



David Boote Consulting Ltd

IRAQ - PETROLEUM SYSTEMS

AN ArcGIS-ENABLED STUDY AND INTERACTIVE TOOLKIT

Multi-Client Prospectus

May 2011
(updated August 2011)

Synopsis

Iraq is credited with 136 Bbbls oil and 108 Tcf gas (3P, Verma et al., 2004) in 84 fields, with 17 additional discoveries of undeclared reserves. Resources are clustered at particular geological horizons ranging in age from Ordovician to Pliocene. This distribution is dictated by particular source-reservoir-seal- combinations and defines a number of distinct petroleum systems.

Lynx Information Systems, Integrated Geochemical Interpretation (IGI), and David Boote Consulting are collaborating on this study.

A comprehensive analysis of each petroleum system (based on source) and detailed mapping of discrete play fairways (based on reservoir) are undertaken, using a logical methodology described by the workflow diagram below.

The results of the analysis are presented in two forms:

- (A) An 8-section report in Adobe Acrobat pdf form (outlined below), providing an extensive, illustrated body of knowledge to support the findings of the study.
- (B) The dynamic aspect of each petroleum system is mapped and manipulated *via* an ArcGIS 'toolkit' which links to ZetaWare's Genesis and Trinity T3 models underpinned by IGI's p:IGI-3 geochemical database.*

This "dynamic deliverable" can be used by oil-company geoscientists to leverage their own unique interpretations, and may be adapted, integrated with other data, and disseminated throughout their organisation. Lynx has already trialled the major aspects of this approach in a recently completed study.

A Section of the report also addresses the 12 exploration blocks on offer in January 2012

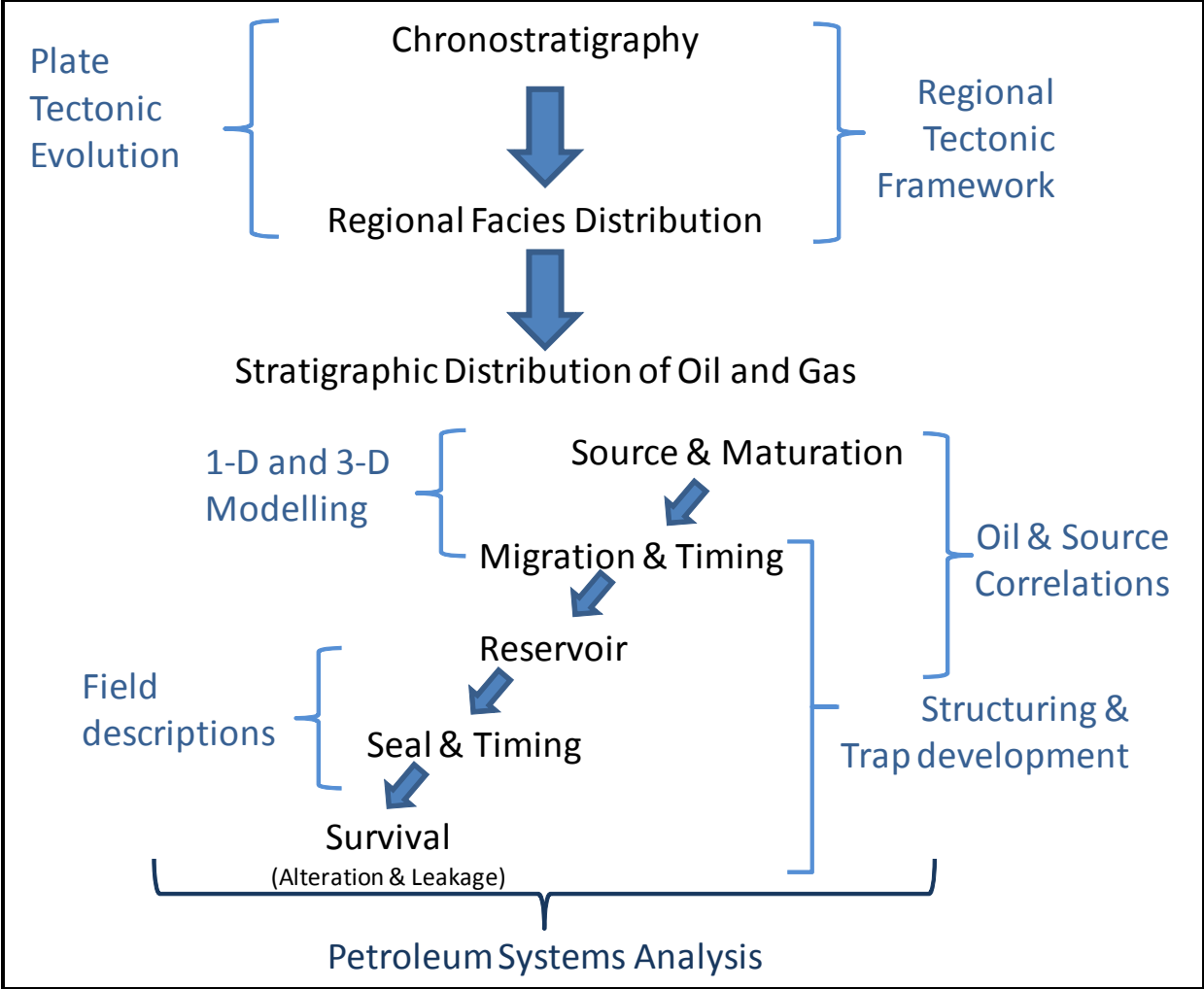
The ArcGIS toolkit also allows the geoscientist to perform *Common Risk Segment mapping*, combining results in order to rank and risk multiple play elements and so develop and assess new play concepts. Given the numerous combinations, a selection of CRS maps will be included with the study results. The toolkit allows each client to develop unique mapping.

Lynx's ArcGIS tools for visualising geological data are included in the package (1 year licence).

The study is already in progress and significant parts are complete. The release date is set for 15 December 2011.

Geoscientists working on the 4th Iraqi Licensing Round will find it indispensable for furthering their understanding of petroleum systems in the region. This unique product provides a dynamic framework for evolving their own play concepts.

