Second Wallace E. Pratt memorial Conference
"Petroleum Provinces of the 21st Century"
January 12-15, 2000
San Diego, California

THE PETROLEUM POTENTIAL OF EGYPT [1]

By J. C. DOLSON[2], M. V. SHANN[3], U.K., DR. H. HAMMOUDA[4], R. RASHED[5], and DR. S. MATBOULY[6]

ABSTRACT

Since the onshore discovery of oil on the Eastern Desert in 1886, the petroleum industry has discovered over 15.5 BBOE of reserves. This paper uses an understanding of the tectono-stratigraphic history of each major basin combined with drilling history and field size distributions to justify the future potential for doubling Egypt's resource base.

Major reserve replacement will come from expansion of existing petroleum plays into the Mediterranean Tertiary gas trends. Additional reserve growth will result from successes using 3D seismic in deeper pool exploration in and around proven fields, and for new stratigraphic plays off-structure. Examples from the Western Desert, the Gulf of Suez and the Mediterranean demonstrate this growth potential.

More remote new exploration areas include the Komombo and other basins in Upper Egypt and the northern end of the Red Sea rift, both of which are currently under re-evaluation by a number of international oil companies.

Despite a relatively complex history, the geological framework of Egypt is highly suited for oil and gas exploration. It comprises eight major tectono-stratigraphic events: 1) Paleozoic craton 2) Jurassic rifting, 3) Cretaceous passive margin, 4) Cretaceous Syrian arc deformation and foreland transgressions 5) Oligo-Miocene Gulf of Suez rifting 6) Miocene Red Sea breakup 7) the Messinian salinity crisis and 8) Plio-Pleistocene delta progradation. Each of these events has created multiple reservoir and seal combinations. Source rocks occur from the Paleozoic through to the Pliocene and petroleum is produced from Precambrian through Pleistocene age reservoirs.

---

[1] Presented to the Second Wallace E. Pratt memorial Conference on Petroleum Provinces of the 21st Century, San Diego, California, January 12-15, 2000. Copyright © 2000 by AAPG
[2] BP-Amoco Egypt, Cairo, Egypt
[3] BP-Amoco London
[4] Gulf of Suez Petroleum Company, Cairo, Egypt
[5] Gulf of Suez Petroleum Co., Cairo, Egypt
[6] Egyptian General Petroleum Corporation, Cairo, Egypt

CONTENTS

INTRODUCTION 2
METHODOLOGY AND PRIOR WORK 7
TECTONO-STRATIGRAPHIC HISTORY 8
  Paleozoic Craton 8
  Jurassic Rifting 12
  Cretaceous Passive Margin 13
  Syrian Arc and ForelandTransgression 13
  Gulf of Suez Rifting 14
  Red Sea Breakup 15
  Messinian Crisis 16
  Plio-Pleistocene Delta Progradation 16
DRILLING HISTORY 16
EXPLORATION POTENTIAL BY PETROLEUM SYSTEM 17
  Western Desert 17
  Upper Egypt 22
  Gulf of Suez, Eastern Desert and Sinai 24
  Red Sea 27
  Nile Delta, Mediterranean and North Sinai 28
  Summary 32
  References 33
  Acknowledgements 37

INTRODUCTION

Despite its long 100+ year petroleum exploration history, many large geographical areas in Egypt remain under-explored (Figures 1 and 2). Although Egypt has the physical size of the state of Texas (United States), it contains only 1754 exploratory tests (Figure 2). Only 245 of these wells penetrate Precambrian strata (Table 1), and many of these are faulted into basement strata. These exploratory tests have resulted in the discovery of thirty giant (>100 MMBOE) oil and gas fields, seven of which have been found in the late 1990's (Table 2). In addition, a substantial number of significant discoveries less than 100 MMBOE in size have also been made (Table 3).

Egypt's geological history is complex and although a full is beyond the scope of this paper, a sequence stratigraphic-based broad tectono-stratigraphic framework is presented to describe the context of the proven petroleum systems and outline future exploration potential. Key references dealing with the petroleum systems and geology of Egypt and it's surrounding areas include MacGregor et al., (1998), Said, (1990b), Sadek, (1992) and Dixon and Robertson, (1984).

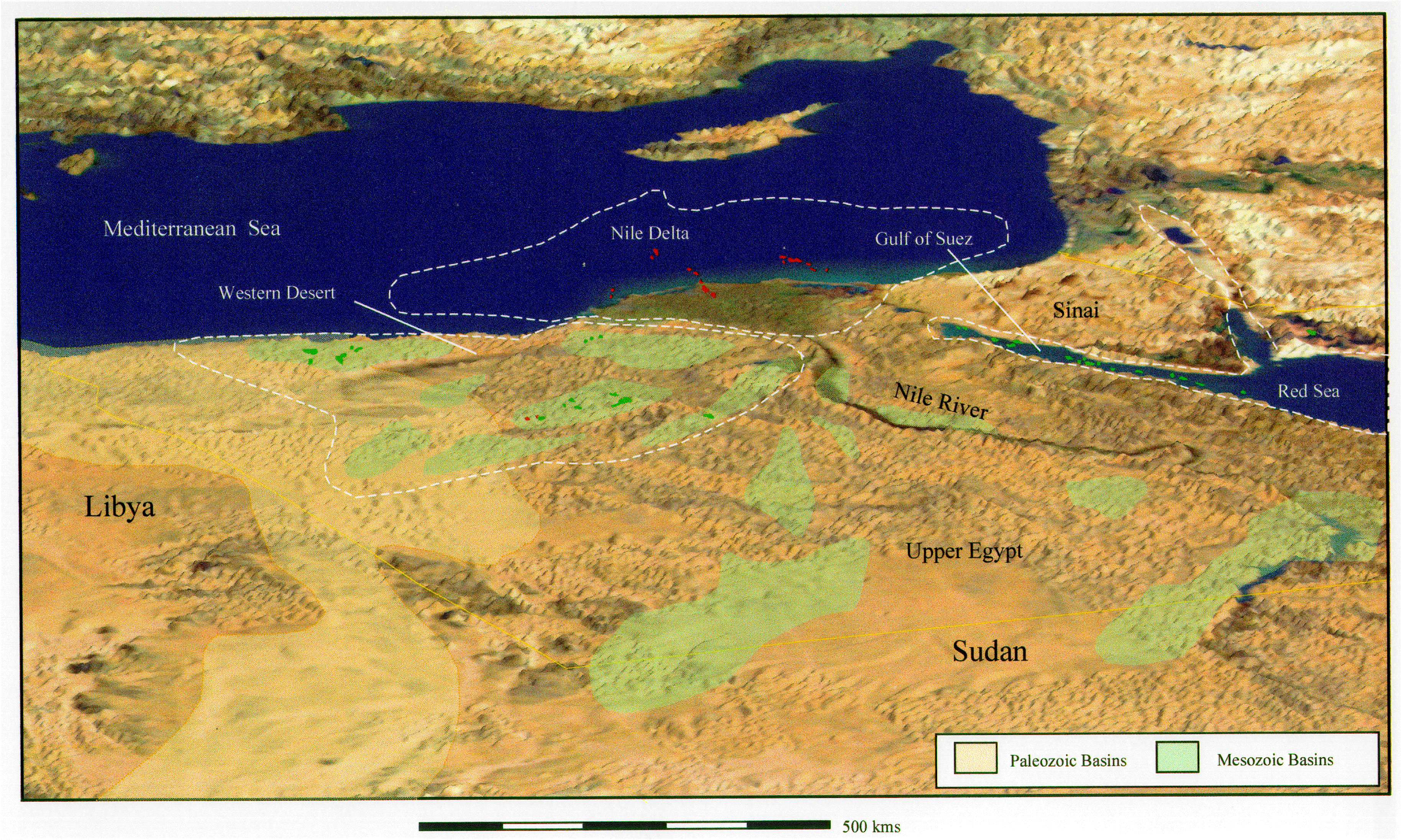


Figure 1. Landsat image of Egypt with Mesozoic, Paleozoic and Tertiary basins and oil and gas fields.

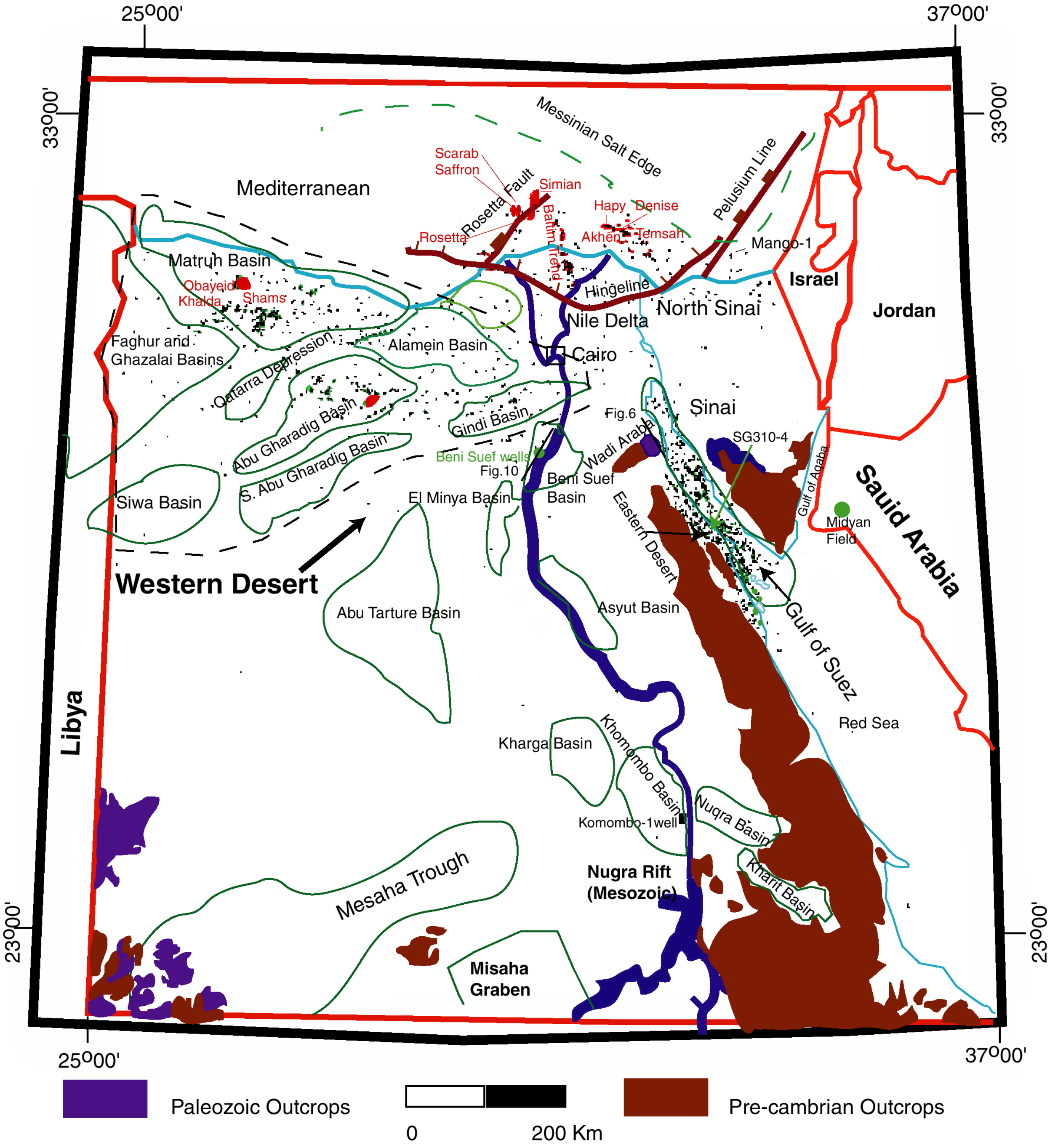


Figure 2. Location map of the study area with location of all exploratory tests in Egypt. Significant wells discussed in the text are highlighted, as are the location of giant field discoveries in the 1990's.

Table 1. Exploratory Well Penetrations by Age at TD and Petroleum System

Petroleum System	Total Wells	Tertiary	Cretaceous	Jurassic	Triassic	Paleozoic	Pre-Cambrian
Western Desert	578	51	319	137	0	40	31
Nile Delta, North Sinai and Mediterranean	247	199	27	20	0	1	0
Gulf of Suez, Eastern Desert, Sinai	902	260	412	13	0	19	198
Upper Egypt	13	0	5	0	0	0	8
Red Sea	14	6	0	0	0	0	8
Totals	**1754**	**516**	**763**	**170**	**0**	**60**	**245**

Table 2. Giant Oil and Gas Fields of Egypt

FIELD	COMPANY	Year	DRILLING PROVINCE	MMBOE	BCF_GAS	DISCOVERY WELL	Age	Trap_major	PRIMARY REFERENCE
BELAYIM MARINE	PETROBEL	1961	GULF OF SUEZ	1593	0.00	BELAYIM M-1	LANGIAN	Structural	Matbouly and Sabbagh, 1996
MORGAN OLD-SOUTH	GUPCO	1965	GULF OF SUEZ	1201	0.00	MORGAN-1	LANGIAN	Structural	Matbouly and Sabbagh, 1996
OCTOBER MAIN	GUPCO	1977	GULF OF SUEZ	848	0.00	GS195-1(OCT-A1)	CRETACEOUS	Structural	Matbouly and Sabbagh, 1996
RAMADAN	GUPCO	1974	GULF OF SUEZ	668	0.00	GS 303-1	CRETACEOUS	Structural	Matbouly and Sabbagh, 1996
SIMIAN	BRITISH GAS	1999	MEDITERRANEAN	416-666	2500-4000	SIMIAN-1	PLIOCENE	Stratigraphic	IHS Energy Group, 1999
BELAYIM LAND	PETROBEL	1955	SINAI	645	0.00	BELAYIM 112-1	SERRAVALIAN	Structural	Matbouly and Sabbagh, 1996
JULY	GUPCO	1973	GULF OF SUEZ	625	0.00	GS 311-1 (J-4)	BURDIGALIAN	Structural	Matbouly and Sabbagh, 1996
SCARAB	BRITISH GAS	1998	MEDITERRANEAN	375-466	2800.00	SCARAB - 1	PLIOCENE	Structural	IHS Energy Group, 1999
TEMSAH	MOBIL	1981	MEDITERRANEAN	333-450	2000-2700	EL TEMSAH - 2	SERRAVALIAN	Structural	IHS Energy Group, 1999
OBAYEID	OBAIYED	1993	WESTERN DESERT	283-366	1700-2200	OBAYID - 3	JURASSIC	Structural	IHS Energy Group, 1999
ROSETTA	BRITISH GAS	1997	MEDITERRANEAN	333-416	2000-2500	ROSETTA - 3	PLIOCENE	Structural	IHS Energy Group, 1999
RAS GHARIB	GPC	1938	EASTERN DESERT	357	0.00	RAS GHARIB-3	SERRAVALIAN	Combination	Matbouly and Sabbagh, 1996
SAFFRON	BRITISH GAS	1998	MEDITERRANEAN	333-416	2000-2500	SAFFRON - 1	PLIOCENE	Structural	IHS Energy Group, 1999
HAPY	BP-AMOCO	1997	MEDITERRANEAN	250-416	1500-2500	HAPY-1	PLIOCENE	Structural	EGPC Records
RAS BUDRAN	SUCO	1978	GULF OF SUEZ	270	0.00	EE 85-1A	CRETACEOUS	Structural	Matbouly and Sabbagh, 1996
BADRI	GUPCO	1987	GULF OF SUEZ	267	0.00	BDR-E-1	SERRAVALIAN	Structural	Matbouly and Sabbagh, 1996
ABU GHARADIG	GUPCO	1969	WESTERN DESERT	220	586.00	ABU GHARADIG-1	CRETACEOUS	Structural	Hegazy, 1992
ZEIT BAY	SUCO	1980	GULF OF SUEZ	215	0.00	OO 89-1	CRETACEOUS	Structural	Matbouly and Sabbagh, 1996
KHALDA	WEPCO	1971	WESTERN DESERT	213	771.00	KHALDA-1	CRETACEOUS	Structural	Hegazy, 1992
ABU MADI	IEOC	1967	NILE DELTA	209	1254.00	ABU MADI-1	MESSINIAN	Stratigraphic	Moussa and Matbouly, 1994
MORGAN OLD-NORTH	GUPCO	1965	GULF OF SUEZ	200	0.00	MORGAN-1	LANGIAN	Structural	Matbouly and Sabbagh, 1996
SHAMS	REPSOL	1997	WESTERN DESERT	176-250	1000-1500	SHAMS-2X	JURASSIC	Structural	IHS Energy Group, 1999
BED-3	SHELL	1983	WESTERN DESERT	153	847.00	BED 3-1	CRETACEOUS	Structural	Hegazy, 1992
RAS FANAR	SUCO	1978	GULF OF SUEZ	143	0.00	KK 84-1	SERRAVALIAN	Stratigraphic	Matbouly and Sabbagh, 1996
HILAL	GUPCO	1976	GULF OF SUEZ	125-140	0.00	GS 391-1	CRETACEOUS	Structural	Matbouly and Sabbagh, 1996
BAKR	GPC	1958	EASTERN DESERT	135	0.00	BAKR-6	SERRAVALIAN	Structural	Matbouly and Sabbagh, 1996
BED-2	SHELL	1982	WESTERN DESERT	132	792.10	BED 2-1	CRETACEOUS	Structural	Hegazy, 1992
SHOAB ALI	GUPCO	1977	GULF OF SUEZ	110	0.00	ALMA-2	SERRAVALIAN	Structural	Matbouly and Sabbagh, 1996
KANAYES	IEOC	1992	WESTERN DESERT	100-116	600-700	KANAYIS - 5	JURASSIC	Structural	IHS Energy Group, 1999

