

GEO 2010 Abstracts Part III

The following abstracts are a selection from those accepted for presentation at GEO 2010, the Ninth Middle East Geosciences Exhibition and Conference that was held in Bahrain on March 7–10, 2010. GEO 2010 was organized by Arabian Exhibition Management (AEM), the American Association of Petroleum Geologists (AAPG) in collaboration with the European Association of Geoscientists and Engineers (EAGE), and was supported by the Society of Exploration Geophysicists (SEG), Dhahran Geoscience Society (DGS), Bahrain Geoscience Society (BGS), Geological Society of Oman (GSO) and Emirates Society of Geoscience (ESG).

The abstracts that are published here by permission of the organizers represent the third group that primarily cover Exploration and Basin Analysis in the Middle East. The abstracts have been slightly edited and/or reworded so as to conform to a more common style and format; for example, capitalization of formal names for formations, geological periods and stages, etc. Some abstracts required rewording to clarify the scientific content or were submitted as short papers. Every effort was made to present these as concisely and accurately as possible. GeoArabia sent the pre-press version of all the abstracts to the primary authors for their approval, but regrettably some could not be reached or did not respond.

In the next issues of GeoArabia, additional groups of GEO 2010 abstracts will be published so that a permanent record of these important studies is available to GeoArabia's readers and the international geoscience community.

680912 Modeling hydrocarbon generation in north Melut Basin

T.A. Abbas and G. Berttoti

The Melut Basin is a continental rift basin, which experienced three phases of extension from late Cretaceous to Oligocene times. Each phase of extension is associated with thermal subsidence stages and possibly with important episodes of non-deposition and/or erosion. The basin constitutes part of the larger Central Africa Rift system. The Melut Basin is considered to be one of the major hydrocarbon provinces in Sudan and has witnessed substantial exploration activities. During the second rift cycle (Campanian – Maastrichtian) normal faults were reactivated allowing for the deposition of organic-rich shale and claystone in lacustrine, marginal lacustrine and deltaic environments. The organic-rich shale and claystone of the Galhak and Alrenk formations form the principle source rock in the Melut Basin. The source rock kerogen is predominantly derived from lacustrine algae with subordinate terrestrial woody plant debris.

This work attempts to model the hydrocarbon generation of source rocks in the north Melut Basin using Petromod 1-D and 2-D packages. The principle objective is to investigate the temporal and spatial variation of thermal maturity of the Cretaceous source rocks in the Melut Basin. Two seismic sections and six wells were selected for this purpose. One-dimensional models were constructed for all six wells. A database was generated including information about the stratigraphy, lithology, tectonic event and geochemical data. Boundary conditions (paleo-heat flow, paleo-bathymetry and paleo-sediment-water-interface temperature) are deduced. The resultant model was calibrated with the vitrinite reflectance (VRo) and bottom-hole temperature (BHT) data to produce a best fit between the observed and model curves.

Using the knowledge obtained from the 1-D hydrocarbon generation model, two geological cross sections were built from seismic sections, then calibrated and simulated. The resultant models show a considerable correlation in timing of oil generation and expulsion. The Tertiary strata are

immature to marginally mature basin-wide. The Cretaceous source rocks are active at the present day only in basement high areas while in the deep basinal areas these rocks are over mature. Peak oil generation of Alrenk and Galhak formations was attained around 54 Ma and 45 Ma, respectively. The present day transformation ratio (TR) of Alrenk source is between 80–90% implying that this unit converted most of its potentiality to hydrocarbons with very little remaining to be expelled.

726609 Basin analysis and organic source facies studies of the Jurassic – Cretaceous sediments in northern Sinai, Egypt

E.A. Abdelgawad, A.S. Alsharhan, M.M. Lotfy and A.K. El-Saiy

The Sinai Peninsula is bounded by the Suez Canal and Gulf of Suez rift to the west, the transform Dead Sea-Aqaba rift to the east and the Mediterranean passive margin to the north. The stratigraphic section in North Sinai ranges in age from Precambrian to Recent and varies in thickness between 2,000 m, of mostly continental facies in the south, to almost 8,000 m of marine facies in the north. The northern Sinai represents an important hydrocarbon province in Egypt, but the origin of the hydrocarbons and their migration is not fully understood. Structural, stratigraphic and combination traps are encountered in the study area. The North Sinai district has a good oil exploration potential, and only a few plays have been tested.

In this study, we evaluated the organic source facies and assess the results of basin modeling in order to improve our understanding of the regional petroleum system in that region. Organic/inorganic geochemical and petrographic analyses of 80 rock samples ranging in age from Early Jurassic to Cretaceous were accomplished. Most of the studied samples had moderate to high total organic carbon (TOC) contents and a mixture of type II/III kerogen with a wide range of petroleum generation potentials from very poor to very good. Thermal and burial history models indicate that the source rocks entered the early-mature/mature stage in very recent times. The top of the oil window ranges in depth from 3,000 m to 4,300 m, whereas the bottom of the oil window was not reached by most of the studied wells. In combination with numerical modeling results, structure contour maps for key horizons reveal possible migration

trends and prospective areas. We tentatively have identified prospective targets for hydrocarbon exploration in the Cretaceous succession, especially where carbonate build-ups are present.

680851 Downthrown trap infill analysis: Case study from the Melut Basin, Sudan

I.Z. Abdelrahim

Melut Basin is an Early to Late Cretaceous rift basin covered by a thick sequence of non-marine sediments, which vary in age from Cretaceous to Tertiary. Exploration results have indicated a proven hydrocarbon system in both Tertiary and Cretaceous sections. This petroleum system has a perfect assemblage of source, reservoir and top seal. The source is the Cretaceous lacustrine shale of Galhak Formation. The reservoir is the braided stream sandstones of the Yabus Formation, and the top seal is the fluvial shale of the Adar Formation. The majority of traps in the Melut Basin are structural faulted blocks requiring fault seal on one or more bounding faults. Therefore the lateral seal plays a critical role in the assessment of trap infill probability.

In an exploration context, the challenge is to adopt the role that the fault either connects juxtaposed reservoirs or makes a side barrier, preventing escape of hydrocarbon from the lower structure. Effective fault-seal model analysis and calibration depends on the quality of available data. The methodology applied in the analysis of fault-seal potentiality in the Melut Basin encompasses: (1) identifying reservoir juxtaposition areas over the fault surface; (2) using the mapped horizons and refined reservoir stratigraphy defined by isochors at the fault surface; and (3) deriving an empirical relationship between rock type and fault displacement to assess the likelihood of sealing fault rocks being developed. Shale thickness and amount of displacement play an important role to estimate shale gouge ratio (SGR) in the fault zone. Buoyancy pressure profiles are examined to identify which data analysis techniques and seal-failure criteria best predict the observed hydrocarbon contacts in a given area. They can also be used to verify the threshold shale gouge ratio values that represent the onset of fault sealing. Results from hydrocarbon tests of drilled well multiples provide a means for adopting some way of analysis and therefore leads to improved prospect risking.

702213 Hydrocarbon generation potential and source rock characteristics of Upper Jurassic – Lower Cretaceous formations in the southern part of the Mesopotamian Basin (Zubair Subzone), southern Iraq

Q.H. Abeer, S. Heim, A. Alkhafaji and R. Littke

More than 60 core and oil samples from different wells and different oil and gas fields were selected to determine the thermal history, hydrocarbon generation and migration in four important formations from the Upper Jurassic – Lower Cretaceous period of the Mesopotamian Basin (Zubair Subzone), southern Iraq. The study area is situated in the southern part of the basin and covers many important oil and gas fields in the Basrah Province. Only a few detailed geochemical studies on these important petroleum systems have been published so far (Alsaadoni and Aqrawi, 2000). The aim of this study is to get a more thorough understanding of source and reservoir rock characteristics of the Sulaiy, Yamama, Ratawi and Zubair formations. Sediment and oil samples from important oil- and gas-producing fields like Rumaila, Nahr Umr, Subba, Zubair, Ratawi, West Qurnah and Toba were analysed by geochemical and organic petrological methods. TOC-analyses, Rock-Eval pyrolysis as well as gas chromatograph-flame ionization detector (GC-FID) and gas chromatograph-mass spectroscopy (GC-MS) measurements on solvent extracted and fractionated samples were performed. To further estimate the thermal maturity of sedimentary rocks vitrinite reflectance values were measured.

Results of this analytical work show that the studied formations from the Lower Cretaceous succession (Yamama, Ratawi and Zubair) are at a moderate level of maturity, whereas the Upper Jurassic – Lower Cretaceous (Sulaiy Formation) is at a stage of maturity beyond peak oil generation. Most of the samples in the studied formations can be classified as type II/III or type III kerogen. This coincides with a suboxic-anoxic depositional environment of the Sulaiy and Yamama formations; while, the Zubair Formation is suggested to derive from a distal suboxic shelf deltaic environment, and the Ratawi Formation from an inner shelf neritic environment. Due to the high total organic carbon (TOC), S_2 and hydrogen index (HI) values, the Sulaiy Formation is considered to be good petroleum source rock and it is probably responsible for the generation of large quantities of oil in the study area. Detailed molecular geochemical studies revealed variability

in pristane/phytane ratios, CPI (carbon preference index) values and biomarker ratios, both for source rocks and oils. These parameters were further used to establish oil families and to correlate oils with their respective source rocks.

681835 Petroleum system and hydrocarbon potential of deep areas of the Sirte Basin, Libya

I.A. Abulkhair and F.A. El Haj

The Sirte Basin, situated in the north-central part of Libya, is the largest oil producer in Africa. It was developed as a series of NW-trending horsts and grabens (platforms and troughs) during the collapse of the Sirte Arch in Early Cretaceous time. The Sirte Basin covers more than 500,000 square kilometers of north-central Libya with recoverable reserves of 50 billion barrels of oil and about 40 trillion cubic feet (TCF) of gas. The Sirte Basin is considered to be the most prolific basin in Libya. Exploration activities of the Sirte Basin commenced during the late 1950s followed by the first commercial discovery in 1958 (Well A1-32). During the first half of the 1960s most of the giant fields were discovered bringing the Sirte Basin to be among the most oil productive basins in the world. This study is the result of combined geological, geochemical, and basin-modeling studies carried out by the National Oil Corporation of Libya (NOC) and other companies. These studies indicate the presence of several thick formations of organic facies of different ages from the Triassic to Paleocene. There is also a possibility of deeper source rocks that have not yet been penetrated. Various depositional and environmental conditions, as well as different thermal maturities, organic matters, and richness, are reported in these source rocks.

Oil generation in the Sirte Basin started in Eocene time and still continues in the shallower parts of the basin. Hydrocarbon generation was mainly in the trough areas that served as the oil kitchens. Hydrocarbon migration commenced in the Oligocene, with vertical migration along the major trough-bounding faults up to the platform areas. Further migrations were up-dip into the present structural positions. Two major discoveries, North Gialo and Block NC98, were recently made in the deep areas of the Sirte Basin by Waha Oil Company. These are very encouraging indications that high hydrocarbon potential still exists in the deep trough areas to be discovered by the applications of 3-D seismic and detailed sequence stratigraphy. The

estimated hydrocarbon generation and expulsion of the multiple source rocks of the Sirte Basin by far exceed the estimated hydrocarbons found so far (oil-in-place 140 billion barrels and estimated gas-in-place 60 TCF). Therefore, further hydrocarbon discoveries are expected in the form of structures and/or stratigraphic traps particularly in the deep trough areas.

680849 Hydrocarbon discoveries in the Melut Rift Basin, Sudan

H.Z. Adam

The Melut Basin is located in southeast Sudan and is characterized by three rift phases: (1) Early Cretaceous, (2) Late Cretaceous and (3) mid-Tertiary times. The sedimentary infill of the basin was dominated by continental siliclastic sediments mainly deposited in lacustrine and fluvial settings. The structural architecture is characterized by three half grabens known as the north Melut, central Melut and south Melut sub-basins. The trap styles are fault-dependent closures, in terms of faulted anticlines, fault nose, and fault steps.

The source rocks are dark-gray lacustrine shales with patchy distribution and high total organic carbon (TOC), which are found within the Alrenk (Albian) and Galhak (Cenomanian – Santonian) formations. The main reservoir is the Paleocene – Eocene sandstone of the Yabus and Samma formations, which is distributed throughout the basin and pinches-out towards the basin flanks. The Adar Formation is considered the main regional cap rock. It reaches a maximum thickness of about 900 m in the depocentre and gradually decreases in thickness towards the basin flanks.

Hydrocarbon discoveries, which took place in the Melut Basin in the last seven years, constitute a considerable addition to the Sudanese oil reserves. More than 18 major oil fields have been discovered in the Tertiary sandstone reservoirs of the Yabus and Samma formations. The northern Melut sub-basin hosts most of these discoveries, compared with the central and southern parts of the Melut Basin where little success has been made. In 2003 the Melut Basin exploration team discovered a giant oil field, Palouge-Fal, which is considered to be the largest oil field in Sudan. Oil reserves are estimated to be about 4,173 million barrels initially in-place. The net-pay thickness is more than 110 m in the Tertiary Yabus and Samma formations. Subsequent discoveries include Moleeta, Gumry, Nahal, Zarzor, and Mishmish oil fields. During the early exploration phases of the Melut Rift Basin,

90% of the oil reserves were found in conventional traps, while the remaining unconventional traps (stratigraphic and fractured basement) yield significant discoveries in the current exploration phase, such as in the Ruman area.

680643 Precambrian fractured basement reservoirs as a new unconventional oil resource in the Melut Rift Basin, southeastern Sudan

A.E. Adam

The Early Cretaceous Melut Basin is one of the large rift basins that have been identified in central Sudan. The basins are generally NW-striking and exhibit half-graben symmetries. These basins are filled with continental clastic sediments, at some places more than 10 km thick, and are the target for oil and gas exploration. These basins are underlain by Precambrian basement rocks, which crop out mainly in the southwest, centre, and northeast of Sudan. The drilling results revealed that basement rocks underlying the Melut Basin are comprised of various types of granitoids, schist, marble and mafic ultra-mafic materials that are altered in different degrees to serpentine, talc and carbonate materials. Such rocks were regarded as non-reservoirs for a long time and failed to draw the attention of exploration activities.

The oil potential of naturally fractured basement reservoirs in the north Melut Basin is manifested by the discovery of the Ruman-N-2 Well. An attempt has been made by Petrodar Operating Company (PDO) to understand the hydrocarbon production and trapping mechanism in basement rocks. The Ruman North Field represents a structural high in the basement created by fault tectonics. It was generally continuously uplifted for long periods of geologic time and subjected to prolonged periods of weathering and erosion. About 400 barrels of oil per day have been tested from fractures in Precambrian metamorphic basement rocks. The depth of the well is 922 m, with hydrocarbons found between 863 m and 915 m in the basement fractures. The well appears to have only two major contributing open-fracture zones, which were not imaged in the seismic data and are characterized by a decrease in velocity and density, and energy loss in Stoneley response.

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683754 A model for gas migration into the Khuff reservoirs

A.M. Afifi

In the Arabian Gulf region, the distribution of gas accumulations in the Permian – Triassic Khuff Formation roughly coincides with the distribution of the terminal Proterozoic (Ediacaran) – early Cambrian Hormuz salt basins. This is attributed to the breaching of thick shale/carbonate/anhydrite seals at the base of the Khuff Formation by faults that propagated upwards into the Khuff during the initial development of high-relief salt domes. Once gas entered the Khuff reservoirs, it migrated laterally into available structures and also spilled towards the edge of the salt basins, where it was trapped in the initial line of structures along the flanks of the salt basins. For example, the Khuff gas in the Ghawar structure, which is located to the west of the Northern Gulf salt basin, was charged laterally from the northeast by progressive spillage through the Qatif and Abqaiq structures. This is indicated by several lines of evidence such as the absence of Khuff gas in structural closures located to the west, east, and south of Ghawar, the presence of effective seals at the base of the Khuff, and the difficulty in charging the Khuff reservoirs vertically through reactivated Hercynian faults that also trapped gas in the underlying Permian – Carboniferous and Devonian sandstone reservoirs. On a regional scale, this model accounts for the spatial association of the Khuff gas accumulations with the salt basins, and the more widespread presence of gas in Paleozoic (pre-Khuff) reservoirs both within and outside the salt basins.

680573 Evaluating basin-centered gas potential in southwest Ghawar, Saudi Arabia

M.A. Al-Duhailan, M.J. Al-Mahmoud and A.A. Al-Naim

A regional study was conducted to evaluate the potential for a basin-centered gas (BCG) accumulation system in the Silurian – Permian sequence at a basin located southwest of the Ghawar Field. Analyzing the critical interaction between the thermal maturity of the Silurian Qusaiba source rock, the low permeability of the Silurian – Permian reservoir rocks and their relationship with reservoir pressure and fluid type distribution indicates a high potential for an effective basin-centered gas system. Local breaching of the system's effectivity is reflected by the presence of water on the flanks of the basin-

centered gas accumulation and around faults located in the center of the basin. This study uses a newly established evaluation process for generating basin-centered gas-play concepts. The evaluation process focuses on analyzing six critical elements denoted as "BCG System Elements". The BCG System Elements include the thermal maturity of the source rock, proximity to source rock, reservoir quality, abnormality of reservoir pressures, regional fluid distribution, and the affectivity of interactions among these five elements. Finding and evaluating BCG is one of the major challenges for gas exploration in Saudi Arabia, as it would result in substantial addition to the current gas reserves. Promoting the BCG from a play concept to an operational E&P project requires using new paradigms in exploration, drilling and production processes.

680580 Case study: Challenges of ADMA-OPCO's gas well situation in a fracture zone, offshore operations, Abu Dhabi, United Arab Emirates

A.S. Al-Kaabi, H.M. Al-Menhali and K.H. Al-Mansoori

ADMA-OPCO Well Value Assurance Team planned to drill a well that was situated between two faults. The primary objective of the well was to inject 120 MMSCFD of gas in order to achieve the injection target into the Upper Jurassic reservoir. This is one of ADMA-OPCO's key performance indicators (KPIs). The well was fully analyzed and evaluated from an engineering and geoscientist aspect to maximize the value and reduce the drilling risk and reservoir uncertainty. In May 2009, the well was drilled successfully until it reached the Lower Cretaceous zones. Severe mud losses occurred at this level. The team undertook a multi-discipline review of the encountered problems and a series of procedures and options were developed to solve the problem. This multi-discipline teamwork involved the following analysis: (1) petroleum engineering analysis which included well prognosis and drilling actions; (2) geoscientist analysis, which included geophysical and geological data; and (3) reservoir engineering analysis to evaluate reservoir properties in the sections above and immediately below the bit. The purpose of this study is to highlight the importance of integrating many teams to solve such situations and to emphasize the role of the geoscientist in the well drilling and decision-making process. In addition, ADMA-OPCO would like to share the experience of tackling such a challenging situation.

