

Seismic Attribute Expression of Differential Compaction*

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Abstract

Differential compaction is routinely used by seismic interpreters to map features of interest, such as identifying carbonate buildups, recognizing sand fans in shallow as well as deep waters, or in seismic geomorphological-based interpretation of fluvial-deltaic systems. Compaction features over laccoliths and dikes are recognized as a means of generating fractures in overlying sediments. Seismic attributes, such as coherence and curvature, are used for mapping structural features such as faults, folds, and flexures, as well as mapping discontinuities that arise at channel edges. In this work we show modern 3-D examples of positive relief, sand-filled channel features in a shale matrix, and negative-relief, compacted Winnepegosis carbonate buildups in a salt matrix in the Western Canadian Sedimentary Basin.

By understanding the depositional environment, differential compaction can serve as a lithologic indicator that can be incorporated with other 'soft' measurements such as reflection amplitude anomalies, AVO anomalies, and velocity pull-ups in a risk-analysis-based prospect evaluation workflow. Positive curvature anomalies over channel features indicate that these channels are filled with a lithology that is less compactable than the surrounding matrix, indicating the presence of sand. Negative curvature anomalies over channel features are more problematic. If the channels are in nearshore environment and have been filled by rising sea level, there is a very high probability that they are filled with shale, indicating that sand should be found in the surrounding, less compacted point bars and levees that often express a positive curvature anomaly. In general, incised channels may be filled with a mix of lithologies, resulting from multiple stages of incisement and fill. If the topography has been exhumed, the surrounding material may already have been compacted, reducing the differential compaction anomaly associated with a sand-filled channel.

Carbonate buildups buried in shale will give rise to structural highs and positive curvature anomalies along the shallower, more easily picked horizons. Carbonate buildups buried in salt, such as our Winnepegosis reef example, will appear as structural lows, giving rise to a negative curvature anomaly. Such compacted structural reef cores may have lost much of their original porosity, resulting in donut-shaped features, where the structurally high rims preserve much of their original porosity.

Selected References

Alves, T.M., 2010, 3D Seismic examples of differential compaction in mass-transport deposits and their effect on post-failure strata: *Marine Geology*, v. 271/3-4, p. 212-224.

Alves, T.M., and J.A. Cartwright, 2010, The effect of mass transport deposits on the younger slope morphology, offshore Brazil: *Marine and Petroleum Geology*, v. 27/9, p. 2027-2036.

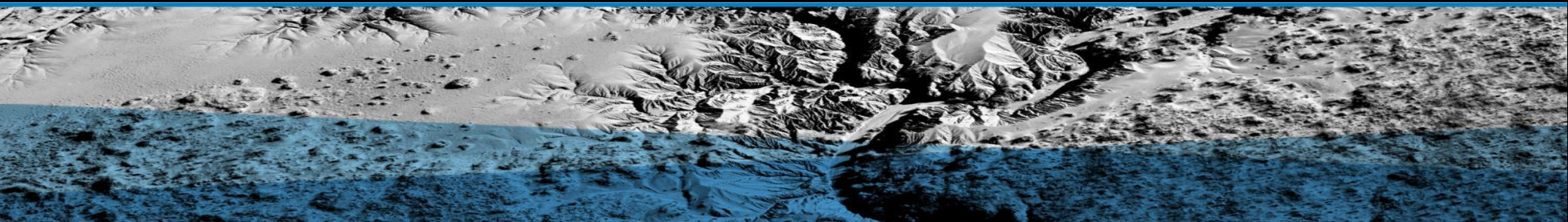
Bubb, J.N., and W.G. Hatlelid, 1977, Seismic stratigraphy and global changes of sea level; Part 10, Seismic recognition of carbonate buildups, *in* C.E. Payton, ed., *Seismic stratigraphy; applications to hydrocarbon exploration: AAPG Memoir 26*, p. 185-204.

Buczkowski, D.L., and G.E. McGill, 2002, Topography within circular grabens; implications for polygon origin, Utopia Planitia, Mars: *Geophysical Research Letters*, v. 29/7, p. 59/1-59/4.

Heritier, F.E., P. Lossel, and E. Wathne, 1980, Frigg Field, large submarine-fan trap in lower Eocene rocks of the Viking Graben, North Sea, *in* M.T. Halbouty, ed., *Giant oil and gas field of the decade 1968-1978: AAPG Memoir 30*, p. 59-79.

Posamentier, H. W., and G. P. Allen, 1999, *Siliciclastic sequence stratigraphy: Concepts and applications: SEPM Concepts in Sedimentology and Paleontology*, v. 7, 210 p.

Seismic Attribute Expression of Differential Compaction



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Norman



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Differential compaction:

- refers to the difference in the extent to which a sediment is compacted.
- may be due to topographic irregularities of the surface on which the sediments are deposited.
- essentially, here we are referring to differences in the irreversible volume change that rocks suffer under pressure, e.g., under the weight of sediments deposited on them.

Differential compaction:

- causes drape over sand bodies and reefs.
- bending is caused by the fact that the sand body or reef does not compress to the same degree as the shales on either side of it or around it.
- such drapes can form closures and can trap hydrocarbons.
- these drapes are formed not by any tectonic activity but by the sedimentary process itself.

Differential compaction:

Where is it observed?

- an erosional unconformity of considerable topographical relief has been covered with a compactable sediment.
- shale bodies contain sand lenses.
- carbonate reefs are embedded in shales.
- pure shales grade into sandy or limy shales – where the compactability of the material itself changes.

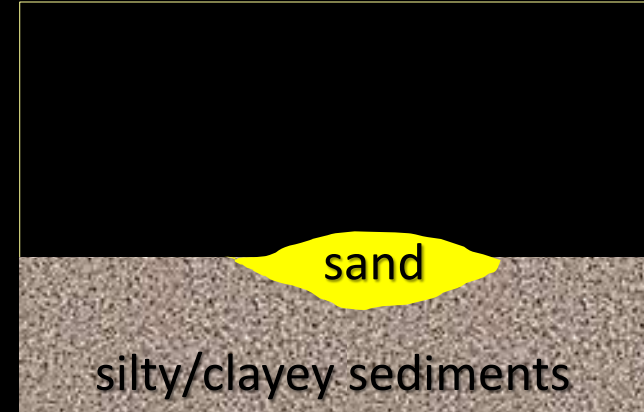
Differential compaction

1.



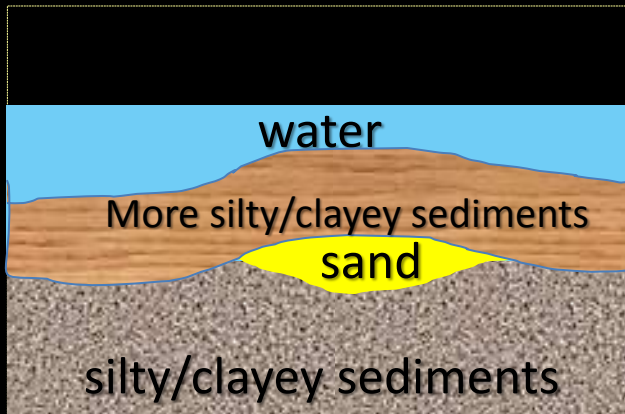
Early water flooding

2.



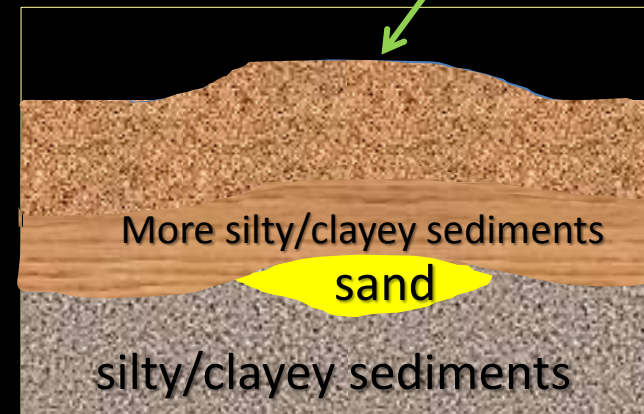
Drained phase

3.



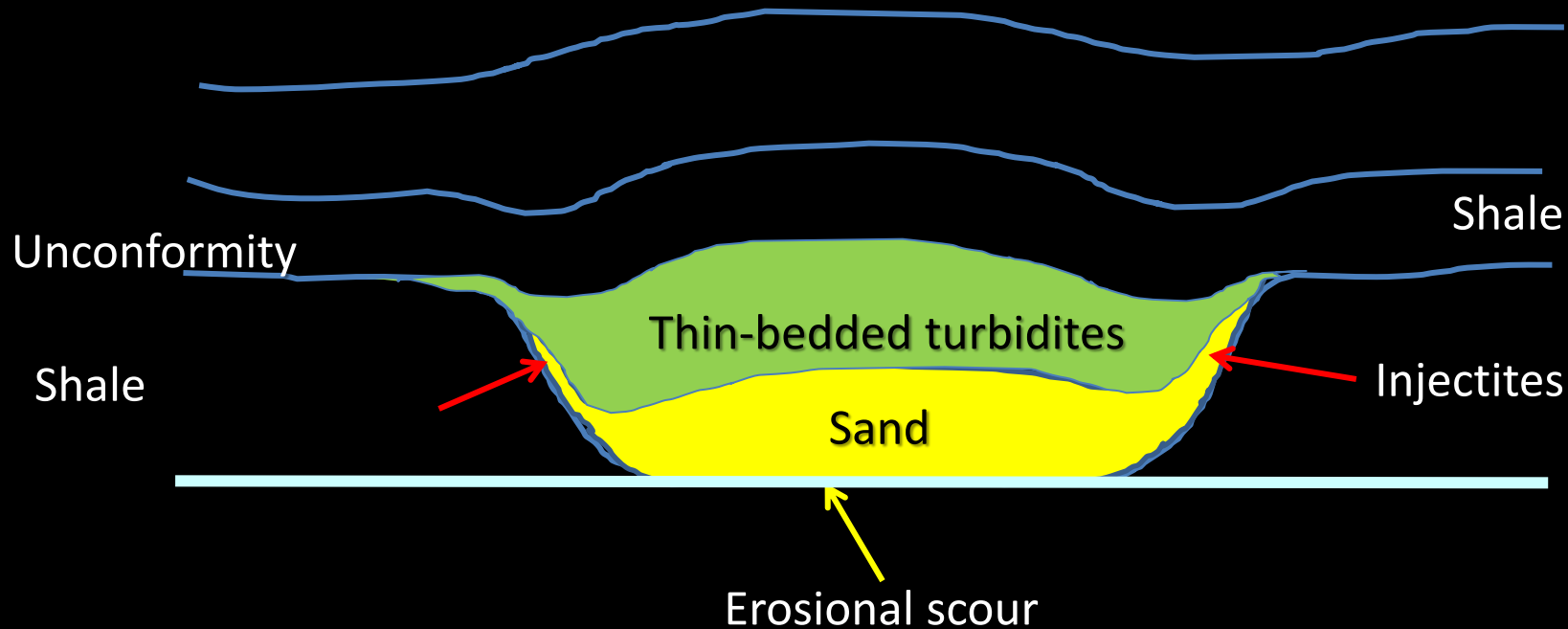
Another water flooding phase

4.



Present-day surface

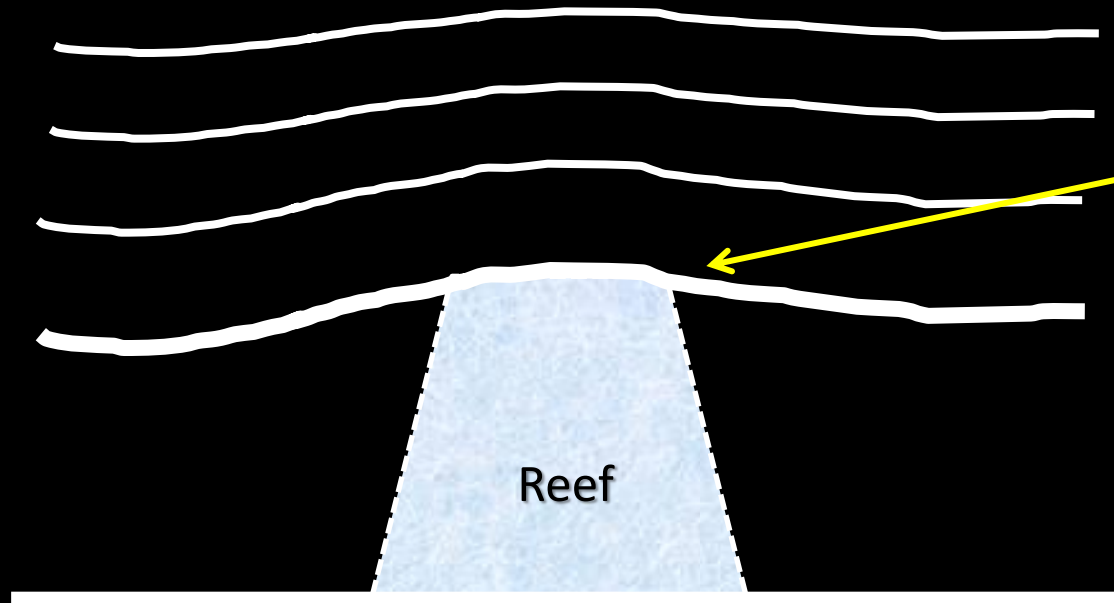
Differential compaction



Sand injectites in the overburden shales could give rise to the wing-like reflections at the edges of the sand.

