	1211	IIIA	A	Sirte (354)
Intisar "D"	173	912	1,097	28.90	20.97	1967	1211	IIIA	A	Sirte (354)
Mabruk	36	295	373	29.95	17.28	1959	1211	IIIA	A	Sirte (354)
Masrab	65	475	593	28.47	21.80	1961	1211	IIIA	A	Sirte (354)
Messla	199	841	987	27.92	22.41	1971	1211	IIIA	A	Sirte (354)
Nasser (Zelten)	57	469	593	28.91	19.80	1959	1211	IIIA	A	Sirte (354)
Raguba	83	607	758	29.08	19.08	1961	1211	IIIA	A	Sirte (354)
Samah	44	308	382	28.22	19.13	1962	1211	IIIA	A	Sirte (354)
Sarir C	187	1,380	1,722	27.64	22.52	1961	1211	IIIA	A	Sirte (354)
Sarir L (L-65)	140	781	945	27.80	22.48	1966	1211	IIIA	A	Sirte (354)
Waha	126	982	1,233	28.40	19.92	1960	1211	IIIA	A	Sirte (354)

Field Name	USGS PROVINCE	Depth (feet)	Primary Trap	Trap code: 1 = stratigraphic or combination stratigraphic/structural, 2 = reef, 3 = structural, 4 = no data	Lithology	AGE	Depth. Km	Ma
Al Wafa	2056 Illizi Basin		Structural	3	Quartzose sandstone	Givetian	0.00	375
Amal (Libya)	2043 Sirte	9900	Fold nose	3	Sandstone	Cambro-Ordovician	3.02	227
Attahadi	2043 Sirte	9000	Fault block	3	Sandstone	Cretaceous U	2.74	99
Augila-Nafoora	2043 Sirte	8250	Anticline	3	Granite-rhyolite, sandstone-limestone	Precambrian, Campanian	2.51	84
Bahi	2043 Sirte	6000	Anticline	3	Carbonate	Paleocene	1.83	60
Beda	2043 Sirte	3310	Anticline	3	Limestone	Paleocene	1.01	60
Bouri (NC041-B)	2048 Pelag	7750	Anticline	3	Carbonate	Eocene	2.36	55
Bu Attifel (A-100)	2043 Sirte	12800	Fault block	3	Sandstone	Cretaceous L	3.90	99
Dahra East-Hofra	2043 Sirte	0	Structural	3	Carbonates	Oligocene	0.00	
Defa	2043 Sirte	4700	Anticline	3	Argillaceous limestone	Danian	1.43	60
Elephant	2045 Murzu	5000	Anticline	3	Sandstone	Ordovician	1.52	460
Gialo	2043 Sirte	2750	Anticline	3	Limestone	Eocene M	0.84	49
Hateiba	2043 Sirte	9000	Anticline	3	Sandstone	Ordovician	2.74	464
Intisar "A"	2043 Sirte	9500	Reef	2	Carbonate	Paleocene	2.90	60
Intisar "D"	2043 Sirte	9400	Reef	2	Carbonate	Paleocene	2.87	60
Mabruk	2043 Sirte	4000	Reef	2	Carbonate	Paleocene	1.22	60
Masrab	2043 Sirte	9950	Fault block	3	Sandstone	Cretaceous L	3.03	99
Messla	2043 Sirte	8250	Offlap (regressive overlap)	1	Sandstone	Cretaceous L	2.51	99
Nasser (Zelten)	2043 Sirte	4975	Anticline	3	Limestone	Paleocene U	1.52	58
Raguba	2043 Sirte	5400	Faulted anticline	3	Carbonate	Cretaceous	1.65	99
Samah	2043 Sirte	9000	Anticline	3	Carbonate	Cretaceous	2.74	99
Sarir C	2043 Sirte	8400	Fault block	3	Sandstone	Cretaceous L	2.56	99
Sarir L (L-65)	2043 Sirte	9000	Anticline	3	Sandstone	Cretaceous	2.74	99
Waha	2043 Sirte	6600	Anticline	3	Carbonate	Paleocene	2.01	60

Table 1. Database for giant fields of Libya (from M.K. Horn, 2003).