680449 Shargi Shale challenge: From geology to drilling

E. Al-Kharusi

The Fiqa Formation is an argillaceous to carbonate sequence that is present over most of North Oman. It is Late Cretaceous in age and the lower member is a shale unit known as the Shargi Shale (Santonian to Early Campanian). Drilling this sequence has been a challenge for PDO throughout the years. The shale frequently reacts with the drilling mud fluids, although reactions can behave differently in some cases. The amount of time the shales are exposed to the drilling fluids is, however, important since the more the exposure, the more the shales swell, often resulting in caving. The consequences of these drilling issues are an over-sized hole, pack-off tendency, induced losses and a stuck pipe. These frequently result in severe problems in running and cement casing.

Recent technological developments have been introduced and deployed, and future technological improvements are to be implemented. Changes in drilling parameters have resulted in mitigating the effect of caving and changes in well design have allowed the sections to be drilled faster, resulting in less exposure to drill fluids, and a reduction in drilling problems. Significant improvements have been seen in drilling performance in terms of time and cost. The presentation shows case studies based on the experiences gained so far. The case studies are taken from gas exploration drilling in North Oman. They will show how various thicknesses of Shargi Shale in the area were encountered and how each was dealt with. Learning gained from drilling these wells has enabled PDO to reduce shale exposure times, prevent the shales from swelling, and reduce caving into the hole.

705405 An integrated approach involving biomarker and isotope data for oil-to-source rock correlation of Najmah and Sargelu formations, north Kuwait

R. Andriany and A. Al-Khamiss

The Najmah and Sargelu formations of Jurassic age are considered as potential source rocks in Kuwait. A suite of samples consisting of 9 rock extracts from 3 wells in Dhabi, Mutriba and Raudhatain fields and 8 crude oil samples from 5 wells in Dhabi, Bahrah, Umm Niqa, NW Raudhatain and West Minagish in northern Kuwait were selected as representative data to establish oil-

source rocks relationships within the Najmah and Sargelu formations in northern Kuwait. A variety of geochemical parameters including normal alkanes, triterpanes (m/z 191), steranes (m/z 217), carbon isotopes, both saturated and aromatic were employed as main component variables in the statistical approach. The multivariate analysis methods, "Hierarchical Cluster Analysis" (HCA) and "Principle Component Analysis" (PCA), have been adopted to speed up the evaluating and interpreting processes. A series of analytical and interpretation processes were conducted by measuring and selecting a number of accurate molecular (biomarker) and isotopic parameters.

A number of 14 geochemical variables have been employed for the HCA technique. Then they were grouped into 4 clusters of oil and rocks samples. The relationship among clusters on the dendrogram confirmed the high responses in their similarity level. Bahrah and West Minagish crude oils were grouped into a common cluster at similarity level of 94.53, while Umm Niqa and Raudhatain crude oils grouped together in a different cluster by having similarity level of 98.67. These crude oil clusters and source rocks are connected by dendrogram at similarity level of 81.28 providing significant evidence that crude oils were generated from Jurassic source rocks. Continuance approach in PCA technique (14 variables) separates all the samples into three main quadrants. Crude oil samples from Bahrah, West Minagish, Umm Niqa and Raudhatain fall in quadrant-III and slightly different in Principle Component from its precursor of source rocks in quadrant-I. Alterations of the hydrocarbon fluids within the reservoir during the filling history are believed to be responsible for the variations of geochemical characteristics within oil samples.

It is concluded that integrated statistical techniques that utilize a selective suite of sensitive geochemical variables in both biomarker and carbon isotope data are best suited for establishing oil-source rock relationships, classifying oil into genetic families, and also addressing problems of reservoir continuity. Thus, the positive correlation found from the geochemical evidences (biomarker and isotope) are believed to establish and propose the Najmah-Najmah (!) as a prolific Petroleum System in Kuwait.

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701366 Petroleum charge and discharge in the Central Arabian Basin

K.R. Arouri and P.J. Van Laer

With the aim to improve prediction and reduce uncertainty following a number of unexpected results from drilling, an integrated geological-geochemical-modelling approach was employed to untangle a complex filling history in a predominantly gas-producing Palaeozoic system of Saudi Arabia.

The occurrence of light oil of variable condensate-to-gas ratios (CGR) both below and above the field-wide gas-water contact in the Permo-Carboniferous Unayzah reservoir at the Ghazal Field precludes a simple oil-rim setting. Gas-washing, water-washing, biodegradation, oil dropout, and source kitchen variations can all be excluded from exerting major control on CGR, which, instead, appears to be primarily a function of differential charging and discharging, as well as compartmentalization. Whether the basin received petroleum heavier or less mature than that currently being produced (40–50° API; calculated vitrinite reflectance, $R_c \geq 1.1\%$), and the likely fate of that oil remains open to speculation. Fluid inclusions contain only light oil and gas condensate with no evidence for heavier oil. The lack of heavier oil in these inclusions perhaps relates to reservoir temperature (< 90°C) being insufficient to form a significant amount of inclusions of early oil prior to the Late Jurassic. This may partly explain the paradoxically long lag between the inferred onset of black oil generation (Triassic) and light oil accumulation inferred from co-existing aqueous inclusions to have started in the Late Jurassic. Nonetheless, sequential extraction of traces of residual oil adsorbed onto mineral surfaces or trapped in smaller pores provided temporal resolution of oil charges, including evidence for the “missing” oil, with maturities as low as 0.89% R_c .

These results: (1) dispute the belief that less mature oil was never expelled from the Lower Silurian Qusaiba source rock; and (2) suggest the presence of active migration pathways, at least over Ghazal, in Late Jurassic. The presence of a trap at that time is only weakly supported from palinspastic reconstruction, and may need better refined mapping of the overburden. Given the regional geology and maturity trends that suggest charging from south and east, shallower or updip structures located to the west and northwest — where palaeo-oil accumulations may have been displaced or spilled — are good prospects for additional oil.

681093 Petroleum system of the Mesozoic Sab'atayn Basin of Yemen

M.A. As-Saruri and R. Baraba'

The Sab'atayn Basin of Yemen contains Upper Jurassic – Lower Cretaceous syn- and post-rift sediments and includes good source and reservoir rocks. It occurs along a Proterozoic NW-trending Najd Fault zone that was re-activated during the Mesozoic times. The first petroleum discovery in Yemen occurred in 1984 in the Marib sector of the Sab'atayn Basin. This was followed by a second discovery in the Shabwah sector in 1986. However, based on the available data, the Hajr sector indicates good hydrocarbon potential, but no productive field has yet been reported.

The bituminous-rich shale of the Kimmeridgian – Lower Tithonian Madbi Formation represents the predominant source rock, and contains type I and type II kerogens. The organic carbon content is between 1–10% and the hydrogen index reaches 800 mg HC/g TOC. Other source rocks occur in the shale and bituminous limestone of the Layadim and Safir members of the Middle – Upper Tithonian Sab'atayn Formation; they contain type II and type III kerogens with organic carbon content ranging between 0.8% and 4%.

The main reservoir rocks are found in several stratigraphic levels, but the sandstone of the Alif Member of the Sab'atayn Formation represents the main reservoir in the Marib sector. In addition, there are several reservoirs which to date are not studied in detail at all stratigraphic levels (fractured basement, Kuhlan and Shuqrah formations). The fractured metamorphic basement and the turbidite within the Lam Member of the Madbi Formation compose the main reservoirs in the Shabwah sector of the basin. The Tithonian salt is only locally developed and represents good seal in all sectors of the Sab'atayn Basin.

Lithostratigraphic correlations between surface and subsurface sections as well as paleogeography of the depositional environments show the differences and the characterization of the hydrocarbon system in the Sab'atayn Basin and distinguish the lateral and vertical variation and facies changes. The main tectonic trend is the NW-trending Najd Fault System, which plays a significant role in the structuring of the hydrocarbon play. The traps are characterized by structural elements represented by horst, tilted fault blocks and to a lesser extent, stratigraphic traps.

684993 Emerging stratigraphic play opportunities of the Jurassic of Saudi Arabia from enhanced workflow

A.M. Bakhiet, D.Z. Tang, A.E. Gregory, P. Lawrence, A. Ahmed, P. Rabiller, M. Crookes, D. Cadiou, B. Macurda, T. Cacem, G. Debruin and T. Harland

The search for stratigraphic traps especially in carbonates is a challenging task and requires careful detailed analysis of the petroleum system elements. Understanding the spatial relationship between source, reservoir and seal layers constitutes a critical success factor. Building a workflow that transforms well and seismic data into 3-D models allows stratigraphic trap prediction and better understanding of stratigraphic trapping components. With the acquisition of modern 3-D seismic data and the advancement in data analysis software, we are able to build 3-D seismic and electrofacies and porosity models that are tied to well-based information such as cores and well logs. The built 3-D models allow the investigation of the spatial relationships of source, reservoir and seal units.

A cornerstone of our workflow for targeting carbonate stratigraphic traps is to integrate all available data into 3-D models of seismic facies, electrofacies and core data. These models were also transformed to porosity models using relationships from seismic (AI), core-measured and well-log-derived porosities. This allows analysis of the stratigraphic trap in great detail. Highly detailed core data and well-log-defined electrofacies are upscaled and used to calibrate seismic-waveform-based facies. The seismic facies volume generated from a combination of seismic attributes allowed lateral stratigraphic prediction.

A workflow for the deliberate search for carbonate stratigraphic traps includes: (1) stratigraphic and sedimentologic analysis from cores and well logs and building of depositional architecture; (2) stratigraphic modeling and Wheeler diagram construction to track lateral and temporal shifts of depositional facies and electrofacies modeling, which uses a combined analysis of well logs and cores, for facies definition; (3) seismic modeling and analysis to investigate the link of the facies response to seismic; (4) hybrid clustering classification; (5) seismic trace based 3-D model integration of the core lithofacies, the electrofacies, and the seismic facies to produce facies and porosity models; and (6) integration of other petroleum systems elements and visualization of the results. Application of

this workflow to a Jurassic interval in an area in eastern Saudi Arabia has proven that carbonate stratigraphic trap can be predicted thus giving us confidence in pursuing these types of traps.

706232 Inverted basins and deepest discovered oil in the Western Desert of Egypt

A.M. Bakr

Increased oil production from the Western Desert is faced by a decline in oil production in the Gulf of Suez, Egypt. Jurassic – Cretaceous inverted basins play a major role in the recent discoveries in the Western Desert. The recent deepest oil discovered by IPR Group at a depth of 16,000 feet is in one of these inverted basins. It shows excellent reservoir parameters and a very good oil column. Excellent 3-D seismic data quality helped to infer an accurate structure model and calibration to the regional structural framework of the area (Syrian Arc system) are the main contributors, which led to the discovery. This presentation shows a case history for a successful exploration team and an aggressive drilling company.

703877 Prediction of hydrocarbon generation from Lower Silurian hot shale source rocks by using bulk and compositional kinetics results in the Murzuq Basin, southwest Libya

A.A. Belaid, S. Heim, M.M. Ismail, R. di Primio and R. Littke

Organic-rich "hot shales" of the Lower Silurian Tanezzuft Formation are regarded as the principal source rocks for Palaeozoic oil fields in North Africa. Thus, the evolution of the petroleum system of the Murzuq Basin, southern Libya, is largely controlled by the lateral extension, thickness, organic geochemical characteristics and maturity of the Tanezzuft hot shale. In this context the petroleum generation potential of Tanezzuft hot shale samples from the Murzuq Basin was studied by geochemical and petrological methods and a numerical modelling study was performed taking into account the structural evolution and thermal history of this basin.

Core and cutting samples of the Lower Silurian interval were selected from two wells of the northern and central part of Murzuq Basin. High total organic carbon (TOC) content and hydrogen index (HI) values from Rock-Eval pyrolysis indicate organic-rich source rocks with moderately hydrogen-rich organic matter, classified as type II kerogen, at different maturity levels.

To enhance the geochemical source rock characterisation as well as to predict hydrocarbon phases and generation, bulk and phase kinetics were performed by open- and closed-system pyrolysis. The bulk kinetic analysis confirmed the early to mid-mature level for the northern part, and immature to early mature level for the central part of the basin. The activation energy distribution for the samples is characterised by a smooth bell-shaped, Gaussian-like distribution, typical of marine type II kerogen. Temperature and timing of petroleum generation were calculated using activation energies and frequency factors with a linear geological heating rate of 3.3 K/My. The compositional kinetic analysis was performed to assess the composition of generated petroleum. The results show that 75% of hydrocarbons are generated as oil and 25% as gas. The gas-oil ratio was calculated and found to increase with increasing maturity.

681056 A basin modeling approach to understanding the heavy oil occurrence in Burgan Sand of Cretaceous age, Burgan Field, Kuwait

M. Bhattacharya

At the base of the Burgan oil column, near the oil-water contact (OWC), a zone of significantly heavier oil column has been observed in some of the wells. A study was undertaken with respect to the heavy oil occurrence to assess the possible processes that could lead to the formation of heavy oil in the Cretaceous reservoirs of the Burgan and Wara formations. The occurrence of heavy oil in the Greater Burgan Field can be explained by a combination of multiple processes.

The study demonstrated hydrocarbon charging by two possible source rocks. Besides the well-known Makhul source, the role of the Kazhdumi source in charging the reservoir was brought to the fore. The Kazhdumi Formation, a time equivalent of the Burgan Formation, was deposited in a more distal area of the Dezful Embayment of the Zagros Fold Belt northeast of Kuwait and is a proven, good to excellent source rock, in the Iranian Zagros Fold Belt.

The initial charge history causes a special distribution of heavy components in the Greater Burgan Field, which might be the reason for the occurrence of heavy oil mainly in the high permeable layers. As these components are transported in a liquid phase, additional processes are needed to explain the heavy oil distribution.

There are strong hints, that water washing, supported by the strong edge water drive, can explain the occurrence of heavy oil in several wells that are positioned in areas of a paleo oil-water contact. Long preservation times of the main accumulations in the Burgan, Magawa and Ahmadi fields are likely to cause gravity segregation within the oil columns of these older accumulations. Biodegradation is believed to have only a limited influence on the heavy oil occurrence. This study will provide an in-depth insight into the heavy oil distribution in the Greater Burgan Field, a key element in the future development plan.

678396 Portfolio rejuvenation in a mature hydrocarbon province, Sultanate of Oman

A. Brandenburg, S. Kindy, S. Scholten, T. Johnson, W. Wilks, K. de Leeuw, F.A. Neves, P. Matheny and J. Schreurs

The Sultanate of Oman has seen over 50 years of exploration and over 40 years of oil production. The petroleum systems span over 800 million years of geological rock record, and over 40 plays have been identified. It comes as no surprise that most of the structural plays are heavily creamed. PDO exploration has continued to be successful in this mature but prolific hydrocarbon basin, by sustained effort and focus on rejuvenating the portfolio. Significant potential remains in stratigraphic traps, deep plays and unconventional hydrocarbon systems. Technology and play-based exploration are seen as key enablers to deliver this potential.

3-D seismic capabilities within PDO are undergoing a revolution at the moment. An aggressive exploration campaign acquiring over 8,000 sq km of high quality 3-D seismic to unlock the potential of pre-salt and intra-salt plays is underway. The step change in seismic imaging quality combined with new quantitative interpretation methods are essential components not just in salt related plays but also in delineating stratigraphic traps within the shallower plays. Alternative delineation methods also considered are novel drilling techniques and non-seismic geophysical techniques.

New technologies, in combination with regional play-based evaluation, have resulted in the identification and high grading of several attractive new play segments: (1) a thrust faulted play segment within the yet to be proven pre-salt play; (2) a northwards extension of the prolific intra-salt stringer play; (3) an extension of the challenging

intra-salt Athel silicilyte play; and (4) a stratigraphic play segment within the Gharif.

680065 Challenges and strategies for near-surface modeling for static corrections

R.M. Bridle

Understanding the geology is vital in modeling the near-surface. The geophysical implications are rapidly varying vertical and lateral velocities, complete with velocity inversions. Modeling strategies include elevation correction with sand dune term, and use of refraction statics and tomography. The modeling challenges include shingling, acquisition geometry, long wavelength and imaging of complex structures. Shingling is a near-surface generated en-echelon effect due to shallow inversions, outcropping refractors, multiple fast thin refractors, or interference. Shingling creates medium and long wavelength anomalies due to poor definition of the layer velocity field. Strategies for model building include picking a consistent refractor and averaging all shallow layers as a single weathering layer.

The recording of near offsets is very important not only for data processing, but also for refraction tomography. Should the near offsets be unavailable then the under-sampled lateral velocity variations will be propagated down into the model. For refraction statics the loss of those offsets creates poor models unless middle or far offsets are picked for time arrivals. Where receivers are laid around an obstruction, the receiver offsets have larger travel times, which can be interpreted as time delays due to low velocity material. Time sections may display near-surface features that increase in magnitude with depth. In this study, a time section will display four major features with an apex at 800 msec. At each of these apexes there is the characteristic "bow tie," of a buried focus point. These anomalies are not corrected by near-surface static corrections. Examination of a source gather shows no additional travel times on the first arrivals. A dynamic correction is required which depends on offset. Pre-stack migration and analysis involving techniques such as redatuming or common focal point processing is the solution for this issue.

Near-surface problems are caused by unconsolidated material and geology. Understanding the causes of the challenges is essential in knowing how to solve them. There is not a single solution to modeling the near-surface successfully everywhere. The physics of the regolith

must dictate strategic modeling decisions, such as the avoidance of refraction methods where there are velocity inversions. Finally, even with a perfect near-surface model, there may still be time imaging problems due to buried paleo-geomorphology.