* *Purchasers are responsible for their own licences to run these applications.*



Flow diagram illustrating the methodology employed throughout the study

Report Table of Contents

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References

Appendix 1 Stratigraphic Distribution of Oil and Gas

Enclosures

THE FOLLOWING PAGES HIGHLIGHT KEY ASPECTS AND PRESENT EXTRACTS OF THE WORK THUS FAR COMPLETED

Section 1 Introduction

Iraq (440,00km²) straddles the North Arabian sedimentary basin, extending from the Arabian-Nubian Platform in the west, to the Zagros Fold Belt in the east and northeast. Its total discovered and undiscovered oil reserves rank second only to Saudi Arabia in the Middle East and gas reserves are tenth in the world (Verma et al., 2004). Much of its reserve base is undeveloped and with comparatively little exploration, there are exceptional opportunities for both improved/enhanced field development projects and new field discoveries. This report is intended to provide a regional geological framework and guide for assessing, evaluating and ranking such opportunities as they arise.

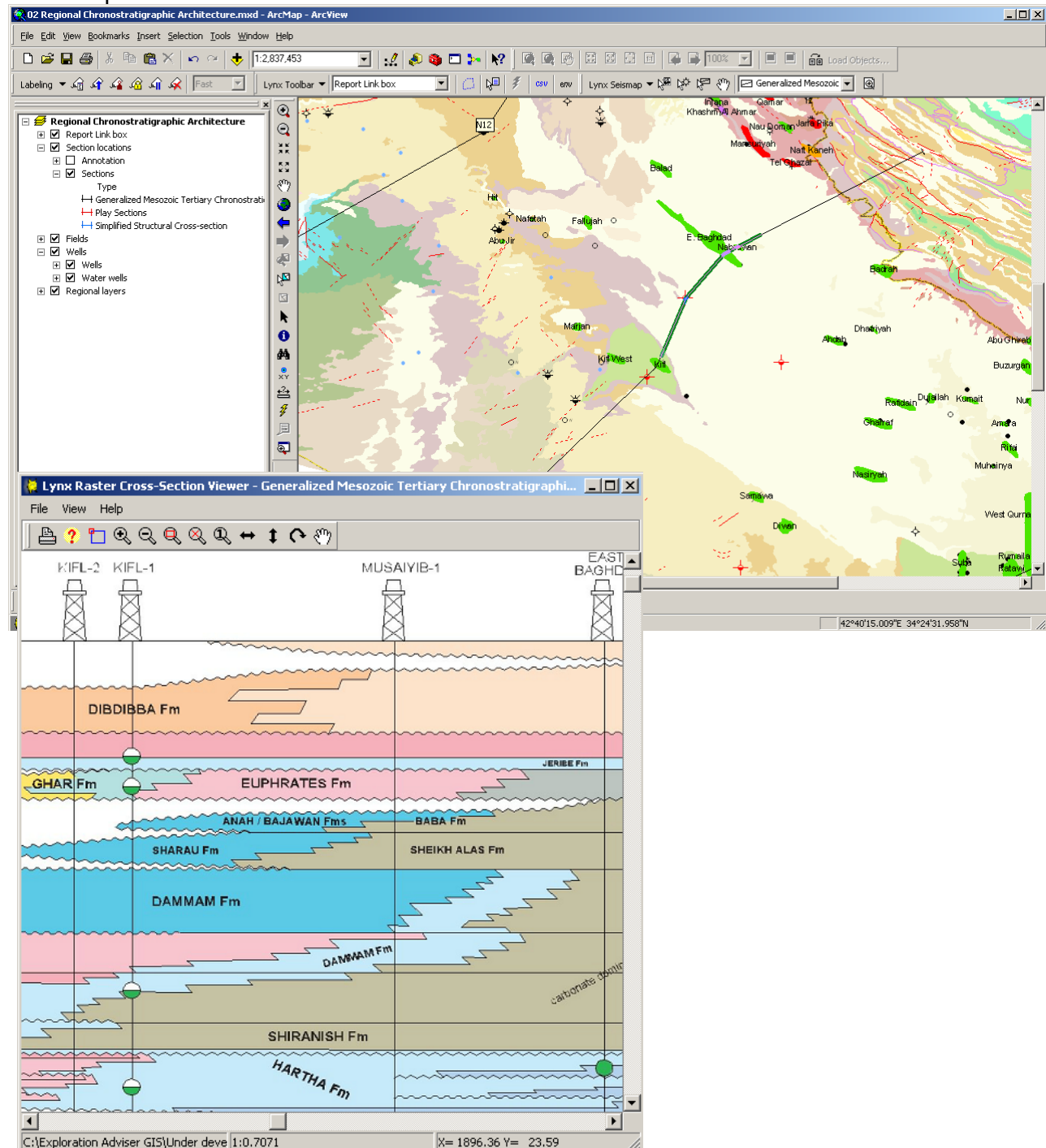
Although hydrocarbons are dispersed throughout the stratigraphic succession, regional correlations highlight a tendency for more significant accumulations to concentrate at discrete horizons, as dictated by reservoir quality and seal effectiveness. In this analysis, each of these more prolific intervals was recognized as a petroleum system defined by its specific source rock. Reservoir, seal and source distribution, source maturity and associated hydrocarbon occurrences were collated for the more important systems and synthesized in play summary maps. Petroleum systems evaluated in this fashion include:

- **Palaeozoic** reservoir-Silurian sourced systems summarized in a general Palaeozoic 'exploration potential' map.
- **Najmah** (Upper Jurassic) speculative petroleum system (shoal water carbonate reservoir and Jurassic source).
- **Yamama** (Lower Cretaceous) petroleum system (carbonate/oolitic reservoir and Lower Cretaceous source).
- **Zubair** (Lower Cretaceous) petroleum system (clastic reservoir and Lower Cretaceous source/plus some vertical leakage from Jurassic source).
- **Burgan/Nahr Umr** (Middle Cretaceous) petroleum system (clastic reservoir and Lower Cretaceous source).
- **Mishrif** (Middle Cretaceous) petroleum system (clastic reservoir and Lower Cretaceous source).
- **Shiranish** (& associated Upper Cretaceous horizons) petroleum system (fractured marl and argillaceous limestones reservoirs with deeper Cretaceous source?).
- **'Asmari'** petroleum system (Oligocene Kirkuk/Main and Lower Miocene Euphrates & Jeribe carbonate and Ahwaz/Ghar clastic reservoirs with at least two Lower Cretaceous sources).

In addition to the above relatively closed systems, the mixing of the charges from two or more source rocks into one reservoir play is recognised. Other hydrocarbon bearing intervals including the Kurrachine and Butmah (Triassic-Lower Jurassic?), Ratawi and Shuaiba (Lower Cretaceous), Mauddud and Rumaila (Middle Cretaceous), Kometan and equivalents (early Upper Cretaceous) and Eocene limestones are considered less prolific based on the findings of this study.

