Seismic Facies Analysis Using Generative Topographic Mapping*

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Abstract

Seismic facies analysis is commonly carried out by classifying seismic waveforms based on their shapes in an interval of interest. It is also carried out by using different seismic attributes, reducing the dimensionality of the input data volumes using Kohonen's self-organizing maps (SOM), and organizing it into clusters on a 2D map. Such methods are computationally fast and inexpensive. However, they have shortcomings in that there is no definite criteria for selection of a search radius and the learning rate, as these are parameters dependent on the input data. In addition, there is no cost function that is defined and optimized and so usually the method is deficient in providing a measure of confidence that could be assigned to the results. Generative topographic mapping (GTM) has been shown to address the shortcomings of the SOM method and has been suggested as an alternative to it. GTM analysis does a nonlinear dimension reduction in latent space, and provides probabilistic representation of the data.

We demonstrate the application of GTM analysis to a 3D seismic volume from central Alberta, Canada, where we focus on the Mannville channels at a depth of 1150 to 1230 m that are filled with interbedded units of shale and sandstone. On the 3D seismic volume, these channels show up at a mean time of 1000 ms plus or minus 50 ms. We first generate different seismic attributes and then using the sweetness, GLCM-energy, GLCM-entropy, GLCM-homogeneity, peak frequency, peak magnitude, coherence and impedance attributes we derive GTM1 and GTM2 outputs. These attributes provided the cluster locations along the two axes in the latent space to be used in the crossplotting that follows. Breaking the 2D latent space into two components allows us to use modern interactive crossplotting tools. While GTM1 shows the definition of the edges very well for the channels, GTM2 exhibits the complete definition of the channels along with their fill in red and blue. We show that the performance of GTM analysis is more encouraging than the simplistic waveform classification or the SOM multi-attribute approach. We expect that by using constrained GTM analysis with the help of well log data, the facies patterns we have derived using the unconstrained GTM method used here would be further tightened and made more distinct.

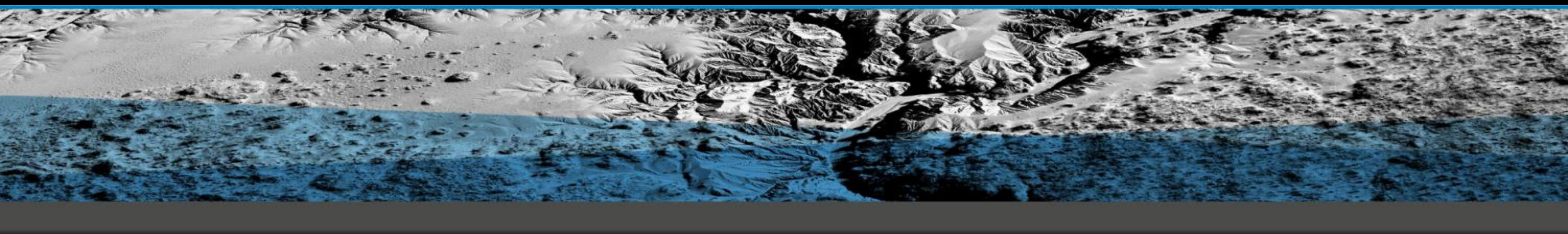
References Cited

Coléou, T., M. Poupon, and K. Azbel, 2003, Unsupervised seismic facies classification: A review and comparison of techniques and implementation: The Leading Edge, v. 22, p. 942-953.

Roy, A., B.L. Dowel, and K.J. Marfurt, 2012, Characterizing a Mississippian tripolitic chert reservoir using 3D unsupervised seismic facies analysis and well logs: An example from Osage County, Oklahoma: 82nd Annual International Meeting, SEG, Expanded Abstracts.

Strecker, U., and R. Uden, 2002, Data mining of 3D post-stack seismic attribute volumes using Kohonen self-organizing maps: The Leading Edge, v. 21, p. 1032-1037.

Seismic Facies Analysis using Generative Topographic Mapping



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Talk delivered at AAPG Convention, Denver, 2nd June, 2015

Seismic Facies Analysis

Facies analysis: classification of subsurface strata into lithofacies

Facies characterization of stratigraphic intervals can be used

1. to interpret depositional environments;

2. to develop a sequence-stratigraphic framework for understanding production and resource potential.

Outcrop and Core Facies Analysis

Facies descriptions from available cores include

1. lithology
2. thickness
3. color
4. composition
5. grain and bedding characteristics
6. nature of the overlying and underlying contacts.

Such descriptions are available only at the location of the wells.

Seismic Facies Analysis

Facies descriptions from seismic data include reflector

1. Amplitude
2. Phase
3. Frequency
4. Continuity
5. Conformity/Parallelism
6. Dip and azimuth
7. Shape/Curvature

Such descriptions can be continuously mapped across the entire seismic survey

Seismic attributes provide such measures to the computer

Seismic Facies Analysis and Cluster Analysis

Supervised

1. Artificial Neural Networks (ANN)
2. Support Vector Machines (SVM)

Unsupervised

1. Kohonen Self Organizing Mapping (SOM)
2. Generative Topographic Mapping (GTM)

This presentation will show that by using interactive crossplotting and color definition, one can add supervision to SOM and GTM

Seismic Facies Analysis and Cluster Analysis

Kohonen Self Organizing Mapping (SOM) aims at using the available seismic data to recognize seismic facies with reference to the geologic environment.

Geometrical relationship between seismic data or derived seismic attributes and the seismic facies is usually non-linear.

Simplistic linear transformation techniques are not applicable in such an exercise.

SOM mines through the available seismic attributes and recognizing distinctive patterns that preserve the geometrical relationship between the data points that could be interpreted as facies.

Seismic Facies Analysis and Cluster Analysis

Kohonen Self Organizing Mapping (SOM)

For a 16 sample vertical waveform in an analysis time window, the samples are projected into a 1D manifold lying in 16-dimensional space, which is then displayed using a 1D color bar.

Attempts have been made to extend such analysis in to 2D or 3D subspace.

Strecker and Uden (2002) made use of seismic attributes such as amplitude envelope, bandwidth, impedance, AVO slope and intercept, dip magnitude and coherence, and projected them into 2D latent space, and plotted the results using a 2D color bar.

Roy et al. (2012) used 3D SOM multiattribute application to generate a 3D seismic facies volume.

Seismic Facies Analysis and Cluster Analysis

Kohonen Self Organizing Mapping (SOM) is easy to implement and computationally inexpensive, but has limitations.

1. There is no theoretical basis for selecting the training radius, neighborhood function and learning rate, as these parameters are data-dependent. (Bishop et al., 1998; Roy, 2013)

2. No cost function is defined that could be iteratively minimized and would indicate convergence during training.

3. No probability density is defined that could yield a confidence measure in the final results.

Generative Topographic Mapping

GTM method begins with an array of grid points on a lower dimensional latent space. (Bishop et al., 1998; Roy, 2013)

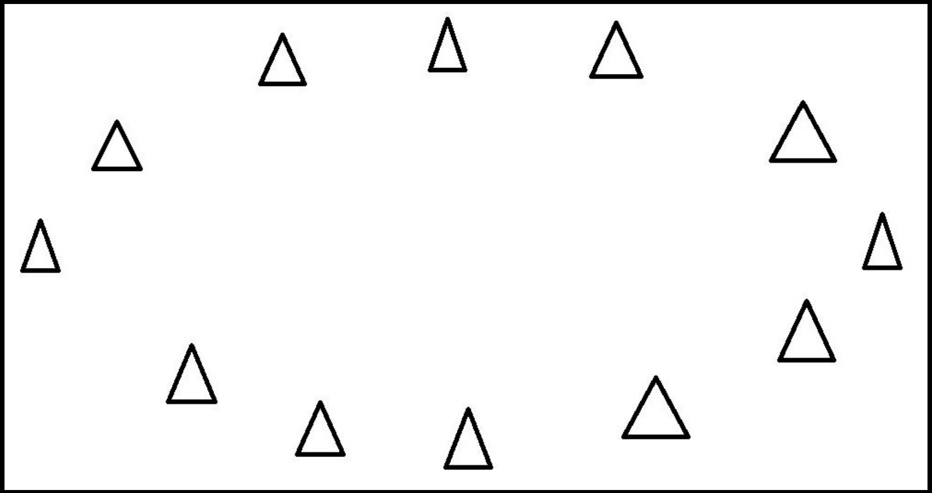
Each of the grid points are then nonlinearly mapped onto a similar non-Euclidian curved surface.