705364 An integrated analysis for the reassessment of hydrocarbon potential of a low prospect area: A case study from the Jurassic Marrat reservoir of the Burgan structure in southeast Kuwait

A.K. Dey, S. Kumar, N.C. Banik, H. Al-Amman and B. Khan

Recent discoveries of hydrocarbon from the Jurassic section in different parts of Kuwait necessitated a re-examination of Jurassic prospects of the Burgan area in light of better understanding of different elements of the hydrocarbon system defining the Jurassic play fairway. An integrated study focused on interpretation of 3-D seismic, fracture, sequence stratigraphy and analysis of reservoir engineering data has enhanced the prospectivity of the Jurassic Marrat sediment over the Burgan structure. The study brings out the structural features that are in sharp contrast to the earlier subsurface picture. Three sets of faults divide the main Burgan structure into seven different blocks. Earlier drilling activities were confined to four blocks leaving the other three blocks totally untested and unexplored. Petrophysical analysis identified two sections in the Middle Marrat as hydrocarbon bearing. The upper section was the better prospect and was tested in five out of six previously drilled wells, but none of the wells threw any light on the oil-water contact (OWC). The reservoir engineering data supplemented with petrophysics and structural synthesis marks three probable OWCs. A section in the lower part of the Middle Marrat, approximately 250 ft below the deepest inferred OWC, was tested in one well and found to be oil bearing. The well was found to be drilled 150 ft down the structure and as a result the potential of this section could not be properly ascertained from previous exploratory efforts. The presence of an equally prospective equivalent sedimentary section in other drilled wells enhances the Middle Marrat prospect. Sequence-stratigraphic analysis identifies the hydrocarbon-bearing zones as part of a highstand systems tract that continues laterally towards the north into the Magwa Field. The present study has demonstrated the necessity of reassessment of hydrocarbon prospects for partially explored areas by continuous revision incorporating the latest data sets, experiences, concepts and technological advancements.

680450 Meeting today's exploration and development challenges with wide azimuth seismic acquisition

F.R. Ebiwonjumi, Z. Rawahi, C. van Eden, M. Mazrui and M. Healey

Recent challenges in the global economy call for efficiency in all aspects of oil and gas exploration and exploitation processes. The South Oman Salt Basin is comprised of a basin-fill complex with a 7-km-thick mixture of clastics, carbonates and evaporites deposited over a period of 600 million years. The prospective sequence of isolated Ara carbonate stringers occurs near the base of the mobile Ara Group evaporites that constitute the main structural control on both intra-salt and post-salt deposits. The area lacked good quality seismic data for consistent interpretation of the self-sourced Ara carbonate stringers. The low confidence in seismic picks, culminating in broad depth uncertainty ranges, in prospecting for the sometimes tectonically altered stringers necessitated a new fit-for-purpose seismic. The recent acquisition of wide azimuth (WAZ) seismic data over the greater Birba area brought relief in exploring and developing the Ara play. By deploying receivers over a large area (8 x 12 km), the WAZ geometry allows sampling of the complete wave-front reflected from the subsurface. This improvement comes with the associated challenge of multi-data cube interpretation, huge IT infrastructure requirements and the need for 24-hour operations. Evaluation of the WAZ seismic (first delivery) showed improvement in ease of interpretation (loop definition and continuity), better structural definition, enhanced attributes (frequency and amplitude) and improved well-to-seismic matches. This implies a more consistent interpretation of top salt with the added value of an improved depth conversion of the intra-salt carbonate stringers. The new WAZ seismic data increased the confidence in the exploration and development evaluation of the Ara stringer play. The improved subsurface imaging will enhance our subsurface de-risking efficiency.

679670 Drilling the longest horizontal well in the history of Kuwait using state of the art technologies

T.M. El Gezeeri, K. Al-Anezi, F. Al-Saqran, O.S. Oyeyemi, E. Archibong, P. Morice and J. Maalouf

The Minagish Field, in West Kuwait, is a North-South trending asymmetrical anticline, dipping from east to west with hydrocarbons contained

in six major reservoirs ranging in age from Early Jurassic to Late Cretaceous. Mishrif is a tight, fractured carbonate reservoir of Upper Cretaceous age developed in a shallow-marine depositional environment. The observed porosity in the upper reservoir layers ranges between 10–30%. The permeability measured from vertical wells is less than 17 milli Darcy. The second Mishrif layer is a fairly high porous peloidal packstone to grainstone sequence, composed of several mechanical sub-layers, mostly fractured and vuggy at the upper 15 feet “dual porosity system”. Production from this particular layer is related to the degree of fracture clustering, corridors and open faults which enhance the permeability of the layer, thereby making it a good prospect for horizontal well placement.

A high geological risk in horizontal drilling is coming from the formation dip uncertainties, which were expected to vary between 2.5–3° upward up to 4–5° downward, with an intensity increase close to the highly faulted areas. Due to the well complexity and uncertainties expected in real time drilling, the logging while drilling (LWD) tools selection for the lateral section were based on providing in real time solutions from deep directional measurements and inversion from the distance to boundary tool primarily and the formation dip information, fractures and faults identification from the resistivity images. In addition, other tools selected provide the basic petrophysical measurements such as gamma-ray, resistivity and density-porosity logs.

The company achieved a landmark in horizontal drilling with its third Mishrif horizontal well. The horizontal section at a length of 5,312 feet was geo-steered in the sweet spot of the upper-most part of the Mishrif layer 2 (about 5–10 feet thick) using the most advanced technologies and high-resolution Q-seismic data.

738973 Data mining in identifying carbonate lithofacies from well logs based on extreme learning and support vector machines

E.A. El-Sebakhy, O. Asparouhov, A. Abdulraheem, A. Al-Majed, D. Wu and K. Latinski

This research investigates the capabilities of data mining in identifying carbonate lithofacies from well logs based on extreme learning and support vector machines. Formation facies usually influence hydrocarbon movement and distribution. Identifying geological formation facies is critical for economic success of reservoir management and development. The identification of various facies, however, is a very complex problem due to the

fact that most reservoirs show different degrees of heterogeneity. In the last decade there has been an intense interest in the use of both, computational intelligence and softcomputing learning schemes, in the field of oil and gas exploration and production to identify and predict permeability and porosity, identify flow regimes, and predict reservoir characteristics. However, most of these learning schemes suffer from numerous important shortcomings. This study explores the use of both extreme learning and support vector machine systems to identify geological formation facies from well logs. Comparative studies are carried out to compare the performance of both extreme learning and support vector machines with the most common empirical and statistical predictive modeling schemes using both real-world industry databases and simulation studies. We discuss how the new approach is reliable and efficient, outperforms, and is more economical than the conventional method.

680733 Risk and portfolio management for exploration and development with SAP-PPM

A. Emmerich and G. Weissmüller

Handling exploration and production portfolios in the upstream oil and gas industry involves assessing risk or chance of success, overall timing, availability of resources or equipment and balancing large investments with possible revenues. This analysis in a multidimensional space is most often a task carried out by entire departments or groups of individuals in oil and gas companies. Corporate standards hereby usually form a framework to ensure assessment and ranking of projects with constant quality and objectiveness. In most cases, the ranking of these exploration and development projects and subsequent decisions drive a company's strategy over years. Hence a portfolio process and toolset that both provide visibility and transparency across all influencing factors and input parameters are required.

A portfolio decision-making process was developed following years of best practice research within the largest oil and gas companies. The underlying process is based on a common assessment of the chance of geological, drilling/completion and economical success. The objectivity of the overall process is assured by questionnaires enabled for true company-wide collaboration, e.g. in peer-review teams as well as by rigid decision milestones. In portfolio management, this process is being tracked, overall quality assured, results analysed and later on published to the upper

management. However, those - nevertheless important - non-financial and financial key performance indicators (KPIs) most often blur the sight on the proper risk of projects. And in many cases the correct ranking in which projects should be executed is not determined. A proper risk and portfolio management process takes into consideration the skill level and the availability of appropriate resources and or equipment. This fact is overlooked in many exploration and development projects where timely project execution is essential. In addition to that, many companies handle portfolio management in quite different ways and qualities on a global scale. Risk is not assessed in the same manner and how it should have been in the different subsidiaries of leading E&P companies. In order to avoid such a biased ranking of E&P projects, a centralised corporate risk and portfolio solution is required. This will ultimately result in greater success and increased reserves as well as better on-time project delivery.

680375 Komombo: A new oil province in Upper Egypt

M. Fathy, L. Salvadori, G. Roberts and M. Abu Gouda

The presentation discusses some of the geological and geophysical work performed in Centurion's Block 2 concession area in Upper Egypt, which resulted in the discovery of the Al Baraka Field in 2007, and led to the opening up of a new petroleum province in the Mesozoic rift basins of Upper Egypt. The Komombo Block-2 Concession is located on the west bank of the Nile River, about 570 km SSE of Cairo, and about 260 km east of the Red Sea. It was part of a larger former Repsol concession that was relinquished in 2001 after the drilling of five wells. Sediments in the Upper Egypt basin are present in distinct depositional depressions separated by low uplifts or platform areas. Basins formed in the Jurassic – Lower Cretaceous as non-marine rifts. The three Komombo wells drilled by Repsol are located in a NW-SE trending half-graben. All three wells had oil shows but were not commercial.

After Centurion obtained exploration rights on Komombo Block 2 in 2004, the coarse 2-D seismic grid was infilled with additional 2-D seismic. Seismic processing of the data sets which was undertaken by Spectrum-Geopex in Cairo, benefited from coherent noise reduction, tomographic statics and pre-stack time migration; allowing the geoscientist to identify structures not previously seen on the original data. A surface

geological mapping project and a basin analysis study were also undertaken. Based on analysis of the newly processed seismic data, Centurion identified a number of leads and decided to drill Komombo-4, later renamed Al Baraka-1. This well was drilled in 2007 to test the potential of Jurassic and Cretaceous reservoirs. Testing of the Early Cretaceous Abu Ballas Formation produced 150 b/d of 37° API oil - with a wax content similar to that of Sudan. The well, drilled to 8,712 feet, penetrating several oil-bearing zones. It tested from three additional intervals in the deeper Lower Cretaceous section.

The Al Baraka well has produced the first oil (ever) deep in Upper Egypt. Four months from discovery, the first crude shipment was delivered on December 27, 2007, to Asyut refinery, 320 km away. The quality of the processed seismic data played an important role in the analysis of the area, with the drilling results proving a working hydrocarbon system with significant exploration potential. The find has helped to speed up economic development in Upper Egypt, which is outside of the country's traditional producing areas. The field has been reported to be producing at 6,000 b/d.

728683 The use of passive adsorbents for the assessment of hydrocarbon charge in the shallow waters around Bahrain

R. Fenstermacher and N. Qassim

This document will summarize the efforts to assess hydrocarbon charge in the shallow waters around Bahrain. Shallow water presents a challenge for the exploration and prospect development of hydrocarbon reserves. The surf zone is a high-energy environment that is frequently avoided due to the expense of seismic acquisition in these water depths.

To help overcome the exploration uncertainty presented by these shallow transition areas, divers deployed over 800 passive devices in the sediment for the collection and assessment of geochemical data as part of this reconnaissance survey. The passive adsorbents were embedded in the sediment to a depth of 10–20 cm, and left in place for an average of 17 days. Samples were deployed in four separate areas with an average distance between points of approximately 1 km. The water depths ranged from less than 1 meter to approximately 20 meters in the deepest block. Many of the samples were embedded near living coral reef with no disturbance to this sensitive habitat, supporting the premise that this technique is environmentally

neutral and does not significantly affect even the most highly sensitive habitats. Samples were also placed around select analog wells in order to provide a means of comparing a known geochemical signature to the unknown areas.

The geochemical signature acquired by each sample was qualified and quantified using thermal desorption followed by gas chromatography and mass selective detection (GC/MS). A broad range of compounds from ethane (C₂) to octadecane (C₁₈) were reported from each sample including normal alkanes, iso-alkanes, cyclic alkanes, aromatics and alkenes as well as biogenic and alteration compounds. In total there were 85 compounds reported from each sample. The data were processed and evaluated using standard signal-to-noise elimination and advanced statistical processing specifically developed for use with these adsorbents. The data interpretation yielded an assessment of the hydrocarbon charge that otherwise would have been impossible, or very costly, to acquire. Geochemical anomalies have been identified for further consideration and have provided a means for narrowing the search for hydrocarbon charge. In one of the areas surveyed, a possible correlation is recognized between interpreted gas chimneys on 3-D seismic data and a cluster of small geochemical anomalies in map view.

680956 Underbalance drilling in tight gas reservoirs

T. Finkbeiner, S. Perumalla, D. Moos and M. Brudy

Deep, tight reservoirs face significant appraisal and development challenges. In particular, it can be difficult proving the presence and mobility of sufficient quantities of gas to make the reservoir economically viable. At the same time, drilling costs are extremely high. In this context, underbalanced drilling (UBD) provides a number of benefits: first, it enables the operator to prove the presence of producible quantities of gas while the well is being drilled. Underbalanced drilling also can minimize formation damage and maximize the rate of penetration. This can result in significant savings of drilling and completion costs relative to conventional drilling. However, not all reservoirs are suitable for UBD as there is a much greater risk of mechanical wellbore instabilities relative to wells drilled overbalanced. Hence, geomechanical analyses prior to drilling are of particular importance in order to evaluate the feasibility of UBD operations.

In the past, the stability of UBD wells has been analyzed using conventional approaches, simply by extending these to stress states in which immediately after the well is drilled one effective principal stress (the radial stress) is tensile; undrained conditions are assumed to develop instantaneously at the wellbore. This approach leads to very conservative predictions, with the result that many wells that would be candidates for UBD are drilled overbalanced.

To apply a less conservative approach, a new analytical model to predict the stability of underbalanced wells has been developed. Based on the recognition that rocks have scale-dependent strengths, the full stress concentration is not developed until some time after the bottom of the well is some distance below the point of interest, and that fluid flow into the advancing wellbore leads to a zone of locally lower pore pressure that extends beneath the drill-bit, it provides rapid assessments of the limit of safe underbalance as a function of drilling rate. The model predicts the regions within which spalling and breakouts will occur. One consequence is that higher permeability leads to the ability to drill both faster and with a larger underbalance. A second consequence is that smaller hole sizes are predicted to be easier to drill underbalanced. In cases where there is a high risk of wellbore collapse of the full-sized well this suggests that drilling an initial pilot well followed by enlargement to full size may mitigate the risk of collapse.

706326 Mapping and reevaluation of the main Unayzah A eolian fairway, southeast of Ghawar Field, Saudi Arabia: Beyond the porosity sweet spot

L. Girolidi

The Lower Permian – Upper Carboniferous Unayzah Group encompasses some of the main Paleozoic reservoirs in Saudi Arabia. It constitutes one of the prime targets of Saudi Aramco's exploration efforts in the Paleozoic section. The upper reservoir interval, Unayzah A, is comprised of a series of fluvial, playa, lacustrine and eolian sandstones, which exhibit lateral variability. The area southeast of the Ghawar Field is characterized by a predominance of eolian sandstones that constitute the main Unayzah A reservoir. They are relatively continuous within a west-east trending depositional fairway that has been defined by both well and seismic data.

Early exploration targeting these reservoirs was centered on structural closures and resulted in the discovery of several large gas fields, like Tinat and Midrikah, the latter having a large stratigraphic trap component. More recent exploration efforts have been focused in the areas northeast of those fields. A re-evaluation of legacy 3-D seismic and interpretation of new 3-D seismic and well data has led to an increased prospectivity within the Unayzah A reservoir interval. Methodologies applied there helped to refine the mapping of the hydrocarbon potential in the eolian fairway. Close re-examination of pre-existing and new seismic reflectivity and acoustic impedance 3-D data sets through visualization, combined with spectral decomposition and rock properties modeling have given new insights into the distribution of the eolian reservoirs. High porosity sweet spots and the potential role of syntectonic structures in controlling sandstone deposition have been recognized. Stratigraphic plays were identified in an area of about 8,000 sq km where no reliable structural closures are present. These plays are based on reservoir quality and the presence of lateral seals as inferred from seismic and well data.

Recent well results have given confidence not only in the ability to detect the porosity sweet spots, but also to discriminate which ones have higher probability of being filled with hydrocarbons, by combining rock properties analysis, modeling and pre-stack seismic data interpretation. The ongoing challenge is to further develop methodologies to discriminate between brine and hydrocarbon filled reservoirs to help prioritize the prospects already identified.

670200 Wavelet consistency assessment for quantitative interpretation: A case study from northeastern Saudi Arabia

M. Hong, M. Alfaraj, J. Wang and J. Rice

An onshore exploration 3-D survey located in northeastern Saudi Arabia and covering an area of approximately 6,300 square kilometers was acquired in 2003. There are two existing oil fields with Upper Jurassic carbonate reservoirs controlled by four-way closures located within the survey. Current exploration activity, away from these fields, is concentrating on stratigraphic plays involving up-dip truncation of regional trends with the hydrocarbon seals being created by dolomitization and cementation within the reservoir.

A multi-well feasibility study confirmed that porosity changes within the reservoir at these seal boundaries could be seen using acoustic impedance inversion. One important question on the use of seismic inversion over this large an area was the wavelet stability. The inversion software used in the project employed a multi-well, multi-trace approach that allowed for very detailed, thorough and semi-automated procedures for conducting a wavelet study.

This study will present the results from wavelet stability tests including analysis of seismic data only by means of a Markov chain Monte Carlo simulation technique. This is followed by scenarios with different combinations of single and multiple wells and seismic data, with varying number of traces around each well used in the calibration and wavelet extraction. The final wavelet determined in the inversion analysis was then cross-checked among the various techniques. This thorough procedure confirmed that the wavelet was zero phase and the Society of Exploration Geophysicists negative polarity, and that it was reasonably stable throughout the survey.

684917 Pathways and possible impacts of accidental CO₂ subsurface-leak in sabkha's environment, Qatar

F.M. Howari, A.M. Sadiq and R. Al-Thani

In Qatar, the industrial and energy sectors mainly depend on fossil fuels, the main cause of carbon dioxide (CO₂) emissions. Though the rate of development is high, the lack of arable land and water resources prevent the development of carbon sinks, forests, and green areas. However, there is no doubt that Qatar shares responsibility with the rest of the world for climate change and carbon management and hence is working to diversify the energy pie and look for more environment-friendly energy sources. Doha Bank, for example, is planning to launch the Arabian Gulf's first carbon credits exchange in 2009/10 to tap an emerging market for emissions trading. Still, Qatar's potential for the application of CO₂ sequestration technologies is huge knowing that onshore deep saline aquifers of Qatar are potentially large-volume carbon dioxide storage sites. The injection of supercritical CO₂ into deep saline aquifers or oil fields is a promising technique for sequestration of large amounts of CO₂; however, if some fraction of the injected CO₂ were to leak and reach shallow groundwater aquifers, it would lead to geochemical alterations that could have detrimental effects on the water quality and other adverse impacts. Thus

early detection and characterization of a potential CO₂ leak significantly increases the probability that a timely and efficient solution can be found. This study presents early results from joint research between the University of Texas and Qatar University on the possible biogeochemical impacts of an accidental leak on the shallow ground water and shallow subsurface environment as well as subsurface fate and pathways. For example, in cases of an accidental leak, the potential leakage pathways are not necessarily known, but our earlier research indicates that monitoring must be done across a region as large as 100 sq km in the vicinity of a CO₂ injection project. If a leak were to happen from a Dukhan oil field well (as an example of one such scenario), this would have an impact on the nearby coastal and/or sabkha environment of Doha, Al-Khor, Al-Wakrah, Umm Sa'id, as well as Salwa areas. The potential for stimulation and enrichment of the growth of existing cyanobacterial mats and algal planktonic blooms, some of which may be toxic, is high. The latter effects have further possible consequences on human health as well as on fisheries in Qatar that are described in this research.