Reefs are often less compactable than surrounding shales

Structure is a function of the applied load of the overburden



Drape structure over the reef

Differential compaction occurs in this interval

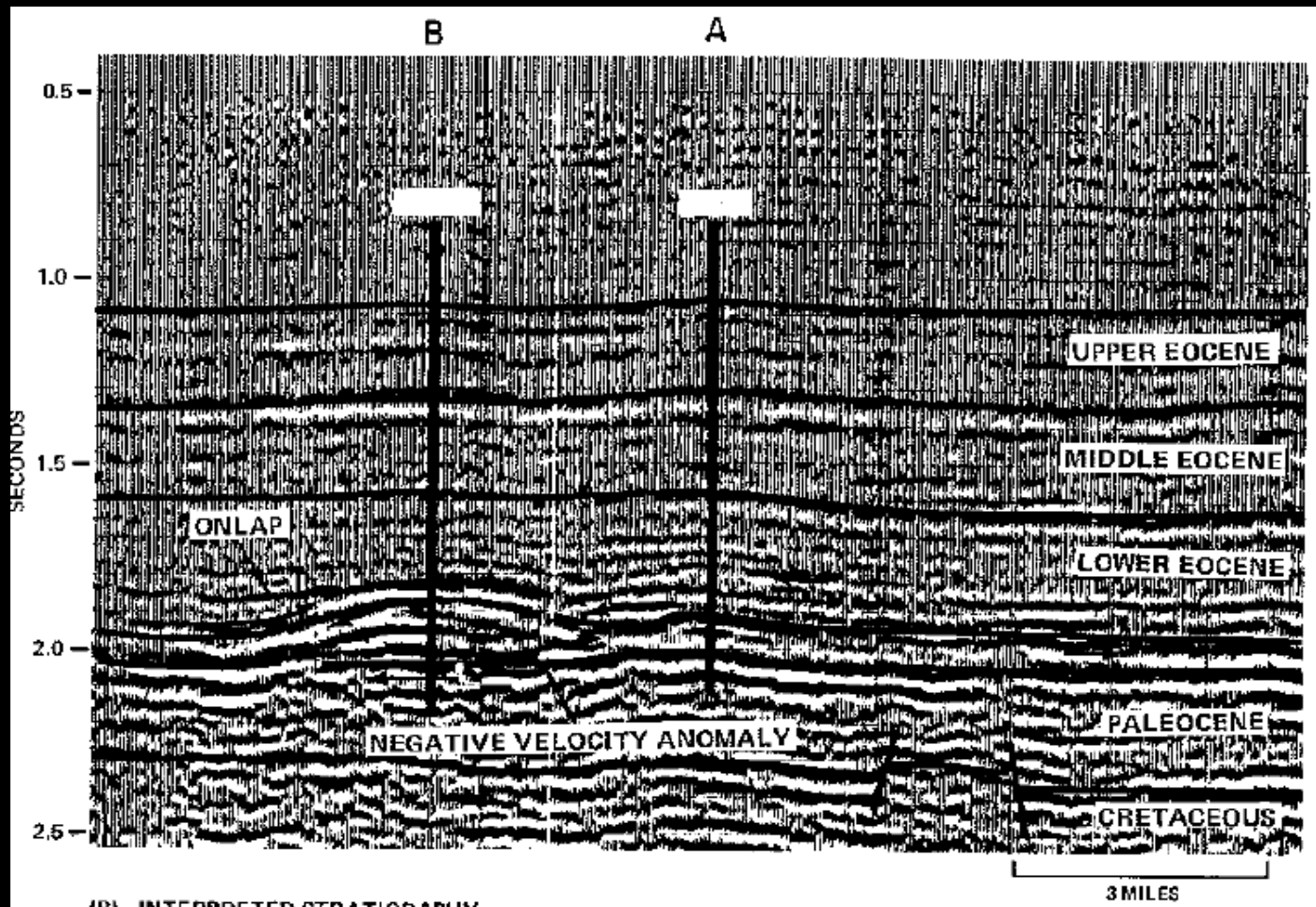
Schematic for development of differential compaction structure

Vertical expression of the drape features becomes smaller gradually with height above the reef.

Differential compaction (DC) has been used by seismic interpreters to map features of exploration interest:

- **Bubb and Hatledid (1979) : DC along with velocity pull up/down as a means of identifying subtle carbonate buildups.**
- Heritier et al. (1980): recognized DC over sand fans in the North Sea.
- Posamentier and Allen (1999): discuss the uses of DC in seismic geomorphology-based interpretation of fluvial deltaic systems.
- Alves and Cartwright (2010): provide an overview of deep-water differential compaction features in Brazil.
- Alves (2010) investigated the role of mass-transport deposits in the shaping of the post-failure seafloor morphology in SE Brazil.
- Buczkowski and McGill (2002) showed using differential compaction models that topographic depressions form over buried impact craters.

Seismic attribute expression of differential compaction



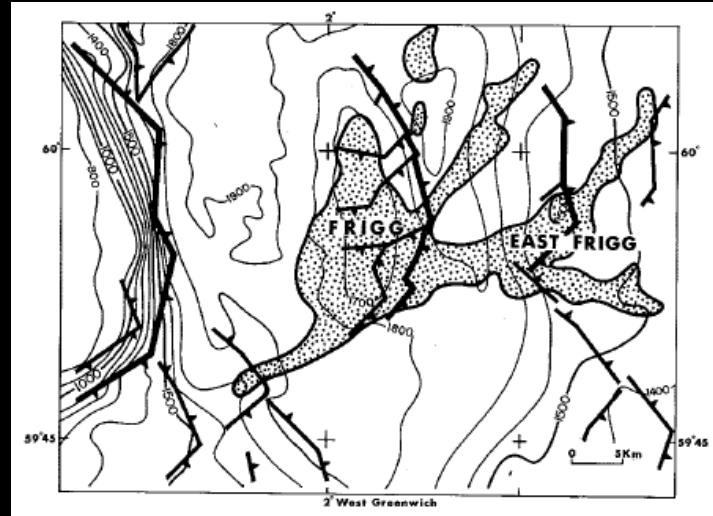
Pinnacle reef interpreted on the seismic section by *reflections on the top and sides of the buildup, three cycles of onlap, drape in overlying beds, and the slower velocity pull down below the buildup.*

Pinnacle reef in North Africa (Bubb and Hatledid, 1979)

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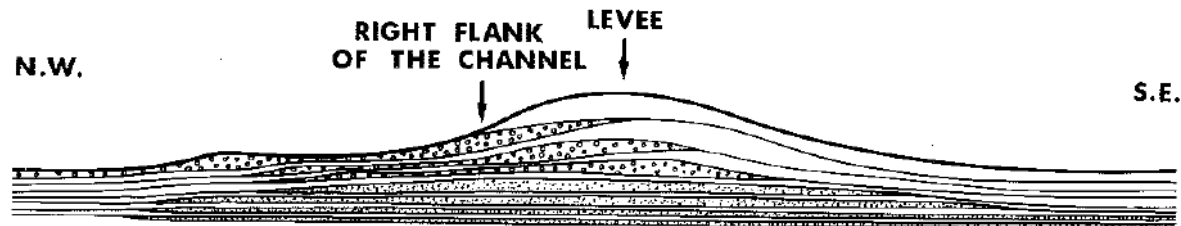
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Seismic attribute expression of differential compaction



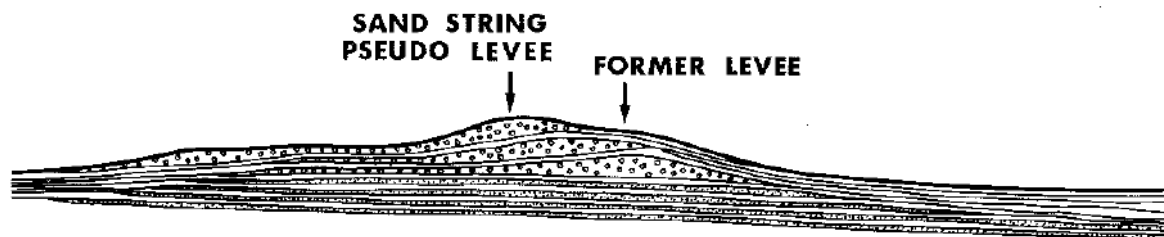
Gas sand at 1850m in a submarine fan in Frigg Field, one of the world's largest offshore gas fields.

a) BEFORE COMPACTION



Levee at the time of deposit

b) AFTER COMPACTION



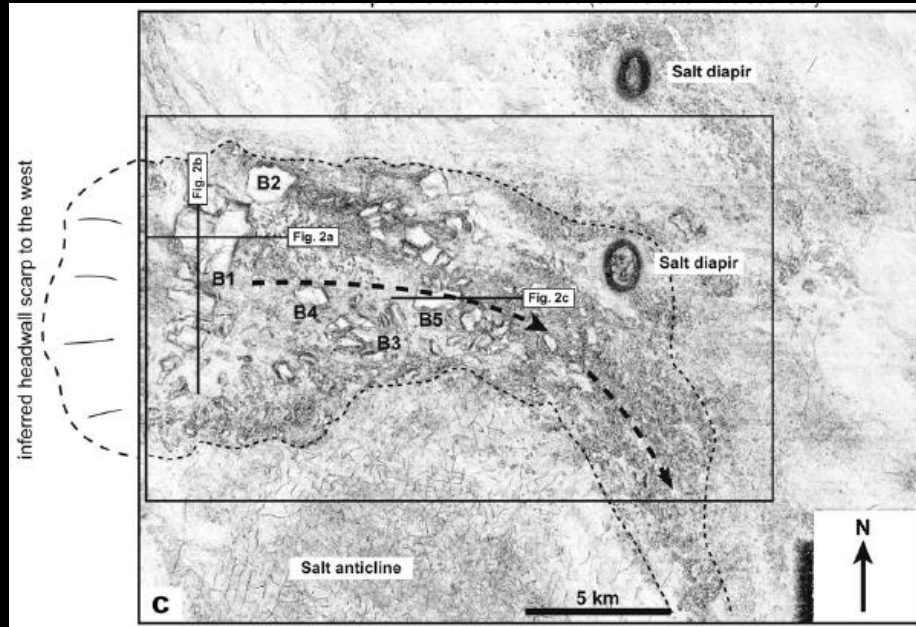
Same levee after compaction

Compaction of the deep-sea –fan channel (Hertier et al. 1980)

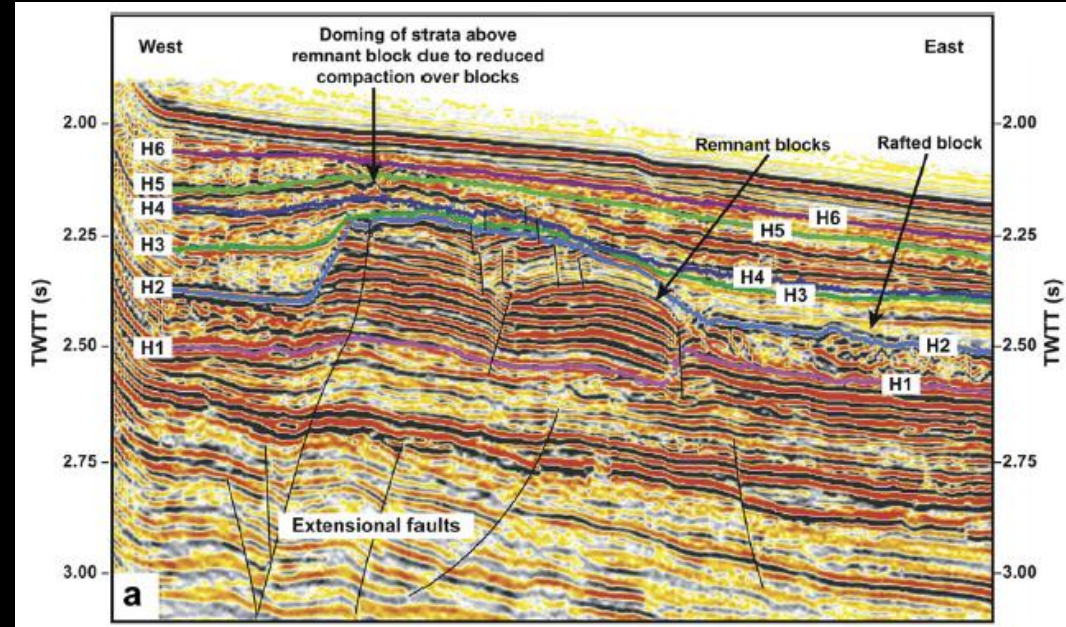
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Seismic attribute expression of differential compaction



Coherence map of a slice 324 ms below the seafloor, crossing the basal Mass Transport Deposit and adjacent marginal strata. Arrows show the inferred path of failed strata when transported down slope.



East-West seismic profile crossing remnant blocks and overlying strata. Note the modern seafloor strata deformed above the remnant blocks.