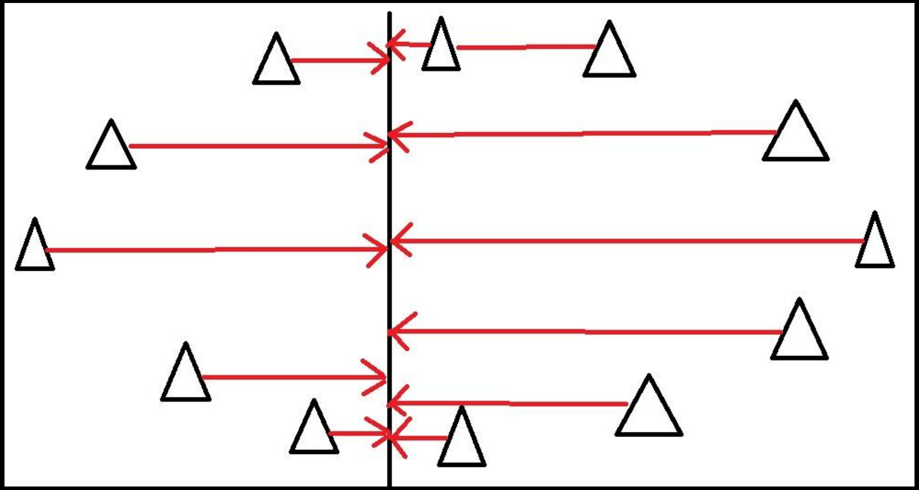
Each data vector mapped onto this space is modeled as a suite of probability density functions.

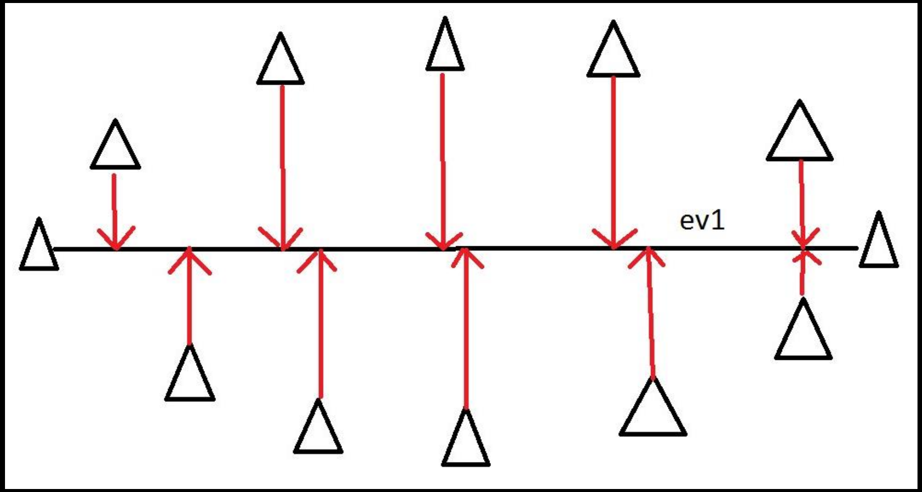
We apply GTM to a couple of datasets from Alberta, Canada.

Principal component analysis

(Represents the underlying structure in the data, or the directions where there is maximum variance)







(https://georgemdallas.wordpress.com/2013/10/30/principal-component-analysis-4-dummies-eigenvectors-eigenvalues-and-dimension-reduction/)

Principal component analysis

A given set of data points can be decomposed into eigenvectors and eigenvalues.

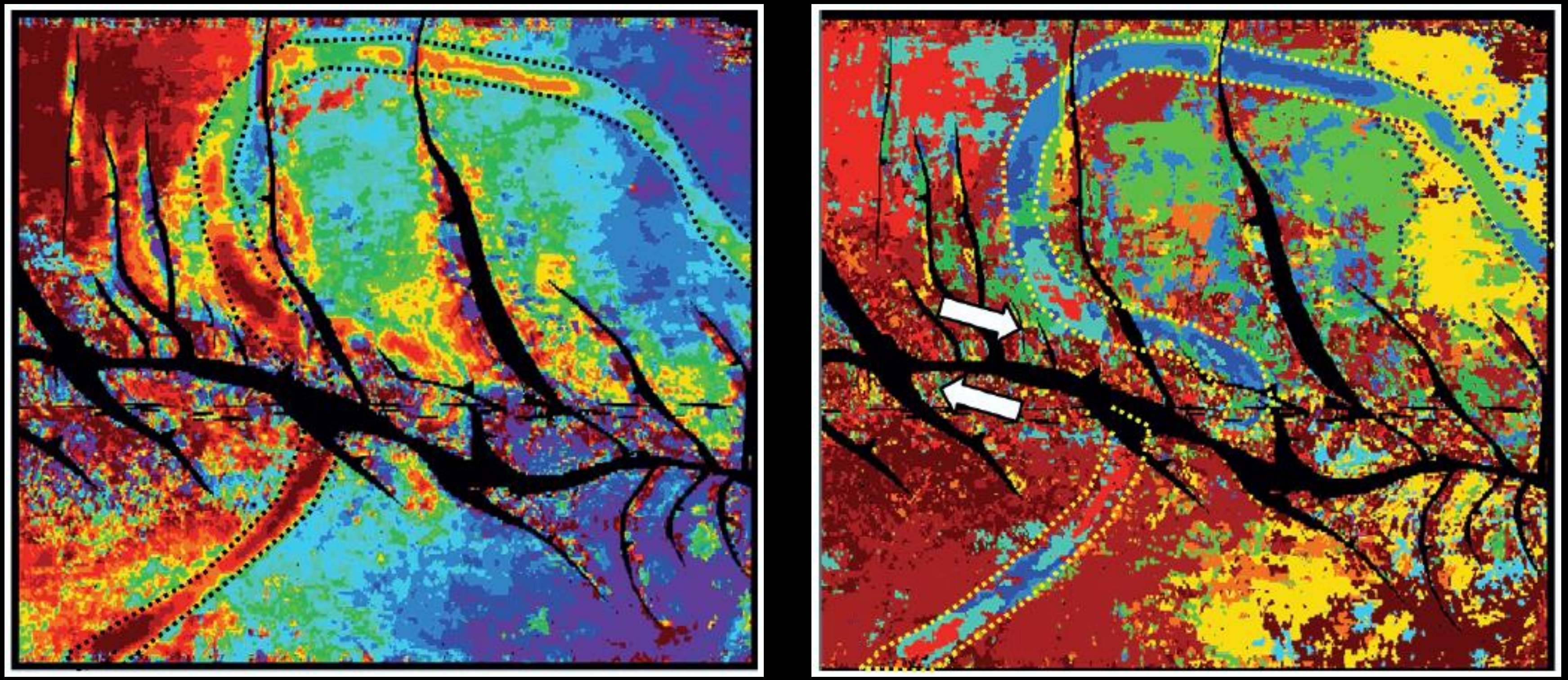
Each eigenvector has a corresponding eigenvalue.

The eigenvector represents the direction, and the eigenvalue represents the variance of the data points in that direction.

The eigenvector that has the highest eigenvalue is called the *principal component*.

The number of eigenvectors/eigenvalues is equal to the number of dimensions of the data. A dataset with two attributes would have 2 eigenvectors and 2 eigenvalues.

