An ArcGIS-based study of the Sirt Rift Province, Libya

"AN ENCYCLOPEDIA AND INTERACTIVE TOOL-KIT"

Lynx Informations Systems Ltd &
DBConsulting

LYNX Information Systems

Sirt Petroleum Systems Analysis GIS

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Over 30 years experience in international new venture oil and gas exploration. Twenty five years international new venture exploration with Occidental Oil and Gas Company, variously as Chief Geologist Worldwide Exploration, Regional Manager and Senior Geological Advisor, responsible for basin evaluations, play analysis, prospect generation and appraisals in most parts of the world. Retired from Occidental in 2000 and now active as an independent consultant focused on regional stratigraphic and hydrocarbon petroleum systems analysis.

RECENT PUBLICATIONS/PRESENTATIONS

Boote, D.R.D & C.Machette-Downs, 2009, Extinct, near extinct and active petroleum systemsof the East African coastal basins, 8th PESGB-HGS Conference: New concepts for the oldest continent, September 2009, London (oral presentation)

Boote, D.R.D., 2009, Stratigraphic Controls of Petroleum Systems in the Sirt Basin, Libya, AAPG Annual Convention and Exhibition, 7-10th June 2009, Denver, USA (oral presentation)

Boote, D.R.D., A.Dardour, P.F.Green, J.D.Smewing & F.Van Hoeflaken, 2008, Burial and unroofing history of the baseTanezzuft 'hot' Shale source rock, Murzuq Basin, SW Libya: new AFTA constraints from basin margin outcrops. 4th Sedimentary Basins of Libya Symposium: the Geology of Southern Libya, 17-20th November 2008, Tripoli, Libya (in press)

Boote, D.R.D., 2007, The Geological History of the Istria'Depression', Offshore Romania: Tectonic Controls on Second Order Sequence Architecture. AAPG European Region Energy Conference and Exhibition, 18-21 November 2007,Athens, Greece (oral presentation).

Boote, D.R.D., R. K. Olson & M. H. Reynolds, 2006, Petroleum Systems Analysis of the Sirt Basin, Libya. Geological Society London ~ Petroleum Systems of Saharan Africa Conference, 19-20 April 2006, London (oral presentation

Boote, D.R.D., 2005, Safah Field, Oman: from blue sky exploration concept to mature development. PESGB Carbonate Conference: Middle to Far East Carbonate Reservoirs: Exploration, Development and Exploitation, 15-16th November 2005

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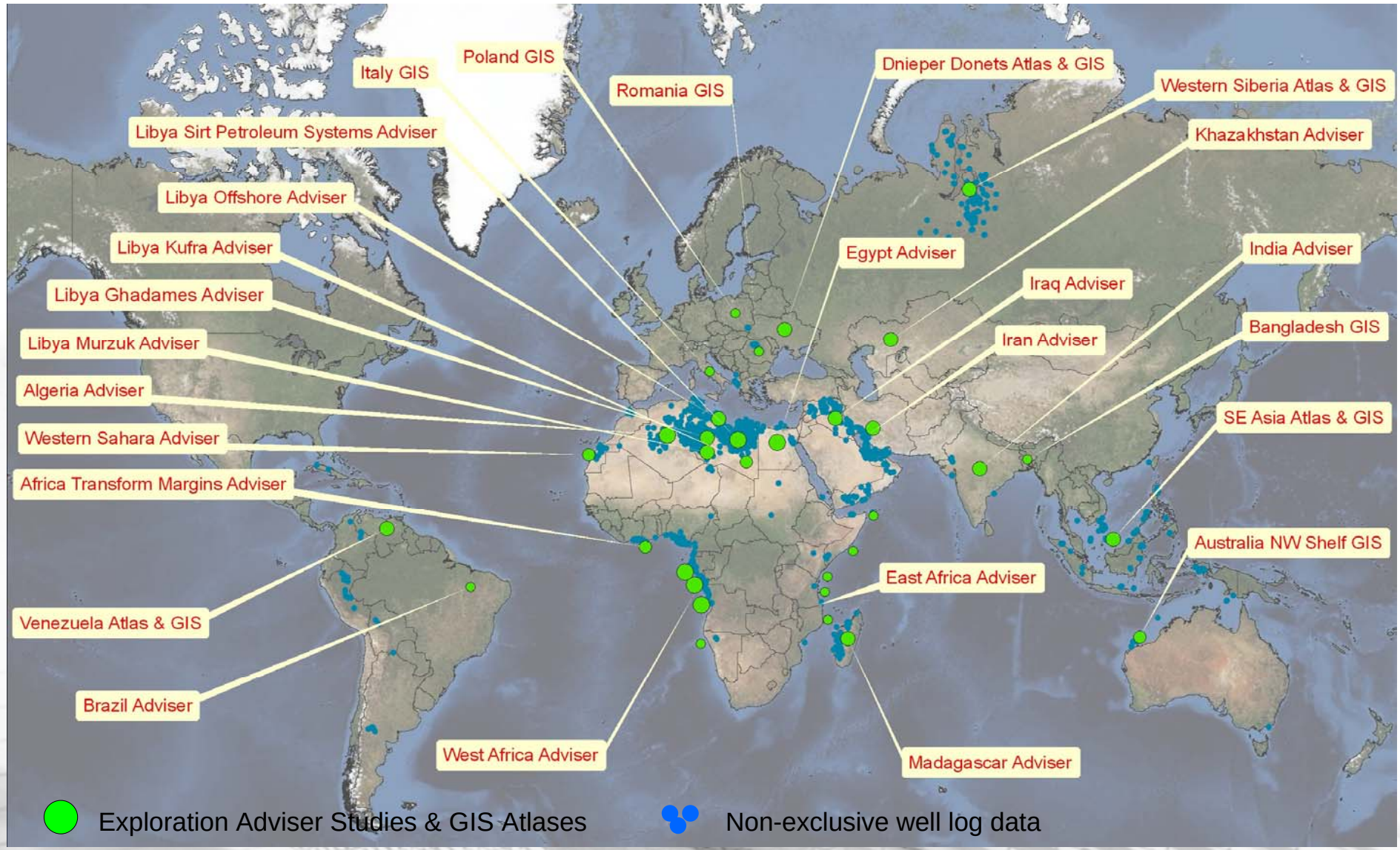
Lynx ‘Exploration Adviser’ ArcGIS projects completed



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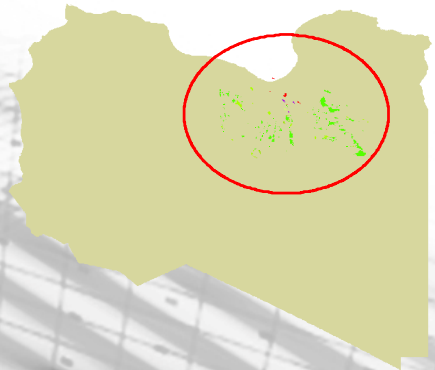
Preamble

The Sirt Rift Province is a prolific hydrocarbon province with approximately 30 Bbbls proven reserves. Oil and gas accumulations are reservoired in granitic basement, sandstones and carbonates ranging in age from Pre-Cambrian to Oligocene, charged by syn and early post-rift, Triassic and intra-Cretaceous organic rich lacustrine and restricted marine shales. The key factors governing the distribution of hydrocarbons in the Province are described in this regional ArcGIS based synthesis.

The analysis is divided into four modules. These can be linked and combined together interactively, allowing the interpreter to evaluate a broad spectrum of petroleum systems by integrating source facies distribution, generative areas, migration conduits, reservoirs, seals and expulsion/charge timing. The analytic capability of this approach provides a very efficient way to rank and risk plays and play trends on both regional and local scales.



LYNX Information Systems

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Study Layout

A dynamically-coupled ArcGIS project with accompanying text, figures and tables.

SECTION I: Regional Stratigraphic Architecture

Tectono-stratigraphic evolution described by regional stratigraphic correlations, facies maps and facies sections with explanatory text.

SECTION II: Hydrocarbon Distribution

Oil and gas distribution summarized in reservoir description, well test and estimated OHIP data bases with field structure maps and cross-sections.

SECTION III: Hydrocarbon Environment

Key factors responsible for hydrocarbon distribution described by oil family analysis, source rock distribution maps, 1D basin modelling, integrated 3D basin models and generative areas with explanatory notes.

SECTION IV: Petroleum Systems Analysis

ArcGIS based petroleum systems analysis capability ~ enabling interactive synthesis of selected reservoir or stratigraphic horizon and associated oil and gas occurrences with regional (reservoir) facies, reservoir descriptions, oil family distribution, generative areas, expulsion timing and migration models for key source intervals.