Mass transport deposits offshore Brazil (Alves and Cartwright (2010))

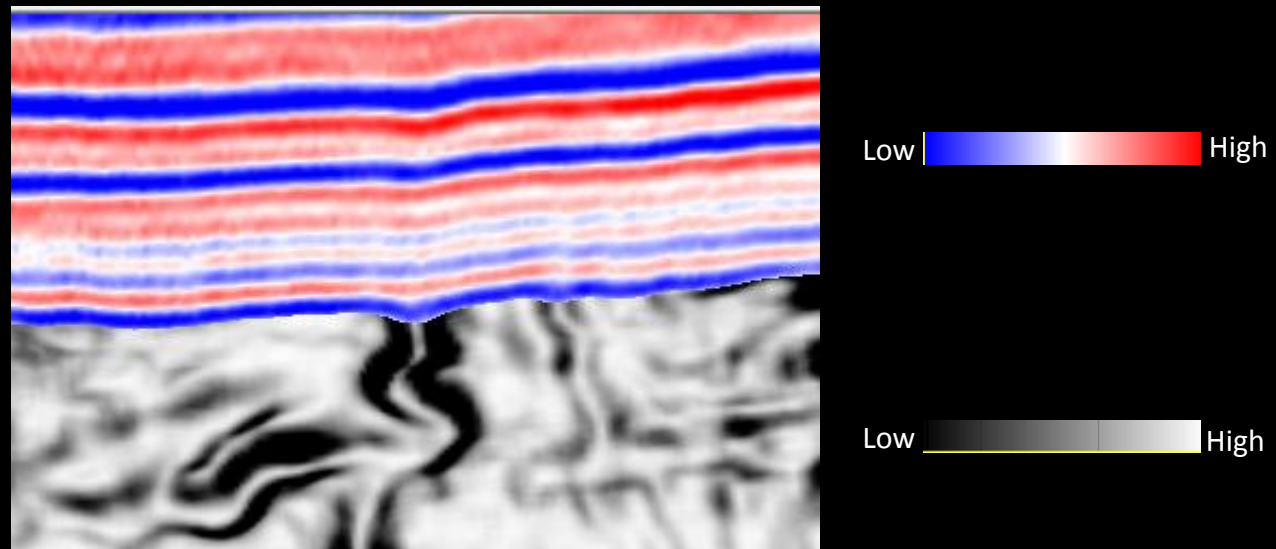
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Differential compaction:

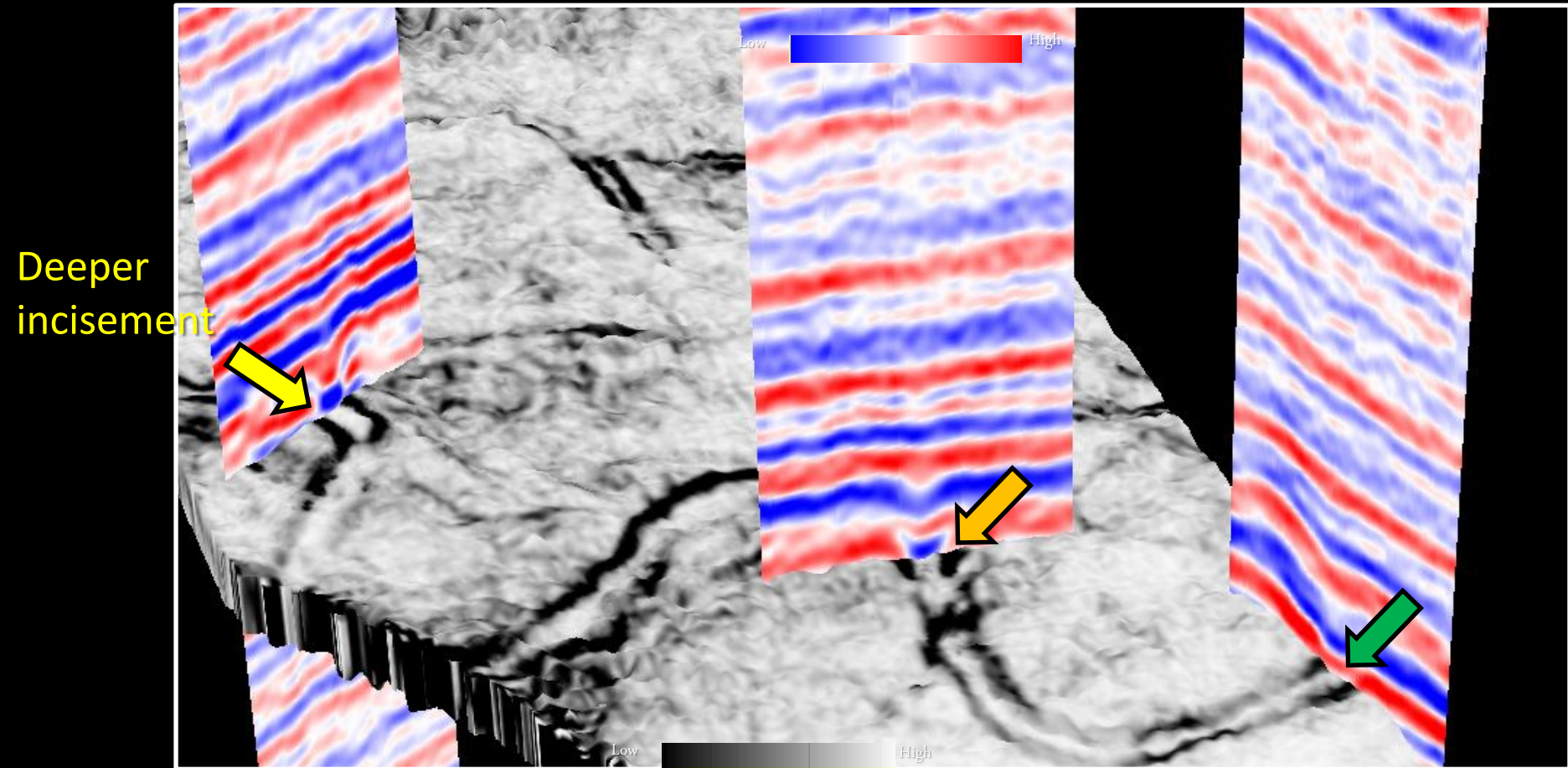
- Geometric attributes such as coherence and curvature are routinely used in mapping structural features such as folds and faults and flexures.
- As differential compaction gives rise to deformation of overlying surfaces, such surfaces can be used to map underlying features of interest.
- We show **examples of positive relief, sand-filled channel features in a shale matrix**, as well as **negative relief, compacted Winnipegosis carbonate buildups in a salt matrix in WCSB**.

- **Incised paleo-channels** exhibit well defined thalwegs and levees.
- Levees may not always be very well defined in incised paleo-channels and so may or may not always be seen as sharp, crisp and prominent features.



Chair display showing an incised channel on a coherence stratal slice and its seismic signature. *We interpret the sag over the channel to indicate that it contains more shale than the surrounding matrix.*

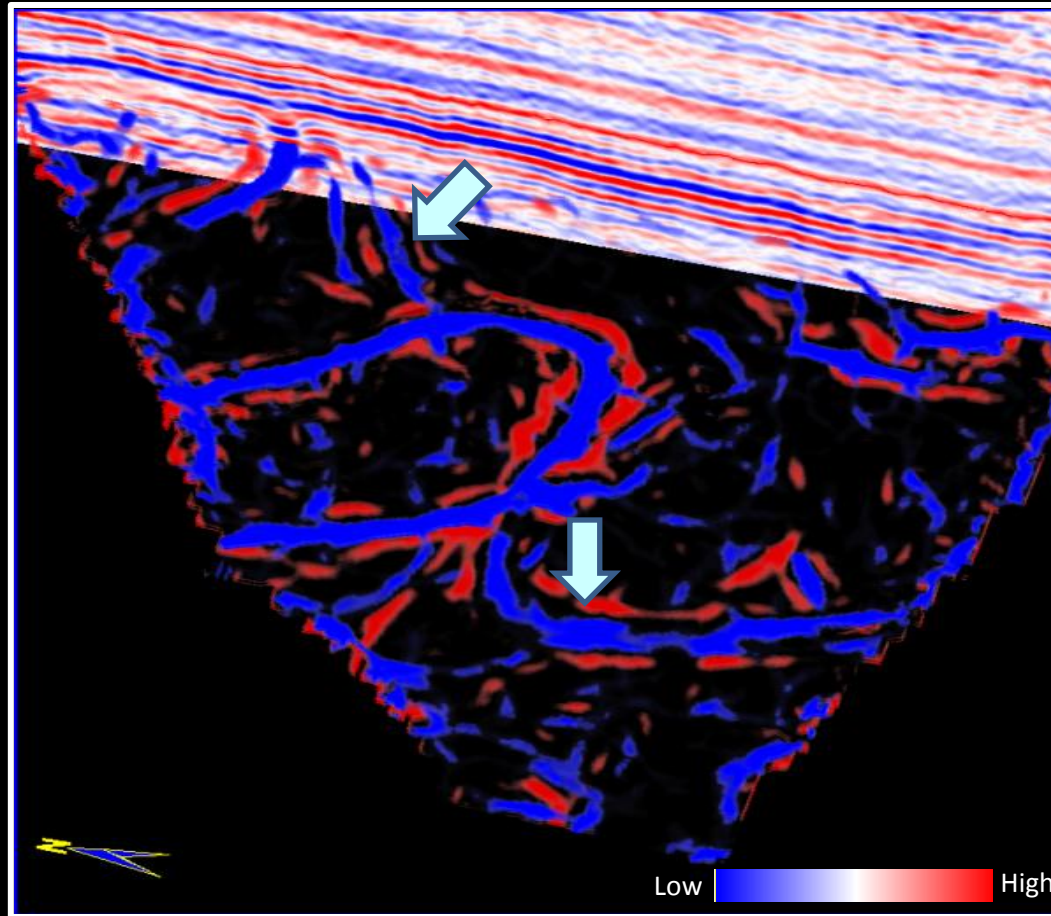
Seismic attribute expression of differential compaction



Stratal slice through a coherence volume exhibiting an incised meandering channel with representative vertical slices through seismic sections orthogonal to the channel axis. Note the deeper incisement indicated by the yellow and orange arrow resulting in a stronger coherence anomaly than that indicated by the green arrow.

Seismic attribute expression of differential compaction

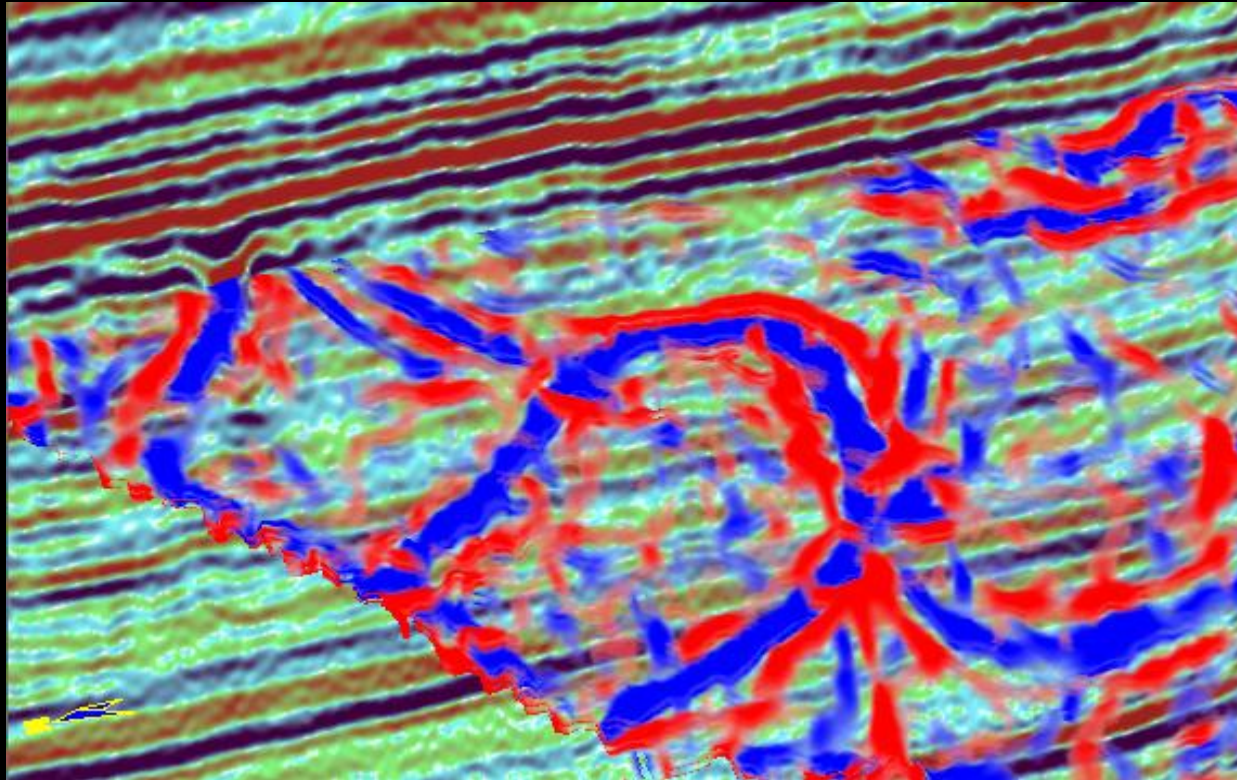
Sediments within the channel have undergone more compaction and give rise to a strong negative curvature anomaly along its axis (in blue).



