Techniques in Subsurface Mapping using Spectral Decomposition and Well Log Character: Case Study of Cenozoic Fluvial & Marginal Marine Reservoirs of Llanos Foothills, Colombia

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SAEID, Essam, KELLOGG, James N., KENDALL, Christopher, DE KEYSER Thomas, HAFIZ, Ibraheem, ALBESHER, Ziyad and MARTINEZ, Jose Antonio
Objective of this study - use spectral decomposition method for subsurface mapping through frequency anomalies in a geologically and seismically challenging area - Llanos Foothills, Eastern Cordillera, Colombia
New techniques of well-to-well correlation

- Spectral Decomposition
- Integration of Well logs and Spectral Decom as subsurface mapping techniques
- Spectral Decom. expression of Tectonic Deformation
- Conclusions
PROPOSED WORKFLOW

Well-Logs

Normalize Gamma-Ray log

Color Gamma-Ray red (sand) black (shale)

Display Gamma-Ray on logarithmic scale

Combine Density & Neutron logs

Color Density log

Color Neutron Log

Core samples

well-to-well correlation

Well log Cross-plots

Z-plots

Sequence Stratigraphic framework
## CHOOSING A COLOR SCALE

### Well Logs Color Scale

<table>
<thead>
<tr>
<th>Grain size Proxy</th>
<th>Mineralogy Proxy</th>
<th>Porosity Proxy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shale</td>
<td>Anhydrite</td>
<td>Clay</td>
</tr>
<tr>
<td>&quot;Mud-supported&quot; fabric</td>
<td>Dolomite</td>
<td></td>
</tr>
<tr>
<td>&quot;grain-supported&quot; fabric</td>
<td>Calcite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quartz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&quot;Argilaceous&quot;</td>
<td></td>
</tr>
</tbody>
</table>

**Scale for GR:** logarithmic, 1-500 (GR logs normalized)

**Scale for RHOB:** normal, 1.95 - 2.95
Shaded red above 2.8

**Scale for NPHI:** reverse, -0.15 - 0.45
Normalized GR & Display on Log Scale

- Normalized GR (Log Scale)
- Normalized GR
- Norm. GR (Log Scale)

**Shale**

**“Mud-supported” Fabrics**

**Sand**

**“grain supported”**
Establishing sequence stratigraphy framework
limited lateral continuity of sand prone units of non-marine reservoirs is challenging relative to marine sequences.
Well logs and cores can identify fluvial, estuarine and/or deep-water fans.

It is impossible to predict channel orientation and correlate channels from well logs alone or from 3D seismic.

My next slide shows 3 different interpretations by three experts interpreting the same geological section displaying fluvial sediments on well logs
Why this research is important?

Three interpretations of the braided-fluvial deposits of the Travis Peak Formation TX.

Tye (1991)

Sandstone connectivity is the major rule in oil exploration and production

Bridge and Tye (2000)

Miall 2006 & 2014
New techniques of well-to-well correlation

Spectral Decomposition

Integration of Well logs and Spectral Decom as subsurface mapping techniques

Spectral Decom. expression of Tectonic Deformation

Conclusions
PROPOSED WORKFLOW

1. Well-Logs
   - Normalize Gamma-Ray log
     - Color Gamma-Ray red (sand) black (shale)
       - Display Gamma-Ray on logarithmic scale
         - Combine Density & Neutron logs
           - Color Density log
             - Core samples
               - well-to-well correlation
           - Color Neutron Log
             - Well log Cross-plots
               - Z-plots
                 - Sequence Stratigraphic framework
What is Spectral Decomposition?

• A way of viewing the data contained in discrete sections of the 3D seismic data frequency spectrum

(Aarre et al., 2012)
Workflow of Spectral Decomposition

Extract (3) dominant frequencies, break into 3 discrete frequency volumes and flatten at the horizon of interest.

Identify seismic horizons

Frequency volume displaying channels within flattened horizons

Blend dominant frequencies volumes by RGB mixer
Types of Spectral Decomposition

1- STFT = Short Time FT
2- CWT = Continuous wavelet
3- MP = Matching pursuit

Vertical Resolution

Frequency Resolution
Spectral Decomposition results similar to modern fluvial analog from Peru

Ucayali River Peru
New techniques of well-to-well correlation
Spectral Decomposition
Integration of Well logs and Spectral Decom as subsurface mapping techniques
Spectral Decom. expression of Tectonic Deformation
Conclusions
Connecting the potential reservoirs based on well logs

Interpretation before use of spectral decomposition
Connecting potential reservoirs based on spectral Decomposition

Interpretation after use of spectral decomposition
New techniques of well-to-well correlation
Spectral Decomposition
Integration of Well logs and Spectral Decom as subsurface mapping techniques
Spectral Decom. expression of Tectonic Deformation
Conclusions
Spectral Decomposition Expression of Tectonic Deformation
Conceptual model of fluvial drainage versus tectonic structure and regional slope

A. Early rift inversion

- Low structural relief
- Gentle regional slope

Longitudinal-dominated streams (structure-controlled)

Late Oligocene (Carbonera C7)

Legend:
- Orange: Lower Neogene syn-tectonic units
- Yellow: Paleogene units
- Green: Upper Cretaceous postrift units
- Dark green: Lower Cretaceous synrift units
Spectral Decomposition Expression of Tectonic Deformation

Eastern Cordillera
Spectral Decomposition Expression of Tectonic Deformation

Early Miocene
C5-C3
22-20 Ma
Spectral Decomposition Expression of Tectonic Deformation

Early Miocene
C5-C3
22-20 Ma
Conceptual model of fluvial drainage versus tectonic structure and regional slope

B. Mature rift inversion

- High structural relief
- Steep regional slope

**transverse-dominated streams**

(slope-controlled)

- Longitudinal river in active thrust sheet or thrust-top basin
- Remnant longitudinal catchment being reduced by capture

**Early Miocene**

*Carbonera C5-C3*

Legend:
- Orange: Lower Neogene syn-tectonic units
- Yellow: Paleogene units
- Green: Upper Cretaceous postrift units
- Dark green: Lower Cretaceous synrift units
By using spectral decomposition we can detect subtle stratigraphic features undetectable in the time domain seismic data and correlate the sand bodies from well to well.

The integration of spectral decomposition and well character are powerful subsurface mapping techniques that make it possible, at last, to resolve the subsurface configuration of the Llanos Foothills of Colombia.
Thank You