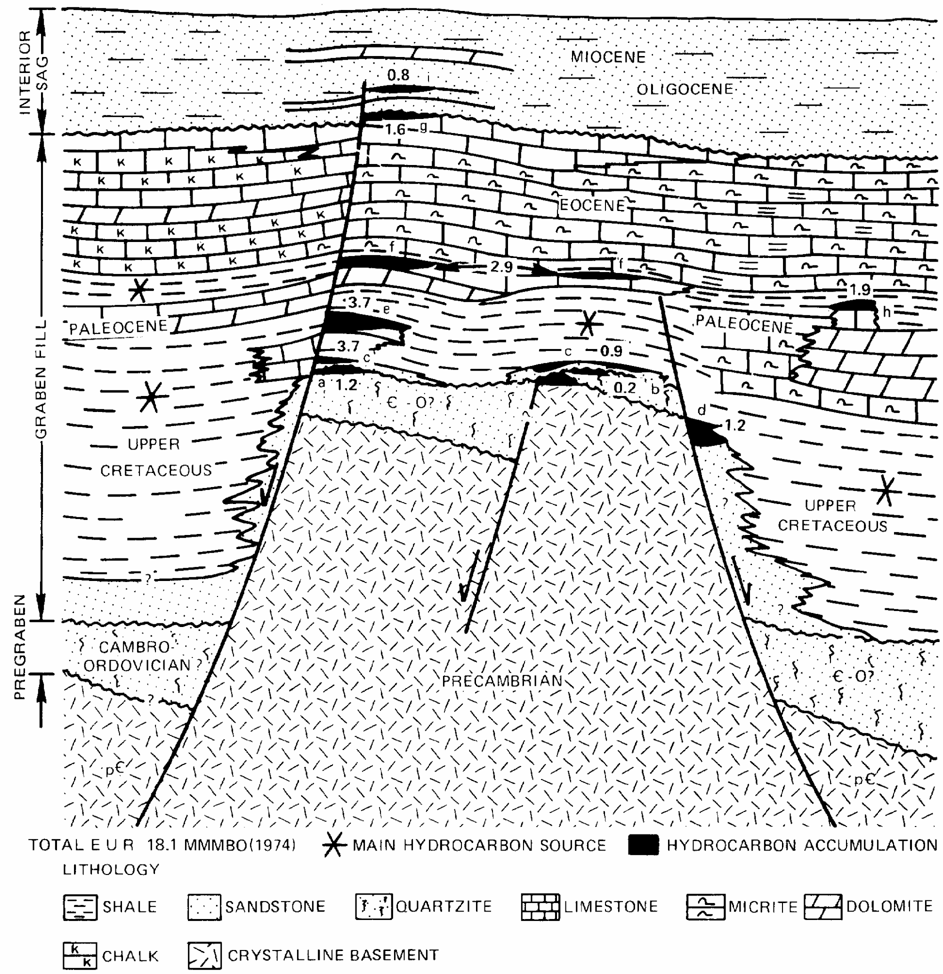

Figure 8. Schematic cross-section of the northwestern part of Sirte Basin, noting stages of graben development, as well as showing character of traps and lithology and stratigraphic positions of productive reservoirs, as of 1984 (from Harding, 1984).

Below are sketch-like summaries of fields that together are fairly representative of the range of features the giant fields possess.

Amal Field (Figures 2, 9, and 10)

Amal Field is on a north-northwest plunging nose, locally with more than 100 feet of closure at the Rakb (Upper Cretaceous) level. The nose is bounded by major platform/trough-bounding faults. The field is some 30 miles long and 10 miles wide.

The main reservoirs are the Cambro-Ordovician Amal Formation, with its fractured quartzose sandstone, and the transgressive-marine sandstones of the Maragh Formation, probably Late Cretaceous in age.

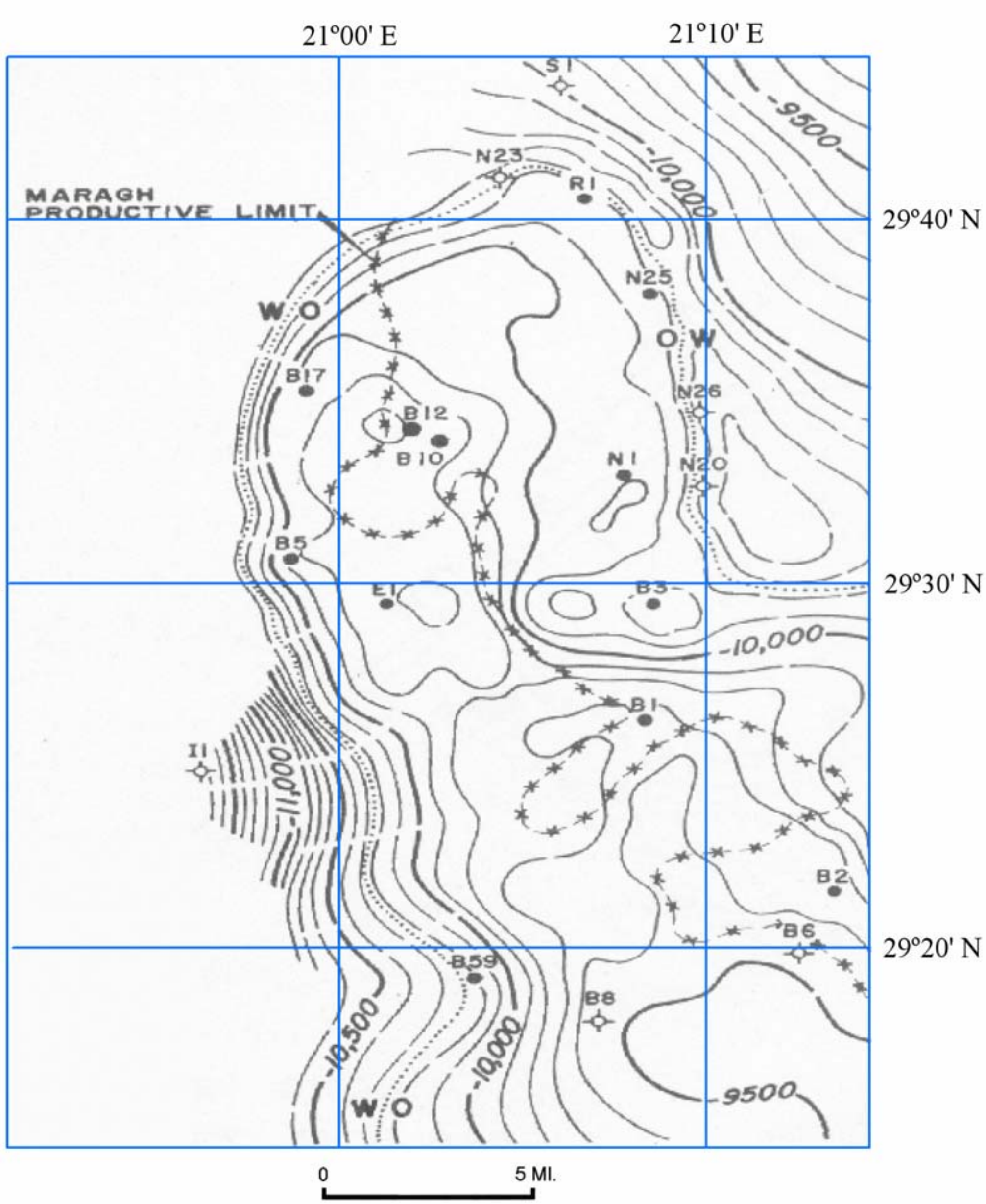

Figure 9. Structural contour map, on base of Upper Cretaceous Rakb Formation, of Amal Field, showing large north-northwest-plunging nose (from Roberts, 1970).