Levees and channel edges appear as ridges and give rise to strong positive curvature anomalies (in red).

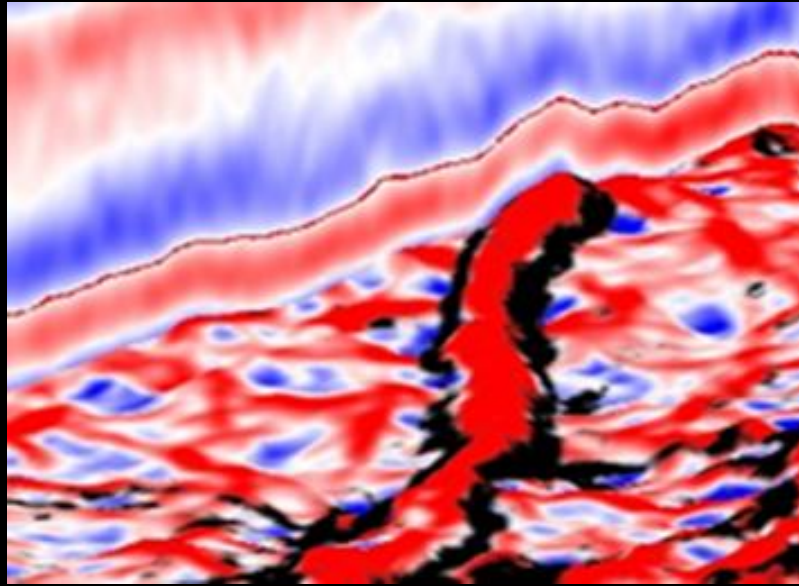
A chair display of the same volume shown in the previous slide showing a vertical slice through seismic amplitude and a thin strat cube through co-rendered most-positive and most-negative curvature volumes where moderate curvature values are rendered transparent.

Seismic attribute expression of differential compaction



A chair display showing the vertical section as seismic and the horizontal section as the curvature (positive and negative) strat-cube. Notice the base of the incised channel is seen clearly in blue (most-negative curvature) and the levees or the edges of the channel are seen defined by the red boundary (most-positive curvature). Other values of the curvature have been made transparent for visualization.

Paleo-channels with differential compaction.



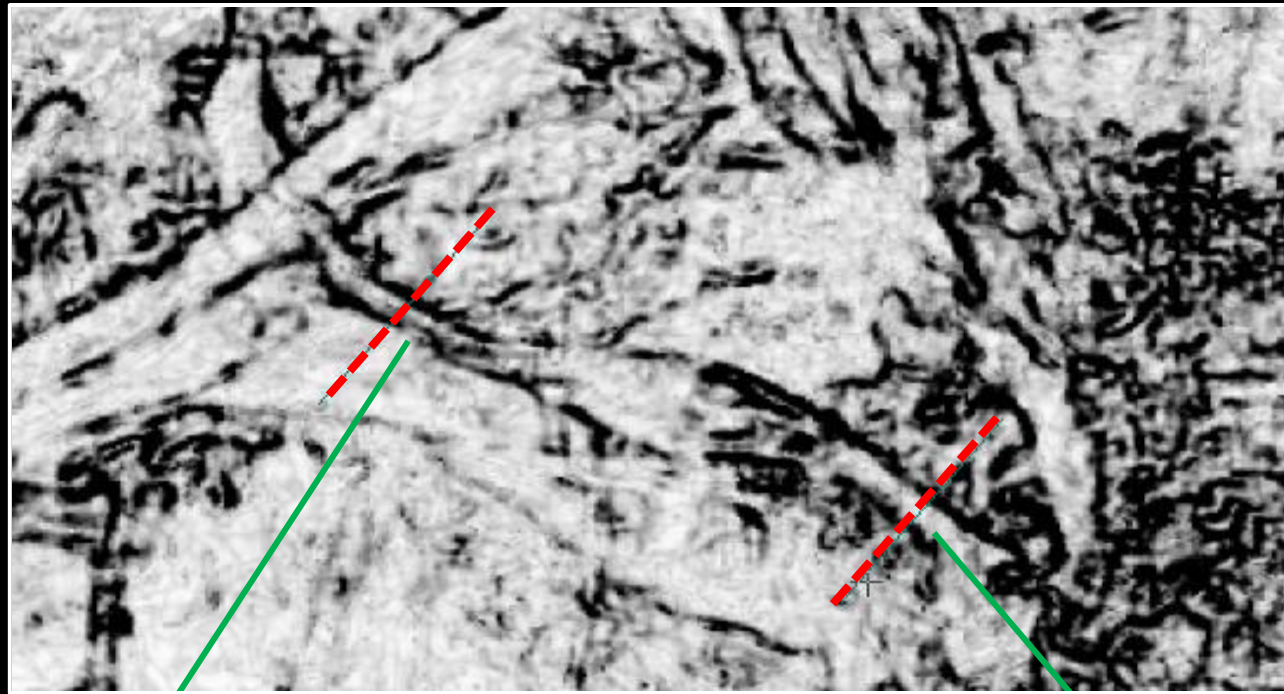
Bulk of the sandstone within the channel does not undergo as much compaction as the sediments outside it.

This leads to positive relief feature over the length of the channel and a slight negative relief features at the edges of the channel.

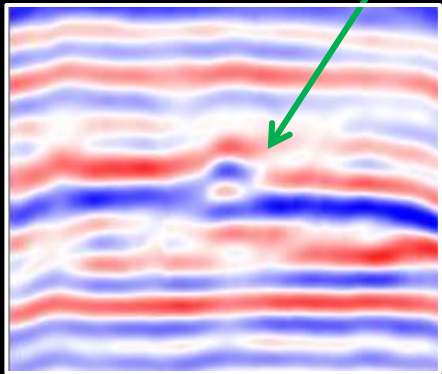
Seismic attribute expression of differential compaction

Paleo-channels with differential compaction.

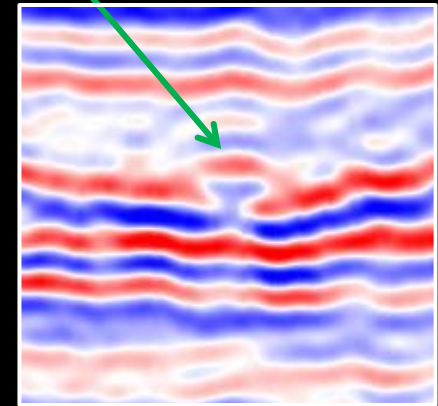
Coherence attribute picks up the edges of such a channel.



Low  High

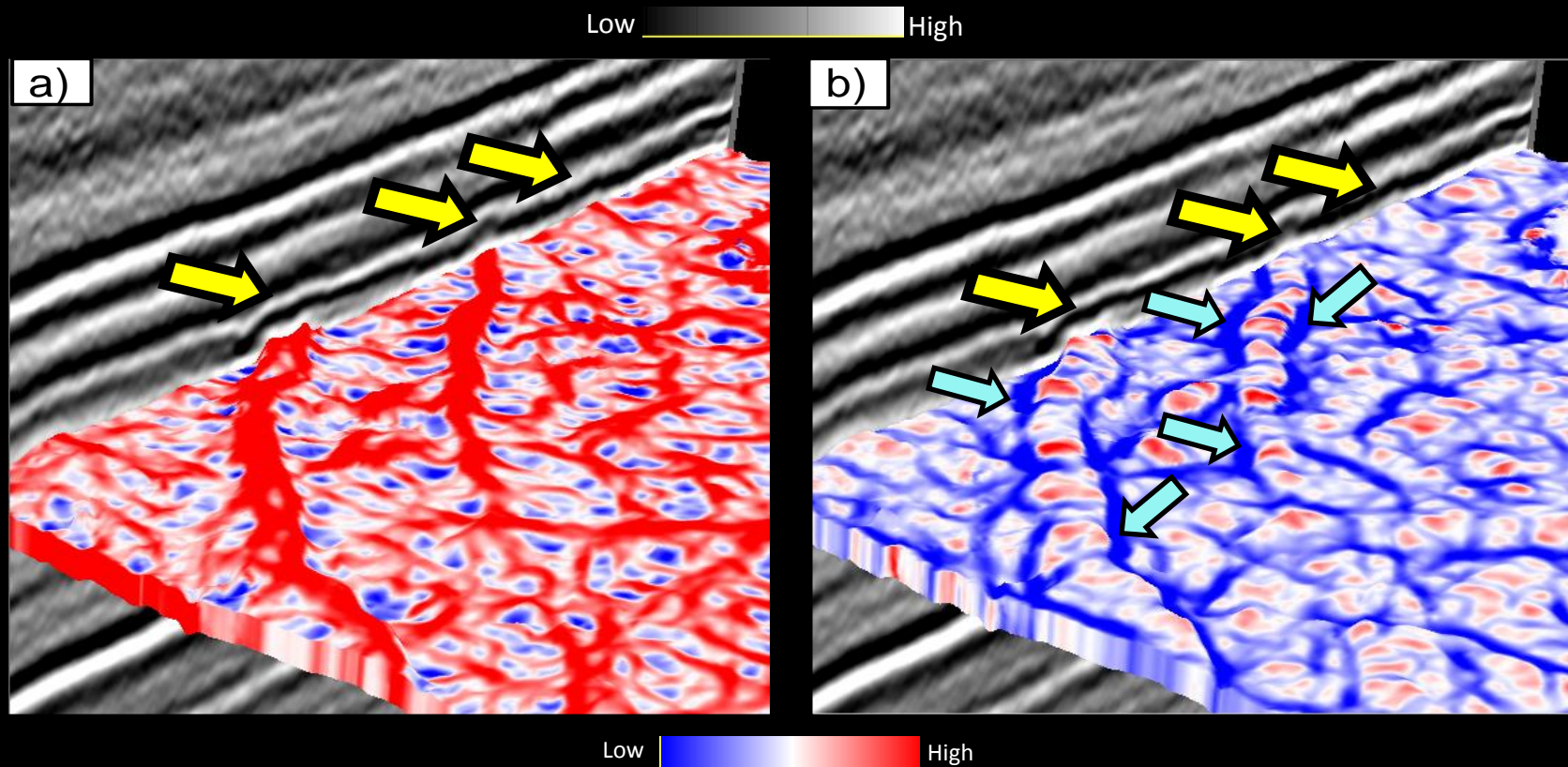


Low  High



Coherence time slice showing a main channel running NW-SE which exhibits differential compaction as seen on the seismic signatures at two points as indicated.

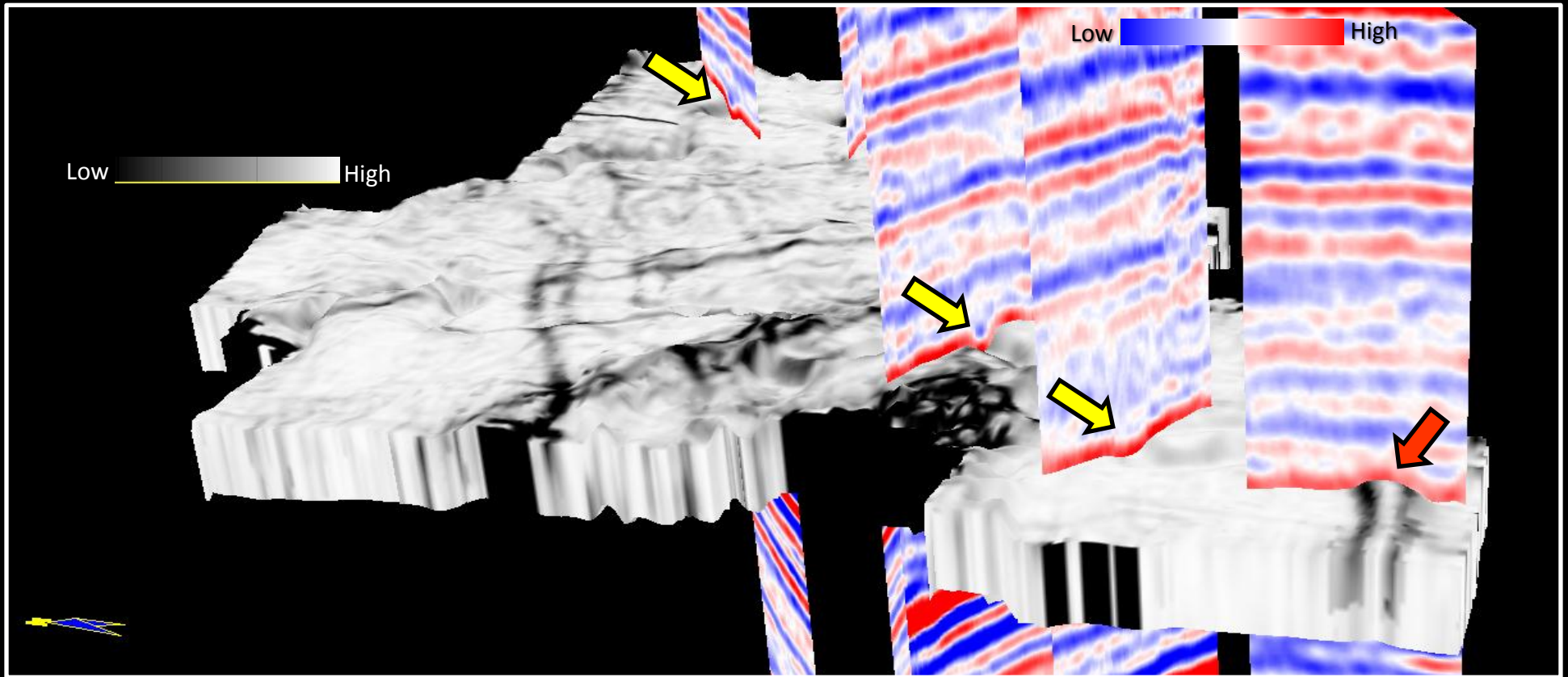
Seismic attribute expression of differential compaction



Chair display of seismic amplitude and stratal slices through (a) most-positive and (b) most-negative curvature showing differential compaction over a complex channel system.

