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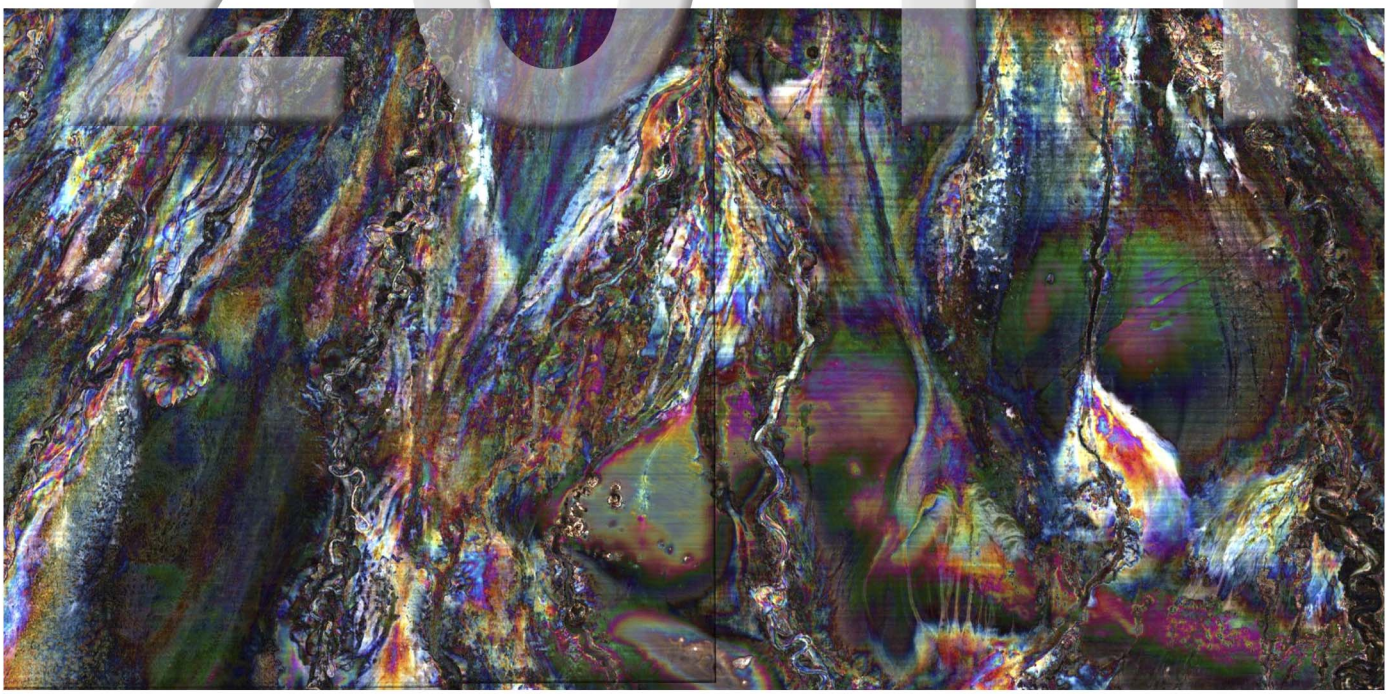

31st Annual GCSSEPM Foundation Bob F. Perkins Research Conference

December 4-7, 2011, Houston, Texas

Attributes: New Views on Seismic Imaging— Their Use in Exploration and Production

Editors: Kurt J. Marfurt, Dengliang Gao, Art Barnes, Satinder Chopra, Antonio Corrao, Bruce Hart, Huw James, Jory Pacht, and Norman C. Rosen

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Program and Abstracts

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Attributes: New Views on Seismic Imaging—Their Use in Exploration and Production

31st Annual Gulf Coast Section SEPM Foundation Bob F. Perkins Research Conference

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Hilton Houston North
Houston, Texas
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Edited by

Kurt J. Marfurt, Dengliang Gao, Art Barnes,
Satinder Chopra, Antonio Corrao,
Bruce Hart, Huw James, Jory Pacht,
and Norman C. Rosen

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Statoil and Hess Corporation.

Foreword

Seismic data have often played a significant, and sometimes dominant role in previous Bob F. Perkins conferences, such as in last year's conference on seismic geomorphology. Nevertheless, the last conference to address the role of seismic attributes was held in 1996. The advancement in algorithm development, 3D multiattribute visualization, interpretation workflows, and more quantitative reservoir characterization during this 15-year interval has been astounding. This year's conference, "Attributes: New Views on Seismic Imaging—Their Use in Exploration and Production," gathers some of the world's foremost attribute software developers, service providers, and oil-company practitioners under one roof at the same time.

The Perkins conference provides a unique opportunity for such an attribute forum. It is small enough, with only one session at a time, to provide a great deal of interaction, particularly at meals and breaks. Yet it is large enough to allow the participation and input of the greater seismic interpretation community. You will find the quality and technical content of the papers provide the feel of a "technical workshop," whereby experts can compare and contrast state-of-the-art innovations with their expert peer group. However, we have instructed the authors that the intended GCSSEPM audience will be primarily practicing geologists and geophysicists, and to pitch their papers and presentations appropriately. Thus, the tone of the conference will be more tutorial, with the expected outcome much like a short-course for the conference participants at large, with the associated "take-aways" and "best practices" that go with such venues.

The organization of the 34 papers mimics the E&P progression of attribute use from early qualitative scoping activities to later quantitative reserve assessment and infill-drilling decisions. The conference begins on Monday morning with (1) data conditioning/case studies, continues through (2) visualization and feature extraction, (3) interpretation workflows, (4) clustering and classification, (5) fault and fracture analysis, (6) seismic inversion and AVO, and ends on Wednesday with (7) reservoir characterization. As attribute practitioner, we the conference co-convenors are truly impressed with the innovation, breath, and quality of the authors' contributions.