Comparison of maps from a fluvial channel deposit from Natuna Sea, Indonesia



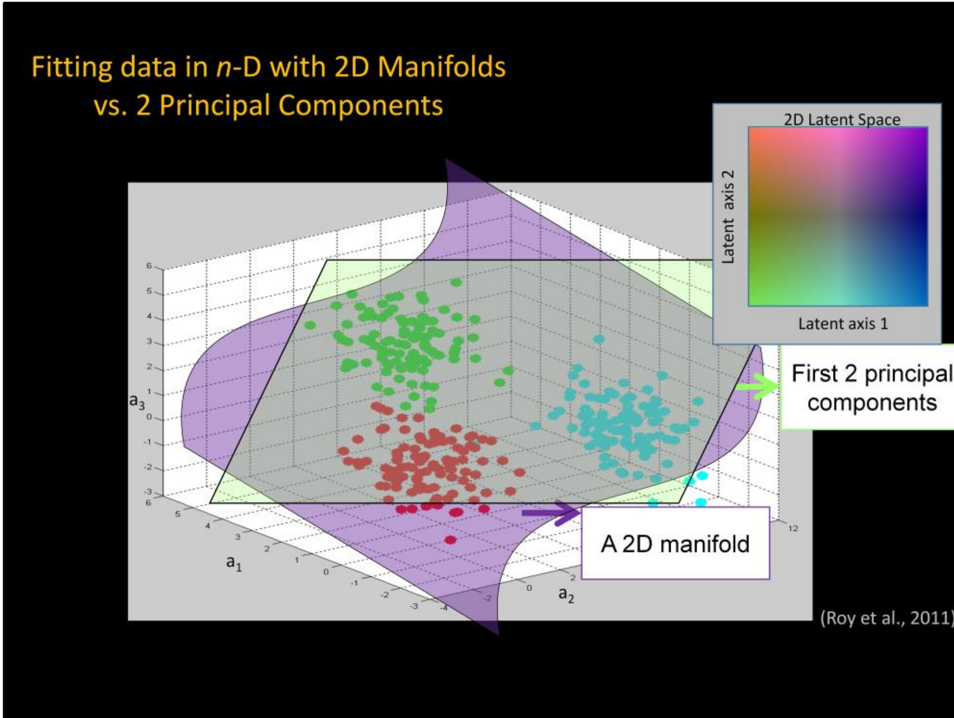
Unsupervised seismic facies map — Unsupervised seismic facies map with PCA

Note that the seismic facies map without PCA does not differentiate the channel facies from the flood plain deposits (same red class). It also tends to bias the interpretation toward a channel system not affected by the W-E strike-slip fault. On the other hand, the PCA seismic facies map differentiates the channel facies (blue class) and clearly highlights the effect of the W-E strike-slip fault in a relatively noisy area. Also, note the development of the overbank deposits to the east (yellow facies outlined by black dotted line).

Coleou et al., 2003)

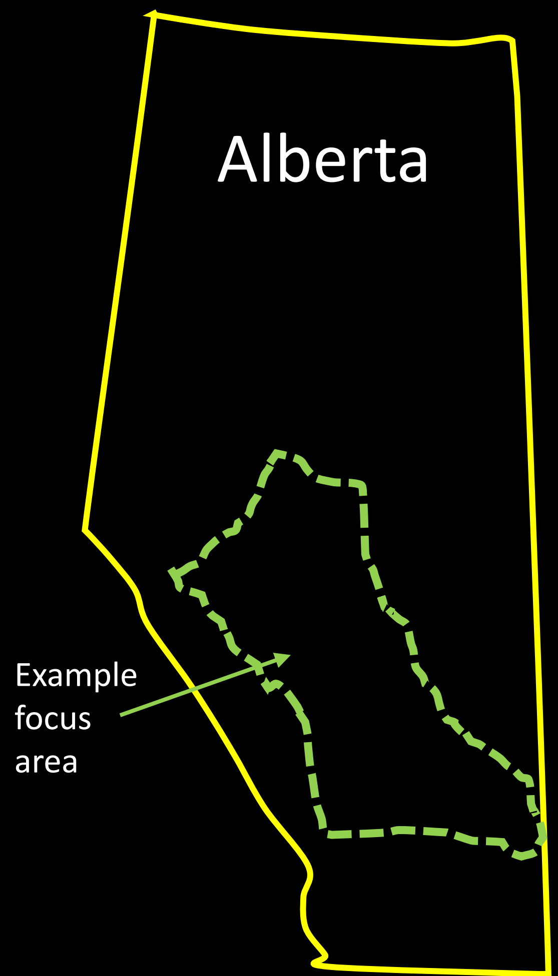
Types of Cluster Analysis

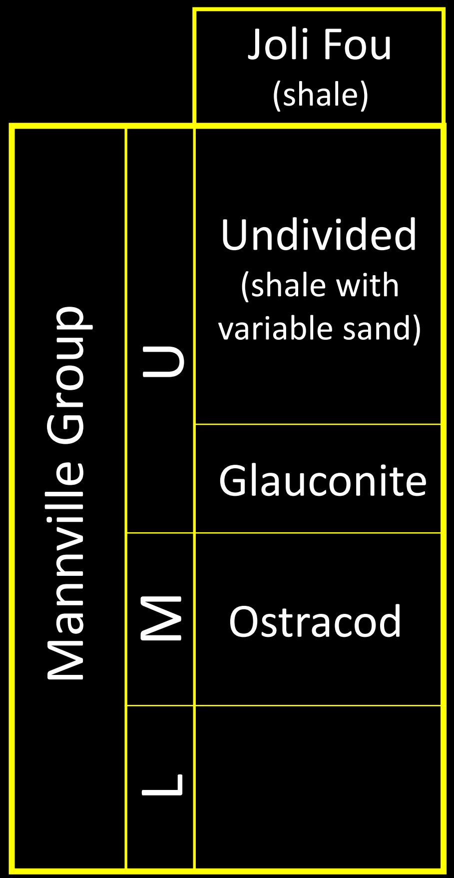
Input	Output
Windowed seismic amplitude along a horizon	Waveform classification
Windowed impedance values along a horizon	Geomechanical stacking patterns
Vectors of attributes at each voxel	Seismic facies analysis



Presenter's notes: An example of a 2D hyperplane defined by 2 principal components and a more-deformed 2D latent space. In self-organizing maps, one can begin with prototype vectors equally distributed within an ellipse lying on the plane defined by principal components. The surface is subsequently deformed, iteration by iteration to more closely approximate the data, but always retaining the lateral spatial relationships (lattice) of the original mesh.

Datasets used in the analysis

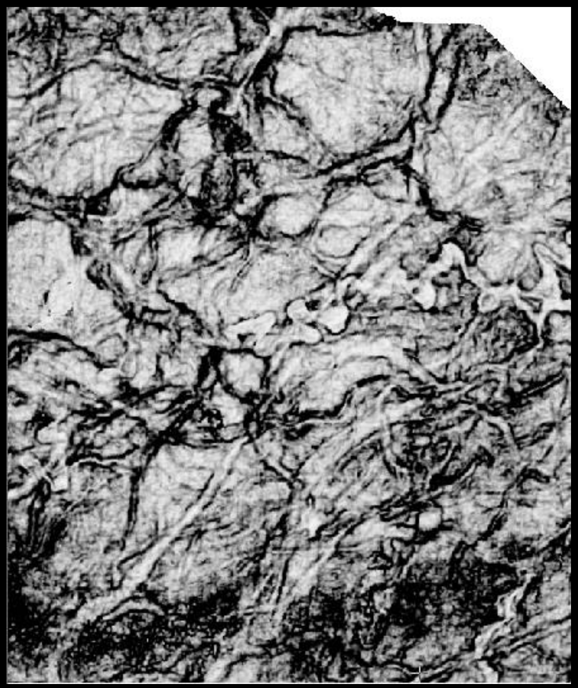




1. Upper Mannville comprises the Glauconite sandstone that traps the hydrocarbons, overlain with an undivided member of shale/sandstone, providing an effective trapping mechanism.
2. Incised valley channel sandstones of the Glauconite unit truncate the Ostracod formation as well as the regional Glauconite facies.
3. The drilling carried out in the area has highlighted challenges in the facies prediction of a shale vs sand-filled incised valley system.

Datasets used in the analysis

Coherence



Coherence

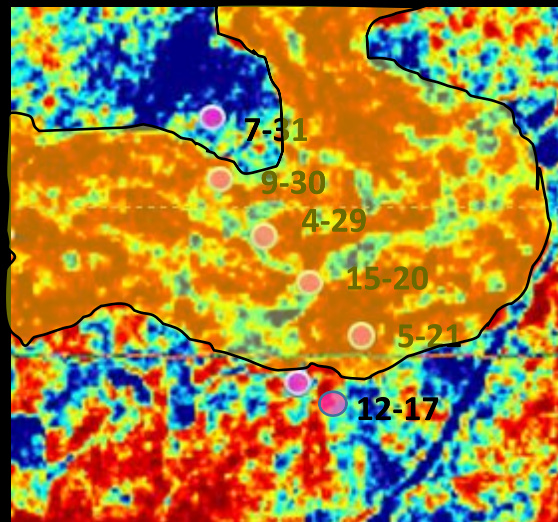
Low High

Stratal slices from two different volumes

Seismic Facies Analysis

At some points within the channel, the incision or cut is more than 30m with multiple fining upward sandy fill cycles, typical of a point bar buildup.

