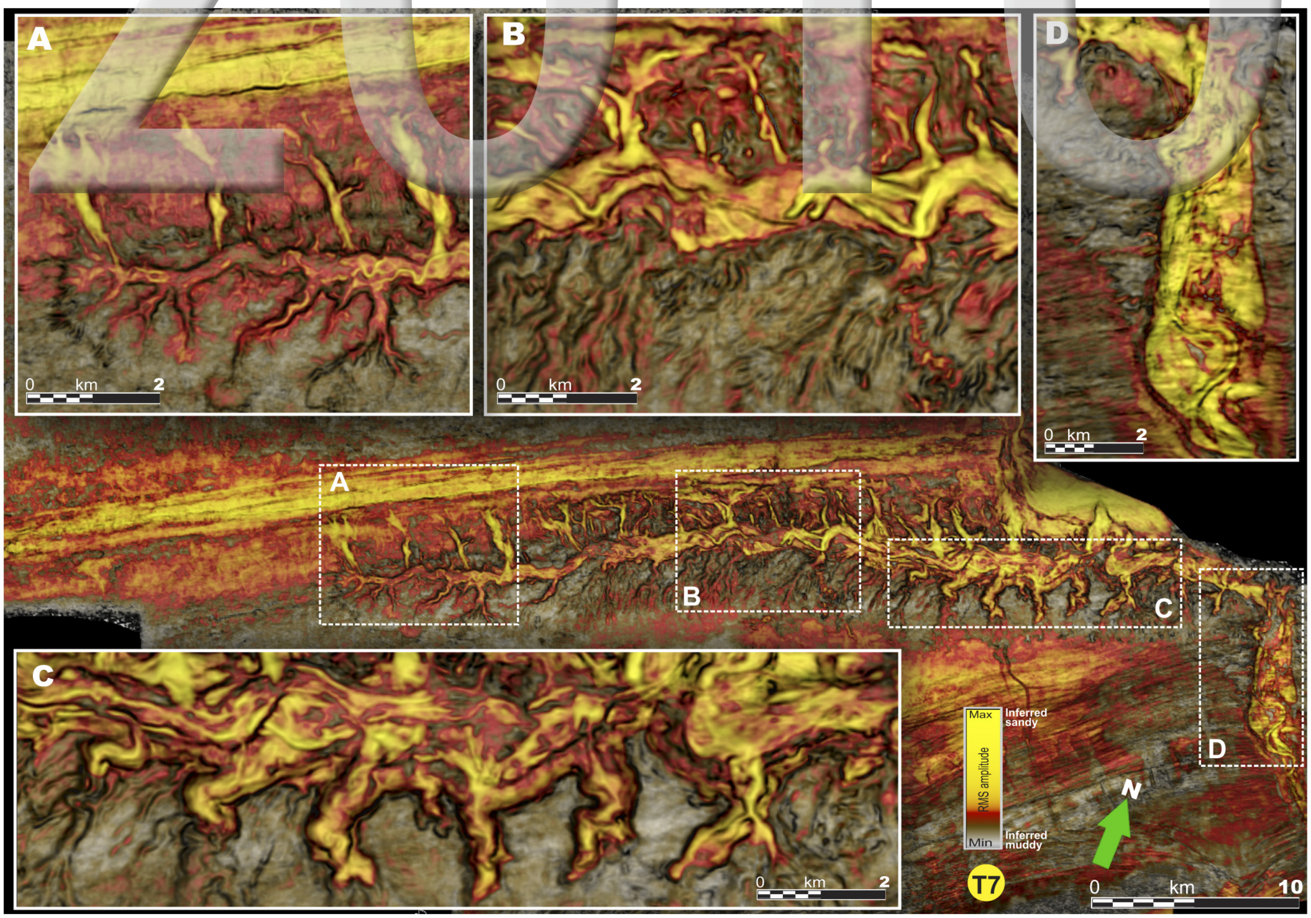
2010



30th Annual GCSSEPM Foundation Bob F. Perkins Research Conference

December 5-8, 2010, Houston, Texas

Seismic Imaging of Depositional and Geomorphic Systems

Program and Abstracts

Seismic Imaging of Depositional and Geomorphic Systems

30th Annual Gulf Coast Section SEPM Foundation
Bob F. Perkins Research Conference

2010

Program and Abstracts

Houston Marriott Westchase
Houston, Texas
December 5–8, 2010

Edited by

Lesli J. Wood
Toni T. Simo
Norman C. Rosen

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Statoil and Hess Corporation.

Foreword

It seems that the time has come to have another Bob F. Perkins seismic conference; it has been too long since the last one. Many new data sets, work flows, and approaches have come to light. Seismic geomorphology is the integration of three-dimensional seismic data and geomorphologic approaches. It allows seeing the ancient morphology of our depositional systems in a spatial detail and at a higher resolution time scale that before now we have not considered possible. Quantitative methods applied to these data enable us to risk and define our subsurface reservoir and seal systems with reduced uncertainty. Quantitative morphologic data measured from surface and subsurface domains allow reexamination of the empirical relationships among system elements and creating models to predict, for instance, channel lithology from channel sinuosity, levee width based upon levee height, and carbonate amalgamation or karst distribution from outcrop and seismic comparisons. This enables us to view the true distribution of petrographic facies within a context of 3D spatial distribution of depositional elements. Application of quantitative seismic geomorphology to existing data volumes around the world has the potential to provide a heretofore unrealized dense, deep, and spatially extensive understanding of older geomorphologic frameworks of the world.

The aim of the 30th annual GCSSEPM Foundation Bob F. Perkins Research Conference "Seismic Imaging of Depositional and Geomorphic Systems" is to discuss the integration of geomorphic and depositional systems principles and three-dimensional seismic interpretation toward an improved understanding of carbonate and siliciclastic paleo-landscapes and seascapes. The conference examines the integration of Holocene, outcrop, modeling and seismic studies and approaches. Thirty three papers are organized in 5 sessions (Tools and Approaches, Carbonate Systems, Shallow Marine and Shelf Systems, Fluvial/Estuarine Systems, Modern Analog and Data Mining, and Deep Water Systems). Four keynote talks will focus on (1) extracting seismic data patterns using predictive painting (Sergey Fomel), (2) process based modeling of deep water systems (Tao Sun), (3) the shape of seismic interpretation (Kurt Marfurt) and (4) integrating seismic stratigraphy and seismic geomorphology; work flows and techniques (Henry Posamentier).

The authors are to be commended for the high-quality ideas and data presented for their talks and posters. We, the organizers, are truly thankful for their efforts and especially those who had to deal with release of information issues. We thank universities and companies for allowing the time dedicated to write the manuscripts and put together the talks and posters, and the release of data. Norm Rosen has been always "behind the scenes" making things happen and without his vigilance we could not have put this together. Thanks Norm!

Lesli Wood and Toni Simo
Program Co-Convenors

Seismic Imaging of Depositional and Geomorphic Systems

30th Annual Gulf Coast Section SEPM Foundation
Bob F. Perkins Research Conference

Houston Marriott Westchase
Houston, Texas
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Program

Sunday, December 5

4:00–6:00 p.m. Registration and Poster Setup (Grand Pavilion)
6:00–8:00 p.m. Welcome Reception and Poster Preview (Grand Pavilion)

Monday, December 6

7:00 a.m. **Continuous Registration (Grand Foyer)**
7:45 a.m. **Welcome Remarks, Paul Weimer (Chair of the Board of Trustees, GCSSEPM Foundation) (Grand Pavilion)**
7:55 a.m. **Introduction to the Conference, Lesli Wood and Toni Simo (Conference Co-Convenors)**

Session 1: Tools and Approaches

8:05 a.m. **Introduction—Session Chairman**

10:20 a.m. Coffee Break

5:00–8:00 p.m. The University of Texas at Austin Bureau of Economic Geology Visualization Center will be open to view various seismic data volumes from around the world. Bring your own data or come view some of the library from UT.

5:30–8:00 p.m. Hot buffet, open bar, and poster session

Tuesday, December 7

7:15 a.m. **Continuous Registration (Grand Foyer)**

Session 3: Shallow Marine and Shelf Systems

7:55 a.m. **Introduction—Session Chairman**

Keynote Address

10:00 a.m. Coffee Break

Session 4: Fluvial/Estuarine Systems

10:25 a.m. **Introduction—Session Chairman**

12:30 p.m. Full hot lunch served in Grand Foyer; included in registration cost

Session 5: Modern Analogs and Data Mining

Wednesday, December 8

Session 6: Deep-Water Systems

Session 7: Deep-Water Systems (Cont.)

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Cover Image

The cover image chosen for this year's conference is Figure 18 from Hadler-Jacobsen *et al*.: "Controls on and Expressions of Submarine Fan Genesis Within a High Accommodation Margin Setting, Santos Basin, Brazil—A High-Resolution Seismic-Stratigraphic and -Geomorphic Case Study."

