High-Resolution Outcrop-Subsurface Correlation Using Biostratigraphy: Unlocking the Late Miocene, Mount Messenger Enigma in Taranaki Basin, New Zealand

Arnot, Malcolm J.[1], Martin Crundwell[1] (1) GNS Science, Lower Hutt, New Zealand

The Mount Messenger Formation represents a highly dynamic deep-water system comprising slope to basin floor fan deposits that occur within stacked 4th to 5th order cycles deposited over timescales of 100-25 kyr. The late Miocene sedimentary patterns reflect a complex history of shelf progradation, tempered by sediment supply and accommodation, and tectonic controls within and adjacent to the basin. The variable nature of the system poses problems for exploration within the Mount Messenger interval, because rapid lateral and vertical variation in facies make it difficult to correlate, date and predict the spatial distribution of intervals containing potential reservoir facies.

In this presentation, we outline the application of new high resolution biostratigraphic data and tools that have been developed by GNS, specifically to address correlation problems associated with the late Miocene Mt Messenger interval. This work has enabled correlation from rocks exposed along the north Taranaki coast to the subsurface at Pukearuhe-1. Currently we are extending the correlation into the onshore Taranaki Peninsula region. In addition, extremely high estimated rates of sedimentation are recognised at intervals within the Mount Messenger succession, based on weight standardized counts of planktic and benthic forams, and sub-millennial scale dating of deep-water sediments, using a non-linear age interpolation method and dynamic facies analysis, based on minimum paleodepth data. When applied in combination, the new biostratigraphic tools provide a robust temporal and paleoenvironmental framework that enables the stratigraphic architecture of Late Miocene depositional systems to be correlated between wells at a level of resolution similar to seismic.

Research Well Data from an Outcrop Analogue Study, Permian Basin Floor Fans, Tanqua-Karoo Basin (South Africa): An Aid for the Development of Fine-Grained Turbidite Reservoirs

Luthi, Stefan M.[1], David Hodgson[2], Cees R. Geel[3], Stephen Flint[2], Jan Willem Goedbloed[4] (1) Delft University of Technology, 2628 RX Delft, Netherlands (2) University of Liverpool, Liverpool, United Kingdom (3) Netherlands Institute of Applied Geoscience TNO, 3058 TA Utrecht, Netherlands (4) Statoil, Stavanger, Norway

Outcrop analogue studies can significantly be augmented by drilling wells through the same stratigraphic interval with the objective to validate the outcrop observations with well log and core data “behind the outcrop”, and thus to improve the use of such data in actual field developments. For research wells located further away from the outcrops, the increased spatial data coverage can give important insights into regional facies changes. In a study of the Permian basin floor fans of the Tanqua-Karoo basin (South Africa), seven wells were drilled to supplement the outcrop data, three of them close to the cliff faces, and four at significant distances away from exposures. The first three wells proved useful in establishing characteristic log responses of the main architectural elements that were identified from the nearby outcrops. Lithofacies were for more than 80% of cases correctly identified using a neural network, and borehole images provided detailed information on sedimentary structures, including a wealth of palaeocurrent data from climbing ripples that significantly enhanced the interpretations from the outcrop measurements. The wells further away from the outcrops proved crucial in defining the lateral geometries of the fans. The combined data indicate that deposition was controlled by subtle basin floor topography, and that intrafan lobe switching took place that led to internal subdivisions, potentially causing an effective compartmentalization of the basin floor fan.

Use of Outcrop Data to Constrain Reservoir Properties of Deep-Marine Mass-Transport Deposits in the Subsurface: Core- to Seismic-Scale

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

We present an integrated approach to the study of mass transport deposits in deep marine environments, using outcrop observations ranging from meso- (core) scale to macro- (seismic) scale from the Guandocól Formation, Carboniferous of La Rioja province, Argentina; the Marnoso Arenacea Fm, Miocene of northern Italy; the Hecho Group, Eocene of northern Spain and the Fossil Bluff Group, Jurassic of Alexander Island, Antarctica.