Intisar D Field (Figures 2, 11, 12, and 13)

Intisar D Field is one of five productive Paleocene pinnacle reefs that grew in an embayment bounded by three carbonate banks (Brady et al., 1980). It is approximately three miles in diameter. The reef consists largely of corals and algae, with grain- and mud-supported skeletal carbonates. Reef development was responsible for the spectacular reservoir (with 22% porosity) and trap (with 995-foot oil column).

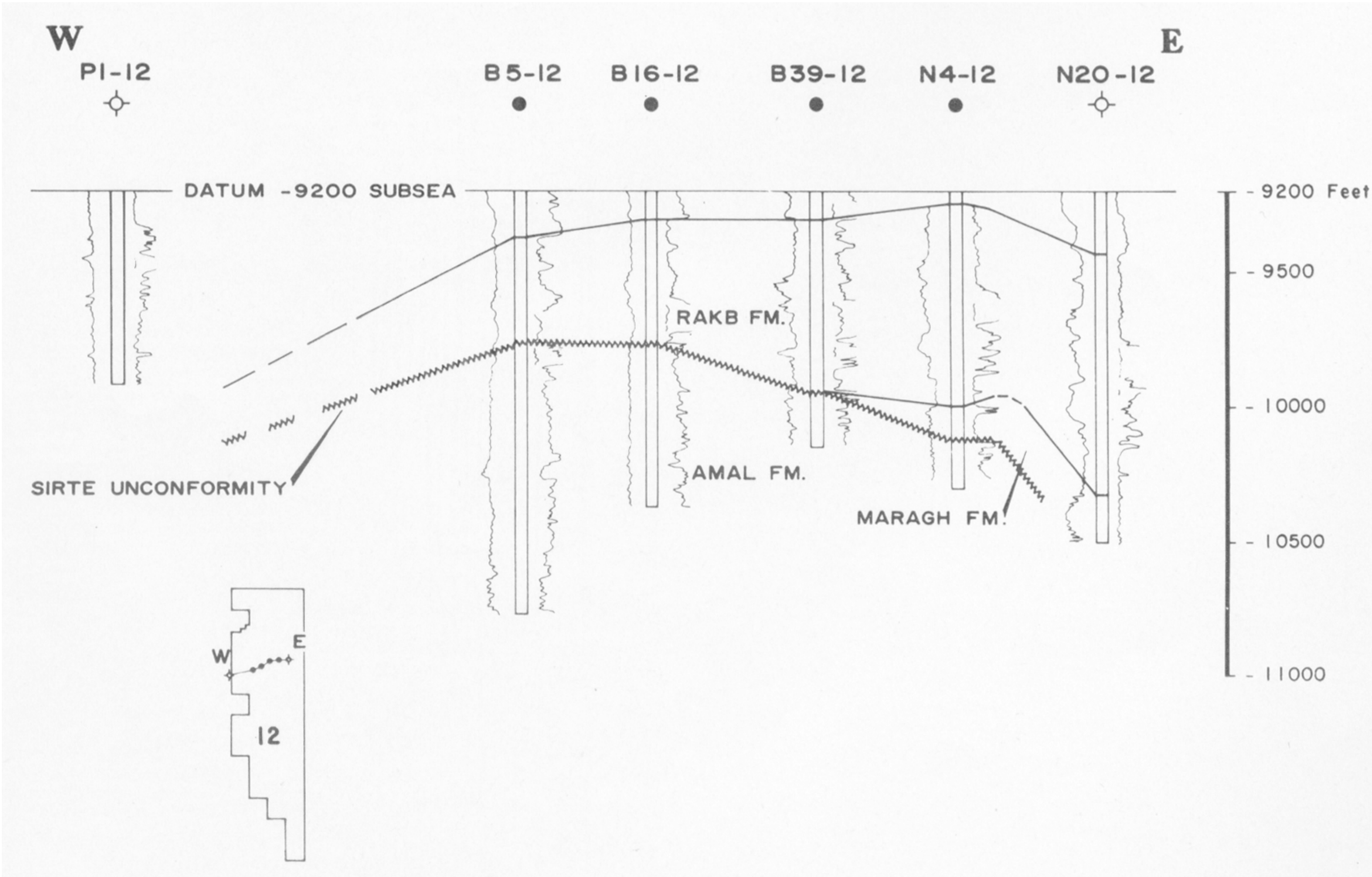

Figure 10. East-west electric cross section of Amal field, illustrating unconformity at base of Upper Cretaceous and the positions of Cambro-Ordovician Amal Formation, the main pay, and the transgressive Maragah Formation, which produces on the northeast flank of the field.