Quantifying the Temporal and Spatial Extent of Depositional and Structural Elements in 3D Seismic Data Using Spectral Decomposition and Multi Attribute RGB Blending

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Abstract

Single and multi-trace seismic attributes are widely used to help to visualize and delineate the spatial extent of depositional bodies on interpreted horizons (*e.g.* Wescott and Boucher, 2000; Wood *et al.*, 2000; Posamentier and Kolla, 2003; and Chopra and Marfurt, 2007). Commonly, the internal complexities of these interpreted depositional bodies are not as well resolved due to spatial resolution constraints and low contrast. This increases the uncertainty of quantitative analyses or inferences that utilize the resulting data; *e.g.*, reservoir presence and thickness (*e.g.* Widess, 1979; Wescott and Boucher, 2000). This also holds true in the delineation of structural elements; *i.e.*, faults in seismic datasets, particularly when attempting to quantify the potential for internal barriers to act as baffles to fluid flow within individual reservoir units. Therefore, there is a need for further development and understanding of seismic attribute work flows used to evaluate geological elements imaged within our poststack seismic datasets, in order to gain an enhanced understanding of the detailed morphology, spatial extent, and temporal location of depositional and structural elements, in order to assess fully their importance and impact.

Frequency Dependency of Seismic Facies and Seismic Sedimentology

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Abstract

Seismic interpretation of stratigraphy and sedimentology is frequency and scale dependent. Frequency dependency offers a new dimension of seismic data that has not been fully utilized in the study of seismic facies and seismic sedimentology/geomorphology. Zero-offset seismic events are a function of a wavelet and an acoustic impedance profile. Seismic interferences, controlled mainly by thickness- and frequency-tuning effects, exert significant influence on the occurrence of seismic events and types of seismic facies. By analyzing an amplitude-versus-frequency plot or panel-filtering seismic data, we can intentionally modify seismic events and seismic facies to a certain degree to better integrate well and seismic interpretation.

Extracting Seismic Data Patterns Using Predictive Painting

Fomel, Sergey

Abstract

(no abstract submitted)

Correlations Among Seismic Attributes and Incised Valley Thicknesses in Recent Stratigraphy of the Sunda Shelf, Indonesia

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Abstract

Channel-form morphologies (channel or valley) proliferate in the rock record and are the target of many exploration and development wells. Their geometry and the nature of their relationships with underlying, laterally adjacent, and overlying strata are often complex and difficult to deduce with 1D, 2D, and even 3D data due to their limited spatial extent and thickness. Three-dimensional seismic has added a new dimension to the exploration of and for channelform deposits, allowing many attributes to be extracted from these data in an attempt to reveal details of channelized deposits. Identifying which among this multitude of attributes are actually useful for mapping channel-form nature (planform, depth, edges, internal architecture, lithology, etc.) is a long-standing challenge for petroleum workers and a future challenge for groundwater workers. A high-quality, large (3,154-km^2) 3D seismic data volume collected in a highly channelized stratigraphic series found in the upper 500 ms of the Sunda Shelf in offshore Indonesia was used to map incised valley development on this shelf. Defined on a seismic grid at 25-m spacing, ten valley bases were then exported to ArcGIS, which was used to define each valley's thalweg. Valley-base elevation and several seismic attributes were then extracted along each thalweg. Resulting correlations and relationships could be used to infer thickness variability and reservoir characteristics of channel forms from 2D planform analysis and profiling. Two seismic attributes, coherency and 30-Hz component amplitude, are somewhat correlated ($|r|>0.23$) with along-valley thicknesses collectively across the ten valleys. Instantaneous frequency, reflection strength, and average absolute amplitude exhibit negligible correlation with thickness ($|r|<0.03$). Spectral decomposition is the most intuitive method for attribute-to-thickness correlation, although a general relationship between spectral component amplitude and thickness of imaged features has not yet been determined. Thickness of Valley 1, the thickest valley analyzed, is best-correlated ($r = 0.62$) with maximum 10-Hz component amplitudes within the lower interval of the valley fill.

Use of Outcrop Analogs to Interpret Seismic Facies in the Karachaganak Field

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Abstract

Slopes of carbonate platforms are composed of a spectrum of deposit types, many of which exhibit complex vertical and lateral facies relationships due to partitioned contributions from multiple sediment factories via a variety of resedimentation processes. This depositional heterogeneity is often in part below the resolution of seismic imaging and poorly constrained through well log and core correlation. Outcrop exposures provide continuous and high-resolution facies, stratal, geometrical, and juxtaposition information that is generally not available from subsurface data but critical for characterizing carbonate slope systems as the framework for reservoir and simulation models.

Karachaganak Field, northern Precaspian basin, Kazakhstan, is a high-rising, Permo-Carboniferous isolated carbonate platform in which the oil leg of a gas condensate reservoir resides primarily within steep, progradational slope strata. Seismic mapping of the slopes at Karachaganak identifies a range of clinoform characteristics (continuity, curvature, declivity), margin configurations (accretionary, escarpment), and stratal terminations (onlap wedges, internal downlap). A narrow corridor of high-quality seismic data and poor core coverage to-date warrants the use of outcrops to develop further play concepts and validate and characterize reservoir attributes. Of the several seismic and geological models proposed for Karachaganak, the Chevron observations described in this paper divide the seismic facies model into five primary seismic facies. These facies have been determined by their amplitude character and include reflector continuity, strength, and geometry. The primary seismic facies are: (1) planar clinoforms, (2) exponential clinoforms, (3) chaotic wedge, (4) proximal sheet-like wedge, and (5) distal sheet-like wedge. These facies exhibit temporal and spatial organization throughout the Karachaganak seismic data. Planar clinoforms and chaotic and sheet-like wedges dominate the eastern slopes of the platform. Exponential clinoforms dominate the west. Chaotic wedges are present in the western and eastern foreslopes; they are associated with a second order turnaround from aggradation to progradation and suggest this was a critical period of margin instability.

Extensively studied outcrop exposures of carbonate foreslopes, including the Upper Devonian (Frasnian and Famennian) of Western Australia and the Lower and Upper Permian (Wolfcampian, Leonardian, and Guadalupian) of West Texas, display similar ranges of clinoform, margin, and internal geometries to those observed at Karachaganak. Application of the outcrop information provides a linkage between seismically determined stratal patterns and sediment type, as well as helps to constrain the timing and distribution of significant processes such as margin collapse, megabreccia emplacement, and bypass of grain-dominated accumulations into the basin. Integration of available subsurface data and insights from outcrop analogs ultimately enables enhanced prediction of reservoir quality, connectivity, and architecture in steep carbonate slopes, as well as other heterogeneous carbonate settings.

Seismic Geomorphologic, Core, and Outcrop Expression of an Ordovician Paleokarst System in North-Central Tarim Basin, China

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Abstract

Numerous paleokarst features in the Lower and Middle Ordovician limestone in north-central Tarim Basin, China, were revealed by integrating 3D interpretation and seismic geomorphologic imaging along with core description and outcrop analog. The paleokarst system was developed on the top and slope of a regional uplift beneath an Ordovician unconformity. Seismic evidence of karst development includes karst-tower- and sinkhole-like features on the unconformity surface and chaotic collapse reflections and bright spots derived from cave sediments. Core observation and local Ordovician outcrop provide additional support for these interpretations. The interpreted seismic travel-time map illustrates erosional topography and seismic geomorphologic patterns on top of the unconformity for fluvial channels and canyons, fluvial valleys, sinkholes, and tower karsts and hills, revealing a matured surface drainage system related to the paleokarst system. Links between surface sinkholes and upstream river initiation and between surface channel segments and subsurface collapsed paleocaves suggest that using seismic geomorphology to predict paleocave systems is possible.

Process-Based Modeling of Deep Water Depositional Systems

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Abstract

Physics-based forward numerical models have a wide variety of applications in areas such as geomorphology, stratigraphy, and geologic modeling. In this paper, the ExxonMobil process-based forward numerical models for simulating shallow and deep water depositional systems are introduced. Based on the physics of fluid flow and sediment transport, these models are capable of modeling many important natural geomorphic processes, such as channel initiation, lobe deposition, knick-point migration, channel avulsion, and formation of sedimentary waves, levees, and channel mouth bars.

A computer model was used to simulate East Breaks basin 4, which is the terminal basin of four interconnected intra-slope basins situated in the northwestern Gulf of Mexico. An interpreted surface from a high-resolution 3D seismic survey was depth converted and used as the initial basal surface for simulations. The inlet location for turbidity flow also was interpreted from the seismic and provided to the computer model. A trial and error approach was used to determine the discharge of the flow as well as the volumetric concentration and the size distribution of particles in the flow. Simulation results were then converted to synthetic seismic and compared with actual seismic from the basin. The comparisons showed that the simulated sediment body geometries and stacking patterns closely resembled those observed in the seismic data.