670153 Paleozoic clastic systems, reservoir quality, and play mapping in the Rub' al-Khali Basin, Kingdom of Saudi Arabia

M. Hulver, A. Azzouni and C. Harvey

The South Rub' al-Khali Company Ltd. (SRAK) is an Incorporated Joint Venture between Shell Saudi Ventures Limited (50%) and Saudi Arabian Oil Company (50%), and was set up in order to explore for non-associated gas in the South Rub' al-Khali Basin as part of the Natural Gas Initiative in the Kingdom of Saudi Arabia. Initial exploration efforts by SRAK in their Contract Area 2 (southwest Rub' al-Khali) were focused on assessing the likelihood of a working Paleozoic hydrocarbon system using a regional grid of legacy and newly acquired 2-D seismic data, geologic data from offset wells, and basin modeling results based on regional trends. Three wells drilled by SRAK in 2006-07 established the presence of source rock in the Silurian Qusaiba Hot Shale; reservoir in the Sarah Formation and Unayzah Group, and charge/migration in gas micro-shows from a mature Silurian source-rock kitchen. Continuing seismic acquisition has enabled SRAK to identify a portfolio of structural closures and stratigraphic traps, and enhanced seismic processing has highlighted areas with acoustic properties consistent with porous rock and hydrocarbon accumulations.

Post-drilling analysis of geologic data and enhanced study of offset wells has enabled SRAK to more thoroughly evaluate plays and prospects and their probability of success, as well as develop strategies for drilling and testing the sometimes fairly tight Paleozoic reservoirs. For example, reservoir quality of the glacial Late Ordovician Sarah Formation was found not to be entirely related to depth-of-burial, but also enhanced by clay coatings or degraded by clay matrix content. These factors are related to primary depositional environments: mixed marine-terrestrial systems such as proximal deltas provide good reservoir, while purely terrestrial glacial tills or shallow shelf environments produce rocks with poor reservoir potential. Paleogeographically, good reservoir is to be expected between the most distal and most proximal facies. Stratigraphically, the best reservoir to be cored and tested is expected in the middle Sarah, where glacial/interglacial and marine/non-marine transitions occur between glacial maxima normally observed at the top and bottom of the glacial succession. Integrating data and applying a structured approach to exploration means SRAK assesses opportunities from a play-based not prospect-based perspective and this allows linkage of independent geological play elements and portfolio polarization.

680640 Charge evaluation of southeast Abu Dhabi Part II: Basin modeling

Ö. Huvaz, A. Bell, P. Nederlof, A. Khouri, A. El Agrab, M.A. Sattar and A. Stankiewicz

The objectives of the basin modeling part of the southeast Abu Dhabi (SEAD) charge evaluation study were twofold: (1) to reconstruct the charge history and explain the known hydrocarbon accumulations including distribution of various oil families; and (2) to provide a framework for the charge risking in ADCO's exploration portfolio.

The basin model was constructed in ADCO's offices in Abu Dhabi, using the modeling software PetroMod®. Key input for the model were 29 regional depth maps and 10 associated erosion maps constructed based on the latest 2-D and 3-D seismic. Isopach maps of the middle Cretaceous and base Tertiary tectonic events were created to allow accurate modeling of the basin tilt, which drives the hydrocarbon migration. The model was calibrated with temperature data from 46 available wells and pressure data from 15 wells. The Bab and Hanifa/Jubaila formations were identified as the main source intervals, with additional contributions from second-order source rocks in the

Thamama dense zones. Oil and gas migration from these source rocks and the filling of accumulations in the Hanifa, Habshan, Asab, Thamama and Bab reservoirs were all modeled in an integrated way.

The model clearly demonstrates that the formation of the Oman foredeep and the tilting of the basin are the main drivers behind the oil generation and migration to SEAD. The migration of the oil generated by the Hanifa/Jubaila source interval in the north is largely lateral until the oil reached the main east-west trending fault zone in SEAD, where vertical leakage along the fault planes took place with most of the oil accumulating in the shallow Thamama reservoirs. The model accurately explains the distribution of various oil families, all discovered accumulations and their phase, as well as the temperature and maturity profile of the basin. The new model allowed ADCO to update its existing charge risking matrix and strategy towards de-risking prospects in SEAD.

680990 Geochemistry of Saudi Arabian natural gas

P.D. Jenden, P.J. Van Laer and A.M. Al-Hakami

Saudi Aramco has measured carbon isotope compositions of C₁-C₅ hydrocarbons and CO₂ on hundreds of gases from exploration tests and producing wells. The isotope data allow the gases to be grouped into thermogenic families with different sources. For example, δ¹³C of gases associated with Jurassic Ghawar-type crudes increases from -54.6 ± 3.0‰ for C₁ to -39.6 ± 1.6‰ for C₂ and -27.6 ± 0.9‰ for n-C₅. In contrast, δ¹³C of Paleozoic gases increases from -42.1 ± 6.1‰ for C₁ to -31.9 ± 4.5‰ for C₂ and -29.5 ± 3.0‰ for n-C₅. The isotopic characteristics of the Jurassic-Ghawar and Paleozoic gas families appear heavily influenced by their source kerogen, Type IIS for the former (Upper Jurassic Hanifa and Tuwaiq Mountain carbonates) and Type II (Silurian Qusaiba hot shale) for the latter.

C₁/C₁-C₅ (mol/mol) of Paleozoic hydrocarbons ranges from 0.65 to 1.00 and is correlated with an increase in methane δ¹³C from -47 to -37‰. Within this range, we judge that liquids abundance and isotopes are controlled primarily by source rock maturation. Gases in Khuff, Unayzah, Devonian and Silurian – Ordovician reservoirs are indistinguishable on common interpretive plots such as C₁/C₁-C₅ hydrocarbons methane δ¹³C, providing evidence for a single dominant Paleozoic source. Most Paleozoic gases contain less than 10% CO₂. δ¹³C of CO₂ in gases from Khuff

carbonate reservoirs typically fall between -3 and +3‰ whereas those from deeper clastic reservoirs fall between -20 and -5‰. Gases containing more than ppm levels of H₂S are restricted to the Khuff. Increasing H₂S is accompanied by a decrease in CO₂ δ¹³C to < -25‰, arguing that the gases have been altered by thermochemical sulfate reduction (TSR).

Paleozoic gas-condensates around the Ghawar structure commonly contain less than 15% N₂. Nitrogen abundance here appears to be controlled by mixing between wet thermogenic gas and a high-N₂ gas component of uncertain origin. Khuff gases in coastal and offshore fields contain less than 10% to as much as 40% N₂ and often far less than 1% C₂₊ hydrocarbons. In one field with incontrovertible petrographic evidence for TSR, C₂₊ hydrocarbons are below detection limits and methane and carbon dioxide both have δ¹³C of approximately -22‰. N₂, accounting for 25% of the gas, appears to have been enriched due to destruction of methane by TSR.

680207 An advanced airborne geophysical approach for exploration of petroleum resources

J. Joseph

Recent advances in mapping technologies coupled with the emerging needs of the exploration industry to precisely characterize the subsurface systems, have led to the resurgence in interest for gravity and magnetic methods in oil and natural gas exploration. These methods are typically used in frontier areas to carry out reconnaissance surveys, to identify new and prospective basins as well as to explore more seismically challenging areas. An integrated approach combining gravity, magnetics and seismic along with other geological data is becoming the modern/latest approach for oil and gas explorers to push the envelope and venture into new frontier environments. Traditionally the potential field (gravity and magnetic) measurements are time consuming. But the need for acquisition of large gravity and magnetic data sets at a greater speed has renewed the demands for a precise airborne measurement system, which has unlimited accessibility over any terrain conditions such as coastal areas covering both land and shallow sea, over remote deserts, marshy lands, thick forests and icy lands, etc. Significance of airborne geophysical approaches have increased with major advances in satellite positioning technology such as GPS and GLONASS, which enables the determination of 3-D position

of the moving platform (aircraft) with greater accuracy. Aeroquest Airborne utilizes the latest version of airborne gravity systems called TAGS (Turnkey Airborne Gravity System) on a fixed wing geophysical survey aircraft, which is already equipped with a magnetic acquisition system as well as radar and laser altimeters. Prior to offering the services of this new system, a pre-purchase test of the gravity meter was undertaken. The system performance was tested mainly in three different ways: (1) repeatability along predefined survey flight lines; (2) crossover errors; and (3) comparison with ground data. The results provided a high level of confidence in offering this multi-system airborne geophysical approach to the petroleum industry. A detailed discussion on the system details and test survey results will be presented.

673544 Exploration campaign drilling for low-relief channel-sand prospects, south Central Oman

R.A. Kazdal, C. van Eden and L. Marcha

During 2009–2010, PDO Exploration is executing a 'peephole' exploration/appraisal campaign for two prospects in the vicinity of a field, which was developed using several grid-drilling campaigns since 1990. The field, discovered in 1986, is a low-relief anticline (approximately 45 m relief and 100 sq km closure) located in Central Oman. The oil is produced from the Permian Upper Gharif channel sands, deposited within a predominantly muddy floodplain and hence with a relatively low net/gross of some 30%. The oil is 24° API with a viscosity of 45 cP. Experience, gained during the appraisal and early development stages of the field, is being brought to bear on the exploration and appraisal of its satellites. The initial field development was based on the drilling of high-angle, deviated wells aimed at maximising the chance of finding the fluvial channels. This achieved a low rate of success at a high drilling cost. A new strategy of drilling multiple, low-cost, vertical wells (peepholes) was implemented. The economics of this campaign drilling could tolerate the expected low success rate, eventually improving understanding of the reservoir distribution patterns and reducing uncertainty in targeting productive sands. The first peephole campaign in the field started in 2001. Twenty wells were drilled with a success rate of 60%. The ensuing second campaign drilled another 12 wells with a success rate of 66%. Both campaigns resulted in a substantial production increase and met both the economic and geological success criteria. Using this field development as an analogue, 12 wells have been incorporated on the

exploration drilling sequence to appraise the first satellite prospect. A further 10 wells are planned on a second prospect in 2010. This presentation will share the results and learnings of the first drilling campaign. The first campaign well proved an oil-bearing zone with a much higher net/gross than the historical exploration well.

681854 A new era in land seismic for the Middle East and beyond

T. Keho and P. Kelamis

In the recent past, the seismic technology focus has been on the marine environment, particularly deep water. However, we are about to enter a new, exciting era in land seismic for the Middle East and beyond due to four key trends: (1) world growth in energy demand; (2) exploration and development focus on low-relief structures, stratigraphic traps, and horizontal well placement; (3) advances in seismic acquisition technology; and (4) advances in seismic processing due to continually expanding computer capability. World population growth and rapid economic development in emerging economies will lead to greater demands for energy. This will motivate more investment in exploration and in increasing recovery factors for existing fields, which will renew interest in areas where hydrocarbon potential occurs in land environments.

As large structures are drilled, focus will turn to low-relief structures and stratigraphic traps. These play types require accurate near-surface velocity models for depth conversion. The use of horizontal wells for field development will continue to grow. The high quality seismic attribute maps required for placing horizontal wells will motivate solutions for data quality problems originating in the near surface. This new era will require solutions to near-surface challenges, such as energy penetration, scattering, source generated noise, surface generated multiples, statics, and source and receiver coupling. Solutions to these problems will become possible due to advances in simultaneous source acquisition and wireless seismic driven ultra-high channel systems. Within a few years 100,000 channels will be common. These technologies will lead us to our ultimate goal - acquisition of true 3-D data with point source/receiver, full azimuth, long offset, high-density geometries.

Growth in computational capability will foster advances in seismic processing technology for the huge data volumes that will be one or two orders of magnitude larger than today. Advances

in computer capability will make non-travel time based methods, such as full waveform inversion, practical for aiding determination of near-surface velocity models. Joint inversion with micro-gravity and other non-seismic data types will become more common. Ultra-high channel counts and point receivers will create new opportunities in multi-component acquisition and processing. And finer spatial sampling will allow the near surface to be addressed more commonly as an imaging problem.

680566 Depth-imaging strategy for low-relief carbonate platform giant oil field, offshore Abu Dhabi, United Arab Emirates

N. Khouri, R. El-Awawdeh, J. Zhang, Z.J. Shevchek, R. Montelli, J. Reilly, P. Traynin and G. Zelewski

An offshore Abu Dhabi low relief carbonate platform giant oil field is characterized by various structural complexities that significantly affect reservoir and deeper level intervals. Inter-bedded clastics and carbonates within the overburden produce rapid velocity inversions and lateral variations that cannot be explicitly accommodated by time migration algorithms. Imaging challenges are due to shallow geology, such as the presence of faulting and small-scale features of about 500 m or smaller in diameter. Project goal was to determine the potential uplift to interpretation of depth imaging over conventional time migration, including the time stretched to depth technique. The depth imaging velocity model created as a result of this project accounts for both the long and the short wavelength velocity anomalies and was constructed by explicitly including all available well data information, interpretation and seismic velocity information. Due to seismic data high amplitude coherent and random noise, strategic data conditioning flows were applied to ensure that high frequency data was retained in the stack, to attenuate the noise, mitigate acquisition footprint and some of the overburden effects. To limit the migration noise and to better account for the effects of the small-scale structures, hybrid time/depth imaging scheme was created which utilizes 3-D dynamically corrected dip move-out (DMO) sub-bin stacks, followed by zero offset wave equation migration. This was determined to be more effective than a conventional Kirchhoff approach. The migration of each individual offset group with a velocity model that honors the 3-D complexity found in the overburden allows each offset group to focus differently, thus providing uplift over the post-stack depth migration, without sacrificing the benefits of signal-to-noise enhancement through

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sub-stack. To accurately evaluate the potential interpretation uplift of pre-stack over post-stack depth imaging and time imaging, it was necessary to implement a fairly exotic post-migration processing flow to ensure that the depth imaging products had similar signal-to-noise, wave-shaping and de-multiple characteristics as the time migrated products. Results from time-to-depth stretching, time migration, post-stack depth migration, pre-stack depth migration, and conventional Kirchhoff pre-stack time (or depth) migration comparisons will be demonstrated and discussed.

704792 How to think further ahead in hydrocarbon prospecting

G.H. Landeweerd and H. Menon

When assessing the value of a collection of prospects and leads, we tend to ignore the more complex and costly development scenarios such as multi-laterals, because we fear that these would erode the value of our venture. In reality, however, a more costly development scenario may actually make more sense by integrating the development of a number of prospects that would not pass the hurdles when considered in isolation.

The approach we advocate (and actively practice) is based on a simple principle: If one can measure and model the performance of an asset, then one can optimize it by considering a wide range of alternative development scenarios at the earliest possible stages of assessment. Think of this simple example: We work in an area where drilling is very hard (and therefore expensive). As a consequence, most operators consider the drilling of vertical wells only. However, by being able to model the use of much more complex well geometries, we can actually assess scenarios that involve the joint development of a number of accumulations, which may more than offset the much higher cost of the more complex well geometry. The presentation will discuss a number of real-life examples.

702699 Volumetrics analysis and field development planning

G.H. Landeweerd, L. Garibaldi, H. Menon and A. Kumar

The process of estimating hydrocarbon-volumes-in-place is usually based on a probabilistic approach that integrates whatever reliable and relevant data, such as geologic/geophysical interpretations, well log and core data is available. This approach makes use of the prior (statistical) knowledge

of parameters such as prospect area, reservoir thickness, porosity and permeability – the intrinsic parameters. The result is a probability (or cumulative-probability) distribution for a range of volumes; companies typically report the 10%, 50% and 90% probable hydrocarbon volumes.

For field development purposes, we further exploit this approach to plan the exploitation by analysing which intrinsic parameters “dominate” along different parts of the S-curve, or in other words where to find the “quick wins” (pick the lower-hanging fruits first) and leave the more risky parts of the field for later. The method comprises three steps: (1) sensitivity analysis; (2) generating a range of scenarios; and (3) generating a development-risk map for the field. The method will be illustrated by results from an actual field development project.

727763 Integrated basin and hydrocarbon systems model, Silurian – Carboniferous, southern Algeria

E.P. Lewandowski, H. Jäger, R. Zuehlke, T. Bechstädt, U.A. Glasmacher and B. Wirth

Paleozoic basins of southern Algeria comprise several hydrocarbon systems: (1) infra-Cambrian (?) source rock, Upper Ordovician reservoirs; (2) Silurian source rock, Lower and Middle Devonian reservoirs; and (3) Upper Devonian source rocks, Lower Carboniferous reservoirs. Since 2006 commercially productive gas reservoirs have been proven by several wells in the Reggane and Ahnet basins. Previous basin evaluation has proposed hydrocarbon generation predominantly during Mesozoic reburial, with pre-Hercynian generation having been largely ineffective (Purdy and MacGregor, 2003). Thermochronological data (Logan and Duddy, 1998) have indicated two-phased hydrocarbon generation: (1) simple burial heating to oil window before peak Hercynian Orogeny (pre-Early Carboniferous); (2) Late Triassic heating to wet and dry gas window in the Latest Triassic, related to the development of the Central Atlantic Magmatic Province (CAMP) and doleritic dykes/sills (Reggane Basin); and (3) subordinate heating of less mature basin margins until recently.

In order to better assess the basin and hydrocarbon development including the recently proven gas plays, an integrated study has been performed including: (1) seismic and sequence stratigraphy at basin and reservoir resolution; (2) numerical basin modeling (subsidence/uplift, sediment flux); (3) palynostratigraphic (miospores, acritarchs) and organofacies analysis; and (4) paleotemperature

analysis including organic maturation, apatite and zircon fission track and (U-Th)/He dating. Focus is on the Reggane Basin, where ample 2-D seismic coverage and calibration wells (logs, samples) have been available. Results include: (1) trans- and regressive trends within the basin fill; (2) intra- and inter-basin correlation; (3) lateral continuation and vertical connectivity of reservoir sandstones; (4) accommodation and sediment flux history; and (5) paleotemperature development related to pre- and post-Hercynian burial and exhumation. The new data show that the existing models of hydrocarbon development for the Upper Silurian – Lower/Middle Devonian and Upper Devonian – Lower Carboniferous systems have to be revised.