Section 2 Regional Chronostratigraphic Architecture

Section 2 presents both a general summary of Palaeozoic stratigraphy and a more detailed description of the Mesozoic-Tertiary chronostratigraphic architecture across northern, central and southern Iraq. The synthesis provides a guiding framework for a regional facies interpretation of the Palaeozoic to Recent succession described in Section 3, and hence a sequence stratigraphic approach is adopted. Deeper well control is limited and consequently the Palaeozoic stratigraphic description is necessarily less complete. The Mesozoic-Tertiary section is better constrained and an attempt has been made to divide it into more regional 2nd order sequences.



Chronostratigraphic construction SW-NE through Central Iraq, viewed dynamically within ArcGIS

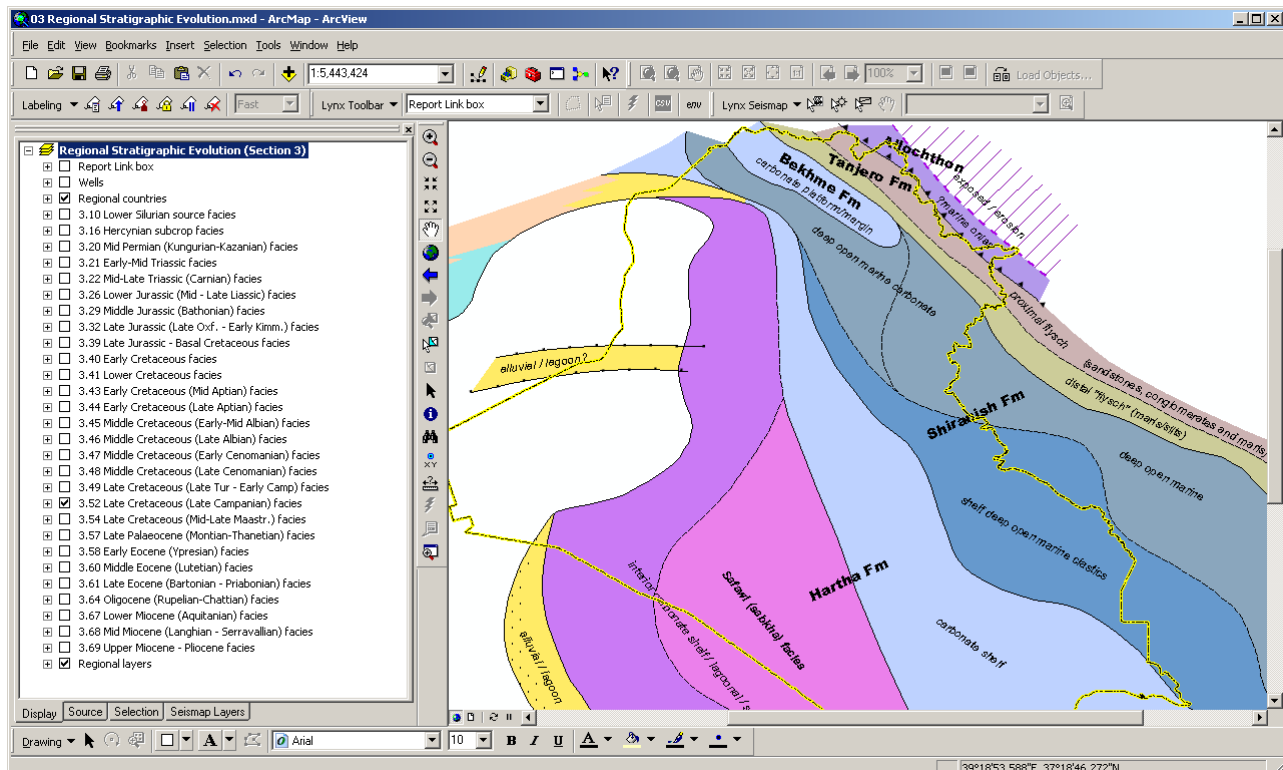
Section 3 Regional Stratigraphic Evolution

Section 3 improves on the mostly broad and lithofacies-biased descriptions that have been published for the Phanerozoic stratigraphy of Iraq. Here, a large number of regional facies maps representing comparatively small intervals of time, have been created.

Each map is a synthesis based on selected information taken from a variety of sources. Where possible, more regional unconformities and lithofacies organizations have been used to help define 2nd / 3rd order sequences.

The following maps have already been drafted as a provisional set, and are being updated with new data.