Simulation results show that many of the complexities observed in such systems originate from the complex interactions between the evolving topography and the flow. The evolution of these systems often follows similar and predictable pathways. A common evolution pathway consists of following steps:

1. Flow expansion at the channel mouth;
2. Scouring in front of the channel mouth;
3. Development of channel mouth bars;
4. Local ponding of the flow by the channel mouth bar;
5. Accelerated growth of levees and the formation of knick-points; and
6. Subsequent avulsion and the extension of the channel.

This pathway appears to be scale invariant which could suggest a predictable distribution of sedimentary bodies in deltas and submarine fans.

The study has demonstrated that the forward numerical model is a powerful new geologic modeling tool. Prerequisites for effective modeling include: (1) accurate restoration of basin paleotopography; (2) realistic flow characteristics, including flow discharge and sediment concentration; or (3) estimates of sediment size distribution in the flow. These data are not obtained routinely from subsurface studies, and may not be obtained directly from subsurface data. However, they may be derived through integrated analysis of seismic volumes and well data. Including such analysis in the seismic interpretation and reservoir-characterization workflow is essential for the development and application of forward numerical models as next generation earth models.

Seismic Geomorphology of a Tertiary-Aged Isolated Carbonate Platform System, Browse Basin, Northwest Shelf of Australia: The Spatial and Temporal Evolution of Carbonate Platform Environments—The Lower Section—Part I

Posamentier, Henry W.
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Abstract

Three-dimensional seismic data from the Torosa Field (Torosa 3D Survey) in the Browse Basin of the Northwest Shelf, Australia, display a series of well imaged isolated carbonate platforms that allow the documentation of platform evolution from initiation to terminal drowning. The application of seismic geomorphology allows recognition of various carbonate geomorphic elements (depositional and diagenetic) including prograding margins, slope deposits, platform interior patch reefs, and karst fabrics. A variety of techniques integrating seismic geomorphology and seismic stratigraphy have been applied to assist in visualization of these deposits. Examples of workflows and techniques including horizon slicing, optical stacking, and facies mapping, along with the integration of seismic section views (*i.e.*, stratigraphy) and plan views (*i.e.*, geomorphology) will be illustrated.

This presentation will focus on the lower part of the carbonate succession. The carbonate factory is initiated through nucleation on a subtle pre-existing structural high. Initially, the carbonate system is characterized by a platform characterized by linear margins associated with progradation marked by clinoform architecture in both directions, suggesting an isolated platform with no direct connection to the Australian continent. An initial ramp style platform gradually gives way to a platform bounded by progradational slope physiography. The platform margin is characterized by reefal buildup repeatedly crosscut by channels that connect the open ocean with the interior platform. Within the interior of the platform small patch reefs and occasional seaways are common. Several flooding events punctuate the platform evolution, with each drowning event immediately preceded by deposition of clusters of small patch reefs, less than 300m wide.

Seismic Geomorphology and Stratigraphic Evolution of a Tertiary-Aged Isolated Carbonate Platform System, Browse Basin, North West Shelf of Australia—Part II

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Abstract

Three-dimensional seismic data from the Torosa Field (Torosa 3D Survey) in the Browse basin of the North West Shelf, Australia display a series of well imaged isolated carbonate platforms that evolve from platform initiation to terminal drowning. The application of seismic geomorphology allows recognition of various carbonate geomorphic elements (depositional and diagenetic) including prograding margins, slope fan and gullied slope deposits, platform interior patch reefs, and karst fabrics. Mapping these features in successive horizon-slices and comparing the spatial changes with changes in seismic geometries (cross-sectional view) allow a more detailed understanding of platform response to relative changes in sea level and the relative complexity of the systems through time.

Platform growth initiates as a series of kilometer-scale buildups characterized by a circular to elliptical morphology (in plan view). These small-scale buildups quickly coalesce into a series of build-up complexes (2-6 km) with progradational margins. These complexes display either elliptical or rhombohedral shapes. Individual patch reefs can be observed in the platform interiors of the build-up complexes. A second phase of coalescence occurs and the build-up complexes combine into a larger platform (25 x 10 km). This large platform then backsteps and is characterized by a strongly elongate and elliptical shape. The backstepped platform progrades up to 3 km prior to final drowning and burial.

The growth of elliptical and rhombohedral buildup shapes appear to be influenced by focused currents between the platforms. A distinct windward-leeward asymmetry has not been recognized in the platforms. The rhombic platform complexes are characterized by a unique “pointed promontory” morphology that develops (perpendicular to the long dimension) as the elliptical complexes evolve into more rhombic shapes through time. Sand waves are also observed in the bottom of the interplatform seaways. The backstepped platforms display prograding seismic reflectors that terminate laterally and are confined to areas of the platform margin protected from influence of currents. Coalescence of the platforms followed the growth of small buildups in the mouths of the interplatform seaways, effectively blocking the seaways and allowing sediment to accumulate in the previously current swept passage. This dataset provides an alternative growth model for platforms strongly influenced by currents, rather than the more common model of progradation with sediment flux dominated by windward-leeward sediment transport.

Seismic Geomorphology of Outcrop-Based 3D Seismic Model of Carboniferous Mounds and Subsurface Analogues

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Abstract

Carboniferous strata in the Sacramento Mountains provide excellent exposures of size, growth style, internal architecture, and facies of carbonate mounds. Mounds occurring in the Mississippian Lake Valley and Pennsylvanian Holder formations, which are exposed in multiple canyons along the western escarpment of the Sacramento Mountains, have been mapped in the field and using GPR. Based on field data, a 3D geocellular model has been constructed. Further, these outcrop-based models are used to build 3D synthetic seismic models at various seismic frequencies. This approach allows for investigating the seismic expression of the various mound stratigraphic architecture and comparing it to subsurface analogs.

Up-dip Mississippian mounds show a clear relationship between initiation and antecedent erosional topography, whereas larger downdip mound architecture can be clearly divided into an initial aggradation phase followed by a lateral accretion phase. The Pennsylvanian mounds size and architecture are controlled by their position along the depositional profile and the hydrodynamic energy. In both Mississippian and Pennsylvanian mound systems, the relationship between muddy mound core and grainier mound-flank deposits is complex but predictable.

The 3D synthetic seismic models built from these outcrops are used to investigate which of these key architectural features are within seismic resolution and detection. The analysis of these 3D seismograms allows for optimizing the interpretation methods and work flow for best seismic attribute or interpretation techniques such as co-rendering of multiple attributes or stratal slicing.

The lessons learned from outcrop-based models are applied to subsurface seismic data from a variety of examples including Pennsylvanian isolated carbonate platforms, Cretaceous patch reefs, and Tertiary carbonate buildups.

Subsurface Identification of a Palaeozoic Carbonate System in the Barents Sea: Build-Up Distribution, Geometry and Development

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Abstract

The Norwegian Barents Sea is used as a subsurface laboratory for improving our workflows to retrieve and quantify geomorphic information from seismic data over ancient carbonate systems. Here, we present a novel volume-based seismic interpretation work flow for improved imaging of carbonate features as, for example, subtle build-up complexes and karst. Frequency decomposition followed by RGB-blending is one of the most powerful tools in this work flow for extracting highly detailed information from seismic. A number of seismic surveys in the Norwegian Barents Sea have been revisited and interpreted with this work flow, revealing information on the Upper Paleozoic carbonate systems that otherwise would have remained hidden from interpreter. The newly retrieved seismic geomorphic data is paramount for suggesting new carbonate build-up growth models for the spectacular polygonal build-ups observed on seismic as widespread build-up complexes expanding over thousands of square kilometers. Systematic quantitative shape analyses provide insights on the geometry and self-organization of the polygonal build-ups. Growth is mainly controlled by the paleo-environmental position on the platform, stable slope, or on active fault blocks, reflecting variations in available accommodation space. Two separate phases of polygonal build-up development having distinct geomorphic expression are recognized through time: (1) Subtle features from the volume-based interpretation reveal low-relief *Palaeoaplysina*—phylloid algae polygonal-elongated ridge systems formed from the warm-water carbonate factory controlling the deposition during the Gipsdalen Group. These subtle systems compete with deposition of more basinal evaporites for space on low angle ramp systems.(2) A second set of polygonal build-ups are recognized in the cooler water carbonate interval of the Bjarmeland Group. These high relief Bryozoan-*Tubiphytes* mound complexes have been recognized in previous studies, but our novel seismic geomorphic analysis allows unraveling the internal growth pattern of these spectacular complexes at a seismic scale. Starting as individual nuclei, these mounds amalgamate quickly into ridges that start to form polygonal networks. Subsequently, different cycles of aggradation followed by progradation are recognized in the build-ups. Geomorphic quantification proves that basinal settings are dominated by aggradation, whereas slope and platform settings are prone to more progradational development of these polygons.

