Forward Modeling of Outcrop Data – a Tool for Improving Hydrocarbon Reservoir Prediction in Deepwater Architectural Elements

Szuman, Magdalena[1], Benjamin Kneller[1], Mads Huuse[1], Vanessa Kertznus[1], Philip Thompson[1], Matteo Molinaro[1], Mason Dykstra[2] (1) University of Aberdeen, Aberdeen, United Kingdom (2) University of California, Santa Barbara, CA

The behaviour of hydrocarbon reservoirs is often profoundly affected by architectural elements that are, or appear to be, below the resolution of conventional seismic data. The ability to predict or recognise sub-surface architecture in mass transport deposits, or the coarse clastic fills of submarine channels, both of which may be economically important for hydrocarbon exploration, is far from satisfactory.

We are planning to improve these skills by simulating the seismic response of architectures mapped from outcrops, and understanding the complicated relationships between the physical properties of the small scale geometries and the form of the seismic wavelet, and finally its influence on low frequency seismic models.

Truly seismic-scale outcrops of deep water elements are rare, but in our opinion, study of the rock record is crucial for understanding of lithofacies distribution and reservoir potential.

We present some models of architecture and lithologic distribution based on the large-scale outcrops, which have been used for generating seismic forward models. They are based on two types of deposit; a Jurassic-Cretaceous slide complex in Antarctica and Cretaceous turbidite canyon/channel complex in a late Cretaceous continental slope sequence, Baja California, Mexico. Forward seismic models were constructed by combining detailed structural and stratigraphic detail from outcrop sections with physical properties derived form representative subsurface datasets from a variety of settings and burial depths. We believe this approach will yield the most useful results for comparison between outcrop sections and subsurface datasets.

Architecture and Reservoir Properties of Submarine Channels: Outcrop Analogues from the Upper Cretaceous Rosario Formation of Canyon San Fernando, Baja California, Mexico

Thompson, Philip[1], Benjamin Kneller[1], Mason Dykstra[2], Katerina Garyfalou[1], Vanessa Kertznus[1], Magdalena Szuman[1] (1) University of Aberdeen, Aberdeen, United Kingdom (2) University of California, Santa Barbara, CA

We present field data from a deep marine channel-levée complex (Late Cretaceous Rosario Formation, Canyon San Fernando, Baja California, Mexico) formed on a continental slope. The Canyon San Fernando field area provides excellent quasi-3D exposure of a third-order sequence consisting of a canyon to levéed slope channel succession with numerous channel bodies and their related deposits. The entire complex spans a total stratigraphic thickness of approximately 1000m including channel bodies that range from entirely canyon confined (some bounded by levées internal to the canyon) to those that are entirely levée-confined. The channel bodies are made up of individual channel elements or 'building blocks'. Each type of channel element has a distinct architectural style and reservoir properties. By assessing the properties of individual channel elements in the field, and observing the way these are combined to form larger scale channel bodies in the outcrop, the reservoir properties of such larger scale bodies in the subsurface can be predicted. The use of 3D digital mapping workflows, allied to the interpretation of digital photomosaics (both of which are calibrated to detailed sedimentary logs), allows us to map geometries and ltihofacies in three dimensions. Quantitative and statistical analysis of the channel element fill allows us to assess the properties of individual channel elements and composite channel bodies in both 2D and 3D.

Multidisciplinary Examination of a Deepwater Turbidite Reservoir Outcrop Analogue, Taranaki Basin, New Zealand

Gartrell, Anthony Paul[1], Brian Evans[2], Derek Woodward[3], Greg Browne[4] (1) CSIRO Petroleum, Perth, Australia (2) Curtin University of Technology, Perth, Australia (3) GNS Science, Wellington, New Zealand (4) GNS Science, New Zealand

Late Miocene basin floor turbidite fans of the Mt Messenger Formation, superbly exposed in cliff sections on the west coast of New Zealand, represent an excellent analogue for deep-water turbidite reservoirs. In the Tongaporutu River area of the Taranaki Basin, these rocks are transected by an array of normal faults of various orientations and throws that are also well exposed within a series of embayments along the cliff face. A high-resolution multidisciplinary examination (TURI Project) of the structural and stratigraphic elements of the field site is currently underway. The main aims of this study are to characterise the hydraulic connectivity and conductivity in complex faulted thin-bedded clastic reservoir rocks. This information will be used to devise upscaling strategies that successfully account for the effects of sub-seismic faulting (juxtaposition, membrane sealing) and sedimentary variability on fluid flow in reservoirs of this kind. Outcrop mapping and 3D photogrammetry of the cliff section are to be combined with behind outcrop 3D Ground Penetrating Radar (GPR), high resolution 2D/3D seismic, drill coring and logging in order to construct a detailed 3D geological framework model. Reservoir flow simulations based on the framework model will then be compared with hydraulic pump tests performed in wells situated on either side of a selected fault. Initial results from the outcrop structural and stratigraphic mapping, 3D photogrammetry and 3D GPR are already providing new insights into the nature of this world renowned turbidite outcrop analogue.