We thank our editorial team of Art Barnes, Satinder Chopra, Antonio Corrao, Bruce Hart, Huw James, and Jory Pacht, for providing two careful peer reviews and timely feedback for each of the contributed papers. Most of all we thank Norm Rosen, who to us is the face of the GCSSEPM Perkins conference for his tireless encouragement, prodding, and yes, worrying, to see this product come to fruition.

Kurt Marfurt and Dengliang Gao,
Program Co-convenors

Attributes: New Views on Seismic Imaging—Their Use in Exploration and Production

31st Annual Gulf Coast Section SEPM Foundation Bob F. Perkins Research Conference

Program

Sunday, December 4

4:00–6:00 p.m. Registration and Refreshments (Donatello Foyer/Ballroom)

Monday, December 5

7:00 a.m. **Continuous Registration and hot Continental Breakfast (Donatello Foyer)**

7:45 a.m. Welcome Remarks, Tony D'Agostino (Chair of the Board of Trustees, GCSSEPM Foundation) (Donatello Foyer)

7:55 a.m. Introduction to the Conference, Kurt Marfurt and Dengliang Gao (Conference Co-Convenors)

Session 1

8:00 a.m. **Introduction—Bruce Hart, Huw James**

10:05 a.m. Coffee Break (Donatello Foyer)

Tuesday, December 6

Session 4

Wednesday, December 7

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Cover Image

The cover image chosen for this year's conference is Figure 3A from Braccini and Adeyemi: "Integrating Seismic Attributes for Geo-Modeling Purposes: Nigeria Deep-Water Turbidite Environment Case Study"

Footprint Suppression Applied to Legacy Seismic Data Volumes

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Abstract

Acquisition footprint often poses a major problem for 3D seismic data interpretation. Ideally, footprint from acquisition is handled at the processing shop through more careful attention to trace balancing statics, noise reduction, and velocity analysis (Hill *et al.,* 1999; Gülünay, 2000). Such reprocessing is not feasible on many legacy data volumes where the prestack data cannot be found or no longer exists. Seismic attributes often provide an effective means of delineating subtle geological features of interest such as channels, small faults, and fractures but can also enhance acquisition footprint. For this reason attributes can be used to both design and evaluate the effectiveness of alternative footprint suppression workflows.

In this work we review, apply, and evaluate the three most popular footprint suppression workflows: structure-oriented filtering, k_x-k_y filtering, and limited data reconstruction using singular value decomposition. We both characterize acquisition footprint and evaluate its suppression by its attribute response through application to legacy data volumes acquired over the shelf of the Gulf of Mexico, the Central Basin Platform of Texas, the Delaware Basin of New Mexico, and the Anadarko Basin of Oklahoma. There is no silver bullet; in most cases it is useful to combine structure-oriented filtering and k_x-k_y filtering workflows as an attempt to remove acquisition footprint from legacy data volumes.

The Effects of Seismic Data Conditioning on Prestack Simultaneous Impedance Inversion

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Abstract

The demands that reservoir characterization places on seismic data far outweigh those of traditional structural interpretation. Because of this, gather conditioning is seen by many as a prerequisite to prestack inversion. This paper discusses three conditioning processes—signal/noise (S/N) improvement, stretch removal, and reflector alignment. It then seeks to document the improvements that these processes achieve in the gathers and in prestack inversion.

Specifically, the gathers were measured for AVO fit using a 2-term Shuey equation and found to be improved by 20%. A comparison of wavelets extracted from each angle stack found the high frequency limit of stable phase to have increased from 30 Hz to 50 Hz. The far angle stack seismic/synthetic inversion residuals showed a 43% drop in amplitude and completely different frequency and reflector character following gather conditioning. Finally, the acoustic impedance (AI) vs. shear impedance (SI) cross-plot showed a much more compact signature that allowed more definitive lithology and pay discrimination. Conversely, the raw data cross-plot contained noisy data that erroneously entered into the area of the cross-plot where the pay signature lay. Geobodies captured from improperly conditioned data are thus (1) inflated in size by 62%, and (2) have lower impedances than is justified from well control. These errors, in turn, would lead to incorrect rock property (hydrocarbon saturation and porosity estimation) and reserve estimations.

Hewett Plattendolomite: Reservoir Characterization by Resolution-Enhanced Seismic Data

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Abstract

We present a work flow for poststack seismic signal preconditioning that comprises noise attenuation and resolution enhancement steps; multiple algorithms have been adopted and their relative advantages and limitations are discussed. Specifically, we evaluate the benefit of two noise reduction approaches (LUM and SVD filters) and two resolution enhancement techniques (adaptive whitening and implicit sparse deconvolution). Such preconditioning work flows are typically used to prepare seismic data prior to detailed reservoir interpretation and characterization studies: as an example the Hewett Plattendolomite case is presented.

Given the complex reflectivity of the Zechstein group (a cyclic sequence of limestones, dolostones, salt and anhydrites) and the limited thickness of the reservoir (close to seismic resolution), seismic characterization is notoriously problematic.

The adoption of a resolution-enhanced seismic volume, supported by forward synthetic modeling and well data, allowed for a semi-quantitative seismic interpretation of the Plattendolomite reservoir and the delineation of its geometry and internal structure that had not been possible to recognize on the original seismic. Bandwidth-enhanced data also permitted a quantitative calibration of several seismic indicators (amplitude dimming, apparent thickness variations, and wave form), to produce porosity and net thickness maps of the new reservoir.

Displaying Seismic Data to Look Like Geology

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Abstract

Seismic reflection data can be displayed to resemble illuminated apparent topography colored by amplitude or other data. In this way, seismic data can be made to look like geology. This fosters geologic intuition and aids interpretation by readily relating geophysical or stratigraphic information to the geological structure. With modern coherency filters, structural and stratigraphic seismic attributes, 3D visualization, and volume blending, it is straightforward to make such displays. Illumination is a key component of the work flow and is introduced through bump mapping or directional attributes. Two important directional attributes are relative amplitude change and seismic shaded relief. Shaded relief is especially powerful and reveals a wider variety of structural elements than other structural attributes.