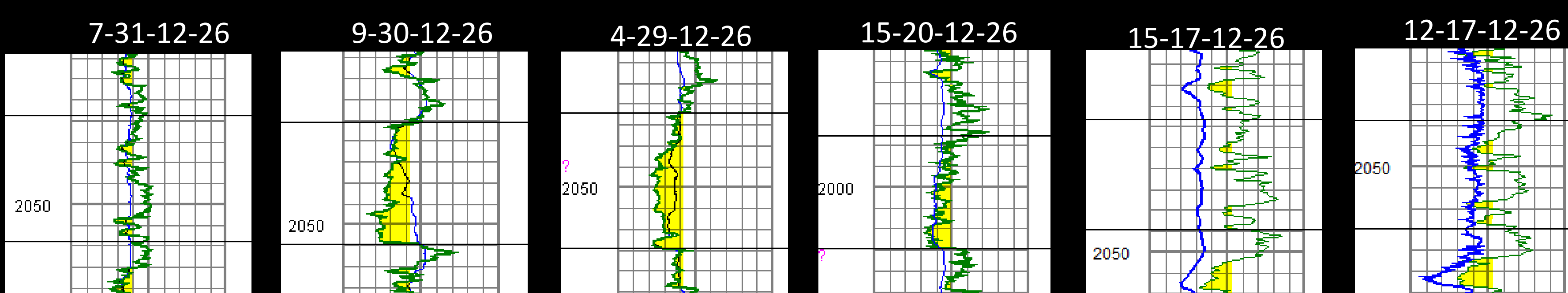
At other points the channel cut does not appear to be as deep and sandy fill is not evident.



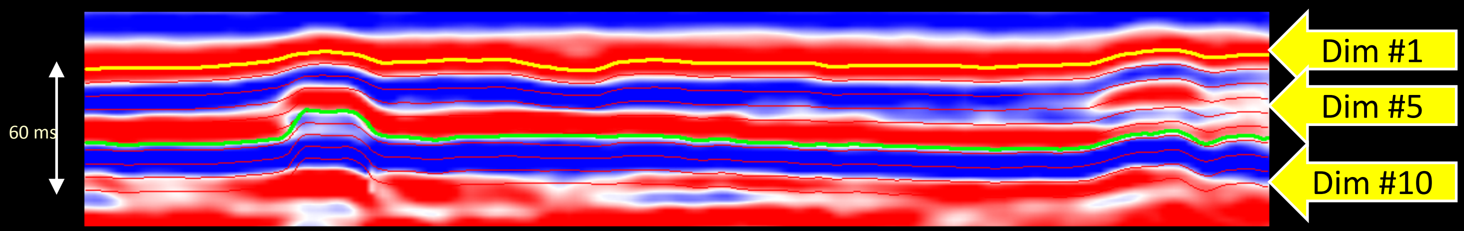
Outside the channel signatures of interbedded sands, silts, shales and coal stringers are seen.

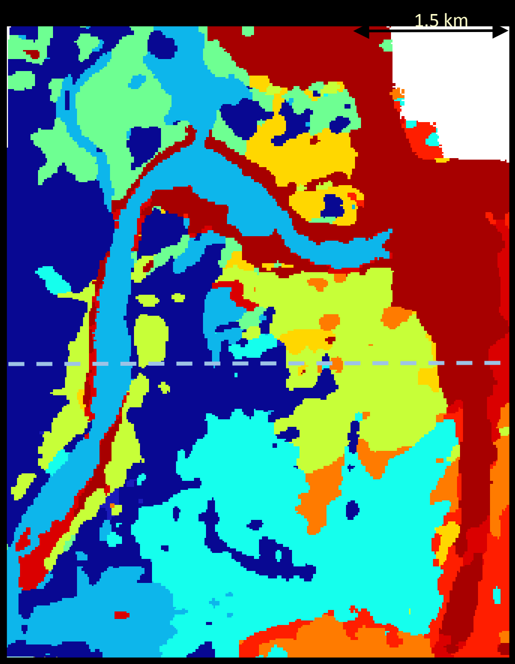
Log correlation in the E-W direction indicates the presence of multiple channels within the main channel, and clean overbank sands (crevasse splays).

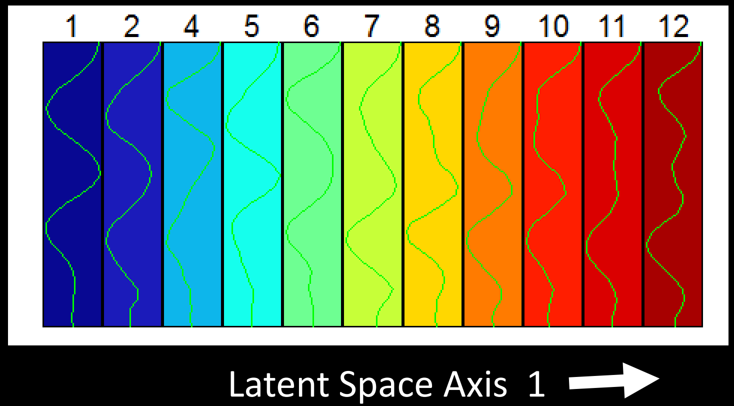
Gamma ray profiles: Upper Mannville channel (NW-SE)