Seismic Geomorphology of Paleokarst Systems in Paleozoic Carbonates, Norwegian Barents Sea

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Abstract

Paleokarst networks are complex, multi-scale, heterogeneous features that are commonly modified by gravitational, structural and diagenetic processes during burial. In subsurface carbonate reservoirs, paleokarst systems can be a source of significant heterogeneity and complexity. Although 3D seismic data commonly can reveal exquisite details of paleokarst systems at the level of the 'top reservoir', the beauty and use of such images is normally superficial. This is because horizon-based interpretations reveal little of the three-dimensional paleokarst network *within* the reservoir. In order to extract a more complete 3D representation of paleokarst systems, we have focused on the utilisation of volume-based methods of seismic data analysis. Specifically, a concerted effort to develop reliable methods and work flows for paleokarst detection has been made through the analysis and comparison of 6 different 3D seismic datasets imaging carbonate reservoirs. The results of one of these studies are presented here.

The work flow is illustrated using an example of extensively karst-modified Upper Paleozoic (Moscovian-Asselian age) carbonates preserved on the eastern flank of the Loppa high, Norwegian Barents Sea. Here it is estimated that some 300-500 m of uplift, erosion, and karstification of a mixed carbonate-evaporite succession occurred during circa 20 million years of subaerial exposure (*i.e.*, Roadian-Induan times). Major drainage systems can be traced across basement rocks and into and through the karstified carbonate succession. The carbonates are cut by steep km-scale canyons and penetrative sinkholes. The dataset shows a range of contrasting paleokarst features, so that some of the key seismic attributes and spectral decomposition methods used to delimit contrasting genetic elements of paleokarst systems can be illustrated. Results from the seismic data analysis have been quality-controlled against well data and horizon-based interpretations. The study reveals: (1) how horizon-based interpretations can potentially be misleading; (2) that different seismic properties/attributes are required to recognise and extract paleokarst features formed by different processes; (3) the important controls of bedrock geology and faulting/fracturing on paleokarst development; and (4) new insights as to heterogeneity within paleokarst networks.

Sequence Architecture and Seismic Geomorphology of the Northern Shelf of Trinidad and Tobago

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Abstract

Shelf deltas are by and large poorly documented in literature. The exception to this is in the Gulf of Mexico where Sutter and Berryhill (1985) developed the original models for shelf versus shelf edge deltaic deposits. Many shelf setting are characterized by more bypass than accommodation, leaving thin to absent regressive shelf deposits. Along many margins of the world, it is simply a matter of focusing accommodation space near the shelf edge that drives the preferential build up of shelf edge deltaic deposits during regression. The North Coast Marine Area is an exception to this trend. Its location along the tectonically active, transtensional/transpressional boundary of the Caribbean and South American plates creates a unique opportunity to build and thus examine these shelf deltaic deposits.

The North Coast Marine Area extends across ~7000 km^2 of the northern Trinidad and Tobago shelf in water depths between 50 to 200 meters. In 2009, the North Coast Marine Area had two exploration blocks under active oil and gas exploration with gas production from the North Coast Marine Area totaling ~1.1 TCF since 2002. All natural gas discovered to date in the North Coast Marine Area has been interpreted as biogenic although one previous worker has speculated that a minor component of thermogenic gas is also present. The North Coast Marine Area is located within a complex tectonic environment characterized by oblique strike-slip displacements between the Caribbean and South American plates at a rate of about 20 mm/yr. The main faults of the 200-km-wide plate boundary zone include: (1) the El Pilar right-lateral strike-slip fault zone to the south on the island of Trinidad and the Gulf of Paria which GPS results indicate to be largely inactive; (2) the North Coast fault zone which coincides with the southern boundary of the Tobago basement terrain and appears to be slightly active, showing down-to-the-north, Miocene to recent oblique-slip movements on the North Coast fault zone producing accommodation space for deposition of sediments along the northern shelf of Trinidad and Tobago; and (3) the Hinge Line fault zone crossing through the North Coast Marine Area. The fault systems set up localized zones of transpression and transtension that influence that accommodation and bypass of shelf sediments bound for the distal basin.

In addition, these localized areas of complex faulting and folding provide important structural traps for Pliocene and Miocene gas reservoirs in the North Coast Marine Area north of the Hinge Line fault zone. Growth sequences along the Hinge Line fault zone indicate that the fault activated during the Miocene and continues to up to the late Pleistocene (~500 k.y.) and in some areas forms active scarps on the seafloor.

A seismic stratigraphic study of the area analyzed two Pleistocene fourth-order shelf and shelf-edge stratigraphic sequences deposited over the past ~500 key in the western part of the North Coast Marine Area. New micropaleontologic data tied to a well through the two sequences B and C constrain the initial deposition of each sequence ~450 ky (Sequence B) and ~260 ky (Sequence C). The lithologic well log shows that the sequences are sand, shale, and thin limestone. Seismic interpretation allows division of sequences B and C into eight system tracts which include: (1) lowstand system tracts, (2) transgressive system tracts, (3) highstand system tracts, and (4) falling stage system tracts.

Two lowstand systems tracts in sequences B and C are characterized by delta plain deposition of the Orinoco Delta with a north-eastward terrigenous source direction coming from the western side of Trinidad, through the Gulf of Paria. The falling stage systems tract of sequence C consists of a suite of ~20 to 45-m-high, 0.1°- to 0.25°-inclined, and north-eastward-pro-

grading muddy, shelf deltaic clinoforms marking the paleo-shelf edge. Fault activity on the shelf influences accommodation in Sequence B forming accommodation "sinks" on the shelf that "thieve" sediments making their way to shelf edge locations. The results are shelf deltaic deposits that thicken landward. In contrast, faults appear to have become dormant, showing little subsidence during deposition of the overlying sequence C. These sediments appear to have aggraded in response to rising sea level.

Structural and isochron maps were made for four horizons underlying the northern shelf of Trinidad including top Mesozoic basement, top Miocene, top Pliocene, and seafloor. These maps indicated a change in terrigenous source area for the northern shelf of Trinidad: during the Miocene and early Pliocene, terrigenous sources were coming from the southeast through the Atlantic Ocean; during the mid-Pliocene to present the source area changed to the southeast through the Gulf of Paria. It is possible at the mid-Pliocene sediments became dominated by muds during highstand and falling stage forming unusually muddy clinoforms in the Pliocene to recent shelf packages.

A Subsurface Taj Mahal: Seismic Geomorphology Calibrated with Core and Log Data Provides Key Building Blocks for Modeling Tidally-Influenced Estuarine Deposits in the Gulf of Cambay, Western India

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Abstract

The present day Gulf of Cambay contains several prolific oil and gas fields in paleo-Cambay estuarine deposits. As these fields mature, there is a need for an improved understanding of their geological framework to enable secondary recovery methods to be employed to optimise recovery. Although traditional seismic interpretation is suitable for structural analysis, a more integrated approach employing multiple tools is necessary if an accurate understanding of these stratigraphically complex depositional systems is to be achieved. A geocellular model using Petrel software has been constructed for the Miocene oil reservoirs of the Lakshmi Field, Gulf of Cambay, integrating quantitative seismic geomorphologic interval analysis with well log facies interpretation, depositional and petrophysical facies from core, and observed production relationships between the eleven wells available in the field.

Studies of the modern environments in the Gulf of Cambay, analog studies of outcrop and other modern systems, and direct seismic morphologic and log analysis of the intervals of interest provided a depositional framework for populating the static stratigraphic model with seven facies. Log correlation panels based on regional flooding surfaces and mapped sequence boundaries were integrated with seismic horizon mapping and seismic geomorphologic interpretations to produce a multi-meter thickness grid of zones for Petrel modeling. The framework was constrained by engineering data and the interpreted connectivity relationships between sands.

Results of this work demonstrate that the Miocene stratigraphy in the Lakshmi Field comprises two large erosion and valley-fill cycles, with the lowermost estuarine fill comprising three parasequence sets. Each parasequences contains tidal bar, tidal channel, estuarine distributary channel, tidal flat and mud flat depositional elements. In more proximal areas, bay head delta elements are thought to be developed. The tidal flat elements show the development of two sub-elements; tidal flat channels and associated crevasse splays. Since structural closures parallel depositional dip, it is important to recognize the elements (depoforms) and their spatial relationship to post-depositional trap orientation.