Visualizing Geological Structure with Subtractive Color Blending

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Abstract

3D seismic attributes enable seismic interpreters to gain a more complete understanding of subsurface geology resulting in more complete and detailed interpretations. Building a thorough understanding of 3D structural variations and fault networks often requires working with multiple seismic attributes due to the fact that different attributes convey different information and that the seismic signature of faults changes through the data set.

Color blending techniques have proven effective in intuitively allowing interpretation of information in multiple seismic attributes simultaneously. One of the most successful techniques uses an RGB (Red, Green, and Blue) color model to present data in a manner which is in tune with the way people perceive color. These types of blend are highly effective at visualizing data such as results of poststack frequency decomposition or offset-stack volumes.

We present an alternate color-blending model based on combining attributes using the subtractive primary colors cyan, magenta, and yellow (CMY). When used with structural attributes, the subtractive model produces displays that are predominately light, and structural variations and faults are associated with darker shades of varying hues and black, and the model is aligned with the way we are accustomed to visualize fault and structural attributes, making these displays very intuitive.

In this paper we provide a number of examples of how these blends can be used to show how fault character changes laterally through a fault network and relate individual faults to surrounding damage, drag zones, and areas of high fault density.

Multiattribute Visualization Using Multivariate Volume Rendering and Glyphs

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Abstract

Software developed for the interpretation and analysis of geoscientific data produces no shortage of attributes designed to measure one salient factor; but as the number of attributes that can be calculated grows, the tools for visualizing these attributes must grow as well. This paper explores some early applications of multivariate visualization tools to interpreting faults, stratigraphy, and microseismic events. The specific tools we examine here are multidimensional transfer functions for volume rendering and glyph displays for multivariate visualization. We present two applications of multidimensional transfer functions: one example combines information from a fault probability volume with a fault azimuth volume to display fault trends very early in the fault interpretation work flow; the second example shows improvements to the definition of a channel boundary by combining an eigenvalue volume with raw amplitudes. Multivariate visualization is presented in the context of visualizing eigenstructure around an interpreted channel and the simultaneous display of several attributes of microseismic events. Although the tools and techniques discussed here are not entirely new, their application in the geosciences is rare, and has the potential to reveal more information to interpreters about their data.

Domain Transform of Seismic Data Volumes to Optimize Visualization of the Geomorphology of Depositional Systems

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Abstract

The interpretation of depositional systems is challenging because the effects of geologic structure obscure the depositional systems in 3D seismic volumes. Even if a combination of attributes can be shown to highlight particular stratigraphy in a volume, it remains difficult to interpret due to the effects of structure (such as faulting, folding, and rotation) obscuring the stratigraphic features of interest.

Domain Transformation™ removes arbitrarily complicated structure from a seismic volume, It is an interpretation-guided 3D transform that creates a volume consisting entirely of stratal-slices. The structural effects removed by the Domain Transform include differential sedimentation/compaction, folds, faults (3D displacement), unconformities (including angular unconformities), canyons, salt bodies, and carbonate buildups.

The transformed volume is ideal for imaging and interpreting depositional systems because every horizontal slice more closely represents a paleodepositional surface. Depositional systems are more readily recognized from their morphology on these slices. Other stratigraphic details are restored to the approximate position and relationships that they had at the time of deposition.

The use of combinations of attributes facilitates the interpretation of depositional systems and depositional stratigraphy in domain-transformed seismic volumes. "Structural attributes (*e.g.*, coherence-related attributes, curvature, and horizon orientation) may be combined with other attributes derived from structure tensor analysis and with waveform related attributes (*e.g.*, amplitude and frequency). Corendering these attributes provides key insights regarding the depositional systems and their internal characteristics.

New Method of Volume Rendering Applied to Seismic Dataset of the Barnett Shale

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Abstract

Recent increases in the memory and power of graphics processing units now allow the rapid interactive computation and visualization use of 3D volumetric attributes. We show how interactive lighting and opacity using this new technology applied to traditional seismic attributes aids in the understanding of the faulting and slumping of the Barnett Shale over sink holes.

The exploitation of unconventional shale reservoirs has heightened interest in the location of natural fractures and faults. The public is concerned about the leakage of reservoir and the liquids used for hydrofracturing into aquifers. In addition to aquifers, the operators are concerned about the loss of hydrofracturing fluids to anywhere outside of the reservoir. The example shows collapse features and faults may be seen with greater clarity for improved interpretation.

Advanced Multiattribute Imaging and Geobody Delineation of Jurassic and Triassic Stratigraphic Targets

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Abstract

We present the results of multiattribute imaging and geobody delineation applied to stratigraphic targets such as Jurassic channels and Triassic beaches and spits, imaged in data from the Norwegian sector of the North Sea. Interpretation based on the examination of seismic amplitude alone is challenging due to the complexity and subtleness of these features.

To improve the definition of these Mesozoic targets, we have applied a multiattribute approach, combining frequency decomposition, seismic attribute analysis techniques, advanced visualization, and a new method of multiattribute geobody delineation. Attributes have been selected that are sensitive to the edge and magnitude response of sedimentary structures, while the use of narrow band spectral magnitude volumes allows small scale frequency variations to be analyzed. These different sources are corendered using advanced color and opacity blending, providing multiattribute composite image volumes for subsequent interpretation and as input to further geobody delineation. The use of such advanced visualization has resulted in a collection of 3D volumes that successfully distinguish the internal and overbank geometry of channels as well as the structure and extent of Triassic sandbars.

A new geobody delineation system has been designed to track visible structures in color blended images. The method is semi-automatic, allowing the interpreter to interactively guide the delineation process. Application of this technique has allowed the user to isolate and extract individual Jurassic channels, the seismic response of which varies considerably, as independent 3D geobodies.