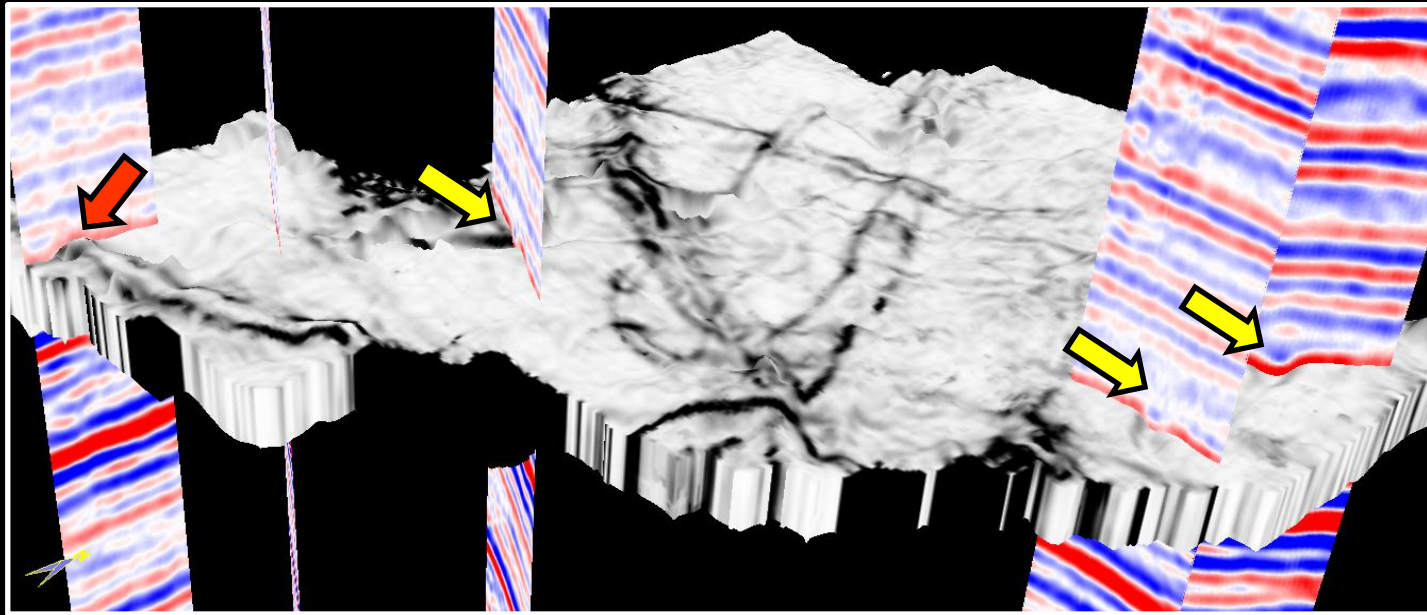
The most-positive curvature image exhibits the classic dendritic channel pattern. Structural highs with less compaction over the channel axes indicate that these channels are more likely filled with sand.

Seismic attribute expression of differential compaction



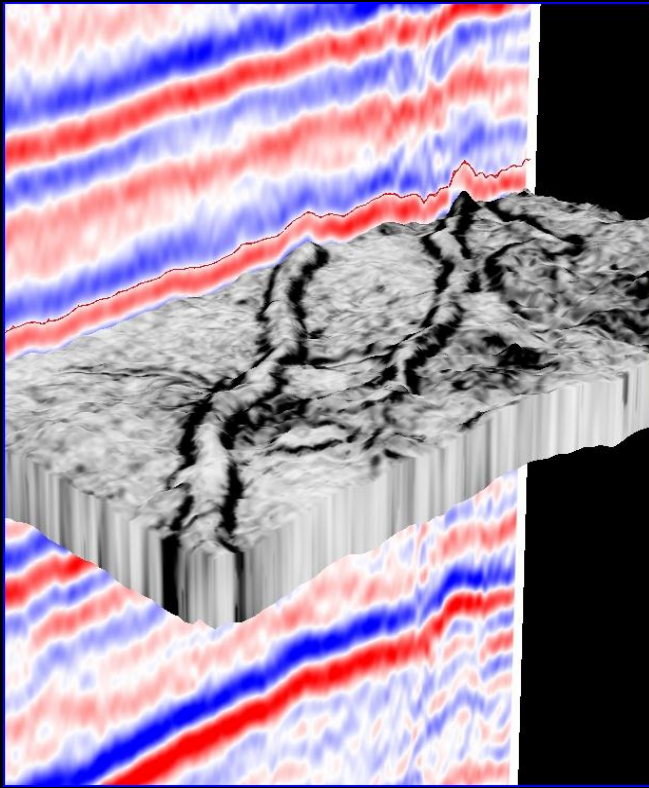
Chair display for a coherence strat-cube and the vertical seismic sections showing both types of channels, the incised channels indicated with the **yellow arrows** and the channel that exhibits differential compaction as indicated with the **orange arrow**.

Seismic attribute expression of differential compaction

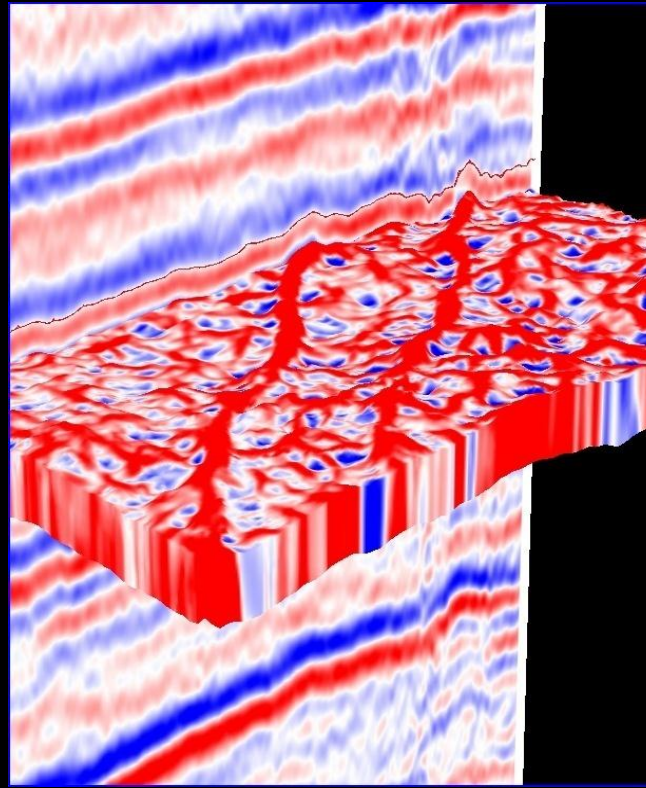


Chair display for a coherence strat-cube and the vertical seismic sections showing both types of channels, the incised channels indicated with the **yellow arrows** and the channel that exhibits differential compaction as indicated with the **orange arrow**.

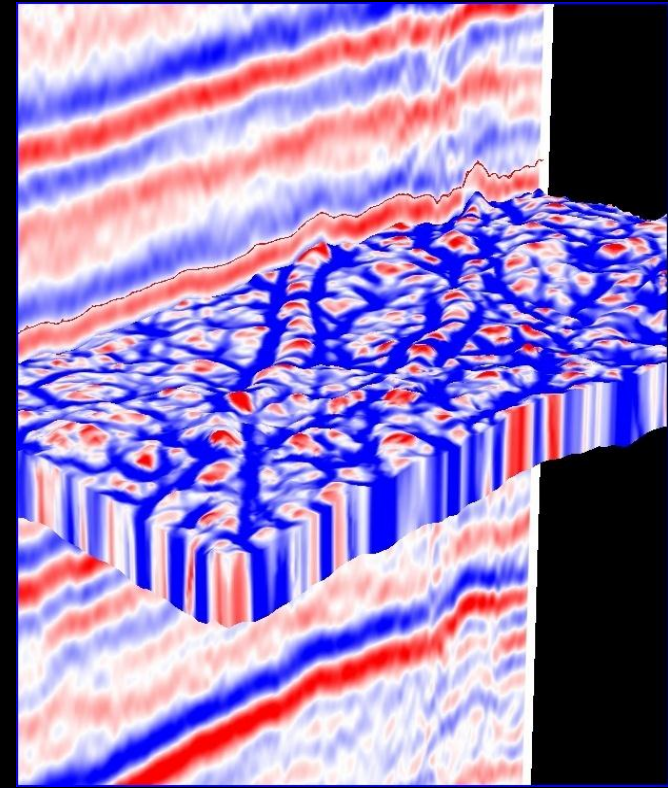
Composite attribute volume visualization



Strat-cube from the coherence attribute seen here in a 3D chair view

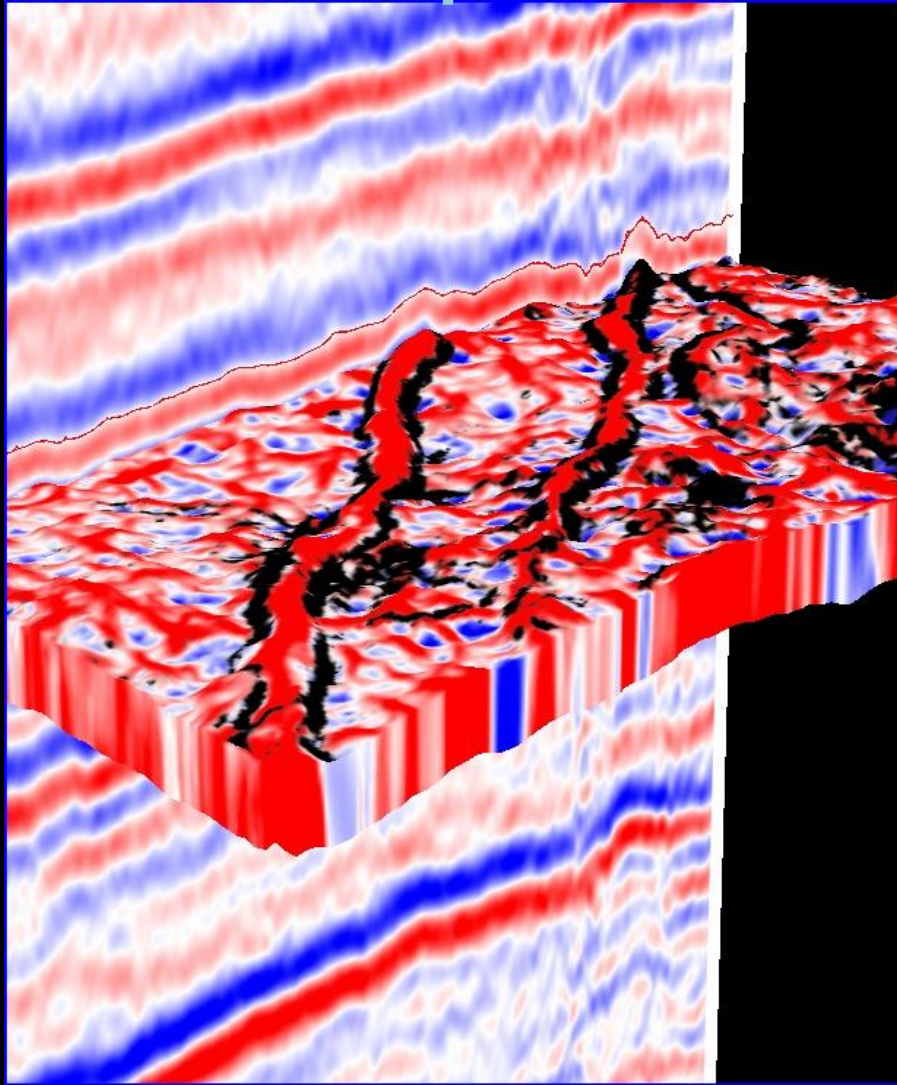


Strat-cube from the most-positive curvature attribute seen here in a 3D chair view