Modern Carbonate Facies: Moving from Description to Quantitative Prediction

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Abstract

Recent advances in remote sensing technology and digital image analysis have been leveraged to significantly increase the level of complexity and precision that can be captured in maps of modern carbonate depositional settings. Satellite mapping efforts in a variety of modern carbonate environments have generated a spectrum of facies distribution characterizations that more accurately reflect the natural complexity of carbonate systems in terms of facies body size and shape. Predictive quantitative relationships are being harvested from this robust data set. Foremost among these is the globally observed power law scaling relationship between facies body size and frequency of occurrence. The scaling dimension, an attribute derived from the slope of the power law trend, describes the rate of change for the probability of encountering a facies body of a particular size. It also provides a robust measure for characterizing and comparing genetically distinct groups of facies. We propose here that the scaling dimension is a quantitative manifestation of the natural complexity inherent in carbonate depositional systems and can be used to test the fidelity of facies maps generated from outcrop, seismic, or other subsurface tools to natural facies patterning. For this study we compare modern carbonate facies trends observed in a series of global carbonate settings to evaluate the natural range of the scaling dimension and the sensitivity of the parameter to changing depositional controls. To demonstrate the persistence of the scaling relationship across widely varying settings, case studies from the Hawaiian Islands, Arabian Gulf, Caribbean Sea, Great Barrier Reef, the Flores Sea, and southern Indian Ocean are presented. Initial results suggest that the scaling dimension ranges between 0.6 and 1.6. Relatively higher scaling dimension values are associated with robust reef margin systems and lower values are associated with platform interior patch reef systems.

The Shape of Seismic Interpretation

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Abstract

Seismic interpreters routinely use the shape of an interpreted surface in developing prospects, in which the classic hydrocarbon trap is a ridge-shaped anticline. Carbonate buildups may appear as dome-shaped and karst collapse features as bowl-shaped. Differential compaction often results in valley shapes over shale-filled channels.

The interpretational value of a given shape is dependent on its depositional, diagenetic, and tectonic deformation context. If the channel fill is sand and the surrounding matrix shale, differential compaction can result in an incised valley appearing as a ridge, thereby providing a lithologic indicator. In flat-lying carbonates, joints will often be diagenetically altered and appear as valleys, while fracture intersections will appear as bowls. As always, the interpreter needs to be aware of the seismic data quality. In areas of limited lateral and vertical resolution, diffuse, or poorly-imaged faults may give rise to a recognizable shape anomaly. Care needs to be taken where velocity pull-up may induce deeper ridges and push-down deeper valleys on what might actually be flat structure.

Coupled with coherence, which delineates reflector edges, volumetric shape helps us rapidly recognize structural and stratigraphic style on horizontal and vertical slices. Pop-up blocks may appear as ridges bounded on both sides by low-coherence faults. Listric faults may be associated with a ridge-shaped roll-over anticline. Gas- and water-charged debris flow that can be drilling hazards may appear as high-coherence, dome shaped blocks.

Quantitative measures of reflector shape computed from uninterpreted seismic volumes are a by-product of volumetric curvature. Volumetric curvature is now well-established in the interpretation community, with work flows developed to correlate healed fracture zones to ridges in shale plays to help guide hydraulic fracture stimulation programs. More recently, advances have been made in the volumetric quantification of pinch-outs and unconformities, providing images of both the magnitude and azimuth of reflector convergence. There is no “best” attribute. Rather, one should co-render mathematically independent attributes that are coupled through the underlying geology.

I will illustrate these concepts through application to land data volumes from North America.

Mapping Sediment-Dispersal Characteristics from the Shahejie-1 to Minghuazhen Sequences Using Seismic Sedimentology: Example from Qinan Sag, Huanghua Depression, China

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Abstract

A seismic-sedimentologic study was performed to map sediment-dispersal characteristics from the Shahejie-1 to Minghuazhen sequences in Qinan sag, Huanghua depression, China. Guided by third-order sequence-stratigraphic correlations from seismic and wireline-log data, we prepared stratal slices from a three-dimensional seismic volume to reveal high-resolution (10-m levels) sediment dispersal characteristics in a relative geologic-time domain. The strata from the Shahejie-1 to Minghuazhen sequences in Qinan sag can be divided into two second-order sequences and 10 third-order sequences. These sequences underwent a structural evolution history from stable rift faulting, to declining rift faulting, to depression with normal subsidence rate, to depression with accelerated subsidence rate. Many factors related to the structural evolution history controlled the sediment-dispersal characteristics, such as type of basin, dynamic mechanism, faulting activity, subsidence rate, presence of paleohighs, and others. Stratal slices depicted that the depositional evolution of these sequences was from braided-delta front, to delta front, to braided river, and finally to meandering river system.

Fluvial Reservoir Analogues in the Malay Basin: Analysis of Shallow 3D Seismic Data of Pleistocene Rivers on the Sunda Shelf

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Abstract

This study focuses on the analysis of Pliocene fluvial depositional systems based on the shallow part (seabed to about 500 m) of a large (>10,000 km^2), mega-merge 3D seismic dataset from the Malay Basin, Southeast Asia. The results of a detailed 3D seismic facies analysis, locally calibrated with high-resolution site survey data, will be presented. The Pliocene interval is up to approximately 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 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 (approximately 18 km wide and up to 90 m deep), which formed an axial drainage system along the length of the Malay Basin during the latest Pleistocene, when the whole Sunda Shelf was exposed. In other intervals, the coastal plain is 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.

Quantitative Seismic Geomorphology Applied to Heterogeneous Sediment Distribution in a Point-Bar Setting, Example from the Fluvio-Estuarine McMurray Formation, Northeast Alberta, Canada

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Abstract

Quantitative seismic geomorphology adds new insight to our knowledge of subsurface reservoirs. By using empirical equations, seismically derived measurements of geobody shapes and morphological evolutions, it is possible to quantify hydraulic parameters at the time of deposition. This methodology can lead to a three-dimensional characterization of heterogeneous architectures and facies distributions, which also suggest depositional environments.

In the McMurray Formation, fine-scale heterogeneity in facies distribution in point-bar depositional settings has proved to be of paramount significance, particularly for hydrocarbon extraction using Steam Assisted Gravity Drainage. Our study area is a point-bar in the Surmont lease in the Athabasca heavy oil province (Alberta, Canada) and presents the typical architecture of a point-bar interpreted as having developed in a fluvio-estuarine setting. The evolution of the point-bar through time leads to a complex arrangement of facies and associated shaly heterogeneities.

Our quantitative seismic geomorphology analysis is based on a 3D survey over about 52 km², with data from more than 32 wells drilled at regular intervals within the studied point-bar. The parameters extracted for each point-bar accretion bed include channel width, depth, width:depth, and paleocurrent directions. Compared with other published datasets, the measured channel morphological characteristics do not appear to be a discriminating factor of the depositional setting; however, changes in these parameters over time and space allow the dynamic evolution of the point-bar to be quantified, and thus, the heterogeneous sediment distribution within the point-bar to be modeled. Morphological measurements are used to quantify hydraulic parameters using empirical equations. The results indicate that hydraulic parameters coupled with facies analysis imply that both tidal and fluvial processes lead to complex point-bar morphology. The comparison between hydraulic parameters and facies proportions extracted from wells allows for production of linear regressions, which help model spatial heterogeneity as a function of measured point-bar morphology. These results can then be integrated into reservoir models in order to optimize heterogeneity distributions and proportions in point bar deposits.

Interpreting the Rift Stratigraphy and Petroleum Systems Elements of the West Natuna Basin Using 3D Seismic Geomorphology

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Abstract

Rift-related tectonics control the deep stratigraphy and many of the petroleum systems in the offshore West Natuna Basin, Indonesia. Most production comes from late synrift reservoirs, and as a result the middle and early synrift are under-explored. Also, the lack of deep well penetrations limits our understanding of the nature and distribution of hydrocarbon systems elements. In this study we show that source rock and reservoir potential can be assessed using 3D seismic geomorphic facies analysis. Geomorphic facies character and stacking suggest three stages of rift development. First, alluvial fans and red beds filled small, isolated half-grabens. As faults began to merge, subsidence increased, and deep lakes were established. Lakes slowly filled and the upper synrift is dominated by fluvial deposits. From this analysis we believe the best remaining exploration targets in the area of interest are deltaic reservoirs in the lower middle synrift.

Sand Distribution along Shelf-Edge Deltaic Systems: A Case Study from Eastern Offshore Trinidad

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Abstract

The study area is situated along the obliquely converging boundary of the Caribbean and South American plates in eastern offshore Trinidad. Major structural elements in the shelf break and deep-water slope regions include growth and counter-regional faults to the south and large transpressional faults to the north.

Well logs and biostratigraphic data were analyzed for 24 wells in the study area to refine previous depositional environment interpretations. Transgressive and regressive cycles were interpreted on the basis of well log patterns and depositional facies shifts. Six T/R cycles were interpreted within the Pliocene to Recent stratigraphic succession. Shelf-edge trajectories were also mapped for each of the six T/R cycles on the basis of earlier stratigraphic correlations. Net-to-gross (NTG) ratios were calculated for each component of the T/R cycles and plotted against total thicknesses and net-sand values. In addition, NTG trends were mapped for each interval and analyzed on the basis of their proximity to the corresponding shelf edge.