We believe that the use of such advanced multiattribute visualization and delineation techniques is applicable to similar provinces globally.

Phase Analysis: A Complementary Tool to Spectral Decomposition?

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Abstract

Spectral decomposition is a standard tool to facilitate and accelerate seismic interpretation. Applications include highlighting changes in layer thicknesses (for example, in meandering channels and turbidite layers) as well as exploring for low-frequency gas shadows. We argue that local phase analysis serves as a complementary aid in seismic interpretation because the layer thickness, type of impedance contrast, and boundary shape determine the amplitude, peak frequency, and phase of the locally observed wavelet.

Integrating Seismic Attributes for Geo-Modeling Purposes: Nigeria Deep-Water Turbidite Environment Case Study

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Abstract

Dense reflection seismic data have become an indispensable source of spatially continuous subsurface information when supported by a correctly calibrated earth model. This has been made possible thanks to the use of multiple attributes computed from 3D seismic data combined with visualization tools enhancing both structural and stratigraphic delineation. In this study, we show the use of conventional and derived seismic attributes for a particular interval in Aderic Field, located in a deep-water offshore turbidite environment.

The upper Miocene-lower Pliocene interval in Aderic Field corresponds to turbidite channel complexes (both erosive-constructive channels and depositional channels), avulsion lobes, ponded lobes structures and regional mass transport complexes (MTC).

Using an a priori sedimentological concept combined with basic knowledge of rock physics, one can infer detailed architectural elements from different seismic attributes where borehole information is not available.

We found that combinations of amplitude maps at different angle stacks, autocorrelation and coherency of seismic traces, and spectral decomposition of the seismic data were valuable in analyzing the interval.

Such analysis provides significant information on architectural element delineation for different channel complexes and sequences in terms of morphology and width. Levee systems, the erosive character of channels, and the morphologies of lobe systems with avulsion or ponded aspects can also be characterized. In some cases, an estimation of internal heterogeneities can also be proposed.

Interpretations derived from these attributes compare favorably with possible analogues in similar depositional environment, as well as with field outcrop analogues and with images from very shallow Holocene-age seismic volumes.

Frequency-Dependent Seismic Attributes Applied to Stratigraphic Interpretation

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Abstract

Seismic amplitude and instantaneous attributes as well as stratigraphic interpretation of these attributes are frequency and scale dependent. Frequency dependence offers a new dimension of seismic data that has not been fully utilized in the study of seismic picking of geologic surfaces, seismic facies, seismic geomorphology, and sequence stratigraphy. Seismic-tuning effects include thickness tuning and frequency tuning. Seismic modeling shows that, whereas thickness tuning determines seismic interference patterns and, therefore, occurrence of seismic events and seismic facies in stacked data, frequency tuning may further influence the nature of seismic-geologic time correlation and modify seismic facies. Frequency-dependent data processing and interpretation are practical ways to study the frequency-tuning effect for improved seismic interpretation and well-seismic integration. Field data examples demonstrate that by using a local geologic model and well data, we can optimize the frequency components of seismic data to a certain degree and intentionally modify seismic interference patterns and seismic facies for better seismic interpretation of geologic surfaces, facies, geomorphology, and sequence stratigraphy.

Utilization of Instantaneous Amplitude Attribute as a Tool for Prospecting and Risk Reduction: An Example from Ada Field, North Louisiana

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Abstract

This paper presents a case study illustrating the successful utilization of the instantaneous amplitude attribute generated from the 3D seismic data in Ada Field, North Louisiana, in delineating channel-body geometry, inferring the depositional environment, and in prospecting, risk reduction, and optimization of infill well location in the Lower Cretaceous Hosston (Travis Peak in Texas) Formation, a prolific, tight-gas sandstone.

Understanding Thin Beds Using 3D Seismic Analysis Workflows

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Abstract

Seismic analysis workflows can help improve vertical resolution and identify thin beds on seismic reflection data. Thin beds are events that fall below the level of seismic resolution and occur in all geologic settings. Thin bed analysis can help define pinch outs, internal bedding geometries, and other subtle stratigraphic features that are not initially visible on seismic data. We present workflows that include noise cancellation and spectral enhancement, as well as terrace, doublet, bed form, and instantaneous frequency attributes to enhance the vertical resolution of 3D seismic data. Geobodies are then extracted from these attributes to produce a three-dimensional view of data zones having shared characteristics. Examples from several 3D data sets from different geologic settings illustrate the wide applicability of these workflows.

Making Seismic Data Relevant in Unconventional Plays

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Abstract

From the dawn of the "digital E&P era" in the 1960s, multi-channel seismic data redefined processes for optimizing well placement and reducing exploration risk. Two-dimensional seismic grids were later augmented with targeted 3D seismic surveys, driving the creation of "Computer Aided Exploration" (CAEX) workstations and automated map work flows. Seismic data emerged as the essential tool for mapping oil and gas prospects in the 1980s and 1990s.

As E&P targets became more geologically complex, seismic data were extended to become a practical for fault interpretation and fluid detection. As plays matured, seismic data again were adapted to provide time-lapse (4D) monitoring capabilities for mapping fluid and gas migration mapping for primary and enhanced oil and gas recovery. Enhanced resolution and accurate acoustic and elastic inversion (*e.g.*, lambda-rho, mu-rho) techniques further propelled the value of seismic data for lithologic and facies mapping, detailed well planning, and geosteering support.

However, in this new era of "unconventional" plays and engineering-driven "factory" field development, the question emerges: **are seismic data still relevant?**

Multivariate Supervised Classification, Application to a New Zealand Offshore Field

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Abstract

This paper presents a new lithofacies prediction method using seismic prestack data and well lithofacies. The Democratic Neural Networks Association (DNNA) is used to perform the prediction. The association of neural networks with a Bayes approach helps to increase the robustness of the prediction and to quantify the uncertainty. The primary aim of this process is not only to qualify reservoir heterogeneity and lateral extension but also predict lithology where no well has yet been drilled.