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Underlying Database

The study draws upon an extensive inventory of interpreted maps, well & seismic data and a number of previous studies undertaken by Lynx, augmented by an exhaustive review of published work. Key data items utilized include the following:

- ❑ Wells database – 8,500 well locations, with formation tops for 3,000+ wells in the Sirt Basin
- ❑ Comprehensive set of georectified and digitised geology maps (IRC 1:1M & 1:250K scale)
- ❑ Regional gravity and magnetic (potential field) data
- ❑ Basin-wide digital seismic and wireline log coverage

Attributes of Wells

OBJECTID *	Shape *	UWI *	WELL_NM *	OPERATOR	WD_FT	ELEV_FT	REF_DEPTH_FT	ELEV_REF	RESULT	WELL_STATUS	TD_MD_FT	TD_TVDSS_F	T
4850	Point	1001397	A-1-33	OASIS	0	280	300		dry	P&A	10768	0	
1657	Point	1001150	A-13-32	OASIS	0	1077	1102		oil	Completed	3900	0	
6252	Point	2002197	A-133-59	WAHA	0	538	0		oil	Completed	6700	0	
1211	Point	1001400	A-1-34	BP	0	564	575		dry	P&A	3496	0	
6305	Point	2002250	A-134-59	WAHA	0	454	0		oil	Completed	6611	0	
125	Point	1001405	A-1-35	BP	0	558	594		dry	P&A	11824	0	
8066	Point	2003926	A-1-35/3	WOODSIDE	2284	0	0		hydrocarbon shows	P&A	17700	0	
3398	Point	1001808	A-13-59	OASIS	0	496	511		oil	Completed	6626	0	

Record: 0 | Show: All | Selected | Records (0 out of 8474 Selected) | Options

Attributes of Formation_tops

OBJECTID *	FORMATION	AGE	VDEPTH	VDEPTHSS	TOPS	TD	UWI *	WELL_NAME	Lat_pt	Lon_pt
1	BIR GAZEIL SS		1370	382	BIR GAZEIL SS		1000000	A-1-1	26.68444	10.42028
2	TANEZZUFT SH.		1430	322	TANEZZUFT SH		1000000	A-1-1	26.68444	10.42028
3		SILURIAN	1430	322	SILURIAN		1000000	A-1-1	26.68444	10.42028
4		SILURIAN LOWER	1430	322	SILURIAN LWR		1000000	A-1-1	26.68444	10.42028
5		ORDOVICIAN UPPER	1850	-98	ORDOVICIAN UPP		1000000	A-1-1	26.68444	10.42028
6		ORDOVICIAN	1850	-98	ORDOVICIAN		1000000	A-1-1	26.68444	10.42028
7	METAMORPHICS		3370	-1618	METAMORPHICS		1000000	A-1-1	26.68444	10.42028
8			3491	-1739	TD	TOTAL VERT DEPTH (DRIL)	1000000	A-1-1	26.68444	10.42028
9		CARBONIFEROUS LOWER	474	1189	CARBONIFEROUS LWR		1000001	B-1-1	27.24778	10.54806
10		MISSISSIPPIAN	474	1189	MISSISSIPPIAN		1000001	B-1-1	27.24778	10.54806
11	MRAR		474	1189	MRAR		1000001	B-1-1	27.24778	10.54806

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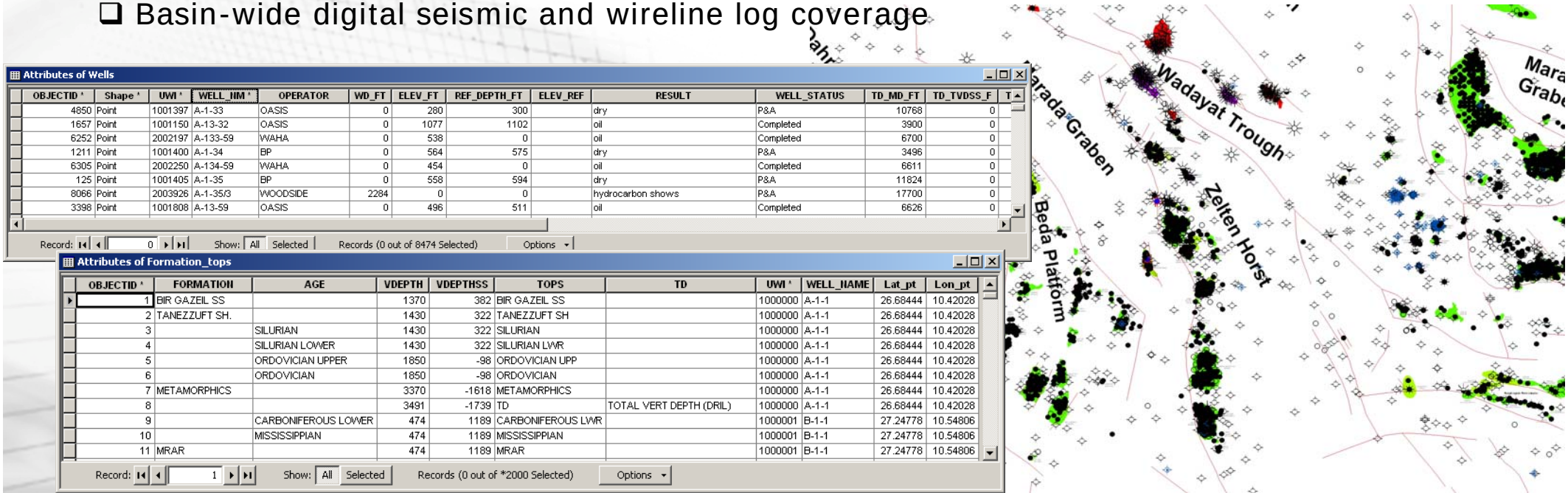

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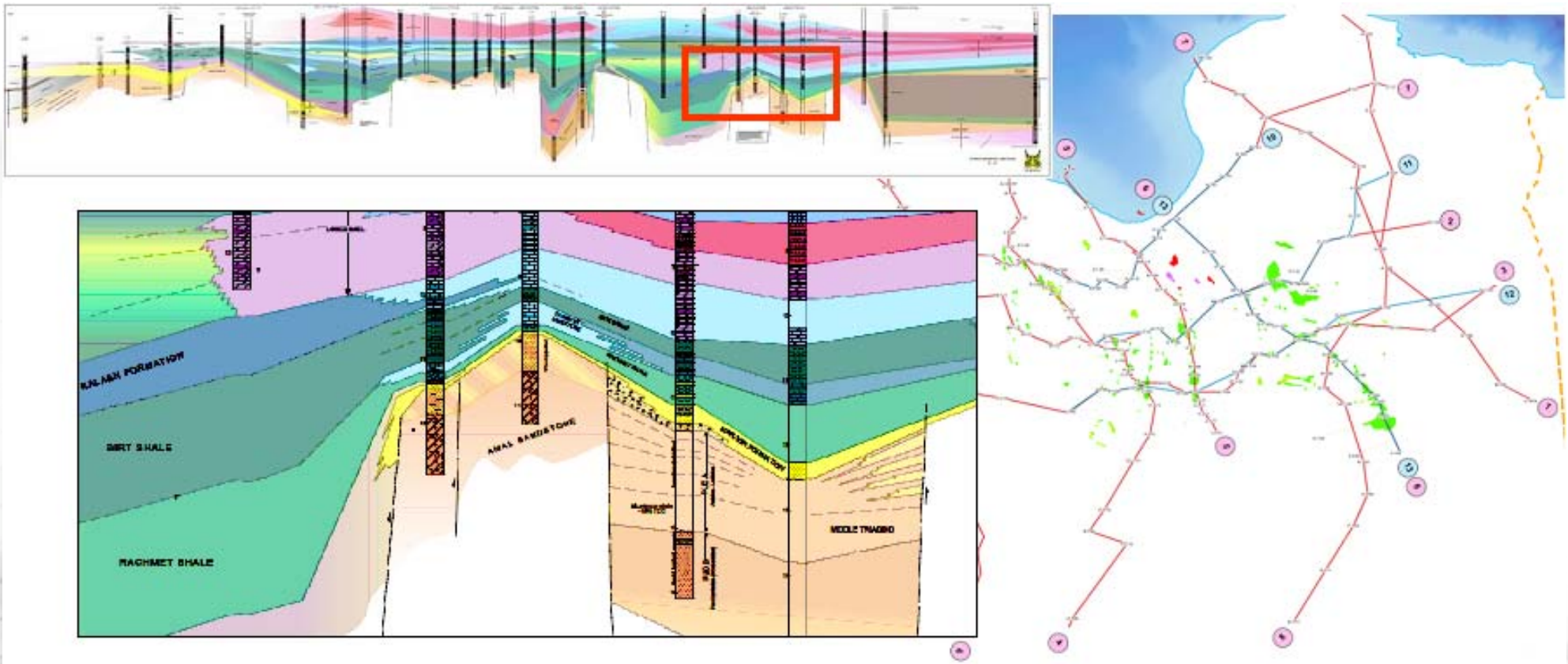
Section I Stratigraphic Cross-sections

A series of regional E/W and N/S well correlation sections were created across the basin. Nine of these correlate lithologic section & formation picks ranging from early & pre-Mesozoic to early Tertiary (datumed on Top Paleocene), and a further four correlate Mid-Late Tertiary section datumed on Top Oligocene.



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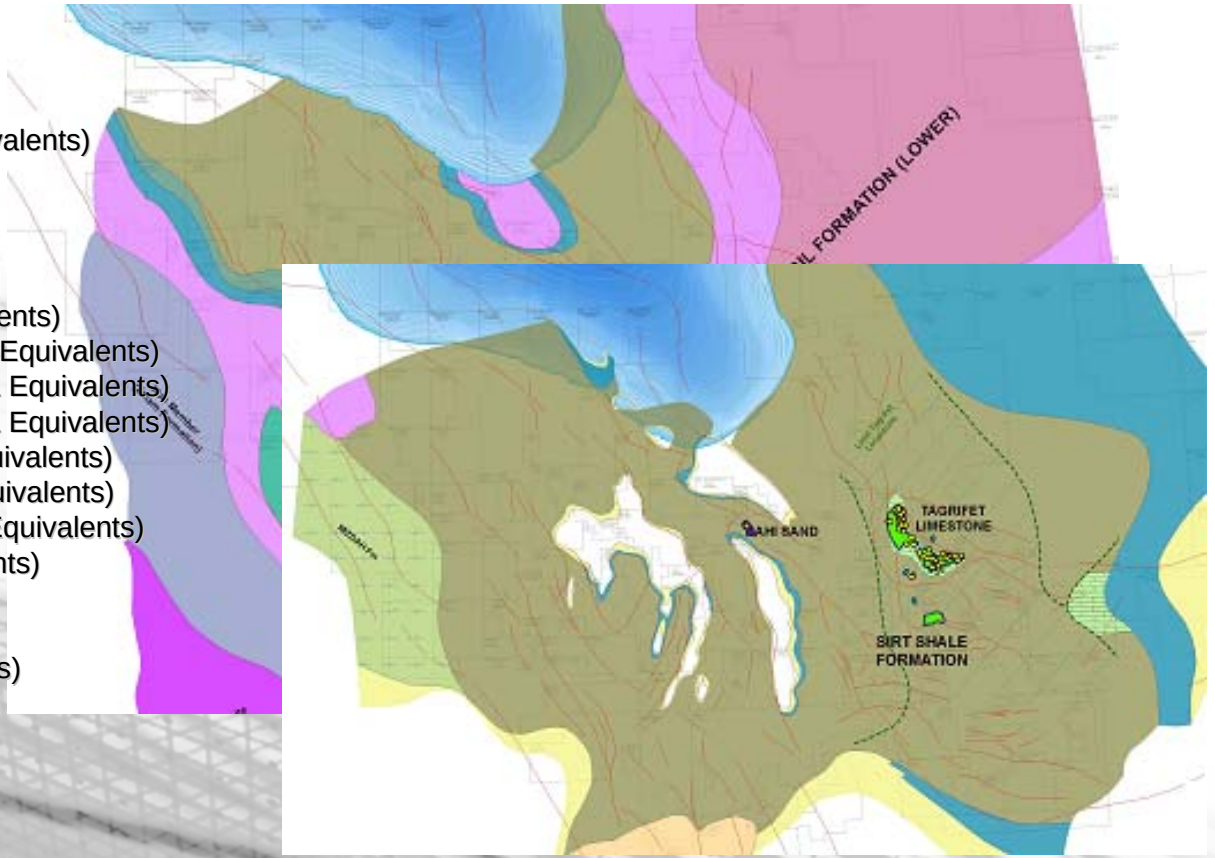
Section I Lithofacies maps