Mapping of shelf-edge trajectories (SETs) revealed that (1) SETs migrate northeasterly across the Columbus basin through time and (2) shelf-edge orientations parallel the strike of growth faults in the south but deflect to the northeast near the Darien ridge, indicating strong, underlying structural control. NTG plots and maps also revealed that (1) for transgressive units, NTG values never exceed 60%, and they are inversely proportional to total thickness; (2) for regressive cycles, NTG values are highly variable, ranging from 35% to 90%; (3) NTG values increase as the shelf break is approached; and (4) distribution of NTG ratios is also controlled by accommodation space created by local structures.

A Quantitative Paleogeomorphic Study of the Fluvio-Deltaic Reservoirs in the Atoka Interval, Fort Worth Basin, Texas, U.S.A.

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Abstract

The Atoka Group (Lower-Middle Pennsylvanian) of the Fort Worth Basin (FWB) forms a significant (~2–3 Tcf), and as yet underexploited, domestic gas resource that is often considered a secondary target for operators drilling the deeper Barnett Shale. Although thousands of wells penetrate the Atoka in the Fort Worth Basin, the origin and character of this unit are still debated. Current models for its deposition range from wave-, to river-dominated, to fan deltas.

A 3-D survey covering 68 km^2 of the Fort Worth Basin has been integrated with wireline logs from 226 wells and core from 3 wells for detailed analysis of the Atoka. Well log mapping reveals that the Atoka can be subdivided into 12 parasequences that stack to form: (A) a lower, regressive; (B) a middle transgressive; and (C) an upper, highstand parasequence set. Seven facies are identified in core, and include channel fill, proximal delta front, delta-plain, fluvio-estuarine, distal delta front, prodelta, and shelf carbonate facies. They are tied to log signatures as a template for interpreting facies using log motifs across the study area. Limited resolution of channelized reservoir elements in seismic necessitates implementing a process for defining channel dimensions using point bar measurements from well logs. Quantitative analysis of channel dimensions in cross-section has been done and results compared to sparse morphometric data observed in seismic. Results indicate that channel widths vary from 34 to 456 m. Channel sinuosities range from 1.09 to 1.32. Calculations of flow characteristics and channel slopes suggest that slope changed over time decreasing from lower to upper Atoka as the basin filled. A review and comparison of modern and ancient analogs to Atoka sediments support the interpretation of a river-dominated delta system. On the basis of the lack of mixed marine/nonmarine influence, lack of mixed grain sizes and distance from the highland sources, the Atoka is not believed to represent a succession of fan delta deposits. Gamma-ray-log motifs, calculated flow characteristics, and channel morphologies suggest the Atoka to represent a simple river-dominated delta system.

Geomorphology and Remote Physical Properties of Late Quaternary Slide Structures using Decimetre-Resolution 3D Seismic Volumes: Insights for Deep Water Geohazard Assessment

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Abstract

Traditional exploration methods, involving a combination of two-dimensional seismic profiles with cores and/or swath bathymetry/side-scan sonar, do not adequately sample all three spatial dimensions for true morphological mapping of submarine mass movement deposits. It is only with the acquisition of three-dimensional (3D) seismic volumes that the complex 3D nature of these features can be correctly imaged. Over the last 5-10 years, the interpretation of industry-scale 3D seismic volumes from numerous continental shelf locations has allowed effective mapping of the deposit morphology. Features such as head scarps, side walls, extensional/compressional ridges, striations on the basal surface, translated blocks, and preservation/deformation of internal reflectors have been shown to constrain the direction and method of material transport. Here we demonstrate the application of these techniques to the shallow-water environment using decimeter-resolution 3D seismic volumes, with case studies from Trondheimsfjorden (Norway) and Lake Windermere (UK Lake District). Through the mapping of top/base reflector morphologies, internal structure, translated blocks, and head scarps/side walls we demonstrate the same techniques can be used to differentiate flow mechanics (coherent slide blocks, slumped material, debris flows, and a mass flow) and quantify direction of motion at this radically different scale.

Seismic Morphology of Pleistocene Turbidites from Southeast Nigeria: Applications to Ancient Deposits Modeling

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Abstract

The shallow part of seismic deep offshore of Nigeria (sea bottom to Pliocene) is generally screened to appraise shallow hazards which could appear during drilling or on a geotechnical point of view. Also, thanks to the very good quality of the 3D high resolution seismic, these time sections are also studied with a morphological objective and reveal geological treasures as well on the level of turbidite architecture features, as on the deposit-remobilization processes.

This quick look study was performed on an area located on the eastern part of the Niger delta–Eastern Lobe (Fig. 1). The objectives were multiple:

1. To perform an inventory of the different turbidite systems in order to understand the stratigraphic link and the deposit process,
2. To provide sub-surface analogues in terms of morphology, size, and seismic response. These analogs are one of the tools currently used for exploration, appraisal, and also modeling. This approach is complementary with outcrop analogs.
3. To evaluate the seismic artifacts generated by the shallow series that could affect the visibility of the seismic in the reservoir objectives.

Seismic Geomorphology of Submarine Slopes: Channel-Levee Complexes versus Slope Valleys and Canyons, Pleistocene, East Kalimantan, Indonesia

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Abstract

Three dimensional seismic data show the geomorphology of deep-water slopes and allow interpretation of depositional systems in offshore East Kalimantan, Indonesia. In this area, channel-levee complexes developed on the slope where deltaic sediment supply was great, and erosional slope valleys/canyons developed where siliciclastic input was relatively small. The Pleistocene slope is dominated by channel-levee complexes immediately basinward of the Mahakam delta. Channels are straight and deep on the upper slope and can be traced upslope to a shelf margin associated with the paleo-Mahakam delta. Channel-levee complexes become sinuous downslope. They have migrated, aggraded, and avulsed on the middle and lower slope; the younger complexes have avoided bathymetric highs created by previous channel-levee complexes. Levees decrease in thickness down slope from 200 ms (170 m) on the upper slope to 80 ms (70 m) on the lower slope. Relief between channels and levees is much less on the lower slope (20 ms, 17 m) than the upper slope (100 ms, 85 m).

Siliciclastic sediment supply is minimal north of the Mahakam delta, and the slope is dominated by valleys and canyons. In this northern area, 3D seismic data indicate that late Pleistocene rivers and deltas were generally not present on the outer shelf, including upslope from slope valleys. Only one lowstand delta was present on the northern shelf margin during the upper Pleistocene, and sediments from that lowstand delta filled a pre-existing slope valley/canyon complex and formed a basin floor fan. Except for that basin-floor fan, strata on the basin floor show no evidence of sand-rich channels or fans, but contain broad areas with chaotic reflectors interpreted as mass-transport complexes. This suggests that slope valleys and canyons formed by mass failures on the slope, not by erosion associated with turbidite sands from rivers or deltas. In summary, large, relatively steady input of sediment from the Pleistocene paleo-Mahakam delta apparently prevented deep slope valleys and canyons from developing basinward of the delta. In contrast, deep valleys and canyons developed on slopes that were relatively "starved" for siliciclastic sediment.

Salt Tectonic Controls on the Location, Geometry and Heterogeneity of Slope Channel Complexes

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Abstract

Deformation above mobile salt along continental margins results in a complex array of structures that have a profound effect on sea-floor geomorphology and create a slope characterised by a 3D array of salt-cored highs and intervening sub-basins. We present examples of the various ways the growth of salt-related fold and fault arrays controls submarine channel complexes at local to regional scales using standard attributes, spectral decomposition and RGB blending of 3D seismic datasets from Tertiary passive margins.

Sediment transport pathways commonly divert around salt-cored highs and become fixed by early-formed structures high on the slope resulting in long-lived, major sediment (channel complex) fairways that are 'pinned.' During early stages of fold growth channels tend to be simple and isolated and are orientated perpendicular to the regional slope. However, as folds grow and interact, the channel belts increase in sinuosity and their cross-sectional and long-profile geometry becomes progressively more variable and complex as slope roughness increases. As a result, channel orientations become increasingly variable with local deviations parallel to fold axes and channel complex sinuosity mimicking the spacing of the main salt-cored structures. Avulsion nodes, channel complex depth and width, levee development, and the internal architecture of component depositional elements within channel complexes all show systematic variation with respect to structural location. Amplification of salt-cored folds and growth of diapirs also leads to local oversteepening and slope failure resulting in development of mass transport complexes that may dam entry or exit points between mini-basin depocentres.