Lithofacies prediction from surface seismic data has been applied to the technically challenging Cretaceous rift of the Taranaki Basin where exploration objectives are focused primarily on the Miocene and the Pliocene turbidite sandstones. The prediction using DNNA is compared with two methods commonly used in the oil and gas industry.

Interpreter-Driven Multiattribute Classification

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Abstract

Facies classification by means of multiattribute clustering is becoming a more widely used method of identifying and extracting multiple facies within a dataset. Typically these methods are entirely data driven, have minimal input, and therefore do not take into account any *a priori* knowledge from the interpreter. We present a new interpreter-driven technique that provides simple, real time interaction with multidimensional attribute space.

Volumetric attribute analysis is an effective way of isolating individual properties of the seismic response. These properties can be drawn from models of the wavelet, from local geometry and shape, or from statistical behavior. Typically, more than one attribute is required to fully characterize an area of interest. Simultaneous interpretation of multiple attributes has been greatly facilitated by modern color blending and opacity blending schemes. However, objectively the simultaneous analysis of multiple attributes is difficult for the human interpreter. The interpreter-driven technique presented here is based on diverse context information stored in the human brain. By defining facies within the 3D sub-surface space these contexts are converted into class, or cluster, centers. These class centers define seismic facies based on the statistical distribution of the attributes included in the classification.

We apply our methodology to diverse hydrocarbon provinces at both regional and reservoir scale classification.

Application of 3D Clustering Analysis for Deep Marine Seismic Facies Classification—An Example from Deep-Water Northern Gulf of Mexico

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Abstract

The most popular seismic attributes fall into three broad categories: those that are sensitive to lateral changes in waveform and structure such as coherence and curvature; those sensitive to thin bed tuning and stratigraphy, such as spectral components; and those sensitive to lithology and fluid properties, such as AVO and impedance inversion. We present a work flow that mimics multiattribute clustering routinely done by human interpreters that can differentiate depositional packages characterized by subtle changes in the stratigraphic column as well as lateral changes in texture. The best input attributes are those that are mathematically independent and rotationally invariant sensitive to the seismic facies of interest.

The two most popular clustering algorithms in the seismic industry are neural networks and self-organizing maps. Each of these algorithms can be implemented in a supervised or unsupervised fashion. The clusters in unsupervised data analysis are defined by the data themselves, without any *a priori* information. In supervised training, a subset of clusters is predefined by the interpreter. The input data volumes are compared to these clusters; some are assigned to the predefined clusters, while others form clusters outside the area of supervision. The self-organizing map (SOM) is one of the most effective unsupervised pattern recognition techniques, and is commonly used for the automatic identification of seismic facies.

To avoid guessing at the number of clusters necessary to represent the data, we have over-defined the number of initial clusters through the use of a large number of "prototype vectors" (prototype vectors), which after subsequent iterations tends to converge to the lesser number of actual clusters using a Kohonen self-organizing map neighborhood training rule. After the training is complete the modified prototype vectors are then color coded by using a 2D gradational color scale. Those traces of a similar seismic nature are assigned the same colors, resulting in a 3D seismic facies volume. Calibration is done *a posteriori* by corendering the colored prototype vectors with the original seismic amplitude data, input attributes, and well control. We apply this clustering work flow to a deep-water 3D seismic survey in the northern Gulf of Mexico and calibrate it to a previously interpretation made using traditional methods.

A Guide to the Practical Use of Neural Networks

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Abstract

Seismic attribute analysis is a great tool to enhance and isolate features related to seismic acquisition, processing, and geology. However, single or primary attributes have two drawbacks that can be addressed by more intelligent work flows. First, seismic attributes may not uniquely identify the seismic feature that is the target of the analysis. For example, assuming that faults are the target of our attribute analysis, a discontinuity attribute highlights any lateral change in the signal, including both incised sedimentary features, and faulting. Second, seismic attributes may reveal some of the target features, but not all. For example, discontinuity attributes will not highlight faults that have small fault offset compared with the seismic resolution. Methods that recombine two or more primary attributes can be used to improve a complete and unique isolation of a target feature in the seismic data. For example, fault detection can be performed by recombining discontinuity and curvature attributes, such that discontinuities attributed to sedimentary structures are suppressed, while low offset faults, represented by seismic flexures are highlighted.

Among other methods, neural networks are one of the most efficient methods to recombine multiple input attributes and achieve a high quality extraction of a target feature or rock property from seismic data. The method is complex and difficult to analyze, and often, the black-box character is cited as a reason to stay clear of this method. However, in specific cases the benefits of using neural networks compared to baseline methods is so large that by far they outweigh any (perceived) negatives, and the neural network work flow is the correct tool to enhance a geological interpretation of seismic data.

The aim of this paper is to "translate" the neural network method from a specialized tool that can only be used in the hand of an expert user, to a general interpretation work flow that can be used by informed (but not specialized) general interpreters. To achieve that, this paper will address the following issues:

- When to choose a neural network work flow (and when not).
- Basic theory of neural networks
- General, but practical, guidelines for designing and training a neural network.
- Methods for quality control and validation of neural network results.
- How to use the neural network results as part of the larger interpretation work flow.

These talking points will be illustrated with actual data examples.

Interactive Seismic Attribute Analysis for Reservoir Characterization

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Abstract

Being "interactive" is not only important for traditional seismic interpretation, which maps subsurface structural and stratigraphic features; it should also be an essential feature in the seismic attribute analysis for reservoir characterization and prediction. In this paper we present interactive workflows that integrate major steps in seismic attribute analysis, namely attribute calculation, visualization, calibration, classification, and prediction. Interactive analysis workflows are demonstrated as more effective and powerful than traditional linear workflows.

