



Sediment Body Geometry and Heterogeneity: Analogue Studies for Modelling the Subsurface

22-23 October 2009

*The Petroleum Group would like to thank BP,
ExxonMobil, Schlumberger and StatoilHydro for
their support of this event:*



ExxonMobil

StatoilHydro Schlumberger

CONTENTS PAGE

Conference Programme	Pages 3-6
Oral Presentation Abstracts	Pages 7-71
Poster Abstracts	Pages 72-78
Fire Information	Pages 79-80

PROGRAMME

Thursday 22 October	
08:00	Registration + coffee
08:50	Welcome and opening
09:00	Naess, A. (StatoilHydro) KEYNOTE: Application of outcrop analogue data in business units. Which types of sedimentological data are important - how are they used
09:40	Gardiner, A. (Heriot Watt University) Use of outcrop-based models of channelised turbidite systems in multidisciplinary reservoir studies
10:05	Pope, D. (BP) Permeability populating of turbidite channel reservoir models from fine scale geological models devised by integrating core data with a conceptual geological model
10:30	Tea / Coffee
11:00	Howell, J. (CIPR) Empirical Understanding of Sedimentary Architecture
11:25	Legler, B. (Imperial College) Characterisation of tide-dominated heterolithic reservoir analogues: Eocene Qasr El Sagha Formation, Western Desert, Egypt
11:50	Howell, J. (CIPR) Impact of deltaic clinothems on reservoir performance: dynamic study of reservoir analogues from the Ferron Sandstone and Panther Tongues, Utah USA
12:15	Rarity, F. (University of Manchester) Constraining 3D geometry and heterogeneity within synrift tidal-shallow marine facies using lidar-based digital outcrop data: Suez Rift
12:40	Lunch
14:00	Bloch, R. (ExxonMobil) Integrating observations from numerical models, physical experiments and outcrop of deepwater fans for improved reservoir modelling
14:25	Storms, J. (Delft) Physics-driven modelling as an alternative reservoir building tool

14:50	<p>Hampson, G. (Imperial College London) High-resolution stratigraphic architecture in regressive and transgressive shallow-marine outcrop analogues</p>
15:15	Tea / coffee
15:45	<p>Ruvo, L. (Eni) Process Oriented Modelling for multi-scale data integration in the 3D reservoir modelling workflow</p>
16:10	<p>Donselaar, R. (Delft) Integrated modelling of the Ten Boer Claystone Member, Southern Permian Basin: a combined log correlation, outcrop analogue and numerical forward modelling study</p>
16:35	<p>Jackson, M. (Imperial College London) Three-dimensional modeling of the shoreface-shelf parasequence reservoir analogue: stratigraphic and sedimentological controls on fluid and hydrocarbon recovery</p>
17:00	<p>Hamon, Y. (IFP) Characterization and geostatistical modeling of facies and diagenesis in a mixed carbonate-siliciclastic reservoir analog . Example of the Ilerdian Alveolina Limestone, Serraduy, NE Spain</p>
17:25	Wine Reception

Friday 23 October	
08:30	Registration + coffee
09:00	Eschard, R. (IFP) <u>KEYNOTE</u> : Constraining Stochastic and process-based simulations with outcrop data-bases: the steps further
09:40	Gardiner, A. (Heriot Watt University) Discontinuous Shales and Their Impact on Reservoir Behaviour
10:05	Hodgetts, D. (University of Manchester) A new approach for outcrop characterization and quantitative fluvial-body analysis of a low-sinuosity fluvial-dominated succession using digital outcrop models: Upper Triassic Oukaimeden Sandstone Formation, central High Atlas, Morocco
10:30	Tea / Coffee
11:00	Thurmond, J. (StatoilHydro) Maximizing analogue data access and capturing user knowledge using off-the-shelf applications
11:25	Miller, J. (ExxonMobil) Unraveling and modeling heterogeneities in reservoirs using process based models
1:50	Hern, C. (Shell) The Impact of Architecture on Fluid Flow with an Aeolian Dune; an Example from the Wahiba Sands, Sultanate of Oman
12:15	Keogh, K. (StatoilHydro) Data capture for multi-scale modelling of the Lourinhã Formation, Lusitanian Basin, Portugal: an outcrop analogue for the Statfjord Formation, Norwegian North Sea
12:40	Lunch
14:00	Boucher, A. (Stanford University) A flexible and expandible design to generate training images for sedimentary environment
14:25	Reesink, A. (University of Brighton) The origin and sedimentology of large sandy mid-channel bars
14:50	Fügel, F. (University of Tübingen) 3-D modelling of cement resources: a case study in economic geology (Jurassic, S-Germany)
15:15	Tea / coffee

15:45	Skorstad, A. (Norwegian Computing Centre) An analysis on the ability of stochastic object and pixel-based models to reproduce the fluvial channel architecture of the Escanilla outcrop
16:10	Johnson, H. (Imperial College London) Fluvial Reservoir Analogues in the Malay Basin: Analysis of Shallow 3D Seismic Data of Pleistocene Rivers on the Sunda Shelf
16:35	Watkins, C. (Furgo) Complex attribution to add value to analogue geometry data: A case study of the large scale controls of fluvial channel geometry
17:00	Dabek, L. (Geomodelling Tech Corp) Modeling of Heterogeneity within Hummocky Cross Stratification and its Impact on Vertical Permeability at the Geocellular Scale
17:25	Conference End

POSTER PROGRAMME

Newell, A. (BGS) Calcrete as a source of heterogeneity in fluvial sheet sandstone reservoirs
Rittersbacher, A. (CIPR) Oblique Helicopter Lidar as a tool for the collection of “very large”, Virtual Outcrops: Examples from selected fluvial outcrops in Eastern Utah
van Lanen, X. (University of Manchester) High Resolution Quantitative Outcrop Analysis of a Fluvial depositional system: An example from the Late Triassic Wolfville Formation, Nova Scotia
Bartenback, M. (University of Tübingen) 3-D modelling of deeper ramp carbonate buildups – a reservoir analog study from the Upper Jurassic (SW-Germany)
Francke, J. (Shell) Imaging the internal architecture of an Aeolian Dune: Trials and Tribulations of GPR in the Desert Sands of the Sultanate of Oman

Thursday 22nd October

Application of outcrop analogue data in business units: Which type of sedimentological data are important – how are they used

A. Næss, StatoilHydro ASA, E&P Norway, P.O. Box 273, NO-7501 Stjørdal, Norway

Successful application of analogue data collected for modelling the subsurface is closely linked to how well this data is suited to support projects providing basis for reservoir management decisions. These decisions are typically driven by subsurface field characteristics, top-side capacities, infrastructure life time, availability of drilling facilities, or any other production measure that will initiate major investments. Any of the drivers mentioned above will set the terms for prioritisation of different subsurface project types and data requirements.

The main task of any subsurface team is to provide a sufficient decision basis regarding:

- a. Quantification of in place hydrocarbon volumes (including volumes for a given reservoir zone or reservoir fault compartment).
- b. Short and long term production forecasts.
- c. Identification of subsurface uncertainties and their influence on volume calculations and production forecasts.

The technical objectives of subsurface studies that follow from this will commonly involve:

- 1) Reservoir characterisation - sedimentological description and interpretation of depositional environments.
 - a. Stratigraphical analysis as basis for reservoir zonation
 - b. Defining conceptual models for heterogeneity modelling
- 2) Implementation in subsurface geological models
 - a. Formulate and/or apply a geostatistical representation of the conceptual model
 - b. Derive actual subsurface parameters needed as model input
 - c. Upscale rock properties (static and dynamic) to modelling scale
 - d. Integration of seismic, petrophysical and dynamic data in property modelling
- 3) Building reservoir simulation models
 - a. Choice of grid resolution
 - b. History matching
 - c. Production prognosis
- 4) Development of field drainage strategy
- 5) Choice of well solutions and definition of drilling targets
- 6) Initiation and execution of various IOR/EOR projects

As outlined in the main theme of this conference, many outcrop analogue studies have (with great success) strongly focused towards points 1 and 2a/b in the list above. There is no doubt that outcrop analogue data has played a strong supporting role in many geological modelling projects, but there are also examples of overuse of outcrop data where geological concepts have been forced into the modelling process without sufficient link to the overall business objective the model is supposed to serve.

Experience also shows that if the concepts derived from the analogue data-sets are too complex to be applicable in point 2b, the data may be easily misused or not used at all. Simplifying the concepts and identifying the most critical elements in the nature

of the reservoir flow response is a key component of all subsurface reservoir modelling studies.

The main objectives of this presentation are to provide examples of how outcrop analogue data can be treated in terms of fit-for-purpose application, and in addition how the outcrop analogue data may be applied indirectly in all parts of the overall reservoir management workflows. The latter may include feedback into geological models following a history matching phase, application of sedimentological concepts in choice of well solutions, or targeting IOR volumes.

Examples will include application of outcrop analogue data from various sedimentological settings (fluvial, tidal-, and wave dominated deltas) commonly found in oil- and gas field offshore Mid-Norway. Finally examples will also be given of how various "business drivers" will define to what degree outcrop analogues are suited or needed in the modelling process.

NOTES

Use of outcrop-based models of channelised turbidite systems in multidisciplinary reservoir studies

A. R. Gardiner, *Institute of Petroleum Engineering, Heriot-Watt University, Edinburgh, EH14 4AS, UK.*

The Ainsa sub-basin in Alto Aragón, northern Spain, contains approximately 3km of deep-water sediments of Eocene age. The succession is dominated by fine-grained sediments (mudstones, siltstones and marls) but contains several sand-dominated intervals several tens of metres thick. These can be demonstrated by mapping to have a lenticular shape and, internally, are composed of vertically and laterally stacked channels.

The Ainsa II channel complex crops out to the south and north of the town of Ainsa and, to the north of the town, forms a N-S trending outcrop up to 60m thick and almost 1km long. Individual channel fills are dominated by turbidite sandstones and subordinate debris flow deposits, interbedded with mudstones and siltstones. In general, the thickest individual sandstone beds and the highest net-to-gross ratio occur towards the base of the channels, especially in the axial zones. Palaeocurrents in the channels were towards the NW, such that the N-S outcrop is oblique to the channel trend.

Although the 2D geometry of the complex north of Ainsa can be well established, data from the third dimension are scarce. Several research wells were drilled behind the outcrop, but it proved to be very difficult to correlate between the wells and the outcrop, so that they provided little useful data on the third dimension.

