Channel Belt Rugosity in Reservoir Characterization*

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Abstract

Fluvial systems are typically classified based on river channel morphology, with meandering and braided river patterns being the two most common end-member types. However, seismic data commonly cannot resolve channel morphologies, only the much larger channel belt. This creates challenges when applying channel classifications to subsurface reservoirs. Log and core data allow the interpretation of bar patterns within river channels that aid in the interpretation of larger channel belts. Typically, downstream accretion results in fewer sand/mud interbeds and is often associated with a braided channel morphology, whereas lateral accretion leads to abundant sand/mud interbeds and associations with a single thread sinuous channel. Still, core and log data do not allow for a direct and confident interpretation of braided or sinuous channel morphology. River channels and channel belts can easily be identified using satellite imagery. Channel-belt margins vary in smoothness depending on the dominant style of bar-form migration: lateral or downstream. We term this smoothness of the channel-belt margin, Rugosity. Rugosity is used in marine science to characterize seafloor habitats. Rugosity is herein used to describe how dissimilar the opposing sides of a fluvial channel belt are in planview. Rugosity (fr) is a measure of small-scale variations or amplitude in the height of a surface, fr = Ar/Ag, where Ar is the actual planform area and Ag is a geometric approximation of the channel-belt area. We found that increasing lateral accretion of barforms (caused by increased channel sinuosity) leads to an increase in channel-belt rugosity. Therefore, rugosity could be a proxy for interpreting the relative degree of lateral vs. downstream accretion within channel belts. This is a potentially powerful tool for resource estimation and extraction, as it may improve predictions of internal heterogeneity using seismic data.
Channel Belt Rugosity in Reservoir Characterization

Tobi Payenberg (Chevron Energy Technology Pty. Ltd.), Brian Wills (Chevron Energy Technology Company), Victor Pusca (Chevron Energy Technology Company), Pete Sixsmith (Chevron Energy Technology Pty. Ltd.), Bryan Bracken (Chevron Energy Technology Company), Henry Posamentier (Chevron Energy Technology Company), Michael Pycz (Chevron Energy Technology Company), Richard Sisch (Chevron Energy Technology Company), Sean Connell (Chevron Energy Technology Company), Kristy Milliken (Chevron Energy Technology Company) and Morgan Sullivan (Chevron Energy Technology Company)

Abstract:
Fluvial systems are typically classified based on river channel morphology, with meandering and braided river patterns being the two most common end-member types. Seismic data commonly cannot resolve reservoir depth channels, but rather only image the larger-scale channel belts. Thus it is a challenge to apply modern river channel classifications to subsurface reservoirs.

Log and core through channel belts are commonly interpreted based on inferences that vertical grain size trends and the abundance of bed-scale heterogeneities reflect specific channel patterns: 1) braided rivers are assumed dominated by downstream accretion deposits with few mud interbeds and subdued upward-fining trend, whereas 2) meandering river deposits are assumed to be dominated by lateral accretion deposits with abundant mud interbeds and more pronounced vertical fining trend. Despite these general rules of thumb, core and log data alone generally do not allow confident distinction of deposits formed by different types of rivers.

River channels and channel belts are easy to define using satellite imagery. Channel-belt margins vary in smoothness depending on the dominant style of bar-form migration: lateral vs. downstream. We quantify the relative channel-belt margin smoothness by defining a Rugosity index. Rugosity is a measure of small-scale variations or amplitude in the height of a surface.

Rationale:
How can one predict channel belt internal heterogeneity? Wireline log and core data make it often difficult to tell the difference between lateral and downstream accretion. Seismic data at reservoir depth typically only images the channel belt, and no internal heterogeneities.

Challenge:

Rationale: Heterogeneity inside fluvial channel belts is typically controlled by the amount of downstream vs. lateral accretion, and the amount of channel migration and abandonment.

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Opportunity: An opportunity exists to predict reservoir heterogeneity using standard petroleum industry subsurface data; more specifically, using 3D seismic data.

Individual river channel(s) within channel belts can be defined in modern satellite images. The margins of different channel belts vary in smoothness depending on the dominant barform migration pattern: lateral vs. downstream. We define a measure of channel belt edge smoothness “Rugosity.” Rugosity is used to describe the un-parallel nature of the opposing channel belt margins. High rugosity is defined as the actual surface area and A is the area of the vertical projection of the surface to the water surface. Rugosity here is used to describe the un-parallel nature of the opposing channel belt margins. High rugosity is defined as the actual surface area and A is the area of the vertical projection of the surface to the water surface.

Rugosity (R) is a measure of small-scale variations (amplitude) in the height of a surface, R = Ag/D, where Ag is the area of the vertical projection of the surface to the water surface. Rugosity is different from river sinuosity, in that rugosity is applied to the entire channel belt (the channel belt across the floodplain, the term “wandering” is introduced.

Channel Belt Rugosity in Reservoir Characterization

Suggested Quantification Approach:

A proposed workflow is to:
• Determine if the channel belt wanders significantly and if channel belt wandering is large, the Rugosity of a channel belt might be better described as the Rugosity and Wandering (RW).

1. Determine area of interest (e.g. from seismic).
2. Create a plan view map of the channel belt.
3. Define L1, L2, L3 and D consistently. Consider the wavelength of the river and of the channel belt.
4. Determine if channel belt wandering is large or small. However, in this example Wandering is low, and hence negligible. Base images from Google Earth.
5. Select R or RW approaches.
6. Calculate channel belt rugosity.

