ArcGIS in the Oil and Gas Exploration Workflow

Petroleum Development Oman

Authors: Kevin McLay, Roland Muggli, Safia Mazrui
Exploration
Petroleum Development Oman
Presented at the 23rd Annual ESRI International User Conference
(San Diego , July 2003)

Abstract

An oil and gas exploration portfolio contains a multitude of data on potential hydrocarbon accumulations (leads and prospects). Major challenges in managing such a portfolio are that of ensuring data is kept up-to-date, a consistent evaluation with a clear audit trial is applied throughout and that data are available for the ongoing lead/prospect evaluation process. In Petroleum Development Oman's frontier exploration, GIS-based (ArcGIS) portfolio management tools and processes have been introduced to address these challenges.

These tools support the exploration workflow from initial play generation, through data acquisition (e.g. seismic) and onto identification of leads which can then be matured into drill ready prospects. Drill ready prospects can be tested for any potential hydrocarbon accumulations. Key datasets are now either stored and maintained via ArcGIS or made available within it. This includes play, lead and prospect, well, geophysical and geological data. The ability to now evergreen this data, together with the strength of GIS in integrating data, has played a key role in the successful adoption of the technology. Enhanced reporting and analysis is now possible which in turn assist in the quality assurance of the exploration portfolio and the generation of new opportunities.

Key to the successful implementation of GIS tools has been the close cooperation between the geomatics discipline, the evaluation teams and the portfolio managers. This cooperation has ensured the tailoring and adoption of the tools to meet the objectives of the workflow. Having joint ownership has greatly facilitated the rapid development and subsequent deployment of these tools.

The ultimate aim for all parties is that the GIS environment will be used as an effective data and knowledge management system throughout the exploration workflow.

Introduction

In order to first set the scene this paper will start with a brief overview of Petroleum Development Oman (PDO) and the exploration workflow. Utilising the exploration workflow as a template, various examples of tools and processes will then be detailed. The paper concludes by summarising some of the learning points accumulated throughout the process and visiting the various ongoing challenges.

Petroleum Development Oman Overview

PDO LLC is the leading exploration and production company in the Sultanate of Oman.

< The majority of the shares (60%) are owned by the Government of the Sultanate of Oman. The remainder are held by Shell International Exploration and Production (34%), which also acts as the operator, TotalFinaElf (4%) and Partex (Oman) Corporation (2%).

The company employs more than 4,000 staff and has, since 1988, gradually evolved from a company with a functional management to an asset-based company with single point accountability.

The first commercial oil discovery was made in 1962. Since then over 850 exploration and 3,700 development wells have been drilled. The current oil production of 700,000 bbls/d stems from over 40 producing fields with the plan to achieve 800,000 bbls/d by 2007. Figure 1 provides an overview of the PDO concession area together with existing hydrocarbon fields and infrastructure.

The company also produces gas for domestic use in power generation and has, since 2000, started exporting liquefied natural gas (LNG) marking the start for an emerging gas market.

The current estimated volumes within the PDO exploration portfolio stand at approximately 800 Million Barrels of Oil and 6.5 trillion cubic feet (tcf) of Gas.

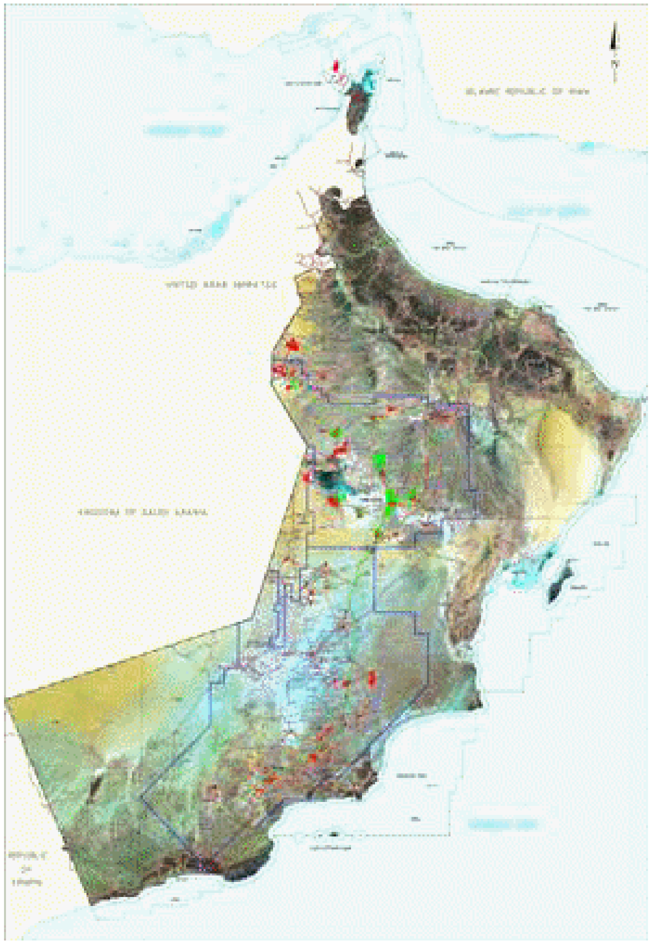


Figure 1: PDO’s Concession Area.