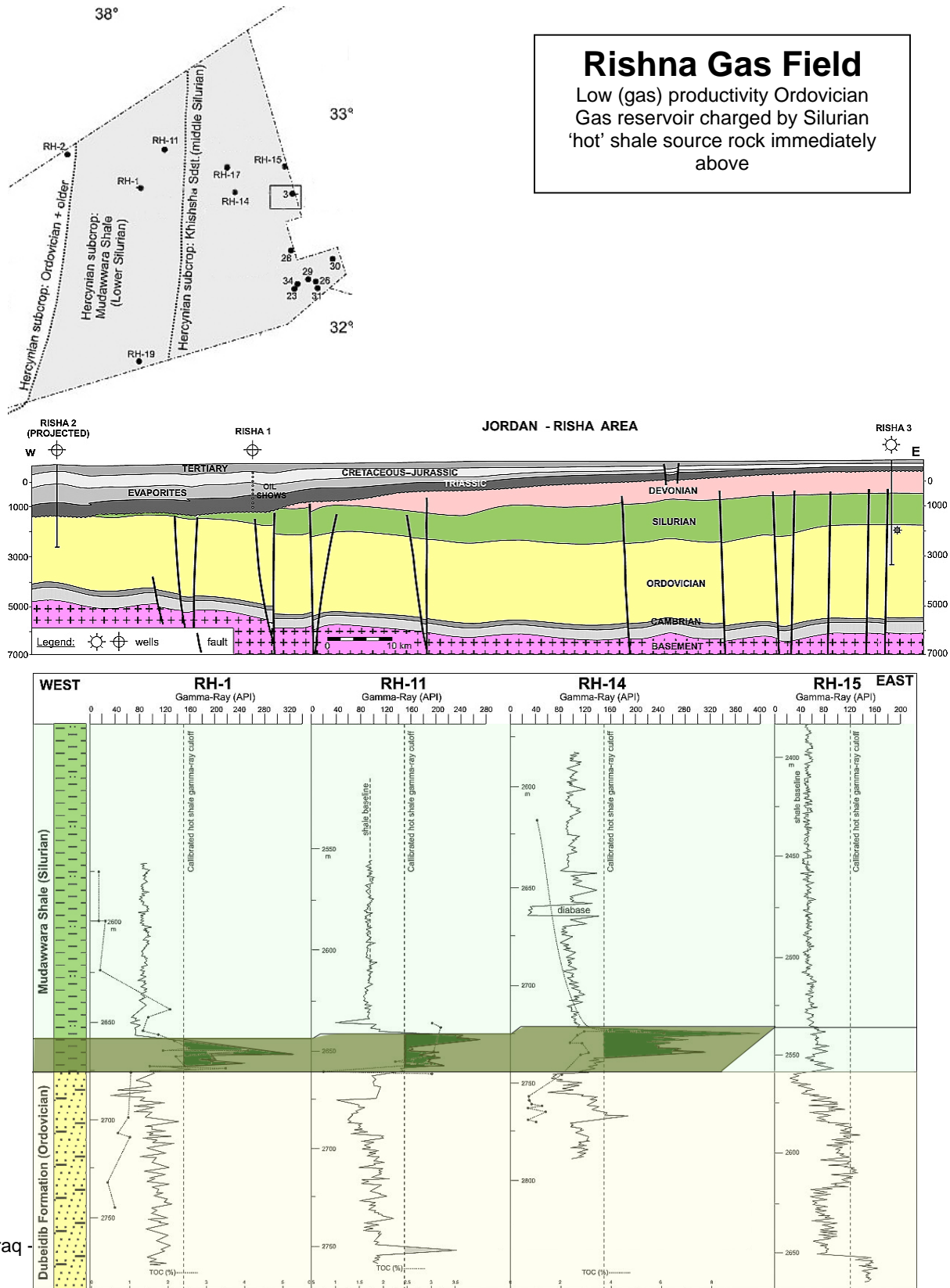
- | | |
|--|--|
| Lower Silurian source facies | Middle Cretaceous (Early-Mid Albian) facies |
| Hercynian subcrop facies | Middle Cretaceous (Late Albian) facies |
| Mid Permian (Kungurian-Kazanian) facies | Middle Cretaceous (Early Cenomanian) facies |
| Early-Mid Triassic facies | Middle Cretaceous (Late Cenomanian) facies |
| Mid-Late Triassic (Carnian) facies | Late Cretaceous (Late Tur - Early Camp) facies |
| Lower Jurassic (Mid - Late Liassic) facies | Late Cretaceous (Late Campanian) facies |
| Middle Jurassic (Bathonian) facies | Late Cretaceous (Mid-Late Maastr.) facies |
| Late Jurassic (Late Oxf. - Early Kimm.) facies | Late Palaeocene (Montian-Thantetian) facies |
| Late Jurassic - Basal Cretaceous facies | Early Eocene (Ypresian) facies |
| Early Cretaceous facies | Middle Eocene (Lutetian) facies |
| Lower Cretaceous facies | Late Eocene (Bartonian - Priabonian) facies |
| Early Cretaceous (Mid Aptian) facies | Oligocene (Rupelian-Chattian) facies |
| Early Cretaceous (Late Aptian) facies | Lower Miocene (Aquitanian) facies |
| Middle Cretaceous (Early-Mid Albian) facies | Mid Miocene (Langhian - Serravallian) facies |
| Upper Miocene - Pliocene facies | |



Example of Late Campanian facies reconstruction

Section 4: Reservoir/Seal Facies and Oil & Gas Field Analogues

Section 4 collates and summarizes published information from selected fields in Iraq and adjacent areas. It highlights the more significant reservoirs, seals, trap styles of fields or groups of fields, in each of the identified petroleum systems. Some emphasis is also placed on charge history with a focus on early entrapment versus late remigration. The *example below comprises the illustrations for the Rishna field.*



Section 5 Regional Source Distribution and Oil-Source Correlation

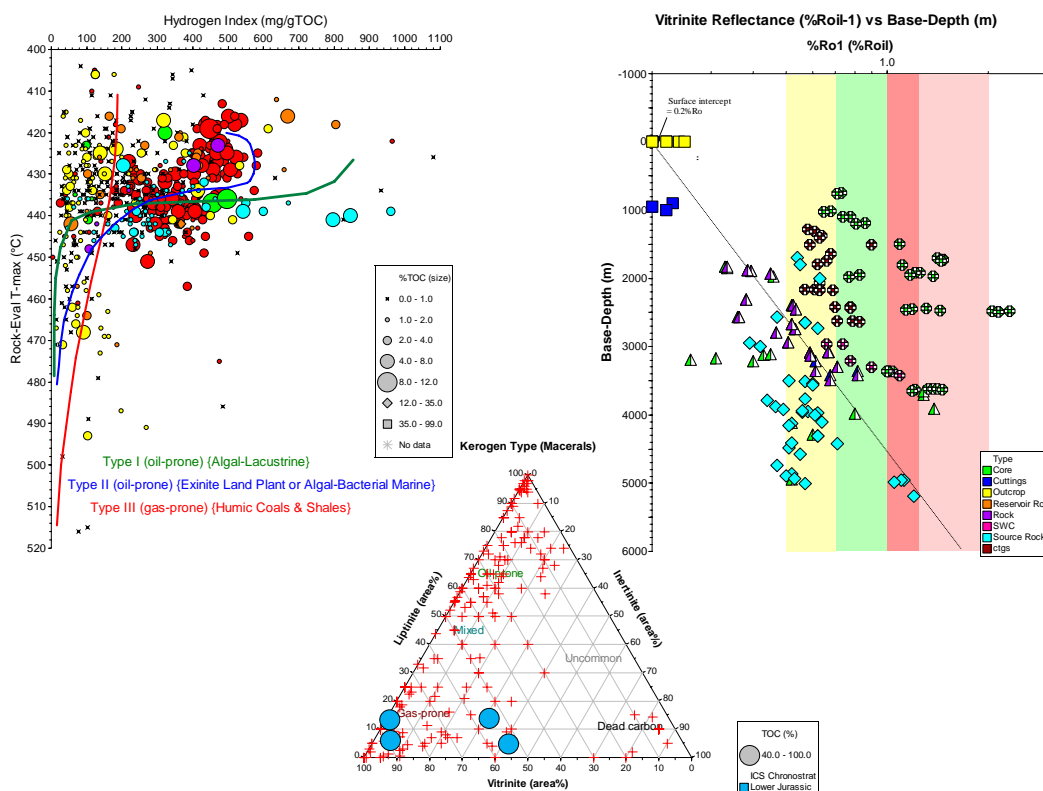
This section draws on the source rock analysis of over 1,000 samples emphasising their richness (TOC), organic matter type (kerogen type from microscopy and pyrolysis), and their yield (kg petroleum/tonne rock). In addition, kerogen type will be linked to lithofacies to produce organofacies maps for key source rock horizons. The organofacies maps will be used to predict appropriate kinetics as a basis for the modelling of generation and expulsion.