Table 3. Significant Exploratory Tests in the 1990's

WELL	REGION	LAT	LONG	YEAR	CLASS	COMMENTS	COMPANY	AGE AT TD	FTD_METERS
KHARIT -1	UPPER EGYPT	23.5155	34.3507	1998	DRY HOLE	P & A; ESTABLISHES PRESENCE OF NEW BASIN IN EGYPT	REPSOL	PRECAMBRIAN	2307.53
KOMOMBO -2 ST	UPPER EGYPT	24.6543	32.8083	1998	DRY HOLE	P & A; ESTABLISHES PRESENCE OF NEW BASIN IN EGYPT	REPSOL	PRECAMBRIAN	2651.63
KOMOMBO -3	UPPER EGYPT	24.5995	32.7390	1998	DRY HOLE	P & A; ESTABLISHES PRESENCE OF NEW BASIN IN EGYPT	REPSOL	PRECAMBRIAN	1281.32
NUQRA-1	UPPER EGYPT	24.4208	33.4982	1997	DRY HOLE	P & A; ESTABLISHES PRESENCE OF NEW BASIN IN EGYPT	REPSOL	PRECAMBRIAN	2549.53
KOMOMBO-1	UPPER EGYPT	24.6665	32.8064	1997	DRY HOLE	Tested oil in Jurassic; proves viability of new basin in Upper Egypt	REPSOL	PRECAMBRIAN	2579.00
BENI SUEF 1X	UPPER EGYPT	29.1533	30.8738	1997	DISCOVERY	Oil Disc. (Kharita & Bahariya); Southern-most Egypt oil extension	SEAGULL	PRECAMBRIAN	3388.60
BENI SUEF -4X	UPPER EGYPT	29.1533	30.8858	1998	DISCOVERY	Oil well in Cretaceous; Southern-most Egypt oil extension	SEAGULL	LOWER CRETACEOUS	2197.50
BENI SUEF -5X	UPPER EGYPT	29.1532	30.8801	1998	DISCOVERY	Oil well Bahariya & Kharita T & A.; Southern-most Egypt oil extension	SEAGULL	LOWER CRETACEOUS	2256.63
ASHRAFI SW 3	GULF OF SUEZ	27.7762	33.7089	1998	DISCOVERY	Nubia oil: Significant southern extension of pay in Gulf of Suez	AGIBA	PRECAMBRIAN	1904.91
E.TANKA - 3 (ET-A1)	GULF OF SUEZ	28.9845	32.9443	1996	DISCOVERY	New field discovery of "downthrown" Asl sand trap: IP 10,000 BOPD	AMOCO	BURDIGALIAN	2834.50
GS 184 - 2	GULF OF SUEZ	28.8794	33.0264	1994	DISCOVERY	New field discovery of "downthrown" Asl sand trap: offset flows 15,000 BOPD	GUPCO	BURDIGALIAN	3554.71
RABEH-1	GULF OF SUEZ	27.2229	33.7466	1997	DISCOVERY	6800 BOPD Nukhul and Matulla (Nezzazat); Significant southern extension of production	COPLEX	PRECAMBRIAN	
SG 310-4	GULF OF SUEZ	28.2532	33.2251	1998	DISCOVERY	Oil well from Asl Sd &Hawara Sd (Burdigalian) flows 20,000 BOPD	GUPCO	BURDIGALIAN	3230.72
SG 310-6A	GULF OF SUEZ	28.2498	33.2100	1999	DISCOVERY	Oil well from Asl Sd &Hawara Sd: significant small field discovery on new fault block	GUPCO	BURDIGALIAN	4462.05
WARDA	GULF OF SUEZ	29.1900	32.7063	1991	DISCOVERY	40+ MMBO oil field discovery beyond limits of Belayim Salt topseal from Kareem and Rudeis Formations	BRITISH GAS	LANGHIAN	2752.21
AKHEN-1	MEDITERRANEAN	31.9067	31.9213	1996	DISCOVERY	New Serravalian Field Discovery (350-700 BCF)	AMOCO	BURDIGALIAN	4421.82
BALTIM E - 1	MEDITERRANEAN	31.7748	31.2449	1993	DISCOVERY	New Messinian valley fill trend extension (500-800 BCF)	IEOC	SERRAVALIAN	3911.92
DENISE-1	MEDITERRANEAN	31.8705	32.0959	1995	DISCOVERY	Pliocene gas discovery (75O-900 BCF)	IEOC	PLIOCENE	2402.93
EL TEMSAH NW-1	MEDITERRANEAN	31.8619	32.1233	1996	DISCOVERY	Significant Serravalian pay extension	IEOC	BURDIGALIAN	4019.81
HAPY-1	MEDITERRANEAN	31.9197	31.8544	1996	DISCOVERY	Giant Pliocene gas discovery (1500-2500 BCF)	AMOCO	PLIOCENE	1861.93
PFM SW -1"ST"	MEDITERRANEAN	31.5506	32.4446	1998	DISCOVERY	Pliocene gas discovery Port Fouad SE (350-500 BCF)	PETROBEL	PLIOCENE	3985.98
ROSETTA - 3	MEDITERRANEAN	31.8408	30.6262	1997	DISCOVERY	Giant Pliocene gas discovery (1500-2000 BCF)	BRITISH GAS	PLIOCENE	1943.92
SAFFRON - 1	MEDITERRANEAN	32.1047	30.5344	1998	DISCOVERY	Giant Pliocene gas discovery (2000-2500 BCF)	BRITISH GAS	PLIOCENE	2374.89
SCARAB - 1	MEDITERRANEAN	32.0474	30.6302	1998	DISCOVERY	Giant Pliocene gas discovery (2250-2700 BCF)	BRITISH GAS	PLIOCENE	2099.97
SIMIAN-1	MEDITERRANEAN	32.1920	30.7990	1999	DISCOVERY	Giant Pliocene gas discovery (2500-4000 BCF)	BRITISH GAS	PLIOCENE	2264.86
TAO - 1	MEDITERRANEAN	31.6142	32.7733	1997	DISCOVERY	Significant Pliocene gas discovery (250-550 BCF)	AMOCO	PLIOCENE	2719.90
TUNA-1	MEDITERRANEAN	31.8961	32.2160	1996	DISCOVERY	Significant Pliocene gas discovery (350-500 BCF)	IEOC	PLIOCENE	1259.98
MARAKIA - 1	MEDITERRANEAN	31.1871	29.6316	1992	DRY HOLE	P & A; Tested 9 liters of oil in the Cretaceous; Northern Extension of Western Desert Cretaceous into offshore Mediterranean	SHELL	LOWER CRETACEOUS	4366.96
EL SAGHA - 3X	WESTERN DESERT	29.7880	30.5814	1995	DISCOVERY	Qarun field discovery, Bahariya (80-100 MMBOE)	PHOENIX	LOWER CRETACEOUS	2936.60
KANAYIS - 4	WESTERN DESERT	31.0609	27.6718	1992	DISCOVERY	Discovery as gas&cond from Khatatba (Jurassic) 19.2MMSCFGD& 1300 BCPD; 77.3 MMBOE	NORSK HYDRO	JURASSIC	4765.01
OBA A-3	WESTERN DESERT	31.1273	26.5693	1996	DISCOVERY	Recovered gas/condensate from Paleozoic strata	SHELL	CARBONIFEROUS	4132.89
OBAYID - 1	WESTERN DESERT	31.0723	27.0502	1992	DISCOVERY	Giant Jurassic and Lower Cretaceous field discovery: (1700-2200 BCF)	SHELL	JURASSIC	5038.10
QARUN A - 4X	WESTERN DESERT	29.7665	30.5977	1995	DISCOVERY	Significant southern extension of Qarun field pay	PHOENIX	LOWER CRETACEOUS	2939.96
S.W.QARUN-1X	WESTERN DESERT	29.7766	30.5226	1996	DISCOVERY	Extension of Qarun field pay	APACHE	LOWER CRETACEOUS	3349.89
SHAMS S-1X	WESTERN DESERT	30.8262	26.9078	1996	DISCOVERY	Discovery gas/condensate in Kharita (380-500 BCF)	KHALDA	JURASSIC	4114.60
SHAMS-2X	WESTERN DESERT	30.8508	26.9284	1997	DISCOVERY	Significant Jurassic discovery (1000-1500 BCF)	REPSOL	JURASSIC	

The Gulf of Suez, Nile Delta, offshore Mediterranean and greater Western Desert basins are the only basins proven to contain economically viable petroleum. At least six sedimentary basins are present in Upper Egypt which have had little to no hydrocarbon exploration activity to date. In 1997, one of these basins: the Komobo basin, tested live oil from Jurassic reservoirs.

The primary focus of this paper deals with the basins with proven play systems where significant well and seismic data are available and where industry activity is continuing to establish significant new discoveries or has the potential to open up new trends. We provide a short overview of the potential of the Upper Egypt and Red Sea basins based on new data acquired in the late 1990's.

METHODOLOGY AND PRIOR WORK

The "yet-to-find" numbers of potential giant fields used to postulate a minimum resource doubling for Egypt in the coming decades is based on the integration of two analyses: field size distribution and drilling success statistics interpreted within a petroleum systems context.

We have utilized an historical exploratory drilling database, made available by the Egyptian General Petroleum Corporation, in conjunction with published field data from over 251 fields Hegazy (1992), Matbouly and Sabbagh (1996),Moussa and Matbouly (1994) to understand the exploratory drilling history by basin and play type. Post 1990 field size data from the IHS Energy Group (London, United Kingdom) have been added to supplement missing data. Additional reserve data is available from El-Banbi (1999). Reserve numbers presented in this paper (Table 4) are 15-20% larger than those reported in this important document, which contains production data current through the end of 1997. Our larger reserve estimate is due to inclusion of a number of significant new discoveries in 1998 and 1999.

This combination of historical drilling and fields database has provided field size distributions for recoverable reserves estimates, from which "yet to find" numbers of giant fields in each basin or trend have been derived using the assumption that field size distributions follow log-normal trends. This technique of estimating "yet to find" by statistical analysis of log-normal plots for known discoveries follows published work by Capon (1992), and Smith and Jones (1992). Historical drilling success rates by basin and trend has also been used to assess which plays are "emerging" in Egypt and which are matured and apparently "played out".

The trend assessments discussed are limited to structural, combination or stratigraphic trap discoveries together with the age of the major producing horizons. Structural discoveries are those consisting of four-way closures or fault bounded traps. Combination traps involve at least one overriding component of the stratigraphic seal and stratigraphic traps represent accumulations independent of any significant structural closure.

Drilling fairways, per nomenclature already established by the Egyptian General Petroleum Corporation, include the Gulf of Suez, Eastern Desert, Sinai, North Sinai, Nile Delta and Western Desert (Figure 2). Exploratory wells are defined in Egypt as any well targeting at a new trap as demonstrated by variant pressures, fluid levels, fault blocks or stratigraphic horizons. Hence, many of the exploratory tests used for statistical analysis in this paper could be viewed as appraisal or field delineation wells in other regions or as deeper pool tests. Further differentiation of these well types has not been undertaken in this paper, although where possible the bulk of the reserves found in a new field discovery have been assigned to the original exploratory test in the field. Where data were available, reserves have been broken out by stratigraphic horizon in multi-storied pay traps and an appropriate discovery well has been assigned to each newly discovered horizon. Gas caps and associated gas in oil fields are not included in the reserve estimates.

Age control (Figure 3) is derived from extensive chronostratigraphic synthesis of the literature, much of which, however, is very general in nature. The most complete synthesis for Tertiary age dating is from Krebs et al. (1996) and Krebs et al. (1997) from outcrops fringing the in the western Sinai peninsula, which is summarized in chart format by Wescott et al. (1998). Ages presented in this outcrop synthesis have been constrained by paleomagnetic data and graphic correlation of biostratigraphic age dating for the major unconformities and flooding surfaces Miller (1977). They provide the basic framework for the event stratigraphy shown on Figure 3 for Tertiary strata. We have also used pre-Tertiary correlations and paleogeographic maps to illustrate a broad pattern of deposition in the Paleozoic, Mesozoic and Tertiary Klitzsch (1990), Kerdany and Cherif (1990), Said (1990a, 1990c) and Boote et al. (1998).

Data provided by Repsol-YPF from the Komombo-1 exploratory test in Upper Egypt have added significantly to our understanding of Upper Egypt. Additional key references include Wycisk (1994), Wycisk (1990), Taha (1992), Matbouly and Sabbagh (1996), Moussa and Matbouly (1994), Morris and Tarling (1996b) and (Hegazy, 1992). The chronostratigraphic age dates for major series and stage boundaries shown on Figure 3 are derived from Haq et al. (1988).

Structural and stratigraphic synthesis is of the Gulf of Suez is taken from Patton et al. (1994) and Schutz (1994), and recent concepts in sequence stratigraphy for the Gulf of Suez Tertiary syn-rift section is covered by Dolson et al. (1996) and Ramzy et al. (1996). For the Nile Delta and Mediterranean, age dating is taken from Harwood et al. (1998) and Moussa and Matbouly (1994), supplemented by unpublished work by BP-Amoco on the combined structural and stratigraphic basin evolution. Higher resolution age analysis of the Tertiary section in the Western Desert is largely unavailable. Purser and Philobbos (1993) and Philobbos and Purser (1993) provide chronostratigraphic data from the Southern Gulf of Suez and Red Sea.

Prior regional summaries of Egypt's geological history include Halbouty and El-Baz (1992), Sestini (1984), Robertson and Dixon (1984), MacGregor et al. (1998) and Morris and Tarling (1996b). These references provide valuable insight into the major tectonic events that can explain the pattern of unconformity development shown in Figure 3.

Lastly, we present some recent case histories in successful exploration for each major basin which highlight the critical technical or economic issues driving significant new field discoveries.

TECTONO-STRATIGRAPHIC HISTORY

The tectono-stratigraphic history of Egypt includes eight major episodes summarized in a chrono-stratigraphic chart (Figure 3). Each episode has created reservoir, source and seal facies juxtapositions which have ultimately determined the hydrocarbon prospectivity of each major basin.

Paleozoic Craton

245 wells have drilled to Precambrian rocks in Egypt (Table 1). The limited well data, plus some outcrop exposures (Figure 2) allow a very generalized history of the Paleozoic of Egypt. Prior to Triassic and Jurassic rifting which resulted in the breakup of the Pangea megacontinent, Egypt consisted of a low relief alluvial plain which dipped north and westward towards cratonic sags developed in Libya and along the proto-Mediterranean (Figure 4). Shallow marine carbonates and clastics generally increase in thickness northward in Egypt, with dominantly fluvial-alluvial lithofacies present in the south.

Most of the facies encountered are light colored sands, glauconitic sandstones and gray or red shales formed as paleosols, sabkhas or well-oxygenated marine environments. But shelfal marine Silurian black shales have been encountered in the Western Desert. Western Desert Paleozoic stratal thicknesses exceed 2500 meters in the Siwa basin. These potential source rocks are proven source facies in the age equivalent Tenzuft Shales in Western Libya (Hegazy,1992).

Table 4. Geochemical Data Summary--Western Desert

Basin	Horizon	Age	Acres	Expelled Oil (bbl/acre-ft)	Expelled Gas (bbl/Acre-ft)	Effective Source Rock Thickness (ft)	Total Expelled oil (BOEB)	Expected recovered Oil 7% expelled	Total Expelled Gas (BOEB)	Expected Recovered Gas 7% of expelled
Shoushan	AEB	Lower Cretaceous	4155775	70	110	30	8.73	0.61	13.71	0.96
Shoushan	Khataba	Jurassic	4155775	190	280	40	31.58	2.21	46.54	3.26
Shoushan	Diffah	Carboniferous	4155775	64	5	30	7.98	0.56	0.62	0.04
Shoushan	Zeitoun	Devonian	4155775	64	5	30	7.98	0.56	0.62	0.04
Shoushan	Kohla	Silurian	4155775	64	5	30	7.98	0.56	0.62	0.04
Subtotal							**64.25**	**4.5**	**62.13**	**4.35**
Alamein	AEB	Lower Cretaceous	2642900	110	180	30	8.72	0.61	14.27	1
Alamein	Khataba	Jurassic	2642900	250	410	40	26.43	1.85	43.34	3.03
Alamein	Dhiffah	Carboniferous	2642900	60	10	30	4.76	0.33	0.79	0.06
Alamein	Zeitoun	Devonian	2642900	60	10	30	4.76	0.33	0.79	0.06
Alamein	Kohla	Silurian	2642900	60	10	30	4.76	0.33	0.79	0.06
Subtotal							**49.2**	**3.46**	**59.99**	**4.2**
Natrun	AEB	Lower Cretaceous	3698825			30				
Natrun	Khataba	Jurassic	3698825	70	160	40	10.36	0.72	23.67	1.66
Natrun	Dhiffah	Carboniferous	3698825	70	13	30	7.77	0.54	1.44	0.1
Natrun	Zeitoun	Devonian	3698825	70	13	30	7.77	0.54	1.44	0.1
Natrun	Kohla	Silurian	3698825	70	13	30	7.77	0.54	1.44	0.1
Subtotal							**33.66**	**2.36**	**28**	**1.96**
Abu Gharadig	Abu Roash A-F	Upper Cretaceous	3902600	240	50	50	46.83	3.28	9.76	0.68
Abu Gharadig	AEB	Lower Cretaceous	3902600	65	180	30	7.61	0.53	21.07	1.48
Abu Gharadig	Khataba	Jurassic	3902600	160	420	40	24.98	1.75	65.56	4.59
Abu Gharadig	Dhiffah	Carboniferous	3902600	110	43	30	12.88	0.9	5.03	0.35
Abu Gharadig	Zeitoun	Devonian	3902600	110	43	30	12.88	0.9	5.03	0.35
Abu Gharadig	Kohla	Silurian	3902600	110	44	30	12.88	0.9	5.15	0.36
Subtotal							**118.05**	**8.26**	**111.61**	**7.81**
Siwa/Faghur	AEB	Lower Cretaceous	14647100			30				
Siwa/Faghur	Khataba	Jurassic	14647100			40				
Siwa/Faghur	Dhiffah	Carboniferous	14647100	23	5	30	10.11	0.71	2.2	0.15
Siwa/Faghur	Zeitoun	Devonian	14647100	41	8	30	18.02	1.26	3.52	0.25
Siwa/Faghur	Kohla	Silurian	14647100	44	8	30	19.33	1.35	3.52	0.25
Subtotal							**47.46**	**3.32**	**9.23**	**0.65**
Guindi	AEB	Lower Cretaceous	1661075	28	35	30	1.4	0.1	1.74	0.12
Guindi	Khataba	Jurassic	1661075	185	270	40	12.29	0.86	17.94	1.26
Guindi	Dhiffah	Carboniferous	1661075	332	61	30	16.54	1.16	3.04	0.21
Guindi	Zeitoun	Devonian	1661075	336	62	30	16.74	1.17	3.09	0.22
Guindi	Kohla	Silurian	1661075	346	65	30	17.24	1.21	3.24	0.23
Subtotal							**64.22**	**4.5**	**29.05**	**2.03**
		TOTAL					***376.84***	***26.4***	***300.01***	***21***

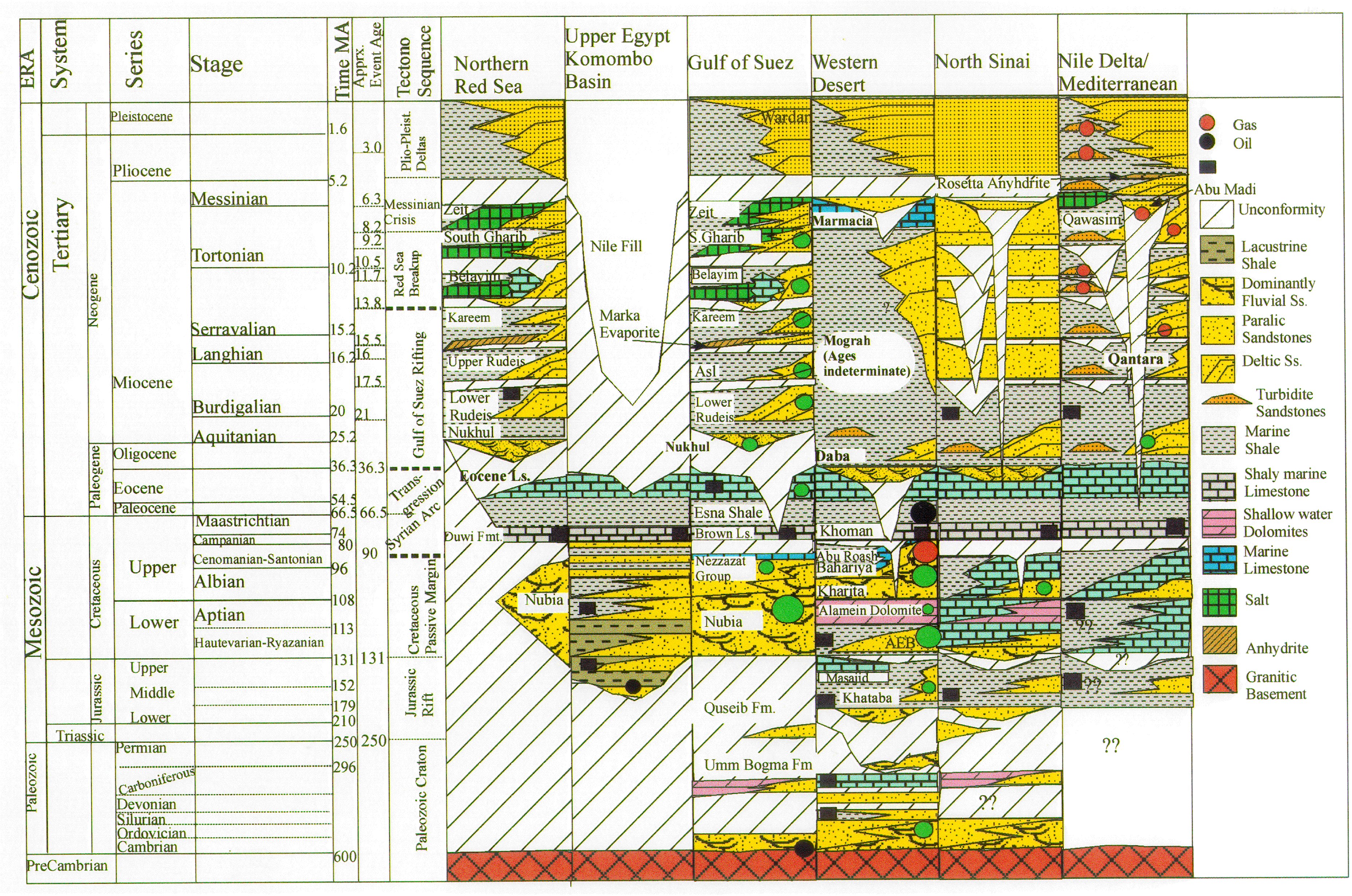


Figure 3. Stratigraphic correlation panel of Egypt. Major tectono-stratigraphic breaks are highlighted on the chart. See text for discussion.