Integrated Seismic Stratigraphy and Seismic Geomorphology; Workflows and Techniques

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Abstract

It has long been recognized that significant geologic information can be derived from seismic data. Initially, these observations were limited to interpretations of 2D seismic data, however, within the last 25 years such observations have been extended to 3D seismic volumes. The workflow that yields the greatest geologic insights involves the integration of seismic stratigraphy and seismic geomorphology. The comprehensive iteration of these two disciplines yields insights as to what depositional elements are present and consequently lead to a prediction of lithology distribution. Stratigraphic insights are based on vertical seismic section views through the interpretation of stratigraphic architecture based on identification of reflection terminations, variations in seismic reflection amplitude and continuity, seismic reflection geometries such as mounding, clinoform patterns, and other patterns indicative of depositional settings. This two-dimensional approach, commonly referred to as *seismic stratigraphy*, was developed and first applied by Vail *et al*. (1977) and Mitchum *et al*. (1977). Although very useful, the ability to identify stratigraphic features in the vertical view is limited by seismic resolution, which is approximately equivalent to ¼ the seismic wavelength. Interpretation in plan view, made possible by the advent of 3D seismic data, is commonly referred to as *seismic geomorphology*. This approach, introduced by Posamentier (2000, 2004), identification of discrete depositional elements such as channels, reefs, sediment waves, and other geomorphic features can indicate depositional setting and in turn afford predictions regarding lithology distribution. The ability to identify stratigraphic features in plan view is limited by seismic detectability, yielding images as much as an order of magnitude finer scale than images in vertical view which, as previously stated are limited by seismic resolution.

The recognition of geologically significant patterns in both plan view and in section view is key to successful application of seismic stratigraphy and seismic geomorphology. Workflows necessarily involve an iterative process of integrating section view derived interpretations—*i.e.*, stratigraphy—with plan view derived interpretations—*i.e.*, geomorphology. In order to successfully do this, interpreters must be familiar with a broad range of meaningful geologic patterns in both section as well as plan view. In other words, interpreters must be familiar with both the stratigraphic as well as geomorphic expression of a variety of depositional systems. For example, Figure 1 illustrates a mass transport deposit in both section and plan view. This figure shows that patterns observed from both perspectives are useful in confirming the origin and hence the lithologic distribution within the depositional feature observed.

In addition to conventional section and plan view interpretation involving vertical and horizontal slices, specific workflows can be employed that can enhance and accelerate the interpretation process. Horizon slicing, whereby a horizon close to a feature of interest is interpreted and subsequently used to flatten and "slice" the seismic volume, is a critical interpretation step. Images extracted from flattened volumes commonly show more complete paleo-geomorphology. Flattened volumes can also be used to create optical stacks. Optical stacks constitute subvolumes that fully contain features of interest and are then rendered transparent, except for amplitudes of extreme value that are left opaque. When viewed from above in this manner, optical stacks can in some instances reveal more completely imaged discrete depositional elements than simple slices can (Fig. 2).

A variation on horizon slicing, referred to as proportional slicing, is critical where reflections converge or diverge. This reflection geometry can occur within settings as diverse as uniformly-subsiding mini-basins or within carbonate reef complexes (Fig. 3). The results of proportional slicing provide a better succession of plan view images than more conventional horizon slices.

Another workflow that has value is creative datuming, whereby a datum for flattening purposes is created based on geological principles rather than on mappable horizons. This datuming can be achieved in multiple ways (Fig. 4). When no single horizon can be mapped extensively, several horizons at different levels, close to one another can be mapped, shifted, and then merged, so as to form a single horizon, which then can be used for flattening (Fig. 4A). When mapping a valley or channel where no single horizon is available for flattening, an artificial horizon can be mapped by creating a surface on a series of strike transects that just touches the base of the valley (Fig. 4B). This surface would not follow any single reflection but rather would be mapped on these transects to be close to parallel to the inferred reflection trend. Subsequently, this surface, mapped only on widely spaced transects, would then be interpolated so as to form a complete datum, which could then be used for horizon slicing. Another example of creative datuming would be in the case of a prograding delta (Fig. 4C), wherein the seismic reflection that constitutes the delta top is mapped to the seaward limit of deltaic progradation. Beyond this point the base of the prograding stratigraphic unit becomes the datum (Fig. 4C).

When interpreting features such as channels, interpreting with a small brush autopicker can be effectively employed. In the case of channels, this approach can be a useful way to leverage geologic insights by “chasing” a channel with the brush in the direction that the channel appears to be trending (Fig. 5). This process of “channel chasing” can yield quicker and more compelling results than simply slicing or autopicking a regional horizon.

As the discipline of seismic geomorphology evolves, new and creative workflows will continue to be developed. However, it is still of great importance to note that it is not seismic geomorphology or seismic stratigraphy alone, which should be employed, but rather a comprehensive and iterative application of these two disciplines, which will yield the most significant insights.

Origin of Lower Pliocene Remobilized Deepwater Mounded Deposits, Yafo Formation, Levant Basin, Southeastern Mediterranean: A Head-Scratching, Group Exercise to Explain Mounded Deposits

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Abstract

The Levant basin is located in the southeastern portion of Mediterranean Sea (Fig. 1). The basin is bordered by the African plate to the south, the Sinai plate to the south and east, and the Eurasian plate to the north (Fig. 1). Although there has been significant petroleum exploration to the west in the Nile Delta region (Fig. 1), there has been substantially less success in the Levant basin between the late 1960 to late 1990's (Gardosh et al., 2008).

Using new exploration concepts, several discoveries have made in lower Pliocene sands in the eastern portion of the basin. The Noa, Mari B, and Gaza Marine fields are estimated to contain reserves of approximately of 3 TCF of gas (Fig. 2). However, Mari B is the only currently producing field (Gardosh et al., 2008). The Noa and Mari B discoveries produce in several unique lower Pliocene Yafo Sand member stratigraphic features (Fig. 3) (Frey-Martinez et. al., 2007). What makes these discoveries unusual is that the reservoir intervals have a dramatic mounded geometry that at the time of formation had prominent bathymetric expression. These Yafo Sand member features are interpreted to have been deformed due to the remobilization of finer grained clastics and subsequent upward injection (Fig. 3) (Frey-Martinez et al., 2007). The remobilized sediment is sourced from turbidite sands in the underlying Oligo-Miocene Afiq submarine canyon (Fig. 3) (Frey-Martinez *et al.*, 2005).

This paper reviews the Andromeda Mound Complex, a lower Pliocene mounded feature northwest of the Mari B and other discoveries. Its formation history is different than the other lower Pliocene mounds, and presents many challenges in interpreting its evolution.

Paleogeomorphologic Bathymetry in Isolated Mini-Basin Development as an Indication of Tectonic State

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Abstract

Recent publications (Hudec, 2006; Hudec *et al.*, 2008) have renewed discussion of mini-basin formation processes and resultant deposits in basins overlying mobile substrate margins (including salt, shale, and crustal subsidence) around the world. Mini-basin provinces produce enormous volumes of hydrocarbons, besides forming supramobile substrate topography that controls how sediment volumes are transferred from shelf edges to ultimate sinks in the deep ocean. Increasing exploration and production in ever-deepening regions of the world's oceans warrant a revisit to many of these concepts of accommodation development, sediment generation, sediment movement, and ultimate geometry and distribution of resulting deposits.

The objective of this study is to utilize an extensive 3D seismic data volume from the Safi Haute Mer (SHM) permit area, offshore Morocco to examine the Cretaceous through Tertiary fill of an isolated mini-basin and to investigate the effect of paleogeomorphologic bathymetry as an indication of tectonic state within the margin. Our hypothesis is that mini-basins change their fill architecture and composition in response to changes in slope, bathymetry, bottom topography, sediment sources, and structural stability. Therefore, in basins undergoing deformation, such as along tectonically active margins, under conditions of rafting or in shelf-distal locations, systematic changes in these variables should be reflected in geometry and morphology of the fill making up basin strata. Seismic attribute analysis is used to investigate the change in character of the fill through time, and the influence of regional structural features developed during the evolution of the Moroccan continental slope is combined with our observations to develop a model for the mini-basin's evolution.

A methodology is proposed to reconstruct the tectonic evolution of the mini-basin by implementing observations from geomorphological and structural analysis using 3D seismic data. Results from this distal slope mini-basin show that the evolutionary history can be described in four phases of structural development, the latter three of which are linked to four distinct phases of sedimentary fill. Observations noted from each stage of the analytical process are compared and contrasted to existing models of mini-basin development to evaluate their validity and application in a distal, sediment-starved setting such as the lower slope of the Morocco continental margin.