A high-resolution 3D model of the outcrop has been produced. The objectives of the Ainsa II modelling were not to reproduce the outcrop in its current orientation but to study the reservoir behaviour of turbidite channel complexes; the top of the channel complex is therefore modelled as horizontal. The input data for the 3D models consist of 2D interpretations of the outcrop, based on vertical sedimentary logs and bed-by-bed correlation between them. On these 2D panels, four facies are shown, turbidite sandstone, debris flow deposits, fines within the channel complex and background fines. Individual beds as thin as 25cm have been correlated.

The full 3D model covers an area 3km by 1.5km, with its long axis oriented towards 320°, parallel to the palaeocurrent trend, and is 70m thick. The grid cells are 5m x 5m x 0.5m. Individual channels were modelled deterministically and the modelled channels then filled with the appropriate facies using vertical facies proportion trends based on the outcrops and by using horizontal correlation lengths appropriate to the sand-bed continuity observed at outcrop. The main constraint on the 3D model is that it should honour the 2D geometry along the trend of the outcrop.

The full geocellular model contains 25 million cells, so is too large for flow simulation and for some other forward-modelling techniques. Where necessary, the model has been coarsened and upscaled and, in some cases, smaller sector models have been extracted from the full, high-resolution model.

Two-phase fluid flow simulation, with producer and injector wells sited in different locations with respect to channel axes, has allowed optimum well placement, judged by productivity index or recovery factor, to be assessed.

Seismic modelling of the 3D model has been undertaken, using a range of seismic parameters appropriate to different geographic locations and stratigraphic ages. Three-

dimensional seismic cubes have been generated representing initial reservoir conditions and then repeated following flow simulation through the model, when fluid distributions and reservoir pressures will have changed. Differences between the seismic cubes indicate the system's susceptibility to 4D seismic analysis and it can be seen that, for some seismic properties, the 4D effect is most visible for far-offset stacks, whilst for others the near-offset stacks show greater differences.

Well test analysis provides useful information on the quality and continuity of reservoir sandbodies and on potential barriers to flow. However, most well test interpretations are non-unique and it is difficult to relate the well test results to the geology. Synthetic well-test analysis using models such as the Ainsa II model allows the well test response to be compared with known reservoir geology. An analysis of what features can and cannot be seen by tests of varying duration can help in well test design.

An additional value of the static and dynamic studies on the Ainsa II models is their use during field seminars. The Ainsa outcrops are used by many universities and oil companies for field trips and seminars and the results of the simulation studies can be discussed in the field, enabling the seminars to cross over from reservoir geology into reservoir engineering and thus provide a useful forum for multidisciplinary discussions.

NOTES

Permeability population of turbidite channel reservoir models from fine scale geological models devised by integrating core data with a conceptual geological model

D. Pope, M. Mayall, A. Jegede, P. Shell, E. Vervest, S. Landu

The objective of this study was to realistically populate reservoir models of deepwater turbidite channels with horizontal and vertical permeability's. The paper will discuss how core data from local analogues was used to populate a range of conceptual 3D fine scale geological models to establish a relationship between Net: Gross and permeability which then could be applied to the coarse scale reservoir models.

A field reservoir simulation model would ideally be built at the scale permeability measurements are taken (core plug scale) and up scaled to allow models to run over reasonable durations. In many deepwater pre-development projects however these measurements are made at only a few discrete locations. This paper will propose one technique to overcome this scarcity of data issue.

The 3D conceptual models were generated by Stochastic population of geobodies representing the typical architecture of these systems as observed on seismic and at outcrop. The study classified over 300m of core by rock type from analogue turbidite systems and used this data to give confidence to the proportions of rock type in the fill of the conceptual geological models. Core plug permeability measurements taken from the same core were used to populate permeability in the fine scale models. Multiple models were generated to compare the variation in the relationship between net:gross and permeability with body architecture.

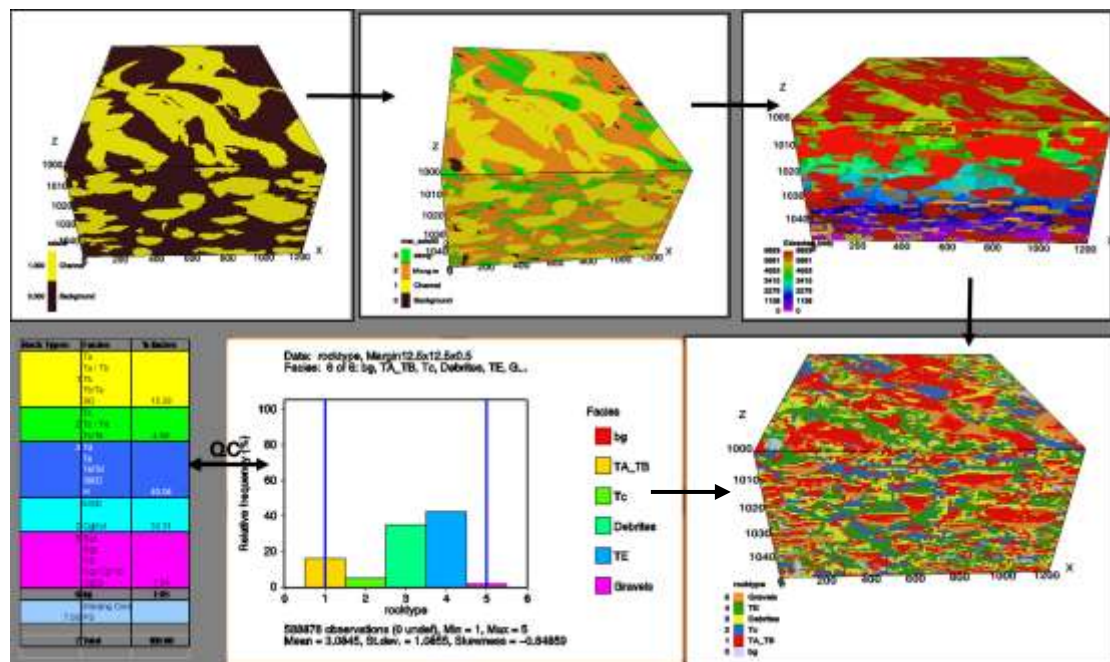


Figure (1) Construction of a 3D Geological Model. Upper row shows the construction of the body architecture. Lower row the proportion of rock types feeding the final populated model in the bottom right corner

NOTES

Empirical understanding of sedimentary architecture

J. Howell^{1,3}, S. Buckley¹, A. Rittersbacher¹, N. Richter¹, K.Keogh²

¹Centre for Integrated Petroleum Research, University of Bergen, Norway

²StatoilHydro, Stavanger, Norway

³Rocksource ASA, Bergen, Norway

It is well understood that depositional environment is the first order control on the architecture of both reservoir sandbodies and intra-reservoir barriers in clastic systems. Factors such as climate, subsidence and sediment supply provide a series of complexly inter-related, second order controls that interact to produce a wide range of potential geometries. Understanding these controls is key to predicting reservoir behaviour and performance.

This project aims to investigate these controls empirically by compiling a very large dataset of new and publically released information on body geometries. The database includes a standardized nomenclature for sand body shape and is fully searchable on a series of different parameters including, depositional system, tectonic setting, palaeo-climate, palaeo-latitude, age and grainsize. The database has three key applications:

1. To allow the empirical investigation of the interaction of key factors on sandbody and baffle geometries
2. To provide a database of body geometry for reservoir modelling
3. To provide a repository for a large volume of data from a variety of vintages and sources.

Publically released data from both published and unpublished sources dealing with both modern and ancient systems are currently being compiled. This process is continuous and the database will be updated and expanded as more information becomes available.

New information has also been collected specifically for this project using novel data acquisition methods including oblique helicopter based lidar scanning (heli-lidar). The heli-lidar allows the very rapid collect of long (tens of km) geometrically constrained, 3D datasets from otherwise inaccessible areas. New methods for the processing and handling of these very large Virtual Outcrops have been developed which allow their visualization and the extraction of large volumes of geometrically constrained sediment body data.

Datasets of fluvial architecture in coal bearing coastal plain systems have been collected from the non-marine part of the Campanian aged, Blackhawk Formation cropping out in the Book Cliffs and Wasatch Plateau areas of eastern Utah. A fluvial dataset has also been collected from the fully non-marine, deposits of the Tertiary aged Green River and Colton formations in Nine Mile Canyon, Utah. These examples will be used to illustrate the utility of the database and to demonstrate its application to empirically understanding large scale controls on sedimentary architecture.

NOTES

Characterization of tide-dominated heterolithic reservoir analogues: Eocene Qasr El Sagha Formation, Western Desert Egypt

B. Legler¹, H. D. Johnson¹, M. D. Jackson¹, G. J. Hampson¹, C. A-L. Jackson¹, A. El Barkooky², R. Ravnas³, D. Alsop⁴, X. Le Varlet⁵

¹Department of Earth Science & Engineering, Imperial College, London.

²Department of Geology, Cairo University & Shell Egypt, Cairo, Egypt

³Norske Shell, Stavanger, Norway

⁴Shell international Exploration & Production, Rijswijk, The Netherlands

⁵Bapetco, Cairo, Egypt

Heterolithic tidal reservoirs are notoriously difficult to characterise, because the wide range of heterogeneity lengthscales is poorly represented not only in typical subsurface data (core, wireline logs, seismic) but also in many outcrops. This study focuses on outcrops of the Late Eocene Qasr El Sagha Formation in the Fayoum Depression, Western Desert, Egypt, because they offer a unique opportunity to provide quantitative data on 3-D facies architecture and heterogeneity distribution on a range of typical subsurface reservoir scales. A 20 km long, nearly continuous cliff section with incised wadis and solitary buttes provides virtually 3-D outcrop control. We have focused to date on the lower Dir Abu Lifa Member in the vicinity of Qasr El Sagha, an area of about 1 km² with a total outcrop length of more than 4 km. The cliff faces are up to 30 m high.

The studied succession is mainly composed of NE-SW to N-S trending channels filled with inclined heterolithic strata, interpreted as tidal point bars, but unconfined heterolithic bars also occur. Channel-fill widths vary from about 80 m to more than 500 m, and they are up to 17 m thick. SW oriented palaeocurrents dominate in some channels, whereas others show W-NW-N-NE dominant palaeocurrent directions. These highly variable palaeocurrent directions support the interpretation of meandering tidal channels. Tidal dominance is proven by megaripple cross-bedding with abundant mud drapes, sigmoidal bundles and rhythmites. The succession is underlain by heterolithics containing pedogenic colour mottling, slickensides and rootlets, interpreted to record episodic subaerial exposure in a supra-tidal marsh/salt marsh environment. It is capped by an intensely bioturbated (*Glossifungites* ichnofacies), fossil rich, calcareous, glauconitic sandstone with wood fragments in a basal lag, which records transgression throughout the study area.