Exploration Workflow Overview

The exploration workflow can be represented as a funnel from play mapping through early lead identification, maturation into prospects, subsequent drilling and discovery with finally booking and handover to production.

Each phase of the funnel feeds the next stage and must be supported by the portfolio.

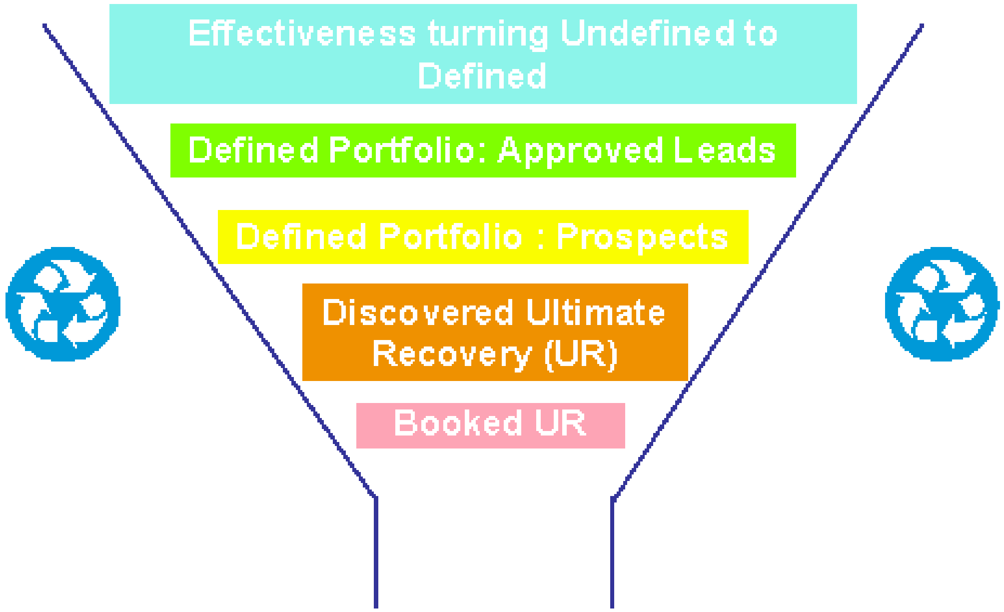


Figure 2: Exploration Workflow (Funnel of Opportunity).

Effectiveness OF turning undefined to defined

The defined portfolio consists of all identified and approved leads and prospects while the undefined portfolio is the remaining unidentified hydrocarbon potential within the concession. Play analysis is undertaken to best identify this undefined potential. A fundamental part of play analysis is data integration and analysis. Data collected and created in this stage is fed into the formal processes for identifying the remaining potential of particular plays.

Prior to covering the process for unidentified potential we will cover some examples of data integration and analysis.

Well Data Integration

A fundamental data source for many types of mapping and analysis, including play analysis, is that of well data. Well data within PDO is held within a proprietary application and database. Making this data dynamically available within ArcGIS has been a major goal for the ongoing success of ArcGIS. A module within ArcGIS has been built that allows predefined queries to be run directly against the well database with results returned into a local geodatabase. With the queries implemented to date, explorationists can quickly and easily produce maps of the following:

- Stratigraphic intervals
- Stratigraphic formations at target depth
- Location of core samples
- Location and presence of hydrocarbon shows and tests
- Location of biozone data

- Porosity distributions
- Gravity variations
- Postdrill analysis results

Results can be displayed in their correct location along the well track or brought to the surface location of the well for general analysis. The well track information is held with the depth as the z unit and along hole depth (AHD) as the measure. With this approach all the results may then be displayed in 3D.

Previous to this application, well data was first selected in the well database interface and exported to Excel prior to importing to ArcGIS. This had many disadvantages, such as the generation of multiple data copies and also it being a very time consuming process for skilled staff.