Seismic Waveform Classification

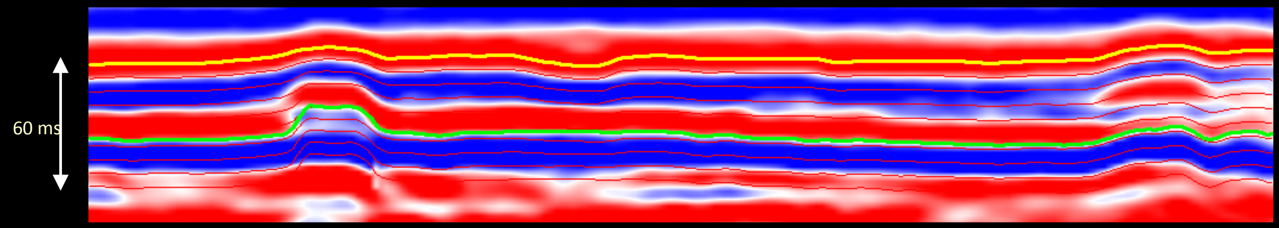


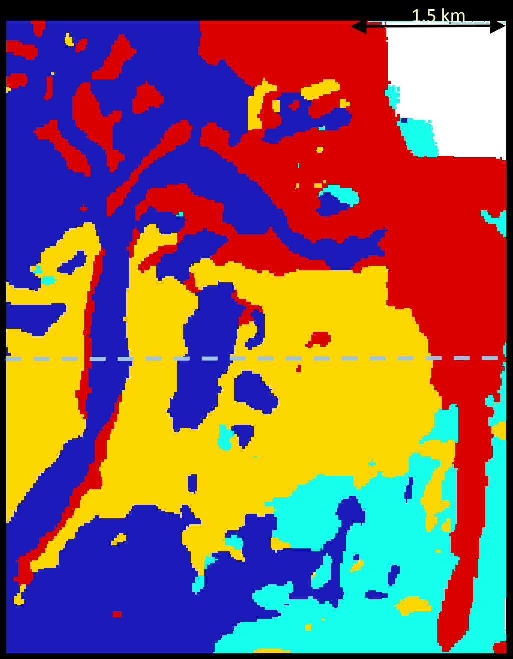


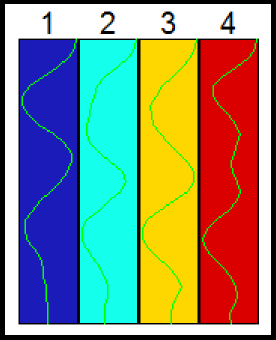


Let the computer represent the data with 12 clusters

Seismic Waveform Classification

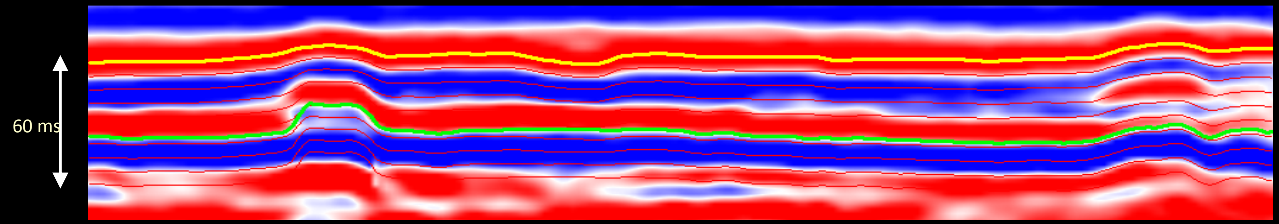


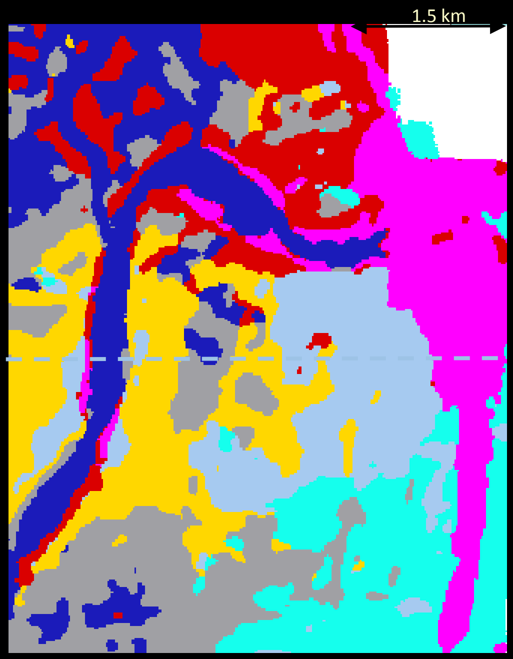




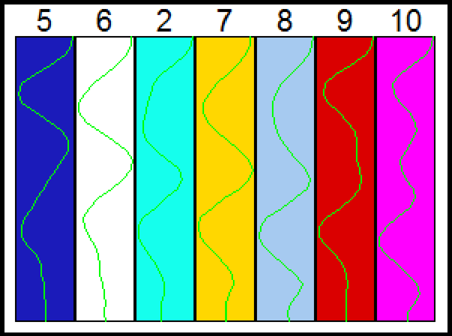
Let the computer represent the 4 most important clusters

Seismic Waveform Classification



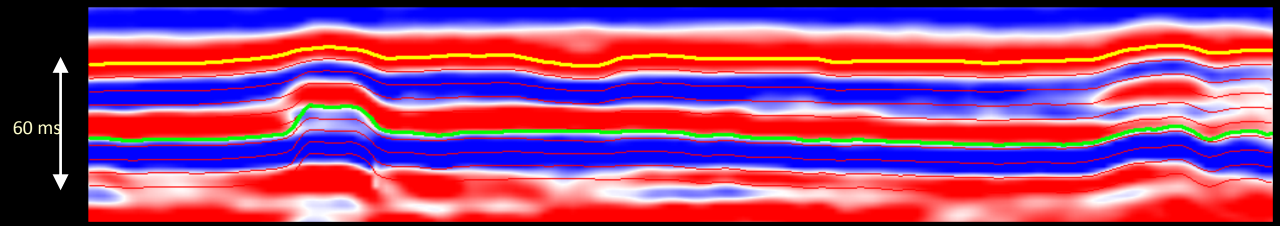


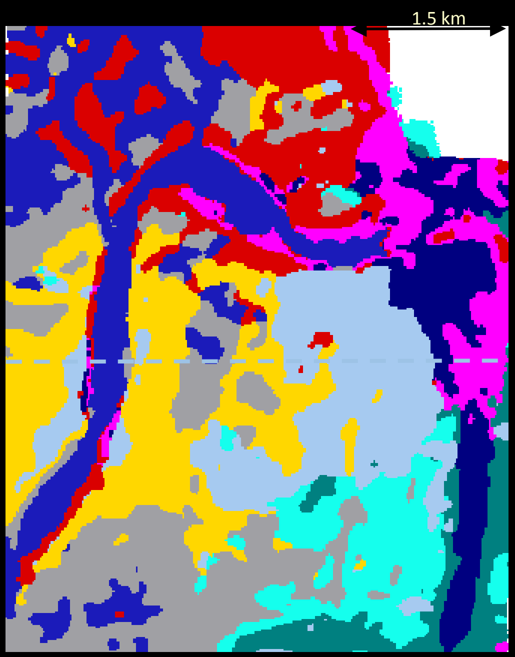
Unconstrained hierarchical classification



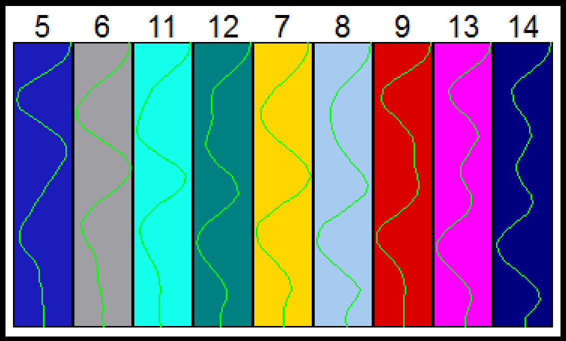
Let the computer represent the 7 most important clusters