Each channel fill contains a consistent internal architecture that varies from channel axis to channel margin. Erosive channel bases are often covered by thin bedded, carbonaceous mudstones. Laterally to or above these mudstones, planar to sigmoidal cross-bedded medium- to fine-grained sandstone with tidal bundles and mud drapes occur; these are interpreted as complex dunes that migrated in channel axes. However, inclined stratified, silty sandstone to sandy siltstone dominates the channel fills. Inclined beds are characterized by rhythmic, parallel bedding with intercalated wavy- to lenticular-bedded layers, interpreted as sub- and inter-tidal point bar deposits. Elongated lenses of flaser to sigmoidal cross-bedded sandstone with mud drapes are intercalated, and are interpreted to represent the deposits of isolated simple dunes. Furthermore, erosively based, trough cross-bedded fine-grained sandstone with mud drapes was deposited in small channels that incise into the point bars. The dip angle of inclined beds and overall grain size both decrease towards the top of the channel-fill successions. Unconfined tidal bars are characterized by a non-erosive base and an overall coarsening-upwards grain size trend. Facies types are similar to those of the channel fills, but complex dunes are absent.

Subsequently, reservoir models constructed from the Qasr El Sagha Formation outcrops will be used to simulate fluid flow, with the aim of quantifying the impact of different heterogeneity scales and associated sand body geometries and connectivities on effective flow properties and hydrocarbon recovery. Flow simulation studies will be directed towards the prediction of reservoir behavior using subsurface measurements.

NOTES

Impact of deltaic clinothems on reservoir performance: dynamic study of reservoir analogues from the Ferron Sandstone and Panther Tongues, Utah USA

J. A. Howell^{1,2}, H. D. Enge^{1,3}, S. Buckley¹

¹*Centre for Integrated Petroleum Research, University of Bergen, Box 7800, 5020 Bergen, Norway*

²*Rocksource ASA, Bergen, Norway*

³*Now: StatoilHydro ASA, Sandsliveien 90, 5XXX Bergen, Norway*

Subsurface reservoir models are typically limited by a lack of spatially accurate geometric data on bedform architecture and geometry, which are key controls on fluid flow. Outcrop analogues have long been utilized as a source of such data, but the capture of sufficiently precise outcrop data for this purposes is a challenge. This study have for one of the first times utilized highly accurate geometrical digital geological outcrop data by ground-based laser scanning (lidar) to build and test three-dimensional geocellular models.

The two well exposed ancient river-dominated delta systems the Panther Tongue and the Ferron Sandstone that both crop out in central Utah, USA, were digitally mapped to precisely recreate their clinothem and clinoform geometries in geocellular reservoir modeling software. Such clinoforms separate the deltaic sandbody into a series of sandstone beds (clinothems). Theses are commonly draped with low permeability mudstones that within a reservoir may significantly impact fluid flow.

Portions of the two systems were analysed in the reservoir modeling software for simulated production by running a series of synthetic test cases to quantify the impact of the heterogeneities on fluid flow. A total of 41 individual models were built and flow simulated. Results quantify how the continuation of the heterogeneities governed the production rate/ recovery factor in the Panther Tongue models. Permeability values were more important in the Ferron models, although they were still influenced by the continuation of the heterogeneities. Steeper dipping and closer spaced clinothems of the Ferron models lowerd the recovery factor by several tens of percent if the related heterogeneities were all or close to continuous and had low enough permeability.

NOTES

Constraining 3D geometry and heterogeneity within synrift tidal-shallow marine facies using lidar-based digital outcrop data: Suez Rift

F. Rarity, *Basin Studies and Petroleum Geoscience, School of Earth, Atmospheric and Environmental Sciences, The University of Manchester, Oxford Road, Manchester, M139PL, UK*

Syn-tectonic tidal systems are inherently complex and heterogeneous over a wide range of scales. These heterogeneities have a marked influence on oil recovery and present major reservoir modelling challenges. This study adopts an integrated approach incorporating quantitative digital outcrop surveying and detailed field geology to model outcrop-scale heterogeneities within an Oligo-Miocene tidally influenced shallow marine rift initiation succession: the Nukhul Formation, Suez Rift. Meandering and cross-cutting wadi systems in the Nukhul half-graben provide exceptional pseudo-3D exposures, thus presenting an ideal outcrop analogue for the complex facies and sedimentary architecture of syn-tectonic tidal reservoirs.

Terrestrial laser scanning (lidar) has permitted rapid acquisition of accurate, quantitative and 3D data from the superbly exposed outcrops. The digitally acquired data has been efficiently integrated with detailed sedimentological field observations, resulting in a quantitative digital outcrop dataset that consists of all field observations in their correct geographical positions. The integrated outcrop dataset has been interactively analysed and interpreted in 3D, and used to build near-deterministic outcrop-scale geocellular models of the tidal exposures. Key sedimentary architecture as well as bed-scale facies and thickness variations has been accurately measured and mapped continuously from the digital outcrops at multiple scales ($<10^{-1}$ to 10^3 metres), thus facilitating the quantification of heterogeneity within individual depositional elements as well as their geometry, orientation, pinch-outs and spatial relationships to one another. Accurate geostatistical information on geobody size, shape and orientation has been extracted as well as quantitative information on the dimensions of facies bodies to help improve variogram estimates.

NOTES

Integrating observations from numerical models, physical experiments and outcrop of deepwater fans for improved reservoir models

R. Bloch, R. Sech, T. Garner, T. Sun, S. Kalla, D. Box, A. Sprague, D. Hoyal, *ExxonMobil Upstream Research Company, P.O Box 2189, Houston, 77252-2189, Texas*

Analysis of process-based numerical models of deepwater fans and physical experiments shows that sand is deposited mainly as bars within channels and channel-mouth lobes. Muddy deposition occurs in channel overbank settings and the outer fringe of lobes. Fan-growth history is characterised by lateral shifts in lobe deposition. The spatial distribution of lobes controls stratal architecture which manifests an organised hierarchy of scale termed “lobe”, “lobe complex” and “complex set”. After a period of lobe building, channel avulsion near the channel mouth or a minor channel-extension event initiates deposition of a new lobe and abandonment of the old lobe. A series of these minor lateral shifts forms a lobe complex composed of sandy lobes juxtaposed with minor intervening finer-grained sediment. A larger shift in lobe deposition (avulsion upstream of the channel-mouth or a significant channel-extension event) initiates deposition of a new lobe complex, and the older complex is often draped by muddy deposits in a channel-overbank or lobe-fringe setting. An even larger shift, due to avulsion far up-channel and/or a major channel extension event, initiates deposition of a new lobe complex set while a significant muddy layer drapes the older complex set. Comparison of these model results with outcrop of Karoo Formation in South Africa shows good agreement in cross-section geometry and relative grain-size relationships. Flow simulation of numerical depositional models demonstrates the relative impact of reservoir elements related to the stratigraphic hierarchy. With this synthesis of observations from depositional models (numerical and physical), natural systems (Karoo Formation outcrop) and flow simulation, improved methods to model and predict reservoir performance can be developed.

NOTES

Physics driven modelling as an alternative reservoir building tool

J. E. A. Storms¹, D. J. R. Walstra^{2,3}, N. Geleynse⁴, M. Hillen³, H. R. A. Jagers³

¹*Delft University of Technology, Faculty of Civil Engineering & Geosciences, Section Applied Geology, Delft, The Netherlands*

²*Delft University of Technology, Faculty of Civil Engineering & Geosciences, Section of Hydraulic Engineering*

³*Deltares (Formerly W L Delft Hydraulics), Delft, The Netherlands*

⁴*Delft University of Technology, Faculty of Civil Engineering & Geosciences, Section of Geo-Engineering, Delft, The Netherlands*

Physics-based modelling of fluvio-deltaic sedimentary systems is becoming an increasingly viable alternative to stochastic and geometric (object-based) modelling for building geological reservoir models. It can be regarded as a *numerical lab* to study sedimentation processes, reservoir architecture and preservation potential. Numerical deltas can be studied under fully controlled boundary conditions. Here we apply a detailed depth-averaged hydrodynamic model with a coupled sediment transport model, to simulate the incipient formation of fluvial-dominated deltas. Two sediment types are modelled: fine sand and silt. Although deltaic formation can be simulated under any combination of tide, wave and fluvial forcing, we will focus initially on the behaviour and stratal response of fluvial and wave-dominated deltaic sediment bodies.

Simulated fluvio-deltaic development shows striking resemblances with real-world deltas such as mouth bar development, a detailed channel network, channel bifurcations, channel abandonment and infill as well a typical clinof orm development at the delta front and prodelta. By including a 10 km long stretch of the fluvial feeder channel we also include the effects of fluvial dynamics on the deltaic development. Stratal patterns show typical fining-up sequences as well as high-quality sands near mouth bars. Yet the simulated deposits are very heterogeneous due to the dense channel network.

To understand the preservation potential of the simulated deltaic sediment body, we ran additional simulations to study the effects of wave reworking under steady sea-level conditions which clearly show delta reworking, channel infill and sediment sorting as the fines are transported offshore while the sands form a newly developed shoreface.

In order to apply the simulated deltaic sediment bodies in reservoir modelling, we have included the stratigraphy in Petrel reservoir modelling software, making it possible to apply the suite of tools commonly used in the hydrocarbon industry to the simulated deltaic reservoir.

NOTES

High resolution stratigraphic architecture in regressive and transgressive shallow marine outcrop analogues

G.J. Hampson, K. Chavin¹, O. D. Jordan², J.E. Morris³, R. P. Sech⁴, P.J. Sixsmith⁵, S. Gupta, M. D. Jackson, H. D. Johnson
, Department of Earth Science & Engineering, Imperial College, London

¹*Present address: Chevron Energy Technology Company, Aberdeen*

²*Present address: StatoilHydro Research Centre, Bergen Norway*

³*Present address: StatoilHydro, London*

⁴*Present address: ExxonMobil Upstream Research Company, Houston, USA*

⁵*Present address: Chevron Energy Technology Company, Perth, Australia*

Much of the world's current and projected hydrocarbon production is from shallow- and marginal-marine reservoirs. Current stratigraphic concepts and their reservoir-modelling implementations assume that such reservoirs comprise one or more stacked parasequences, each with a simple internal stratigraphic architecture and associated rock-property distribution. Here we critically evaluate this assumption using data from several outcrop analogues deposited in both net-regressive and net-transgressive settings. These data imply that more complex, high-resolution stratigraphic architectures are present at intra-parasequence through parasequence-set lengthscales. Such architectures may significantly impact upon reservoir behaviour, particularly where they are associated with large contrasts in permeability.