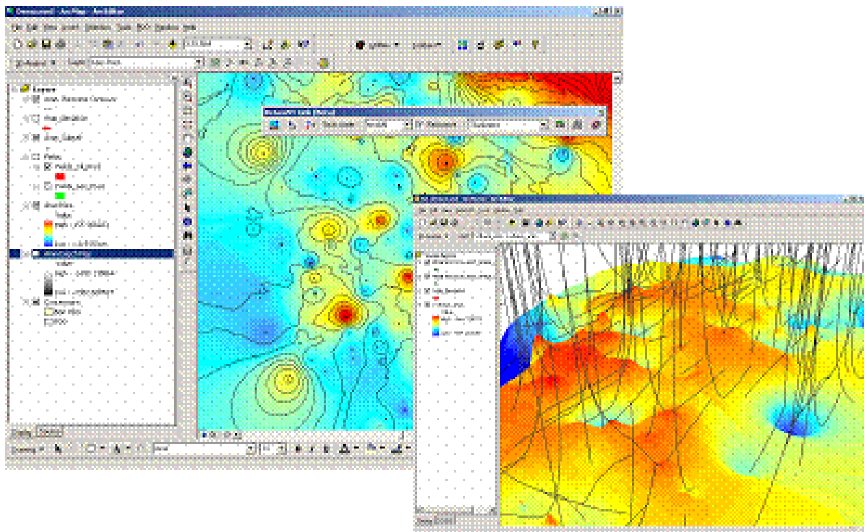


Figure 3: Well Database Module (ArcMap) and a 3D view of well track combined with stratigraphic depth map.

Future plans for this module include the remote launching of individual components within the well database application, such as a well log viewer. This will further integrate well data within ArcGIS.

Geological Mapping

The following two examples highlight the benefits and novel uses of ArcGIS in building understanding of plays:

1. Play Fairway Mapping

By mapping the subcrop formations below an unconformity and subsequently overlaying the mapped supercrop (seal) formation it was possible to enhance the interpretation of potential play fairways. Figure 4 illustrates this with the intersection of the data layers providing the extent of the play fairway. Although relatively simple in GIS terms, the real power of this is in the new ways of working and utilising GIS in the exploration workflow. The ability to easily do this was facilitated by:

- Ability of ArcGIS to extract and display horizon information from the well database.
- Ability of user to easily define and create user-defined data.
- Ability to dynamically overlay multiple data types.

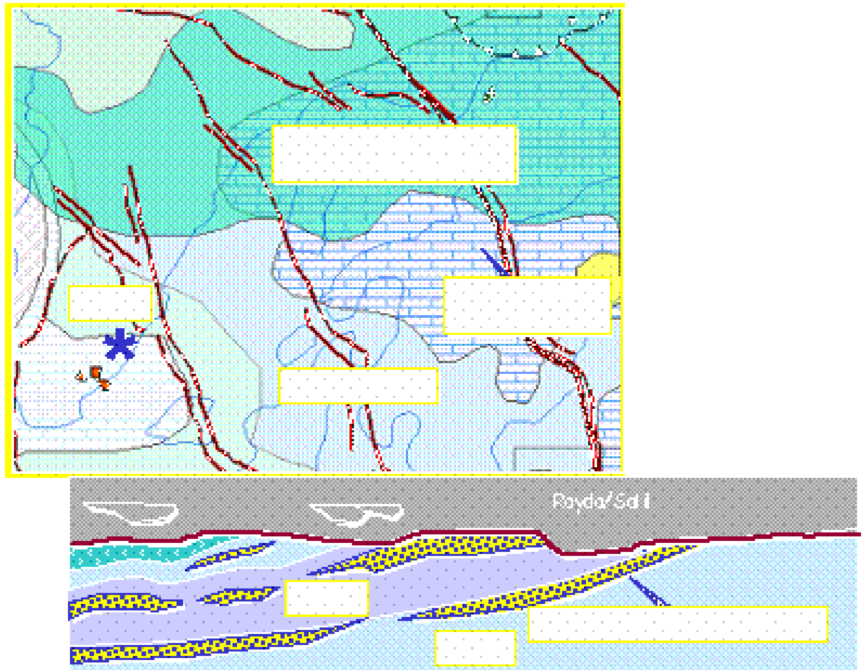


Figure 4: Play Fairway Mapping. Cross section illustrates formation structure.

2. <u>Mapping and Analysis of Trapping Configurations</u>

A fundamental part of play analysis is the identification of potential trapping structures. The following example illustrates mapping and analysis of these structures in ArcGIS.

As before, one of the key datasets is that of well data. The horizons representing the bottom and top of the seals were extracted from the well database. A depth map was created from the horizon depth values and subsequently contoured. In order to better identify the trap, profiling with 3D analyst functionality was conducted (Figure 5). As this area was prone to heavy oils, which are difficult to produce, it was decided to extract gravity measurements from the surrounding wells. Again this data was taken from the corporate well database. A raster gravity map was created and contoured. From this, sweet spots of low gravity oil could be detected and their relationship to the trap identified (Figure 6). This process was used for initial screening and planning for subsequent seismic acquisition.