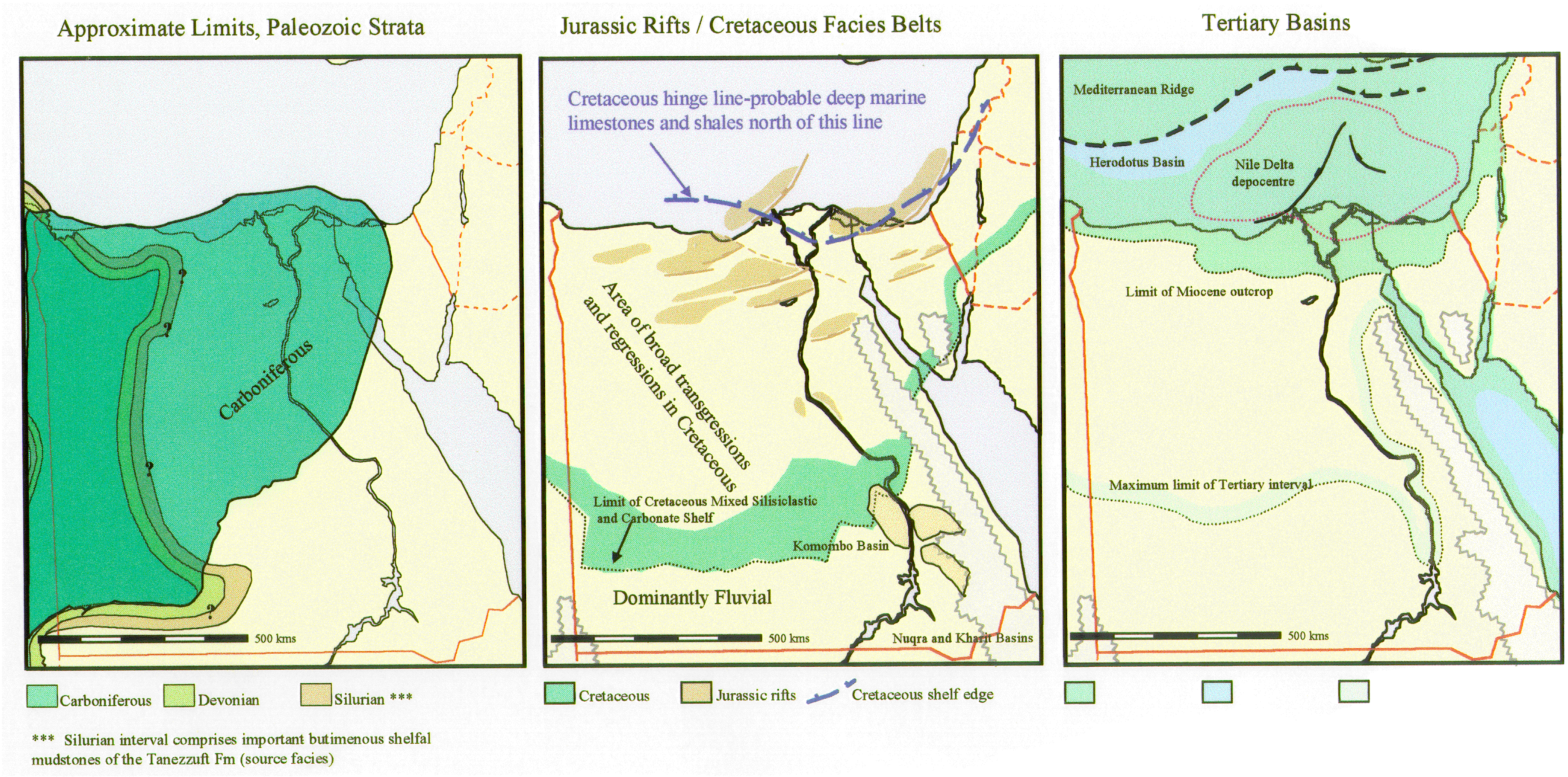


Figure 4. Paleogeographic reconstructions with time for major tectono-stratigraphic intervals (modified from Boote et al., (1998)).

Paleozoic strata are absent over large areas in Egypt due to erosion during Triassic and Jurassic rift episodes and onlap around pre-existing basement highs. Production from Paleozoic strata has been minimal, but still remains to be systematically explored.

Jurassic Rifting

In the Late Triassic through Jurassic, a series of multiple rift basins formed during the breakup of Pangea which eventually resulted in the opening of the proto-Mediterranean Tethyan basin (Figures 4 and 5). The sedimentary record of Triassic and Jurassic strata is one reflecting a typical three-phase rift development of 1) rift initiation 2) rift climax 3) post rift sag (Prosser, 1993). Jurassic strata are best developed within the northeastern corner of the Western Desert where syn-rift grabens fill exceeds 2500 meters.

Rift grabens in northern Egypt are oriented perpendicular to the published divergent plate vectors between the African and European plates (Figure 5). The direction of other Jurassic rift systems across northern Africa may reflect inherited trends from a pre-Hercynian Paleozoic structural grain. The NW-SE orientation of the newly discovered Mesozoic rifts in southern Egypt may have another genesis entirely.

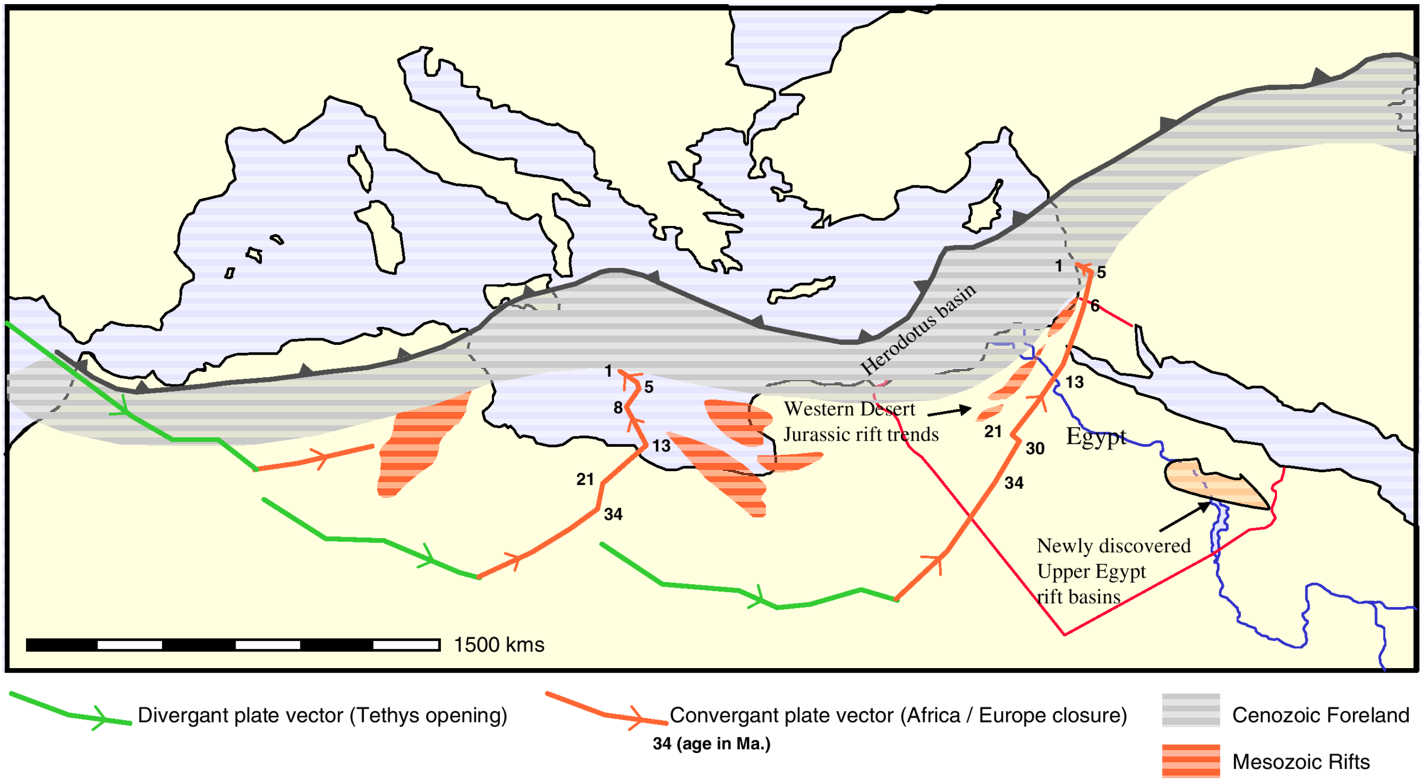


Figure 5. Summary diagram of plate reconstructions in North Africa and the Mediterranean Region (modified from (Morris and Tarling, 1996a)

Late Triassic and early Jurassic strata record an early rift phase of non-marine and shallow marine sediments that thin progressively southwards away from the Tethyan margin. In the south these strata are dominated by sandstone, red shale and thin anhydrite deposited in rift-bounded fluvial, lacustrine and sabkha environments. Northward, toward the proto-Mediterranean, time equivalent rift-fill lithofacies contain progressively more carbonate and marine shale. Early movement of rift-related structures created paleostructural highs onto which many of these strata onlap.

By middle Jurassic time, during the rift climax phase, fault blocks had fully developed and progressively deeper marine strata were deposited. The carbonate-prone Masajid Formation contains black marine shales that form local thick proven source rocks in the Western Desert. Towards the south, there is a change to progressively more non-marine facies which contain carbonaceous shales and coal of the Khataba Formation, also considered as proven source rock facies.

In addition, Taha (1992) and Schull (1988) document the development of additional Mesozoic rift basins in Upper Egypt and Sudan which appear to contain dominantly non-marine lacustrine sediments. These basins were probably not physically connected to the Tethyan open marine rift systems in the Western Desert and North Sinai areas. Repsol successfully proved the presence of three of these basins (Nuqra, Kharit and Komombo, Figure 2) with exploratory wells drilled in the 1990's (Table 2). The northwest-southeast orientation of these basins may indicate rifting associated with breakup of the Afro-Arabian plate, possibly as far south as Yemen (M. Winfield, personal communication) in trends which remain poorly understood.

Cretaceous Passive Margin

By Early Cretaceous time, an extended period of thermal sag associated with wide passive margin development occurred across the northern margin of the African plate, resulting in a mixed silisiclastic and carbonate system. There are some local unconformities between the Lower Cretaceous and Upper Jurassic plus the vertical transition from marine shale to lignite and carbonaceous shale near the base of the Alam el-Bueib (AEB) Formation which seem to indicate some local continuation of rift episodes into the Early Cretaceous. The AEB Formation is progressively overlain by a pattern of carbonate micrite and oolitic limestone that suggest episodic series of transgressions and regressions related to regional sea-level oscillations. The AEB Formation contains proven marine carbonate source rocks. Age equivalent strata in the Nubia Formation to the south generally consist of red shale and coarse-grained reservoir sandstones deposited in fluvial environments. Between the two areas, (Darwish, 1992) documents shallow marine and sabkha environments within portions of the Nubia Formation along Sinai outcrops in the Gulf of Suez. The Aptian Alamein Dolomite marks a period of widespread sea level rise which provides a useful flooding surface marker horizon throughout the Western Desert and North Sinai. Age equivalent marine strata in the Komombo basin (Figure 3) indicate that this Aptian age transgression reached into southern Egypt.

Continued thermal subsidence throughout the Western Desert was accompanied by continued south-directed transgressions across the stable carbonate shelf that resulted in the deposition of additional widespread source rocks in the Kharita and Bahariya Formations. Time equivalent strata to the south are dominantly fluvial (Nubia Formation) and shallow marine (Lower Nezzazat Group Raha Formation).

The northern edge of the Cretaceous carbonate platform system is seen in the Nile Delta area where it has been mapped as the Cretaceous hingeline. The carbonate margin crops out in southern Israel as local thick carbonate slope breccia of the Talme Yafe Formation (Bein and Weiler, 1976). To the north of this carbonate margin, deep marine carbonate and shale were deposited across the offshore Nile Delta and Mediterranean Sea areas.

Syrian Arc Deformation and Foreland Transgression:

The onset of Tethys closure between the European and African plates during Cenomanian through Turonian resulted in regional uplift characterized by rift-basin inversion occurred throughout the Western Desert as a series of "Syrian Arc" northeast-southwest trending folds (Moustafa and Khalil, 1990) and Moustafa et al. (1998). This structural deformation resulted in development of pronounced unconformities across inverted structural crests (Figure 6). Deposition locally continued off-structure with onlap along the flanks of these evolving highs. This important tectonic event continued episodically through Santonian time as the African plate moved northward and completely cut off the Tethyan seaway as it collided with the European plate.

Turonian through Santonian carbonate of the Abu Roash Formation show widespread high cyclicity and some of these correlative units (Nezzazat Group, Gulf of Suez) contain oolitic limestone and grainstone that can be traced using well control as far south as the southern end of the Gulf of Suez. At the same time, deep marine shale and limestone were deposited northward of the remnant carbonate margin across the Mediterranean and Nile Delta areas.

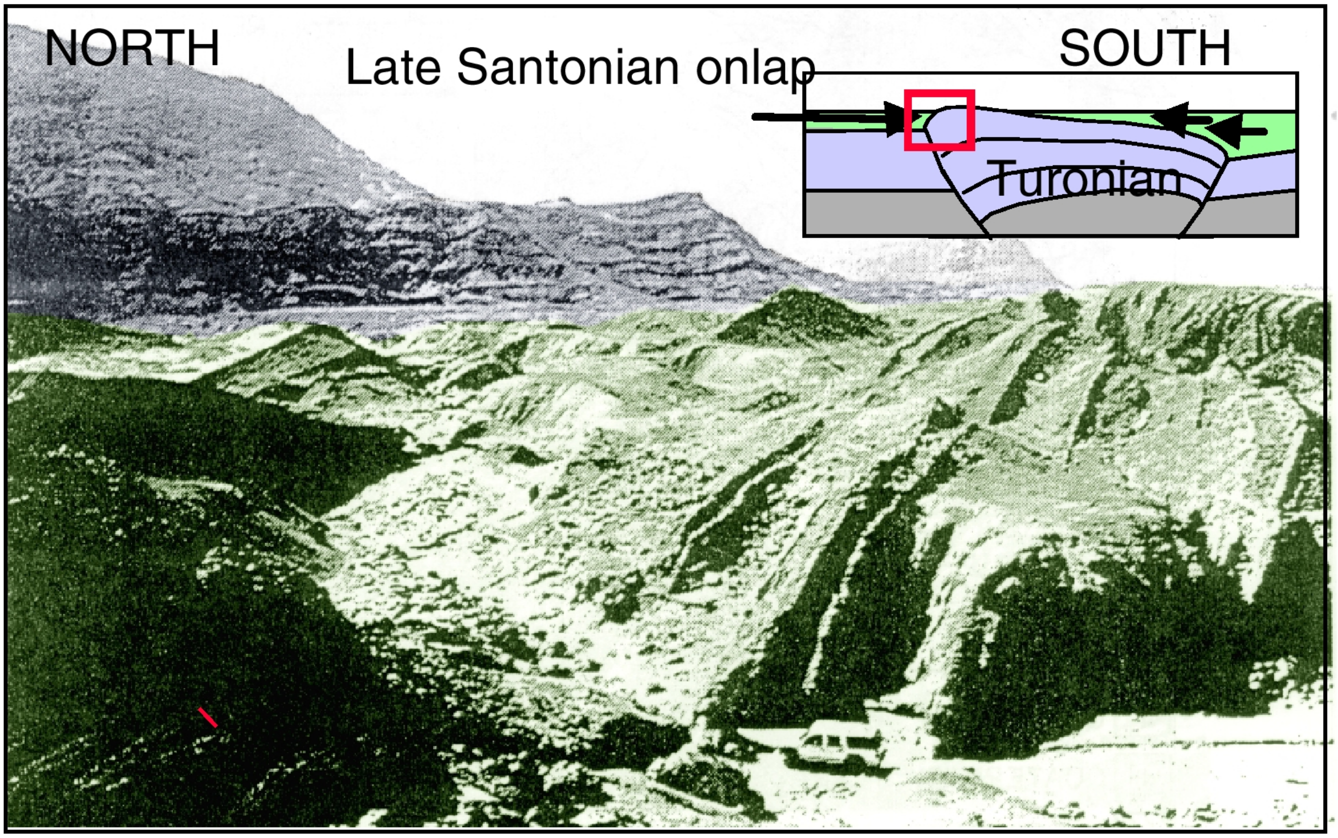


Figure 6. Outcrop example of an inverted Syrian Arc structure at Wadi Araba (see Figure 1 for location).

Syrian Arc related structural trends form the bulk of the productive traps discovered to date in the Western Desert. Extension of these productive trends eastward into the onshore part of the Nile Delta has proved disappointing.

By early Campanian time, most of the structural deformation associated with the development of the Syrian Arc had ceased. A major sea level rise (Haq et al., 1988) resulted in widespread flooding and deposition of source-rich anoxic shelfal shale and limestone of the Khoman Formation and its southern equivalent, the Brown Limestone. Where not removed by Tertiary uplift and erosion, these important oil source rocks are encountered in all Egyptian basins as far south as the northern end of the Red Sea.