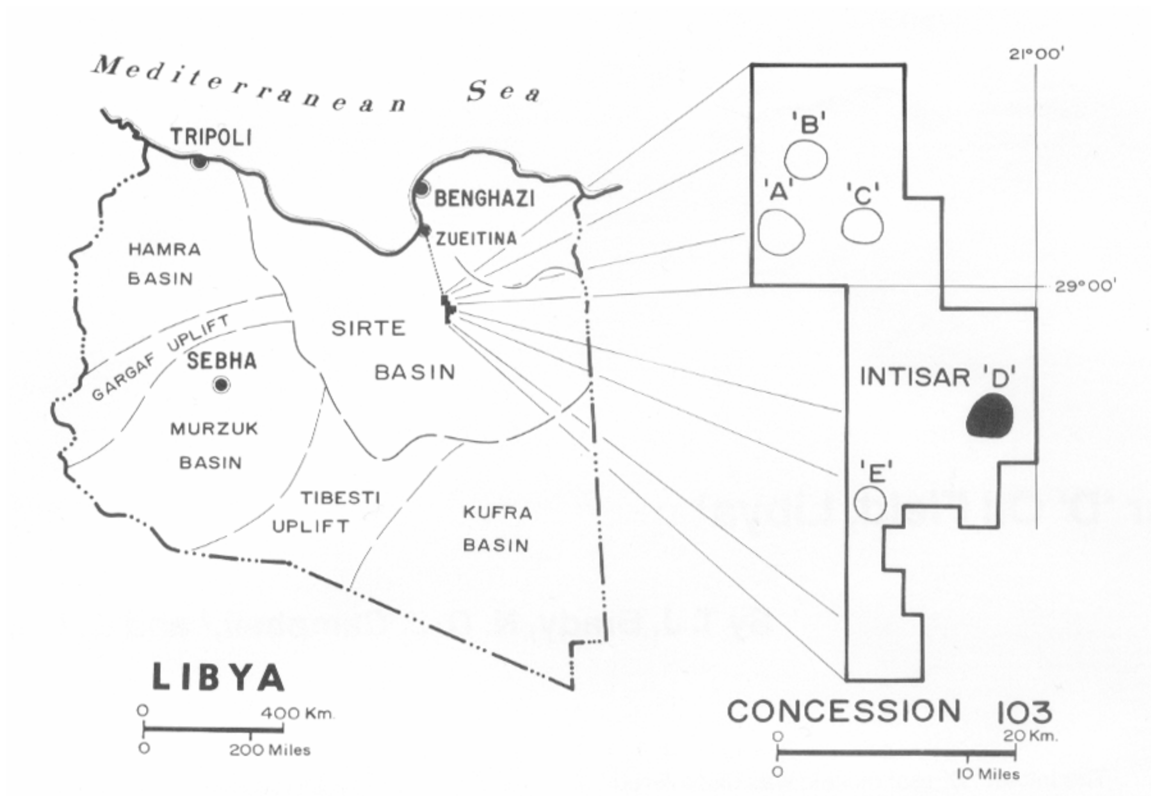

Figure 11. Location map of five fields, representing five Paleocene pinnacle reefs (from Brady et al., 1980).

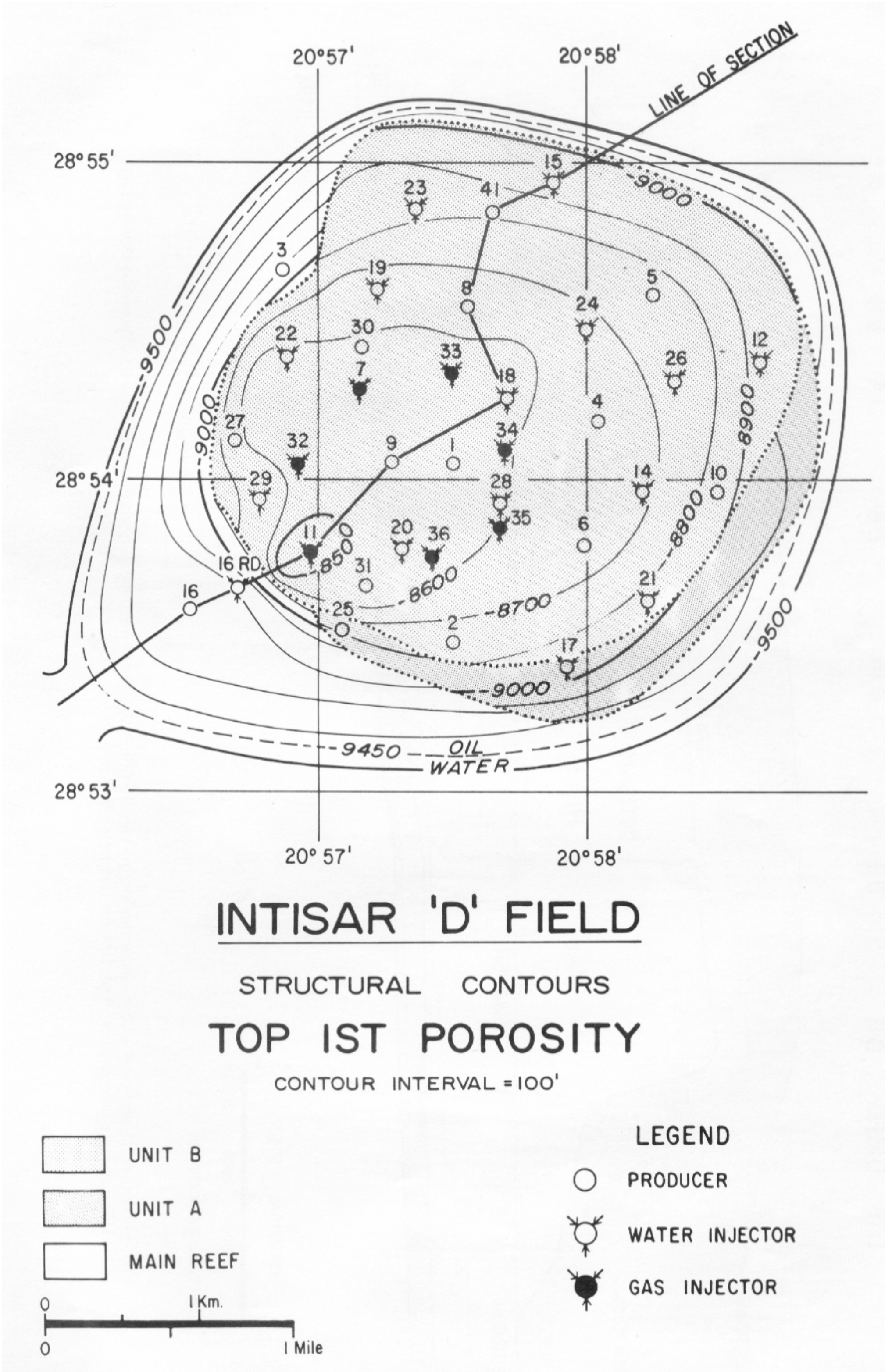

Figure 12. Structural contour map, top lst porosity (Paleocene Upper Sabil Formation), of circular Intisar D Field. Pinnacle shows about 1000 feet of relief. Line is for cross-section in Figure 13. (From Brady et al., 1980.)