Seismic Architecture and Morphology of Mesozoic-Age Sediment Waves, Offshore Morocco, Northwest Africa

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Abstract

The lower continental slope of Morocco's west coast has three varying morphologies of buried deep-water sediment waves. Detailed mapping of a 1,064 km^2 seismic survey acquired in the Safi Haute Mer seismic block reveals numerous Jurassic- and Cretaceous-age features that range from small, <12 m thick amplitude anomalies to 130 m high migrating waves. Early proto-Atlantic deposition in Safi Haute Mer initiated in the Triassic with syn-rift accumulation in basement half-grabens basinward of the modern Moroccan salt front. Sedimentation continued through the Mesozoic with the deposition of turbidites, progradation of clinoforms, and culminating in multiple Late Cretaceous regionally expansive mass-transport complexes (>20,000 km^2). Tertiary stratigraphy consists of multiple thin, pelagic drapes and unconformities. The complex history of sedimentation and tectonics gave rise to three styles of sediment waves found within the study area. These three types are the (1) type J1, small poorly imaged, Jurassic age, locally generated wave forms that have crestal lengths of up to 12 km and wave lengths less than 1 km with little or no vertical expression; (2) type K1 are Early Aptian constructional sediment waves (~130 m thick) built by contour currents that moved along-slope adjacent to sea-floor highs produced by shallow buried salt; and (3) type K2, Late Albian and Early Cenomanian sediment waves built by along-slope currents on a relatively stable slope showing updip migration. The type K2 sediment wave field exhibits wave heights of 40 m and wavelengths of 1 km, and is continuous over the entire study area.

Controls on and Expressions of Submarine Fan Genesis Within a High Accommodation Margin Setting, Santos Basin, Brazil—A High-Resolution Seismic-Stratigraphic and -Geomorphic Case Study

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Abstract

High-resolution seismic stratigraphic and geomorphic analysis reveals the evolution of a shelf to intraslope basin on the Santos Basin continental margin, offshore Brazil. Within a late Cretaceous framework of high confidence 3D-seismic-stratigraphic correlations, exceptional quality seismic-geomorphic beach ridge-, canyon-, channel- and lobe- elements are analyzed with particular focus on their temporal and spatial relations. Shallow and deep marine, partly gravity-driven processes associated with depositional outbuilding of the continental margin generate local gradients and sea-floor topography that determine cyclic changes in aggradational and degradational patterns. This is manifested in the proportion, distribution, size, shape and orientation of shoreline, shelf edge, canyon, slope-channel and intraslope submarine fan depositional elements. The evolution of the continental margin is a response to the dynamic changes in sediment delivery, shelf accommodation, local slope gradient, seafloor topography, and mobile salt substrate geometry. The study documents significant sandy submarine fan deposition development along an over-all high accommodation margin, typically associated with higher frequency episodes of relatively low shelf accommodation expressed as normal progradation, flat shoreline trajectory, and narrow (<10km width) shelf development. Genetically connected, continuous sediment fairways develop and span from beach-ridge/shore-face systems via combined shelf/slope positioned canyon to intraslope basin submarine fan systems. Longshore drift and/or storm re-suspension processes is inferred to deliver sandy sediment to shelf-portion of submarine canyon. Farther down-dip transport and deposition is driven by gravity flows. The observed (wide) longitudinal to lateral aspect ratio (~10 km x ~20 km) is explained as a direct response to the salt-influenced intraslope basin topography, as well as significant lateral-directed drive to fan growth relative to basin-restricted longitudinal (downdip) growth. Negative shelf accommodation manifested by subaerially incised valley(s) features are not observed and is thus not a necessity for submarine fan development.

Quantitative Seismic Geomorphology of a Confined Channel Complex, Southern Atwater Fold Belt, Gulf of Mexico, U.S.A.

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Abstract

The front of any salt margin is an important geomorphologic area for understanding the manner in which sediments move from the proximal mini-basin regions of sedimentation to the distal unconfined basin floor regions of sedimentation. The link between tectonics and the development of major geomorphologic features of sediment bypass is an important but poorly understood process across this boundary. The purpose of this study has been to map and quantify the morphology, sedimentology, and architecture of a large Plio-Pleistocene-age deep-water valley outboard of the Poseidon mini-basin, near the salt front along the southwestern edge of the Atwater fold belt in the deep water Gulf of Mexico. Objectives were to not only better document the architecture of these large confined valley reservoir systems but also, due to their importance for moving sediments from the salt province to the basin floor province, to understand their timing and relationship to the salt movements.

The data available for this study includes ~2200 km sq. of 3D seismic data, along with information from several wells. Wireline logs show that the Tertiary deposits outboard of the Sigsbee Salt Escarpment to be several hundred feet thick, sharp-based, dominantly coarse-grained (sandy) but fining up cycles interpreted to be sandy basin floor fans, mass transport complexes and leveed channels developed in a confined setting within deep water "valleys."

The largest valley in this deep-water system formed in five main stages: initiating from narrow channel incisions, widening through lateral incision and sidewall slumping, straightening, and finally flooding and infilling. This valley system is ~20,000 feet across and ~ 1,400 feet deep, and has what look like well-developed master levees ranging from 700 to 1300 feet at their thickest point extending ~19000 feet away from the channel. This system is underlain by a ~700 foot thick mass transport complex and overlain by younger, low sinuosity leveed channel systems. Both of these systems appear to have been sourced by large submarine drainages, originating from a shelf edge sediment source system to feed the rugose slope with deep-water channel pathways uninhibited by salt wall inflation at the time of valley deposition.

Major phases of salt thrusting along the southern edge of the Atwater were contemporaneous with the formation of this large, through-going valley system. These valleys appear to be associated with a period of sheet thickening and development of monoclinal basinward dip related to rafted mini-basin docking.

Internally, these fills are composed of multiple, medial, and lateral accretionary wedges, which only fill a portion of the valley at any one time. Well log signatures show evidence for armored clay drapes along the valley margins. Seismically, the armored lateral accretionary packages appear to "flattening" toward the distal end of the valley, which runs off the seismic volume to the south. This flattening accretionary dip might signal proximity to the fan terminus.

Development and Seismic Geomorphology of a Miocene Slope Channel Megasystem, Offshore Taranaki Basin, New Zealand

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Abstract

Through the Neogene to the present day, large marine channels have transported sediment from uplifting and eroding mountains into deep-water environments around New Zealand. We reconstruct the development of one such Miocene slope channel network in Taranaki Basin, using a basin-wide grid of 2D and 3D seismic reflection data. The system evolved within a regressive depositional succession in a retroarc foreland setting controlled by convergence across the Australian-Pacific plate boundary.

We visualize the detailed evolution of the depositional system on 3D data via simple single and multitrace attributes in the central basin, whilst its regional character is depicted by integrating single and meta-attribute 2D data. Well data constrain the inferred ages and guide the lithological interpretation of morphologic features. Discrimination of fan and channel morphometrics provides insights into the distribution and migration of depositional elements and sandstone reservoir facies throughout the system.

Initial uplift of the hinterland is evidenced on seismic by the onset of shelf progradation and local fault activity in southeastern Taranaki Basin. Changing azimuths and depositional flow directions of successive channel generations outline the foreland basin morphology, subsidence loci, regional base-level fluctuations, local fault activity, intra- and extra-basinal uplift, and generally northwest shelf/slope progradation. With subsequent increase of detrital supply, localized channels and fans developed into a vast sinuous and anastamosing channel network that transported sediment westwards into the head of the New Caledonia Trough. The fully-fledged channel mega-system can be traced over a distance of >500 km, comparable in size to the modern Hikurangi, Bounty, and Hokitika/Cook channels that surround the New Zealand continent.

Seismic Geomorphologic History of Mini-Basin Filling, Mad Dog Area, Gulf of Mexico, U.S.A.

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Abstract

Minibasins located in the distal regions of the Sigsbee salt sheet in the Gulf of Mexico have fill character that is different than fills found in more proximal minibasins. Fill and spill models, popular as template for understanding the more eustatic influenced processes of sedimentation in basins located proximal to the shelf edge are inadequate for explaining fills in basins located quite distal to the shelf edge. In distal areas, tectonics control accommodation, gravity deposits dominate the stratigraphic record and deep water process sedimentology is strongly influenced by sea floor bathymetry. The Poseidon minibasin located along the southern edge of the Atwater Fold Belt in the central Gulf of Mexico lies at the very edge of the modern salt sheet. It contains a complex three phase fill. The first phase shows interplay of ponded and wedged fill types. During this time, surrounding topography interacts with flows of varying height and lithology, to result in either deposition of flow material or bypass and partial stripping of coarse components from flows. This is followed by a period of major bypass characterized by two periods of valley incision and complex fill. These valleys extend well out in front of the modern salt front, which post-dates emplacement of these valleys. The final phase of fill, occurring over the past ~800ky is marked by flat lying, draping pelagic sediments, interspersed with episodes of mass wasting. Although eustacy may play an important role as a first order control on the type and amount of sediment coming into the basin, tectonics supersede as a control on the geometry and nature of fill within individual minibasins.

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