From the Cenomanian onwards, the African plate was gradually subducted northward under the European margin, resulting in the development of a wide foreland basin across northern Egypt (Figure 5). Continued transgression resulted in the deposition of Paleocene shale (Esna Shale and equivalents) and Eocene cherty carbonate and thinly laminated shale of the Thebes Formation and equivalent strata. The Campanian through Eocene interval throughout Egypt forms significant topseals to underlying reservoirs, as well as mechanical structural boundaries which impact faulting and folding geometries.

Gulf of Suez Rifting

The opening of the Gulf of Suez began in the Early Oligocene and culminated with the Red Sea breakup in the Serravalian stage of the Miocene. Biostratigraphic data (Krebs et al., 1996), (Patton et al., 1994), (Wescott et al., 1996) indicate that extension was initiated in the northern portion of the Gulf of Suez and spread southward during the Miocene. Marine deposits of the Nukhul and Lower Rudeis Formations show a Mediterranean fauna consistent with a limited sea-way connection northward to the Mediterranean. Mixed northern and southern faunal assemblages occur in the Gulf of Suez during the Burdigalian (rift climax event) showing that a full connection was developed between the Red Sea and the Mediterranean at that time. By middle Serravalian time, however, the faunal assemblages show only a southern connection to the Indian Ocean. Structural uplift across reactivated Syrian Arc structures had closed off the northern end of the Gulf of Suez.

A number of significant basin-wide unconformities occur in the Gulf of Suez which have been dated by a combination of high resolution outcrop studies, biostratigraphy and paleomagnetics. Dolson et al. (1996) and Ramzy et al. (1996) illustrate that these surfaces formed primarily in response to regional tectonic adjustments associated with different phases of rift evolution.

Rift initiation deposits in the Gulf of Suez consists of conglomeratic braided and meandering stream sandstone interbedded with brick-red paleosols and playa lake lithofacies of the Abu Zenima and Nukhul Formations. These formations grade upward into bioturbated sandstone interbedded with progressively more "coquina" and limestone intervals deposited in estuarine and shoreface environments. A series of closely spaced marine ravinement surfaces cap the initial rift fill, which is then progressively overlain by deeper water marl and shale of the overlying Lower Rudeis Formation. Isopach maps and outcrop paleocurrent directions indicate a north-south orientation for most of the Nukhul Formation which is preserved in half-grabens that run sub-parallel to the regional structural fabric of the opening rift.

Oligocene strata are only partially preserved in the Gulf of Suez, but consist of conglomeratic sandstone and marine shale in the Western Desert and Nile Delta areas. Many of the reservoir sandstone units formed as deltas fed by the erosion of the emergent portions of the Gulf of Suez and other topographically high areas to the south. These deltaic reservoirs and associated deep water fans represent a deep, largely untested play across much of the Nile Delta and Mediterranean areas. In the Nile Delta, Oligocene to Early Miocene shale of the Qantara Formation also contain some lean source potential.

By Early Burdigalian time, the Gulf of Suez was fully developed and parts of the basin had reached bathyal water depths. Large fan-deltas continued to enter the basin through major structural transfer zones, depositing important reservoir sandstone units. A major unconformity developed at 17.5 MA (T20 or Mid-Rudeis unconformity). This hiatus records a rapid basin shallowing in late Burdigalian time which may have resulted from regional isostatic rebound of the basin floor (Wescott et al., 1998).

An important basin-wide lowstand event in the Gulf of Suez (Asl Formation) resulted from this relative sea level lowering which culminated in widespread deposition of the supratidal Markha Anhydrite. The paleobathymetric shift was profound, as areas that were once at bathyal conditions shallowed in less than two million years to supratidal conditions with only the deep structural synclines still filled with deeper water shale (Dolson et al., 1998). During this shallowing, coarse-grained detrital sediments prograded far beyond the limits of earlier Lower Rudeis deltas, reaching, in many cases, the axis of the basin.

Miocene reservoirs continue to be primary targets for flank and basin-floor fan exploration. Although this event may relate to a global sea-level lowstand, it also corresponds to regional uplift across Egypt. Harms and Wray (1990) show a marked bathymetric change in the Nile Delta from bathyal to inner neritic water depths during this same time interval in the Qantara-1 and Qallin-1 wells for the same 17.5 to 15.2 million year time interval.

Red Sea Breakup

The isolation of the Gulf of Suez from the Mediterranean sea due to reactivation of the Syrian Arc structural trend may have been due to an overall shift to north-south (vs. northeast-southwest) rift extension (Meshref, 1990). The isolation of the Gulf of Suez from the Mediterranean is marked by cyclical deposition of basin-centered salts and anhydrites. These strata are intermixed with coarse grained sandstone derived from point-sourced deltas along the basin flanks. The evaporites of the Belayim and South Gharib Formations from critical regional seals to many structural accumulations and the interbedded sandstones significant reservoirs.

By contrast in the Nile Delta, the Serravalian to Early Tortonian strata record a strong pulse of basinward progradation of deep water clastics from south to north into the Mediterranean. The precise entry points of feeder systems remain unknown but were presumably from the proto-Nile, which would have been developed west of the Gulf of Suez uplifts and from coastal uplands along the North Sinai.

Messinian Crisis

Within the Mediterranean and Nile Delta region, the frequency of erosional unconformity development in Late Miocene time appears to increase upwards stratigraphically, culminating with the Messinian crisis at 6.7 MA. This was essentially a tectonic driven event related to late-stage closure of the African plate against Europe, causing the closure of the Straits of Gibraltar and evaporation of the Mediterranean Sea. Basin-wide lowstand deposits of salt and anhydrite occur throughout the deeper portions of the Mediterranean (see Figure 2 for limits of Messinian salt).

Compressional deformation in the Nile Delta area created wide uplifted arches and local strike-slip grabens which were deeply incised during the evaporitic draw-down. Grand Canyon scale incisions of these arches occurred along many coastal areas and within the proto-Nile valley (Harms and Wray, 1990). Large volumes of sediment were transported offshore through these canyons in deltas into deepwater trends that remain undrilled. As the Mediterranean finally refilled, subsequent flooding back-filled these valleys with fluvial and estuarine strata which are productive in many combination traps. Moussa and Matbouly (1994) document further examples of canyon incisions and petroleum traps related to the Messinian crisis. Transgressions which back-filled the Messinian canyons were episodic and numerous intra-Messinian erosional surfaces are recognizable on seismic sections. The drainage networks established around the rim of the Mediterranean provided focal points for sediment input in the Pliocene and offer numerous exploration targets.

No similar pattern of deep shelfal incision is noted in the Gulf of Suez in the equivalent strata of the Wardan Formation, although a significant hiatus developed and a long period of basin-centered salt deposition occurred at this time. Drainage patterns around the Gulf of Suez were apparently diverted to the west by drainage capture into the Nile canyons.

Plio-Pleistocene Delta Progradation

The Pliocene section in Upper Egypt and the Gulf of Suez lies well above potential mature source rocks. The presence of intervening shale and evaporite seals has meant that the Pliocene has not been a successful exploration target. In the Nile Delta and Mediterranean areas, however, Pliocene deltaic sandstone form very significant reservoirs and have become the dominant "big play" of the 1990's. The Messinian canyons were completely overstepped and infilled by 5.6 MA, but large volumes of sediment from the Nile Valley continued to prograde into the Mediterranean. Up to 17 sequences have been documented for the Pliocene (Harwood et al., 1998) and the associated facies shifts have formed important reservoir fairways and traps.

A switch in the plate convergence direction towards the northwest, from ca. 5 MA. onwards (Figure 5) probably caused the Nile Delta depocentre to tilt downwards to the northwest into the present-day basinal low of the Herodotus Basin.

DRILLING HISTORY

Exploration drilling continues to result in significant new field discoveries (Figure 7). Egypt's most prolific period of growth prior to the late 1990's in the Western Desert and Mediterranean was 1955-1979 period of exploration in the Gulf of Suez. This time interval was marked by successive discoveries of 4-way closures and large 3-way upthrown fault block traps easily discernible with 2D seismic and, in some cases, water bathymetry maps. The Gulf of Suez and Eastern Desert discovery rates have flattened significantly in the last 15-20 years, indicating a maturing of the exploratory history and/or a need to discover new trends with different technology or play concepts. The onshore Sinai has had only limited success since the discovery of the giant Belayim Land field in 1955 and has limited "running room" due to the proximity of the rift basin margin immediately east of this drilling province.

In contrast, substantial growth has occurred in the Western Desert and Mediterranean provinces. This growth has been fueled largely with the awarding of gas rights in both basins in the late 1980's. The cumulative discovery vs. time data for the Mediterranean offshore is closely paralleling that of the Gulf of Suez early discovery rate.

Although drilling statistics don't show significant volumes in Upper Egypt, this area has seen some limited but significant exploration activity (5 wells) in the 1990's (Table 3) which has established the presence of oil with the drilling of the Komombo-1 well by Repsol in 1997 and new resources in the Beni Suef basin. And a new phase of drilling in the Red Sea may soon be underway as several companies complete interpretations of newly acquired 3D and gravity data and attempt to open up new discoveries in this frontier province.

Discussion of the potential and technical challenges in each trend follows.

EXPLORATION POTENTIAL BY PETROLEUM SYSTEM

Western Desert

The Mesozoic basins of the Western Desert provide rewarding but difficult exploration opportunities. It has proven a challenge to understand because of its complex history of a Paleozoic margin, Jurassic rift, Early Cretaceous passive margin and subsequent inversion during the Syrian Arc deformation. In addition, seismic data quality degrades rapidly beneath the Alamein Dolomite, so much of the productive AEB and older Jurassic reservoirs are difficult to image. Drilling has been almost totally confined to structural culminations and successful exploitation of numerous stratigraphic pinchouts has not been fully tested. Surface acquisition is also difficult, and widespread 3D seismic surveys which have the potential to decrease risk on future drilling opportunities have only been shot recently, and most of these are local in extent.

Nevertheless, the Western Desert field size distribution shows a large number of small fields but some room does exist in the field distribution statistics for 100 MMBO and larger discoveries (Figure 8). Indeed, the Kanayes, Shams and Obaiyed fields were all discovered since 1993 (Table 2), producing mainly from Jurassic reservoirs. The interpreted number of potential giant field "yet to find" discoveries shown on Figure 8 are derived by assuming that there is one field left to find larger than Obaiyed Field, the largest field yet found in the trend. In theory, since the field size clusters shown are lumped in exponential classes on the x-axis, missing field sizes can be estimated from the difference between the diagonal line and the number of fields in each class. The diagonal line is picked by estimating the largest field yet to be found in the trend and then pinning the line in that field class and connecting back to the number of the smallest fields. The gaps are theoretical missing field numbers.

By comparison, for example, data provided by the IHS Energy Group, Inc., for the distribution of non-U.S. and Canada oil fields in the world (Figure 9D) shows a much closer fit to a similar straight line. The gaps under this line suggest possible numbers of new field discoveries in each class. Note that with this larger sampling of fields, the gaps have narrowed between the known and the speculative "yet to find" line. This simplified technique relies heavily upon the interpreter's knowledge of the basin and what the "biggest" fields left to find might be.

We view these interpretations as useful tools to gauge relative potential growth in each province and acknowledge that additional assessment by play, trap or reservoir age provide more refinement, especially if coupled with source, maturation and migration studies which can quantify volumes of hydrocarbons expelled in each trend. Nevertheless, these data suggest up to 30 new giant fields might be discovered in the Western Desert. The location of most of these new fields would almost certainly have to come from deeper Jurassic and/or Paleozoic objectives or new stratigraphic trap concepts drilled in flank and basinal areas.

Table 4 provides some summary data (courtesy of the Egyptian General Petroleum Corporation) which shows the potential volumes of oil and gas generated in each sub-basin within the greater Western Desert. The presence of the source facies shown has been confirmed by a large number of wells (Hegazy, 1992). But the eastward extent of Paleozoic source rocks into the Natrun basin remains conjecture. An assumption has been made that the thickness of source bearing interval will be uniform across each basin area. The "expected recoverable" oil and gas numbers shown represent an estimate of 7% of the generated hydrocarbons actually migrating out of the basin toward potential traps. A similar number of 10% was used by (Barker and Dickey, 1984) to estimate the volume of migrated hydrocarbons in Saudi Arabia. While this table contains much speculative data, maturation profiles have been generated for each basin which constrain the expulsion predictions and the petroleum volumes generated are significant.

These data suggest that 26.4 billion barrels of oil and 21 BBOE gas (144 TCF) may have migrated toward traps in the Western Desert basins (for a total of 47.4 BBOE migrated hydrocarbons). The 578 exploratory tests drilled in the large region have discovered 1.15 BBO and 12.6 TCF gas (3.2 BBOE) (Table 5). Using only the mid-points of the giant field numbers speculated as "yet to find" (Figure 8) an additional 11.1 BBOE of resources may exist in new field discoveries in these basins. This number is well under the migrated hydrocarbon estimate shown of 47.4 BBOE on Table 4. We believe these numbers of potential giant fields represent long term "upside" requiring a significant investment in technology and willingness to pursue deeper and more difficult targets.

As discussed earlier, Paleozoic source strata extend under some of these rift grabens and thicken westward from the Western Desert into Libya. They may provide petroleum charge for lightly drilled Paleozoic reservoir horizons. In the Western Desert 137 exploratory wells penetrate the Jurassic interval, but only 40 reach the Paleozoic section (Table 1). In 1996 the OBA-A3 well established Paleozoic production in the Matruh basin. The Paleozoic potential remains an interesting target, as Devonian and Silurian age source strata are important sources for oils in Libya (Boote et al., 1998), Traut et al. (1998) and Keeley and Massoud (1998).

The emerging play of the 1990's is exploration for Jurassic traps. Figure 9 illustrates the complex distribution of basins and intervening highs in the northern portion of the Western Desert near Obaiyed Field. Mahmoud and Barkooky (1998) demonstrate over 250 meters of paleotopographic relief across the Obaiyed feature regionally, with rapid lateral facies changes (Figure 9) and reservoir pinch-outs which could set up additional stratigraphic traps. The Jurassic targets have been very difficult to image seismically and more structural traps will be discovered as seismic imaging is improved.

Southward, in the Beni Suef and Gindi basins recent new field discoveries have also been made in Cretaceous reservoirs (Table 3) and Qarun (Geizery et al., 1998) and Beni Suef fields (Figure 10) . These new field discoveries have proven that hydrocarbon systems exist in these smaller basins where little to no prior successful exploration activity has occurred. The extent of the Jurassic source rocks in the deeper portions of these basins is unknown and drilling as concentrated on the structural high along the basin boundaries.

The field size distributions and significant reserve growth shown by the strong cumulative finding rate in the 1990's suggest the Western Desert will continue to be an attractive exploration target into the future. Extensions into the offshore Mediterranean should also prove attractive.

Table 5. Reserves by Age and Petroleum System

GULF OF SUEZ, EASTERN DESERT, SINAI	***MMBOE***	***OIL MMBO***	***GAS BCF***
TERTIARY	5335.848	5298.115	226.4
CRETACEOUS	2682.192	2680.525	10
JURASSIC	0	0	0
TRIASSIC	0	0	0
PALEOZOIC	0	0	0
PRECAMBRIAN	0.6	0.6	0
SUBTOTAL	***8018.64***	***7979.24***	***236.4***
NILE DELTA, MEDITERRANEAN, NORTH SINAI	***MMBOE***	***OIL MMBO***	***GAS BCF***
TERTIARY	4247.046	35.476	25269.42
CRETACEOUS	7.78	3	28.68
JURASSIC	0	0	0
TRIASSIC	0	0	0
PALEOZOIC	0	0	0
PRECAMBRIAN	0	0	0
SUBTOTAL	***4254.826***	***38.476***	***25298.1***
WESTERN DESERT	***MMBOE***	***OIL MMBO***	***GAS BCF***
TERTIARY	5	5	0
CRETACEOUS	2432.633	1059.995	8235.83
JURASSIC	816.1833	92.35	4343
TRIASSIC	0	0	0
PALEOZOIC	5.5	0.5	30
PRECAMBRIAN	0	0	
SUBTOTAL	***3259.317***	***1157.845***	***12608.83***
UPPER EGYPT (Beni Suef)	***MMBOE***	***OIL MMBO***	***GAS BCF***
TERTIARY	0	0	0
CRETACEOUS	10	10	0
JURASSIC	0	0	0
TRIASSIC	0	0	0
PALEOZOIC	0	0	0
PRECAMBRIAN	0	0	0
SUBTOTAL	***10***	***10***	***0***
TOTAL ALL BASINS	***15542.78***	***9185.561***	***38143.33***

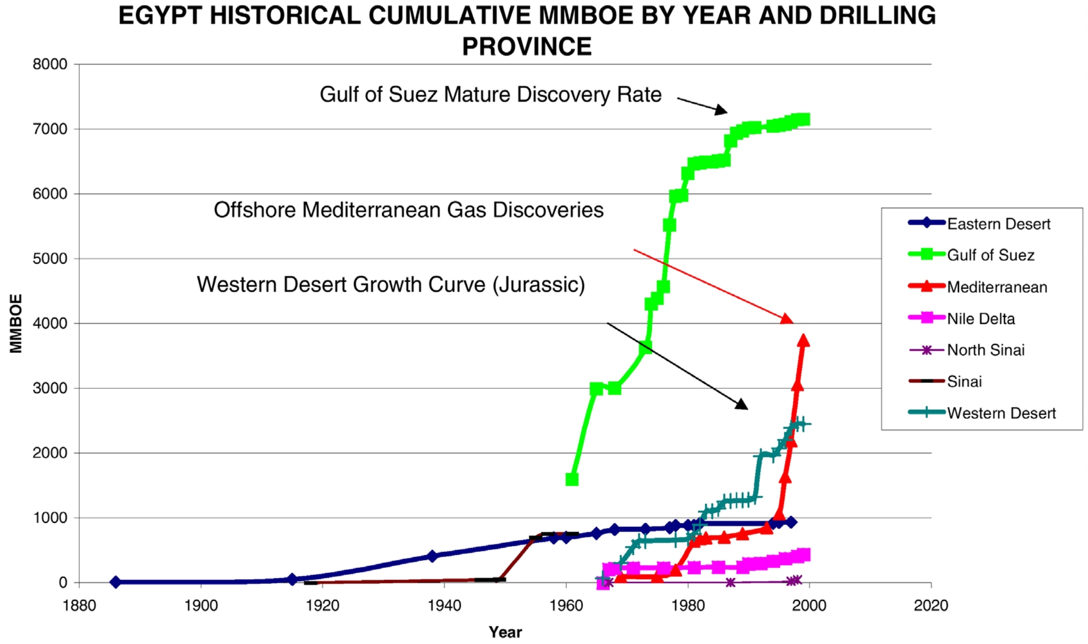


Figure 7. Cumulative discovery volume (MMBOE) vs. time by drilling trends. The data shown breaks the drilling history into "drilling provinces" as defined by the Egyptian General Petroleum Corporation. The "Western Desert" provinces includes all sub-basins, as shown on Figure 2, the "Nile Delta" represents all onshore wells within the Nile Delta and the "Mediterranean" refers to all offshore drilling in the Mediterranean sea. "North Sinai" applies to all wells drilled onshore east of the Nile Delta. The "Sinai" trends are onshore extensions eastward of the Gulf of Suez and the "Eastern Desert" the onshore extension westward of the Gulf of Suez. The "Red Sea" and "Upper Egypt" provinces contain the remaining wells as defined in this study.