Source rock maturity from microscopy (vitrinite reflectance and spore colour) and pyrolysis (Rock-Eval T_{max}) are being used together with limited molecular data to calibrate the 1-D Genesis models. The 1D models (Section 6) are built from the Lynx well database and are also being thermally calibrated against well- or field-specific downhole temperatures and/or regional heatflow mapping.

As far as data allow, bulk, molecular and isotopic characters of the source rocks are identified as a basis for oil-source rock correlations.

An oils database is being assembled from published sources, which include oils from adjacent countries of Kuwait, Iran, Turkey and Syria. The objective of this aspect of the study is to identify genetic families of oils and compare these with the most plausible source rocks. Mixed oils may also be identified, and the effects of migration fractionation processes are shown frequently to control the bulk properties of the petroleum. In addition, use of molecular oil maturity parameters (e.g. sterane and hopane isomerisation, and other ratios of terpanes and aromatics) will be used to validate the migration paths modelled using Trinity T3 software.

The geo-referenced database containing the quantifiable information used in the source rock and oils aspects of the study will be provided in p:IGI-3 and Microsoft Excel formats. This allows purchasers with appropriate software licences to add their own data, review the conclusions of the study or develop their own interpretations.



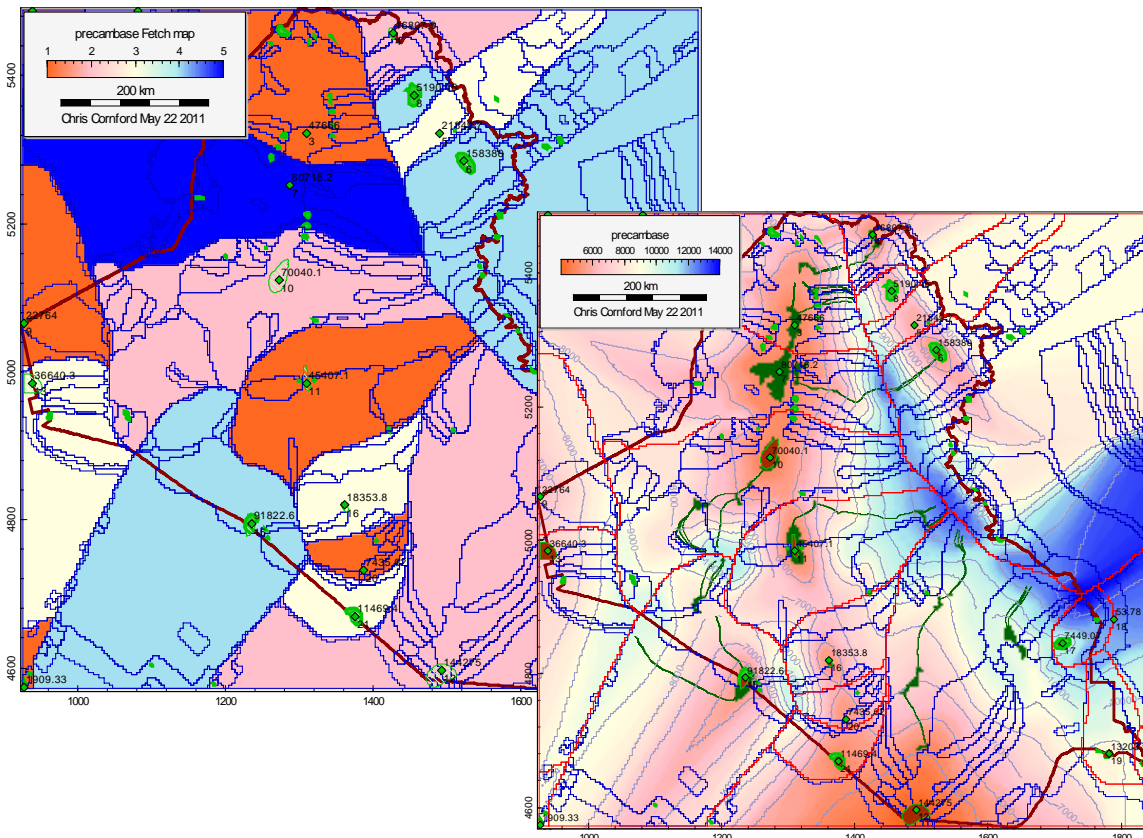
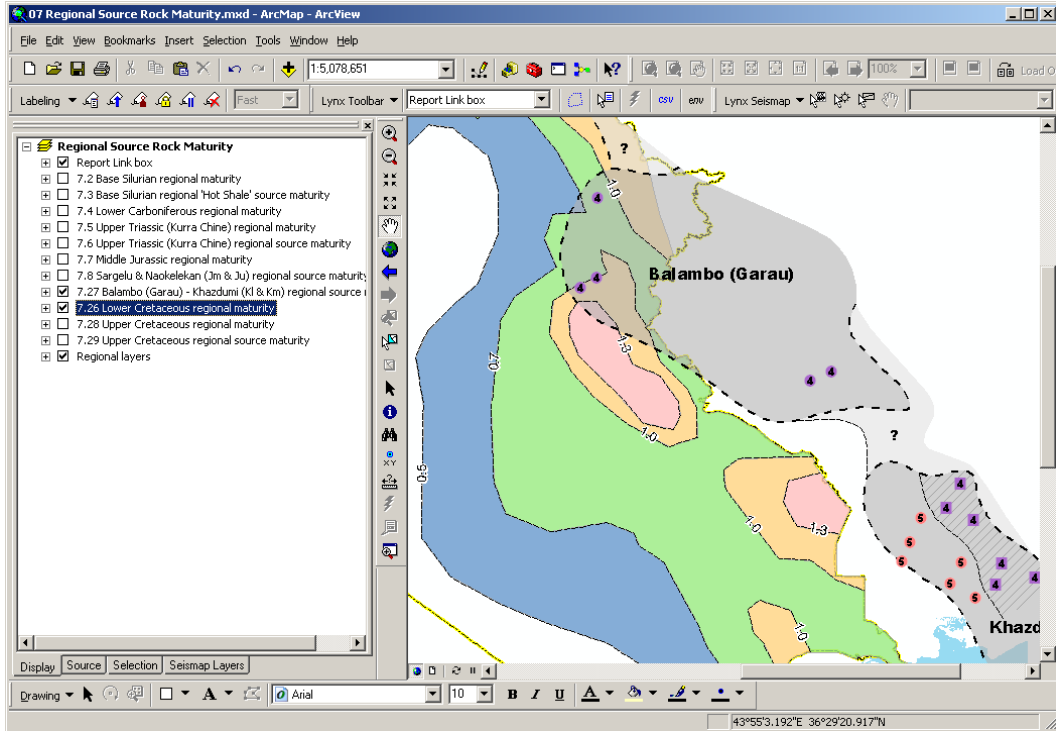
Section 6 Basin History Modelling