23 Paleogeographic lithofacies maps were composed which correspond geologically with the correlation sections, and these demonstrate changing depositional environment over the area from Early Mesozoic to Late Tertiary.

Triassic-Early Jurassic: distribution and lithofacies
Late Jurassic-Early Cretaceous Lithofacies (Nubian Fm)
Cenomanian Lithofacies (Lidam Formation & Equivalents)
Turonian Lithofacies: Etel /Argub Formations & Equivalents)
Coniacian-Santonian Lithofacies (Rachmet Formation & Equivalents)
Campanian Lithofacies (Lower Sirt Shale & Equivalents)
Sirt-Rachmet Net Organic Rich Shale Isopach
Lower Maastrichtian Lithofacies (Waha &Equivalents)
Upper Maastrichtian Lithofacies: Kalash & Equivalents)
Lower Paleocene (Danian) Lithofacies: Upper Satal & Equivalents)
Middle Paleocene (basal Montian) Lithofacies (Lower Beda & Equivalents)
Middle Paleocene (Lower Montian) Lithofacies (Lower Beda & Equivalents)
Middle Paleocene (Upper Montian) Lithofacies (Upper Beda & Equivalents)
Upper Paleocene (Lower Thanetian) Lithofacies (Dahra & Equivalents)
Upper Paleocene (Upper Thanetian) Lithofacies (Zelten & Equivalents)
Lower Eocene (Early-Middle Ypresian) Lithofacies (Facha & Equivalents)
Lower Eocene (Middle Ypresian) Lithofacies (Hon & Equivalents)
Late Tertiary uplift-doming & unroofing
Middle Eocene (Lutetian) Lithofacies (Gialo Formation)
Mid-Late Oligocene Lithofacies, Najah Group (Arida, Diba Fms)
Miocene Lithofacies



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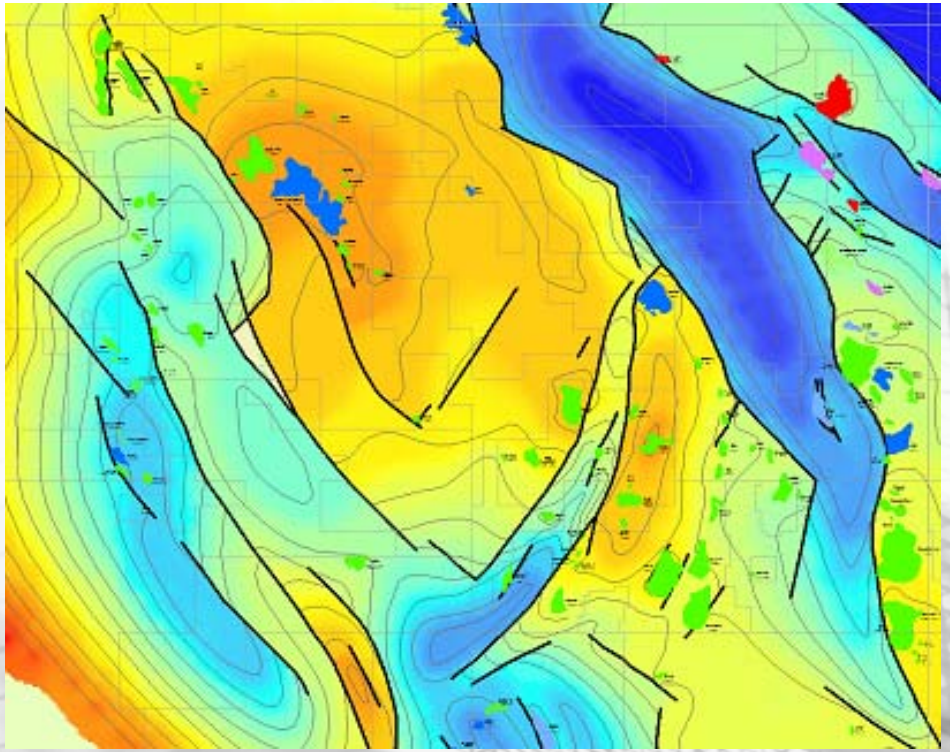
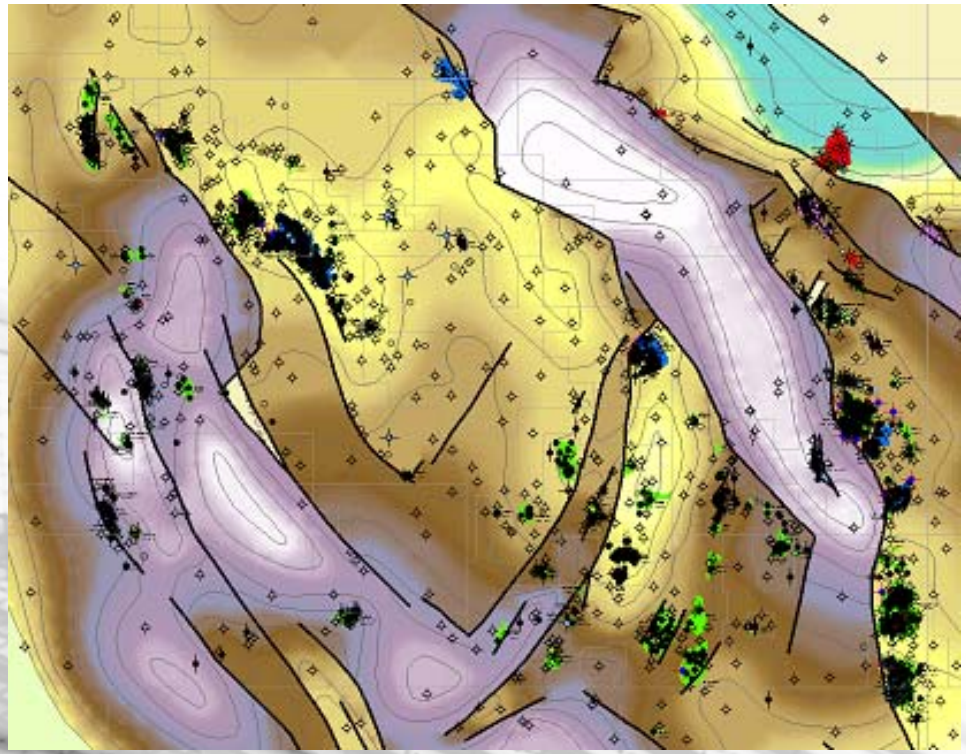
Section I Regional structure & isopach maps

A series of (8) regional top horizon surface maps were created, ranging from Top Nubian to Top Oligocene. Regional isopach maps (15) were then derived from these, with isopach intervals chosen to show increasing sediment loading over time on four of the key source intervals (Top Nubian, Top Etel/Base Rachmat & Top Sirt Shale)