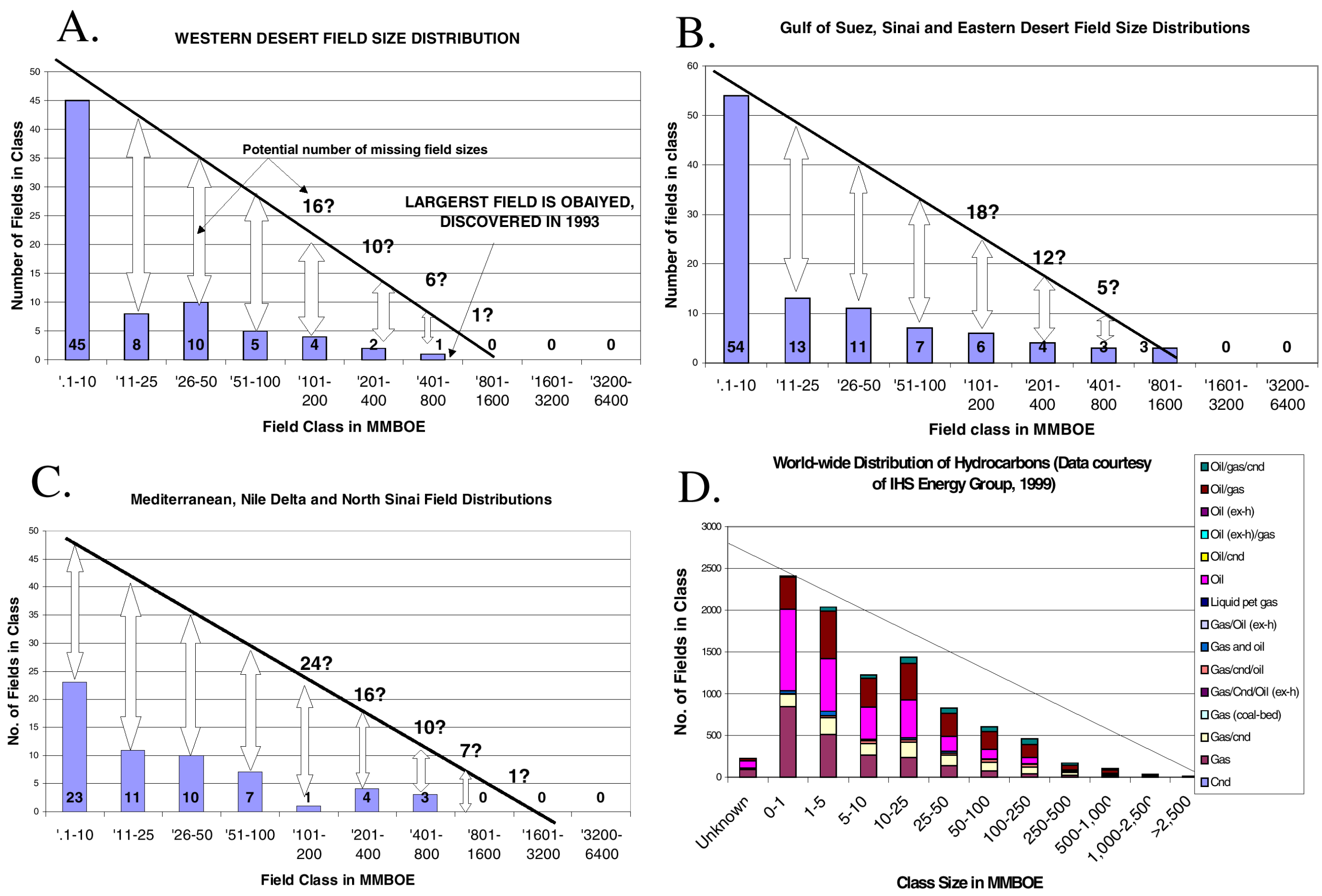


Figure 8. Field size distributions Western Desert, GOS and Nile/Mediterranean region. Field classes are arranged logarithmically, so "yet to find" number of new fields are shown with arrows under the straight line. Plot D is a comparison plot of similar field size distributions using all of the known fields in the world (excluding the U.S. and Canada) which illustrates a mature pattern of log-normal field distributions (data for plot D courtesy of the IHS Energy Group, London, United Kingdom).

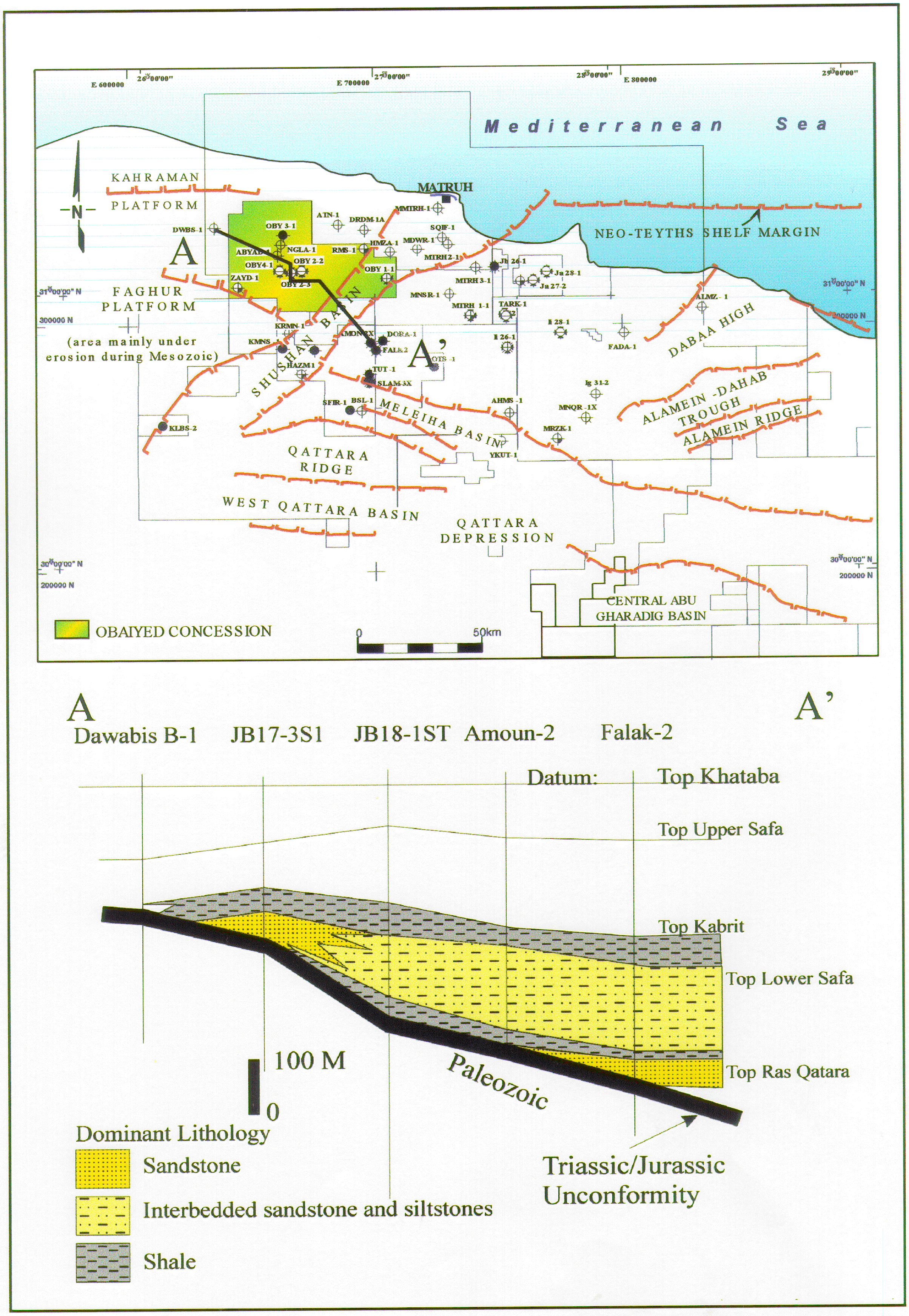


Figure 9. Obaiyed Field, Matru Basin, Western Desert. This structurally trapped 2.2 TCF giant was a 1993 discovery which opened the currently active Jurassic play (modified from (Mahmoud and Barkooky, 1998)). A) Location of Obaiyed field and rift basins formed predominately in Jurassic time B) Degree of onlap and paleotopographic relief shown across the top of the Obaiyed feature. Not all wells on this line of section are shown on Figure 9A.

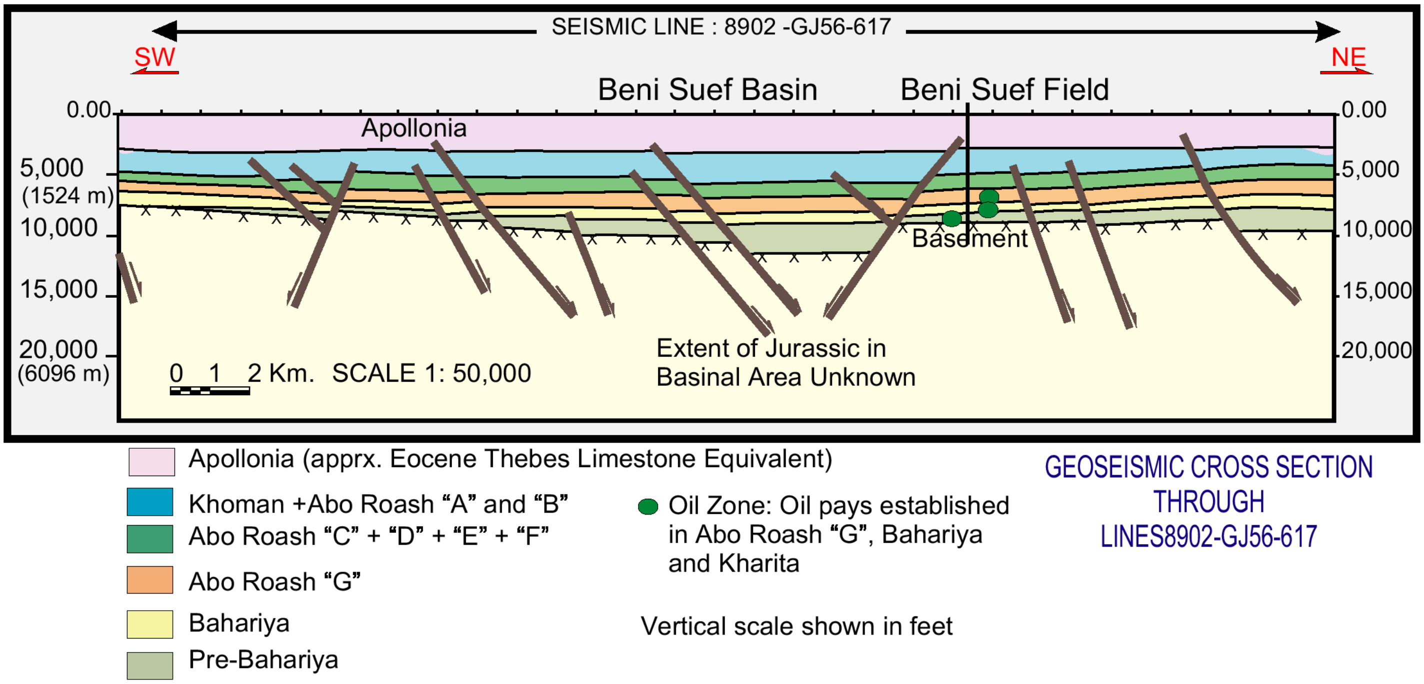


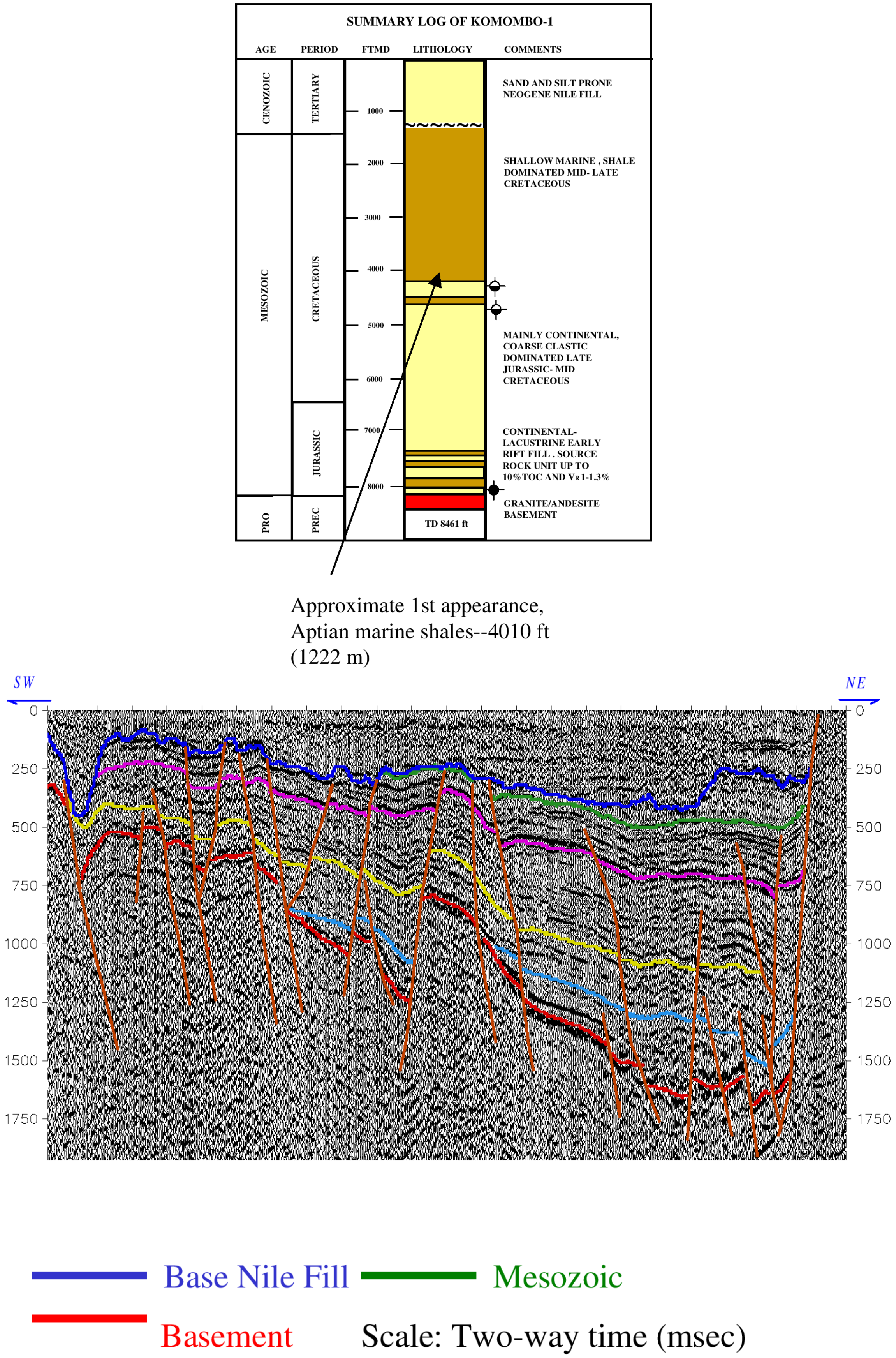
Figure 10. NE-SW structural section taken from a 2D seismic line across the Beni Suef basin and newly discovered Beni Suef field, Upper Egypt (data and interpretation courtesy of the Apache Egypt Companies). This field is the southern-most extension of commercial pay into Upper Egypt.

Upper Egypt

Mesozoic basin exploration is not confined to the Western Desert and Northern Egypt. One of the most interesting and truly frontier exploration plays is just now being tested in Upper Egypt. In the late 1990's (Table 3 and Figure 2), Repsol began exploring the Komombo basin, a Mesozoic age continental rift. The rift geometry has been detected from outcrop patterns and gravity data (Kamel, 1990) and five exploratory tests have now been drilled. The Komombo-1 well tested 37-39 API degree oil from the Jurassic and proved the existence of a working petroleum system (Taha and A/Aziz, 1998).

The Komombo well (Figure 11) penetrated non-marine Jurassic lacustrine Type II-III source rocks from in the middle-Late Jurassic. Additional source rocks as well as marginal marine and marine strata were encountered in Aptian and younger Cretaceous strata. These Cretaceous source rocks were also present to the south in the Nuqra and Kharit basins, but are thermally immature. Although additional drilling has so far been unsuccessful, shows were encountered in all wells in the Komombo basin. The nearby Nuqra and Kharit basin wells had no oil and gas shows. The representative seismic line shown in Figure 11 over prospective leads illustrates the source, reservoir and seal potential of this sparsely drilled province. The Komombo basin is potentially an ideal petroleum system, with deeply buried lacustrine source rock (3000-5000 meters paleoburial depth), thick clastic reservoirs and an overlying shallow marine shale dominated section which can potentially form basin-wide seals. Therefore, the potential exists for both structural and stratigraphic trapping in an area covering more than 2000 square kilometers.

Schull (1988) and Taha (1992) document production from similar non-marine rifts in Sudan which have an analogous tectono-stratigraphic history, possibly related to Mesozoic rifting of the African/Arabian plate. With further integration of data from these important new wildcats and additional seismic, this new basin may one day become Egypt's newest oil province.



Approximate 1st appearance, Aptian marine shales--4010 ft (1222 m)

Scale: Two-way time (msec)

Figure 11. Representative seismic line and stratigraphic column, Komombo basin, Upper Egypt. Patterns of onlap of Jurassic source and reservoir strata around Mesozoic age rift structures are clear on this seismic profile. The Komombo-1 well proved the existence of oil in a previously unknown Mesozoic rift basin in Upper Egypt and is one of the most significant wells in Egypt. Data courtesy the Repsol-YPF.

Gulf of Suez, Eastern Desert and Sinai

The Gulf of Suez rifting and Red Sea breakup events have set up ideal petroleum systems in the Gulf of Suez and, potentially, the Red Sea. Collectively the Gulf of Suez, Eastern Desert and Sinai drilling provinces are part of the Gulf of Suez petroleum system. Known source rocks are the Campanian Brown Limestone and Eocene Thebes Formations, with a minor contribution from Lower Miocene shales (Barakat et al., 1997) and Robison (1995). Precambrian through Serravalian age rocks produce in the basin, with the bulk of the reserves coming from Tertiary interval. Most wells and producing fields are located along the crests of tilted fault blocks and four-way closures charged from numerous flanking basins (Figure 12). The 900+ exploratory wells that have been drilled in this basin continue to target structural blocks, with little basin-centered exploration. All fields appear filled to their sealing capacity, such that the petroleum system is unlikely to be charge limited. Topseals are dominantly provided by Middle Miocene shale and evaporite of the Belayim and South Gharib Formations.