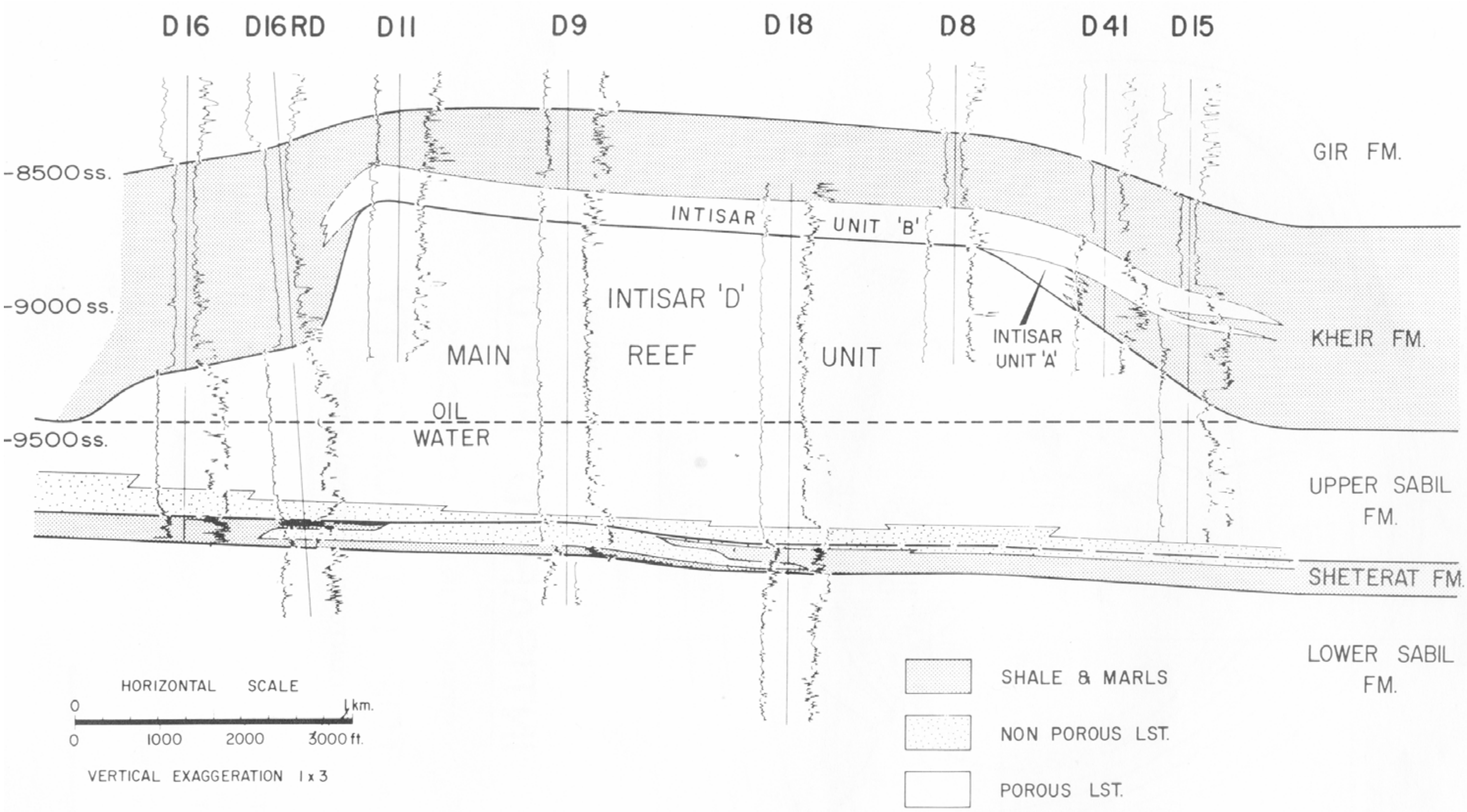

Figure 13. Stratigraphic cross-section of Intisar D reef, illustrating relations of reservoir rock to shale and marls in trough and capping reef (from Brady et al., 1980).

Messlah (Messla) Field (Figures 2, 14, 15, 16, and 17)

Messlah field, more than 25 miles long and 5 miles wide, is a stratigraphic trap located on the east flank of a broad Precambrian basement high (Clifford et al., 1980). The reservoir is Lower Cretaceous fluvial Sarir (Nubian) Sandstone, which wedges-out to the west onto the basement. It is truncated by the widespread unconformity at the base of the Upper Cretaceous section. It is similar in type and size to East Texas Field.

Figure 14. Structural elements in the area of Sarir (Nubian) Sandstone fields, including Sarir and Messlah. The latter is on the east margin of an extensive basement high. (From Ambrose, 2000.)