Top Nubian Structure



Top Sirt - Top Eocene Isopach



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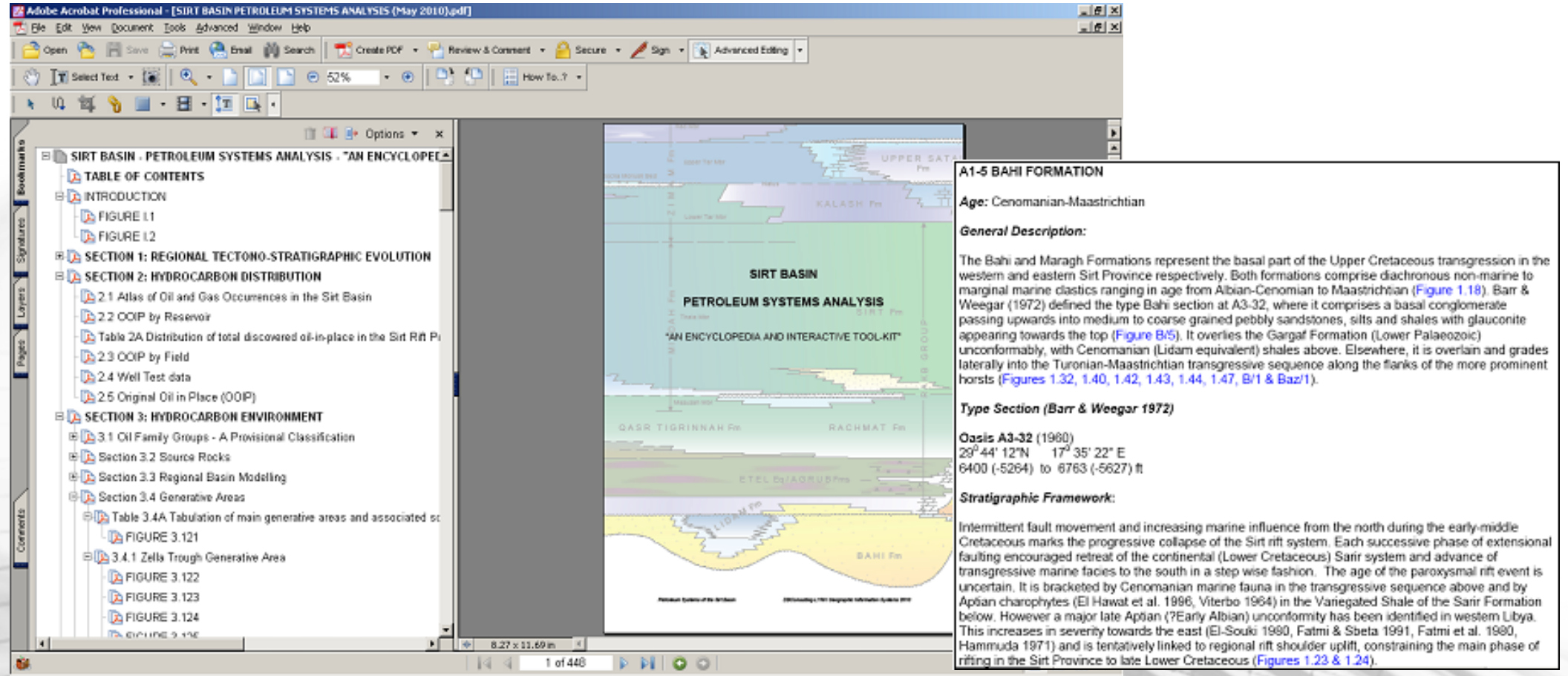
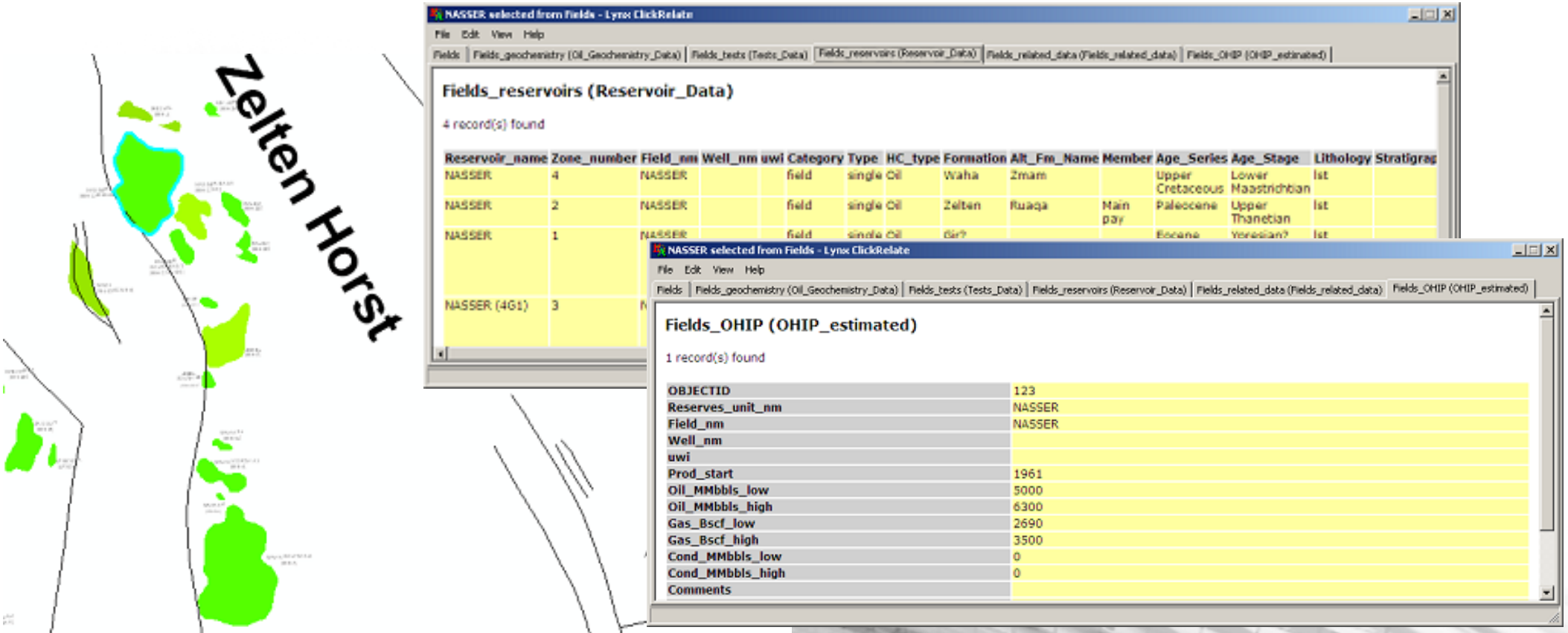
Section I Report text

This material was used to support a 450-page written tectono-stratigraphic summary of the Province, with an appendix updating the classic Barr & Weegar (1972) treatise with detailed descriptions of each significant lithostratigraphic unit.



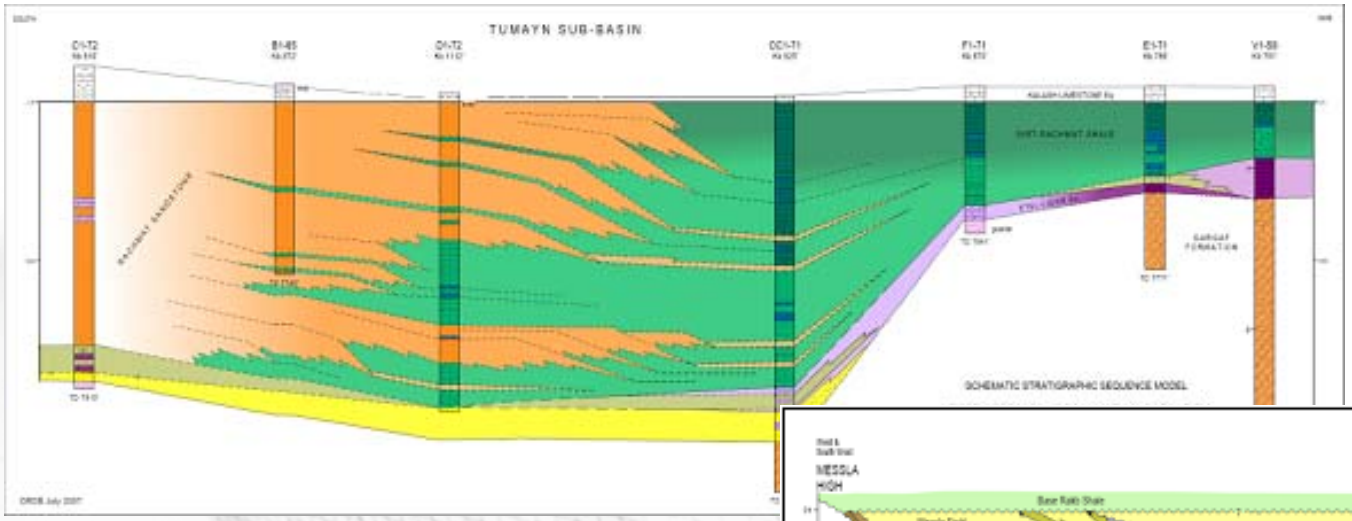
Section II Hydrocarbon Distribution

An systematic effort was undertaken to tabulate oilfield data describing stratigraphy, reservoir character and estimated reserves for all significant hydrocarbon discoveries, corroborated and normalised from multiple (and often conflicting c.f. reserves) sources.



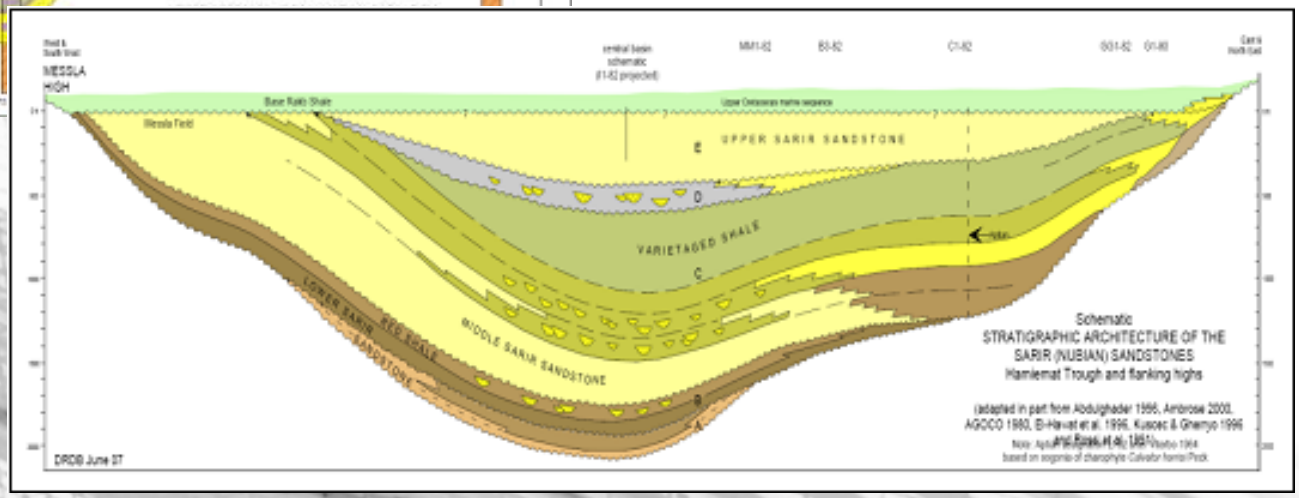
Section I Report diagrams

A library of selected & redrafted illustrations together with descriptive captions was constructed to show the regional tectonic framework, key tectonic drivers and stratigraphic architecture of the more significant 2nd/3rd order sequences of the basin fill.