A1 Satellite images illustrating differences in Rugosity (R) between channel belts: A) Rio Colorado, B) Lena River, C) Mississippi River, D) Brahmaputra River.

Example of a rugosity measurements along a reach of the seismically-imaged channel belt, Triassic NWS, Australia. Note the difference between R and RW due to channel belt wandering.
Alternative Quantification Approaches:

Several alternative quantification approaches have been investigated, each with its own strengths and weaknesses

**Rugosity Index:**

\[ RI = \frac{C_{\text{max}} - C_{\text{min}}}{C_{\text{max}}} \]

where \( C_{\text{max}} \) is the maximum channel belt width and \( C_{\text{min}} \) is the minimum channel belt width.

- Low rugosity = 1 to 1.5
- Moderate rugosity = 1.5 to 3
- High rugosity = >3

**Channel Belt Width (Centreline) Variations**:

- Automate channel belt measurements perpendicular to belt axis so that finely spaced measurements can be sampled.

**Area Difference of Channel Belt vs. a Straightened Belt**

- Could combine many segments in an interval
- Segments binned by mean width
- Channel versus belt parameters

**Perimeter Length/Area**:

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<thead>
<tr>
<th>River Name</th>
<th>Area</th>
<th>Perimeter</th>
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</tr>
<tr>
<td>K</td>
<td>23.9</td>
<td>25.7</td>
<td>1.4</td>
</tr>
</tbody>
</table>

**Morphodynamic diversity of the world's largest rivers**

**Channel Belt Rugosity in Reservoir Characterization**

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- Several alternative quantification approaches have been investigated, each with its own strengths and weaknesses
- Alternative width measure is to define distance along tangents to the centerline.
- This challenge is that there is a behavior not found in a measure of rugosity (more of a measure of normalized variance of some kind).
- Also the method is prone area, both because different operators will define different tie points and because when there is nested scales of edge irregularities the larger scales with hold the max width value out even when there are variable amounts of smaller-scale interstices between tie points which will be poorly sampled by this method.
- A simple Rugosity Index (RI) could be defined based on the maximum channel belt width divided by the minimum channel belt width, similar to a sinuosity index. The challenge with this methodology is that the margin of a channel belt is not a wave form, and the measure could be a local phenomenon not representative of the entire channel belt.
- rugosity is defined in other sciences in a specific way. For marine biologists, rugosity is basically the same as sinuosity applied to a surface, defined by keeping track of length on the sea floor and measuring its horizontal span across the water surface. Like sinuosity, it is a dimensionless number (length/length) greater than 1.
- In materials science, rugosity is more or less the same, but is measured digitally from surface projections. In this case, rugosity is the area of a segment on the surface divided by the area of the vertical projection of that surface segment. Note that projected areas are always equal to or less than the original surface, and thus, just as for the case of line sinuosity, rugosity of a surface has a dimensionless (area/area) value less than 1.

The problem of defining a measure of channel belt edge rugosity carries on the need to define an orthogonal projection plane (without a horizontal "sea level" reference) and what to do with the two surfaces each of the channel belt) rather than having just one. The latter question depends on what you want to measure: 1) a metric of the true size of the irregularities or 2) a shape indicator such that edge irregularities are defined relative to the size of the belt (example, a percent of channel belt width). Possible alternatives include:

1) The easiest and most "true to the definition" measure of Rugosity is just a measure of the external edge sinuosity. Rugosity (RI) \( = P/D \), where \( P \) is a polygon perimeter length and \( D \) is the distance between the two points furthest apart on the polygon. The resulting measure appears to scale, in that Rugosity appears to stay the same when the same shape is simply enlarged. There are two potential problems: 1) One needs to define the projection, the straight line distance, which can be impacted when the belt wanders along the floodplain, and 2) A wide channel belt and a name one with otherwise the same edge geometry would have almost the same Rugosity even though the wider one would appear relatively smoother. So this provides a measure of true roughness rather than a measure relative to average width.

2) Perimeter Length/Area: This method does not seem to work well for very elongate objects like a channel belt. The test was to calculate this ratio on a channel belt trace polygon and then calculate it again for 1) two of the exact same polygons attached end to end, and the same shaped polygon enlarged in size. It is undesirable to have a rugosity measure dependent on measurement length.

3) Channel belt width. Variation is the upshot is can be used to define a number of different roughness measures (including rugosity). The downers are the problem of defining width measures perpendicular to the channel centerline along a wandering channel belt and on developing an automated process. Once width measurements are made, the test is fairly easy: one can use the resulting data to calculate rugosity, magnitude of edge changes, and wavelength of variations. To measure rugosity from evenly spaced width measurements, sum the obsolete value of the difference in successive widths and calculate the length of the hypotenuse of a right triangle with horizontal on one side and sum of vertical changes on the other. Divide this hypotenuse length by the horizontal distance.

4) Area difference defines an outer boundary through the edge maximum around the trace of the polygon. The ratio of the areas of the inner and outer boundaries measures the maximum/mean polygon width scales of edge irregularities the larger scales with hold the max width value out even when there are variable amounts of smaller-scale interstices between tie points which will be poorly sampled by this method.

5) A simple Rugosity Index (RI) could be defined based on the maximum channel belt edge width divided by the minimum channel belt width, similar to a sinuosity index. The challenge with this methodology is that the margin of a channel belt is not a wave form, and the measure could be a local phenomenon not representative of the entire channel belt.