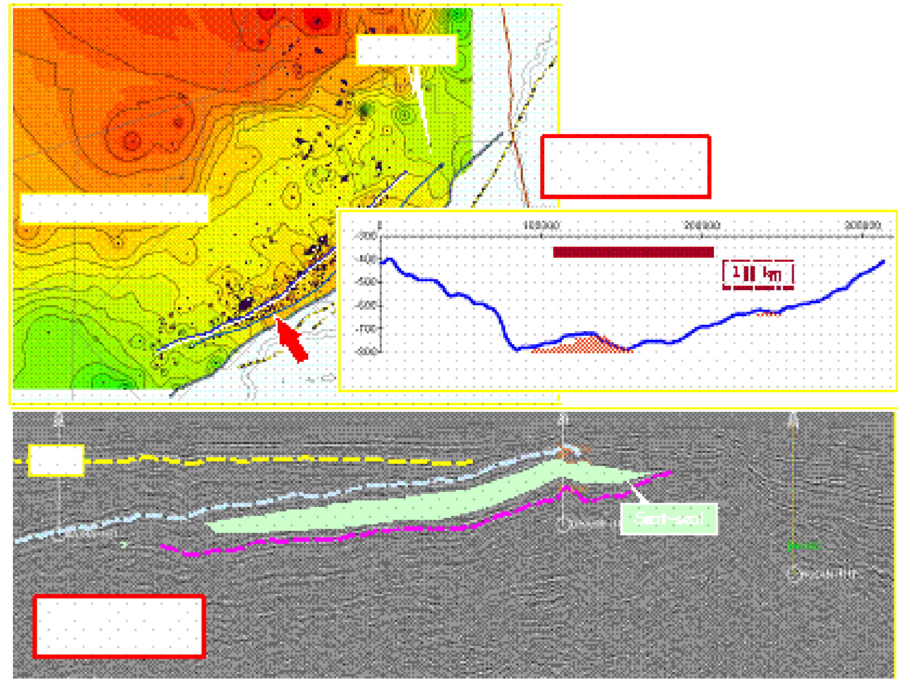
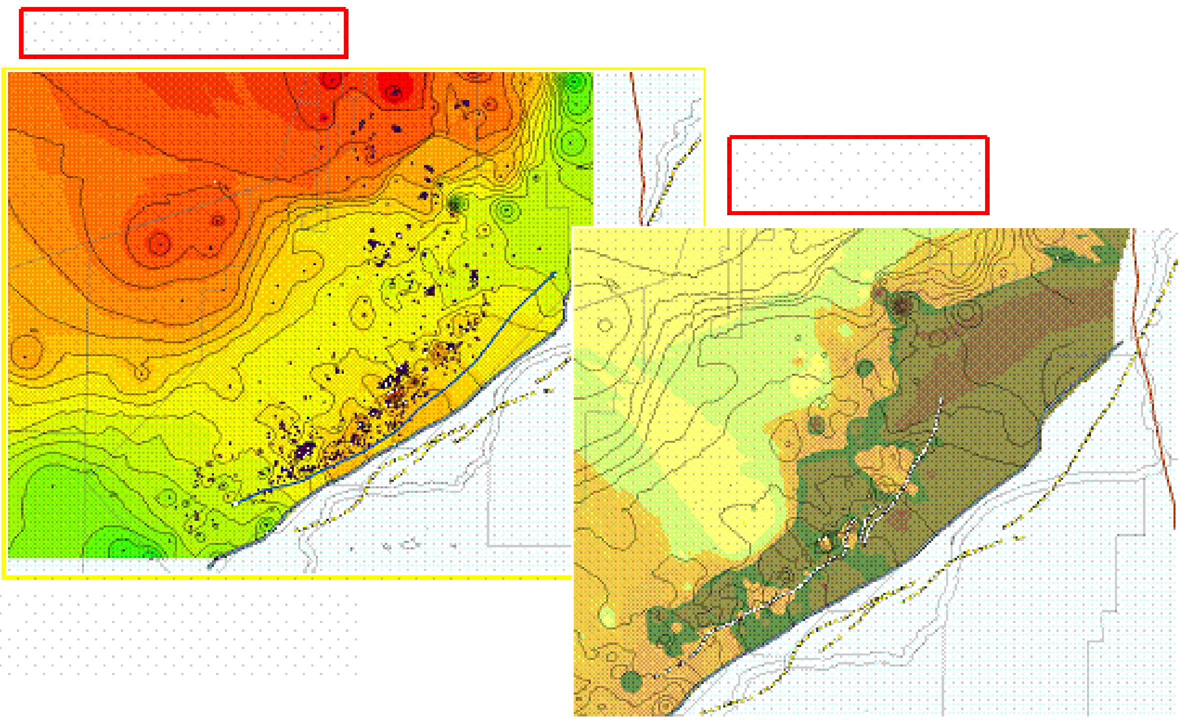


Figure 5: Mapping and analysis of trapping configurations.