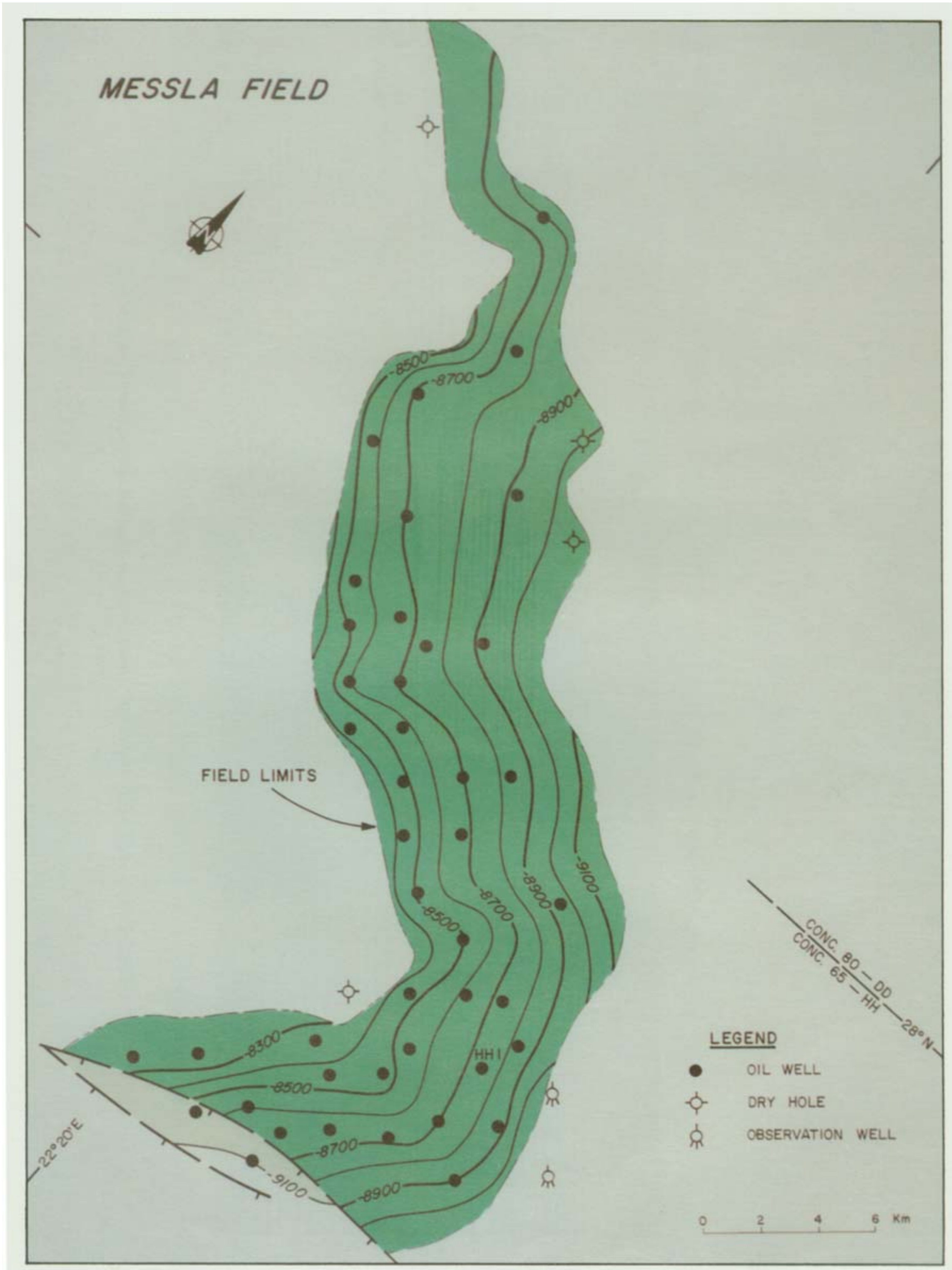

Figure 15. Structural contour map, on intra-Sarir Sandstone zone, with limit of field. Over much of the field, the dip is rather uniformly ½ to 1° east to northeast. (From Clifford et al., 1980.)

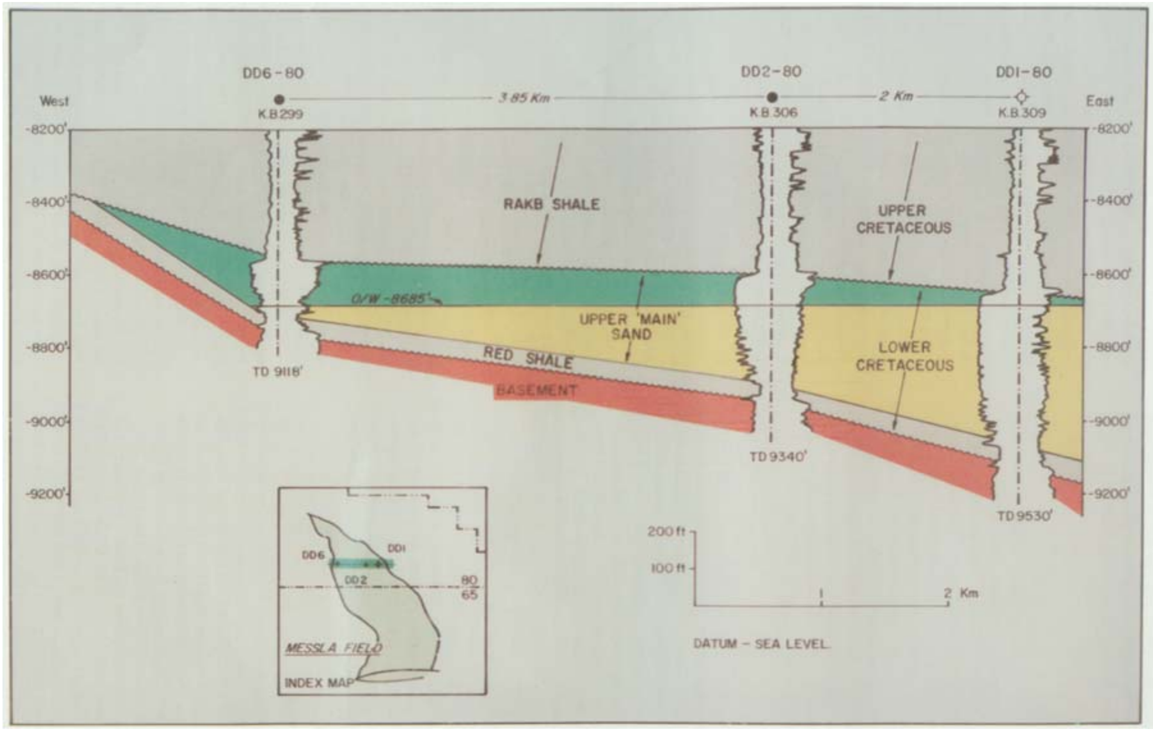

Figure 16. West-east cross-section A-A' in Concession 80, Messlah Field, showing sand development, wedge-out, and truncation (from Clifford et al., 1980).