707715 Mineralogy and illite/smectite mixed-layer expandability of Rudies Formation and its relation to maturation of organic matter in the southern sector of the Gulf of Suez, Egypt

A.F. Maky and A.S. Mousa

The X-ray diffraction analysis of 29 bulk samples and 21 clay fraction samples derived from the Rudies Formation, that is present in the Jabal El-Zeit and El-Morgan basins in the southern part of the Gulf of Suez, are used to define the mineralogic composition of this formation. This rock unit is composed mainly of quartz, dolomite and calcite associated with minor amounts of phyllosilicates, such as kaolinite and illite/smectite mixed-layer, as well as traces of K and Na feldspars, and hematite. The analysis of clay fraction of the studied samples indicated that, illite/smectite mixed-layer is the main mineral component in Jabal El-Zeit Basin, followed by kaolinite, in which kaolinite is the main clay mineral, followed by illite/smectite mixed-layer in the El-Morgan Basin. Illitization of illite/smectite mixed-layer is the main process in this study, which indicated that the random interstratification ($R=0$) of illite/smectite mixed-layer is present in two stages of organic matter maturation at Jabal El-Zeit Basin. Smectite percentage ($S\%$) ranges between 85% and 80%, present in a temperature range from 28° to 46°C indicating an immature stage. Whereas random interstratification in the El-Morgan Basin associated with smectite percentage ranges between 60% and 50% and a temperature range of 90° to 91°C reflects mature source rock.

The ordered interstratification ($R=1$) has $S\%$ ranging between 40% and 25% present at a depth of 2,413 to 3,055 m and a temperature range from 94° to 103°C is also detected. While ($R=3$) illitization

stage is identified with $S\%$ ranges between 15% and 10%, is present at depths of 3,250 and 3,480 m and has a temperature range of 115–137°C which reflects the end-of-oil generation stage, whereas $R \geq 3$ illitization stage with $S\%$ of 10% or less is present at depth ranges from 3,445 to 3,550 m and temperature from 139° to 143°C indicating a wet gas stage. Generally, these illitization stages and temperature ranges show that, the organic matter content of the Rudeis Formation at Jabal El-Zeit Basin is present in immature stage, whereas the organic matter in the Rudeis Formation at El-Morgan Basin is in a range of oil window and wet gas stage.

681130 Formation evaluation challenges in high pressure and high temperature tight sand reservoirs

R.K. Mallick, T. Klimentos and S. Dubey

Rising demand for energy has pushed the oil and gas exploration and production operations to harsher environments. High pressure and high temperature (HPHT) is one of such challenging areas. Conventionally, wireline-log measurements are rated for operations up to 350°F temperature and 20,000 psi pressure. However, since many reservoirs exceed these pressure and temperature limits, HPHT wireline tools have been developed. The most significant challenges occur at “ultra-HPHT” environment, i.e., at 400–500°F and up to 35,000 psi, which represents the practical upper operating limit of the existing logging tool electronics technology.

Indian HPHT operations have seen remarkable growth in the past few years. More specifically, the gas field operations in Krishna Godavari (KG) basin, offshore of Andhra Pradesh, east coast of India, qualify as an ultra-HPHT environment. During the KG exploration activities numerous operational challenges were encountered due to extreme HPHT conditions.

This study presents experience gained in drilling and formation evaluation of deep tight gas reservoirs at ultra-HPHT conditions in the KG basin. Moreover, new technologies and formation evaluation methodologies used to address HPHT related challenges are discussed along with recommendations for future HPHT operations. More specifically, this study highlights the data acquisition challenges in the ultra-HPHT environment and presents an innovative formation evaluation technique using wireline logs at HPHT conditions to optimize the perforation strategy

in tight gas reservoirs in the absence of resistivity logs. Moreover, borehole stability related problems were evaluated and a Mechanical Earth Model was developed to improve the drilling performance at HPHT conditions. This study describes the application of the model in the exploration wildcat environment. The material presented will facilitate other well construction teams facing challenging drilling objectives in similar hostile remote environments.

680904 Maximizing recovery from thin oil columns Part 1: Geosteering horizontal wells to maximize oil recovery from an integrated team effort

*T. Mamary, G.M. Warrlich, J.P. Watkins,
H. Shabibi and P. Leighton*

Petroleum Development Oman (PDO) has been using geosteered horizontal wells in a thin oil column in a Cretaceous carbonate field (Shu'aiba Formation) to maximize the oil recovery rates and to minimize attic oil. The objective of the geosteering in this field is to stay in the pay-zone, an interval of 1.5 meters below the Shu'aiba/Nahr Umr interface without exiting into the Nahr Umr Shale – a challenging task for the steering and drilling teams.

A separation between the log signatures of resistivity measured from attenuation and that measured from phase is observed in the Nahr Umr shales, but it is absent in the Shu'aiba. The increase of this separation as the drill-bit approaches the Nahr Umr shales while drilling horizontally in the reservoir is used to place the wells in the pay zone, along with gamma-ray log response and cuttings information. Understanding the geology of the about 5 My long unconformity at the top of the reservoir with outcrop analogues helped interpreting the drilling data into a clearer picture of the subsurface and make better geosteering decisions.

Daily updates of the static reservoir model structure and properties with the drilling results help the geosteering and predictions from geophysical quantitative interpretation volumes (semblance and discontinuities) reduce the risk of unexpected drilling into fractures and sub-seismic faults. Close co-operation between planning, steering and directional-drilling teams at the rig-site is paramount for successful drilling of these complicated wells.

680929 Tectonic, depositional, and thermal history of the Levantine Basin resulted in numerous structural and stratigraphic plays

L. Marlow, N. Wattrus, J. Swenson and C. Kendall

The tectonics, deposition and thermal history of the Levantine Basin was conducive to the generation, expulsion and migration of hydrocarbons; as indicated by many hydrocarbon shows and a recent major gas discovery in the basin. Tectonics and deposition have led to the formation of numerous unexplored structural and stratigraphic traps including: anticlines, flower structures, reefs, talus, turbidites, and stratal pinchouts adjacent to salt. Traps are ubiquitous in the 15 km thick stratal package of the Levantine Basin, many with direct hydrocarbon indicators (DHI's) including flat spots, bright spots and gas chimneys with positive play potential. Tectonics in the Levantine Basin followed a similar progression to that of the rest of the southern Tethyan margin; rift-extension followed by passive margin and then compression beginning in the Late Cretaceous with the collision of the African-Arabian Plate with the Eurasian Plate. These tectonic systems along with the reoccurring strike-slip activity resulted in structural traps throughout the basin: anticlines and flower structures. One of the anticlinal structures is a trap for the recent "giant" gas discovery from the Tamar Well (5+ TCF gas). Deposition in the basin was equally conducive to trap formation; several stratigraphic traps exist. Triassic Salt deposits (the Kurra Chine equivalent) likely extend well into the Levantine Basin; in fact, seismic evidence indicates doming of the Triassic Salt through overlying strata and development of traps adjacent to the salt. Jurassic to Early Cretaceous deposits are dominantly carbonate platform and interplatform basins; carbonate platforms extend over 200 km to the north of the present southern continental margin. The carbonate platforms, which are up to 75 km in diameter, contain several stratigraphic traps in the form of reefs atop the platform and the talus and turbidites adjacent to the platform core. Late Cretaceous chalk deposits that onlap anticlines in addition to the Paleocene and Oligocene turbidites complete the pre-Messinian stratigraphic traps.

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680642 Managing talent to improve your team's performance

A.F. Marsh and P.S. Ford

How do you know you have the correct mix of talent for your team? And, even if you do, is it being effectively managed? We present a 5-step methodology that ensures your team performs successfully and effectively.

First we need to establish the strategic direction of the team. (I can't know if I have the right people on the bus if I don't know where the bus is going.) The functions and responsibilities are defined to achieve the stated strategy. Next we establish the correct mix of skill sets needed to successfully, and effectively, carry out the strategic efforts of the team. These would include both technical and intangible skills. The third step is to organise the required skills into desired roles or positions resulting in a set of job profiles. At this point the optimal team structure has been developed. Next, you have to gather information from the people who are available to you, to best match their skills and responsibilities with the optimal roles you have defined. A Gap Analysis will identify skill gaps that, unless addressed, will prevent the team from being a high performing team. The final step is to develop the team members to eliminate any skill gaps and thus ensure the team's strategic objectives set in the first step are being met. Our methodology allows an individual's skill and performance levels to be objectively measured and compared over a period of time and thus the individual's development can be effectively managed.

We have found that interactive web technology makes our methodology easy to apply and provides the team and the individual with the instant results that they need. We present a real world application of the methodology in an oil exploration team with staff from diverse backgrounds.

670162 Joining the dots: Cretaceous prospectivity in the South Rub' al-Khali Basin, Saudi Arabia

M. Moir, H. Droste, C. Harvey and A. Weedon

The South Rub' al-Khali Company Ltd. is an Incorporated Joint Venture between Shell Saudi Ventures Limited (50%) and Saudi Arabian Oil Company (50%) and was set up in order to explore for non-associated gas in the South Rub' al-Khali Basin as part of the Natural Gas Initiative in the Kingdom of Saudi Arabia. Regional geological

work by SRAK in its Contract Area 1 has identified both Upper Jurassic and Cretaceous stratigraphic play opportunities. Contract Area 1 borders the Sultanate of Oman and the United Arab Emirates where Mesozoic carbonates contribute significant hydrocarbon volumes. In the area across the border into Saudi Arabia the same play levels are relatively immature. However, subtle stratigraphic play and trap types have now come into focus as the majority of identified large structural traps have already been drilled. Mature source rocks are primarily contained within the Jurassic Hanifa and Cretaceous Safaniya, Mishrif and Bab intervals.

SRAKs main challenge is to identify and map these plays using relatively sparse 2-D seismic. The Asab 'Oolite' level appears as a distinct, mappable belt with reservoir potential and trapping configurations. The Thamama level reveals northeast to eastward prograding units. Differences in clinoform angles may help to distinguish between reservoir and non-reservoir facies. Within the Lower Cretaceous Shu'aiba Member three play types are identified: (1) reefal; (2) off-lapping wedges; and (3) lowstand clastic wedges.

This presentation will focus on the stratigraphic trap potential within Contract Area 1 in the northeastern part of the Rub' al-Khali Basin. We will outline how regional geological models coupled with seismic analogues have driven seismic interpretation and enabled SRAK to identify, map and develop subtle but potentially rewarding play types.

703065 An integrated study of basement rocks in the Bayoot Field, Say'un-Masila Basin, Yemen

A. Murray, P.W. Whiteley, M. Taha, D.W. Montgomery, J. McKidd, C.M. Simpson and I.G. Anderson

An integrated study of high resolution borehole images, petrophysical logs, production data, 3-D seismic, sidewall cores and cuttings was undertaken on basement rocks from six deviated wells located in the Say'un-Masila Basin, Yemen. The wells were drilled into the Rudood Ridge, a basement high positioned in the footwall of a locally significant SW-dipping fault. Hydrocarbon emplacement is through fault juxtaposition of the fractured basement against Late Jurassic organic-rich shale source rocks of the Madbi Formation. Structural analysis of borehole image logs focused on fracture characterisation and determination of principal horizontal stress directions inferred

from borehole breakout, induced fractures and borehole shape. Structural image facies were used to highlight fracture intensity and internal fabrics. Fracturing within the basement is intense, with in excess of 20 fractures per metre detected. Fractures have extremely scattered orientations.

Petrophysical log data show variation that implies compositional layering and image logs indicate inclined fabrics. Petrographical analyses of cuttings and sidewall core samples support a variety of rock types including diorite, granodiorite, granite and monzonite. Fracture fills include quartz, sericite, calcite, dolomite, pyrite and epidote. Many fractures contain more than one mineral phase along their trace. Rare matrix and fracture porosity was identified in some of the samples. Rocks were classified into four broad types based on petrophysical log responses and petrographical analysis. These include felsic, intermediate, mafic and possible metamorphic rocks. Relationships between rock type and fracture properties were explored.

Geomechanical analysis shows that present-day principal horizontal stresses are directed NE-SW and that the local stress regime is likely to be strike-slip. Fractures were divided into sets based on their relationship to principal stresses. Hydrocarbon shows correlate closely with those fractures predicted to be critically stressed. Seismic attribute analysis indicates that the seismic character of the basement is highly variable. Specialised processing of 3-D seismic data to identify anisotropy attributes from P-wave data provides a tool to determine the heterogeneous spatial distribution of the fractured zones within the basement. Integration of these attributes with geological information will aid the future development of the Bayoot Field.

680922 Petroleum prospects of Lebanon

F.H. Nader

This contribution presents an updated comprehensive review of the petroleum prospects of Lebanon through description of the known hydrocarbon shows as well as their host rock formations and structures. Tectonic and depositional evolutions will be discussed and placed in the larger context of the Eastern Mediterranean Levant region. A generalized model for hydrocarbon migration in Lebanon is presented disclosing data about Paleozoic, Mesozoic and Cenozoic prospects.

Since no economical petroleum prospects have been exploited to date in Lebanon, the necessary regional correlations and comparisons with adjacent hydrocarbon producing countries were undertaken in this contribution. This approach helps in explaining the Lebanese data in a regional framework, filling certain gaps and confirming or negating proposed ideas. Major lithological rock units are described and their aspects with respect to hydrocarbon prospects are assessed (source rocks, reservoirs, cap-rocks). The tectono-sedimentary evolution is reviewed together with the major structural configuration (e.g. Syrian Arc deformations and basinal inversions, Dead Sea strike-slip fault and transpression). The role of diagenesis (e.g. dolomitisation, karstification, dissolution) in enhancing reservoir properties is also highlighted and linked to the major structures and tectonic events that are believed to provide traps.

Hence, the present understanding of the petroleum systems in Lebanon proposes two major plays: (1) onshore the Qartaba structure (or similar anticlinal structures), associated with the Syrian Arc Deformation, where Triassic (or pre-Jurassic) prospects are considered to be of major interest; and (2) offshore northern Lebanon where various Cretaceous and Neogene rock formations may be charged by the Upper Cretaceous source rocks and sealed with volcanics, marl/clay, and evaporites. Local reef platform structures of Miocene age, sandstone and turbidites (Cretaceous and Cenozoic) offshore northern Lebanon, especially within the southern Levant Basin, are believed to provide attractive reservoirs. The timing of hydrocarbon migration should be constrained. Potential reservoirs may be isolated by evaporites, volcanics, clays and marls, as well as the Messinian salts, which acts as heat conductors and may save the underlying source rocks from over-cooking. This contribution is a general, updated review of the petroleum prospects of Lebanon within its regional framework.

681123 Exploring the Ordovician Ghudun play in North Oman: Challenges and way forward

H. Najwani

As conventional hydrocarbon plays have become highly mature after more than 50 years of exploration, Petroleum Development Oman (PDO) is increasingly focusing on un-conventional plays. The Ghudun stratigraphic play is one example

where Ordovician Ghudun sandstone reservoirs are sealed, vertically and laterally, by shales of the overlying Ordovician – Silurian Safiq Group. The Safiq Group consists of three member formations namely Saih Nihayda, Hasirah and Sahmah, listed from old to young.

Evaluation of the play was initiated with studies reviewing serendipitous Ghudun discoveries and subsurface data gathered over several decades. From these studies emerged the Ghudun stratigraphic play with several sub-play segments. The risks and uncertainties associated with the play are spatially variable, reflecting the various play segments, span multiple geological domains and have variable oil and gas charge potential. The main challenge associated with this play is the difficulty in mapping top Ghudun on seismic data (due to low impedance contrasts). This challenge forced PDO to seek alternative technologies such as gravity modeling and advanced seismic techniques, e.g. neural net approaches to effectively unlock the play potential.

The play segment, which is described, is the Safiq Canyon Play Segment where canyons have eroded most of the Saih Nihayda and some part of the Upper Ghudun and are sealed by the Safiq shales. A cluster of prospects has been matured and a well was drilled in 2008. The drilling results have been disappointing but they highlighted risks that were not originally captured and technologies have been recognized which can mitigate these risks. The drilling results have resulted in updating our understanding of the Ghudun play. In this study we propose to describe the play elements and the techniques that to date have been used to unravel the challenging Ghudun play.

680616 Fluid property and geochemical evaluation of exploration well in the South Rub' Al-Khali Basin: Implications for the regional subsurface model

P. Nederlof, A. Bell, D. Naafs, T. Carlson, E. Clarke, M. Hashem, G. Holstege, E. Daou and A. Briner

The sampling and analysis of sour gas and its associated condensate is a difficult task: H₂S is highly reactive and the route from reservoir to laboratory is covered with potential 'sulphur sinks'. The down-hole sampling program is further complicated by the fact that gases with high H₂S concentrations tend to have low condensate-gas ratios (CGRs) and the slightest drilling mud contamination can potentially affect the fluid

composition and lead to erroneous concentrations of H₂S. Yet, accurate fluid property data like H₂S content and condensate-gas ratios are critical for reserve estimates and economic evaluation, for field development planning and for facility design. The South Rub' al-Khali Company Ltd. (SRAK) recently completed a deep exploration well which targeted objectives at several stratigraphic levels. The well found sour gas in the Jurassic Arab Formation and an extensive down-hole sampling program was initiated to acquire representative fluid samples from all potential Arab pay-zones. In addition, a comprehensive geochemical analysis program was carried out with the objective to update the regional hydrocarbon habitat and basin models.

This study discusses the integration of all fluid property, geochemical and basin modeling data, which together provide a rigorous quality check of the sampling and analysis program. H₂S concentration and CGR, for instance, are not independent parameters, as both are governed by thermochemical sulphate reduction (TSR), the in-reservoir process that leads to the formation of H₂S and CO₂. Also the molecular and isotopic compositions of the gases are dependent on the TSR process and provide an important consistency check. Subsurface temperatures and source rock quality and maturity data were used to calibrate the regional basin model and to update the understanding of the hydrocarbon habitat of the Southern Gulf region. Finally, the newly acquired subsurface temperatures provided further insight into the hydro-dynamic flow regime of the South Rub' al-Khali Basin, which were described earlier after the first SRAK exploration well.