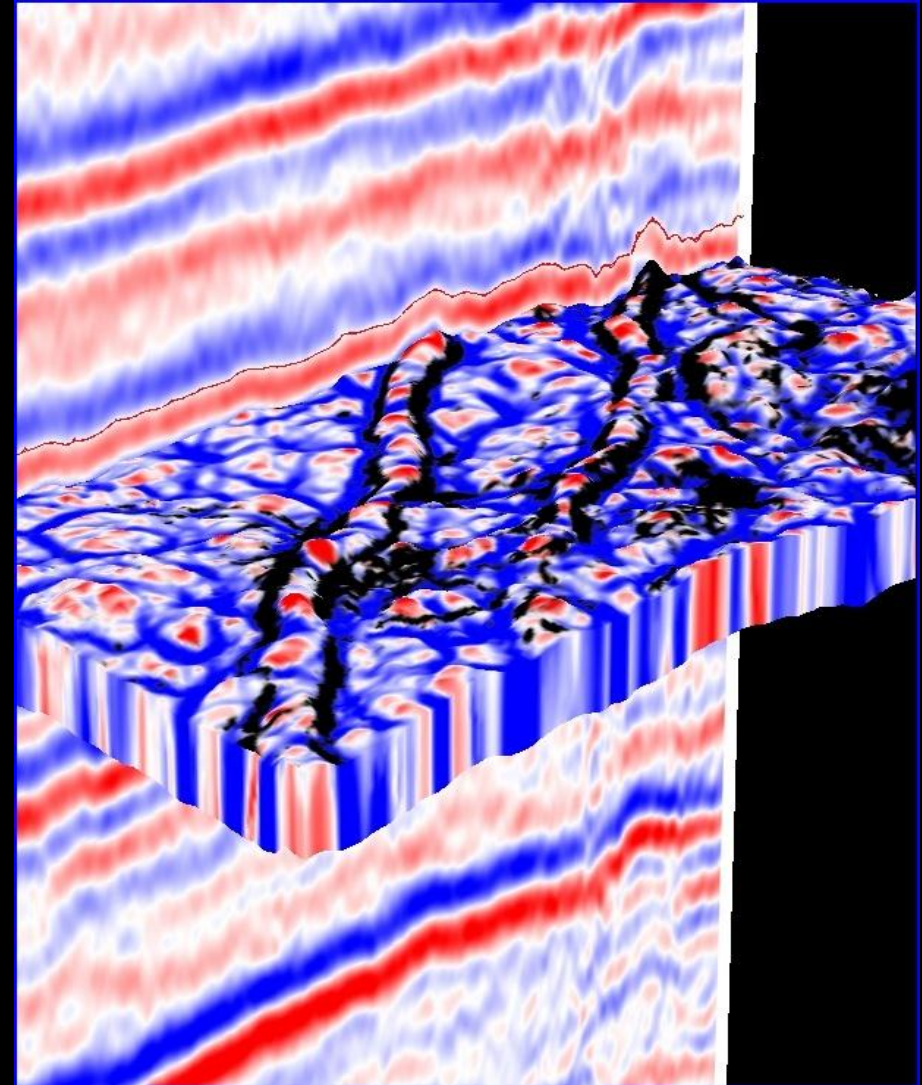


Strat-cube from the most-negative curvature attribute seen here in a 3D chair view

Composite attribute volume visualization



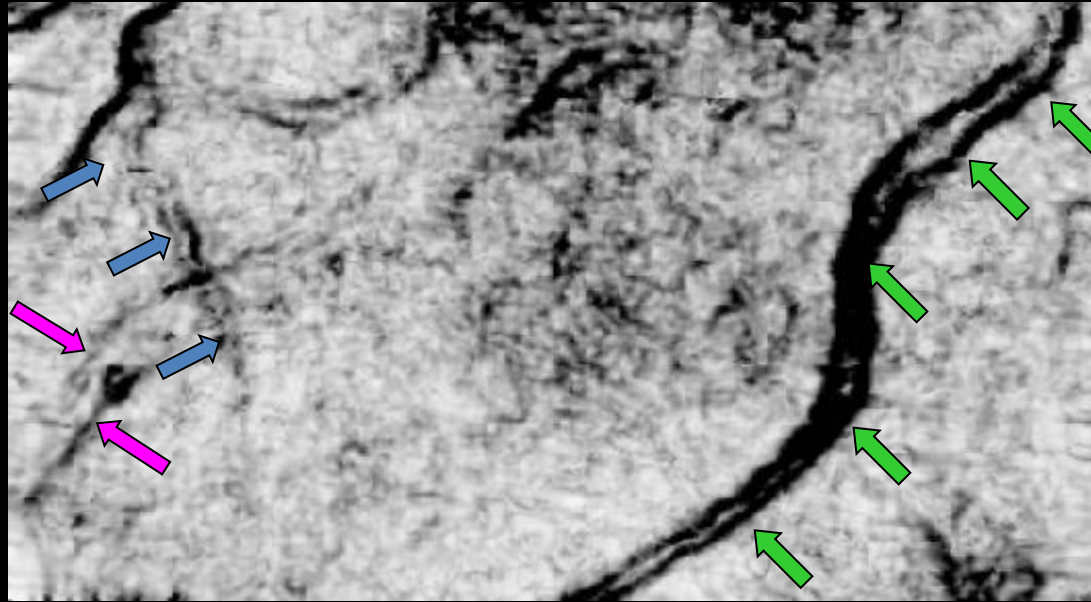
Strat-cube from the most-positive curvature attribute co-rendered with coherence seen here in a 3D chair view



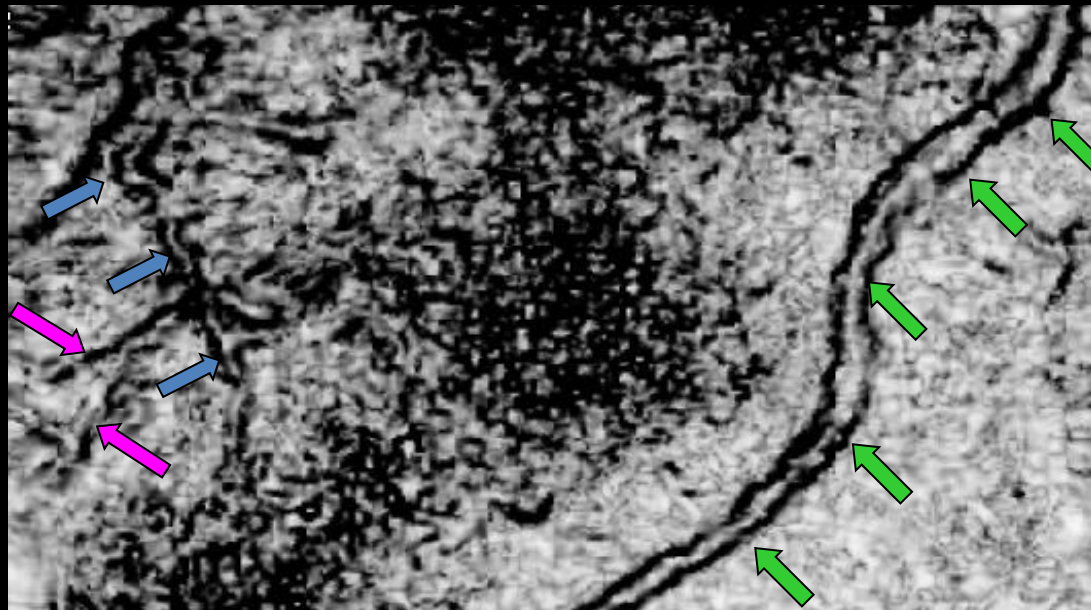
Strat-cube from the most-negative curvature attribute co-rendered with coherence seen here in a 3D chair view