Play Analysis

Play data is now managed within an application and database built within ArcGIS. The methodology of the system represents a structured and auditable way to estimate the exploration potential for a given play or basin. It is based upon well-established industry ‘best-practice’ statistical evaluation techniques. With this system in place, play data is now consistently managed, readily accessible for a wide range of additional processes and most importantly, fully auditable.

The basis of this approach is in the interpreter interactively defining Common Risk Segment (CRS) Maps. These CRS maps are polygons with associated Possibility Of Success (POS) factors. CRS maps are commonly defined for chance of seal, charge, reservoir and recovery. These maps are then intersected and further combined with lead density maps to produce final maps that depict statistically generated unidentified hydrocarbon volumes. Data integration is fundamental to this process in order to accurately and consistently define these polygons together with the POS values.

The initial implementation of the play analysis system was, due to an urgent business requirement, built on Arcview 3.2 utilising a series of flat files (shape files) for data storage. The obvious weaknesses of this approach (limited data management structure, no common data model, access security issues) were then addressed by porting it to ArcGIS with data storage in Oracle Spatial. A data model, utilising stratigraphy as a primary key, was developed in conjunction with the Subsurface IT department. The data model is versioned thus allowing play analysis runs from previous years to be stored and subsequently retrieved. In conjunction with the play data, specific audit information is also maintained. This includes user details, time stamps and any calibration data used in the process.

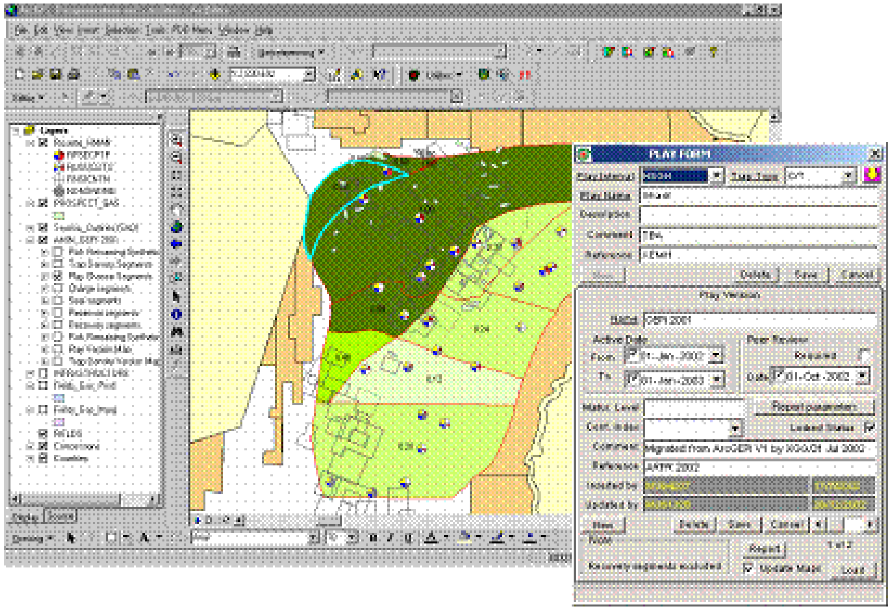


Figure 7: Play Analysis System within ArcGIS.

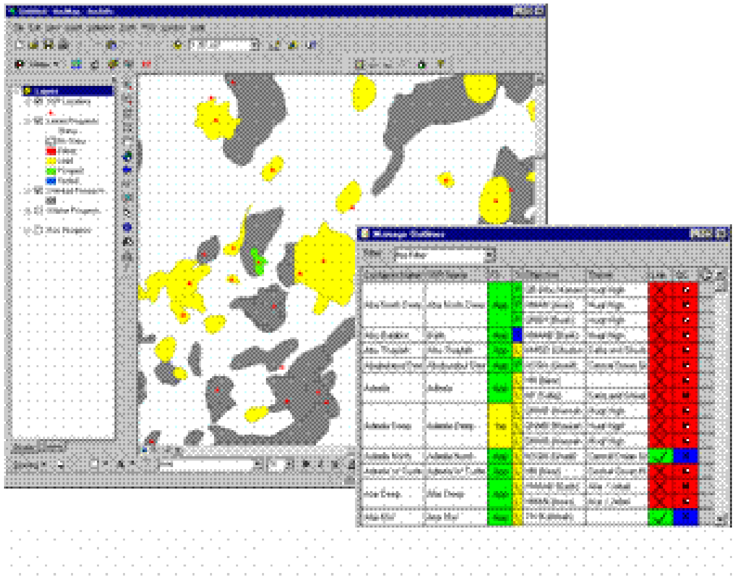
The Arcview 3.2 play analysis system was successfully utilised for 15 plays in the 2001 Annual Report of Petroleum Reserves. Data from the 2001 play analysis runs has now been migrated into the new ArcGIS/Oracle Spatial system. The 2002 play analysis has also been successfully conducted within the new system