681094 Charge evaluation of southeast Abu Dhabi Part I: Petroleum system analysis

P. Nederlof, Ö. Huvaz, A. Bell, A. Khouri, A. El Agrab, M.A. Sattar and A. Stankiewicz

The Abu Dhabi Company for Onshore Oil Operations (ADCO) is exploring for oil in a contract area in southeast Abu Dhabi (SEAD). In order to understand the regional charge variations and to identify the best oil prospects, a large-scale petroleum system analysis was carried out. Results of this study supported portfolio ranking and optimization of the drilling sequence. The petroleum system analysis was carried out following Shell's workflows for Integrated Charge Evaluation which is comprised of three main elements: (1) a source rock evaluation; (2) a regional oil typing exercise; and (3) a 3-D basin

modeling study. The study was based on ADCO's and Shell's regional knowledge, experience and database. The results obtained revealed that the petroleum systems in SEAD are different from the main Tuwaiq Mountain/Hanifa (TM/H) petroleum system in Central Arabia. For instance, the oils recovered from the Hanifa reservoirs in SEAD are different from those in Central Arabia. The absence of the 'typical' TM/H hydrocarbon family in SEAD was supported by source rock screening, which revealed that the Tuwaiq Mountain/Hanifa has little to no source potential in the immediate area. However, several source rock intervals were identified in the Cretaceous Thamama Group, in agreement with an earlier study by Taher (1997). The regional oil typing suggests that the oils present in SEAD were generated by a separate kitchen area to the north and migrated up-dip in a southerly direction. The source rock maturation and hydrocarbon migration history was modeled in 3-D and the results are the subject of a separate presentation.

**670167 Listening to the right thing:
The integration of low frequency seismic
data with other geophysical methods as
a frontier exploration tool in the South
Rub' al-Khali Basin**

C. Nunweek, M. Hulver and P. van Mastrigt

The South Rub' al-Khali Company Ltd. (SRAK) is an Incorporated Joint Venture between Shell Saudi Ventures Ltd. (50%) and the Saudi Arabian Oil Company (50%) and was set up in order to explore for non-associated gas in the South Rub' al-Khali Basin as part of the Natural Gas Initiative in the Kingdom of Saudi Arabia.

Following an initial three well exploration drilling campaign in SRAK's Contract Area 2 (CA2), SRAK embarked on a second major phase of 2-D seismic acquisition. Low frequency seismic data has been acquired on all new 2-D seismic lines via an embedded recording set-up. This has resulted in the largest combined PSTM/LF (pre-stack time migration/low frequency) exploration data sets acquired to date.

One of the key challenges facing low frequency seismic as an effective exploration tool is the lack of signal-depth discrimination. This presentation will focus on the combination of low frequency seismic with conventional seismic products in order to constrain the depth of the low frequency signal

and how combining these workflows with geologic models has led to the identification of a potentially new hydrocarbon play in the southern Rub' al-Khali Basin.

**681078 Description of subsidence
phenomena due to gas extraction in
deep layers with advanced three-phase
constitutive model**

M. Nuth, L. Laloui and B.A. Schrefler

In coastal regions, the land subsidence due to industrial pumping of underground fluids such as methane is documented on the basis of surveys. Some laboratory characterizations of the soils hosting those fluids have also been published to complement the knowledge on compaction due to changes of fluid pressures. The withdrawal of gas is simulated in the laboratory by injecting water under a constant uniaxial or hydrostatic load, which results in the plastic compaction of the samples. This study proposes a new attempt to model the observed collapse of samples, as well as the changes in compressibility and preconsolidation pressure during the process of wetting. The conceptual framework essentially relies on unsaturated soil mechanics, as the subsidence phenomenon concerns a three-phase material with solid grains, liquid water and gas. The developed constitutive model provides a description of the water retention capability of the studied soils that is coupled with the mechanical behaviour. Consequently, the elasto-plastic volumetric changes within the porous medium incorporate the effects of saturation and suction, also called capillary effects. The formulation of the preconsolidation stress is such that the shape of the yield limit depends on suction so that the apparent added stiffness brought by low saturation is predicted. The modelling framework, based on the generalization of the effective stress principle to three-phase media, also provides an elasto-plastic comprehension of the well-known "wetting pore collapse" phenomenon. The Advanced Constitutive Model for Environmental Geomechanics (ACMEG-s) shows consistent understanding of changes of compressibility with the quantity of retained water. The successive phases of isotropic compression and uniaxial mechanical compaction are used for the model calibration. Interestingly, the phases of plastic compression during injection are captured with accuracy, which evidence the applicability of this model to the boundary value problems that are the large-scale cases of subsidence.

689568 Using advanced technologies to solve complex reservoir challenges in Shedgum Field, Saudi Arabia: A case study

U.U. Obot, R. Iwan, M. Javalagi, W. Al-Alqum, W. Jawad and M. Al-Otaibi

In order to meet world energy demand, wells have to be drilled in more challenging frontiers and within very thin reservoir beds. Conventional geosteering and logging while drilling (LWD) measurements face considerable challenges with chasing thin targets. However, geosteering into such thinner reservoirs has been successfully achieved through the application of next generation LWD measurements. Deep, directional resistivity (DDR) from the PeriScope LWD allows well placement to be optimized in real time by using the tool's sensitivity to approaching bed boundaries and the ability to accurately map distance to such bed boundaries and formation dip. The PeriScope technology has proven its ability to unlock previously uneconomic targets in both clastic and carbonate reservoirs all over the world by providing for proactive well placement.

In Saudi Arabia, Aramco has made use of applying the PeriScope LWD and well placement services for its more challenging targets. A case study is outlined where 2 laterals were drilled into a carbonate reservoir, with and without PeriScope LWD. A comparison is made between results achieved drilling lateral 1, using PeriScope LWD and in lateral 2, drilling using a conventional LWD approach. In both cases the objectives of the well were to place the well 1 ft below the top of an anhydrite cap rock and also to keep the well away from possible water encroachment thereby improving total oil recovery.

Conventional geosteering relies on logs from offset wells and real-time measurements. An assumption is made that the formation follows a layer-cake model, in which properties are assumed to be laterally continuous. This assumption is often invalid, as smaller-scale variations in structure can also significantly impact on geosteering, especially in thinner targets and provides a considerable challenge for conventional geosteering. By using PeriScope these changes can be proactively managed in real time. In this case study lateral 1 was planned and drilled using PeriScope LWD in the BHA while Lateral 2 was later drilled with a conventional LWD BHA. Lateral 1 was placed in a porous stratum from target entry (TE) to total depth (TD) with no reservoir exit. Whereas 16.8% borehole-to-reservoir exposure with formation

greater than 0.15 porosity units was achieved in the lateral drilled with conventional LWD. The results confirm the added value of proactive well placement through the use of the PeriScope LWD technology.

670186 West Esh El Mallaha concession fields: Pre- and syn-rift multi-oil-bearing reservoirs as a structural and stratigraphic model in the eastern desert onshore southern Gulf of Suez rift province, Egypt

H.S. Osman

The Gulf of Suez is a failed extensional rift basin. Rifting initiated during Early Miocene time and reached its peak at the end of Burdigalian. Three major fault trends are observed in the Gulf of Suez: (1) rift parallel or clysmic; (2) north oblique; and (3) rift orthogonal cross elements. The Gulf of Suez rift is divided into three dip provinces separated by two transfer zones. Each dip province has its own geologic characteristics which makes the hydrocarbon trapping mechanisms different from one province to another. The southern province is dominated by SW dipping pre-rift sequences and is characterized from the central and northern parts by more severe extension, more frequent faults, smaller structural block size, thicker sand reservoir accumulations during the Miocene in syn-rift sequences, thinner pre-rift sequences and well developed Miocene salt diapers. As a result, the southern GOS province is more favorable for Miocene and Pre-Miocene (including the basement rocks) hydrocarbon traps. West Esh El Mallaha concession has oil production from three separate structural closures (Tanan-Tawoos, Rabeh and East Rabeh). Its total area is 52 sq km with 45 wells having been drilled in the concession.

The structural style of West Esh El Mallaha fields is dominated by tilted fault blocks bounded by NW-oriented normal, down to the northeast faults and dissected by oblique and orthogonal faults. Reservoirs range in age from Cretaceous to Miocene.

The first commercial hydrocarbon, Rabeh Field, in the West Esh El Mallaha concession was discovered by Coplex in 1997. The discovered oil was placed on production in February 1998. Currently, the West Esh El Mallaha concession fields are operated by LUKOIL/ESHPETCO, a joint venture company. Cumulative oil production from the concession as of June 2009 was 27.5 MMB, of which 90% was produced from the Pre-Miocene Nubia and Matulla formations and the remaining 10% from the Miocene reservoirs, Nukhul and Rudeis.

691746 Knowledge management from Saudi Aramco exploration

*S.M. Qahtani, R.A. Bahrani, A.M. Rebh,
P. Attewell and J. Griffiths*

This presentation describes the knowledge management system "GeoKnowledge" that we have developed to ensure that the assets for key knowledge areas are identified in the various corporate repositories, then collected, integrated and passed to our successor generation as knowledge in a way that can be accessed and shared usefully and in a timely manner.

In a top-down process for each knowledge area we identify a collection of raw information items from our corporate repositories with the help of a supporting taxonomy. The metadata for information items relevant to end-user disciplines is enriched and transferred to a central metadata repository. The knowledge areas are accessed by a domain-specific search that focuses on specific slices of content with attributes such as spatial location, and chrono-stratigraphic criterion. To transform the raw information into useful information and knowledge, we describe the characteristics and inter-relationships that exist using a common and controlled vocabulary.

Management of the knowledge repository includes registration of knowledge sources and encompasses both content and metadata repositories. Within the repository, issues of knowledge governance are addressed to include sensitivity classification, access control, and rights management. Finally we describe our approach to managing the time value of knowledge. By implementing this process of knowledge management, we help our geoscientists become more productive.

703875 Hydrocarbon potential of the Kazhdumi Formation, offshore Iran

*O. Rahmani, J. Aali, H. Mohseni and
M. Khoshmoodkia*

The study area is located in one of the largest hydrocarbon reservoirs of Iran, offshore in the Persian Gulf. Exploration data proved the presence of hydrocarbons in the Cretaceous interval of the Zagros Basin. Because the Kazhdumi Formation with predominant black shale lithology is the most effective source rock of Dezful Embayment that has reached the oil window, this formation was the first candidate for a potential source interval in the study area. The Kazhdumi Formation was

sampled from a depth interval of 985 to 1,098 m from cuttings of boreholes 2 and 3. Using Rock-Eval pyrolysis, 22 samples were analyzed. Total organic carbon (TOC) content of these shale samples varies from 0.12 to 1.2 wt%. Rock-Eval results (e.g. HI Tmax) indicate that the Kazhdumi Formation comprises type II-III kerogens and did not pass through the oil window ($R_o < 0.5$) in this region. Accordingly, it is concluded that Kazhdumi Formation had no contribution to any hydrocarbon generation in the study area and an alternative possible source rock may be considered for further investigations.

680484 Geochemical characterization of petroleum in Fahliyan reservoir, Abadan Plain, Iran

M. Rashidi

Geochemical investigation and basin modeling were used to infer the age, lithology, organic matter input, depositional environment and burial history and timing of source rock generation. The study focused on geochemical studies to better understand the origin of the recently discovered oils in the Lower Cretaceous Fahliyan Formation from Mahshar, Juffair and Arvand fields in Abadan Plain, Iran. Biomarker parameters of Pr/nC17 and Ph/nC18, pristan/Phytan carbon isotope ratio, sterane ternary diagram, C29 Hopane/C30 Hopane, Gammacerane/C31R Hopane, dibenzothiophen/phenanterane ratio, show that oils are derived from source rocks deposited in a marine marl-carbonate environment under suboxic-anoxic conditions with higher plant input, low salinity and type II kerogen. The level of maturity is in peak oil generation zone and the age of the source rock is Jurassic – Middle Cretaceous ($StrC28/C29 = 0.5$ to 0.7). Geochemical correlations among the oils and prospective source rocks show the oils genetically originated from Garau (Lower Cretaceous) and Sargelu (Mid-Upper Jurassic) formations. The Rock-Eval pyrolysis of cuttings samples from Garau and Sargelu formations in the wells of the studied area contain very good quantities of organic matter, oil-prone maturity (zone of generation and expulsion), and type II kerogen organic matter. For reorganization of kerogen chemical structure at the molecular level in source rock evaluation, the pyrolysis gas chromatography was carried out in one sample from the Garau Formation. The results indicate organic matter of kerogen is rich in aliphatic chains and poor in aromatic structure that corresponds to type II kerogen. The phenols and thiophens compounds detected in the sample indicate a contribution of a woody lignin (from

higher land plants) environment. One-dimensional petroleum system modeling of three wells was designed to evaluate the petroleum system in terms of burial-thermal history, source rock maturity and timing of generation using Beicip-Franlab Genex software. In Juffair and Arvand, model results indicate that peak oil generation of Sargelu source rock started during the Oligocene, and for Garau source rock during Late Miocene to present day. In the Mahshar well, maturation started earlier and peak oil generation occurred in the Late Cretaceous for Sargelu, and Oligocene to present day for the Garau Formation.

680627 Bayesian direct hydrocarbon indicator using passive seismic low frequency data

N. Riahi, M. Kelly, M. Ruiz and W. Yang

We present a procedure for producing a Bayesian direct hydrocarbon indicator (DHI) using low frequency passive seismic (LFPS) data. The approach utilizes two LFPS attributes to classify and determine the likelihood of hydrocarbon presence in the subsurface. These attributes are based on statistical characteristics of the empirically observed hydrocarbon (HC) tremor. It is shown that these characteristics provide a more accurate and complete description of the tremor energy as compared to an integrated single value measure. An interpreter-driven Bayesian classification is employed both to accommodate uncertainties in the data and to provide a risk estimate. The class models are built from a subset of exemplar receivers that are selected by an interpreter based on tremor quality and low noise interference. Prior knowledge from wells or structural information from active seismic can also be incorporated into the analysis.

The process is tested over four fields with known surface projection of the oil-water contact (OWC). Prediction results correlate well with reservoir locations. A classification success rate based on the proposed process is calculated. Due to the relatively small number of measurement locations (ca. 50–100), the significances of the results are checked through standard statistical tests including Monte Carlo simulations.

The approach provides a rigorous method for producing quantitative HC probability maps that are easy to interpret and can be used for risk analysis. Possible applications for the method include: (1) more informed drilling decisions over fields with none or poor active seismic data; (2) expanding production into areas near existing

wells (exploitation); and (3) interpretation aid for ambiguous features in conventional seismic attributes.

680369 Plays and prospectivity offshore Lebanon, Syria and Cyprus: New insights from depth imaged seismic data

G. Roberts, C. Harmer and D. Peace

This study illustrates the nature of the Levantine Basin and adjacent areas based on an analysis of modern seismic data. It shows that the basin is comprised of a substantial thickness (> 10,000 metres) of Mesozoic to Cenozoic sediments above a rifted terrain of probably Triassic – Early Jurassic age.

Depth imaged sections are used to show the nature of the basin including its relationship to the Eratosthenes Seamount and the Larnaca Thrust Zone. Depth imaged sections (with time migration comparisons) are also used to illustrate some of the numerous plays seen in the area. These consist of: (1) Jurassic and older: faulted structures, rollovers and basin margin plays; (2) Upper Jurassic to middle Cretaceous: mounds, reefs, progrades, drape structures, structural/stratigraphic plays and unconformity plays; (3) middle Cretaceous to Paleogene: anticlines, fault blocks, rollovers, mounds, drapes, structural/stratigraphic plays and basin margin pinch-outs; (4) Sub-Salt (with salt as the seal) and Intra-Salt (Messinian): pinchouts, bright spots, channels and mounds; and (5) Post Salt (Pliocene to Recent): channels and mounds. Depth imaging of the seismic data is shown to aid the evaluation of many of these plays and to highlight the prospectivity of offshore Lebanon, Syria and Cyprus.

Reference will also be made to both the ongoing and future bid rounds and to some of the issues involved in producing velocity models for pre-stack depth migration including the subsequent time conversion of depth migrated data.

705410 Exploration document management

J.E. Robinson, A. Kok, R.M. Jawad and A. Al-Khater

Since 2003 the Saudi Aramco Exploration Data Management Division has been working to support document management in the Exploration Organization. The task of discovering and archiving documents in today's diverse and busy

E&P environment is particularly challenging. To meet this challenge, we developed a framework for document management, and deployed an integrated system that provides exploration staff with several methods for document archiving. The framework provides the workflow and the system provides document archiving options ranging from a simple drag-and-drop application to customized web applications.

The framework requires that quality control (QC) is applied to metadata for each document to ensure consistent and reliable search results. Web applications allow QC staff to view both the document and its metadata, and correct the metadata when necessary. The applications are underlain by Oracle™ for recording the existence of documents (document discovery), and progress through the workflow. The system provides simplified audit and activity reporting. Documentum™ is used for document and metadata archive and search. Ultimately, the system provides for document searches that differentiate between large numbers of similar documents as rapidly as possible.

678392 Evaluation of petroleum generation potential in Qom-Ardestan structural zone in a geographical information systems (GIS) environment by fuzzy method

M. Roosta, N. Fathianpour and J. Sadouni

Due to concentration of petroleum potentiality studies in south and southwest Iran (Zagros Basin), it is necessary to evaluate the potential of other areas especially some parts of Central Iran, which have thick sedimentary strata and sometimes-organic matter potentiality (e.g. Qom and Shemshak formations). Exploitation possibilities from this huge resource are of interest to economic administrators of the country. Compilation and analysis of all information in a suitable environment and exploration framework will lead to assessment of satisfactory petroleum zones for further studies. Therefore, the Qom-Ardestan Area that bears probable high reserves of petroleum and gas is explored here. After studying the geology of this area, segregation of the area into anticlines as trap layer, faults as migration layer, and the whole Qom Formation and its prospect member (C3) as reservoir rock took place. In organic geochemistry discussion, considering a three-dimensional thermal model, vitrinite reflectance values, and total organic carbon in different wells in the area, we derived the maturity and geochemical layers. This research resulted in the establishment of

nine information layers including geochemical, geological, maturity, and structural group-layers. These layers were integrated by using a knowledge-based fuzzy method. Modeling based on this method was made using 22 educational points. The output was settlement of 100% of drilled wells in the area with high potential in this model (e.g. in Alborz and Sarajeh oil fields). The areas with high potential for further exploration drilling are defined in the studied area.