Seismic attribute expression of differential compaction

**Frequency
enhancement
of data**



Coherence on input
data

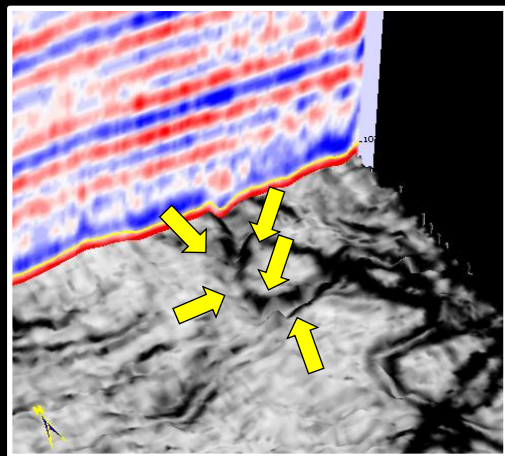


Coherence on input
data with thin-bed
reflectivity and filtering

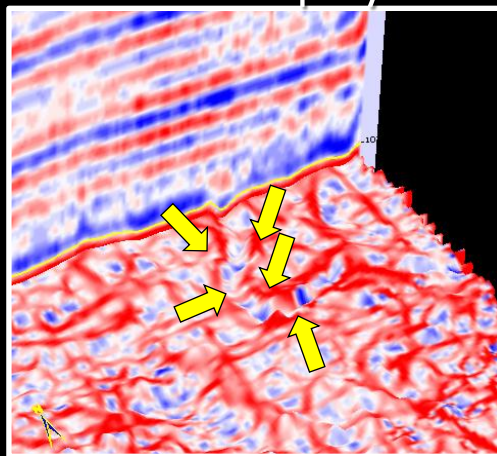
1.5 km

Seismic attribute expression of differential compaction

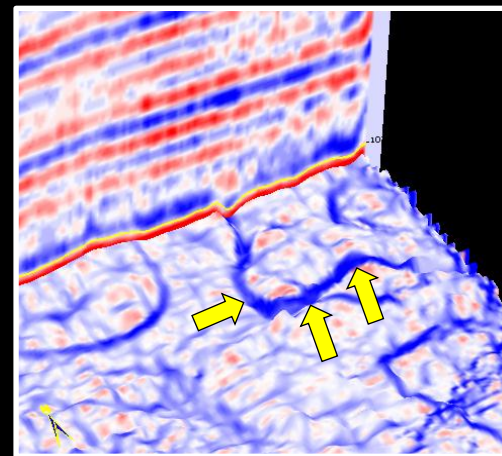
Chair displays



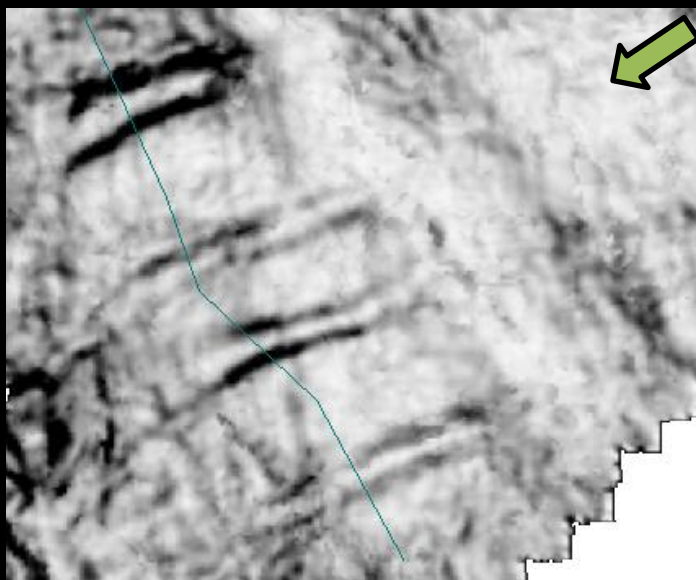
Coherence



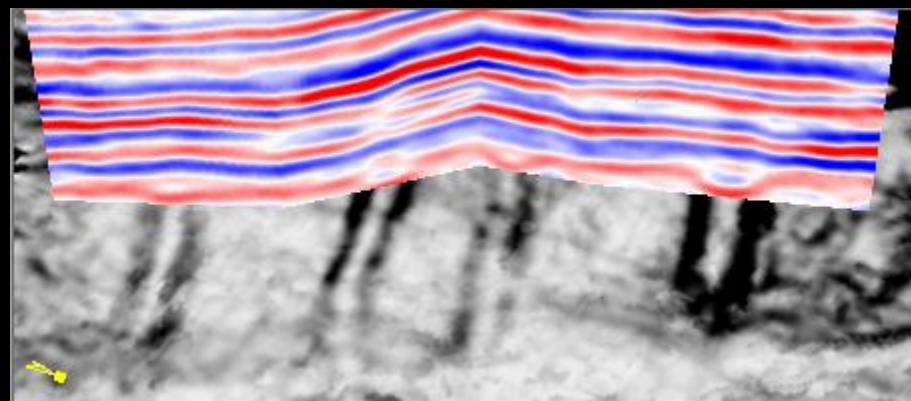
Most-positive curvature



Most-negative curvature

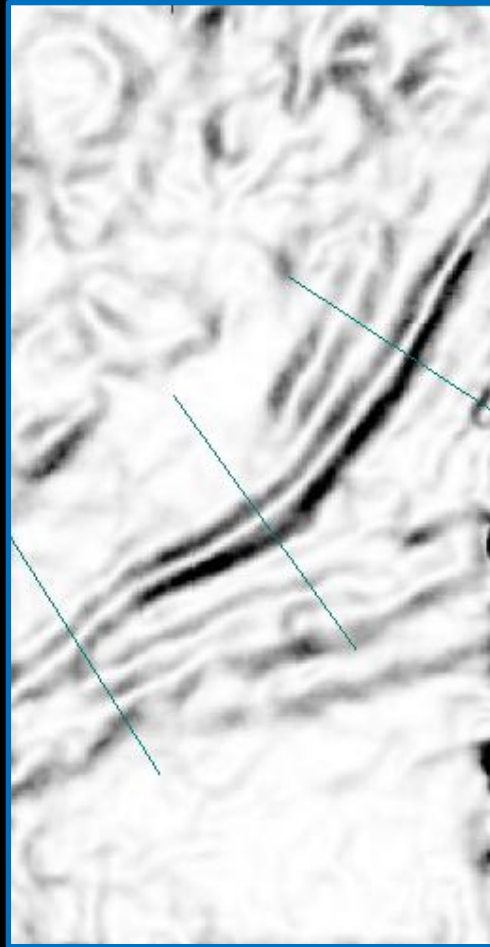


Zig-zag line through the
coherence strat-slice

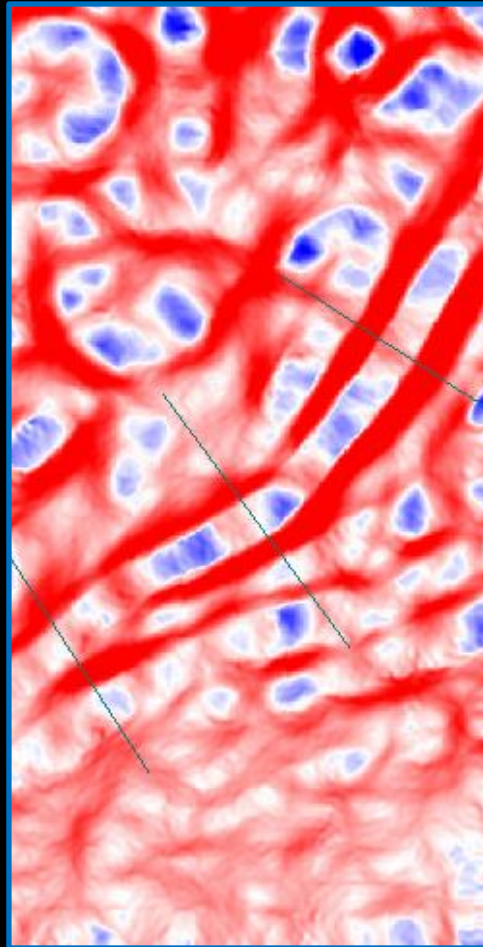


Chair display for the zig-zag line and the
coherence strat-slice

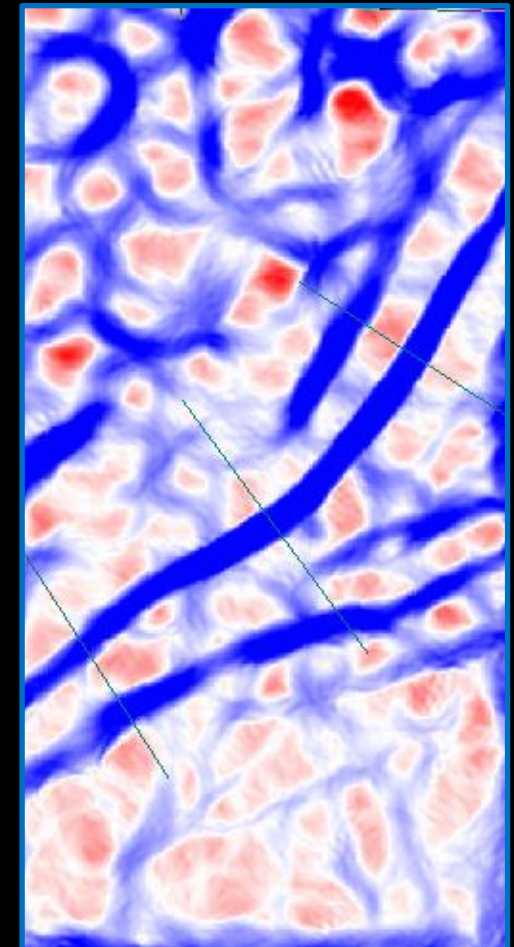
Seismic attribute expression of differential compaction



Coherence



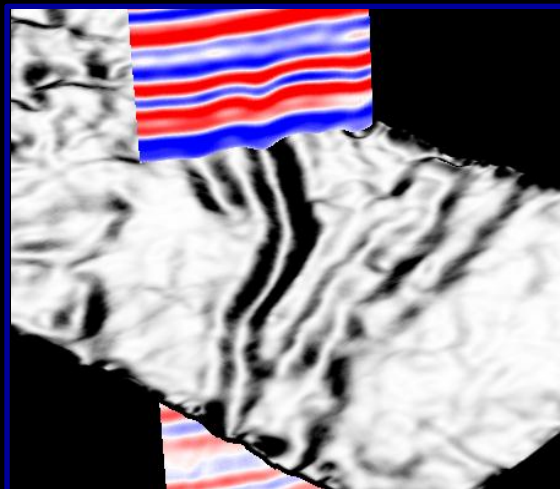
**Most-positive
curvature**



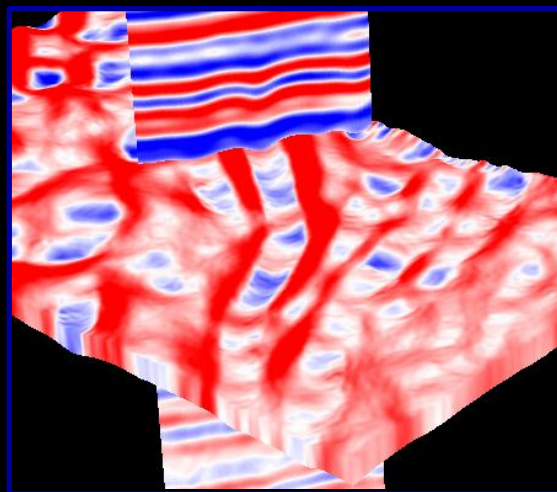
**Most-negative
curvature**

Strat-cube displays

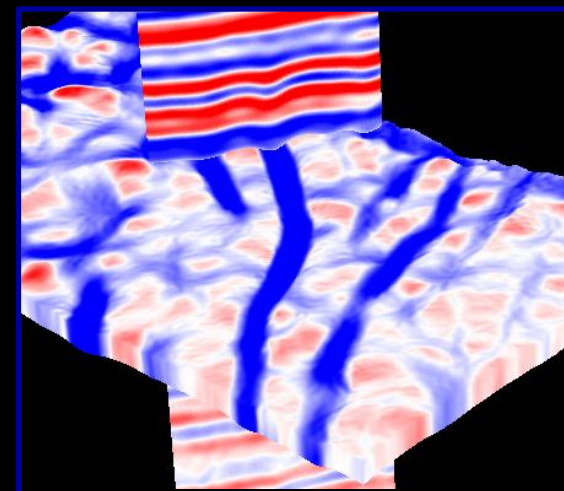
Seismic attribute expression of differential compaction



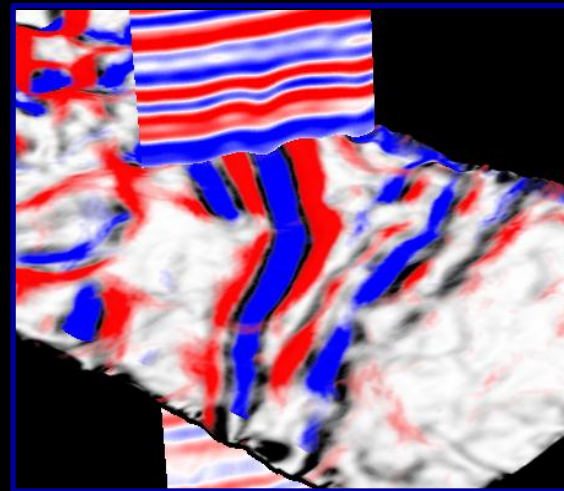
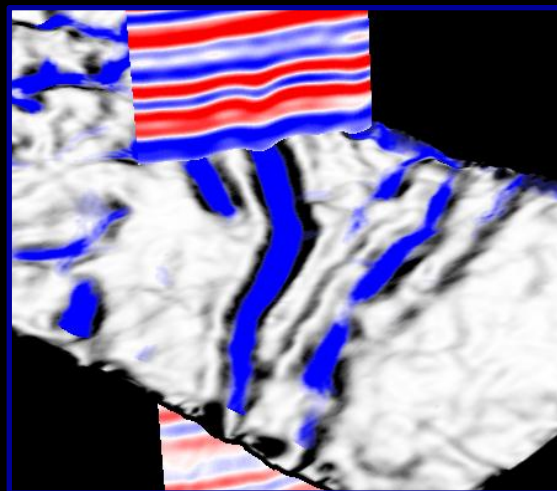
Coherence



Most-positive curvature



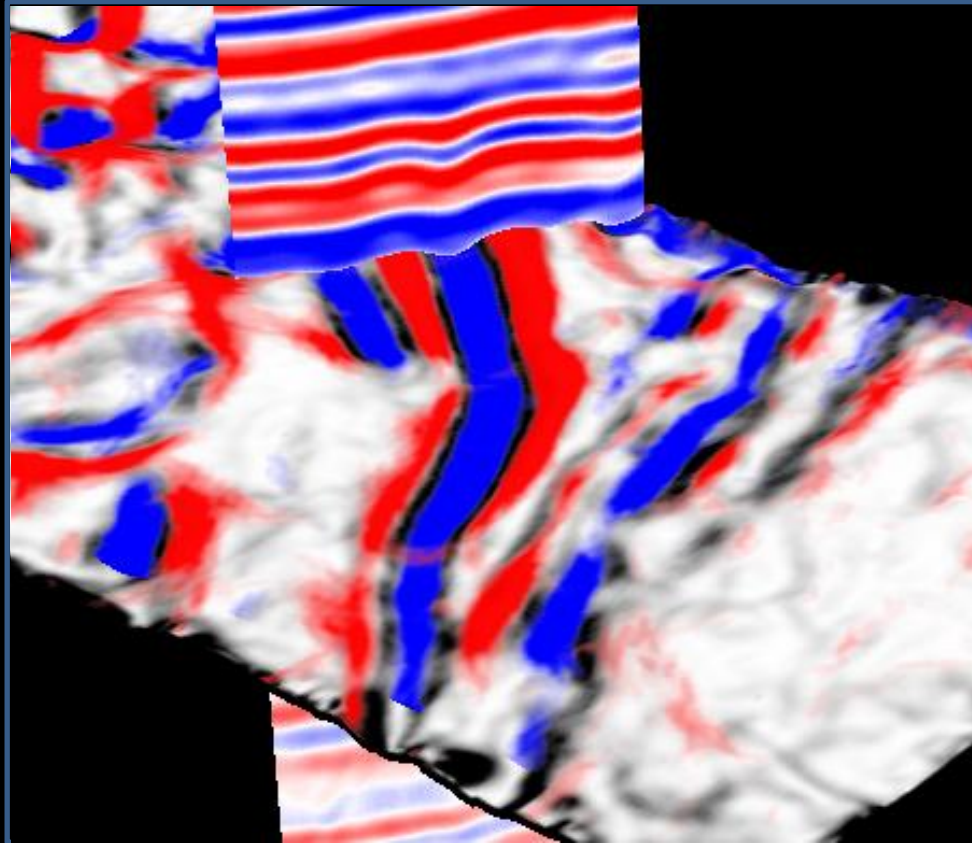
Most-negative curvature



Merge of most-positive and most-negative curvature with
coherence using transparency

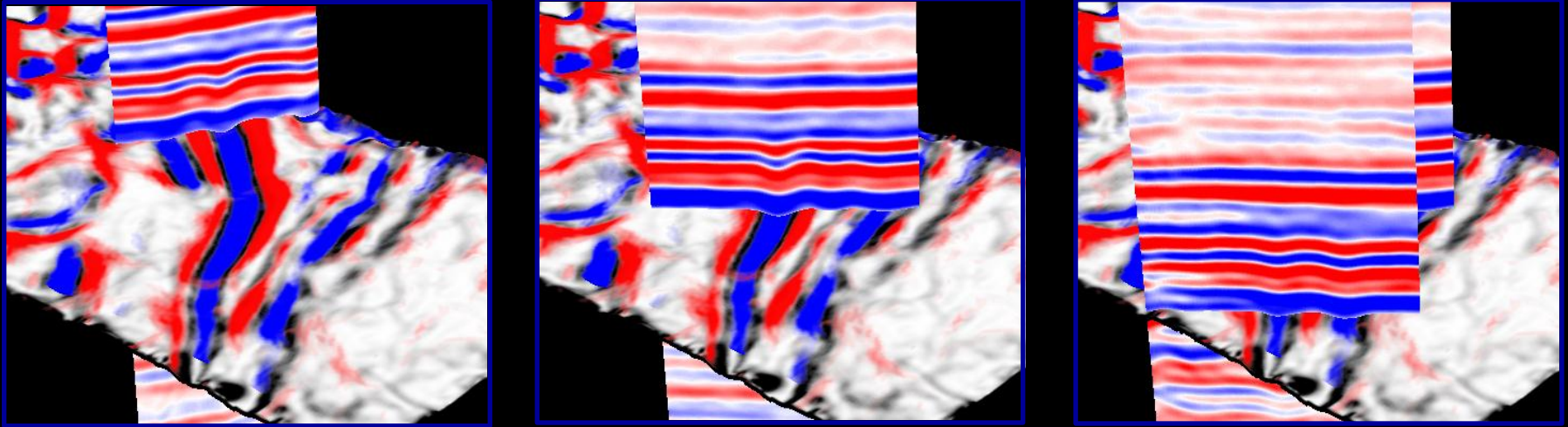
Chair displays with seismic as vertical and strat-slices from different attributes

Chair display



Merge of most-positive and most-negative curvature with coherence using transparency