Figure 12 shows an idealized rift model and schematic petroleum system showing the major Miocene syn-rift traps of the Gulf of Suez. A multitude of proven play types exist in this basin. The largest fields, such as Belayim Marine, Morgan and July Fields are rotated fault blocks with 3-way and 4-way closures against sealing shales or evaporites. In the late 1980's, "downthrown" traps were discovered on the flank of October Field (Dolson et al., 1996). These structural and combination traps should be also be developed elsewhere and provide an attractive future exploration target (Table 3 for examples). Exploration in synclinal lows for deep marine turbidites stratigraphic plays remains essentially untested. Exploration in Miocene strata of the Gulf of Suez is complicated by syndepositional movement around fault blocks which has created complicated reservoir distributions. Synchronous onlap around the high dip-slopes of structures and downlap into basinal areas has created difficult well log and seismic correlations which must be understood to predict the location of stratigraphic and combination traps which have the most "running room" to explore.

The Gulf of Suez petroleum system has a very mature drilling curve (Figure 7). But field size distributions (Figure 8B) still show room for a umber of new giant fields and large numbers of intermediate fields. These data suggest that up to 35 giant fields remain to found, assuming that no fields larger than the top 3 found to date will be found. Given its mature history and dense drilling, most new fields will be under 100 MMBOE in size. Indeed, the last significant giant field (Table 2) was discovered in 1987. However, this basin is exceptionally difficult to explore seismically, with severe multiples masking real structural and stratigraphic signatures. As a result, significant structural traps (see Warda Field, Table 2) are still being found. As seismic imaging improves, significant new reserves may be found in stratigraphic traps and combination traps.

Dolson et al. (1997) discuss an exploration "turn around" in the mid 1990's through the application of integrated technology, 3D seismic and seismic multiple suppression techniques in the Gulf of Suez. An example of overcoming difficult seismic imaging problems is the SG310-4 discovery (Table 2) which flowed 20,000 from the Burdigalian Hawara Sandstone (Ramzy et al., 1998). The well was drilled between four dry holes (Figure 14) which had missed the updip termination of the fault block. This culmination was completely undetectable with conventional seismic processing. Multiple removal techniques, plus dipmeter derived dips displayed correctly on seismic depth sections using geotechnical software and computer workstations made the updip trap imageable. Continued seismic image enhancement will undoubtedly be the key to new field discoveries in this petroleum system.

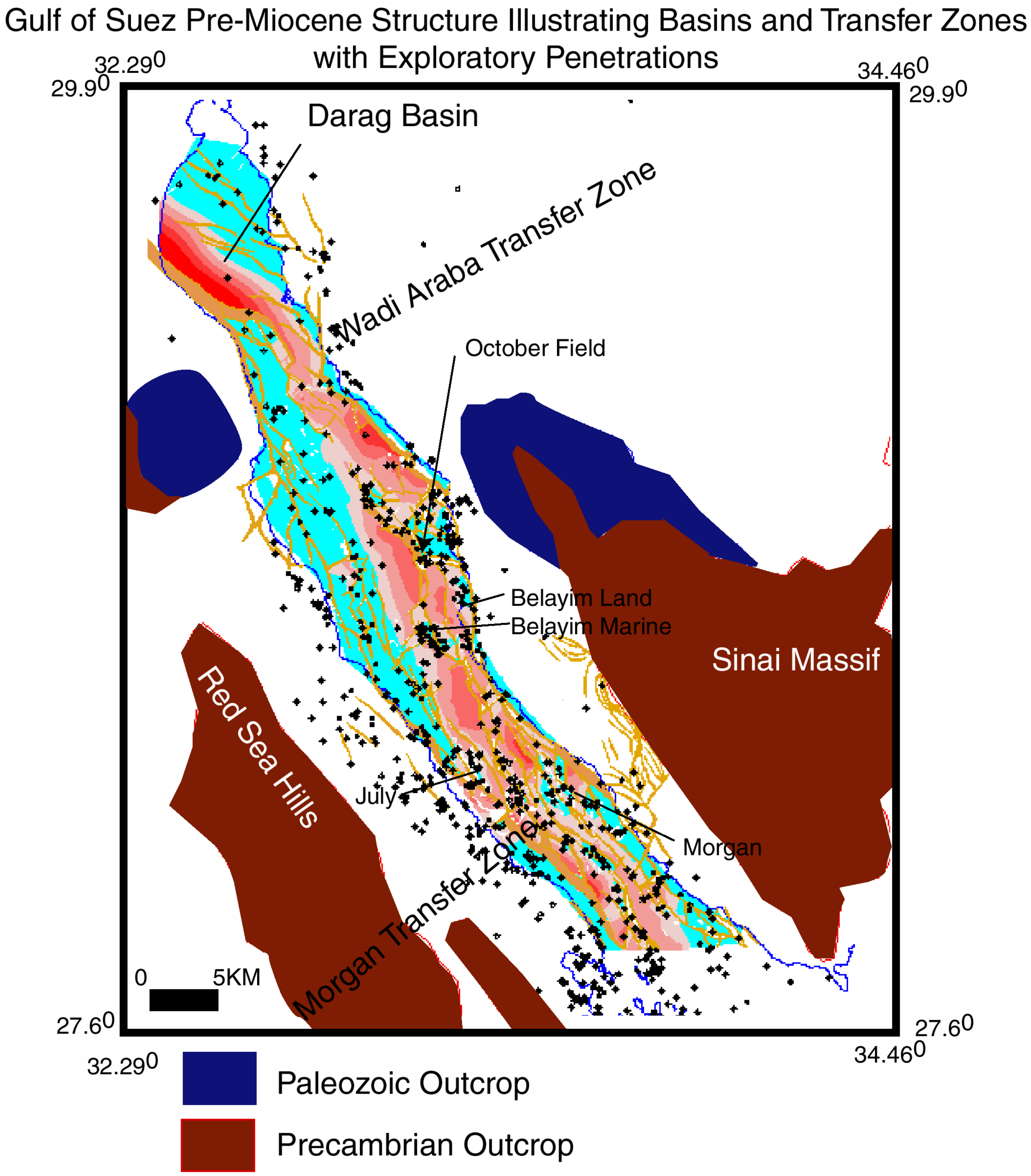


Figure 12. Gulf of Suez structural map with major faults and exploratory penetrations, Gulf of Suez. The locations of basinal areas shown (orange-red colors) generate petroleum from Cretaceous and Eocene strata which migrate into flanking structural traps. Regional highs are shown in blue. Exploration in deep synclinal troughs and flank positions remain future challenges and growth opportunities. See text for discussion.

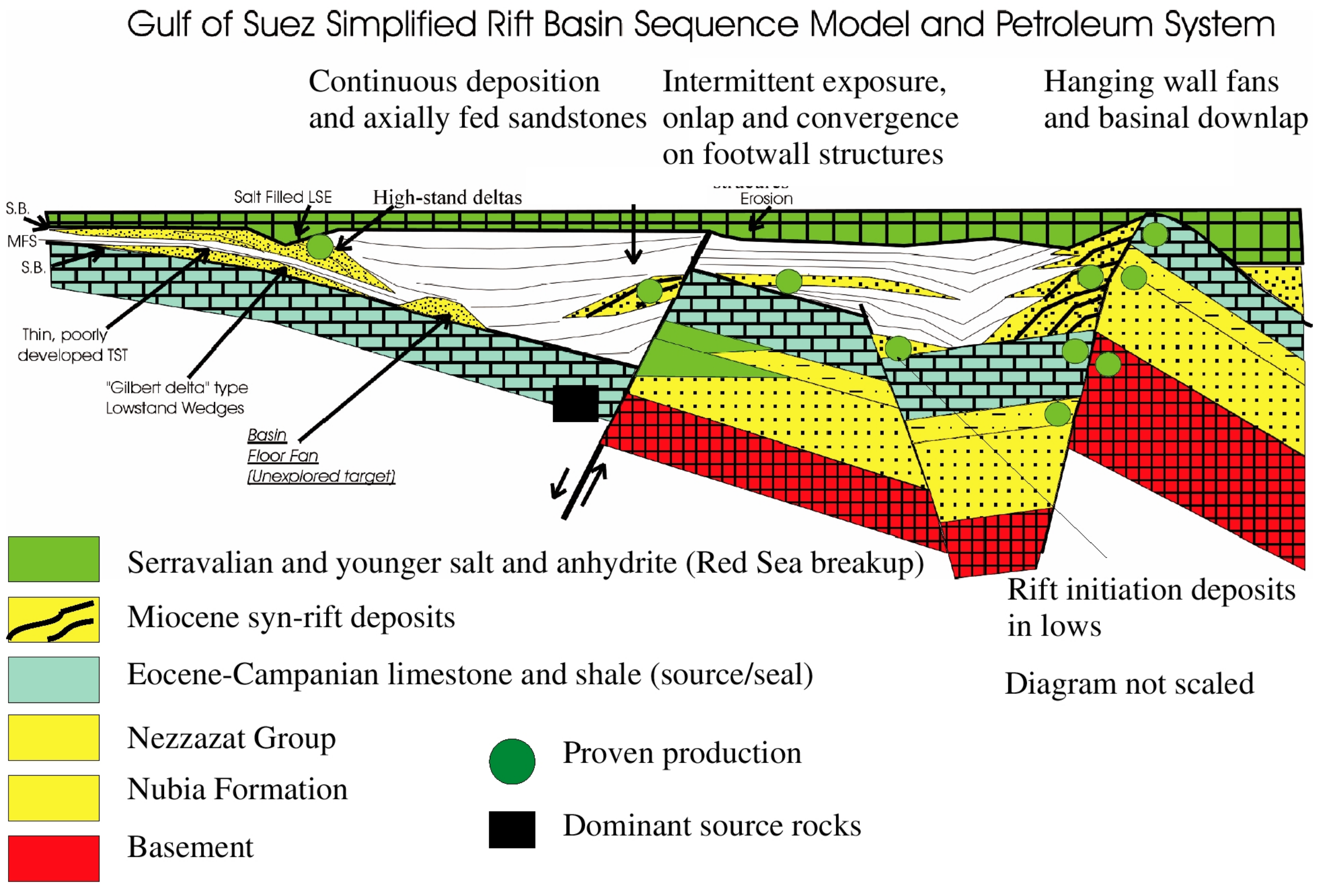


Figure 13. Simplified syn-rift petroleum system and Miocene sequence stratigraphic diagram, Gulf of Suez (not to scale). Eocene and Cretaceous limestones and shales are source rocks which can charge reservoirs from Precambrian through Miocene strata through vertical migration along faults and through structural juxtaposition. Complex patterns of syndepositional reservoir facies preservation occur in the Miocene section. See text for discussion.

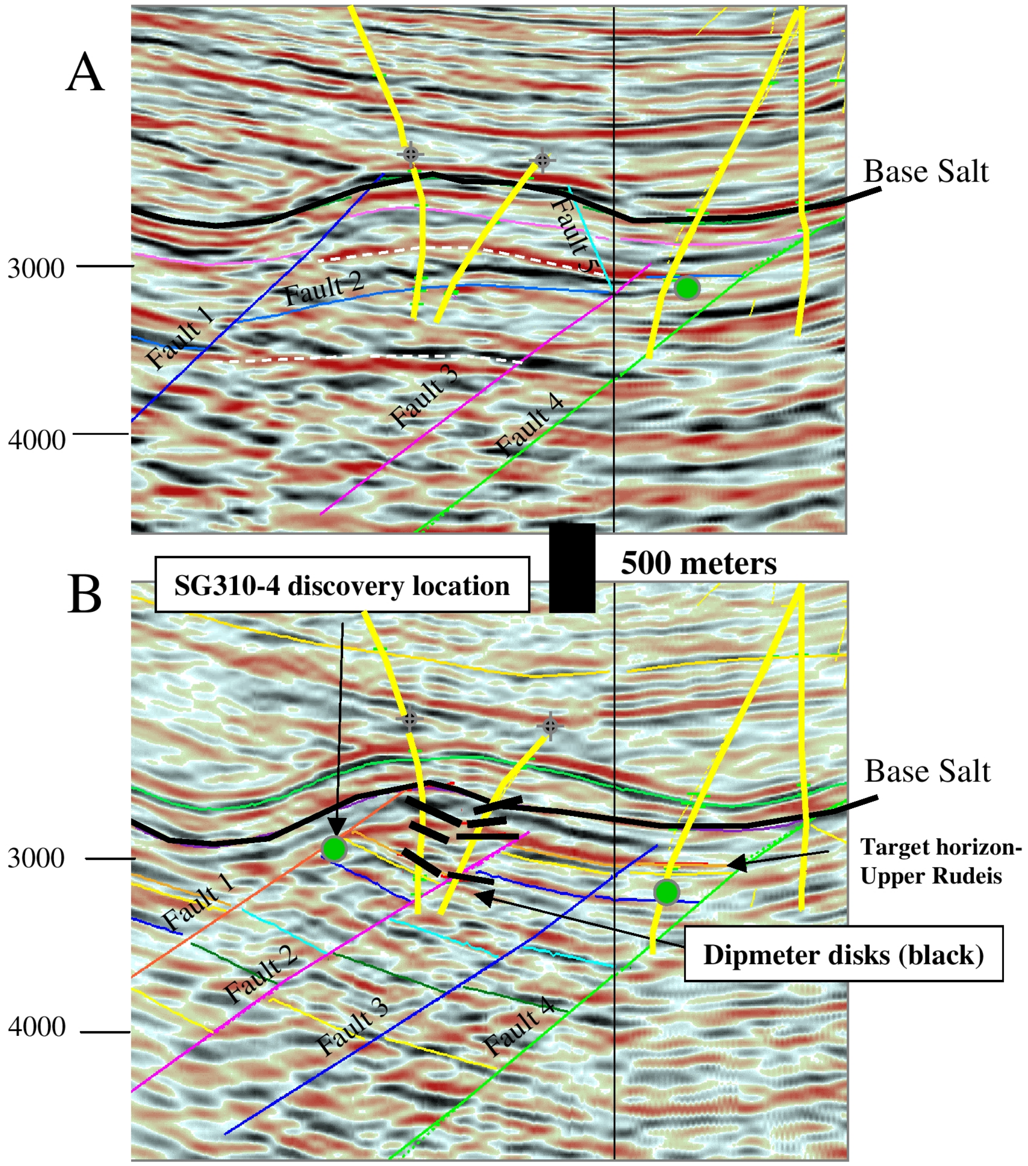


Figure 14. Example of successful step-out exploration in the Gulf of Suez. The SG310-4 well flowed 20,000 BOPD from Hawara (Burdigalian) sandstones in an attic position of a tilted fault block. Prior seismic interpretations (A) did not show the presence of a prospective corner due to severe multiples originating from overlying Serravalian salts. Posting of dipmeters directly on the seismic (B) on 3D volume depth sections and successful reprocessing to remove multiples showed the updip corner location.

Red Sea

The obvious southeastward extension of the Gulf of Suez productive trends has proved difficult, with discovery of a number of relatively small fields in highly complicated structural blocks. But recently acquired 3D surveys and regional gravity and aeromagnetic data (Figure 15) illustrate the potential of this large geographic area. The Red Sea breakup phase was initiated by the development of the Gulf of Aqaba and the southwestward extension of the Dead Sea transform can clearly be seen in Figure 15. This lineament continues southwest into the northern end of the Gebel Duwi area, where it sets up a major structural transfer zone along the Egyptian side of the Red Sea coast.

Only 14 wells penetrate the Red Sea province, only the northern half of which is shown on Figure 15. The Red Sea has over twice the aerial extent of the Gulf of Suez, which has proven reserves in excess of 8 BBOE (Table 5). Most significantly, Cretaceous source rocks are present along outcrop sections at Gebel Duwi immediately east of the Red Sea hills (Heath et al., 1998) and Khalil et al., (1998) and are likely to be present throughout the graben areas of the Red Sea. The structural style and proven petroleum system of the Gulf of Suez should continue southward into the Red Sea, although the dominant petroleum product is likely to be gas. In addition, geochemical studies (Alsharhan and Salah, 1997) show that common Miocene source rocks have charged reservoirs in the southern end of the Gulf of Suez and eastward in the Midyan Field of Saudi Arabian (Figure 2).

As in the Gulf of Suez, sub-salt seismic imaging poses the greatest challenge to success (Figure 15). Multiple reservoir and seal combinations should be present in the Red Sea within Tertiary strata and significant future discoveries may be predicted. In addition, targets drilled off the flanks of the highest structural culminations may also encounter reservoirs in pre-Tertiary strata.

Nile Delta, Mediterranean and North Sinai

The Nile Delta, Mediterranean and North Sinai provinces occur within a petroleum system dominated by play trends involving turbidite fans and channels, deformation of Pliocene deltaic sandstone, Messinian valley fills and older Miocene turbidite deposits. Most activity is currently located in the offshore Mediterranean area.

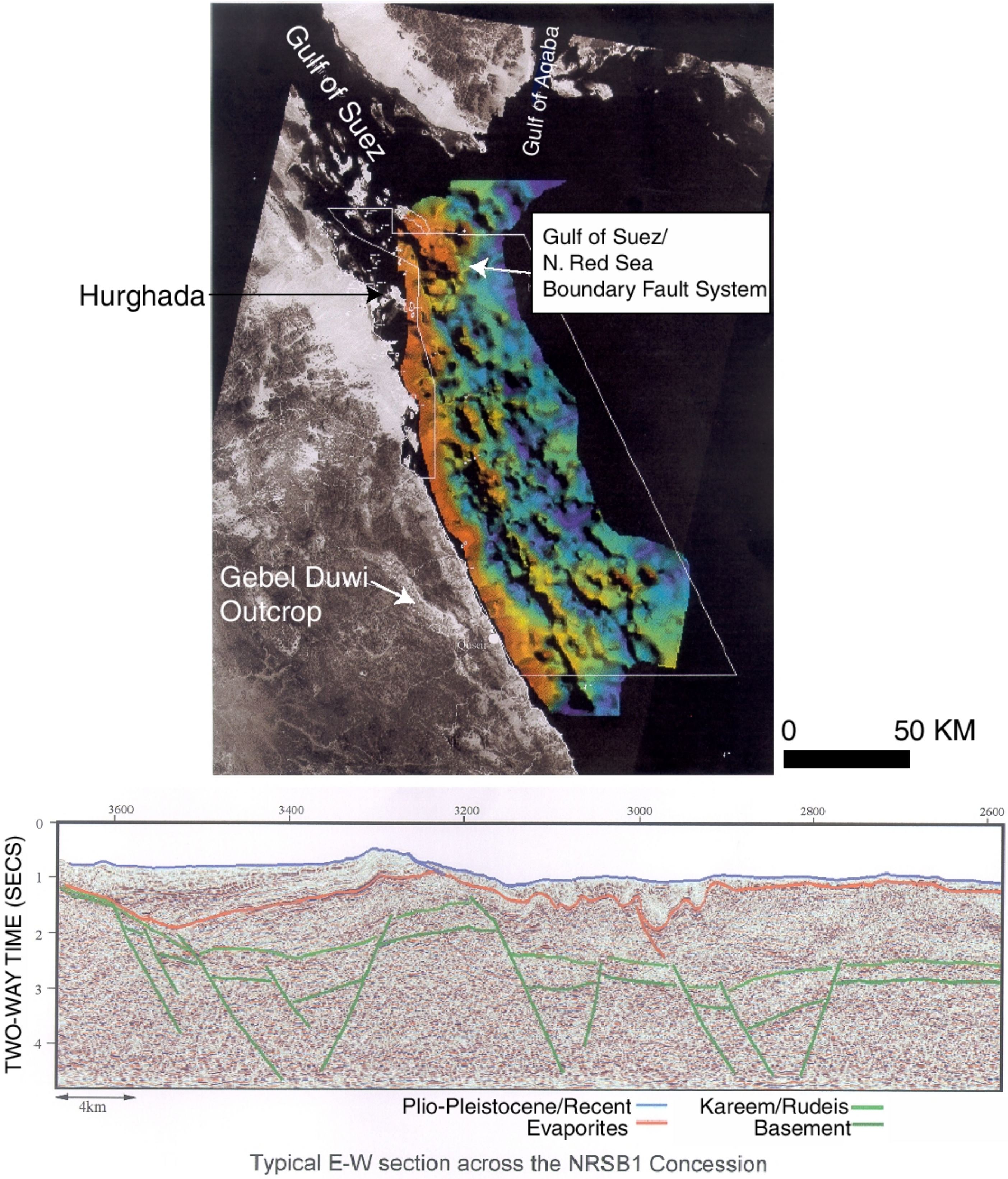
The North Sinai province occurs south of the Pliocene structuring limit (Cretaceous "hingeline" shown on Figure 2), and drilling has been targeted on Oligocene and older structural plays which represent northeastward extensions of Syrian Arc structures common to the Western Desert.