703787 Source rock characterisation of sediments from the Tarfaya Basin and adjacent areas, Morocco

V.F. Sachse, S. Heim, O. Kluth, J. Schober, H. Jabour, S. Lahsini, L. Boutib and R. Littke

Thermal maturity information has been compiled for the Tarfaya Basin, Morocco and surrounding areas. Tarfaya Basin is bounded by the Anti-Atlas, the Reguibat High/Tindouf Basin and the Mauretanides and developed since the opening of the Atlantic in the Permian to Triassic with continental extension. Little is known about source rock potential in Tarfaya Basin, excluding Cenomanian/Turonian black shales which were investigated, e.g. by Kolonic et al. and Kuhnt et al. in great detail. In general Lower Silurian, Upper Devonian, Lower Jurassic, Lower Cretaceous, Albian, Cenomanian as well as Lower Tertiary shales are considered to be source rocks. To get more information about their potential, cuttings and cores from on- and offshore wells, as well as outcrop samples covering a large area (locations in Tarfaya Basin, Tindouf Basin and Bas Draa area) were collected. TOC/TC and sulphur measurements, Rock-Eval pyrolysis, vitrinite reflectance measurements and organic-geochemical analyses were carried out on these samples to get basic information on their thermal maturity and the potential to generate hydrocarbons. Based on these data the burial and thermal histories of several wells/pseudo-wells were modelled using PetroMod 1-D. The modelling results lead to the conclusion that in some areas highest temperature was reached at recent times in accordance with deepest burial. The reconstructed temperature history shows moderate heat flow, excluding times of rifting at present. The present-day heat flow was modelled with values between 50 and 60 mW/m². In other areas, strong erosion took place and diagenetic paleotemperatures by far exceeded present-day temperatures.

High TOC values were established for Eocene sediments in the southern part of the Tarfaya

Basin (up to 7%). In the Santonian, Coniacian and Campanian TOC values range between 1% and 6% and are even higher in the Cenomanian/Turonian black shales. Most of the samples are representing a type-II kerogen, whereas some of the Eocene samples contain type-I kerogen. Maturity of the samples is low, i.e. they are immature or at the beginning of the oil window. Tmax values range between 400° and 450°C and Production Index is lower than 0.1. Furthermore molecular geochemical data provide a more specific overview about the depositional environment and the maturity distribution.

709696 Hydraulic fracture and natural interface interaction in tight gas sweet spots

M. Sarmadivaleh and V. Rasouli

Tight formations are considered as those with low porosity and permeability. Large volume of hydrocarbons is proven in the tight formations in the U.S. and also tight gases largely exist in such formations in Australia. Producing hydrocarbon from tight formations is not economical using conventional methods. Hydraulically induced fractures are known as one of the most effective methods of stimulation in tight formations. However, fracturing operations in tight formations need special care compared to conventional formations. This is due to the different mechanical properties of tight formations.

In this study, firstly, the influencing parameters in initiation and propagation of a hydraulic fracture including formation and fluid properties and stresses are introduced and a sensitivity analysis is performed to determine the impact of each parameter on the fracturing process. To do this, analytical formulae developed based on elastic and poro-elastic approaches were used. The sensitivity analysis was repeated again this time considering tight formation properties in the formulae. This allowed the most effective parameters for fracturing in a tight formation to be identified and the interaction between different parameters to be studied. Also, the transition of a fracture once it passes from a tight to another formation was studied.

In the second part of this work, the above analyses were carried out numerically using HFRANC 3-D software. The software allows studying the effect of changing formation and fluid properties as well as stresses. In general, the results are in agreement with those obtained from analytical solutions; however, in some instances the numerical approach

appears to provide more accurate results than the analytical solution. The results of this study indicated that fracture toughness and stress ratios are the two important parameters to be considered in fracturing tight formations.

683705 Multi-tool approach to well placement in a heavy oil column of the Manifa Field - A case study

M.H. Sarraj, A. Garg, A.B. Badri and A. Abdul Aziz

Manifa Field is located north of the giant Ghawar Field in the Eastern Province of Saudi Arabia. The field is currently under development with more than 300 wells planned for drilling in two major reservoirs, the Manifa (Upper Jurassic) and the Lower Ratawi (Lower Cretaceous). An approximately 30 to 40 ft thick column of heavy oil exists in both of these reservoirs. Well test records indicate that the oil quality degrades towards the flanks of the structure causing complexities in the placement of wells, especially for power water injector (PWI) wells. A multi-tool approach has been applied to address the challenge of placing the PWI wells to achieve the targeted water injection rates.

The successful approach to optimally placing PWI wells combines the use in real time of: (1) formation pressure while drilling (FPWD) for measuring formation pressure and fluid mobility; (2) slim-hole nuclear magnetic resonance (NMR) for providing the free and bound fluid volumes as input to a viscosity model; (3) pyrolytic oil productivity index (POPI) for computing apparent API gravity of the oil; and (4) logging while drilling (LWD) for calculating parameters such as permeability.

Using this multi-tool approach, a significant number of PWI wells have been drilled and geosteered through sections with a heavy oil column. To date, the injectivity test results of both short- and long-term duration have been encouraging.

702634 Petroleum systems and assessment of undiscovered oil and gas resources of the Levant Basin, Eastern Mediterranean

C.J. Schenk

The United States Geological Survey is currently reassessing the potential for undiscovered oil and gas resources in priority basins worldwide,

including the Levant Basin. For this study, the Levant Basin is defined to the east by the Levant transform system, to the north by the Cyprus thrust system, to the west by the Eratosthenes terrain, and to the south by an assessment boundary with the Nile Delta Province, which was also assessed for undiscovered oil and gas resources. The Mesozoic – Cenozoic stratigraphic section in the Levant Basin is as much as 10 km thick and two main petroleum systems were defined within this stratigraphic section, as most of the volumes of oil and gas probably originated within these systems. The Mesozoic Composite Petroleum System includes potential and hypothetical oil and gas source rocks of Triassic, Middle to Upper Jurassic, Lower Cretaceous, and Upper Cretaceous (Cenomanian-Turonian, Santonian) age. Assessment Units (AU) within the Mesozoic Composite Petroleum System that were assessed for undiscovered resources include the Carbonate Reservoirs AU, which encompasses limestone and dolomite reservoirs of Jurassic through Miocene age formed in reef, fore-reef, back-reef, and deepwater environments and are largely in stratigraphic traps, and the Clastic Reservoirs AU which includes shelf-edge delta, incised valley fill, confined and unconfined slope systems, and basin-floor fan reservoirs in stratigraphic and structural traps. The Neogene Biogenic Gas System includes all source rocks in the Neogene that contributed to known post-salt occurrences of biogenic gas. The Neogene Biogenic Gas System includes the Neogene Reservoirs AU that encompasses clastic reservoirs of alluvial fan, fluvial, incised valley fills, shelf-edge delta, slope systems, and basin-floor fan origin in both structural and stratigraphic traps. Each of these AUs was assessed for potential undiscovered conventional oil and gas resources in this frontier basin.

677297 Offshore Cyprus: A future hydrocarbon player

P.H. Semb

Offshore Cyprus, located in the Eastern Mediterranean close to the already proven hydrocarbon provinces offshore Egypt and Levantine Basin covers a huge unexplored area. This area has recently drawn a lot of attention from the oil and gas industry after arranging its first license round in 2007 and from the news of the very encouraging Lower Miocene gas discoveries in offshore Levantine Basin. The Cyprus Ministry is currently ramping up for the second license round after completion of the first round which

resulted in the award of one block to the American company, Noble Energy Inc. In the second round all open blocks will be offered, in total 12 blocks, each ranging in size from 4,000 to 6,000 sq km, which sums up to more than 50,000 sq km of unexplored acreage.

The offshore blocks are covered by more than 19,000 line km of newly acquired 2-D seismic and 750 sq km 3-D seismic data. About 12,500 line km of the 2-D data was acquired in 2008/2009 with a dual sensor streamer technology giving a broader frequency range in the seismic data which is crucial for penetration and imaging of the pre-Messinian structures. The recently acquired 2-D seismic reveals a full set of new potential plays offshore Cyprus. In the thick pre-Messinian sediment package in the Levantine Basin a lot more details are seen and more of the deeper low frequent structures are revealed giving a better understanding of the potential plays. The enormous Eratosthenes structure located south of Cyprus whose origin has been the subject of many discussions is now revealing a lot more of its structural elements, supporting the idea that the structure is a potential hydrocarbon source/reservoir. The western offshore and the Herodotus Basin is in a general complex with a lot of thrusting and faulting where several big four-way closure structures have been identified together with a set of interesting pre-Messinian fault blocks. Several hydrocarbon indicators such as flat spots, amplitude anomalies and gas chimneys identified both in the pre- and post-Messinian sediments further enhance the hydrocarbon potential in offshore Cyprus.

Based on the promising structures and elements identified in the seismic data and the recent Dalit, Tamar and Leviathan discoveries (0.5, 8 and 16 TCF of gas) in offshore Levantine Basin, offshore Cyprus is expected to receive a lot of attention from the oil and gas industry with regards to the second license round and will be an important player in the future search for hydrocarbons.

714083 Evaluation of the effect of wettability alteration from oil recovery in carbonate reservoirs

J. Sheng, D. Morel and P. Gauer

More than 60% of the world's oil reserves are held in carbonate reservoirs. Many unfavorable factors contribute to low oil recovery in these reservoirs. Two leading factors are fractured and oil-wet

reservoirs. Therefore, much research focuses on these factors. Apparently, there is an increasing interest in using chemicals to alter wettability. Injection of chemicals can result in various effects, for example, wettability alteration and reduction in interfacial tension (IFT). The question is how much each mechanism contributes to the increase in oil recovery. There is lack of such information in the literature. The information is very important because it will guide us to select which chemicals are to be used.

This study evaluates the effect of wettability alteration on oil recovery in carbonate reservoirs. The main objective is to quantify different mechanisms of wettability alteration in oil recovery related to chemical enhanced oil recovery (EOR). In particular, we compare the effects of wettability alteration and interfacial tension. Both fractured and non-fractured reservoirs are addressed. Analytical models and numerical simulation models are used. Our results show that wettability alteration only plays important roles when IFT is high, and it is effective in the early time. IFT plays very important roles with or without wettability alteration and is effective during the entire process. The implication is that anionics used to reduce IFT is preferred to cationics used to alter wettability. Other observations are that in surfactant-induced wettability alteration with low IFT, gravity drive is a very important mechanism. Molecular diffusion of chemicals affects oil recovery rate in the early time, but not ultimate oil recovery.

728171 Mobility control requirement in enhanced oil recovery processes

J. Sheng

Mobility control is essential in any enhanced oil recovery (EOR) process. We know that the displacing phase mobility should be less than or equal to the displaced phase mobility. If we take polymer flooding as an example EOR process, the displacing phase is polymer solution, and the displaced phases are oil and water phases. Based on the conventional concept, the polymer mobility should be less than or equal to the sum of oil and water mobilities. The problem is that the conventional concept is based on the conditions that the displacing phase and displaced phase move at the same velocity and one fluid is displaced by another fluid. However, in the polymer flooding case, two phases, oil and water, are displaced by polymer. And the oil and water phases move at different velocities. Therefore, the conventional

concept cannot be applied to the polymer flooding process or a general EOR process.

In this study, we first use a simulation approach to demonstrate that the above conventional concept is invalid in the polymer flooding case. Based on the theoretical stability analysis of displacement front, we propose that the displacing polymer mobility should be less than or equal to the oil phase mobility. The above mobility requirement is validated by extensive simulation results at different conditions. It is also justified by field practices. The new concept helps us to select the correct polymer concentration for a practical EOR process.

705858 Unraveling complex velocity anomalies: A case study in Bahrah area, Kuwait

A. Singavarapu, A. Salah Abdulla, M. Ahmed, S. Thakur, H. Al-Owihan and R. Busi Venkata

The role of velocities in understanding seismic data is very significant. Layers or features with a high seismic velocity surrounded by rocks with a lower seismic velocity cause in the time domain what appears to be a structural high beneath it. After such features are correctly converted from time to depth, the apparent structural high is generally reduced in magnitude or sometimes turns out to be flat. Understanding of the depositional environment, tectonic movements and lithology is very important in converting the seismic section from time to depth domain. One such example is the Bahrah area, which is situated in the Kuwait onshore and lies on the northern plunging anticline of the Kuwait Arch. Very sharp lateral velocity variations coupled with strong vertical velocity variations extending over very short intervals caused depth conversion that is much more difficult in this area.

In the Bahrah area, the dominant NNW-SSE fault system is intersected by an East-West fault system that formed as a result of transpression. The transpressional features are overlain by well-defined grabens formed as the result of the collapse of these features. As a result of this complex tectonic activity and the subsequent diagenetic transformation that took place resulted in the forming of dolomitisation/cementation in the carbonates which in turn produced very high velocity zones within localized areas of limited areal extent, both laterally and vertically. In the seismic section these areas come up as very

distinctive and pronounced structural highs, evident in the otherwise horizontal and uniform sedimentary reflection sequence, and are leading the interpreter to map them as structural highs/four-way closures. The depth maps prepared using the available velocities turned out to differ by around 300 feet to the actual well data. To overcome the problem, an initial velocity model was built using all the hard data. Later, zones of anomalous velocity in the area are identified. To restrict and effectively isolate the influence of zones of sharp velocity variations, suitable velocity functions are introduced in and around the anomalous zones by giving due weight to the drilled well data and depositional environment surrounding these zones. Once the seismic volume is converted into depth domain using the corrected final velocity model, structural highs in time turn out to be reduced in magnitudes in depth. A clear understanding of depositional environments, tectonic movements and paleo-structural reconstruction may give insight into the sharp velocity variations and will add confidence to the subsequent time-to-depth conversions. Proper understanding of velocity anomalies may help in reducing surprises in exploration.

680470 A study from source rock causing false bright spots

R.K. Singh, M.G. Al-Otaibi and H.H. Soepriatna

A strong 3-D seismic amplitude anomaly, thought to be associated with the Upper Jurassic Hanifa reservoir, was interpreted to be due to an increase in the porosity of Hanifa carbonates. The Hanifa Formation overlain by the Jubaila source rocks is present in the Jafurah Basin, east of the Ghawar Field in Saudi Arabia. After drilling exploratory well 1, the targeted Hanifa carbonates proved tight with porosity generally less than five percent. A post drilling study was taken to evaluate the rock properties and the cause of the seismic bright anomaly. The study investigated the effect of reservoir thickness, porosity, lithology, pore fluid type, and total organic content (TOC) on acoustic impedance in both the Hanifa and Jubaila formations. Synthetic normal incident traces were generated to understand the effect of changes in these reservoir properties on the seismic. This presentation summarizes the results of investigations for finding the cause of seismic amplitude anomalies as seen at the top of the Hanifa carbonates.

It was concluded that porosity is the dominant factor in the strength of the observed anomalous seismic amplitude in the study area. The porosity was mainly caused by high TOC in the Jubaila source rock. The study finds an inverse proportional relation of TOC with the acoustic impedance. As the acoustic impedance decreases with increasing TOC within Jubaila, the impedance contrast between the base Jubaila and the top Hanifa increases. Hence, amplitude brightening would result at the Hanifa top due to increased TOC within the Jubaila Formation.

703907 Pore pressure prediction using seismic inversion and velocity analysis

H.R. Soleymani, S. Seyed Ali and M.A. Riahi

The concept of abnormal pressure is among the most important concepts in hydrocarbon exploration and production. Overpressured formations, in which the pore fluid pressure is higher than the corresponding hydrostatic pressure, form an excellent trap for hydrocarbons. However, if the pore fluid pressure exceeds a threshold dictated by the strength of the rock, the seal may have been breached. This will cause the hydrocarbons to migrate away. This process will be further facilitated by the presence of hydrocarbons in dipping formations due to fluid migration and buoyancy effects. Thus, reliable estimates of formation pressure are critical to understanding the hydrocarbon habitat, from regional to prospect scale.

In addition, drilling through geopressured zones is challenging, and requires extra care. Knowledge of the pore pressure in an area is important for several reasons. In overpressured zones, there is often little difference between the fluid pressure and the reservoir fracture pressure. In order to maintain a safe and controlled drilling, the mud weight must lie in this interval (i.e. between fluid pressure and fracture pressure). If a too low mud weight is used (underbalanced drilling) while drilling through high pressure zones, there is danger of well kicks.

Generally pore pressure can be estimated from elastic wave velocities using a velocity to pore-pressure transform. Velocities obtained from processing seismic reflection data are clearly required, but these velocities often lack the spatial resolution needed for accurate pore-pressure prediction. This low spatial resolution results from assumptions such as layered media and hyperbolic moveout. In this study we obtain velocities at a

much finer scale at one of the Iranian southwest oil fields using seismic inversion of amplitudes in conjunction with any acceptable low-frequency model, such as SCVA and available sonic logs. This is a new approach for generating velocity model and our aim is to obtain a high resolution velocity model that is more appropriate for pressure prediction. The next step is calculating effective stress with Bower's equations (1995) that are calibrated using available wells within the basin. The main reason for conducting such a study in this area is to predict formation fluid pressure prior to drilling. As a result of this study, high-resolution pore pressure cube that has enough detail for drilling applications can be obtained with the use of Terzaghi's empirical equation.

680374 The Levantine Basin: Prospectivity in a frontier basin

T. Sortemos, C.J. Lowrey, C. Skiple and M. Trayfoot

The prolific Nile Delta to the south is an active petroleum province, but exploration activity in the deep-water Eastern Mediterranean offshore Cyprus, Levantine Basin and Lebanon has been limited. However, the recent deep-water sub-salt gas discoveries offshore Levantine Basin, the announced second licensing round offshore Cyprus in 2009 and the planned first licensing round offshore Lebanon has spurred a significant increase in industry interest in the area. The Levantine Basin is bound to the east by the Levantine margin, to the north by the Latakia Ridge and to the west by the Erastosthenes Seamount and is interpreted as a Mesozoic transform rift graben. Our interpretation and the Tamar discovery indicate that much of the pre-Messinian sedimentary package in the Levantine probably consists of Oligocene to Miocene successions, rather than the Lower Cretaceous/Senonian successions suggested previously. Acquisition and interpretation of new 2-D and 3-D seismic, in the Levantine Basin offshore Cyprus and Lebanon has revealed several attractive large, and possibly giant, sub-salt traps associated with the Syrian Arc folding that is also identified with many of the discoveries in the Eastern Mediterranean area.

While the recent gas discoveries offshore Levantine Basin prove the presence of a mature source rock, a detailed assessment of potential source rocks in the Levantine Basin is hindered by the absence of any released well data. However, several potential source rock intervals are known from onshore

wells and outcrops. These include a number of possible Mesozoic source rocks of both terrestrial and marine origin and there is at least one possible Lower Miocene organic-rich source rock.

In the Eastern Mediterranean and Middle East areas there are reservoir intervals throughout the Mesozoic and into the Cenozoic. In the Levantine Basin itself the predominant reservoirs are expected to be Miocene deep-water fans but Middle Jurassic to middle Cretaceous carbonate platforms may also contain potential reservoir sections on the Levant Margin. Seals for these reservoir intervals include Upper Cretaceous to Tertiary shales in addition to the major regional seal of the Messinian evaporites. Using modern and state of the art seismic, together with other available data, this study will present the prospectivity of the Levantine Basin. Focus will be on the frontier areas that are sparsely drilled or undrilled but the prospectivity of these areas will be placed in a regional context.