Regressive, wave-dominated deltaic reservoir analogues (Cretaceous Blackhawk Formation, Book Cliffs, USA) conform closely to conventional parasequence models. Each parasequence contains shoreface or delta-front clinofolds whose distribution defines variations in shoreline trajectory down depositional dip and along depositional strike. Individual clinofolds may be associated with mudstone or carbonate-cemented barriers along their lower, distal parts (e.g. Jurassic Bridport Sand Formation, Wessex Basin, UK); shoreline trajectory patterns control the distribution of such barriers. Mudstone-prone fluvial deposits are generally poorly preserved, because abandoned deltaic headlands are reworked by wave processes. However, fluvial-dominated delta front deposits occur near the down-dip terminations of some parasequences, suggesting limited wave reworking and an associated preservational bias in such locations.

Net-transgressive reservoir analogues deposited under mixed wave- and tide-influence (Cretaceous Hosta and Cliff House Sandstones, San Juan Basin, USA) show less similarity to conventional parasequence-set models. The Hosta Sandstone exhibits a moderate net-transgressive shoreline trajectory, caused in part by a low sediment supply via wave-driven longshore currents. Packages of genetically-related shoreface sandstones are bounded by wave-formed transgressive erosion surfaces (wave ravinement surfaces), exhibit small thicknesses due to erosional truncation, and have only limited extent down depositional dip. Back-barrier deposits are relatively thin, incompletely preserved and contain abundant stacked tidal channel-fill sandstones. In contrast, the Cliff House Sandstone exhibits a steep net-transgressive shoreline trajectory, caused by a high sediment supply with a direct fluvial component. Shoreface sandstones are more completely preserved, such that they are similar to conventional parasequences, and have large down-dip extents. Back-barrier and coastal plain deposits are thick and mudstone-dominated, although both shoreline-normal fluvial channel-belt sandstones and shoreline-parallel tidal channel-belt sandstones are developed at particular stratigraphic levels.

A comparison of these various datasets suggests that similar high-resolution (intra-parasequence) stratigraphic elements are common in both net-regressive and net-

transgressive settings, but the preservation and distribution of these elements differs markedly. These stratigraphic elements form the appropriate building blocks for high-resolution static and dynamic models of shallow-marine reservoirs, where such detail is warranted. The challenges lie in consistently recognising such elements in subsurface datasets, and in representing them accurately in flow-simulation models.

NOTES

Process Oriented Modelling for multi-scale data integration in the 3-D reservoir modelling workflow

L. Ruvo, *Eni E&P Division*

High-resolution, 3D digital models of small-scale heterogeneity, generated using a Process-Oriented Modeling (POM) approach, were used to complement 3D geocellular modeling workflows in silici-clastic reservoirs where heterolithic facies play a major role.

The 3D geocellular models of the studied reservoirs were built according to the two-step approach commonly adopted in the E&P industry - a geostatistical facies modeling first and a geostatistical petrophysical property modeling next. In all case studies, sedimentological facies (sed-facies), either heterolithics or single-lithology, were first identified on cores and used for generating a conceptual depositional model of the reservoir. At the same time, the conventional wireline log recordings from both cored and uncored wells were processed using a multivariate statistical technique (cluster analysis) to provide a log-facies classification for use in populating the 3D geocellular model. The relationship between sed-facies and log-facies was not always straightforward, as in some cases, log-facies were found to include different amounts of different sed-facies, either heterolithics or not.

In fact, the presence of beds below the vertical resolution of conventional log curves, makes some of the identified log-facies strongly heterogeneous from the lithological/petrophysical point of view: this means that a petrophysical characterisation of such log-facies by averaging petrophysical parameters from core plugs can be misleading, because of the plug sampling bias and consequent inadequacy in terms of statistical representativeness of the true lithological abundances. Hence, the petrophysical characterization of log-facies was carried out using a POM approach: stochastically generated fine-scale, 3D digital models of the different sed-facies were populated at the lamina scale using the statistics of poro-perm measurements from a selected subset of the core plugs, and the statistics of permeability measurements from a mini-permeameter, when available. Next, the 3D models of the sed-facies were stacked according to their observed amount in each log-facies, analytically and numerically upscaled to respectively provide effective porosity and directional permeability statistics for use in the property modeling phase of the 3D geocellular models. Whenever possible, POM derived permeability values were matched/validated against permeability measured during actual field tests.

The presented case studies show that integrating POM in the standard 3D reservoir modelling workflow provides the advantage to use data types acquired at different scales in a consistent manner with respect to their volume of investigation, and improves accuracy in the definition of petrophysical parameters for use in a 3D geocellular model.

NOTES

Integrated modelling of the Ten Boer Claystone Member, Southern Permian Basin: A combined log correlation, outcrop analogue and numerical forward modelling study

M. E. Donselaar¹, I. Overeem², J. H. C. Reichwein³, C. A. Visser³

¹ *Department of Geotechnology, Delft University of Technology, Delft, PO Box 5048, 2600 G A Delft, The Netherlands*

² *Institute of Arctic & Alpine Research, University of Colorado, Campus Box 450, Boulder, 80309-0450, Colorado, USA*

³ *Nederlandse Aardolie Maatschappij B.V., Assen, The Netherlands*

The Ten Boer Claystone Member (TBCM) is part of the Silverpit Formation (Rotliegend, Lower Permian) in the Southern Permian Basin of NW Europe. The TBCM comprises a 40-110-m-thick low net-to-gross stack of mudstone and thin, 5-50-cm-thick, very-fine to medium-grained sandstone beds that formed as distal fluvial deposits on a mud flat bordering the Silverpit Desert Lake. Core and well-log analysis allowed for the subdivision of the TBCM in lithofacies cycles. Each cycle comprises a shaley base, a sandy-silty middle part and a shaley top, interpreted as the result of wet-dry-wet climate cyclicity. Log correlation of the TBCM succession in a 300 by 160 km area onshore and offshore The Netherlands yielded a 3-D static reservoir architecture model of the fluvial sandstone and showed the development in space and time of nested sandstone sheets at the end of widely spaced south-north elongated fluvial pathways.

The TCBM fluvial sandstone is the target for a study on secondary reservoir potential, with the aim to boost gas production in declining smaller fields surrounding the giant Dutch Rotliegend Slochteren Gas Field. Challenges are to assess the size, shape, spatial distribution and connectivity of the sheet sandstone. To achieve this, an outcrop analogue study and process-driven forward modeling experiments were carried out. The outcrop study in the distal part of the Huesca Fluvial Fan (Miocene, Spain) provided a depositional model and size and shape data of terminal sheet and crevasse splay and associated meandering river sandstone in a low-gradient lower coastal plain setting bordering the Ebro evaporite Lake. The data sets were used as input in forward modeling experiments. Depositional scenarios were performed for two populations of fluvial channels: larger channels representative for the lower floodplain and smaller, distributary channels at the most distal fringes of the fluvial fan. The model results provided insight in plume depositional thickness, area and volumes and distribution of sand deposited at the mouth of these channels.

The results of this study provide scenarios to assess volume and connectivity potential of thin-bedded distal fluvial reservoir sandstone bodies in the Ten Boer Claystone Member.

NOTES

Three-dimensional modelling of a shoreface-shelf parasequence reservoir analogue: stratigraphic and sedimentological controls on fluid flow and hydrocarbon recovery

M. D. Jackson, G. J. Hampson, R. P. Sech¹, *Department of Earth Science & Engineering, Imperial College, London*

¹*Present Address: ExxonMobil Upstream Research Company, Houston, USA*

We present a surface-based modelling procedure that enables explicit representation of heterogeneity across a hierarchy of lengthscales and which is ideally suited to modelling high-resolution geological datasets derived from well exposed outcrop analogues. Numerous surfaces are used to construct complex facies-body geometries and distributions prior to generating a grid, allowing sampled and conceptual data to be fully incorporated within field-scale models. Our approach is driven by the improved efficiency that surfaces introduce to modelling through their geologically intuitive design, rapid construction and ease of manipulation. Cornerpoint gridding of the architecture defined by the surfaces reduces the number of cells required to represent complex geometries, thus preserving geological detail and rendering upscaling unnecessary for fluid-flow simulations.

The application of surface-based modelling is demonstrated by reconstructing the detailed three-dimensional facies architecture of a wave-dominated shoreface-shelf parasequence from a rich outcrop dataset. The studied outcrop dataset describes reservoir architecture in a generic analogue for many shallow-marine reservoirs. The process of model construction demonstrates the role of (1) shoreface-shelf clinoforms, (2) palaeogeographic changes in shoreline orientation and (3) storm-event-bed amalgamation in controlling facies architecture. These subtle geometrical features cannot be accurately represented using conventional stochastic reservoir modelling algorithms, which results in poor estimation of facies proportions and associated hydrocarbon volumes in place. In contrast, the surface-based modelling approach honours all data and captures subtle geometric facies relationships.

Fluid flow simulations directly on the outcrop model demonstrate that waterflood sweep efficiency is affected by barriers to flow along clinoform surfaces, such as calcite-cemented layers, mudstones and siltstones. Sweep efficiency is low when waterflooding is down-depositional-dip, because oil is bypassed at the toe of each clinothem as water flows preferentially through high-quality sandstone facies in the upper part of the parasequence. Sweep efficiency is higher when waterflooding is up-depositional-dip, because the gravity-driven, downward flow of water sweeps poorer quality sandstone facies in the lower part of the parasequence. In both cases, injectors may offer limited pressure support to producers. Waterflooding along-depositional-strike yields good pressure support but poor sweep, because the gravity-driven flow of water into the lower part of the parasequence is significantly reduced. This yields highly variable fluid saturations but a uniform pressure gradient and these results may explain the variations in pressure and fluid saturation observed in data from the mature Rannoch Formation reservoir, Brent Field, UK North Sea.

NOTES

Characterisation and geostatistical modelling of facies and diagenesis in a mixed carbonate-siliclastic reservoir analogue. Example of the Ilerdian Alveolina Limestone, Serraduy, NE Spain

Y. Hamon¹, B. Doligez¹, P. Joseph¹, O. Lerat¹, J. Schmitz¹, R. Deschamps¹, V. Védrenne¹, Y. Backheuser², R. Trajano De Faria², F. S. Costa Mourão de Brito², P. Martin²

¹IFP

²Petrobras

This study is a perfect example of detailed geological data acquisition from an outcrop for modelling and simulation purposes. High resolution photogrammetric acquisition merged in a digital DEM built from aerial photos gave the main geometrical skeleton of the model. The multi-scale description of facies and sedimentary bodies allowed to build a conceptual depositional model and some paleogeographic maps directly usable for the simulation. The use of those information from a very detailed conceptual depositional model, associated to the use of a sequence stratigraphy approach, resulted in a well constrained and realistic 3D model.