Seismic Waveform Classification



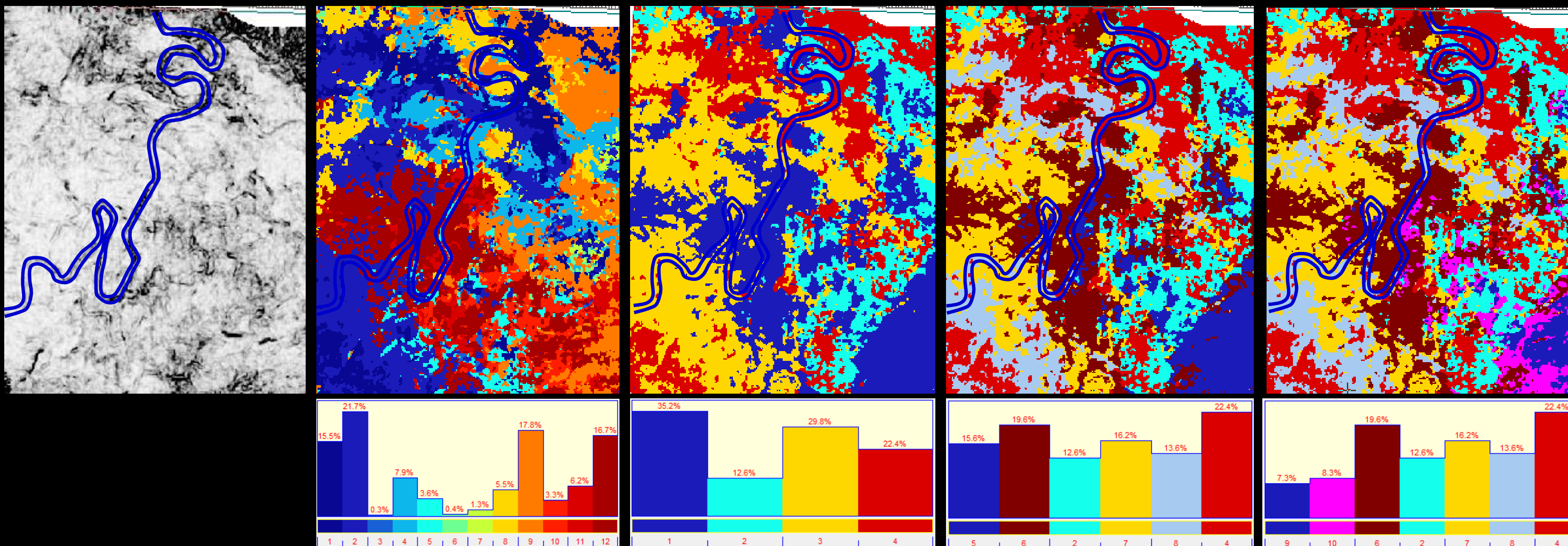


Unconstrained hierarchical classification



Let the computer represent the 9 most important clusters

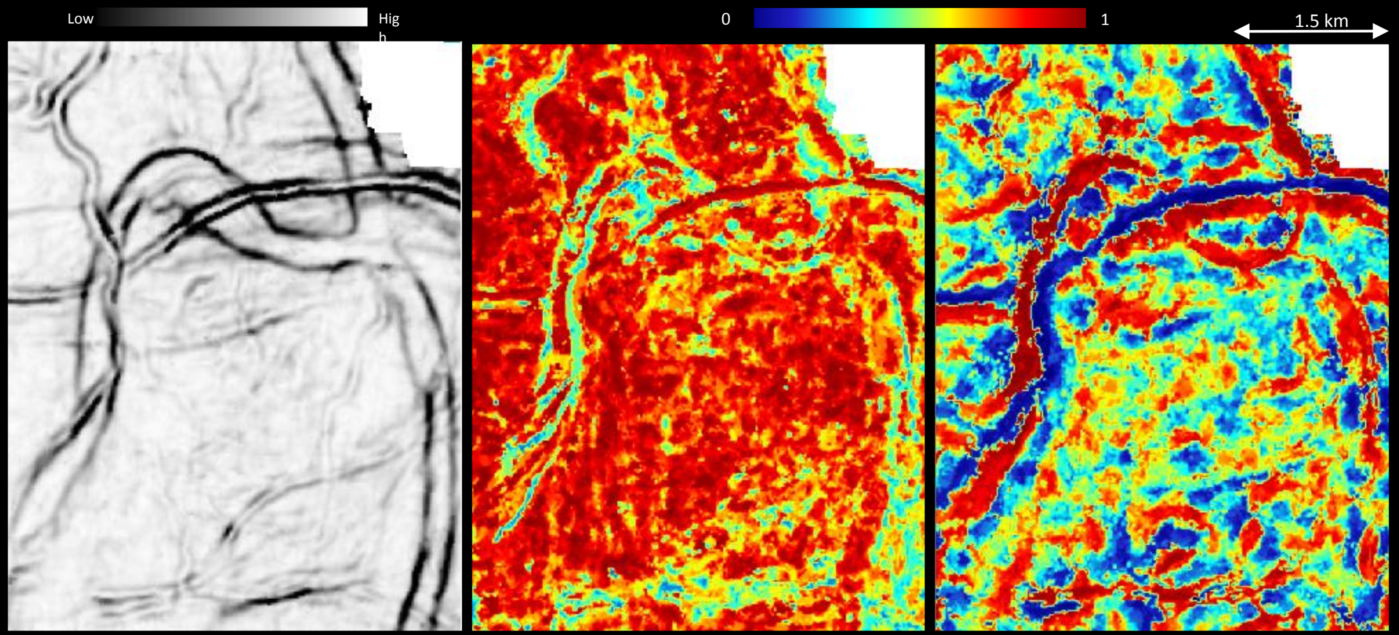
Seismic Facies Analysis



Classification with
fixed no. of groups

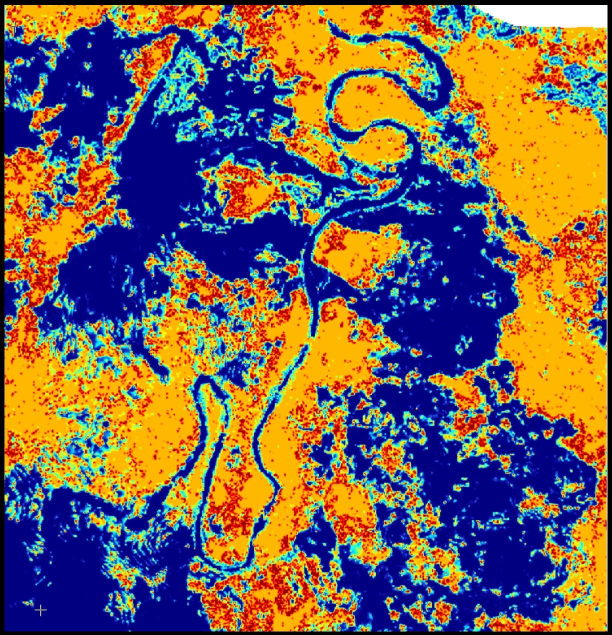
Unconstrained hierarchical classification

Seismic facies classification using a 9D vector of attributes at each voxel

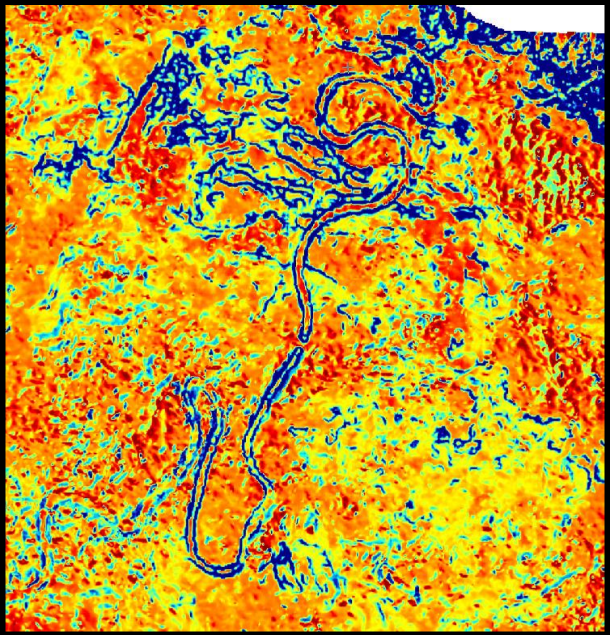


Coherence GTM 1 GTM 2

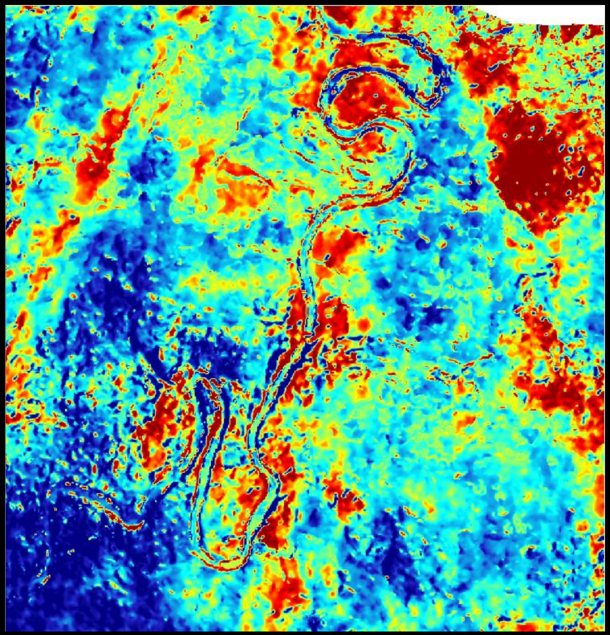
1. Most-positive curvature
2. Most-negative curvature
3. Peak frequency
4. Peak spectral magnitude
5. Bandwidth
6. GLCM contrast
7. GLCM homogeneity
8. GLCM entropy
9. GLCM energy



3D SOM (1D Latent Space)