Developing and implementing the system in ArcGIS with Oracle Spatial as a storage mechanism posed various challenges. A particular problem was the need to sacrifice some data modelling rules in order to fit the ESRI geodatabases. One particular example is the use of relationships classes as they cannot support the use of composite foreign keys. An additional challenge with the play analysis system, as with many enterprise systems, was the desire to maintain vendor independence in the underlying data structures thus promoting interoperability and data sharing. The specific ESRI versioning implementation, although providing many benefits, constrained this desire. Multi-version views were initially implemented, but due to specific architectural constraints, were not considered fast enough. As a compromise, database compression is undertaken nightly. In terms of ensuring data integrity the main drawback encountered was the lack of acknowledgement of definition queries during the editing process. Awareness of this is essential to prevent serious corruption of your data.

Defined Portfolio Leads & prospects

The defined portfolio is stored and managed in Fastrack, a proprietary Shell database and application. Fastrack primarily concentrates on volume and risk parameters for the analysis of hydrocarbon accumulations. This database and application does not currently support the storage, maintenance and display of lead and prospect outlines.

In order to facilitate all stages of portfolio management it was deemed essential to have geographical outline data closely integrated with this technical data. To achieve this, the prospect module was built within ArcGIS. The prospect module provides a storage location (Oracle) for lead and prospect outlines and dynamically combines the two databases to provide a seamless view within ArcGIS.



Exploration staff can now maintain lead and prospect outlines in direct relation to the Fastrack entries. Detailed prospect data, such as risks and resource characteristics, can be directly accessed, visualised and analysed within ArcGIS. This approach ensures outlines are kept in step with Fastrack entries and facilitates cross portfolio display and analysis.

The prospect module provides the following functionality:

- Management Tool:
    - Reviewing the status of prospect outlines in relation to Fastrack.
    - Linking outlines to Fastrack entries.
    - Managing outlines throughout their lifecycle: add, modify, delete.
- QC and Reporting: determine confidence between Fastrack entries and the outlines.
- Filter Tool: to enhance visualization and analysis, the filter tool allows leads and prospect to be subsetted according to characteristics such as stratigraphy and status.

Important to the ongoing success of this tool is the change in working practises and responsibilities. Ownership, and thus responsibility, for the outlines has passed back into the exploration teams. Previously the geomatics team updated this data. Explorationists must now populate outline information along with the technical details in Fastrack. Focal points have been appointed within all the explorations teams to ensure the evergreening of the portfolio.

The ownership and responsibility for Fastrack presented a particular problem in terms of application architecture. Fastrack is centrally controlled within the Shell group and used at various operating unit sites. As such, it was not immediately possible to alter the underlying data model to support geometries within PDO. In order to accommodate this limitation the outline data is stored in a separate database instance with database links to the Fastrack instance used to provide one seamless database. This merged data is then available within ArcGIS for editing, display and analysis.

The ESRI versioning structure presented further challenges in implementation due to the complexity of the SQL queries involved in extracting detailed lead and prospect information. Using the development tools (ArcObjects) it was possible to maintain the outline data without the use of the versioning structure.

Ideally the outline information should be stored alongside the detailed lead and prospect information in Fastrack. The prospect module application and approach is now being considered as a part of the global lead and prospect database. The Fastrack database would be spatialised and the ArcGIS application would be distributed to relevant operating units.

Portfolio Management

Active portfolio management is an ongoing task that utilises the data generated from all the preceding steps.

With the lead and prospect outlines now consistently managed, portfolio status maps can be produced with a high degree of confidence. These maps are produced quarterly and distributed to all exploration users. To promote consistency, a standard look and feel has been implemented. The portfolio maps depict the current state of the portfolio along with the major relevant geological elements. They are frequently used in planning and strategy meetings and for reporting to shareholders. The maps are an excellent tool to promote and facilitate knowledge sharing.

A further step in dynamic portfolio management is in the definition of clusters. Clusters define a collection of dependant prospects. The dependencies may be based on one or more attributes, for example, stratigraphy, reservoir types etc. Drilling one well within the cluster will have a knock- on effect on risks and potential volumes for other prospects within the cluster. These clusters also provide a means to derive and rank drilling/development programme options. Clusters are defined interactively within ArcGIS and stored centrally. Work is ongoing to further benefit from the dynamic use of these.