The outcrop of Serraduy (*Alveolina limestone Formation*) has been studied in a common research project between Petrobras and IFP. The *Alveolina limestone Formation* was deposited as a carbonate ramp, characterized by a shallow lagoon with important tidal influence closely associated to bioconstructed mounds evolving toward open lagoon and open-marine ramp facies. This system is influenced by siliclastic continental inputs in its more proximal part (fluvial- and tidal-dominated deltaic complexes).

The diagenesis study has enlightened the complexity and the diversity of the diagenetic scenario undergone by the Ilerdian series. A cross-comparison of these results and a study of fracture fillings may help to better constrain the timing of the paragenesis in relation with major deformation phase.

In a second phase, a 3D grid model has been compiled to reproduce the facies organization of the carbonate system. Each stratigraphic unit defined previously has been the object of different simulation, offering the opportunity to test different geostatistical methods (Truncated Gaussian simulation, mono and bi-pluriGaussian simulation, Boolean method...). A specific attention has been given to the megadune grainstone body as it could be a potential reservoir in subsurface. The property modelling was then focused on facies and also on diagenesis distribution.

The use of geostatistical nested simulations, combining plurigaussian and boolean simulations, allowed to obtain more realistic results for the main sedimentary units. The use of plurigaussian simulation combined with the adoption of a vertical proportion matrix constrained by different well data in each depositional region was adequate to represent most of complex facies relationships observed in the outcrops. However, some facies, characterized by strong anisotropy like those corresponding to distributary channels and tidal channels, were better represented by an object-based simulation.

The relationships between sedimentary facies and diagenesis have finally been used to define lithofacies simulation rules for the bi-plurigaussian algorithm, that aims at simulating both the distribution of sedimentary facies and the diagenetic overprint.

NOTES

Friday 23rd October

Constraining Stochastic and process-bases simulations with outcrop data-based: the steps further

R. Eschard, *IFP*

During the last two decades, major efforts have been put on the characterization of the reservoir heterogeneity distribution to better constrain reservoir simulation. Reservoir geologists quickly realized that the new geostatistical approaches needed to be constrained by geological data-sets to reproduce reservoir the heterogeneity distribution in a realistic manner. Outcrop quantification helped to compile these data-bases. In the mid-eighties, for example, a study was carried out along the Jurassic cliffs in Yorkshire, with the drilling of core-drills beyond the cliff faces to study Brent equivalent reservoirs. Core and log signatures were compared to outcrop logs, and the sedimentary bodies were mapped in 3D. The main output of such studies, beyond improving our understanding of the reservoir sedimentology, was the definition of reservoir simulation workflows, from definition the lithofacies in logs and of the relevant petrophysical attributes, to the choice of the appropriate algorithms to simulate a given sedimentary architecture, and the definition of relevant upscaling techniques in function of the effective permeability barriers and recovery processes.

Since that time, reservoir data-bases were constantly enriched with 3D reservoir attributes either coming from high-resolution shallow seismic data, LIDAR acquisition, or shallow seismic or radar surveys acquired beyond the outcrops. The emergence of new geostatistical techniques, such as the multi-point or the pluri-gaussian algorithms, still requires more accurate data-sets, to define 3D training images for the reservoir simulations.

Outcrop geo-models are also commonly used as reservoir analog to test reservoir simulation scenarios and optimize field development. The Pab turbiditic system which outcrop in Pakistan is for example a spectacular analog of turbiditic channel complexes in the subsurface. A full workflow of reservoir simulation was tested on 3D gridded models of different channel complexes. The outcrop data were first used to benchmark different geostatistical approaches in function of the reservoir geometry. Seismic simulation were then performed together with fluid-flow simulations to image the variation of the seismic signature during a water injection scenario, and optimize the design of 4D seismic survey acquisition. Well tests and interference tests were also simulated in order to investigate the sensitivity of the flow to thin permeability barriers below seismic resolution. Thin shale layers draping the channel bases were then identified as a critical heterogeneity reducing the connectivity between the different channel conduits.

The reservoir characterization is today focusing on new emerging topics. In heavy oil fields produced by steam injection (SAGD), the steam chamber development is very sensitive to small-scale heterogeneity acting as conductivity barriers to the steam diffusion. Fine-scale phenomenological models are then required to simulate the steam chamber development taking into account the heterogeneity geo-mechanical behaviour during heating. Outcrops models of heterogeneity distribution in estuarine point bars studied in outcrops helped to optimize the field development plan of some heavy oil reservoirs in Alberta.

A new challenge will be to predict the distribution of diagenetic facies, and outcrops can also provide some guide-lines to constrain the reservoir simulation and also, fluid-rock interactions. In a Spanish outcrop, the distribution of hydrothermal dolomites was studied in function of the fault and fracture distribution. A 3D model combining both fracture and facies distribution realistically reproduced the dolomitic patch geometry.

We then tested a fluid-rock interaction simulation module to predict the extension of dolomite patches away from the main fault conduits.

The development of CO₂ storage pilot projects is promoting a new type of reservoir study in which fluid-rock interactions also plays a major role. The sensitivity of the mineral to the alteration induced CO₂ leaching must be investigated in order to secure the long-term storage seal integrity. Mineral dissolution or precipitation are also studied to optimize the well injectivity. Some outcrops in which reservoir and seals were in contact with CO₂ natural fluxes during long period of times are studied in order to understand the mineral stability to the CO₂ alteration. The outcrop models provide also time-constrain to geochemical simulation of the fluid-rock interactions during CO₂ injection.

Finally, the emergence of a new generation of process-based models simulating the stratigraphic architecture of basins and reservoirs implies a better understanding of the physical processes which control the sedimentation. At the basin scale, sediment flux variation is a very sensitive parameter for stratigraphic simulations, and the relative influence of climate, tectonic... has to be documented on natural case studies to provide guidelines to the modellers. At the reservoir scale, process-based models even oblige us to review the physics of the depositional processes and calibrate them to flume experiments and present-day sedimentation process. An open field for research...

NOTES

Discontinuous shales and their impact on reservoir behaviour

A. Gardiner¹, T. Good^{1,2}, J. Clark^{1,3}, M. Arnot^{1,4}

¹Institute of Petroleum Engineering, Heriot-Watt University, Edinburgh, EH14 4AS, UK

²currently ExxonMobil International Ltd, Leatherhead, KT22 8UX, UK

³currently ChevronTexaco, San Ramon, CA 94583, USA

⁴currently GNS, Lower Hutt 5040, New Zealand

The majority of analogue studies of clastic reservoirs have concentrated on the geometry of reservoir sandbodies. However, in high net-to-gross reservoirs, the most important features in terms of reservoir behaviour are often found to be thin beds of non-reservoir facies (siltstones, mudstones and shales). These fines represent low energy sub-environments or periods of low energy and generally form thin beds draping the existing topography or bathymetry. As such, they are commonly sub-horizontal, but inclined shales can also occur, for example in delta front and fluvial point bar environments. This paper describes the geometry and dimensions of shales observed in shallow marine, deepwater and fluvio-deltaic environments.

Within reservoir sandbodies, shales may act as barriers and baffles to fluid flow. Clearly, sub-horizontal shales will have a greater impact on vertical permeability than horizontal but, if the shales are convergent, they will also impact effective horizontal permeability. Inclined shales will reduce both horizontal and vertical permeability. The impact of the shales on fluid flow will depend on the contrast between their permeability and that of the reservoir sandstone.

The dimensions of intra-sandstone shales in the shoreface environments of the Grassy Member of the Blackhawk Formation in the Book Cliffs, Utah can be measured both parallel and perpendicular to depositional dip. Average shale lengths in lower to middle shoreface environments range from 20m to 50m and shales are near-equidimensional in plan view. The shales drape lenticular sandstone beds and, where sandstone beds terminate, the shales converge and meet to form a single shale. These convergent shales act as barriers to both vertical and horizontal flow.

In sheet-like turbidite systems, individual turbidite sandstones are draped by fines which represent the final phases of turbidite deposition and possibly also hemipelagic deposition. These shales will initially be laterally extensive but may be locally eroded by subsequent turbidity currents to produce smaller, discontinuous shales. Shale lengths have been measured from a range of sheet-like turbidite systems and exhibit a range of average lengths from a few metres to hundreds of metres (the upper limit being controlled by outcrop dimensions). In those systems with shorter shales, the larger degree of sandstone amalgamation allows greater vertical fluid flow. Modelling of these systems indicates that the ratio of vertical to horizontal permeability (kv/kh ratio) can be calculated from the proportion of shale removed, if the permeability of the sandstone and shale are known.

In channelised turbidites, more localised shale erosion may occur and these erosive features may be draped by shales. Modelling of high net-to-gross systems with a significant proportion of inclined or undulating shales indicates that the shales have a significant impact on both horizontal and vertical flow.

As described above, thin fine-grained beds can have a significant impact on reservoir behaviour. The extent to which they will baffle or act as barriers to fluid flow depends both on their geometry and their petrophysical properties. Most analogue work has concentrated on the former, but it remains the case that the permeability of fines and,

equally importantly, their relative permeability curves, is commonly unknown. More work is required to properly describe the fine beds, differentiating more rigorously between clay-rich shales and more silty sediments, before their impact can be fully understood.

NOTES

A new approach for outcrop characterization and quantitative fluvial-body analysis of a low-sinuosity fluvial-dominated succession using digital outcrop models: Upper Triassic Oukaimeden Sandstone Formation, central High Atlas, Morocco

D. Hodgetts¹, I. Fabuel-Perez^{1,2}

¹*Basin Studies and Petroleum Geoscience, School of Earth, Atmospheric and Environmental Sciences, The University of Manchester, Oxford Road, Manchester, M139PL, UK*

²*ExxonMobil*

The use of digital outcrop models in combination with traditional sedimentological field data improves the accuracy and efficiency of qualitative and quantitative characterization of outcrop analogues for reservoir modeling purposes. In this study, an innovative technique is applied to an Upper Triassic fluvial-dominated system to analyse outcrop body geometries. This technique uses LiDAR digital outcrop models in outcrops that are subparallel to paleoflow (reduced 3-D exposure) to improve accuracy in the measurement of apparent widths and thicknesses of exposed fluvial bodies.