Charge is from underlying Cretaceous and Jurassic source beds (Moussa and Matbouly, 1994). The North Sinai has had very limited exploratory success, with follow-up offsets to initial discoveries being unsuccessful. For instance, the Mango-1 well (Figure 2), drilled in 1986, tested 10,000 BOPD from Cretaceous sandstones on an extension of these trends into the offshore Mediterranean. It was offset with two dry holes and the structure does not appear to be filled to spillpoint.

By contrast, the Nile Delta and Mediterranean region Tertiary targets are undergoing significant growth (Figure 7). Field size distributions (Figure 8C) indicate very substantial room for continued large field discoveries, with up to 58 giant fields "yet to find". This number assumes that at least 1 field will be found in the 1600-3200 MMBOE grouping (9.6 to 19 TCF). This is based on the sheer size and volume of undrilled rock in this rich hydrocarbon province. The area is geographically about half the size of the Gulf of Mexico slope province and has similar multi-storied pay potential. The plays are numerous (Figure 16) and provide a multitude of opportunities in both structural and stratigraphic traps. Tertiary reservoirs are likely to be underlain by the deep marine equivalent facies of the same Mesozoic source horizons that occur in the Western Desert, with some additional source identified in the prodelta shales of the Early Miocene to Oligocene Qantara Formation (Moussa and Matbouly, 1994).

The 17.5 MA "mid-Rudeis" structural event caused seaward progradation of large deltas and associated turbidite deposits (TS30 and TS40 on Figure 16). By Serravalian and Tortonian time, these deltas and turbidites had prograded far offshore and now produce gas and condensate in a number of giant fields on structural and combination traps. The best examples are the are the Serravalian turbidite reservoirs of the Akhen and Temsah Fields (2+ TCF) fields (Bertello et al., 1996).

The Messinian crisis and Pliocene deltaic progradation tectono-stratigraphic events have set up the "big plays" of the 1990's in Egypt. Underlying traps related to the Messinian crisis and drawdown occur mainly in the Baltim trend.



Typical E-W section across the NRSB1 Concession

Figure 15. Top: Regional gravity interpretation of the northern portion of the Red Sea merged with the onshore Landsat image.. The Gebel Duwi outcrop highlighted contains preserved Cretaceous source rocks and Nubia age reservoirs (see (Heath et al., 1998)). Offshore, the shallower basement of the southern Gulf of Suez and the near-shore terrace is shown by the red shading. The broad structural fabric is highlighted by the shaded-relief created by illuminating from the NE. The large number of undrilled sub-basins resembling those of the Gulf of Suez are apparent. Bottom: Representative arbitrary seismic line across a portion of the gravity survey shown above. Data courtesy of British Gas International and Edison Gas.

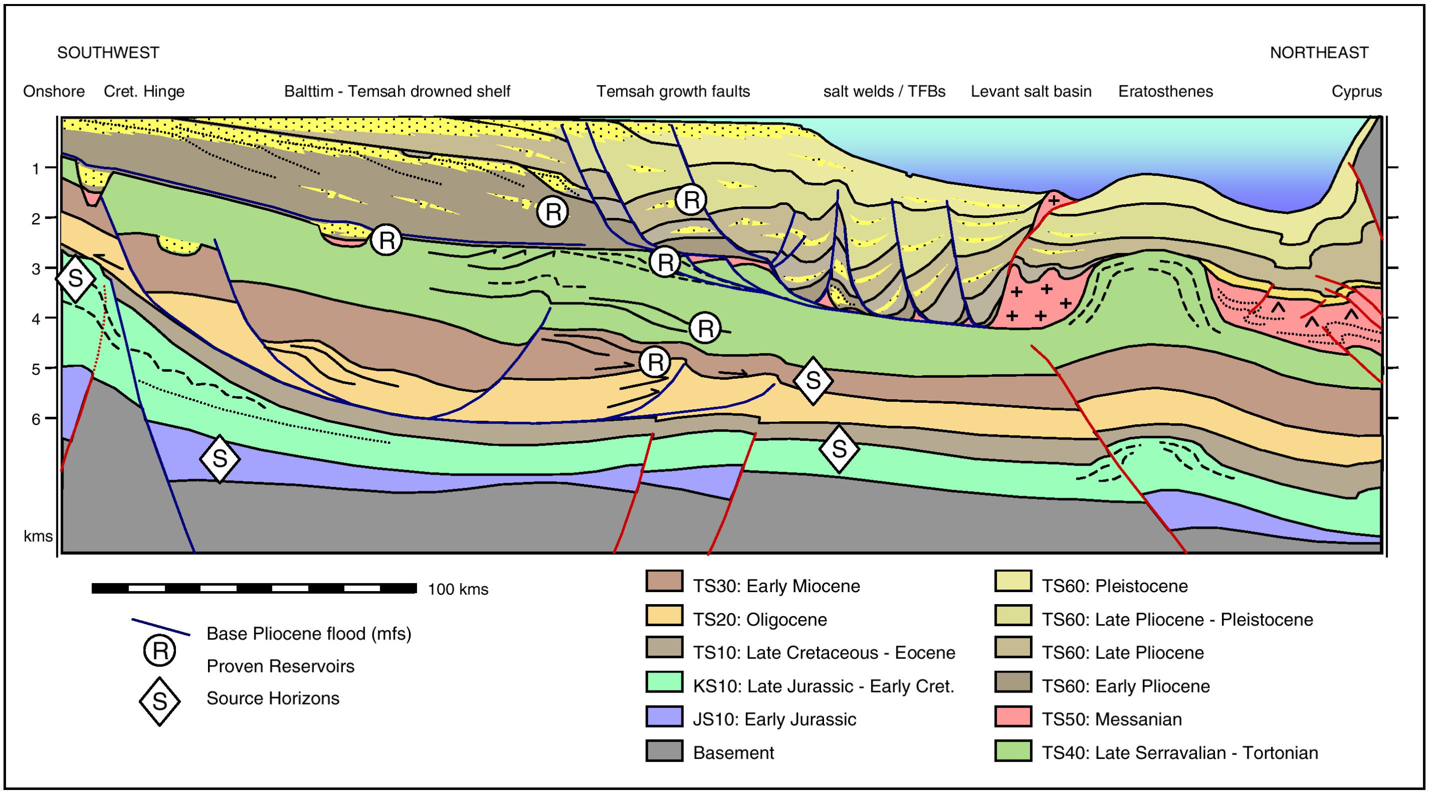


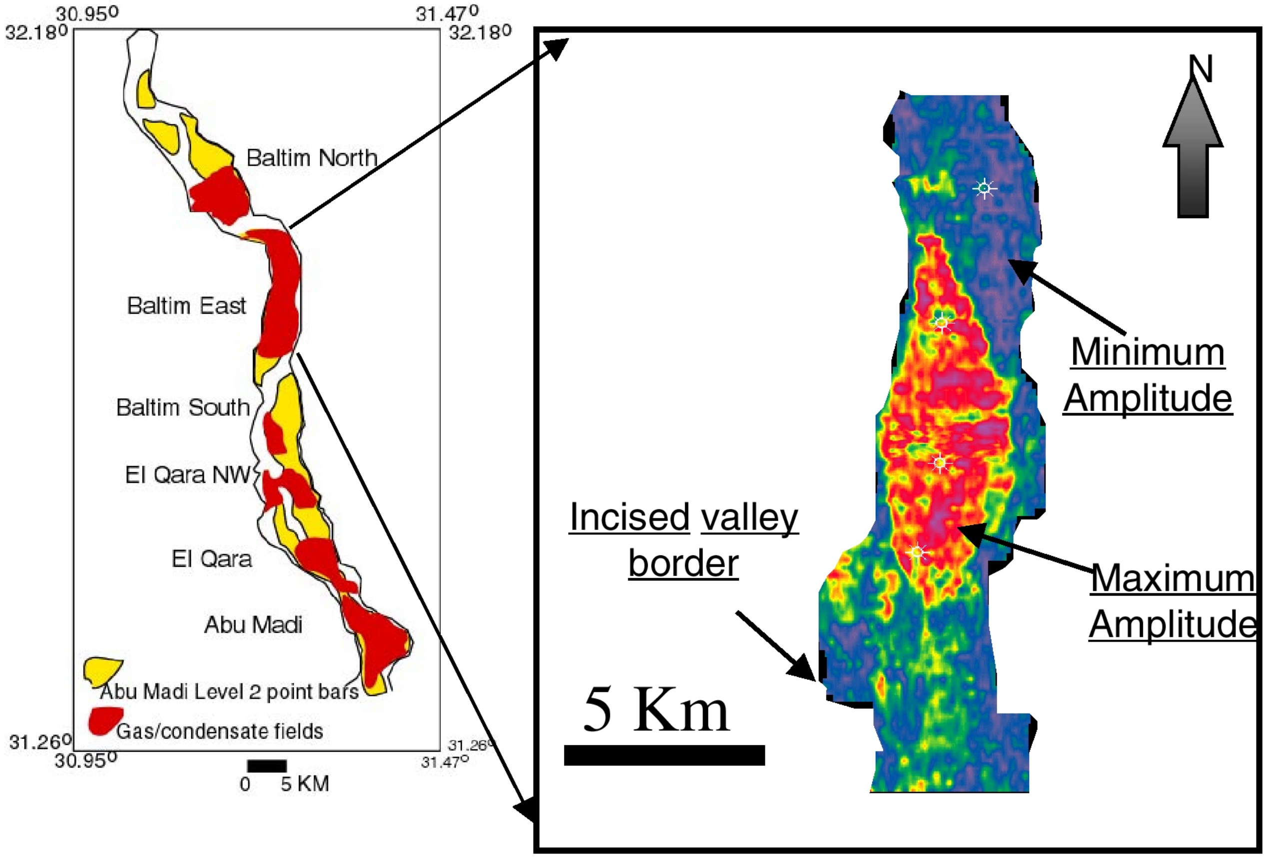
Figure 16. Schematic cross-section based on regional seismic profiles across the Nile Delta and Mediterranean showing major petroleum plays. Most current activity targets the higher seismic data quality Pliocene and Messinian section, but deeper potential exists throughout the basin. See text for discussion.

The Messinian crisis has resulted in a number of significant gas/condensate discoveries. Bright spot seismic methods have proven successful repeatedly in the Nile Delta and Mediterranean region (Figure 17). The Baltim trend provides a typical example. The incised canyon fill of the Baltim trend is complexly layered with multiple stacked point bar and estuarine deposits which form structural and stratigraphic traps within the canyon walls. The 1993 Baltim East discovery is a recent giant field addition to Egypt's resources. Messinian canyon cuts are not confined to the Baltim trend alone. These incisions occur throughout the Mediterranean and additional exploration opportunities exist. Exploration for the associated down-dip deltas and turbidites has not been made, as that play trend exists into the offshore deep water as yet untested by any drilling.

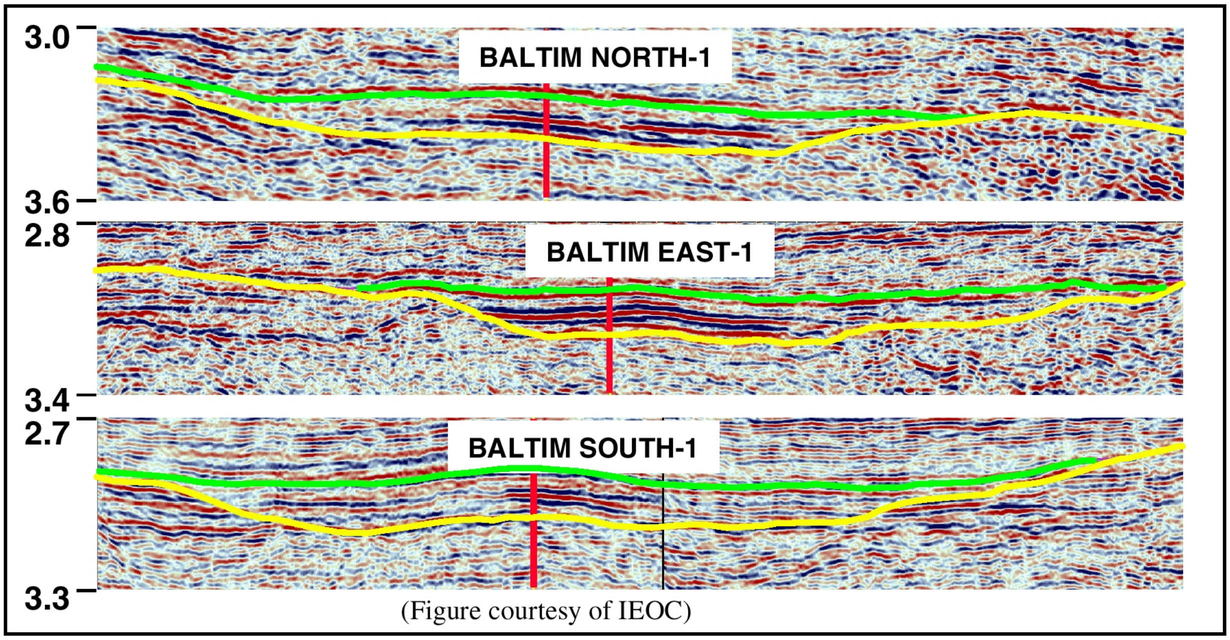
Pliocene deltaic and turbidite sandstone plays are currently dominating Industry activity. The Scarab field (Figure 18) is a trap in shelf canyon turbidite channel sandstones. Its discovery was made possible through direct seismic hydrocarbon indicators, such as flat spots at the gas/water contacts. This 2 TCF accumulation is typical of the "bright spot" plays in this Mediterranean area, which was speculated about as early as 1994 (Moussa and Matbouly, 1994) and has now proven successful.

This region offers by far the biggest short-term large reserve growth potential and drilling for gas targets in deep water areas in front of the Nile Delta (water depths greater than 500 metes) has only recently been attempted. In addition, oil has been encountered on the fringe of the delta in Abu Qir and Tineh fields, and the potential exists to discovery oil in other parts of the Nile Delta and Mediterranean region (Moussa and Matbouly, 1994).

SEISMIC AMPLITUDE MAP:
BALTIM EAST FIELD



WEST TO EAST SEISMIC LINES ACROSS THE DISCOVERY
WELLS IN THE BALTIM VALLEY FILL COMPLEX
(scale in two-way time, seconds)



(Figure courtesy of IEOC)

Figure 17. Seismic expression of gas pays in the Messinian incised valley fill Baltim trend in the Nile Delta (modified from Dalla et al. (1997) and Palmieri et al. (1996). Canyon incision exceeds 1000 meters in places and Individual fields within the trend are sealed dominantly by abandoned channel shales, small closures and fault traps encased within the valley walls. Most production occurs within fluvial point bars and thin estuarine deposits. Seismic amplitudes have proven effective for identifying the gas prone traps (data courtesy IEOC).

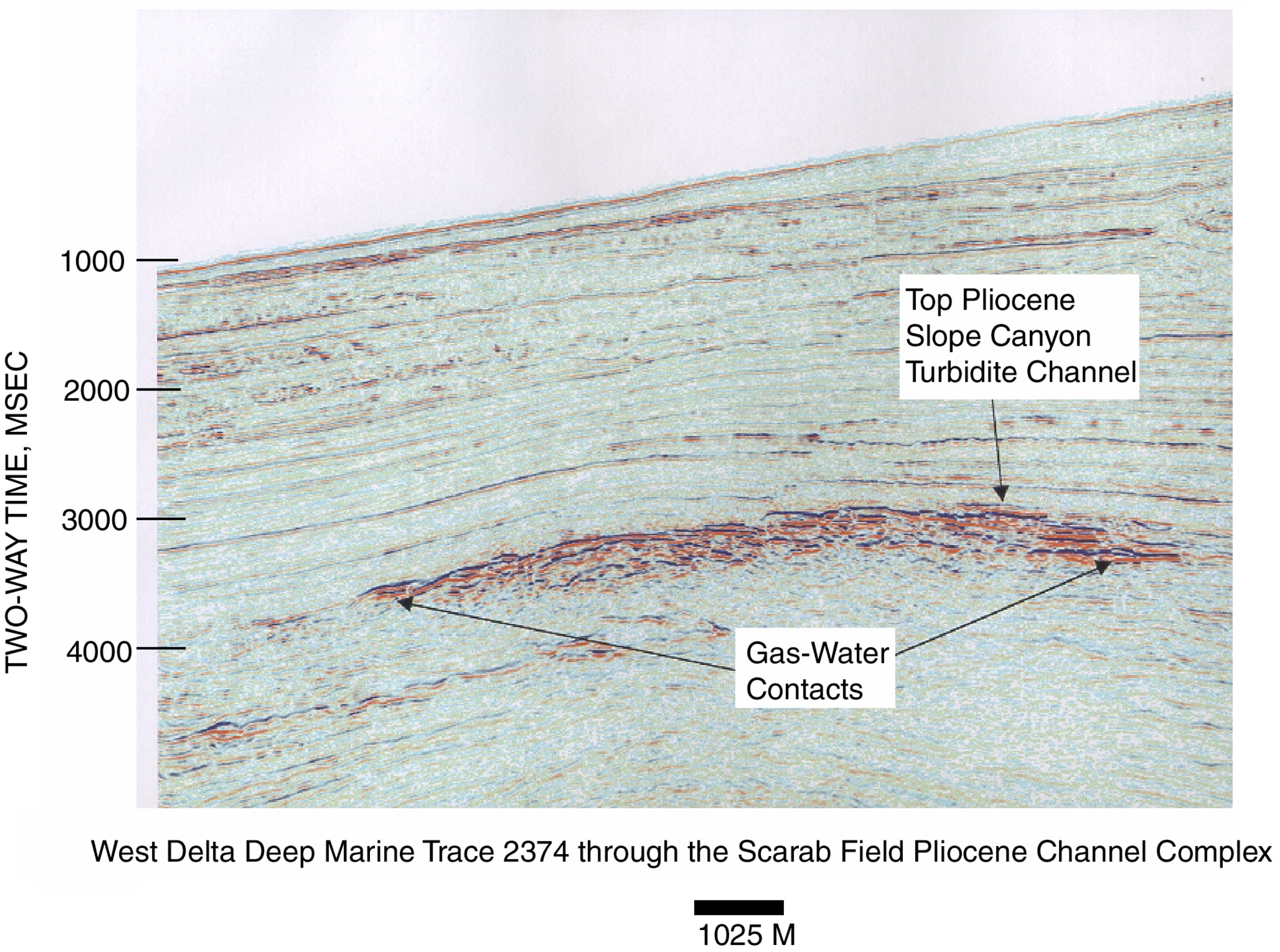


Figure 18. Scarab Field Discovery, Nile Delta (courtesy British Gas International and Edison Gas). This Pliocene slope canyon turbidite channel was found through direct hydrocarbon detection of gas bearing amplitudes. This 3D volume arbitrary line is shown in two-way time and is a strike view trending north-south down the channel axis.