As previously mentioned, a critical part of the portfolio is that of auditability. To address this, a web based tool has been built to capture additional metadata regarding leads and prospects. This provides portfolio managers an additional set of key data to prioritize the portfolio and formulate strategy.

Built around ArcIMS and making use of the lead and prospect data from the prospect module, interpreters now capture additional lead and prospect information that otherwise would not be captured in Fastrack. Information includes; seismic crossline and inline sections (rasters), seismic quality indicators, well coverage and team ownership. Based on data input, a confidence index is automatically generated, providing an overall measure of the quality of the prospect. Information captured, as well as providing an audit trial, provides an excellent method for filtering the portfolio.

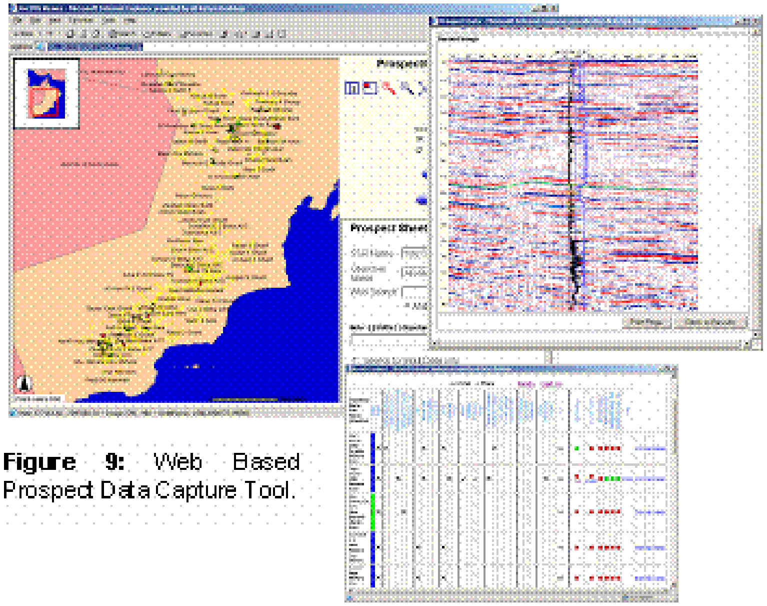


Figure 9: Web Based Prospect Data Capture Tool.

Strategic Framework

The strategic framework represents the basis for both the formulation of an exploration programme and the subsequent targets. It is built up from many elements, all of which require alignment. Reserves addition (finding hydrocarbons) and early time-to-production (developing hydrocarbons) are typically two important strategic aspects to be considered and balanced.

More often than not, when it comes to target settings and resource allocation, a compromise has to be achieved. Frequently, early development options reside in small hydrocarbon accumulations close to existing producing fields. These can be produced relatively fast and easily via the existing infrastructure. Large accumulations however tend to be found off bounds and therefore require a longer lead time to reach production as the hydrocarbon evacuation routes require construction.

A strategy can only be successful if the underlying portfolio is able to support it. In considering this, the notion of an aspired portfolio becomes relevant. This can be defined as the ideal portfolio required for the realisation of the specific strategy. If a large discrepancy exists between the aspired and actual portfolio, then either the strategy needs to be updated or activities are required to move towards the desired portfolio. ArcGIS, together with the data types previously mentioned, is a powerful tool to facilitate this comparison.

Conclusions

The implementation of ArcGIS within the exploration workflow is an ongoing process. Tools developed, although important, are not the critical items. Data is the fundamental component as over time tools will come and go, while data remains a common factor. It is important to note that no matter how technically good the tools are, they are only as good as the users who have the discipline to utilise them and populate the databases.

ArcGIS is a key enabler due to its power to integrate data and its flexibility in allowing users to develop their own workflows. It is the best practise from these workflows, as they develop over time that must be captured and embedded in the formal processes to ensure the initiatives do not die over time.

An all important factor for successful implementation is that of cooperation between disciplines. The GIS/geomatics discipline does not necessarily have the domain expertise for portfolio management. Together with the portfolio managers however, a tailored fit-for-purpose workflow and/or application can be jointly delivered to meet the underlying business requirements. It is of great benefit if the other disciplines have a basic understanding of GIS. Cooperation is also essential with disciplines that manage the underlying infrastructures. This includes Information Technology (IT) and other data management disciplines. Many databases within an enterprise are not under the control of geomatics and cannot be easily modified for spatial entities due to various application dependencies. The GIS applications themselves are becoming more flexible, allowing distributed solutions with web solutions now commonplace. All this, together with locked down desktop environments, demands close cooperation with IT. Together it can all be achieved.