Both qualitative and quantitative data resulted from this analysis are used to build a deterministic geological outcrop model constrained by the outcrop characterization. Qualitative analysis of the outcrop allows the subdivision into architectural intervals, providing information on reservoir compartmentalization which is used for the geocellular model zonation. The quantitative analysis provides a detailed dataset of geobody dimensions used as conditioning data for the model.

Statistical analysis of the final model provides empirical relationships which can be applied in subsurface analogue systems to reduce uncertainty related to stochastic modeling approaches.

NOTES

Maximising analogue data access and capturing user knowledge using off the shelf applications

J. Thurmond¹, C. Pedersen², K. Keogh², T. Høye², A. Martinius³

¹StatoilHydro Research Centre, Bergen

²StatoilHydro Technology & New Energy Subsurface Technology

³StatoilHydro Technology & New Energy Global Exploration Technology

One of the major challenges of utilizing outcrop analogue data is to communicate it and make it accessible to those who may need to use it – often in unanticipated ways. Analogue data is frequently collected for a very specific purpose, often to attempt to characterize a single reservoir interval or field, with little thought that it may have broader implications or be applied in other similar plays. Due to this specificity, it can be difficult to make the broader geoscientific community within a company aware of applicable (and potentially costly) work that has been done. This can create situations of duplicate effort, deficient characterization of well-understood reservoir types, and poor application of analogue data to the exploration risking process. Therefore, maximizing the impact of outcrop analogue data can have a significant impact on both bottom line costs and overall exploration success for a given company.

In order to remedy this situation, one must break out of the typical mode of analogue data collection and reporting where the emphasis is on results being used by a single power-user (or a small group of users) with expertise on a particular field or depositional environment type, and instead focus on making analogue studies discoverable and accessible to the entire geoscientific community in such a way that the results can be quickly internalized and utilized by those who are not directly involved in the process. Traditionally, this has been done through effective reporting and cataloging of reports, but the average reservoir modeler does not typically have the time to invest in wading through a broad swath of marginally-applicable analogue studies to retrieve the few nuggets of information that may be applicable to their specific problems. Additionally, this fails to capture the necessary feedback when analogues are used in unexpected ways – and how the results of the analogue studies must be altered or biased in order to be applied differently. An alternative that has been explored is construction of analogue databases, but these also fail to capture the feedback from end-users, can often have cumbersome front-ends, and typically make it difficult to find the underlying context that lies beneath the raw numbers derived from a specific analogue study. At the same time, one must balance the need for *less* software training – as developing new methods for accessing data often yields new software applications, which users must be trained to use. This results in an undesirable drain on resources and creates a higher threshold of entry into the analogue data – which defeats the purpose of making the data available.

Our response is to utilize existing off-the-shelf applications which users are *already familiar with* and are *inherently intuitive* in order to make analogue data available across the entire company. The current research architecture utilizes two major software entry points – an internal Wiki-based solution (similar to Wikipedia) and an internal Google Earth server. Users can choose to access data via either, and are provided pervasive links to data in the other application. In the Wiki, the user is presented with categorical (and cross-referenced) analogue studies with a results-first reporting method – the front page of an analogue study contains the bottom line results of the study, and the user may choose to dig deeper to find details, if they wish. As the Wiki is user-editable, an end-user can easily add notes or references to how they have utilized the data and where it has been applied. In the internal Google Earth server, the user is presented with categorized geospatial data (including three-

dimensional outcrop models) with informative links back into the Wiki. This provides the user with the ability to immediately visualize where we have captured data and what is contained within each area. The user can also use Google Earth as a launching point to go deeper into applications such as ArcGIS to do more advanced spatial and statistical analysis of outcrop data. Through the use of these two applications, we can immediately present both internal and external (i.e. sponsored research) analogue data to users in a way which provides them user-friendly access to bottom line numbers and also the ability to research in more detail at their own discretion. Additionally, the user can provide feedback about their use of the data, which other users can learn from, thereby also creating a valuable feedback loop to those who are responsible for gathering the data.

NOTES

Unravelling and modelling heterogeneities in reservoirs using process based models

J. Miller, H. Li, C. Genty, T. Garner, T. Sun, *ExxonMobil Upstream Research Company, P.O. Box 2189, Houston, 77252-2189, Texas*

Improving the ability to model internal reservoir heterogeneity and predict reservoir connectivity is a primary goal of reservoir modeling research. Current geologic modeling techniques, which are primarily based on geostatistics, are very limited in their ability to model the distribution of key stratigraphic features (eg. flow baffles and scours) in a geologically accurate way.

Process-based modeling techniques build realistic analog models of reservoirs that can be used to improve our ability to predict reservoir performance. Based on the physics of fluid flow and sediment transport, these techniques model the natural processes of erosion, sediment transport, and deposition to produce more realistic stratigraphic architecture, sedimentary body geometry, and property distribution than traditional geologic modeling methods. These results can be used as digital analogs, from which statistical, relational and geometrical information can be extracted to aid the placing of heterogeneities into reservoir models. We will present an example application of this method which we call process-aided modelling

NOTES

The impact of architecture on fluid flow with an Aeolian Dune; an example from the Wahiba Sands, Sultanate of Oman

C. Hern, R. Nursaidova, D. Tatum, A. G. Gardiner, S. G. Fryberger, *Shell*

The magnitude of small (lamina) and medium (bed) length scales of heterogeneity in aeolian systems has been known for more than 20 years. Likewise the mega-scale (system) architecture has also been conceptualized through various means for a similar length of time. One key scale that remains almost absent from explicit imaging or modelling however (excepting the seminal work of Bristow et al. 2000 and Sweet et al., 1996), is that of the internal architecture of dunes or draa. Of course, the standard question remains – ‘Does it matter?’

With new developments in ground penetrating radar (GPR) technology a study was undertaken to image the internal architecture of part of a contemporary complex linear draa. The objective being to use the resulting radargrams to build deterministic 3D models that could be simulated in order to assess the impact of architectural heterogeneities, constituent of this type of system, on fluid flow over a range of parameter scenarios. This enables ranking and mapping of the heterogeneities for a suite of circumstances and progresses the to-date assessment of impact for a given set of fixed parameters.

In this paper, we describe acquisition, modelling and sensitivity testing, and conclude with implications for application to the management of subsurface developments.

NOTES

Data capture for multi-scale modeling of the Lourinhã Formation, Lusitanian Basin, Portugal: An outcrop analogue for the Statfjord Formation, Norwegian North Sea

K.Keogh¹, S. Leary², A. Martinius³, A. Taylor⁴, S. Gowland⁴

¹TNE SST RGG GRC, StatoilHydro ASA, 4035 Stavanger, Norway

²TNE RD RCT GG SSP, StatoilHydro ASA, 7035 Trondheim, Norway

³TNE GET GME S&S, StatoilHydro ASA, 7035 Trondheim, Norway

⁴Ichron Ltd, UK

Even with the extensive well log and core database available on the Norwegian continental shelf together with log production experience, predicting the occurrence and distribution of hydrocarbon bearing sands within the fluvial-dominated Statfjord Formation in the Tampen Spur area of the Norwegian North Sea is still a very difficult task. Current recovery from the Statfjord Formation on the majority of the Tampen fields is low and a contributing factor to this is an incomplete understanding of facies types and distributions and their lateral extent and morphology in inter-well areas. The use of outcrop analogues for studying the facies types, their relationships and stratigraphic development together with collecting geometrical and relational data for reservoir modelling input is a key tool for better understanding the subsurface Statfjord Formation reservoirs.

The Upper Jurassic (Kimmeridgian-Tithonian) Lourinhã Formation within the Lusitanian Basin of Portugal comprises over one thousand meters of stratigraphy that is considered a good analogue for collecting such field data to assist in our conceptual understanding of the deposition of the Statfjord Formation. These data also provide input data to reservoir modelling studies of the Tampen fields.

A multi-phase field data collection methodology has been devised to allow systematic recording of both qualitative and quantitative sandbody observations. Traditional field data collection techniques have been supplemented with the collection of LiDAR data and the incorporation of Digital Terrain Models.

A digital workflow facilitates rapid data analysis, and better data visualisation with results more easily utilised in multi-scale modelling studies. These scaled models are used to increase our understanding of lithofacies / facies association distributions together with internal architectural elements and heterogeneities associated with fluvial sandbodies which are often not represented within field-scale subsurface modelling studies.

NOTES

A flexible and expandable design to generate training images for sedimentary environment

A. Boucher¹, A. Satija²

¹*Department of Environmental Earth System Science Stanford University, USA*

²*Department of Energy Resources Engineering, Stanford University, USA*

Contact: Alex Boucher (afboucher@gmail.com)

The recent developments of training image-based geostatistics, termed multiple-point statistics (mps) algorithms, has permitted the creation of stochastic models with greater realism than before. A mps algorithm aims at reproducing spatial patterns, such as connectivity, that are depicted in a training image. A training image contains the possible spatial configurations for any given geological object and relationships between objects. Significant algorithmic advances now permit the reproduction of complex systems conditional to wells, seismic and even production data. However, algorithms for generating the training images are still incomplete and unsatisfactory.

The proposed design overcomes a major hurdle of rigidity of pre-defined geological objects in the current training image generators, which requires new objects to be added at the source code level. This is not always possible or desirable due to unavailability of that code or lack of programming competency from the modeler. This talk presents a software design that allows modelers to generate geological objects with complex geometries and the relevant interactions between these objects using an XML-based approach.

First, a geological object is built either from pre-coded shapes, such as ellipsoid, cuboid, kernels, or can be user defined. These basic shapes are then assembled with geometrical operations (difference, union and intersection) to create new complex shapes. For added flexibility, any shape can be translated, rotated and sheared. A second set of parameters control the interactions between the geological objects. Each parameter used in the training image construction (e.g. size, the rotation angles, number of stacks) can vary in space. This locally varying parametrization allows the representation of trends in geological body geometry, interactions, and locations.