677627 Dual sensor seismic examples from around the Middle East

M. Spencer-Jones and P.H. Semb

New dual-sensor streamer 2-D data have been compared to legacy conventional streamer data throughout the Middle East (Cyprus, Egypt, Lebanon, Libya, and Saudi Arabia) to analyze the differences and quantify the improvements in seismic resolution. A comparison of PSTM (pre-stack time migration) stacks after processing through the same flow of the vintage hydrophone data and the up-going pressure field (P-up) showed in general a higher signal-to-noise ratio and better resolution of the P-up image. Spectral analyses quantified the amplitude frequency level and showed a significant increase of low and high frequencies. The low frequency enhancement was particularly significant deeper in the sections with spectacular penetration below the highly reflective Messinian Salt/Mansiyah Formation layers.

The dual-sensor streamer measures the pressure wave field using hydrophones and simultaneously the vertical component of the particle velocity using motion sensors, overcoming the limitations of hydrophone-only acquisition systems. Its unique ability to de-ghost signals and to optimize data quality, not just for one target depth, but for all depths shallow to deep, promises to significantly improve our customer's exploration success ratio, well targeting and recovery efficiency. Besides data quality improvements, the streamer is operationally

efficient because it records in one pass, with one streamer depth, in seas no other system can handle. The technical benefits of this step change are seen in three key areas: (1) enhanced resolution of the final seismic image; (2) better penetration revealing deeper targets; and (3) improved operational efficiency. The first two points result from the increased bandwidth at both low and high frequencies due to removal of the receiver ghost. The third point results from the ability to tow deeper, which is operationally attractive as weather and operational noise are minimal and the streamers are better behaved.

677671 Remaining exploration potential of the Paleozoic section in Abu Dhabi

A.A. Taher, K.H. Al Mehsen, M. Al Zaabi and H.S. Alsenani

The pre-Khuff principal reservoir, Unayzah Formation consists mainly of distal braid plain sandstones with minor aeolian deposits. Facies controls on reservoir quality are weak. Quartz cement, illite and compaction are the main causes of reductions in reservoir quality in the Unayzah. Quartz cementation tends to be most severe in the cleanest, coarsest sandstones and near certain fractures. Paleozoic seals are provided by the Basal Khuff Clastics, tight basal Khuff carbonate and Middle Khuff Anhydrite. The base Khuff carbonate seal does not appear to be regionally extensive, but localised and potentially prospect specific. However, there are insufficient data to accurately define the seal for the Unayzah hydrocarbon accumulations.

The main challenge that faced the Paleozoic source evaluation and basin building was the presence of few deep-well penetrations. Therefore, much of the unknown source and tectonic information were derived from the surrounding countries. This comes from understanding regional tectonics and depositional trends of the southeastern Arabian Plate, which helped extrapolate source trends into the Abu Dhabi area. The Silurian source rocks basin modeling was constructed to define the timing of hydrocarbon charge from these source rocks. Also, the objective of this modeling was to gain an understanding of how the Paleozoic hydrocarbon system works and, specifically, comparing the timing of hydrocarbon charge with the timing of the field's structural growth history. The basin modeling work of the Silurian Hot Shale source rocks started by building an extensive database, which includes the information related

to source rock distribution, heat flow of the basin and the construction of the stratigraphic and the lithological models. Additional inputs such as tectonic events and estimating the magnitude of the removed section, during the erosional events, were added.

The current maturation modeling indicated that oil from Silurian source rocks was generated early in the basin history and was widespread by the Late Triassic (220 Ma). Significant gas was present by Early Cretaceous (140 Ma) and dominated the hydrocarbon system by middle Cretaceous (110 Ma). Significant high mature gas was generated in the early Tertiary (50 Ma). At present-day, charge is still active in the north of Abu Dhabi.

702037 Prediction of reservoir and seal capacity for exploring Jurassic carbonate stratigraphic traps, northern Saudi Arabia

D.Z. Tang, P. Rabiller, A.E. Gregory, P. Lawrence and A.M. Bakhiet

The exploration for stratigraphic traps, especially in carbonates, is challenging and requires carefully detailed analysis of petroleum system elements. Accurately defining the spatial and temporal distribution of source rock, reservoir, and seal facies is essential for exploring stratigraphic traps. This study presents an integrated approach for evaluating reservoir and seal capacity of Jurassic carbonates to explore stratigraphic traps using well-log electrofacies prediction and calibrated seismic facies modeling techniques.

Core-based rock types were generated for selected Jurassic carbonate reservoir formations by integrating core descriptions, thin-section petrographic data, core plug porosity/permeability, and capillary pressure (MICP) measurements. Reservoir quality and sealing capacity were thoroughly evaluated using core-derived pore-throat size and capillary pressure data from a full spectrum of reservoir and sealing facies. This was followed by calibration of core-derived reservoir and seal facies to well-log responses by constructing Facimage models for selected "Reference Wells" that are extensively cored and analyzed. The Facimage models were rigorously tested by validating predicted electrofacies/capillarity and core-derived rock types, and their sealing capacity. The optimized Facimage model was used to predict electrofacies that represent rock types of varying reservoir quality and seal capacity for all the selected "Application Wells"

within the area of interest. The derived electrofacies (rock types) of reservoirs and seals can be upscaled to a seismically detectable level. The upscaled facies were then output as numerical codes into the calibrated seismic facies modeling of 3-D seismic volumes using state-of-the-art technologies for analysis, integration, and visualization.

The calibrated seismic facies, rock types and porosity models provide lateral and vertical facies changes of reservoirs and seals within 3-D volumes. These are critical elements for exploring stratigraphic traps. The Middle and Upper Jurassic reservoirs have been taken as examples for the above approach. Preliminary results have demonstrated that existing stratigraphic trap analogue and potential new stratigraphic traps can be successfully predicted, as shown in the Upper Fadhili and Arab-D reservoirs.

702169 A novel approach towards semi-automated lithofacies identification from image logs

A. Thomas, M. Rider, A. Curtis and A. MacArthur

Visualization is an important aspect of modern hydrocarbon borehole geophysical measurements. Downhole tools are now able to acquire high-resolution 2-D and 3-D maps of the acoustic and electrical properties of the borehole wall and display them in real time as false-colour images of the formations encountered during drilling. These data now form a huge industry database. However, the interpretation of these images under-utilizes the data. To date, the only regularly used quantitative methodology applied to image log interpretation is for the derivation of orientation data (dip and azimuth). Other, occasional quantitative methods use the resistivity measurements themselves, and not the images. However, from the images themselves, much additional information can be extracted, by using advanced object-based image analysis software which is widely available and is successfully employed for analyzing digital images at all scales, from microscopic cell structures to satellite pictures.

We present a method for identifying lithofacies from image logs employing image analysis methods used in remote sensing and medical science. The new technique presented synthesizes expert knowledge and digital image analysis, to recognize physically and/or chemically consistent objects within an image and relate these to geologically meaningful groups, such as lithofacies. Filters

are used to mark bed boundaries and are created from a derivative log extracted from neutron and density logs and from bed orientation calculated using automated sinusoid fitting at every pixel depth in image log within a formal uncertainty framework. The resultant lithofacies classification is then validated through the interpretation of cored intervals by a geologist.

The image interpretation calibrated to core ensures the accuracy in the result obtained and the good match between the two gives the confidence to extrapolate the automated image analysis result from areas with core control to areas with poor to no core recovery. The developed method can be quickly adapted to other wells or applied field-wide by defining the lithofacies in each case and by appropriate sample selection for each lithofacies. In addition, the methodology is applicable to several kinds of borehole images, for example wireline electrical borehole wall images, core photographs and the more specialized LWD images.

670180 "Just listen": Acquiring and using low frequency spectroscopy data for exploration in the South Rub' al-Khali Basin

P. van Mastrigt, A. Al-Dulaijan, A. Khalil and G. Pike

The South Rub' al-Khali Company Ltd. (SRAK) is an Incorporated Joint Venture between Shell Saudi Ventures Ltd. (50%) and Saudi Arabian Oil Company (50%) and was set up in order to explore for non-associated gas in the South Rub' al-Khali Basin as part of the Natural Gas Initiative in the Kingdom of Saudi Arabia. In addition to the acquisition of conventional data (regional 2-D seismic, (airborne) gravity, magnetics, uphole and well data), SRAK experimented with alternative, and more speculative methods, notably magnetotelluric and low frequency seismic spectroscopy (LF). A total of three LF experiments were recorded in 2005–2006, with promising results, after which SRAK decided to routinely implement the method alongside the acquisition of its seismic data. This provided a means to gather very large LF data sets at economical rates. The total acquisition now comprises well over 8,500 stations, along 5,600 km of 2-D seismic lines, spread over an area of more than 30,000 sq km. This is by far the largest LF data set worldwide.

Whilst initial Industry publications and presentations concentrated on the experimental nature of the LF method and the speculative source

of the observed anomalies, it is clear that large quantities of data would provide unprecedented insights into the robustness and repeatability of this technology. Together with its contractors, SRAK climbed a steep learning curve, not only to streamline the reliability of the acquisition on this scale, but also in the processing and presentation of the data. Normalization between lines acquired at different times requires a hands-on approach as the sources of the LF signal appear to vary by at least one order of magnitude.

Initial results from the LF program, combined with robust geological models and conventional seismic interpretation, have helped to high-grade prospects in the SRAK portfolio. We describe the implementation of the acquisition, processing, normalization and display of the data. Interpretation of the data is discussed in a companion paper at this conference.

680622 Using spectroscopy logs to enhance formation evaluation and to guide high-resolution facies determination in the Nile Delta, Egypt

M. Van Steene, A. Farghaly and A. Abu El Fotoh

A wide variation in rock quality exists in the sands and shaly sands of the Nile Delta. The mineralogy is complex, including the presence of feldspars, calcite, heavy minerals, and several different clay types. To improve evaluation of these gas-bearing reservoirs, neutron capture spectroscopy data is routinely acquired. The spectroscopy tool measures elemental concentrations, which are then converted into mineral concentrations.

Comparison of core mineralogical data with log spectroscopy data showed that the clay content from the standard clay matched the core data in the clean sand zones. However, in the more shaly parts of the reservoir, clay content from the spectroscopy model was overestimated. Because of the relatively complex mineralogy, a linear calibration of minerals log data to core data was found not to be appropriate. It was, however, found that the clay volume could be more accurately computed from a multiminerals solver using the elemental spectroscopy logs (rather than the mineral volumes output from the spectroscopy model). The computation process is described. It was also found that the aluminum log from direct aluminum yield measurement leads to the best clay estimation, as opposed to using the aluminum log from the

aluminum emulator algorithm. Results of the clay volume computation were used to calibrate the nuclear magnetic resonance (NMR) clay cutoffs.

The mineralogical evaluation was further combined with calibrated microresistivity image data to generate a high-resolution lithofacies column, generating an accurate stratigraphic interpretation. Moreover, cutoffs were applied to generate a high-resolution sand count, sorting the reservoir units from the poorest to the best quality sands. Examples illustrate how the use of the spectroscopy data enhanced standard formation evaluation in these shaly sand reservoirs. The examples also demonstrate that combining mineralogical information with high-resolution images can improve the understanding of the distribution of the best reservoir quality in the well.

670176 "Brighter than the moon": Illuminating the hydrocarbon prospectivity in the South Rub' al-Khali Basin

W. Voggenreiter

The South Rub' al-Khali Company Ltd. (SRAK) is an Incorporated Joint Venture between Shell Saudi Ventures Ltd. (50%) and Saudi Arabian Oil Company (50%) and was set up in order to explore for non-associated gas in the South Rub' al-Khali Basin as part of the Natural Gas Initiative in the Kingdom of Saudi Arabia.

In order to achieve its objectives within the timeframe of the first exploration period, a play-based rather than prospect-based exploration strategy had been devised during the start-up of the venture to maximise the chances of identifying working hydrocarbon systems and to optimally position the company for a second exploration period. This encompassed a two-pronged approach pursuing pre-Khuff Formation sweet gas prospectivity in SRAK's Contract Area 2 in southwest Saudi Arabia and Khuff and Arab Formation sour gas prospectivity in SRAK's Contract Area 1 in southeast Saudi Arabia. A concerted technology effort was made to help polarize drilling opportunities.

As SRAK's first exploration period is drawing to a close in mid-2010, this study will summarise the exploration results, review how the exploration strategy evolved through time in response to early exploration results and distill learnings applicable to similar frontier exploration ventures elsewhere.

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725566 Al Rayyan Field: Case study of a subtle structural trap and implications for exploration in the Arabian Gulf

G. Warren, L. Smith and L. Van Wijhe

The Al Rayyan Field is an example of a very low relief structure located on the western flank of the Qatar Arch. The structural analysis of the field is an ideal template for the exploration of subtle traps in the region. Different seismic data sets and processing techniques (in both time and depth) have produced ambiguous structures over the field. Isochron mapping of geologically significant intervals successfully resolves the field's structural evolution through time. This same mapping strategy can be employed as an exploration tool to screen and validate subtle prospects observed in both the time and/or depth domains within the Gulf region.

The top early Cretaceous to top Jurassic isochron is the critical geological interval for understanding the trap geometry of the field. The field is located on a paleo-structural nose that previously plunged counter to the present-day regional dip direction. The thinning and faulting evident on the middle to late Cretaceous isochron are in sharp contrast to the structurally featureless early Cretaceous isochron. The Jurassic isochron thins eastward towards the Qatar Arch and gives no indication of the present day field. The isochron characteristics observed locally are consistent with a regional geological history that begins with stability throughout the Jurassic and early Cretaceous; is followed by collisional tectonics during the middle to late Cretaceous; and culminates with down-warping and northward tilting in the Cenozoic. The latter event transformed the Jurassic reservoir at Al Rayyan from a structural nose into its current low relief, four-way closure geometry.

The foregoing suggests that a valid exploration strategy for the region should consider a search for subtle structural features that formed during the middle to late Cretaceous. Paleo-structural noses identified within the Cretaceous section, especially those that are associated with isochron thinning and faulting of the middle to late Cretaceous section, represent prime exploration targets. This strategy should help the explorationist distinguish between structurally valid velocity-induced leads within these target sections.

680867 Maximising recovery from thin oil columns Part 3: Maintaining from 'Evergreen' subsurface model to optimise a waterflood development

G.M. Warrlich, D.M. Alexander, I. Abu-Shiekhah, F. Zhu, P. Goossens, S. Tull and A. Lamki

Over the last three years the first stages of a waterflooding project comprising 200 horizontal producers and injectors were implemented in a thin oil column (20 m) transition zone carbonate field (Shu'aiba Formation) in the Sultanate of Oman. The reservoir is composed of a high porosity, low permeability matrix. Porosity and rock quality vary across the field to such a degree that wells in some areas of the field are not economic. Therefore prediction of reservoir quality is critical to successful field development. The field development plan (FDP) that underpins this project utilised sequence stratigraphy, acoustic impedance and production behaviour of existing wells to create static and dynamic models which formed the basis for the development well patterns.

This study focuses on the updates made to the static model since the FDP model, integrating drilling results from the first 60 wells of the project and continued reservoir characterisation and modelling work, to ensure that the planned wells remain economic and the well sequencing and placement optimised. Automated workflows were established to incorporate drilling data on a day-to-day basis for improved reservoir performance predictions and well design. Information from appraisal wells and production behaviour from the production wells was used for improved well sequencing and property model rebuilding. Updated methodologies for rock typing, permeability and saturation height functions were established. The overburden model is updated to give accurate formation top predictions for the drillers. Keeping an 'evergreen model' has proven a best practise to ensure continuously optimised drilling and recovery from the field.

681125 Exploration risk management: A play fairway led approach

H. Wilson

We describe an integrated framework for exploration risk management, driven by business reserves and production requirements. A structured approach to play fairway evaluation

should underpin strategies to manage exploration risk. Sub-optimal decision-making results through failure to articulate geoscience risks. Managing exploration integrates technical evaluation and business needs. We describe the exploration decision-making framework. The company's reserves and production growth requirements should drive all exploration investment decisions. The exploration funnel (basin entry through to production) should be managed so that there are enough high-quality opportunities to meet current and future demand.

Exploration is a risk business and the ability to predict outcomes at portfolio basis is fundamental to exploration success. We present examples of how a company's risk and volume estimates should be continually calibrated against past performance. Management must believe in the cost/volume projections provided by the explorers! Most companies start a portfolio review exercise by mapping current assets against business demands. It is vital to take a hard look at the existing portfolio and test its ability to deliver. If it cannot deliver, it will need reshaping. Geoscience understanding and the ability to de-risk plays underpin the whole business of exploration. In most companies, staff are the critical resource that needs rationing, not capital. We describe a structured approach to play fairway evaluation in which we use this as a tool for de-risking plays and planning investments in time and capital.

We have suggested that the business requirements be presented in terms of a production profile. This means that exploration outcomes should also be modelled in this way. The classic way of modelling an outcome of an exploration portfolio is through presenting the risked weighted sum of the production profiles arising out of the given drilling campaign. However we find that this does not adequately represent the likely outcomes.

Most companies have some high volume wells in their portfolio (perhaps associated with high risk). Success in these would transform the shape of a company as happens in most successful exploration companies. We therefore prefer the scenario modelling approach in which we model success/failure in certain wells. The story outlined above shows how a structured approach to geoscience enables informed business decision making.

725562 Petroleum system modeling as a useful tool for exploration stage: A case study from Muglad Basin, Sudan

M.A. Yassin and A. Gibreel

The Geological & Geophysical (G&G) study's work scope, which is running after structural mapping and prospects assessment, is not enough to be a guide for the exploration stage. It can easily be shown that this kind of scope is often dangerously incomplete without petroleum system modeling. Petroleum system modeling technology is used to investigate charge risks by special simulators that can calculate the processes of hydrocarbons generation, expulsion, migration, accumulation and loss through geologic time.

Structural analysis and sequence stratigraphy are an essential part of basin modeling. Integration of these two disciplines with others such as geochemistry, petrophysics and geophysics will be very helpful to reduce the basin modeling's uncertainties.

This work answers questions such as: Have hydrocarbons been generated in a basin? Where were the hydrocarbons generated? When were the hydrocarbons generated? Could the generated hydrocarbons have migrated to my prospect? What are the possible properties of the hydrocarbons that could have migrated to my prospect?

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