Channel Architectural Element Analysis of Deep Marine Channels: Examples from Outcrop and Implications for the Predictability of Channel Systems

Dykstra, Mason[1], Benjamin Kneller[2] (1) University of California, Santa Barbara, CA (2) University of Aberdeen, Aberdeen, United Kingdom

Submarine channels may take any of three forms: aggradational, graded, or erosional. These states correspond more or less with distinct stratigraphic architectures that form channel elements. Channel elements are the building blocks of composite channel bodies or channel complexes.

Channel elements are divided into those of a predominantly laterally accreting style, an aggrading style, or an erosional/amalgamational style, which form the end-members of a channel-element continuum, each with its own distinctive properties. Lateral accretion channel elements are shown to have high width/thickness ratios, and entire channel-elements are commonly preserved; paleocurrent data show a wide spread, with flow down-channel, perpendicular

to, and up-channel. Aggradational channel elements are shown to have intermediate width/thickness ratios, again with entire channel-elements commonly preserved; paleocurrent data trend predominantly down-channel. Erosional/amalgamational channel elements are shown to have the lowest width/thickness ratios, with entire channel elements never preserved (always eroded laterally and/or vertically). Paleocurrent directions are generally subparallel to the channel-trend. Channel element data from a Campanian-Maastrichtian channel and canyon complex on the Pacific coast of Baja California, Mexico, are used to illustrate these properties.
Extension of these data into seismic-scale indicates that this type of element analysis carries over into the subsurface, where lateral accretion, aggradation, and amalgamation are again recognized as end-member type systems, typically at larger scales. This analysis may be scalable, and can be used to help predict the internal complexity of reservoirs.

Characteristics of Deepwater Deposits from Outcrops: Depositional Models and Processes, Architectural Elements, and Statistics

Nilsen, Tor H.[1], Roger D. Shew[2], Gary S. Steffens[3], Joseph J. R. Studlick[4] (1) Deceased, N/A, CA (2) University of North Carolina at Wilmington/Consulting Geologist, Wilmington, NC (3) Shell International E & P Inc, Houston, TX (4) Consulting Geologist, Houston, TX

Reservoir characterization (setting, models, external and internal geometries, architectural elements, and flow unit properties) is critical to the modeling and economic development of deepwater reservoirs. Analogs, including subsurface, “modern” depositional systems, and outcrops, are an essential part of that characterization effort. Outcrops have historically provided one of the best analog data sets for conceptual data and modeling but quantitative data is often limited. For example, connectivity factors that are important for field development and for constraining potential reservoir performance are most often extracted from a very limited data set. To meet the need for more comprehensive descriptions and statistics on deepwater reservoirs, we have compiled data on more than 100 classic and new deepwater outcrops from around the world and summarized them in an AAPG Atlas of Deepwater Outcrops. In addition to descriptions of the architectures, which are broadly classified into sheets, channels, and thinbeds, a uniform collection of statistical data has been obtained with bed thicknesses, bed lengths, and other physical properties of reservoir, non-reservoir, and mass transport complex elements. A summary of the statistics, architectural elements, models, and classification are included in the presentation.

The Donkey Bore Syncline, South Australia – an Outcrop Analogue of a Deepwater Sediment-Filled Salt-Withdraw Mini-Basin

Payenberg, Tobias H.D.[1], Simon C. Lang[1], Mark, R.W. Reilly[1], Blaise Fernandes[1], Carmen Krapf[1], Nathan Ceglar[1] (1) University of Adelaide, Adelaide, Australia

Mini-basins filled with deepwater sediments are significant exploration targets around the world. Reservoir and seal facies distribution within such mini-basins are highly variable and often difficult to predict. As a result, many development programs face a higher degree of compartmentalization than originally anticipated, which often leads to higher development costs, and lowered reserves. Outcrop analogues are one way of gaining a better generic understanding of compartmentalization commonly encountered within sedimentary successions.
The Cambrian Donkey Bore Syncline, Flinders Ranges, South Australia is an outcropping analogue of a complete mini-basin fill. Next to the Wirrealpa Diapir over 400m of section are exposed in a doubly-folded syncline. The gently-dipping sediments within the syncline cover an area of approximately 20 km2. The mini-basin fill comprises basal shallow marine, cross-stratified carbonates including Archaeocyatha reef complexes. Towards the top of this limestone slumping occurs frequently, and reef complexes are found as allochthonous blocks. This mass wasting shows the re-initiation of the mini-basin.
Overlying the carbonates are massive densite and debrite beds separated by mudstone. These rocks form the initial clastic fill of the basin. Up section the densites and debrites decrease in thickness and frequency, and turbidite beds start occurring. This is interpreted as the result of a decreasing slope through filling of the mini-basin. The overall transgressive deepwater succession ends with thin turbidite and thick mudstone packages overlain by chloritic siltstones. Sandbody continuity within the basin is mainly dependent on the type of flow mechanism and the input location relative to the diapir.