We introduce the "strata-grid" as the major object for analyzing attributes in the interactive attribute workflow. A strata-grid defines a target stratigraphic volume, based on stratigraphic relationships, that is proportional, top-conformable, or bottom-conformable. Seismic attribute features are better delineated on stratigraphic slices within a strata-grid, rather than through traditional time slices or simple horizon slices. The strata-grid makes the interaction with the data possible, not only for visualizing the data but also for quantitatively analyzing attributes for large 3D seismic surveys - without handling the whole data volume.

Interactive analysis of attributes not only improves the interpreter's efficiency, it allows users to identify reservoir features that would otherwise be missed in a non-interactive approach. For example, the real-time link between attribute generation and visualization makes it possible to quickly fine-tune calculation parameters to generate quality attributes and to find better attributes to characterize reservoir properties.

The power and usability of facies classification and prediction methods are greatly enhanced in an interactive workflow, since results based on different assumptions can be verified and calibrated with well data quickly. In addition to the real-time link between analysis methods and visualization; a co-rendering of multiple attributes in 2D or 3D can generate seismic facies maps or facies volumes interactively, which complements the algorithm-based classification methods. Through real-world examples, we illustrate that the full potential of seismic attributes are better realized through interactive workflows.

An Integrated Workflow to Optimize Discontinuity Attributes for the Imaging of Faults

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Abstract

In the first part of this paper, we give an introduction in seismic attributes for fault detection to set the context to understand imaging of faults with seismic attributes as an integrated workflow. Several well-known attributes for discontinuity analysis are discussed: coherency, similarity, variance, and semblance. After discussing these attributes and their different representation of the seismic and geological characteristics of a dataset, we focus on the dip-steered similarity attribute.

In the second part of the paper, we describe an integrated workflow to produce optimized discontinuity volumes for fault detection First we discuss several preprocessing options to optimize the data for the application of the discontinuity attribute. Second we show the effects of several parameter settings of the similarity attribute. Finally, we discuss the application of postattribute filters (filters applied to the discontinuity attribute) to demonstrate how the attribute image can be enhanced by improving the completeness, resolution, and contrast of the similarity attribute.

Analysis and Interpretation of Fracture Direction and Intensity from Full Azimuth Seismic Data

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Abstract

Unconventional plays represent sources of opportunity for oil and gas companies and the global oil and gas economy. Successful wells in such plays depend upon effective hydraulic fracture treatment design which requires the knowledge of *in-situ* stress, reservoir property, fracture presence, and reservoir pressure. Seismic data carry such information. A determining factor for *in-situ* stress and fracture determination is the azimuthal behavior of the seismic data and associated measurements made from these data. Properly processed, imaged, and inverted seismic data can be used to estimate stress intensity, stress orientation, and rock properties. In this paper, we discuss how technologies such as full-azimuth seismic decomposition and imaging, full-azimuth anisotropic velocity inversion, and full-azimuthal AVO inversion can be applied to characterize a Barnett Shale dataset. The results show areas of low and high stress intensity. These results, with other data, can be used to choose areas to drill, areas to avoid, and preferred drilling directions based on minimum horizontal stress determinations.

A Robust and Compute-Efficient Variant of the Radon Transform

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Abstract

In 2003 AlBinHassan and Marfurt explained that the Hough transform can be used to detect fault lines in 2D seismic data. Their conclusion was that "The Hough Transforms method is a good candidate for enhancing lineaments associated with fractures and faults." But, they also observe that "the problem with the running window code is that the new code will be more sensitive to noise such that the image may not be as clear as we wish." Another problematic issue with the windowed Hough transform, though not discussed in the AlBinHassan's paper, is that the run-time is not very favorable for long operators (*i.e.*, long line segments). In general, if an image contain *m*n* pixels, and we search for line segments of length *k*, the runtime complexity will be in the order of *m*n*k*k* computational units. In practice, this means that if we double the scan line length, the run-time will be four times as long. Clearly, if we look for very long fault lines for every 2D section in a 3D seismic attribute volume, run-time will be an issue. The Hough transform is generally known to be very similar to the Radon transform (it can be convincingly argued they are equivalent), which in turn is closely related to the Fourier transform, so any issues observed with the Hough transform will have the same issues in a Radon- or Fourier-based approach, although Fourier can sometimes be more computationally efficient through the use of the FFT. We have over the last year tried to overcome these two problems for the windowed Hough transform. Specifically, by improving the transform slightly and by calculating varying properties along the scanned line segments, we manage to make the approach more robust in the presence of random noise. We have also found a twist to the algorithm which makes the run-time linearly rather than fourth-power dependent on the line segment length, giving rise to an algorithm that can be applied to large seismic 3D volumes. In this paper, we present some of the theoretical details of how these two issues are solved, and also demonstrate the results on a 3D seismic dataset.

Automatic Fault Extraction in Hard and Soft Rock Environments

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Abstract

Advanced fault imaging and automatic interpretation of faults was initially developed in the late 1990s. Using a structural attribute such as coherence as input, the two most common approaches to automatic fault interpretation (AFE™ from TerraSpark Geosciences and Paradigm; Ant T racking™ from Schlumberger) use very different technologies to highlight faults imaged as discontinuities in the seismic data.

The quality of fault imaging has improved substantially over the last ten years as algorithms have been refined and workflows have improved. Use of horizon orientation volumes (also called 3D dip volumes) has improved measures of discontinuity in a seismic volume. These discontinuity measures have been improved further by applying volumetric estimates of fault orientation. Fault probability volumes (for example as in AFE) have also been improved by the elimination of troublesome artifacts and by extending the algorithm's ability to image lower angle, intersecting, and antithetic faults.

Experience with fault imaging processes and workflows in 3D seismic surveys from a variety of geologic environments has shown how input and control parameters can be adjusted to optimize the imaging and interpretation of faults with varying styles in both hard and soft rock environments.