Several high frequency sequences can be identified building out to the north (**Figure 1.41**), constrasting with the more typical transgressive backstepping cycles elsewhere. Rising sea level gradually isolated the more prominent horsts from the clastic source area in the south.

Although regional stratigraphic correlations are poorly constrained, Ambrose (2000) has identified several unconformity bounded cycles in the larger Hameimat region (**Figures 1.20** & 1.21), typically with fluvial and alluvial sandstone facies passing up into playa and lacustrine shales.



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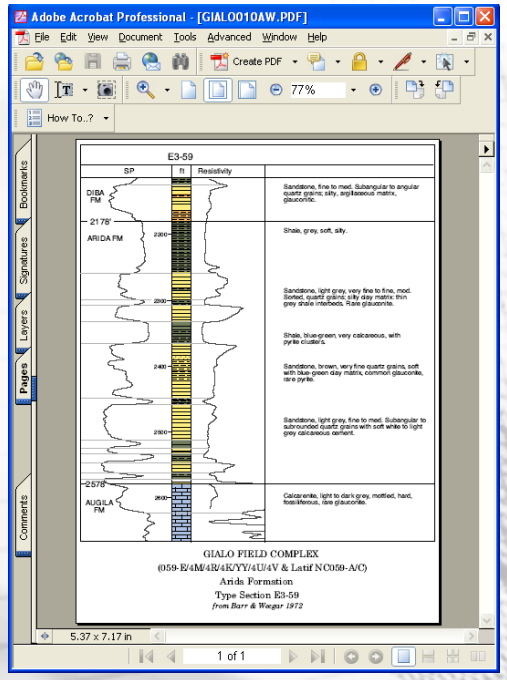
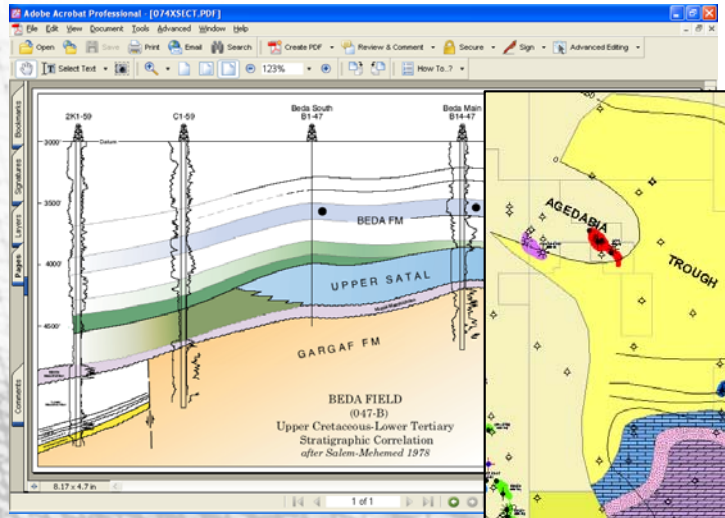
Section II Field Analogue data

Part of this effort involved the gathering and synthesizing of 200+ published field maps, cross-sections, seismic examples and type-wells from open file published field data.

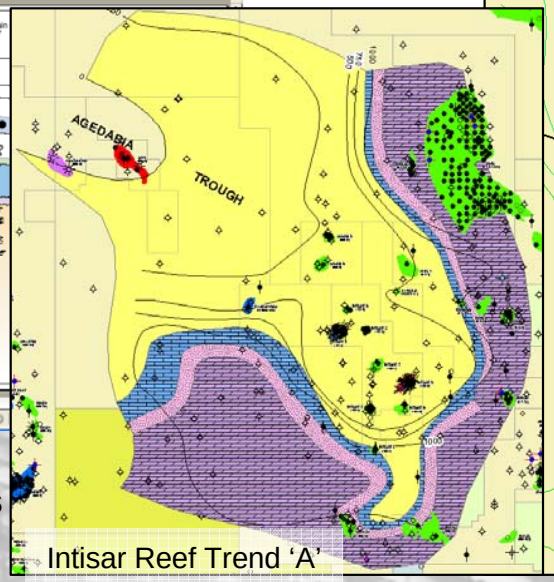
43 wells with type-logs



78 field cross-sections

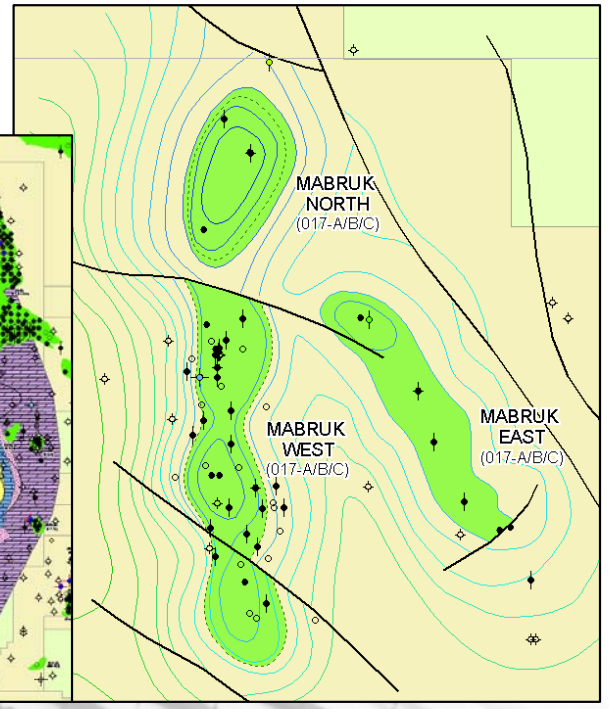


Assorted field facies maps



Intisar Reef Trend 'A'

237 field map layers



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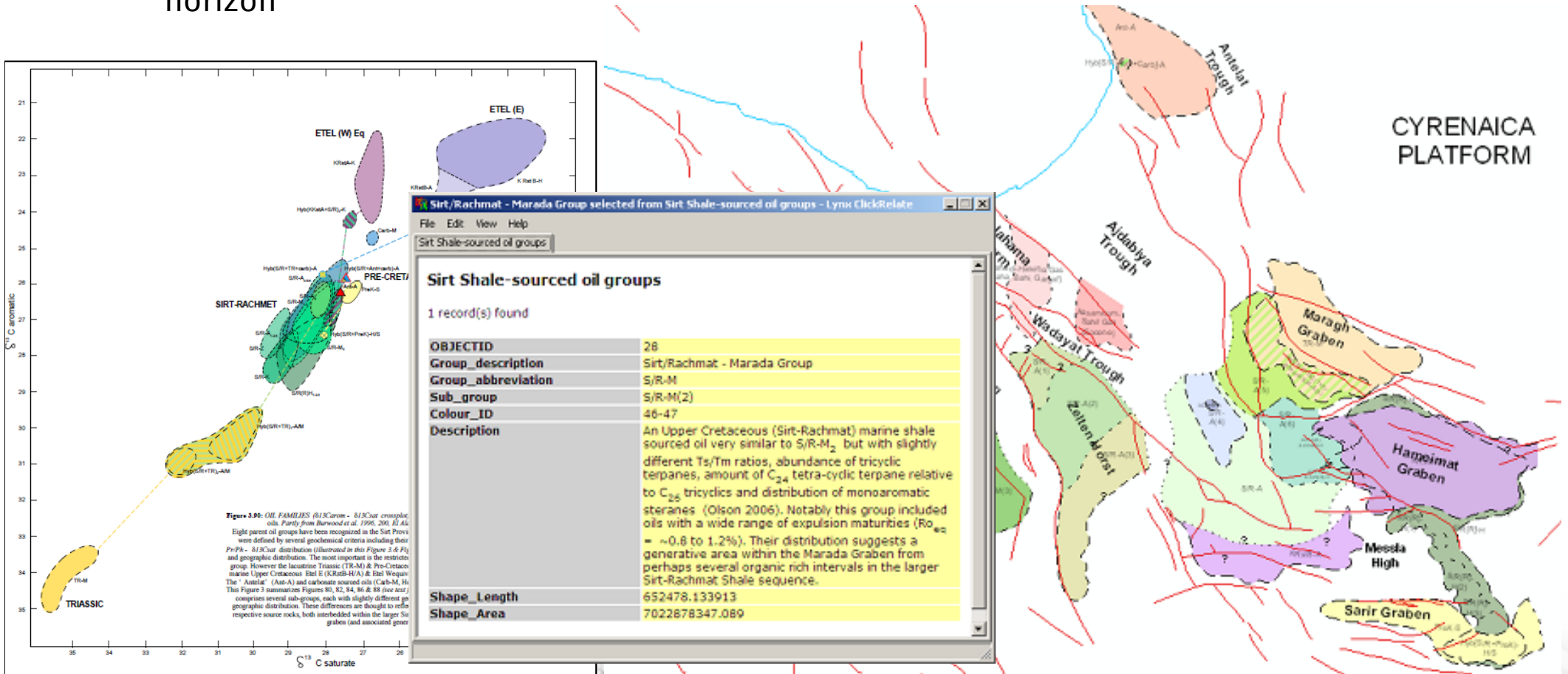
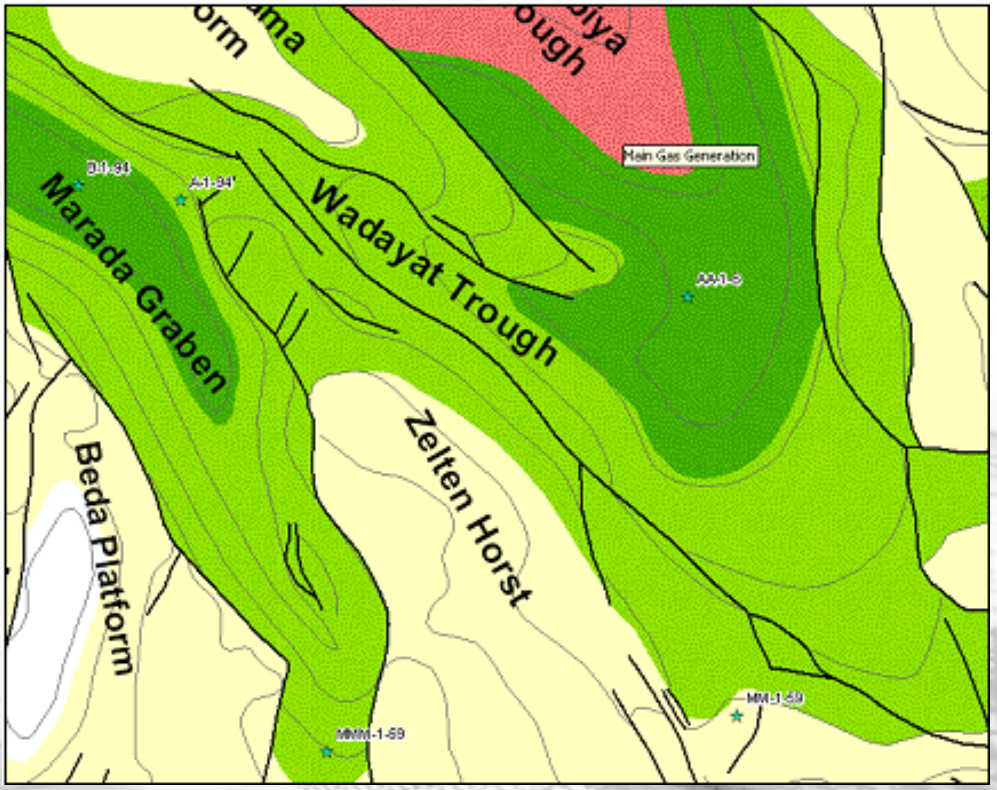
Section III Hydrocarbon Environment – Oil Geochemistry