Basin History Modelling pulls together the various aspects of the Petroleum Systems as discussed in the previous sections, i.e. source volumes, yields, and via kinetics, generation, followed by expulsion, migration and entrapment. Controls on these processes will be based on GDE mapping and geothermics, together with present and palaeo- basin geometries. The results will place limits on the timing of generation and entrapment, and finally allow prediction of intra reservoir processes such as biodegradation, water washing, asphaltene precipitation, sulphate reduction, cracking, etc.

Basin History reconstruction will be based on a 3-D model constructed using ZetaWare's Trinity T3 application and broad regional grids (Section 2). Rock properties will be consistent with the lithofacies mapping (Section 3), and source rock richness, type and kinetics as concluded in Section 5. The grid-based T3 model will be calibrated using 1-D Genesis models, which will be calibrated with respect to thermal and maturity data (Section 5). The 1-D modelling of key locations is allowing the definition of uplift and erosion events which affect the present and palaeo-geometries of major surfaces. The mapping of uplift is a major objective of this part of the project.

In addition post-charge events will be examined including continued structural growth, uplift & unroofing, loss of seal integrity and re-migration, particularly of gas. These processes lead to the destruction of palaeo (primary)-fields and either to the dispersal of the oil & gas or to concentration in secondary accumulations. Chemical alteration such as biodegradation, cracking and sulphate reduction will be constrained by the thermal aspects of the modelling.

The deliverables will include the individual calibrated Genesis files together with the Trinity project file.



Section 7 Petroleum Systems Analysis

This section integrates the various critical factors discussed in Sections 1 to 6 in as far as they control the regional distribution of hydrocarbons in Iraq, and can be used to predict prospectivity in undrilled areas. This integration brings together:

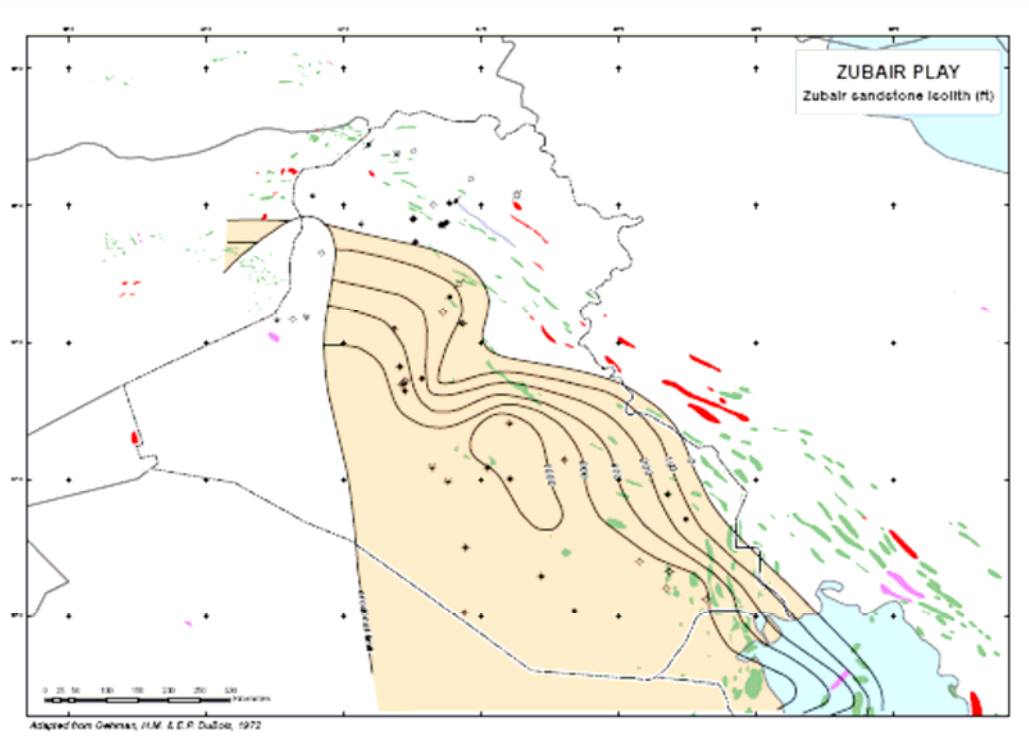
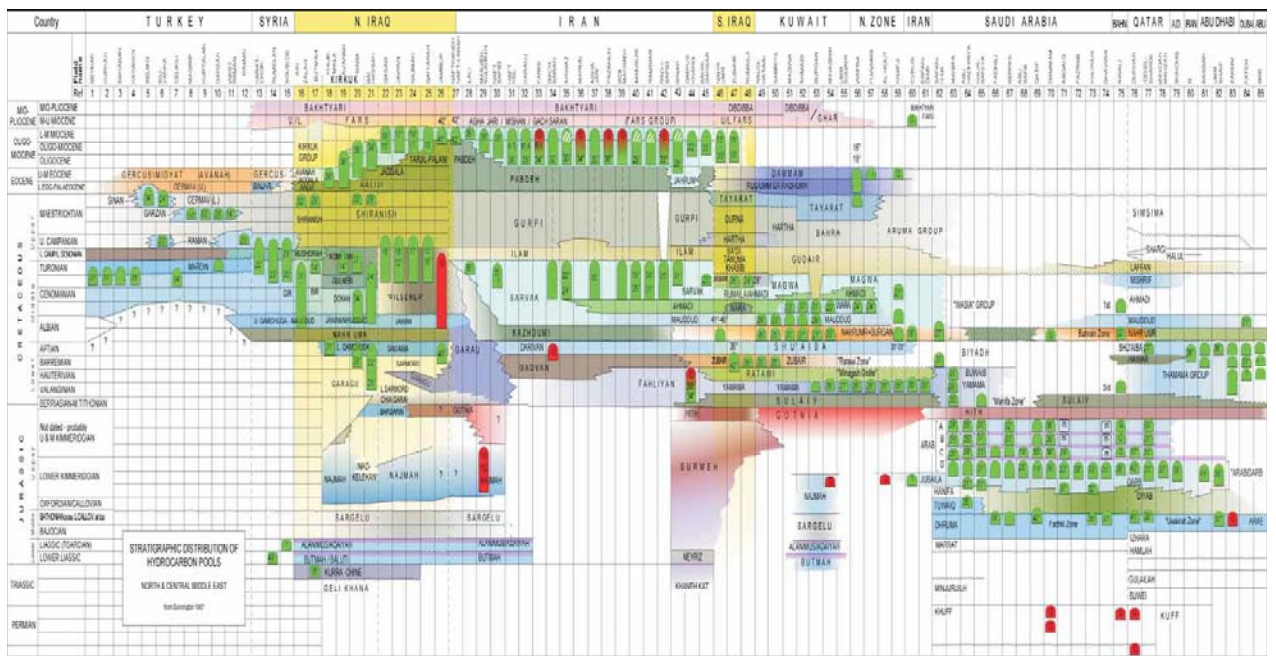
- Regional facies distribution/architecture from Palaeozoic to Neogene
- Geographic distribution, quality and effectiveness of reservoir/seal facies
- Quality and distribution of source facies, source maturation through time
- Generation and expulsion with an estimate of phase and charge timing
- Trapping geometries with seal expressed in terms of petroleum column height
- Severity of post-charge modification processes (alteration/remigration/dispersal)