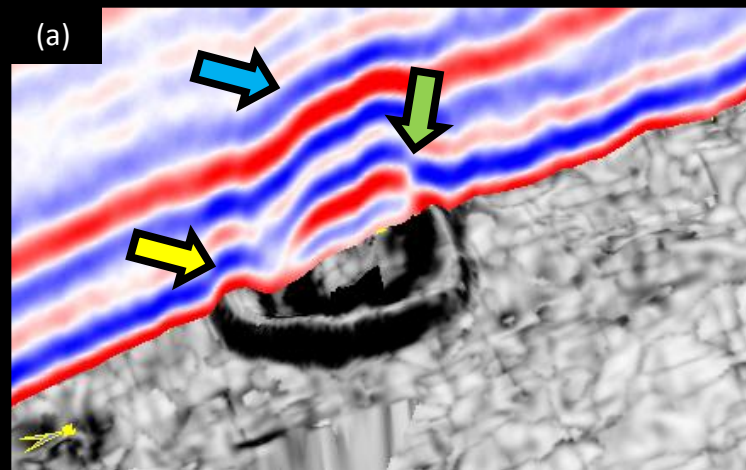
Seismic attribute expression of differential compaction



Merge of most-positive and most-negative curvature with coherence using transparency
with the vertical seismic profiles at different positions

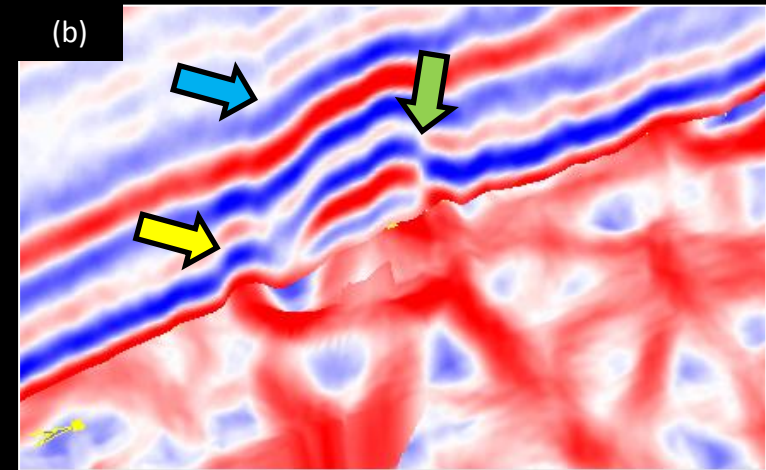
Chair displays

Seismic attribute expression of differential compaction



Low High

Coherence



Low High

Most-positive curvature

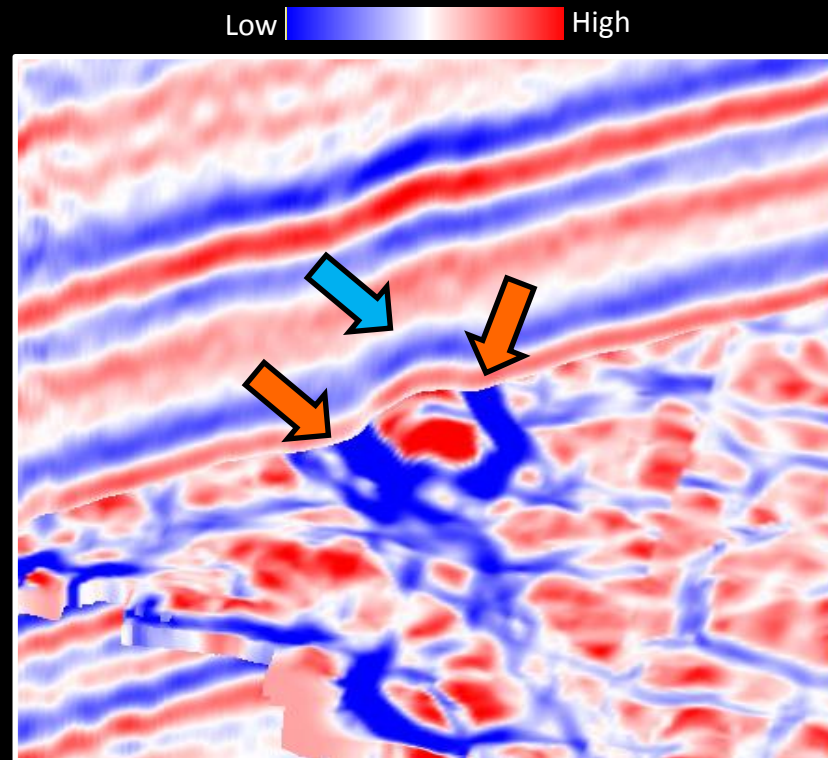
Chair displays of seismic amplitude and stratal slices through coherence and most-positive curvature showing differential compaction over a carbonate reef.

Yellow arrow indicates the rim or atoll.

Strong compaction often gives rise to discontinuities (**green arrow**).

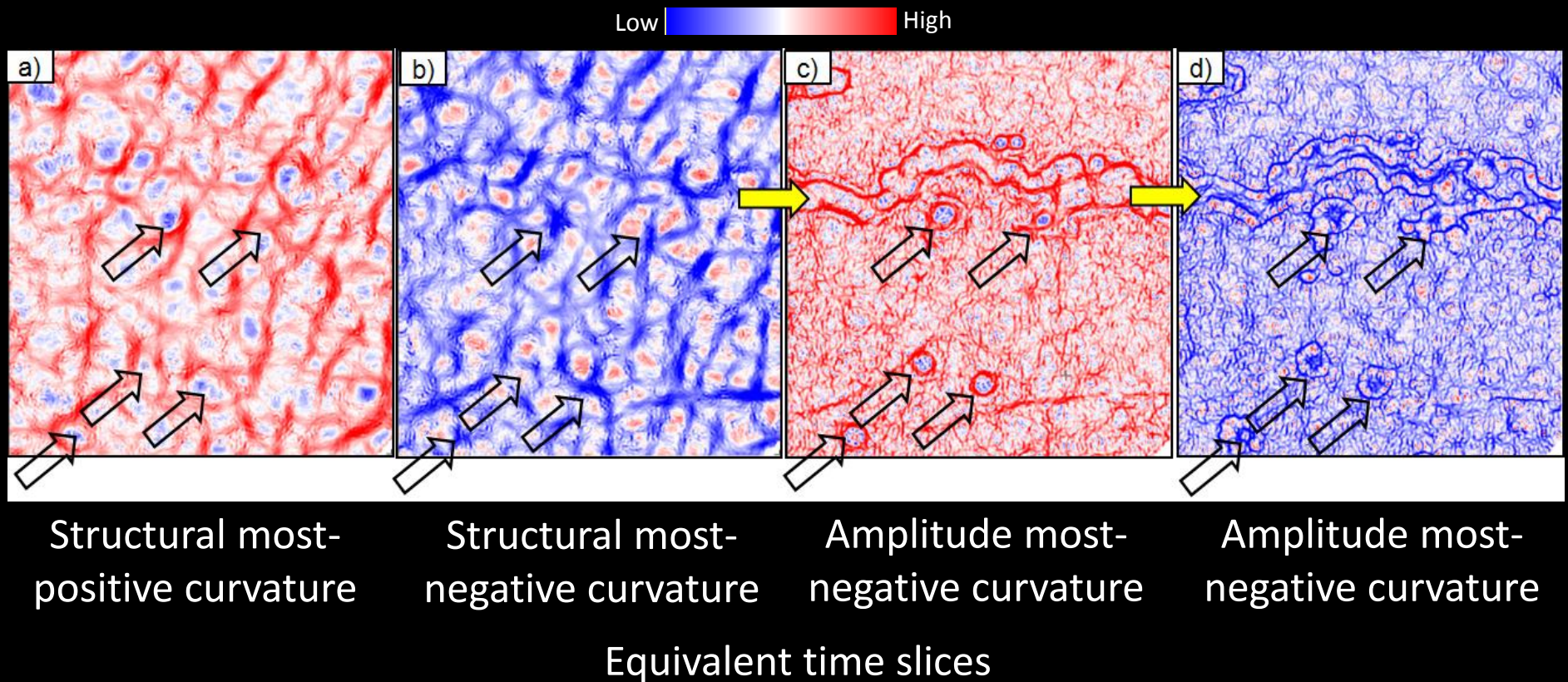
Note compaction drape well above the structure (**blue arrow**).

Seismic attribute expression of differential compaction



Chair display showing the boundary of the reef on the most-negative curvature strat-
cube (**orange arrows**), with the drape over the crest of the reef (**blue arrow**) seen
clearly on the vertical seismic.

Seismic attribute expression of differential compaction

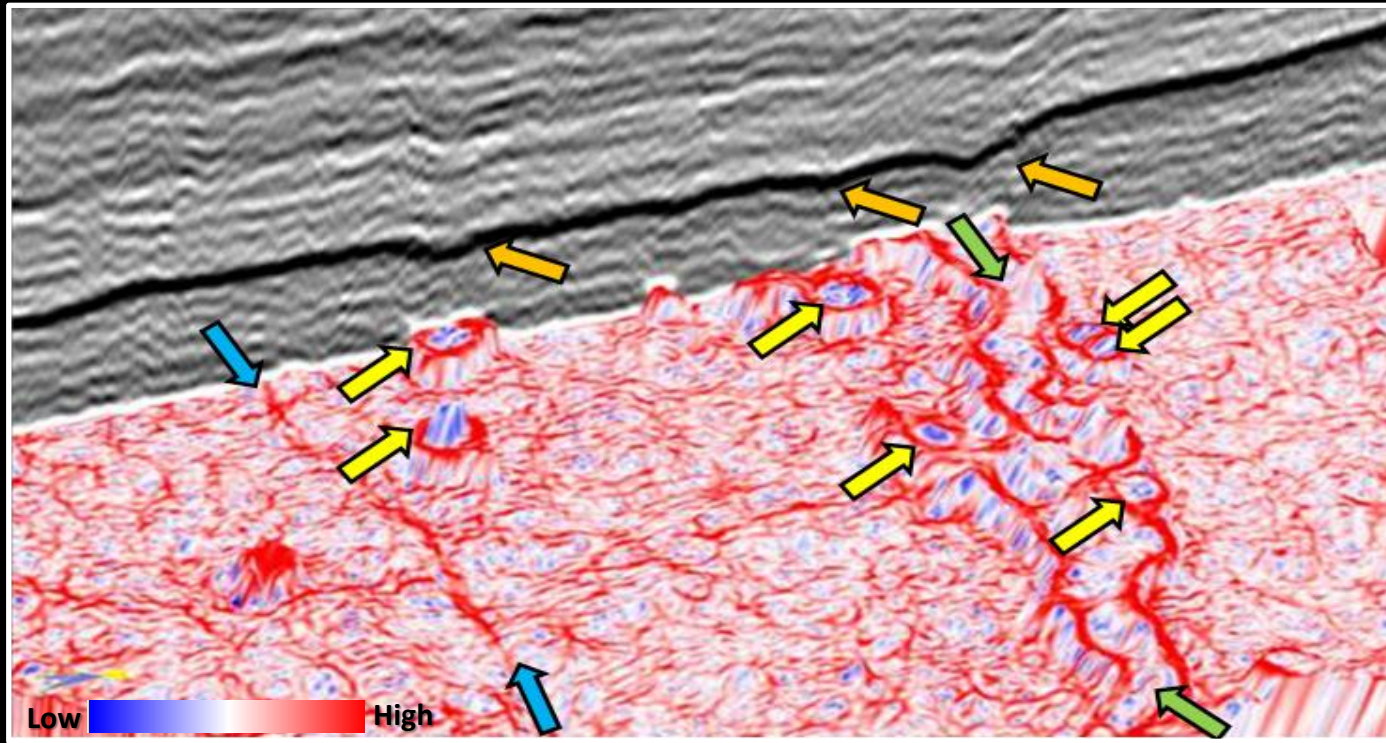


Circular features indicated by hollow arrows are Winnepegosis reefs that appear as low amplitude structural lows.

East-west-trending feature indicated by yellow arrows is also a reef.

(Data courtesy of Fairborne Energy Ltd., Calgary.)

Seismic attribute expression of differential compaction



Vertical slice through seismic amplitude and horizon slice along the top Winnipegosis through a most-positive principal curvature volume.

Orange arrows indicate structural sags at the top of the Prairie Evaporite section due to differential compaction over the core of the underlying Winnipegosis reefs.

Yellow arrows on the horizon slice indicate rim highs (in red) and reef-center lows (in blue) described on 2D sections by Anderson and Franseen (2003).

Green arrows indicate a long amalgamated reef trend that may have been controlled by growth on a paleo-high such as the structural feature indicated by the cyan arrows. Data courtesy of Fairborne Energy Ltd., Calgary.

Conclusions

1. By understanding the depositional environment, differential compaction can serve as a lithology indicator.
2. Channel features are often identified by their meandering and/or dendritic morphology on maps.
3. Positive curvature anomalies over channel features indicate that these channels are filled with a lithology that is less compactable than the surrounding matrix, indicating the presence of sand.
4. Amplitude curvature could indicate the features somewhat better than the conventional structural curvature that is often used.

Conclusions

A clear understanding of the depositional environment

- and the effects of differential compaction,
- coupled with high-quality 3D seismic, and
- a modern seismic geomorphology workflow

can facilitate rapid interpretation of subtle, perhaps overlooked, geologic features of interest.

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THANK YOU for your attention...