An analysis of over 150 broadly distributed oil samples from across the Province, used to identify and map a number of discrete oil families. These were defined by their Δ13C and Pr/Py character and described using cross plots and maps with supporting text and tabulation listing the family (group) of each oil by stratigraphic horizon

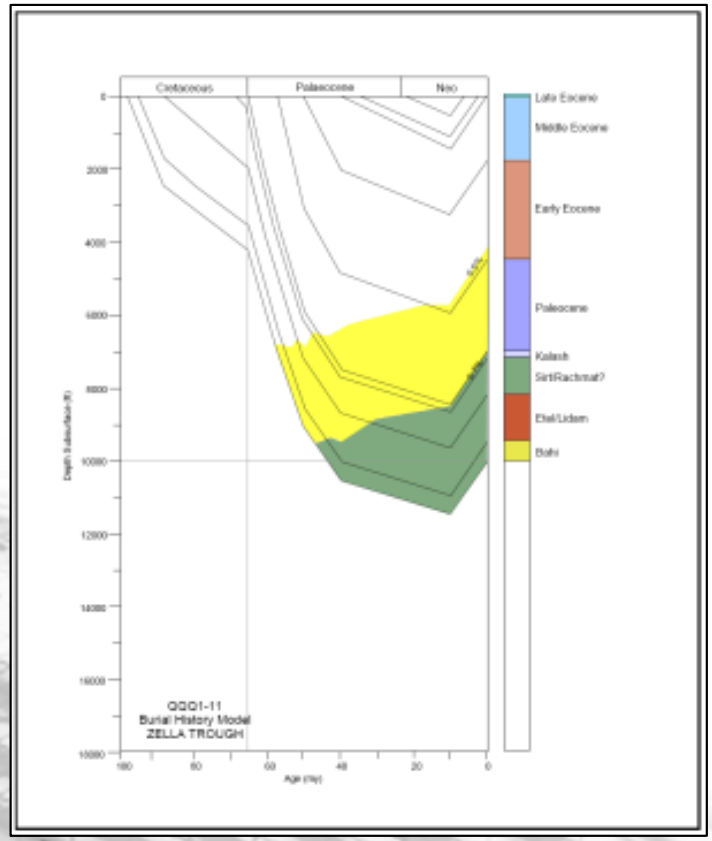


Section III Source Horizon maturation maps

The Interval isopach maps prepared for each key source horizon in Section I, were converted into regional maturation maps, constrained by 1D basin models obtained for 10 wells spread across the basin.



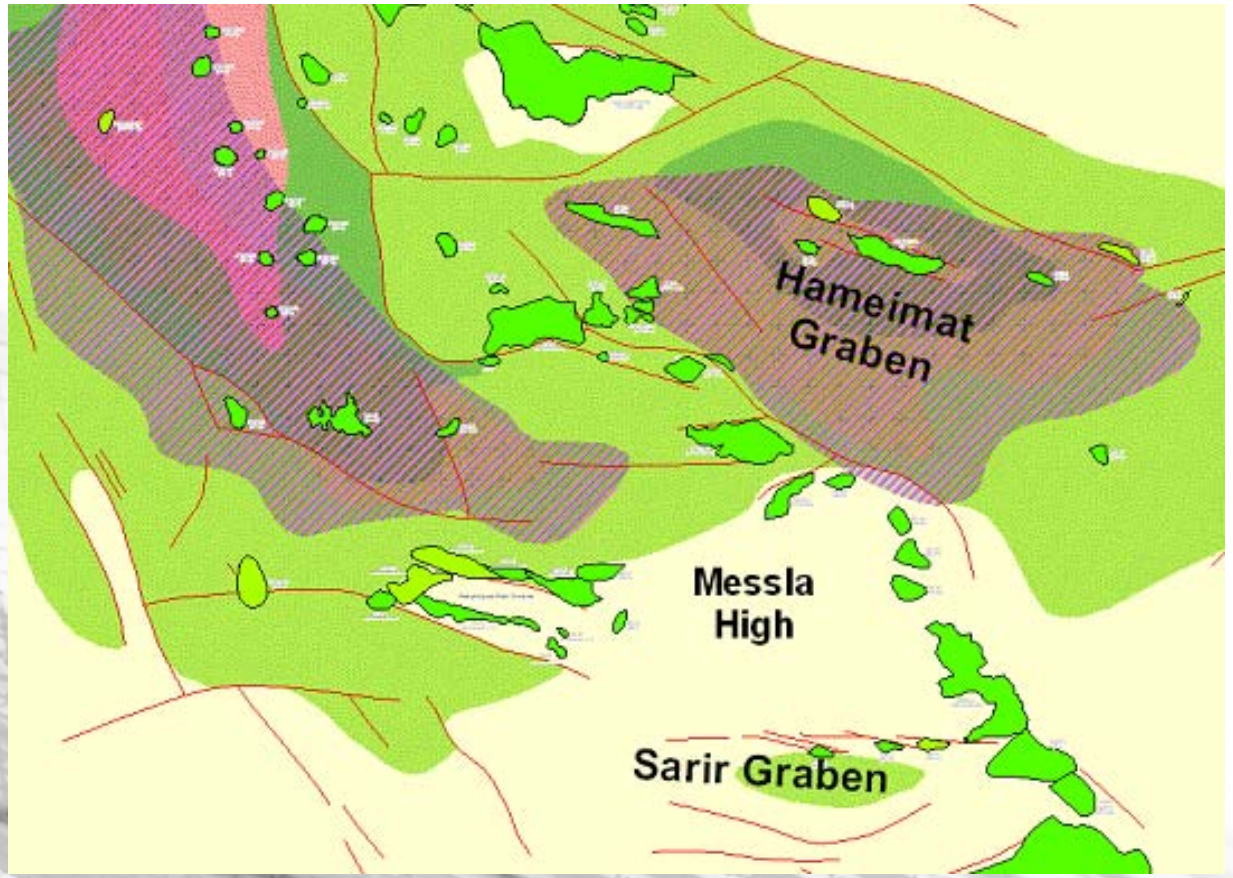
Sirt maturation, at present day



Section III Source kitchens/Generative areas

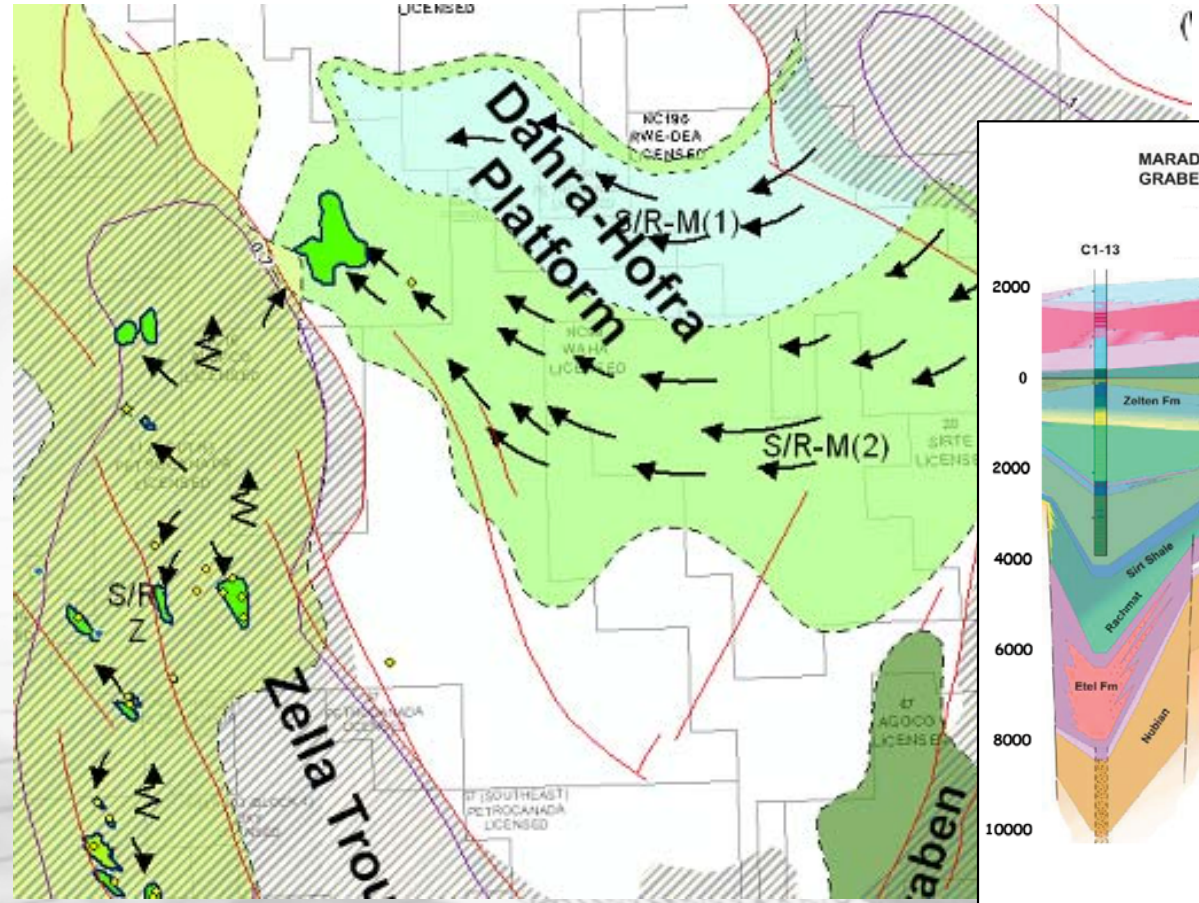
These basin history reconstuctions were then integrated with source rock distribution maps to create generative area maps of each recognized source horizon through time.