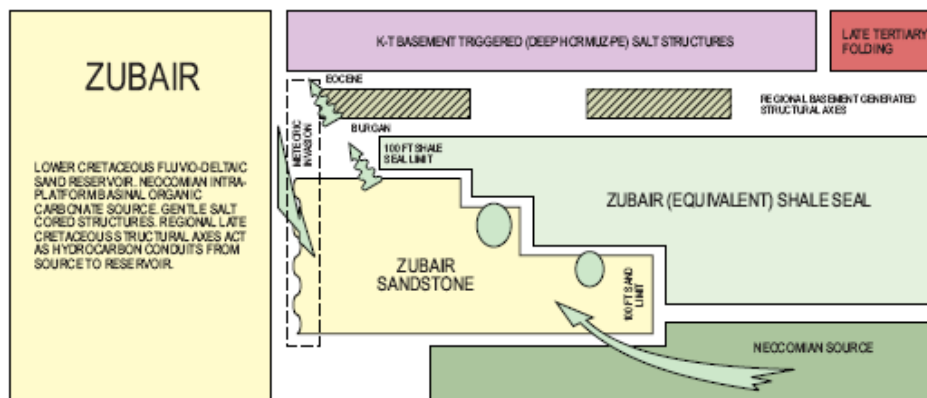
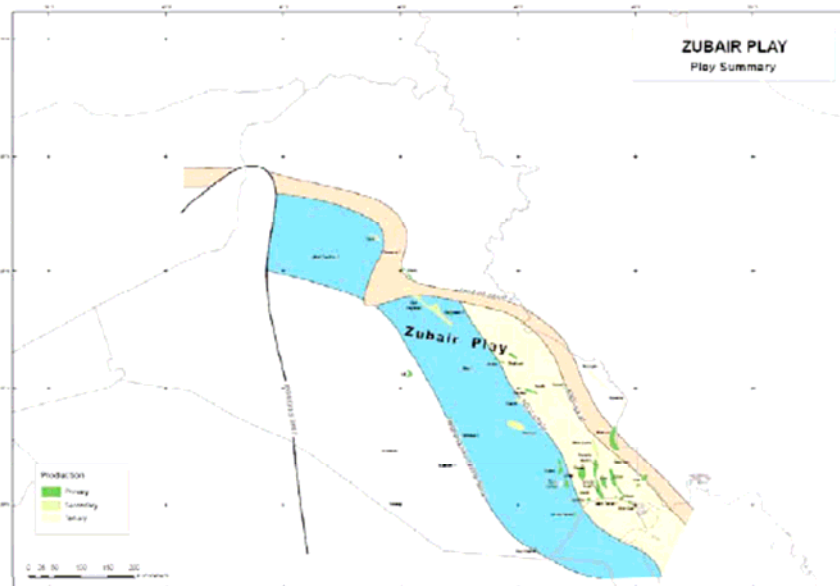
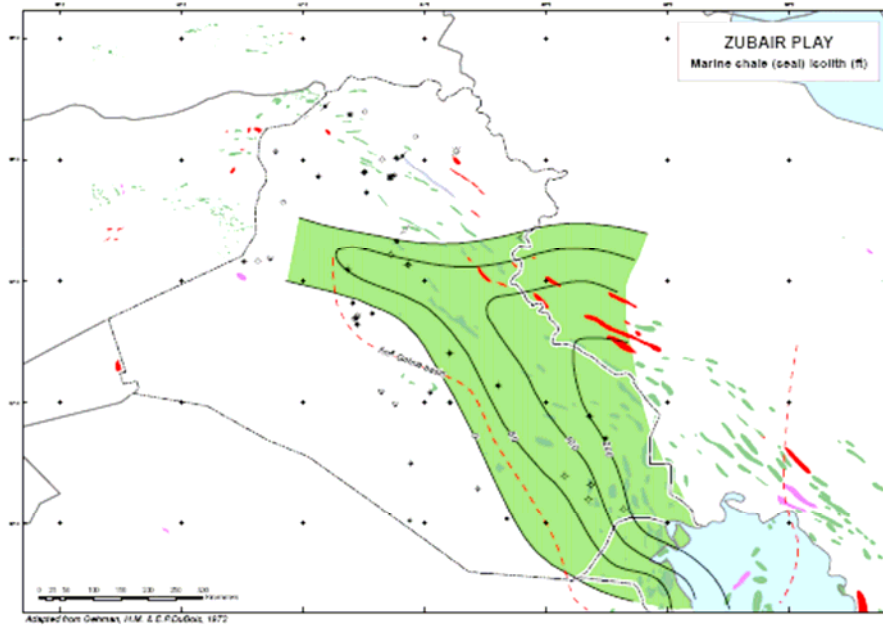
This is summarized in a series of petroleum systems play maps highlighting the most likely areas of hydrocarbon accumulation for the intersection of each source-defined Petroleum System and trap-defined play horizon, as noted in the Introduction.

The greater part of this section will be presented in ArcGIS, with appropriate context-related hyperlinks to support non-spatial information & explanatory text, palaeo-tectonic models and analogue data.