NOTES

The origin and sedimentology of large sandy mid-channel bars

A. J. H. Reesink^{1,8}, P.J. Ashworth¹, M. L. Amsler², J. L. Best³, R. J. Hardy⁴, S. N. Lane⁴, A. P. Nicholas⁵, O. Orfeo⁶, D. R. Parsons⁷, G. H. Sambrook-Smith⁸, S. D. Sandbach^{4,5}, R. N. Szupiany²

¹*School of Environmental Technology, University of Brighton, UK*

²*Universidad Nacional del Litoral, Facultad de Ingeniería y Ciencias Hídricas, Centro Internacional de Estudios de Grandes Ríos, C.C 217 – (3000) Santa Fe, Argentina*

³*Departments of Geology and Geography and Ven Te Chow Hydrosystems Laboratory, University of Illinois, Urbana-Champaign, IL, USA*

⁴*Department of Geography, University of Durham, UK*

⁵*Department of Geography, University of Exeter, UK*

⁶*Centro de Ecología Aplicada del Litoral, Consejo Nacional de Investigaciones Científicas y Técnicas, Corrientes, Argentina*

⁷*School of Earth & the Environment, University of Leeds, UK*

⁸*School of Geography, Earth & Environmental Sciences, University of Birmingham, UK*

Unit-bar and dune sets are sub-seismic scale structures that strongly influence alluvial reservoir heterogeneity. Parameterization of the geometry and spatial distribution of these structures is often based on measurements from 2D reservoir outcrop analogues and deposits from small (< km wide, < 5 m deep) rivers. This paper describes a new alluvial architecture dataset being assembled for mid-channel bars from the World's 6th largest river, the sandy braided Paraná River, Argentina.

Data on the architecture and internal structure of 10 mid-channel bars have been collected using ~40 km of Ground Penetrating Radar and 28, 4m-deep suction cores. Mid-channel bars are characterized by stacking of 2-7 unit bars with thicknesses up to 10 m and lateral extents in the order of 10^2 - 10^3 m. Mid-channel bars develop from the stalling of a large unit-bar, followed by lateral accretion and the development of downstream wings/tails. Bar growth is primarily associated with the stacking of dunes and small-scale bedforms. The downstream bar tail commonly contains large-scale angle-of-repose sets that enclose a bar-top hollow in which finer grained sediment can accumulate. The overall mid-channel bar morphology thus controls the spatial distribution of large-scale angle-of-repose sets and fine-grained sediment.

The internal structure of the unit-bars that make up the mid-channel bars comprise fine-grained bottomsets, coarse-grained foresets, and coarse-grained topsets. Comparison of cores and GPR suggests that unit-bar foresets are dominantly composed of down-climbing dune sets. These inclined dune sets are 2-2.5 times thicker than the near-horizontal dune sets that make up the unit-bar topsets. Thus, large-scale alluvial morphology forms a dominant control on the geometry and preservation of dune sets.

NOTES

3-D Modelling of cement resources: A case study in economic geology (Jurassic, S Germany)

F. Fügel, T Aigner, *University of Tübingen, Institute for Geoscience, Sedimentary Geology, Sigwartstraße 10, D-72076, Tübingen, Germany*

Upper Jurassic limestones and marls of the Swabian Alb provide important raw materials for the cement industry in Southern Germany. Facies distribution and architecture of deeper water carbonate buildups and interfingering marl basins were studied in order to capture heterogeneities on a local scale. Therefore sedimentological observations on cores and outcrops were combined with geochemical and gamma-ray data. A further objective was to achieve the best estimation of the spatial distribution of resource quality parameters (CaCO_3 , SiO_2 , Al_2O_3 and Fe_2O_3) with a special focus on SO_3 which causes operational problems in the cement manufacturing process.

9 cores (427m of borehole distance) were sedimentologically logged and geochemically analysed using XRF- and XRD-methods. Core description and 2D outcrop wall mapping allowed a differentiation of 6 lithofacies associations, described in a detailed lithofacies atlas. For modelling purposes the lithofacies associations were grouped to 4 "modelled facies associations".

21 wells and 55 (outcrop wall projected) "pseudo-wells" were used to correlate and compute a high-resolution 3-dimensional facies- and property model of the study area using the software Petrel. For both facies- and geochemical modelling, stochastic and deterministic modelling algorithms were applied and contrasted. Different approaches were used in order to assess the impact of facies on the distribution of geochemical properties. Spatial variability of facies and geochemistry was depicted in sliced model grids and true scale cross-sections.

NOTES

An analysis on the ability of statchastic object and pixel based models to reproduce the fluvial channel architecture of the Escanilla outcrop

A. Skorstad¹, A. MacDonald², J. I. Tollefsrud², U. Lægneid²

¹*Norwegian Computing Centre*

²*Roxar*

A set of various stochastic models, routinely used by petroleum companies to model the geological features of petroleum reservoirs, are tested on the Escanilla outcrop from the Spanish Pyrenees. The suite of geostatistical techniques includes both object and pixel based models.

Outcrops should play an important role in testing the ability of various modelling techniques to represent the sedimentological characteristics of different depositional settings. The Escanilla data set is well documented, and therefore ideal to use for comparison with analogue fluvial reservoirs.

Besides the important visual inspection of the simulated realization, a proper comparison should also include quantifiable criteria. This analysis includes well match and volume fraction maps. The object based models also compares thickness and widths of the simulated geological geometries with the outcrop data.

Comparison is done in both 2D and 3D, and the important distinction between these domains is emphasized.

NOTES

Fluvial reservoir analogues in the Malay Basin: Analysis of shallow 3-D seismic data of pleistocene rivers on the Sunda Shelf

H. D. Johnson¹, F. A. Alqahtani¹, C. A-L. Jackson¹, M. R. B. Som², D. P. Gosh²,
W. K. W. Sulaiman²

¹*Department of Earth Science & Engineering, Imperial College, London*

²*PETRONAS Research Snd. Bhd. Banghi, 43000 Kajang, Selangor, Malaysia*

Fluvial sandstones constitute one of the major clastic petroleum reservoirs around the world, especially in the Tertiary basins of Southeast Asia. These relatively mature basins display a wide range of fluvial channel reservoirs, which are increasingly the focus of improved and enhanced oil recovery projects and the targets for relatively subtle, stratigraphic traps. In these situations, understanding fluvial channel style, geometry and connectivity are key risks. This study demonstrates how a better understanding of these parameters can be obtained through the analysis of high-resolution, shallow 3D seismic data (seabed to c. 500 m), which can provide exceptional imaging of fluvial channel planform geometries and other dimensions. This is demonstrated here in a study of part of a large (>10,000 km²), mega-merge 3D seismic dataset from the Malay Basin, which comprises a thick (>8 km), rift to post-rift Oligo-Miocene to Pliocene basin-fill. The youngest (Miocene to Pliocene), post-rift succession is dominated by a thick (1-5 km), cyclic succession of coastal plain and coastal deposits, which accumulated in a humid-tropical climatic setting during repeated periods of relative sea-level fluctuation. The deeper Miocene coastal plain successions contain multiple (several 10s), vertically-stacked hydrocarbon reservoirs, including a wide variety of fluvial channel sandstones, which are highly productive, but stratigraphically-complex. This study focuses on analogous, but better imaged, fluvial channel systems within the largely non-prospective, Pliocene part of the 3D seismic dataset (c. 0-500 m below sea-bed), supplemented locally with very high-resolution site survey datasets. The aim is to use these data to constrain the analysis of less well imaged Miocene fluvial reservoirs.

The Pliocene interval is up to c. 500 m thick and comprises a range of seismic facies, which reflect changes in fluvial channel style and gross stratigraphic architecture. The succession has been divided into five stratigraphic units, bounded by basin-wide stratal surfaces. The results of a detailed 3D seismic facies analysis will be presented to illustrate the exceptional level of sedimentological detail that is contained within the mega-merge survey. The expression of these fluvial systems will be illustrated in seismic sections, stratal and proportional slices and through various 3D volume extraction displays. This will include the youngest channel complex, which forms part of a major incised valley (c. 18 km wide and up to 90 m deep), which formed an axial drainage system along the length of Malay Basin during the latest Pleistocene, when the whole Sunda Shelf was exposed. In other intervals, the coastal plain was characterised by a range of unconfined high- and low-sinuosity fluvial channel systems. Planform geometries and other dimensions have been documented using GIS methods in order to develop a quantitative database of the Sunda Shelf fluvial systems.

These data and other observation from the Pliocene fluvial systems are being used to determine reservoir body dimensions, geometries and estimates of connectivity that will aid the interpretation of similar, fluvial reservoirs in the deeper prospective Miocene interval, including the construction of better constrained, 3D reservoir geological models. In regions such as the Sunda Shelf, where climate has remained relatively uniform, the shallow parts of regional mega-merge 3D seismic datasets provide may provide an extremely valuable source of reservoir analogue information.

NOTES

Complex attribution to add value to analogue geometry data: A case study of the large scale controls of fluvial channel geometry

C. A. Watkins, T. Hewitt, S. Etches, *Fugro Robertson Ltd, Llandudno, North Wales, UK*

The large scale controls on variations in fluvial channel geometry are investigated using a recently built database of reservoir geometry analogue data. The relationship between channel body width and thickness is explored and linked to planform geometry in terms of common descriptors of sinuosity and channel planform classification. Whilst selection of individual (or best fit) analogues for a particular subsurface case can be a useful process, we have taken an alternative approach by building a large database of reservoir geometry analogue data. These analogue data were subsequently attributed with additional descriptors derived from a variety of global GIS coverages, to include tectonic setting, climate/palaeoclimate and other potential controls on geometry. As a result, data searches allow creation of a suite of composite analogue data that fit a particular sub-surface case and can allow investigation of the controls on observed geometries. The generation of composite analogue data suites also provides potential to limit case-specific variation and retain a greater amount of inherent variability.

In this case study, a large volume of global channel data extracted from the public domain, satellite imagery and subsurface data sources have been filtered to investigate the relationship between modern and ancient data in different climatic and tectonic settings. The results of statistical tests of outcrop data are presented here as plots of width versus thickness. Applying the same broad geological filters to modern data, corresponding planform channel geometry (wavelength, amplitude and sinuosity) have been generated, and validated using a series of tests. The relationship between channel width and thickness under different climatic regimes varies significantly. The relationship between channel wavelength, amplitude and absolute sinuosity taken from modern satellite imagery also varies dramatically with climate regime

NOTES

Modelling of heterogeneity within hummocky cross stratification and its impact on vertical permeability at the geocellular scale

L. Dabek¹, P. Phillips¹, J.M. Boyles²

¹*Geomodeling Technology Corp, Calgary, Alberta, Canada*

²*Shell Canada Ltd, Calgary, Alberta, Canada*

Hummocky cross-stratification is considered to be diagnostic of inner shelf storm deposits. It typically forms above a storm wave base, where aggradation rates during storms are high enough to preserve hummocks but unidirectional current velocity is low enough to generate low-angle, isotropic cross-stratification. The lamina types associated with hummocky cross-stratification range from mud through sand, providing a challenging heterolithic environment for predicting porosity and directional effective permeability at the geocellular scale.