Lateral Variations in Diapir-Constrained Deepwater Sediments of the Donkey Bore Syncline, Flinders Ranges, South Australia

Fernandes, Blaise[1], Tobias H.D. Payenberg[1], Carmen Krapf[1] (1) University of Adelaide, Adelaide, Australia

Cambrian deepwater sediments outcrop uniquely in the Donkey Bore Syncline, Flinders Ranges, South Australia adjacent to a salt diapir. They present a significant analogue of intra-formational, lateral variation in a syn-diapir depositional setting. It is situated adjacent to the Wirrealpa Diapir and contains over 400 m of sediment over approximately 20 km2. The strata are shallow dipping and due to the arid climate outcrop are of great quality allowing detailed field analyses of stratigraphic variability within the units of interest.
Field studies involving detailed measured sections were carried out along the southern flanks of the syncline. The predominantly debrite and densite deposits have bed thicknesses between a few cm to 4 m. Two type of sequences/sedimentary units have been distinguished: up to 10s of m of thinly interbedded calcareous sandstones and muddy limestones as well as up to 4 m thick individual massive sandstone beds. Both sequences are laterally extensive but vary in thickness within a distance of 2 km, determined through walking individual beds between sections.
Within the major sandy units, prominent slumping plays a dominant role in thickness variations, imparting a heterogeneity on an apparently constant sequence. There is also general thickening of the sequences with distance from the diapir. These sub-seismic factors are important to consider when predicting reservoir units and their flow characteristics in similar, subsurface salt related sequences.

Observations and Thoughts on Sands Associated with Mass Transport Deposits

Meckel, Trey[1] (1) Woodside Energy Ltd, Perth, Australia

Many sands deposited on continental slopes occur immediately above a mud-prone debrite or are inter-bedded within a series of debrites. This characteristic stratigraphic succession, observed in numerous outcrop and subsurface examples, allows three possible temporal and genetic relationships between the sands and the debrites to be considered: (i) that the deposition of the sands preceded externally-driven mass failure, and the sands were subsequently re-mobilized as part of a mass-transport deposit; (ii) that rapid deposition of the sands triggered the failure of the underlying muds as a co-genetic failure; or (iii) that the deposition of the sands post-dated the deposition of the underlying debrite, and the two units are genetically un-related.

These three hypotheses have significant implications in terms of reservoir quality and distribution. In the first case, the sands can have been re-sedimented relatively coherently or not, potentially resulting in a high degree of lateral variability. This variability may be accompanied by a disruption of any existing internal barriers and baffles, leading to improved reservoir characteristics. In the second case, the connectivity and reservoir quality of the sands is often improved by (in particular) dewatering and injection, but may be offset by internal syn-depositional faulting and folding. In the third case, reservoir distribution is often controlled by topography on the tops of the preceding debrites, but reservoir quality is independent of debrite characteristics.

Outcrop analogues, supplemented by subsurface cases, allow us to make detailed observations of the three associations, leading to improved understanding of this reservoir type.

Can Mass Transport Complexes Form Viable Hydrocarbon Reservoirs: Examples from the Silverwood Group, Southeast Queensland, Australia

van Noord, Kenrick A. A.[1] (1) Norwest Energy NL, Perth, Australia

As new plays are sought in deep marine environments to maximise exploration targets, the question arises whether Mass Transport Complexes (MTC) can form a viable reservoir capable of producing hydrocarbons. In this regard, the absence of suitably well described analogues from which to draw comparisons and predict reservoir quality, greatly increases exploration risk in successions containing MTC's.

The Silverwood Group of southeast Queensland, Australia, contains several examples of MTC which differ greatly in scale, texture and composition both within and between each example. These differences reflect the nature of the substrate at the site of initiation and their mechanism(s) of formation. In general, MTC's from the Silverwood Group can be broadly arranged into three main textural styles: i) grain supported blocks/rafts in a pebble to boulder matrix, ii) matrix supported blocks/rafts in a very fine to coarse grained sandstone with occasional pebble-boulder clasts, and iii) matrix supported blocks/rafts in massive mudstone, whereby the long axes of the blocks/rafts are aligned sub-parallel to bed base.

Internally, each MTC may consist of one or more discrete events, some of which may be genetically related to each other as a process continuum (the deposit encountered is dependent on the relative distance from source). The first textural style is interpreted as rock-fall deposits, in this case associated with large-scale failure of the shelf-edge. The latter two textural styles are cohesive debris flow deposits, the first of which is the most common (ii), and can form a viable hydrocarbon reservoir where clay contents are low.