The ArcGIS 'Toolkit' methodology – enabled by specialist plug-in software developed by Lynx – will allow users to overlay maps from look-up lists and assemble information from each section of the study, with the ability to access supportive explanatory text and metadata for each layer. The result is a system which provides the means to critique and adapt each Petroleum System or Play as it is developed. The coupling of data generated from Trinity modelling will provide the 3D aspect to this approach.

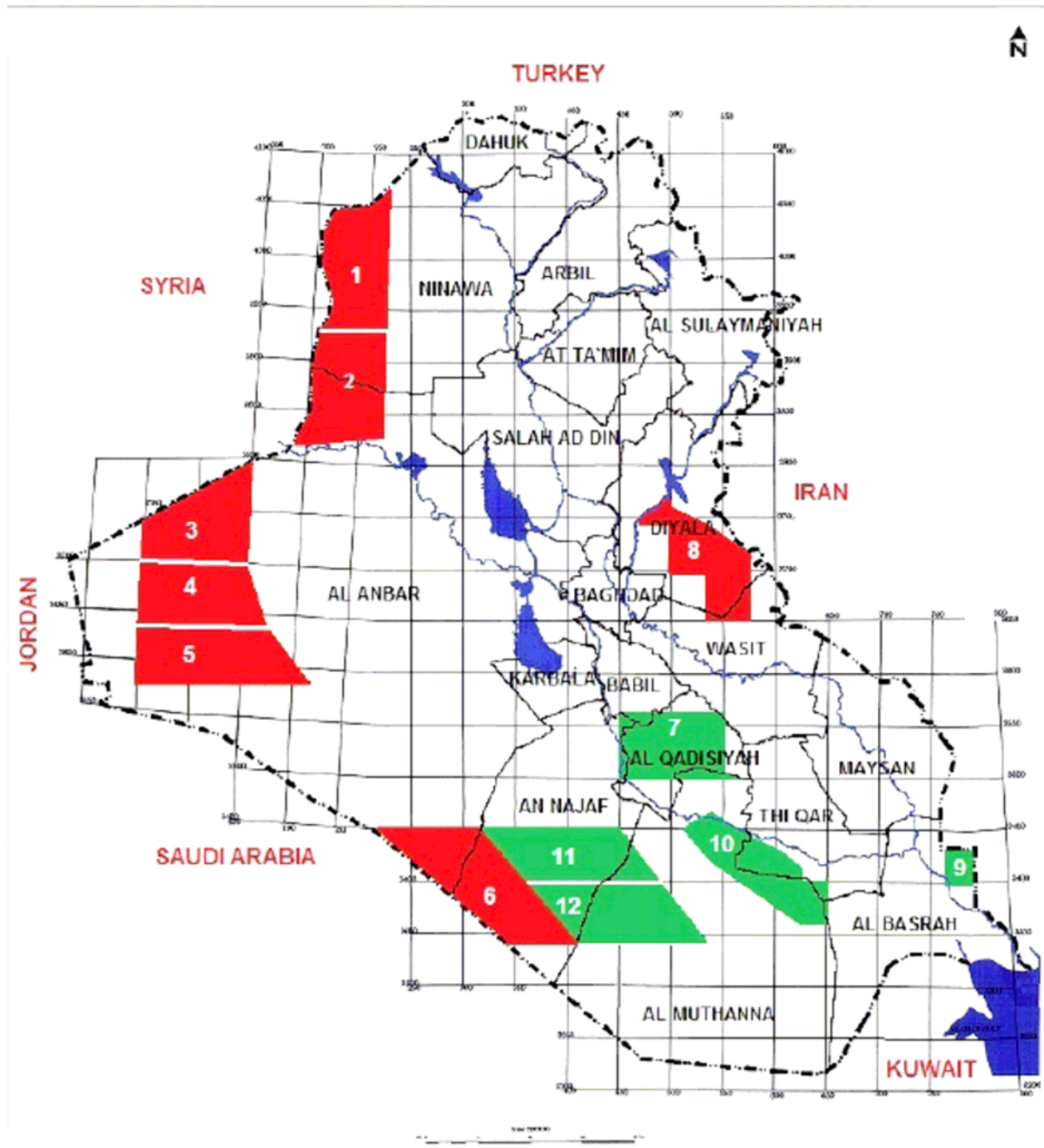
The following images give an example of the Zubair play analysis. In the final project, the elements of every significant play are analysed in a similar way.





Section 8 Evaluation of Exploration Blocks on offer

In an additional stage of analysis and interpretation, each of the 12 exploration blocks on offer in the 4th Licensing Round will be examined in the context of the overall regional Petroleum Systems and Play types defined in the main report.



References

The study references the relevant scientific literature for Iraq and analogues worldwide. The references are hyperlinked to allow quick navigation between text, illustrations and references.

Deliverables

- (1) *Regional lithostratigraphic sections (7)*
- (2) *Regional structural sections (~3)*
- (3) *Regional chronostrat correlations (3)*
- (4) *Regional facies maps (~50)*
- (5) *Regional reservoir horizon summary maps (based on facies maps ~ 5-10)*
- (6) *Regional source rock summary maps (based on facies maps ~ 5)*
- (7) *Regional seal summary maps (based on facies maps)*
- (8) *Facies models / summary sections*
- (9) *Data base(s) for oil and gas distribution (= geographic and stratigraphic), basic reservoir parameters and estimated reserves*
- (10) *Field analogue file (grouping field geology data by play ~ and highlighting them as prospect analogues for each play/system we recognize). Relevant data - open file maps, sections etc)*
- (11) *Source rock characteristics data base (IGI)*
- (12) *Oil type data base (IGI)*
- (13) *Play summaries*
- (14) *'Report' compilation - (A) a pdf version designed along the lines of a PowerPoint presentation (i.e. mostly diagrams with captions arranged in a geologically logical way; (B) the 'ArcGIS' version organised by play fairways (i.e. by significant reservoir horizon)*
- (15) *Geochemical and geothermal database for Iraq and neighbouring regions, compiled from published sources (in p:IGI and Excel formats)*
- (16) *A review of the hydrocarbon potential of relevant source rocks in the project area, including richness and kerogen type, with appropriate graphics for the report*
- (17) *A review of the composition of hydrocarbons in the project area, including relating distinct oil families to their source rocks, with appropriate graphics for the report*
- (18) *1-D models for (~30) drilled wells in Zetaware's Genesis format, and all relevant graphics to be presented in the report*
- (19) *A regional Trinity model in Zetaware's Trinity format, with key outputs presented in the report (source rock maturity maps, estimates of hydrocarbon volumes generated/expelled, migration maps)*
- (20) *Concise technical notes to accompany the graphics in the hard copy report*