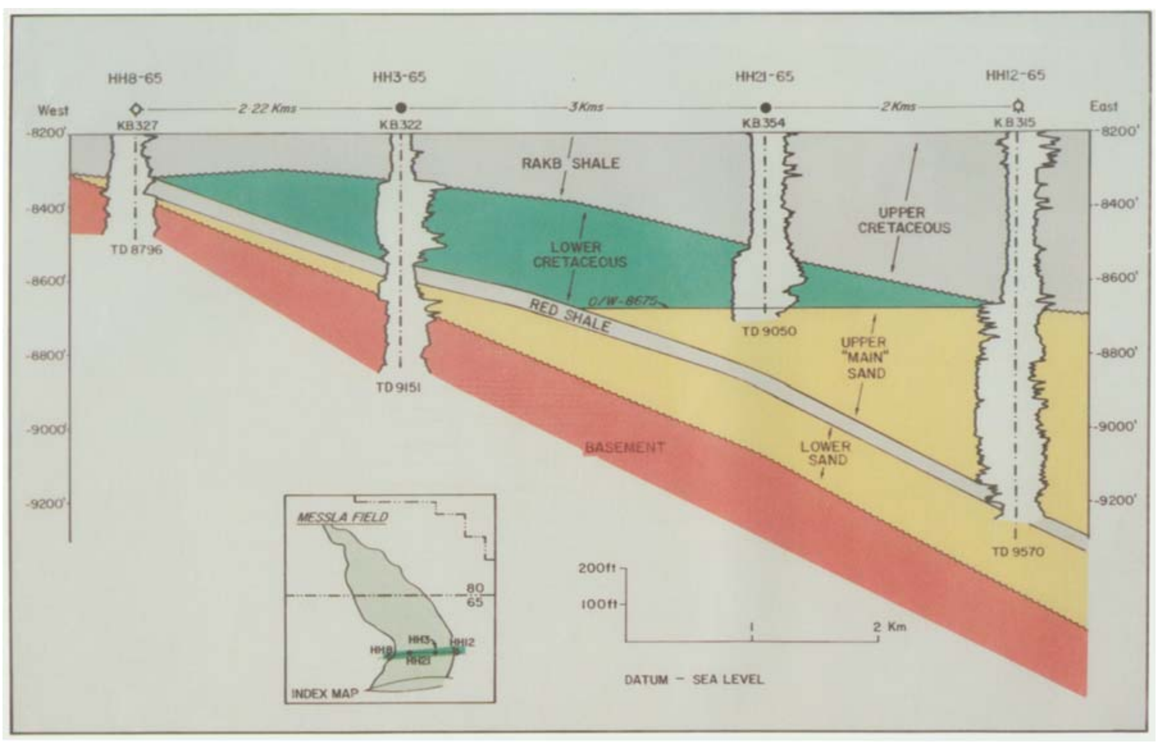

Figure 17. West-east cross-section B-B' in Concession 65, Messlah Field, showing sand development, wedge-out, and truncation (from Clifford et al., 1980).

Nasser (Zelten) Field (Figures 2, 18, and 19)

Nasser Field produces from highly porous Paleocene-Eocene limestone in a faulted anticline that borders the Maradah Graben. The field is more than 16 miles long (parallel to the fault) and 9 miles wide. The Paleocene Zelten "Member," which is the main pay, experienced porosity enhancement due to groundwater leaching, and secondary porosity as high as 40% has been reported from three skeletal grain-supported shelf limestone facies (Bebout and Pendexter, 1975). These limestones characterized deposition on the platforms separating the arms of the Sirte Graben during some of the Late Cretaceous and much of the Paleocene, while deeper-water deposits characterized the troughs. During the sag phase, Eocene carbonates extended across trough and platform alike.