Using a combination of seismic forward modeling (see companion abstract), core studies, and field techniques such as sedimentary logging, structural measurements, and digital interpretation of photomosaics, we identify various styles of mass transport deposits as reflected in meso-scale (outcrop/core) texture and structure and macro-scale (seismic) structure and lithology distribution. We are able to generate architectural models for the different types of mass transport deposits (e.g. slumps, slides, debris flows) from outcrop data. From meso-scale outcrop measurements we calculate the bulk permeability for examples of the different styles of deposit, based on statistical transformations from 2D to 3D. We then generate multi-dimensional diagrams which identify the range of core-scale parameters that differentiate connected from non-connected volumes of reservoir lithologies within an MTD. Finally we link these back to seismic scale properties, and make comparison with high-resolution 3D seismic data from deep marine systems.

Reservoir Geometry, Lateral Facies Continuity and Permeability Heterogeneities in Outcropping Shoreface Sandstones, Brunei Darussalam

Lambiase, Joseph J.[1], Ms. Ovinda[2] (1) Universiti Brunei Darussalam, Tungku, Brunei (2) Universiti Brunei Darussalam,

A wave-dominant, shallow marine succession includes an upper shoreface sandstone unit that can be traced laterally for more than 4.5 km through 12 outcrops. The fine to medium-grained sand is typically clean and parallel laminated with some swaley and trough cross-bedding and little bioturbation. The unit has a nearly constant thickness of 5 m over the entire distance, except where it decreases to 2.8 m approximately 300 m before pinching out. The decrease in thickness

is accompanied by an increase in the amount of mud that occurs as thin beds, laminations and drapes, as well as interspersed mud resulting from increased bioturbation. There are other discrete zones laterally along the sandstone unit where the amount of mud and bioturbation is significantly greater than background values; these are presumably related to alongshore hydrodynamic variations at the time of deposition.
In situ permeability measurements are consistently in the 350 to 500 mD range in the weakly bioturbated, clean sandstone that dominates the unit, but drop to 150 to 200 mD in the relatively muddy and more intensely bioturbated zones and to <100 mD where the sandstone thins adjacent to the pinchout. Permeabilities may be even lower where vegetation covers the unit and the mud content is almost certainly higher, suggesting that upper shoreface sandstone reservoirs can be laterally heterogeneous or compartmentalized. The reduced volume and recovery factor caused by thinning and increased mud content could lead to significant overestimation of recoverable reserves in the last several hundred meters adjacent to a pinchout.

Predicting Calcite Cement Distribution in the Sunrise Gas Field Using Analogues

Alsop, David B.[1], R. Bruce Ainsworth[1] (1) Woodside Energy Ltd, Perth, WA, Australia
Vertical reservoir connectivity within the Sunrise field is influenced by calcite cement, which occurs at discreet intervals in many of the sandstones within the Bathonian Plover Formation. The objective of this study was to characterise the lateral extent of the carbonate cements and their impact on fluid flow within the reservoir.
Core from three wells along with wireline logs, isotope and petrographic data were used to characterise the origin and vertical distribution of the carbonate cement within a sequence stratigraphic framework. Outcrop analogues were then used to predict the lateral continuity of the cements.
The reservoir units were deposited in lowstand incised valley fill and shoreface environments. Shell beds overlie transgressive surfaces near the top of two units with some biogenic carbonate also occurring within the reservoir units.
Gas inclusions between quartz overgrowths and calcite cement indicate that calcite precipitated after gas charge entered the reservoir. The calcite cement formed as concretions on a nucleus of biogenic carbonate such as shell debris. This biogenic carbonate has been the primary source of material for the calcite cement along with CO2 from the maturation of organic material.
Calcite cement concretions which have formed at the tops of shoreface sandstone units with abundant shell debris are most likely coalesced to form laterally continuous beds.
Incised valley fill sandstones show only minor biogenic carbonate suggesting a limited extent of calcite cement and non-coalescence of calcite concretions.
The dominant factor influencing distribution of calcite cement within the Sunrise Field is the lateral distribution and amount of biogenic carbonate as observed in analogues. The distribution of transgressive shell beds is an important factor in controlling vertical connectivity within the Field.