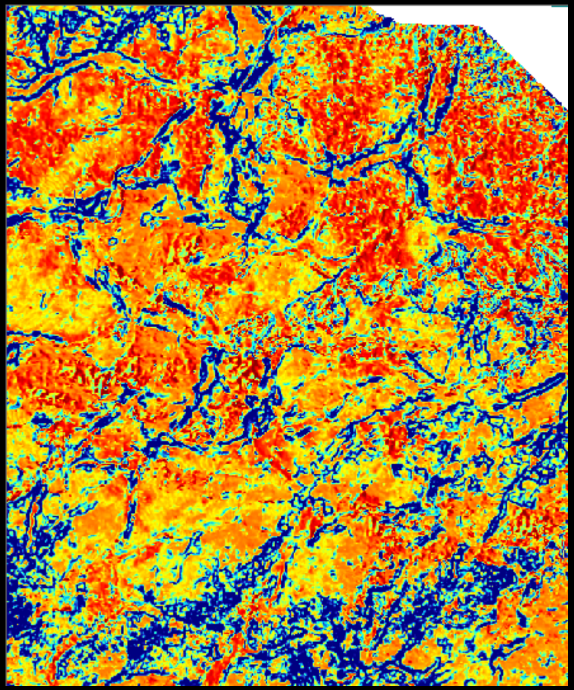
GTM_Proj1



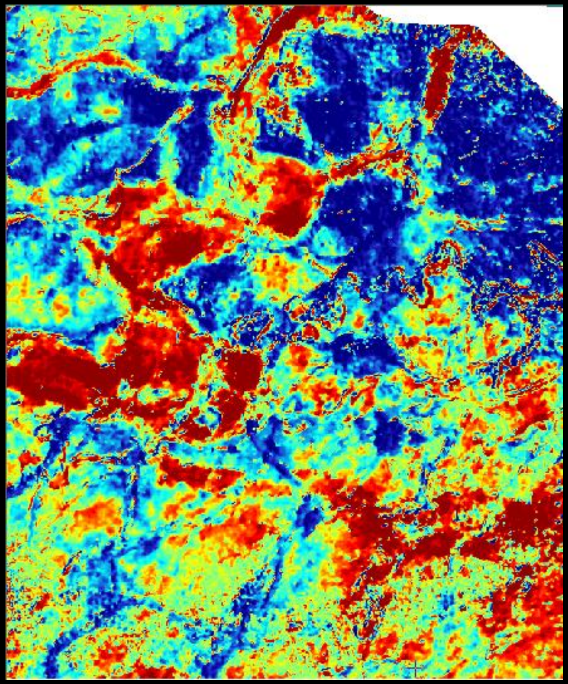
GTM_Proj2

88 ms below a flattened marker

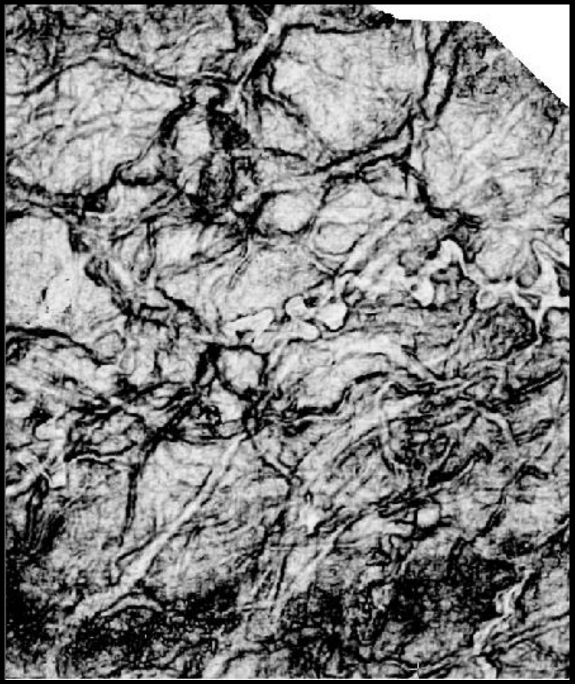
Using coherence, Sobel-filter, inline energy gradient and crossline energy gradient attributes



GTM_Proj1



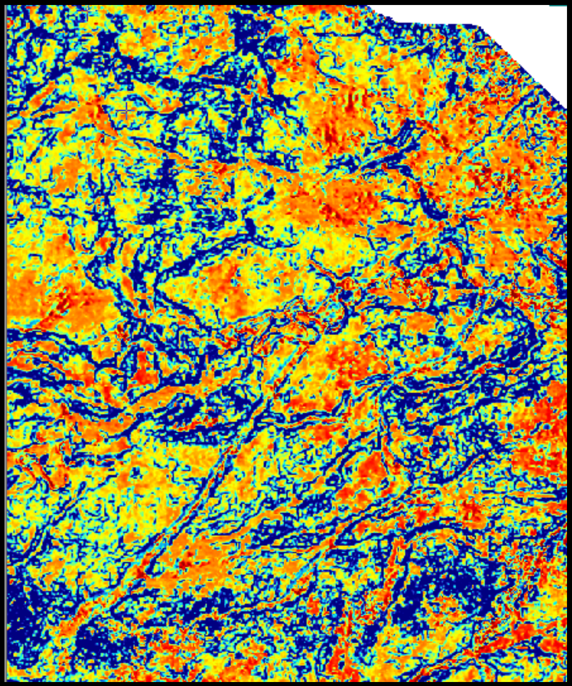
GTM_Proj2



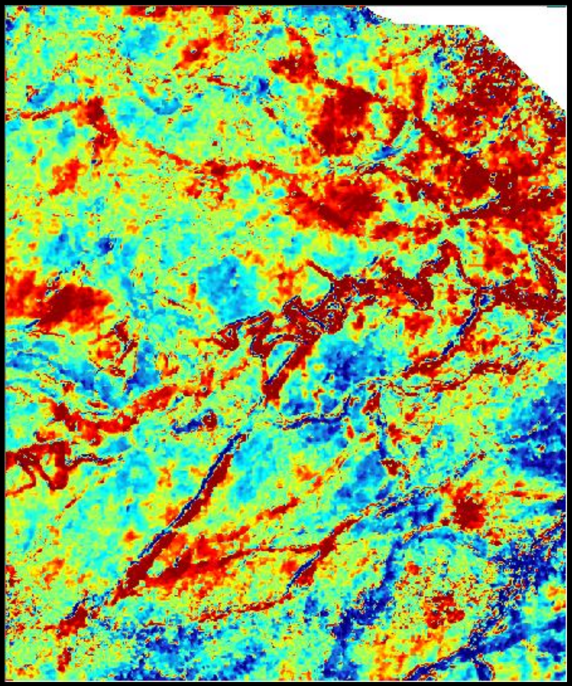
Coherence

156 ms below a flattened marker

Using coherence, Sobel-filtering, inline energy gradient and crossline energy gradient attributes