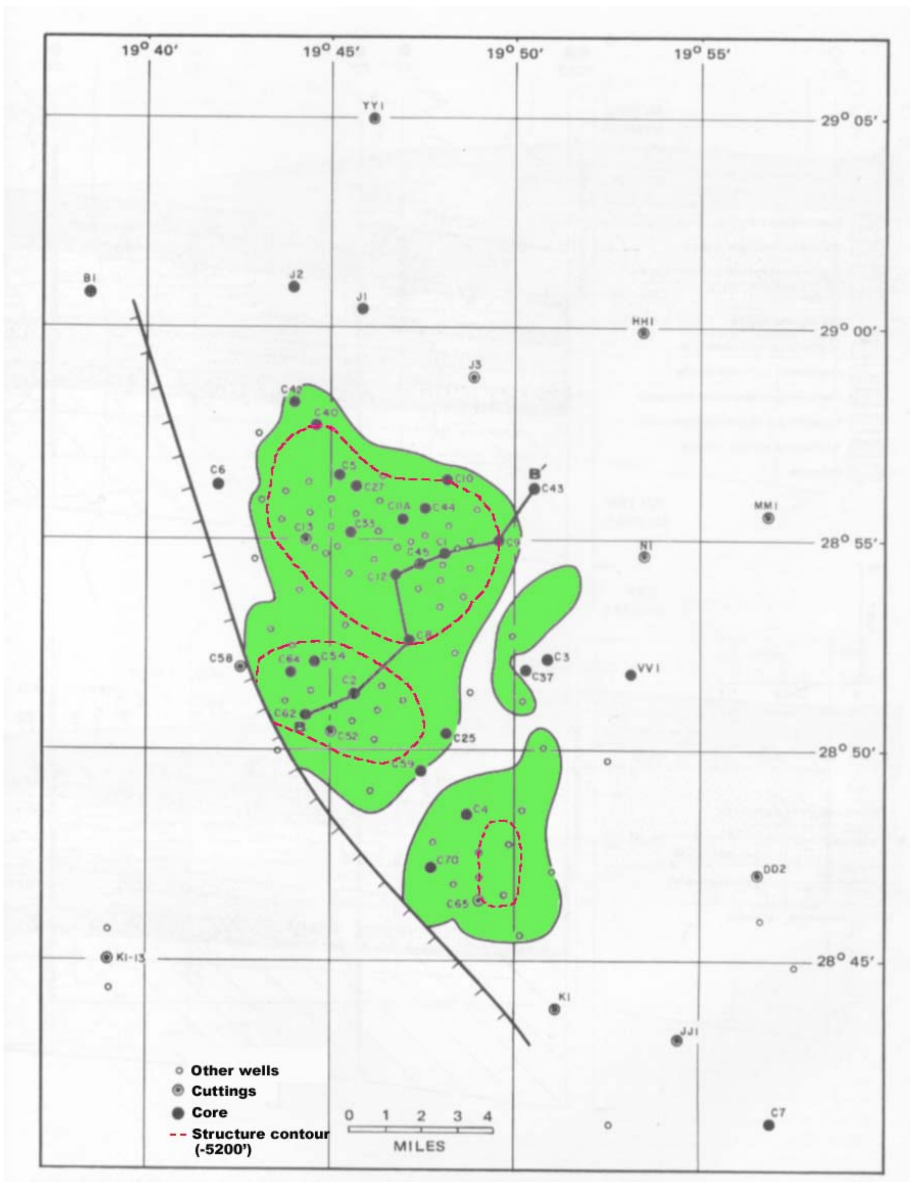

Figure 18. Location map of Nasser (Zelten) Field and platform-bounding fault, with generalized structure on top of "reservoir unit." B-B' is line for facies cross-section in Figure 19. (Modified after Bebout and Pendexter, 1975; Harding, 1984).

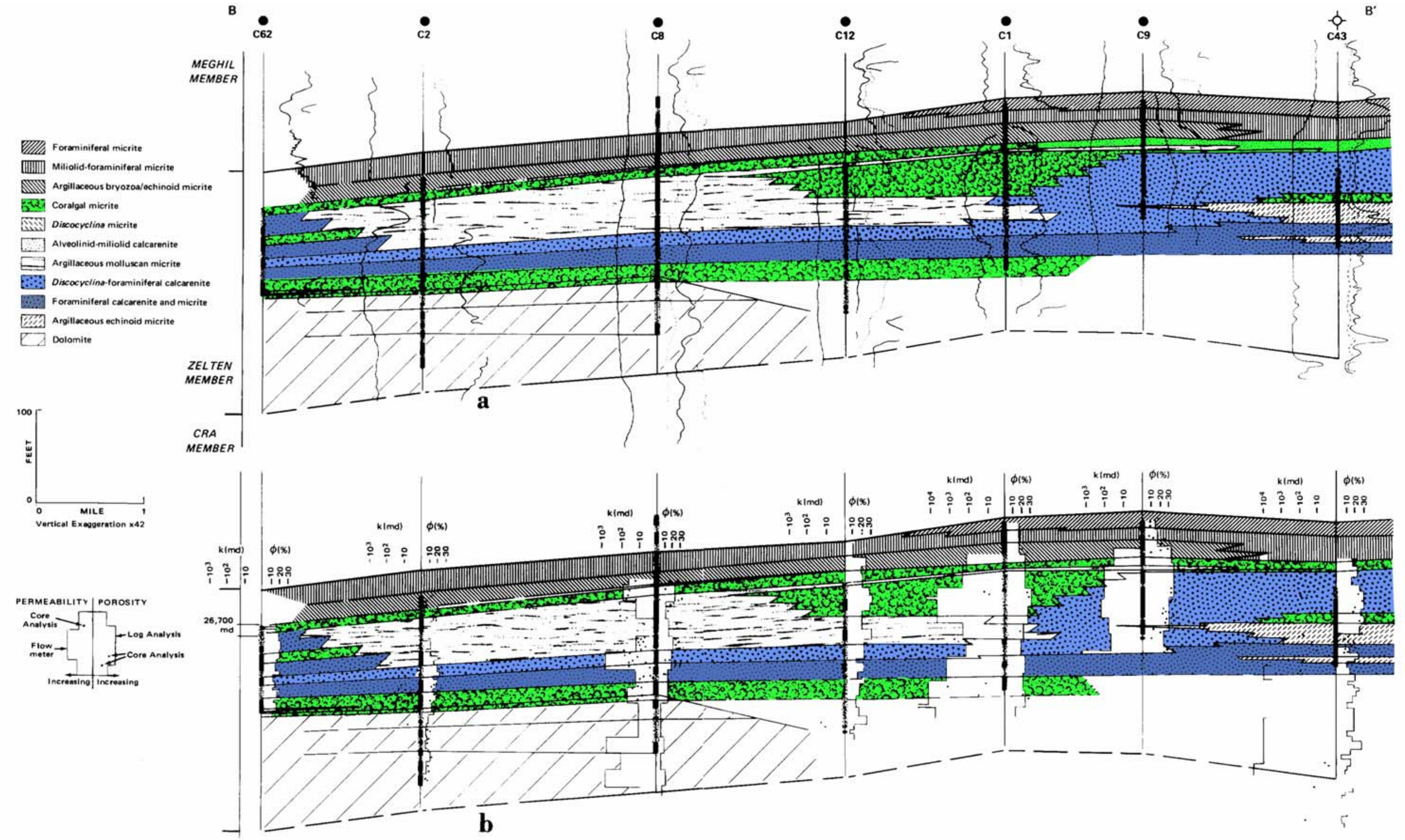

Figure 19. Facies cross-section B-B', showing the facies with the highest porosities in color; datum is top Meghil Member (lower Eocene) overlying the main pay (Zelten "Member"). Structure shows modest growth during deposition of the productive shelf limestones. (Modified from Bebout and Pendexter, 1975.)

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