This study investigates the impact on vertical and lateral permeability imposed by mudstone in wave-dominated shoreface and river-dominated deltaic rocks of the Spring Canyon Member (Upper Cretaceous), Blackhawk Formation, Utah. Realistic three-dimensional heterogeneity models were created using a process-oriented methodology for the Spring Canyon Member bedforms. Probe permeameter and gamma-ray measurements from outcrop were assigned to lamina types in each bedform model. We then upscale the heterogeneity model to derive effective directional permeability using flow-based upscaling techniques. The upscaling results were then used as input to the geocellular grid to do the sensitivity study of hummocky cross stratification geological model parameters for the effective permeability.

We found that variations in permeability assigned to mudstone at the lamina scale can have a significant impact on permeability that is carried forward to the geocellular scale. This impact is particularly notable in effective permeability in the vertical direction, which is of concern to those operators working in tertiary production environments, such as steam-assisted gravity drainage.

NOTES

Poster Presentations

Calcrete as a source of heterogeneity in fluvial sheet sandstone reservoirs

A. Newell, T. Milodowski, A. Butcher, *British Geological Survey*

Carbonate is not generally considered as a potential source of large-scale heterogeneity in fluvial sheet sandstone reservoirs. This talk will show that carbonate, in the form of early diagenetic calcrete, forms an abundant component of the Triassic Otter Sandstone Formation in south Devon. Three main types of calcrete are recognised in this important aquifer/hydrocarbon reservoir: (1) rhizocretions, (2) calcrete sheets and (3) laterally extensive calcrete conglomerates. Laser scanning and Gocad 3D visualisation has been used to create outcrop maps to understand spatial variation in calcrete-related porosity reduction. A wide range of laboratory techniques have been applied to understand cement history and the 3D distribution of porosity, permeability and pore-throat size. The talk will show how a detailed understanding of changes in fluvial environment based on field sedimentology can be used as a tool to predict the location and extent of calcrete-related flow baffles.

Oblique Helicopter Lidar as a tool for the collection of “very large” Virtual Outcrops: Examples from selected fluvial outcrops in Eastern Utah

A. Rittersbacher¹, J. Howell^{1,4}, S. Buckley¹, J. Vallet², N. Richter¹, K. Keogh³

¹*Centre for Integrated Petroleum Research, University of Bergen, Norway*

²*Helimap System, CH-1066, Epalinges, Switzerland*

³*StatoilHydro, Stavanger, Norway*

⁴*Rocksource ASA, Bergen, Norway*

The collection of accurate, spatially constrained, outcrop data that can be used to measure sandbody geometry has been significantly advanced with recent developments in the application of ground based lidar technology. Ground based lidar involves the scanning of outcrops from a series of locations in front of the cliff to produce datasets that contain several million points and a set of digital photos. The points are triangulated to generate surfaces which are then draped with the digital photos to produce a Virtual Outcrop. Although highly successful for smaller outcrops the application of the ground based approach to larger outcrops required to obtain representative samples of geobody dimension is limited by the following factors:

1. The lidar system has a typical range of 600 – 800 m which is insufficient for many of the biggest, high quality outcrops.
2. Views are generally taken looking up, which results in “scan shadows” at ledges and breaks.
3. The photos are commonly highly oblique, reducing the quality.
4. Data collection is slow and manually intensive.

A solution to these problems is the application of an oblique, aerial lidar, in which the scanner is mounted on the side of a helicopter and flown along the outcrop giving access to the largest and most inaccessible areas, and providing optimal range and orientation for both scanning and photography. While solving many of the problems, heli-lidar produces a series of new challenges, not least related to the processing and handling of datasets that including 100s of millions of points and hundreds of digital photos.

This method has been tested on 3 “very large” outcrops in eastern Utah. Two exposures of the Blackhawk Formation were studied. The first was a 30 km section in the Book Cliffs and the second was a 14 km section in the Wasatch Plateau. The third dataset includes 22 km of data from the Tertiary, Green River Formation that crops-out in Nine Mile Canyon.

These datasets have been used to develop a stratigraphic framework for the sections. Within this framework several hundred individual sandbodies have been mapped, measured and reconstructed, providing a unique insight into vertical and lateral controls on geometry and stacking patterns.

High Resolution Quantitative Outcrop Analysis of a Fluvial depositional system: An example from the Late Triassic Wolfville Formation, Nova Scotia

X. van Lanen¹, D. Hodgetts¹, J. Redfern¹, S. Leleu²

¹*School of Earth, Atmospheric & Environmental Sciences, University of Manchester, Oxford Road, Manchester*

²*Department of Geology & Petroleum Geology, College of Physical Sciences, Meston Building, King's College, Aberdeen*

Digital outcrop data collection techniques are applied to the fluvial deposits of the lower part of the Wolfville Formation, Minas Basin, Nova Scotia, in order to quantify facies geometry and distribution for generating geocellular outcrop models.

The lower Wolfville represents the initial syn-rift phase of the Fundy Basin, one of a series of Early Mesozoic rift basins that developed along the margin of the proto North Atlantic Ocean. In the Minas Sub-basin the sediments of the Wolfville Formation are superbly exposed in both cliff sections and on extensive wave-cut platforms along the shore of the Minas Basin. The laterally extensive outcrops and three-dimensional nature of the exposures offer a valuable insight in the evolution of a red bed fluvial system and the geometries and distribution of sedimentary bodies. A detailed sedimentary analysis of the predominantly fluvial successions of the lower part of the Wolfville Formation allows the determination of a high-resolution and large-scale sedimentary architecture in the fluvial system. It has a thickness of 115 m and consists of alluvial fan deposits at the base overlain by sediments of a bedload pebble dominated fluvial system, and ends abruptly with an overlying ephemeral lake-margin facies association

Quantitative outcrop data, collected with LiDAR and DGPS is integrated with traditional geological field and laboratory data (sedimentological logs, palaeocurrent information, structural and petrophysical measurements) into a digital outcrop model (DOM). The DOM is then used for mapping the observed geological objects, and to evaluate their geometries and distribution using novel analyse techniques (e.g. projection planes, classified point clouds). The results offer a better understanding of the heterogeneity of the depositional system, accurate geostatistical information on the characteristics of sedimentary bodies and provide a geological framework for geocellular outcrop models. Such information aids improved reservoir characterisation and geostatistical modelling, as well as explain seismic reflection data and better understand flow model simulations in subsurface reservoirs using the geocellular outcrop model as a controlled testing environment.

3-D Modelling of deeper ramp carbonate build-ups – A reservoir analog study from the Upper Jurassic (SW Germany)

M. Bartenbach, T. Aigner, *University of Tübingen, Institute for Geoscience, Sedimentary Geology, Sigwartstraße 10, D-72076, Tübingen, Germany*

Contact: Martin Bartenbach (m.bartenbach@gmx.net)

The distribution of sponge/microbial buildups on an Upper Jurassic carbonate ramp in SW-Germany were modelled in 3-D. Detailed three-dimensional facies models were generated using an object-based modelling algorithm and compared with stochastic algorithms. An understanding of the lateral and vertical distribution of facies associations is crucial for the distribution and internal complexity of hydrocarbon reservoirs in analogous hydrocarbon systems.

20 outcrops, one cave and 46 wells were investigated sedimentologically, accompanied by integral- and spectral outcrop gamma-ray measurements. Seven facies associations were defined and assembled into three modelled facies groups. Detailed sedimentological logging was used to determine 2-dimensional growth patterns in quarries within the study area. Using additional literature data, three-dimensional buildup-geometries were reconstructed as input for the 3-D modelling.

The main reservoir facies types consist of dolomites and dedolomites with measured porosities of up to 14 percent and permeabilities of up to 123 mD. In addition, the reservoir potential may be significantly enhanced through carstification.

Imaging the internal architecture of an Aeolian Dune: Trials and tribulations of GPR in the desert sands of the Sultanate of Oman

J. Francke, D. Tatum, A. R. Westerman, C. Y. Hern

The bounding surfaces of dunes have long been known to impart significant permeability contrasts to aeolian sequences. Several near-surface, genetic processes may be implicated, from construction and migration to stabilization and accrual into accommodation space. The resulting permeability contrasts can affect fluid flow in subsurface aeolian reservoirs. The scale of the effect depends upon a suite of factors, and the impact often increases later in the life of a hydrocarbon field.

In order to optimally manage petroleum reservoir development, the spatial arrangement of bounding features needs incorporating into subsurface models. However, the information required cannot be obtained directly from the reservoir as we lack high-resolution imaging techniques for the inter-well area. At best, indirect inferences from an ensemble of remote data can be used to broadly constrain major features. However, many spatial parameters remain poorly constrained, especially in 3D.

Yet ground penetrating radar (GPR) can provide direct 3D imagery of near-surface deposits at a relevant scale and resolution. The resulting models may not be directly transferable to a specific subsurface scenario, but the generic spatial information can be a useful guide.

In this paper we describe the acquisition, processing and modelling of GPR data from two localities in the Sultanate of Oman and compare these results with those from trials in other aeolian systems. We also discuss the diminishing restrictions on this approach, particularly for data acquisition over different types of sand and dune architecture.

NOTES

Burlington House Fire Safety Information

If you hear the Alarm

Alarm Bells are situated throughout the building and will ring continuously for an evacuation. Do not stop to collect your personal belongings. Leave the building via the nearest and safest exit or the exit that you are advised to by the Fire Marshall on that floor.

Fire Exits from the Geological Society Conference Rooms

Lower Library:

Exit via Piccadilly entrance or main reception entrance.

Lecture Theatre

Exit at front of theatre (by screen) onto Courtyard or via side door out to Piccadilly entrance or via the doors that link to the Lower Library and to the main reception entrance.

Piccadilly Entrance

Straight out door and walk around to the Courtyard or via the main reception entrance.

Close the doors when leaving a room. **DO NOT SWITCH OFF THE LIGHTS.**

Assemble in the Courtyard in front of the Royal Academy, outside the Royal Astronomical Society.

Please do not re-enter the building except when you are advised that it is safe to do so by the Fire Brigade.

First Aid

All accidents should be reported to Reception and First Aid assistance will be provided if necessary.

Facilities

The ladies toilets are situated in the basement at the bottom of the staircase outside the Lecture Theatre.

The Gents toilets are situated on the ground floor in the corridor leading to the Arthur Holmes Room.

The cloakroom is located along the corridor to the Arthur Holmes Room.

Ground Floor Plan of the Geological Society, Burlington House, Piccadilly

ROYAL ACADEMY
COURTYARD

MUSTER POINT
(outside Royal
Astronomical
Society)