Applying the Clinoform Concept to Correlation of Deltaic and Shallow Marine Deposits

Bhattacharya, Janok P.[1] (1) University of Houston, Houston, TX
A fundamental problem in subsurface reservoir characterization is determining the continuity of flow units and flow barriers (i.e. sandstones, shales and cements). In any given field, there will typically exist a combination of field wide-elements, elements that may extend between wells, but not across the entire field, and elements that do not extend between wells.
The subsurface geologist must use facies models and sequence stratigraphic concepts to correlate well data. I show several examples of deltaic reservoirs originally depicted as consisting of horizontal layers (i.e. the layer-cake). Outcrop examples suggest that sandstones within the delta front dip seaward. This fundamentally challenges reservoir models that invoke flat versus dipping beds and I demonstrate how this can be applied to correlation of core and well log data sets. Regional-scale stratigraphic results study also suggest very different exploration models in the search for basin-distal reservoir sandstones.
A key problem remains the correlation of deltaic sandstones along depositional strike, for which we have far less outcrop data and do not yet understand the main controlling parameters.

High-Resolution, Three-Dimensional Outcrop Modeling of a Fluvial-Dominated Deltaic Reservoir Analogue

Deveugle, Peter E.[1], Matthew D. Jackson[1], Gary J. Hampson[1], Craig S. Calvert[2], Michael Farrell[2], Anthony R. Sprague[2]
(1) Imperial College London, London, United Kingdom (2) ExxonMobil Upstream Research Company, Houston, TX
Deltaic deposits, such as those found in the Prudhoe Bay and Sahkalin Fields, contain significant hydrocarbon reserves and are a major focus of future exploration. However, the way in which their inherent geological heterogeneities impact on hydrocarbon recovery, and how this should best be captured in reservoir models, is still unclear.
We have used an extensive outcrop dataset to construct high-resolution, 3-D models of parasequence-set, parasequence, and facies architecture within the two lowermost parasequence-sets of the late Cretaceous Ferron Sandstone, exposed in Utah, USA. The dataset comprises measured sections, cliff-face photomontages, GPS-measured spatial data, laser-surveyed thicknesses and well-log data obtained over an area of circa 7 by 4 km, within which there is excellent 3-D data coverage.
To properly capture this rich, complex dataset requires the use of a new modeling methodology. We adopt a top-down, surface-based approach, in which each level of heterogeneity is represented using one or more surfaces. These surfaces may be deterministically interpolated between control points, or incorporate a stochastic element.
The advantages of this approach over traditional grid-based stochastic techniques are that (i) any level of heterogeneity may be captured using additional surfaces; (ii) it is trivial to condition the surfaces to control data, however complex; (iii) surfaces are much less computationally expensive than large, 3-D grids, and (iv) the models can be efficiently gridded or

meshed for flow simulation using adaptive techniques.
We can simulate fluid flow directly on the model without recourse to upscaling. It also allows us to resolve details of the sedimentology which could not be otherwise determined. Although we have developed the modeling methodology for rich outcrop datasets, it could be applied to sub-surface reservoirs.

Outcrop to Desk-Top, Modern and Ancient Analogues Provide Geological Controls for Reservoir Layering and Object Modeling in a 'Wet' Eolian Depositional System, Unayzah 'A' Reservoir, Saudi Arabia

Heine, Christian J.[1] (1) Saudi Aramco, Dhahran 31311, Saudi Arabia

The borehole image log is a critical tool for facies recognition of the Permian Unayzah sandstone of Saudi Arabia. Four distinct depositional facies: dune, sand-sheet, paleosol and playa have been identified on image log and confirmed with detailed core description. The core and image log studies indicate the Unayzah reservoir was laid down in a 'wet' eolian transverse dune depositional system. The Unayzah reservoir was then layered based on a 'wet' eolian depositional model using the Permian Cedar Mesa sandstone in Utah as an outcrop analog. In well log cross-section 'wet' and 'dry' eolian depositional cycles were recognized and incorporated into the geocellular model as 'time lines' based on field observations from Cedar Mesa outcrops. A numerical proportion of each facies was determined from well data for each reservoir sequence. An object-based modeling technique was used to distribute the image log identified facies. The transverse dunes were modeled as 3D objects oriented with the dune crest striking N-S based on image log data. The interdune was incorporated as elongate 3D objects paralleling the transverse dunes. Object sizes and shapes were measured from satellite images of present-day transverse dune fields in Saudi Arabia. The dune-interdune relationship is modeled after the satellite images as well. The resulting geocellular model was viewed in cross-section, which displayed the characteristic 'wet' and 'dry' cycles observed in the Cedar Mesa outcrop. In plan view, we captured the facies distribution seen in satellite images from present-day transverse dune fields.