Characterization of Vuggy Porosity and Fractures Using Poststack Seismic Attributes: Application to a Carbonate Reservoir

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Abstract

This paper describes a workflow that fully utilizes the poststack seismic attributes to derive reliable geologic and fracture models that are validated during the study with blind wells and actual wells drilled after the study. The first step in the workflow is to run poststack seismic processes, which includes volumetric curvature, high resolution poststack inversion, and spectral imaging. The second step consists of using the various poststack seismic volumes to derive 3D geologic models constrained by multiple seismic attributes. The third step consists of using the various poststack seismic volumes and the derived geologic models to build predictive fracture models validated with wells not used during the modeling effort.

This workflow was applied to a complex Paleocene fractured carbonate field in North Africa. A large number of poststack seismic attributes were generated in time and then depth converted within a 3D geocellular grid. These seismic attributes were used simultaneously to create geologic and fracture models. The resulting porosity and fracture density models were validated during the study with a blind well and after the study with a newly drilled well.

Which Curvature is Right for You?

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Abstract

Since they are second-order derivatives, structural curvature attributes can enhance subtle information that may be difficult to see using first-order structure derivative attributes, such as the dip magnitude and the dip-azimuth. Structural curvature provides quantitative measures of quadratic shapes–domes, ridges, saddles, valleys, bowls, and if no deformation exists, planes. As a result, these attributes form an integral part of most seismic interpretation projects. In the 1760s, Leonhard Euler evaluated the apparent curvature of arbitrary slices through a cylinder. Since the finite strain associated with folds and flexures can give rise to fractures, one can compute the apparent (or what mathematicians now call "Euler") curvature parallel to the axis of minimum horizontal stress for subsequent correlation with production data.

Not all seismic surfaces are quadratic. Nonquadratic "shapes" of interest include angular unconformities, asymmetric syntectonic associated with salt withdrawal and faulting, channel-levee deposits, and rotation of otherwise parallel reflectors about a fault. Such features of interest can be measured by second-derivative measurements based on the mathematical rotation of reflector dip about or perpendicular to the locally averaged reflector normal.

Finally, the formalism of volumetric structural curvature (and second-derivative attributes in general) can be extended to measurements more-directly sensitive to lithology: RMS amplitude, energy computed within a small analysis window, acoustic impedance, and other prestack inversion products. Such "amplitude curvature" volumes can enhance lateral changes in reflectivity associated with fault gauge zones and infilled joints and cleats.

We illustrate the value of these attributes through examples from Alberta, Canada, and the Midcontinent, U.S.A.

Developing an Exploration Tool in a Mature Trend: A 3D AVO Case Study in South Texas[1]

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Abstract

If at first you don't succeed, try something unconventional. Successful exploration for new reservoirs in mature trends often requires trying techniques unproved in the area. In a mature play onshore Gulf of Mexico, our initial exploration campaign with conventional 3D seismic was disappointing. However, attention to rock properties, coupled with application of a novel processing technique, allowed us to develop a solution to our dilemma.

1. First published in the November 2000 issue of *The Leading Edge*. Reprinted with permission by the Society of Exploration Geophysicists.

Seismic Acoustic Impedance: An Indicator for Deep-Water Depositional Processes

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Abstract

Deep-water siliciclastic sands have been deposited in pelagic basins by accumulations of epigenic clastic materials carried by turbidite flows from shelf or slope margins. The classic sequence stratigraphy model calls for the existence of basin-floor fans deposited during the lowstand systems tract (LST) within the depositional profile; however, alternative models suggest that turbidite sedimentation is limited to the slope area. The question that needs to be answered is that if there are indeed basin-floor fans, what is the depositional process controlling the formation of these fans, and where can one find reservoir sands within these fans. This paper discusses processes controlling the deposition of deep-water turbidite sands, and presents a case study in which seismic acoustic impedance data are used to reveal the deep-water depositional processes. These data suggest that the deposition of reservoir sands is accomplished by two major processes—downlapping and backstepping, as revealed by the analysis of seismic acoustic impedance volumes, and the subsequent integration of additional geosciences and engineering analysis. Backstepping sand bodies are associated with sea-level rising stages (corresponding to the LST), while downlapping processes are associated with sea-level retreat stages (corresponding to the highstand systems tract, or HST). The resultant depositional model allows one to successfully predict the occurrence of reservoir sands during development drilling. The model also provides useful guidance for deep-water exploration and exploitation that can be tested. These classic sequence stratigraphic concepts can be used to construct a chronostratigraphic framework. By applying advanced seismic technology, detailed lithostratigraphic correlation within each third- or fourth-order sequence can be performed to characterize the patterns of flow unit distribution, effectively enhancing the results of deep-water exploration and exploitation, especially in the frontier areas.

A Seismic Reservoir Characterization Work Flow for Reducing Risk Utilizing AVO, Simultaneous Prestack Inversion, and Rock Physics

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Abstract

In this paper, an integrated seismic-based reservoir characterization work flow is presented which includes fluid substitution, AVO modeling, prestack simultaneous inversion, and lithology and petrophysical property prediction. Forward modeling is normally the most effective way to commence an AVO analysis, which begins with determining the fluid response by calculating seismic velocity and offset-dependant reflectivity changes due to different fluid saturations. The investigation of amplitude variations with offset seeks to extract information about the reservoir rock by measuring changes in amplitude with varying incident angle. Next, the seismic data are analyzed in order to determine whether a conditioning process must be implemented to extract the most out of the seismic data. The aim is to preserve the AVO response while flattening events as much as possible as well as adequately attenuating noise without generating artifacts. Prestack simultaneous AVO inversion follows seismic conditioning, where the data are converted from interface properties to layer properties by the use of a global optimization algorithm with a nonlinear cost function to simultaneously invert a number of input stacks to an earth model. The final process in the characterization work flow is determining a spatial distribution of lithology and petrophysical properties based on rock physics and Bayesian statistics using the acoustic and elastic output volumes from the simultaneous inversion.