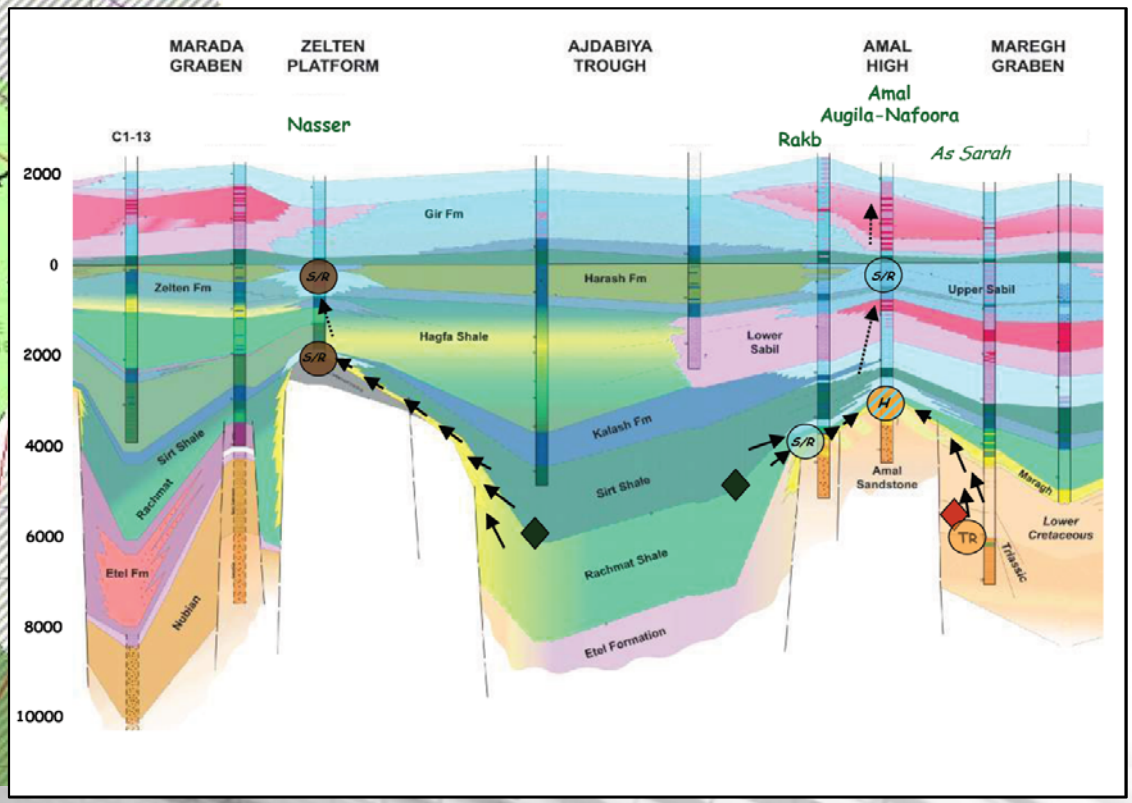
- Etel generative area at present
- Tertiary tectonic influences
- Etel Maturation, at present day
  - Isopach contours
  - Maturity
    - Early Mature
    - Mid Mature
    - Late Mature
    - Main Gas Generation
- Etel source facies
  - Annotation
  - Etel Source Facies
    - [Restricted marine]
    - Interbedded anhydrites and halite
    - Organic rich shales (poorly constrained) distribution



Section III Oil migration & charge models

Charge models in both section and plan view were constructed by overlaying field pool locations, source generative areas and the oil family maps, allowing migration pathways to be drawn for each contributive source rock through time.





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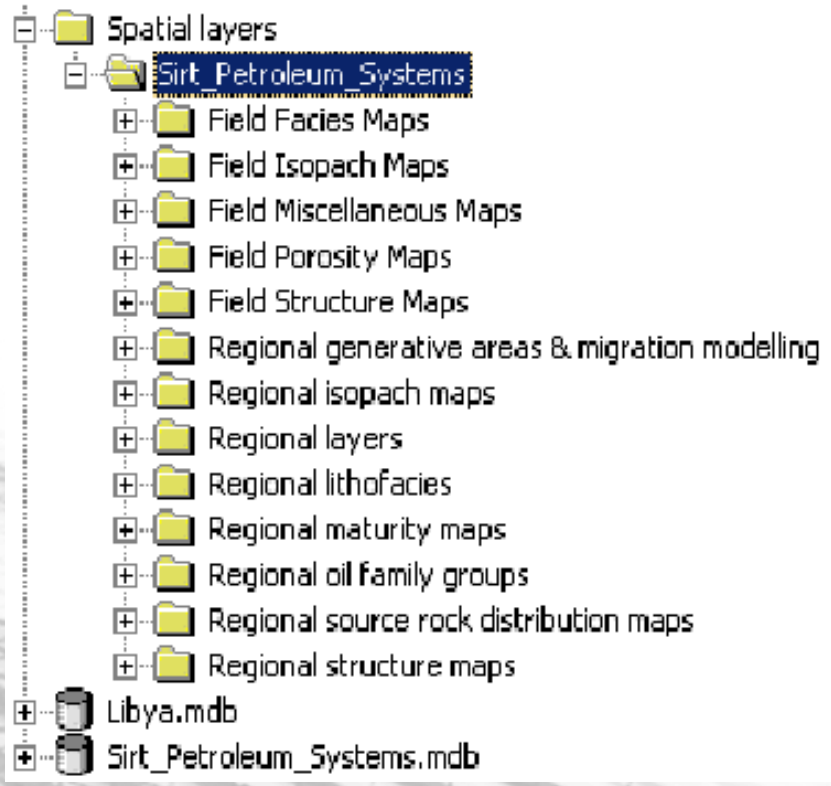
Section IV ArcGIS integration

Section IV is essentially a logical workflow describing how map layers, sections, tabular data and supporting text can be selected and assimilated in ArcMap for a chosen petroleum system, enabling play fairway maps to be constructed

RESERVOIR	*AGE*	*LITHOLOGY*	*SEAL*
Palaeozoic/Basement	pre-Hercynian	clastic/igneous	Etel/Rachmat/Sirt
Nubian	Late Jurassic-Lower Cretaceous	clastic	Etel/Rachmat
Lidam/Bahi	Cenomanian	carbonate/clastic	Sirt/Rachmat
Etel/Agrub/Bahi	Turonian	carbonate/clastic	Sirt/Rachmat
Tagrifet/Bahi	Santonian-Campanian	carbonate/clastic	Sirt
Waha/Samah/Bahi	Maastrichtian	carbonate/clastic	Kalash/ Hagfa
Upper Satal/Defa	Danian	carbonate	Rabia /Thalith
Beda	Montian	carbonate	Rabia/Khalifa/Upper Beda
Dahra	Thanetian	carbonate	Khalifa
Zelten/Upper Sabil	Thanetian	carbonate	(Harash)/Kheir
Facha	Lower Eocene	carbonate	Hon
Gialo	Middle Eocene	carbonate	
Diba/Arida	Oligocene	clastic	