Summary

Over 38 TCF of gas and 9.1 BBO have been proven to date and the large number of giant fields discovered in the 1990's attest to future growth potential.

Egypt's position along the proto-Mediterranean Tethyan margin during the Mesozoic created abundant source rocks in rift grabens across the Western Desert, Nile Delta and North Sinai regions. A probable Afro-Arabian plate separation still poorly understood created non-marine lacustrine rifts in Upper Egypt, depositing additional source rocks in large geographic areas which remain lightly explored but have now been proven to contain light hydrocarbons. The widespread transgressions during the subsequent Cretaceous passive margin episode added a further blanket of rich source rocks and seals over large areas. Paleocene and Eocene transgressions provide additional source and seal strata.

Rifting in the Gulf of Suez and Red Sea created a world class petroleum system which is in its mature phase of exploration in the Gulf of Suez and yet still provides a frontier exploration play in the Red Sea.

The Nile Delta and Mediterranean region is undergoing an early phase of exploration due to the recent awarding of gas rights in these trends. The significant number of giant fields discovered since 1990 attests to the exploration potential of these areas. The large volume of undrilled rock and large aerial extent of this trend suggests a long period lies ahead of giant field discoveries, most of which will be in gas trends, although additional oil potential does exist.

Although the data presented in this paper are scoping in nature, it does strongly suggest that the petroleum industry will continue to enjoy a long period of success as the offshore Mediterranean and Jurassic and deeper Paleozoic plays in the Western Desert continue to be developed. We have demonstrated that more than 100 giant fields may statistically remain to be found in Egypt. And the large volume of undrilled deep Jurassic and older in the Western Desert and its offshore extensions and the vast area of the offshore Mediterranean may provide room for that new reserve growth. The Gulf of Suez has been on a declining discovery curve since the mid 1980's and will continue to decline unless real breakthroughs are made in sub-salt imaging of increasingly smaller targets and/or new concepts are proven viable. The Red Sea and Upper Egypt trends offer further growth potential, but with multiple technical challenges.

"Yet to find" resource numbers are a difficult thing to quantify with any degree of accuracy. But the missing field size distributions shown in this paper, the large aerial extent of rich source rocks, multiple play and basin types and relatively sparse drilling in many trends suggest a very positive future. We believe these data show that Egypt should be able to fully replace its current proven reserve base of 15.54 BBOE in the coming decades.

References

Alsharhan, A. S., and M. G. Salah, 1997, A Common Source Rock for Egyptian and Saudi Hydrocarbons in the Red Sea: American Association of Petroleum Geologists Bulletin, v. 81, p. 1640-1659.

Barakat, A. O., A. Moustafa, M. S. El-gayar, and J. Rullkotter, 1997, Source-dependent biomarker properties of five crude oils from the Gulf of Suez, Egypt: Organic Geochemistry, v. 27, p. 441-450.

Barker, C., and P. A. Dickey, 1984, Hydrocarbon habitat in main producing areas, Saudi Arabia: discussion: The American Association of Petroleum Geologists Bulletin, v. 68, p. 108-109.

Bein, A., and Y. Weiler, 1976, The Cretaceous Talme Yafe Formation: a contour current shaped sedimentary prism of calcareous detritus at the continental margin of the Arabian Craton: Sedimentology, v. 23, p. 511-532.

Bertello, F., K. Barsoum, S. Dalla, and S. Guessarian, 1996, Temsah discovery: A giant gas field in a deep sea turbidite environment, in M. Youssef, ed., Proceedings of the 13th Petroleum Conference, Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 165-180.

Boote, D. R. D., D. D. Clark-Lowes, and M. W. Traut, 1998, Paleozoic petroleum systems of North Africa, in D. S. MacGregor, R. T. J. Moody, and D. D. Clark-Lowes, eds., Petroleum Geology of North Africa: Special Publication No. 132, London, United Kingdom, Geological Society, p. 7-68.

Capon, E., 1992, Dealing with exploration uncertainties, in R. Steinmetz, ed., The Business of Petroleum Exploration: Treatise of Petroleum Geology, Tulsa, Oklahoma, The American Association of Petroleum Geologists, p. 29-61.

Dalla, S., H. Harby, and M. Serazzi, 1997, Hydrocarbon exploration in a complex incised valley fill: an example from the late Messinian Abu Madi Formation (Nile Delta basin, Egypt): The Leading Edge, v. 16, p. 1819-1824.

Darwish, M., 1992, Facies developments of the Upper Paleozoic-Lower Cretaceous sequences in the northern Galala Plateau and evidences for their hydrocarbon reservoir potentiality, Northern Gulf of Suez, Egypt, in A. Sadek, ed., Geology of the Arab World, Cairo, Egypt, Cairo University, p. 175-214.

Dixon, J. E., and A. H. F. Robertson, 1984, The Geological Evolution of the Eastern Mediterranean, in A. J. Fleet, ed., Special Publication No. 17, London, U.K., The Geological Society, p. 836.

Dolson, J., O. El-Gendi, H. Sharmy, M. Fathalla, and I. Gaafar, 1996, Gulf of Suez rift basin sequence models--Part A. Miocene sequence stratigraphy and exploration significance in the greater October Field area, Northern Gulf of Suez, in M. Youssef, ed., Proceedings of the 13th Petroleum Conference, Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 227-241.

Dolson, J. C., B. Steer, J. Garing, G. Osborne, A. Gad, and H. Amr, 1997, 3D seismic and workstation technology brings technical revolution to the Gulf of Suez Petroleum Company.: The Leading Edge, v. 16, p. 1809-1817.

Dolson, J. C., J. W. Stewart, B. Golob, O. El-Gendi, I. Gaafar, and G. Azazi, 1998, Synchronous onlap and downlap, Asl Formation lowstand wedge, October Field, Gulf of Suez (abs): Integrated Structural and Sequence Stratigraphic Analysis in Rift Settings--AAPG Hedberg Research Conference, p. 37.

El-Banbi, D. H. A., 1999, Exploration, Production and Reserves in Egypt-Statistical Data (1886-1997): Cairo, Egypt, The Egyptian General Petroleum Corporation, 1999 p.

Geizery, M. E., I. A. Moula, S. A. Aziz, and M. Helmy, 1998, Qarun field geological model and reservoir characterization: a successful case from the Western Desert, in M. Eloui, ed., Proceedings of the 14th Petroleum Conference, Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 279-297.

Halbouty, M. T., and F. El-Baz, 1992, The Mediterranean region: its geologic history and oil and gas potentials, in A. Sadek, ed., Geology of the Arab World, Cairo, Egypt, Cairo University, p. 15-60.

Haq, B. U., J. Hardenbol, and P. R. Vail, 1988, Mesozoic and Cenozoic chronostratigraphy and eustatic cycles, in C. K. Wilgus, B. S. Hastings, C. G. S. C. Kendall, H. W. Posamentier, C. A. Ross, and J. C. V. Wagoner, eds., Sea-level Changes: An Integrated Approach: Special Publication No. 42, Tulsa, Oklahoma, Society of Economic Paleontologists and Mineralogists, p. 71-109.

Harms, J. C., and J. L. Wray, 1990, Nile Delta, in R. Said, ed., The Geology of Egypt, Rotterdam, Netherlands, A. A. Balkema Publishers, p. 329-344.

Harwood, C., M. Ayyad, and N. Hodgson, 1998, The application of sequence stratigraphy in the exploration for Plio-Pleistocene hydrocarbons in the Nile Delta, in M. Eloui, ed., Proceedings of the 14th Petroleum Conference, Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 1-13.

Heath, R., S. Vanstone, J. Swallow, M. Ayyad, M. Amin, P. Huggins, R. Swift, I. Warburton, K. McClay, and A. Younnis, 1998, Renewed exploration in the offshore North Red Sea region-Egypt., in M. Eloui, ed., Proceedings of the 14th Petroleum Conference, Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 16-34.

Hegazy, A., 1992, Western Desert, Oil and Gas Fields (A Comprehensive Overview), Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 431.

Kamel, H., 1990, Gravity map, in R. Said, ed., The Geology of Egypt, Rotterdam, Netherlands, A. A. Balkema Publishers, p. 45-50.

Keeley, M. L., and M. S. Massoud, 1998, Tectonic controls on the petroleum geology of NE Africa, in D. S.

MacGregor, R. T. J. Moody, and D. D. Clark-Lowes, eds., Petroleum Geology of North Africa: Special Publication No. 132, London, United Kingdom, Geological Society, p. 69-78.

Kerdany, M. T., and O. H. Cherif, 1990, Mesozoic, in R. Said, ed., The Geology of Egypt, Rotterdam, Netherlands, A. A. Balkema Publishers, p. 407-438.

Khalil, M., E. E. Nagdy, H. A. Rahman, and M. Comisso, 1998, Frontier exploration in the southern Egyptian Red Sea: Superimposed Cretaceous and Tertiary rift tectonics in the newly discovered, untested Ras Banas sub-basin., in M. Eloui, ed., Proceedings of the 14th Petroleum Conference, Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 1-15.

Klitzsch, E., 1990, Paleozoic, in R. Said, ed., The Geology of Egypt, Rotterdam, Netherlands, A. A. Balkema Publishers, p. 393-406.

Krebs, W. N., W. A. Wescott, D. Nummedah, I. Gaafar, G. Azazi, and S. A. Karamat, 1996, Graphic correlation and sequence stratigraphy of Neogene rocks in the Gulf of Suez, in M. Youssef, ed., 13th Petroleum Conference, Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 214-226.

Krebs, W. N., W. A. Wescott, D. Nummedahl, I. Gaafar, G. Azzazi, and S. Karamat, 1997, Graphic correlation and sequence stratigraphy of Neogene rocks in the Gulf of Suez: Bulletin of the Society of Geology, France, v. 1, p. 63-71.

MacGregor, D. S., R. T. J. Moody, and D. D. Clark-Lowes, 1998, Petroleum Geology of North Africa: Special Publication No. 132, London, United Kingdom, Geological Society, p. 444.

Mahmoud, A., and A. E. Barkooky, 1998, Mesozoic valley fills incised in Paleozoic rocks: potential exploration targets in the North Western Desert of Egypt, Obaiyed area, in M. Eloui, ed., Proceedings of the 14th Petroleum Conference, Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 84-100.

Matbouly, S., and M. E. Sabbagh, 1996, Gulf of Suez Oil Fields (A Comprehensive Overview), Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 735.

Meshref, W. M., 1990, Tectonic framework, in R. Said, ed., The Geology of Egypt, Rotterdam, Netherlands, A. A. Balkema Publishers, p. 113-156.

Miller, F. X., 1977, The graphic correlation method in biostratigraphy, in E. G. Kauffman, and J. E. Hazel, eds., Concepts and Methods of Biostratigraphy, Stoudsburg, Pennsylvania, Hutchinson and Ross, Inc., p. 165-186.

Morris, A., and D. H. Tarling, 1996a, Introduction, in A. J. Fleet, ed., Geological Society Special Publication No. 105, London, United Kingdom, The Geological Society, p. 1-17.

Morris, A., and D. H. Tarling, 1996b, Palaeomagnetism and Tectonics of the Mediterranean Region, in A. J. Fleet, ed., Geological Society Special Publication No. 105, London, United Kingdom, The Geological Society, p. 422.

Moussa, D. S., and D. S. Matbouly, 1994, Nile Delta and North Sinai: Fields, Discoveries and Hydrocarbon Potentials (A Comprehensive Overview), Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 387.

Moustafa, A. R., R. E. Badrawy, and H. Gibali, 1998, Pervasive E-ENE oriented faults in Northern Egypt and their effect on the development and inversion of prolific sedimentary basins., in M. Eloui, ed., 14th Petroleum Conference, Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 51-67.

Moustafa, A. R., and M. H. Khalil, 1990, Structural characteristics and tectonic evolution of north Sinai fold belts, in R. Said, ed., The Geology of Egypt, Rotterdam, Netherlands, A. A. Balkema Publishers, p. 381-392.

Palmieri, G., H. Harby, J. A. Marini, F. Hashem, S. Dalla, and M. Shash, 1996, Baltim fields complex: an outstanding example of hydrocarbon accumulations in a fluvial Messinian incised valley, in M. Youssef, ed., Proceedings of the 13th Petroleum Conference, Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 256-269.

Patton, T. L., A. R. Moustafa, R. A. Nelson, and S. A. Abdine, 1994, Tectonic evolution and structural setting of the Gulf of Suez rift, in S. M. Landon, ed., Interior Rift Basins: AAPG Memoir No. 59, Tulsa, Oklahoma, The American Association of Petroleum Geologists, p. 9-56.

Philobbos, E. R., and B. H. Purser, 1993, Geodynamics and Sedimentation of the Red Sea-Gulf of Aden Rift System, in M. E. Sharkawi, and S. E. Ansary, eds., Special Publication No. 1, Cairo, Egypt, The Geological Society of Egypt, p. 456.

Prosser, S., 1993, Rift-related linked depositional systems and their seismic expression, in G. D. Williams, and A. Dobb, eds., Tectonics and Seismic Sequence Stratigraphy: Special Publication 71, Geological Society, p. 35-66.

Purser, B. H., and E. R. Philobbos, 1993, The sedimentary expressions of rifting in the NW Red Sea, Egypt, in E. R. Philobbos, and B. H. Purser, eds., Geodynamics and Sedimentation of the Red Sea-Gulf of Aden Rift System: Special Publication No. 1, Cairo, Egypt, p. 1-45.

Ramzy, M., B. Steer, F. Abu-Shadi, M. Schlorholtz, J. Mika, J. Dolson, and M. Zinger, 1996, Gulf of Suez rift basin sequence models--Part B. Miocene sequence stratigraphy and exploration significance in the central and southern Gulf of Suez, in M. Youssef, ed., Proceedings of the 13th Petroleum Conference, Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 242-256.

Ramzy, M., B. Steer, J. Thorseth, and J. Garing, 1998, Integrated exploration: the SG310-4 case history, in M. Eloui, ed., Proceedings of the 14th Petroleum Conference, Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 359-373.

Robertson, A. H., and J. E. Dixon, 1984, Introduction: aspects of the geological evolution of the Eastern Mediterranean, in J. E. Dixon, and A. H. F. Robertson, eds., The Geological Evolution of the Eastern Mediterranean: Special Publication No. 17, London, U.K., The Geological Society, p. 1-74.

Robison, V. D., 1995, Source rock characterization of the Late Cretaceous Brown Limestone of Egypt, in B. Katz, ed., Petroleum Source Rocks, Heidelberg, German, Springer, p. 265-281.

Sadek, A., 1992, Geology of the Arab World, Cairo, Egypt, Cairo University, p. 541.

Said, R., 1990a, Cenozoic, in R. Said, ed., The Geology of Egypt, Rotterdam, Netherlands, A. A. Balkema Publishers, p. 451-486.

Said, R., 1990b, The Geology of Egypt, Rotterdam, Netherlands, A. A. Balkema Publishers, p. 734.

Said, R., 1990c, Mesozoic, in R. Said, ed., The Geology of Egypt, Rotterdam, Netherlands, A. A. Balkema Publishers, p. 439-450.

Schull, T. J., 1988, Rift basins of interior Sudan: petroleum exploration and discovery: American Association of Petroleum Geologists Bulletin, v. 72, p. 1128-1142.

Schutz, K. I., 1994, Structure and stratigraphy of the Gulf of Suez, Egypt, in S. M. Landon, ed., Interior Rift Basins: AAPG Memoir No. 59, Tulsa, Oklahoma, The American Association of Petroleum Geologists, p. 57-96.

Sestini, G., 1984, Tectonic and sedimentary history of the NE African margin (Egypt-Libya), in J. E. Dixon, and A. H. F. Robertson, eds., The Geological Evolution of the Eastern Mediterranean: Special Publication No. 17, London, United Kingdom, The Geological Society, p. 161-176.

Smith, M. D., and D. R. Jones, 1992, Trend Analysis, in R. Steinmentz, ed., The Business of Petroleum Exploration: Treatise of Petroleum Geology: Handbook of Petroleum Geology, Tulsa, Oklahoma, The American Association of Petroleum Geologists, p. 215-236.

Taha, M. A., 1992, Mesozoic rift basins in Egypt: their southern extension and impact on future exploration, Proceedings of the 11th Petroleum Exploration and Production Conference, Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 1-19.

Taha, M. A., and H. A/Aziz, 1998, Mesozoic rifting in Upper Egypt Concession (abs.): 14th International Petroleum Conference, p. 5 (abstract only).

Traut, M. W., D. R. D. Boote, and D. d. Clark-Lowes, 1998, Exploration history of the Paleozoic petroleum systems of North Africa, in D. S. MacGregor, R. T. J. Moody, and D. D. Clark-Lowes, eds., Petroleum Geology of North Africa: Special Publication No. 132, London, United Kingdom, Geological Society, p. 69-78.

Wescott, W. A., W. N. Krebs, D. Nummedal, and J. C. Dolson, 1998, Field trip guidebook: Miocene sequence stratigraphy, chronostratigraphic correlation and subsurface exploration and production analogues, Gulf of Suez: outcrop to subsurface.: Integrated Structural and Sequence Stratigraphic Analysis in Rift Settings.

Wescott, W. A., D. Nummedal, W. N. Krebs, and S. A. Karamat, 1996, Depositional facies of the early synrift strata on the Sinai margin of the Gulf of Suez, in S. Matbouli, ed., Proceedings of the 13th Petroleum Conference, Cairo, Egypt, The Egyptian General Petroleum Corporation, p. 297-312.

Wycisk, P., 1990, Aspects of cratonal sedimentation: facies distribution of fluvial and shallow marine sequences in NW Sudan/SW Egypt since Silurian time: Journal of African Earth Sciences, v. 10, p. 215-228.

Wycisk, P., 1994, Correlation of the major late Jurassic-early Tertiary low and highstand cycles of southwest Egypt and northwest Sudan: Geol Rundsch, v. 83, p. 759-772.

Acknowledgements

This paper would not have been possible without co-operation from numerous oil companies in Egypt, which have agreed to release proprietary data, review the text and contribute key figures. Special thanks goes to Chuck Fetzner and David Allard (Apache Corporation), Marco Boy and Marco Serazzi (International Egyptian Oil Company), Mike Winfield and Jamie Suarez (Repsol) for contributing valuable data and ideas. Marc Gerrit, Bill Horsefield and Marcus Schwander (Shell Egypt New Ventures) provided data from Obaiyed Field. David Pivnik, Bill Chandler and Tim Marchant provided valuable comments on the content and text. The IHS Energy Company provided critical missing field size data and world-wide field distribution comparisons. Lastly, we thank BP-Amoco and the Egyptian General Petroleum Corporation for permission to publish this paper.