3D Seismic Curvature and Curvature Gradient for Fractured Reservoir Characterization at Teapot Dome (Wyoming)

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Abstract

Curvature is a popular attribute that has been widely used to delineate faults and fracture zones in seismic structural interpretation; however, our observations from 3D prestack, depth-migrated seismic data at Teapot Dome (Wyoming) indicate that many faults do not correlate with any curvature anomalies, while many curvature anomalies do not correlate to any faults. Instead, the major faults are typically located at the maximum absolute gradient of curvature. Inspired by these observations, we extend the curvature algorithm and construct a new curvature gradient algorithm by calculating the maximum change in curvature along the bedding. We then extract both maximum curvature and maximum curvature gradient attributes to describe the Teapot Dome fractured reservoirs. Our results indicate that the maximum absolute curvature gradient is more descriptive of the northeast-trending transfer faults and the northwest-trending thrust faults that are seismically visible; whereas the maximum curvature is more descriptive of the folded but unfaulted crestal portion of anticlines. These observations from seismic data, along with image logs, cores, and outcrops reported from previous studies, lead to our interpretation that curvature may be more indicative of tensile fractures whereas curvature gradient may be more indicative of shear fractures. Although tensile fractures can be directly observed on image logs, cores, and outcrops, they usually fall below the limit of seismic resolution. In contrast, shear faults give rise to significant offset of reflectors such that they are easily recognizable on seismic images. We propose using a combination of curvature and curvature gradient attributes for discriminating reservoir fracture facies (tensile versus shear fractures), evaluating reservoir storage capacity and caprock integrity, and modeling reservoir fracture networks at Teapot Dome.

Facies Probabilities from Multidimensional Crossplots of Seismic Attributes: Applications to Jonah and Mamm Creek Tight Gas Fields

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Abstract

We propose a simple method to estimate facies probabilities based on statistical analysis of multidimensional crossplots of seismic attributes. Log scale facies flags related to thick sand bodies are created using petrophysics and rock physics analyses. These flags are then used to color crossplots of seismic scale attributes derived from AVO inversion of PP data (V_P, V_S, and density) and inversion of poststack fast and slow PS components of a 3C-3D survey. We show that by using these five seismic attributes and facies flags (like a colored five-dimensional crossplot), we can estimate the probability of thick sand bodies much better than when we crossplot two attributes at a time. Unlike commonly used approaches to map facies or lithologies from seismic data based on selecting regions in seismic attribute crossplots, our approach accounts properly for overlap among different facies and quantifies the probability of their occurrence.

Overview of Seismic Attribute Analysis in Shale Plays

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Abstract

Unconventional shale gas and shale oil plays have jumped into the spotlight over the last several years and appear to be the future of our business, at least in the U.S. (James Baker Institute for Public Policy, Rice University, 2011). These new plays are the catalyst for much of the new developments in geophysics and especially for the use of new seismic attributes. In the past, geophysical methods in shale plays have been used primarily to understand the depth and thickness of the reservoir and to avoid possible completion hazards caused by karsting and faulting. More recently, 3D seismic data and attribute technologies have supplied information on localized stress, fault/fracture orientation and density, reservoir sweet spots, possible hydraulic fracture barriers, pore pressure, rock and mechanical properties, and stimulation effectiveness and optimization. I will present the information that can be obtained from 3D surface seismic data and how it can impact the development of these unconventional plays. I will limit the scope of the paper to the conventional surface seismic methods. My investigation will include the use of azimuthal velocity and amplitude attributes, geometric attributes, simultaneous inversion for rock and mechanical properties, and calibration of the seismic attributes to log and production data.

Stratigraphic Analysis in Carbonate Zones: An Investigation Using 3D Seismic Analysis Techniques on an Offshore UAE Field

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Abstract

Carbonate reservoirs in the Arabian Gulf are complex integrated systems which are often hard to interpret. The identification of pinch-outs and build-ups is further complicated by poor data quality. We present the results of applying 3D seismic analysis techniques to create attribute and geobody volumes which provide insight into the stratigraphy at the reservoir level of a producing field, offshore UAE.

This investigation focuses on the middle Cretaceous Mishrif reef build-ups which form major reservoirs and were controlled by localized salt diapirism and associated bathymetric variations. A good understanding of the geomorphological evolution as well as the structural and stratigraphic properties of these formations is crucial in defining reservoir properties.

The work flow applied to the data was split into two sections: data conditioning and stratigraphic analysis. The post stack depth-migrated seismic data were dominated by steeply dipping coherent noise. Application of structurally oriented edge preserving filters as well as spectral enhancement successfully attenuated the noise and provided a high resolution input dataset for the remaining work flows. Identification of a prograding rudist reef with associated clinoform features as well as pinch-outs formed from the truncation of the reef by the Mishrif erosional surface was achieved by use of a bed-form attribute which identified individual reflectivity events by isolating constant phase events. A combination of the bed-form attribute with the instantaneous frequency was used to create an attribute for the analysis and extraction of stratigraphic clinoforms, pinchouts formed from truncations, and onlapping and downlapping events. Extraction of potential pinchout features as geobodies enabled their lateral extent and shape to be easily visualized and analyzed throughout the area.

Eagle Ford Exploration and Development—The Application of Regional Geology and Geophysical Technologies

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Abstract

The Eagle Ford Shale in South Texas is one of the more exciting shale plays in the United States at the current time. Recently published reports of well tests describe initial gas well rates exceeding 17 MMcf/d and initial oil well rates in excess of 2000 BOPD. Acreage lease rates continue to climb as additional positive results come from drilling within the trend. A key issue for the exploration companies is finding where to focus acreage acquisition and optimize drilling plans for optimal gas and oil recovery. This review first considers the geologic context of the Eagle Ford and then examines at the geologic drivers for locating economic producing wells. With improved understanding of local rock properties, our focus shifts to geophysical techniques, in particular, comparing and contrasting the value of seismic attributes in building a successful exploration and development plan.

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