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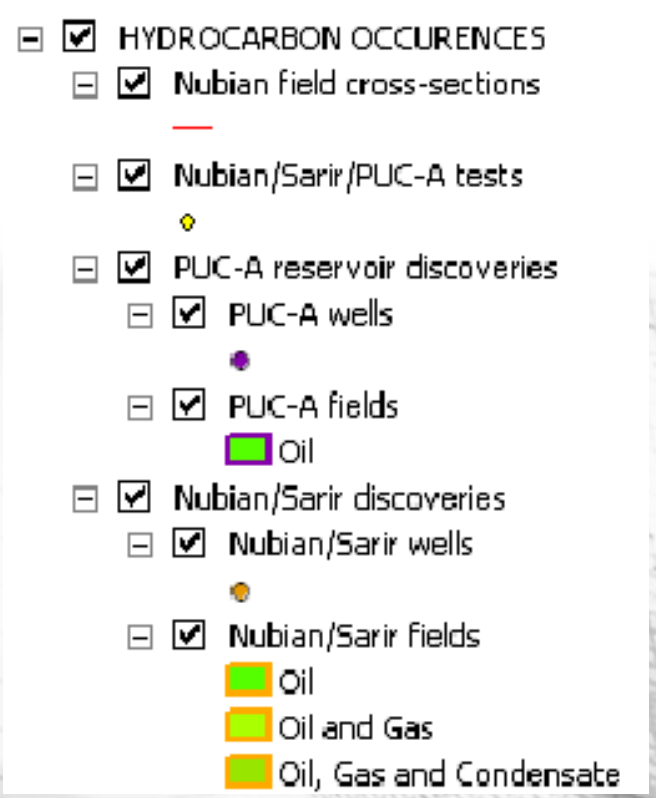
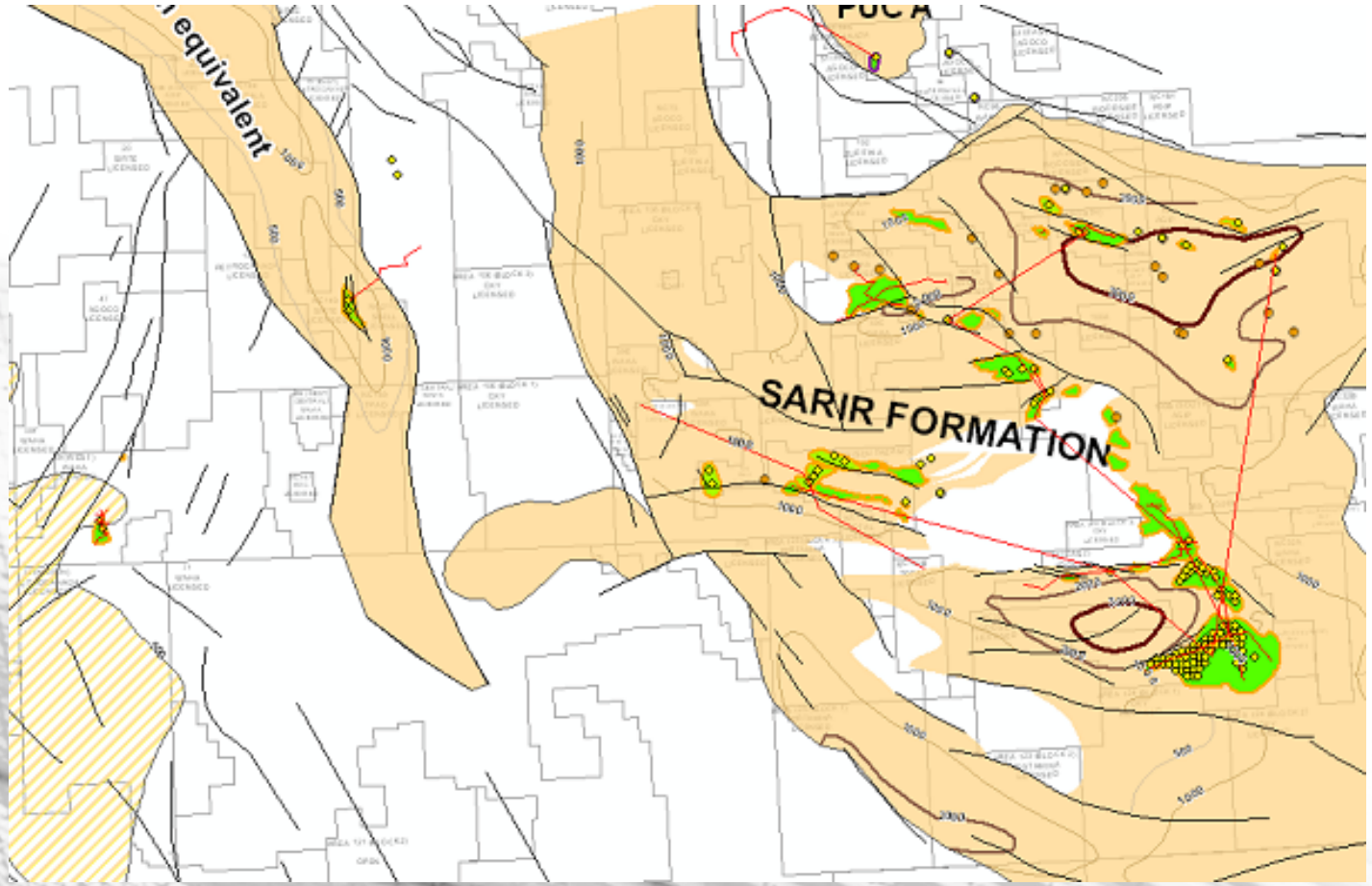
Section IV Play Summary maps in ArcGIS

The ArcGIS framework allows users to develop their own ideas by allowing easy incorporation of in-house company data, and ultimately provides a means for users to export maps and tables for presentations and shared discussion.





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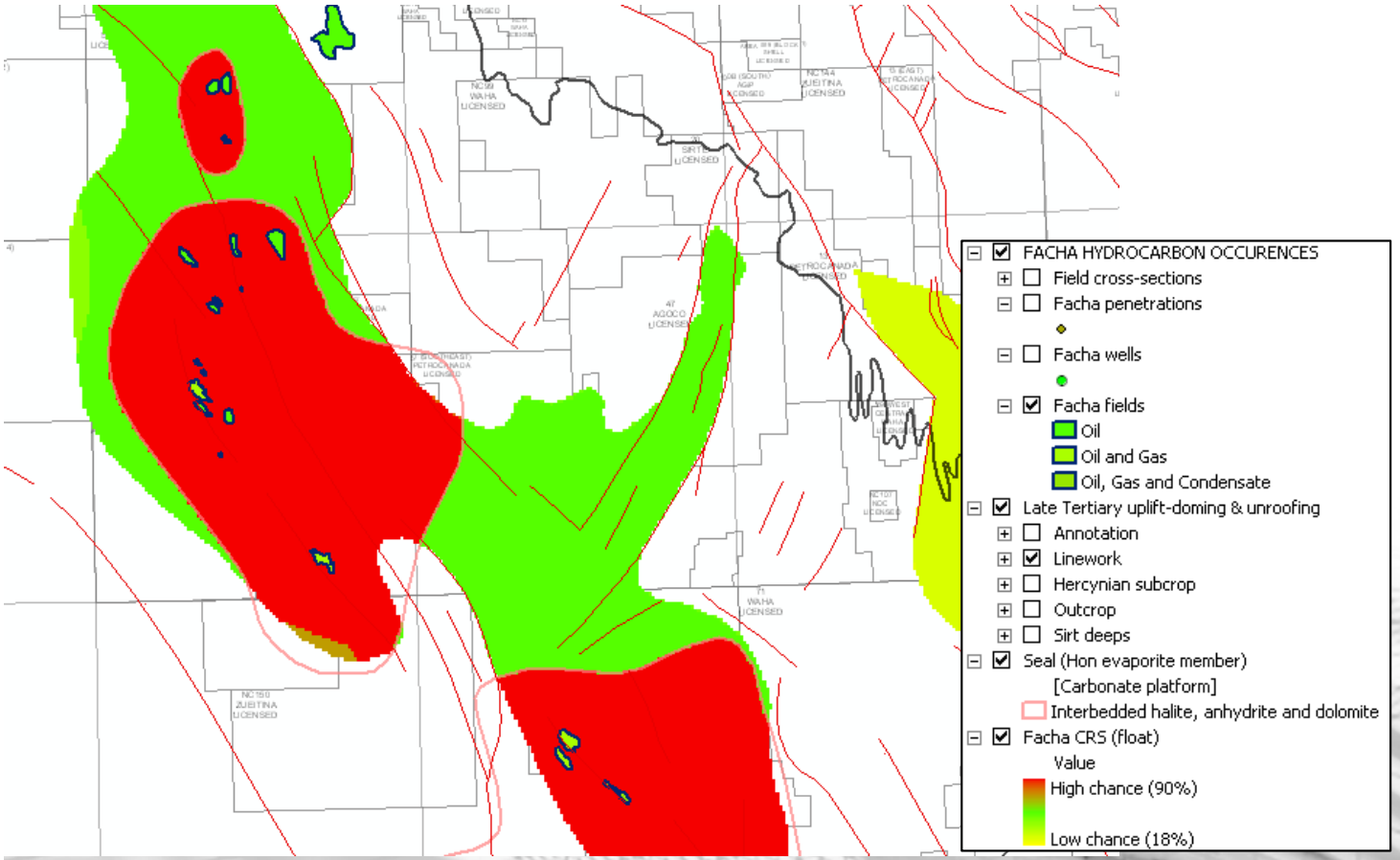
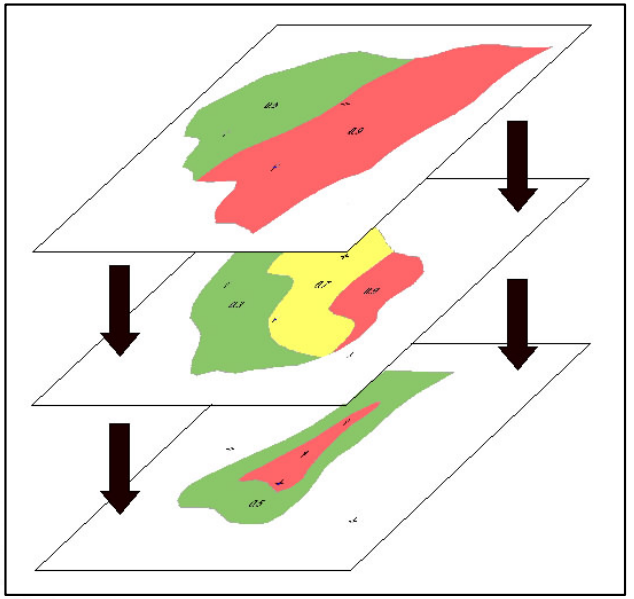
Section IV Common Risk Segment mapping in ArcGIS

This module forms an interactive toolkit for reasonably experienced ArcGIS users to create combined risk segment maps, a popular method for assessing play risk and chance potential.





Using the ArcGIS Spatial Analyst extension, these segment polygons are converted into grids, which are then multiplied to derive a combined play chance map