ACKNOWLEDGEMENTS

We wish to acknowledge the support and blessing from the Ministry of Oil and Gas (MOG) and PDO management for permission to publish this paper. We also acknowledge the many colleagues who have contributed to the ongoing implementation of the GIS within Petroleum Development Oman. In particular we would like to thank Pieter Spaak, Jack Filbrandt and all the Geomatics staff. We would also like to acknowledge the support of the Shell GIS Technical Advisory Panel in establishing and promoting GIS within the Shell group.

Glossary

Chance Factor: Probability that an event will materialise; (oil exploration) Probability of finding some hydrocarbons (but not necessarily in commercial quantities). Chance factor = 1 - Risk. See also POS.
Charge chance factor: Probability that hydrocarbon charge generation and migration took place and that the hydrocarbons reached the prospect.
CRS: Common Risk Segment.
Fastrack: A Shell prospect appraisal programme that introduces the capability of handling alternative models of the sub-surface as well as the uncertainty in each model.
Identified Potential: All identified approved leads and prospects.
Lead: Subsurface feature with the potential to have entrapped oil or gas, and which is constrained by at least two intersecting traverses (e.g. seismic lines).
Lead Density Map: Map consisting of polygons representing the lead density within a given area. Lead Density is commonly defined as the number of expected leads per 1000 square kilometres.
Play: A set of common ingredients related to trap, charge, reservoir, seal, and timing that conspire to form similar types of hydrocarbon accumulation.
Portfolio Management: Process by which the (exploration) portfolio is managed to achieve multiple and conflicting objectives. Involves continually testing scenarios for future production growth whilst trying to balance long term and short term requirements, the need to deliver both value and volume, meet cost targets, deliver robust projects with a suitable balance of risk and reward whilst keeping within spending limits.
POS: Probability of Success. POS = 1 - total of all risks.
Prospect: Subsurface feature with the potential to have entrapped oil or gas, and which has a relatively well-defined geometry from available data based on several traverses (e.g. seismic lines).
Recovery chance factor: Probability of recovering hydrocarbons at commercial rates (irrespectively of the size of the accumulation).
Reservoir (presence) chance factor: Probability of the reservoir being present in the prospect area.
Reservoir formation: Vertical subdivision of the total reservoir interval between the top seal and the seat seal.
Seal: Rock layer impermeable to hydrocarbons which either overlies (top seal) or underlies (seat seal) or laterally seals (sealing fault, salt diapir) a reservoir rock.
Seal chance factor: Probability that an effective sealing lithology is present over the structure since the latest charge phase. Seal presence (play), expressing the probability of the seal having been deposited and preserved in the crestal area of the prospect.
Trap: Structure composed of reservoir rock enclosed in sealing rock capable of retaining hydrocarbons
Unidentified Potential: Estimated Undiscovered Resources (play potential) beyond identified prospects and leads.

References

Naylor, M.A. and Spring, L.Y. 2001. Exploration Strategy Development and Performance Management: a Portfolio-based Approach. GeoArabia, v. 6, no. 4.

Author Information

Kevin McLay is currently the Team Leader for the GIS Services section of Geomatics within Petroleum Development Oman (PDO). He graduated from the University of Glasgow in 1990 with a B.Sc. (Hons) in Topographic Science and subsequently worked offshore as a Senior Hydrographic Surveyor for Racal Survey Ltd. until 1994. He completed an M.S.c. in GIS at The University of Edinburgh in 1995 and subsequently joined the GIS Company LaserScan as Technical Support Engineer prior to joining Shell UK Exploration and Production (Expro) in 1997 as a GIS consultant. He is currently on assignment in PDO from Shell UK .

Roland Muggli graduated from the ETH Zurich in 1992 with a M.Sc. in Earth Sciences (Geophysics) and a MBA from Hull Business School in 1999. He joined Shell International Exploration and Production (SIEP) in 1993 and worked initially in the Netherlands (SIEP) and the UK (Shell Expro) as a Seismic Interpreter in Exploration. In 1997 he took on a new assignment in PDO as a Quantitative Seismic Interpreter/Reservoir Characterisation Team Leader before taking over his current position as Head of Exploration Portfolio Management in 2002.

Safia Al Mazrui joined PDO in 1986 with SSLC from Zanzibar . She spend 5 years as a technical assistant in Economics and Planning before spending 4 years in the Qarn Alam Asset Team (North Oman) as a Seismologist Technical Assistant. Since then she has joined the Exploration Department as a seismic interpreter and worked on various plays: Haushi, Kahmah, Huqf and Aruma. In 2002 she worked within the New Opportunity Team as a portfolio and data management focal point. Currently she is working in the Exploration Planning Team. \