GTM_Proj1

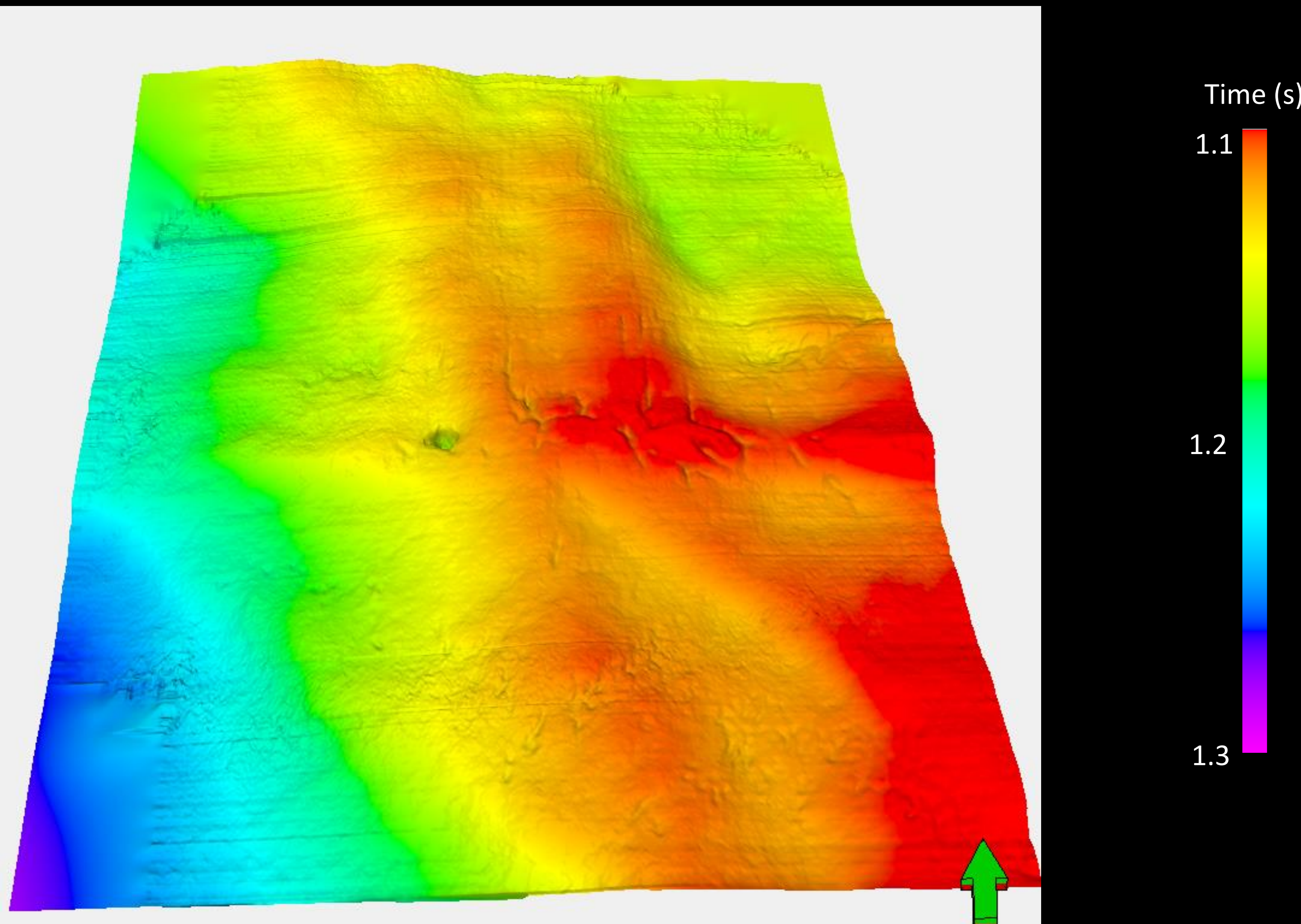


GTM_Proj2

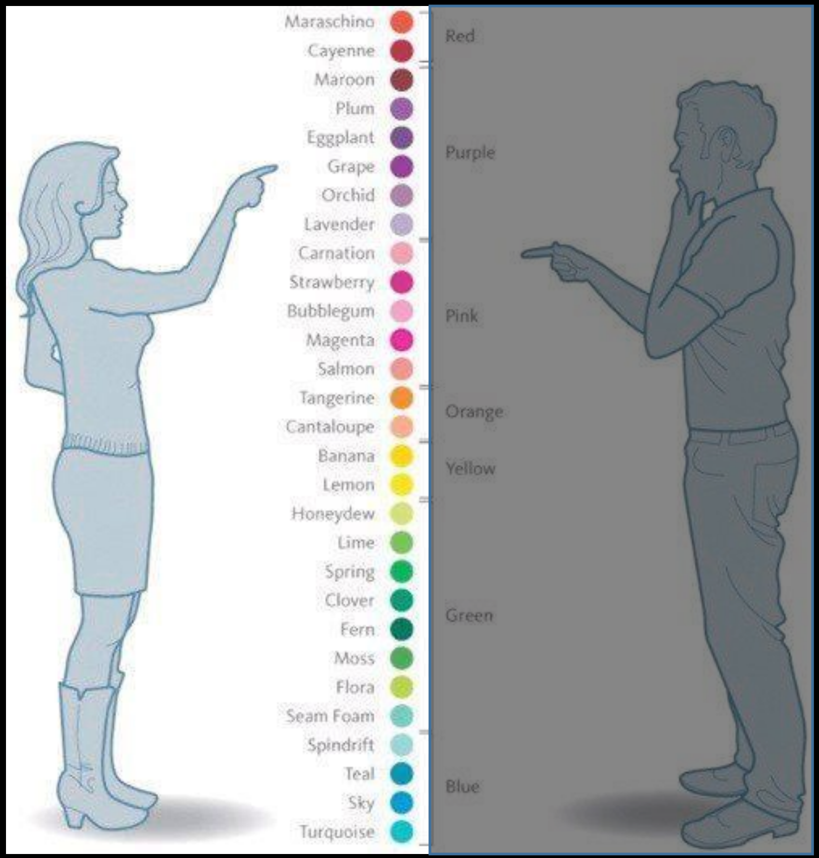
Coherence

176 ms below a flattened marker

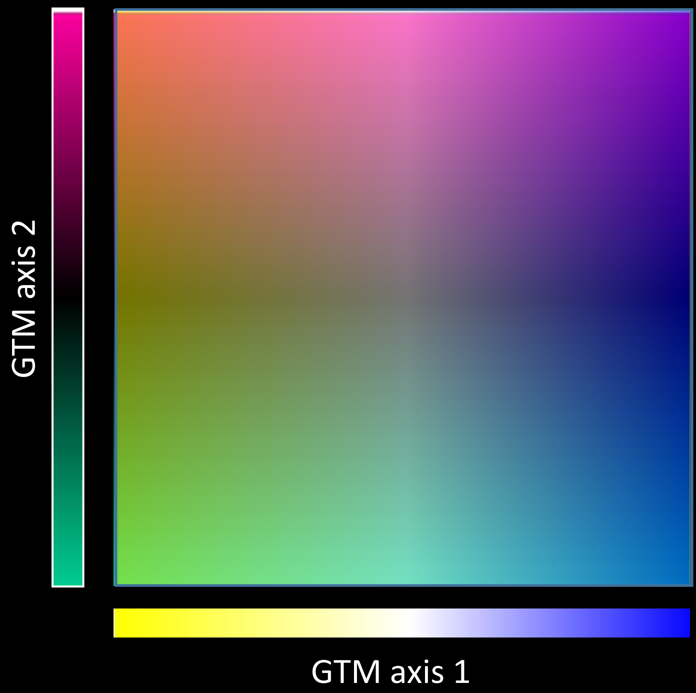
Using coherence, Sobel-filtering, inline energy gradient and xline energy gradient attributes


Time (s)
1.1
1.2
1.3

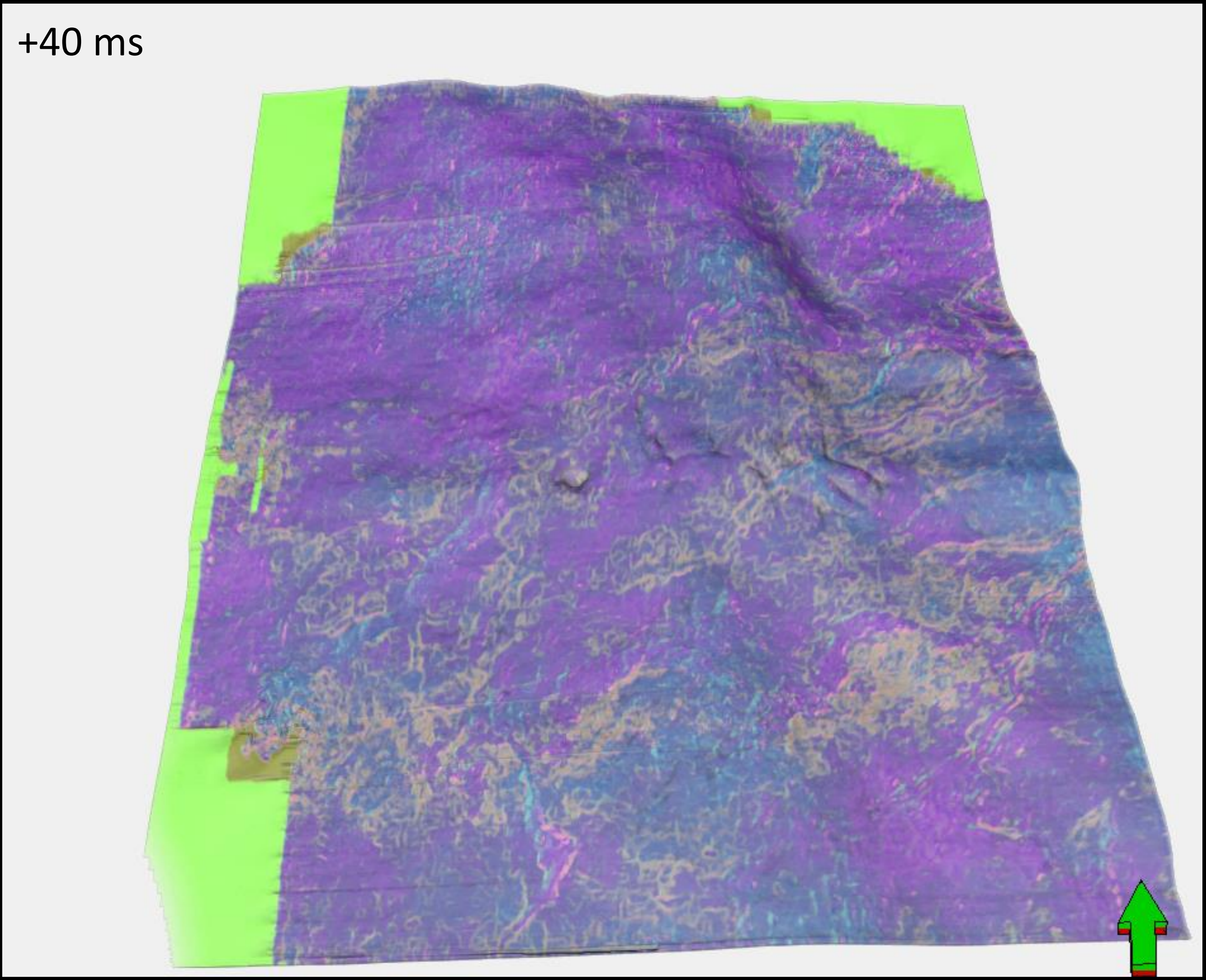
Color perception: Men vs. women.



Interactive color bar definition

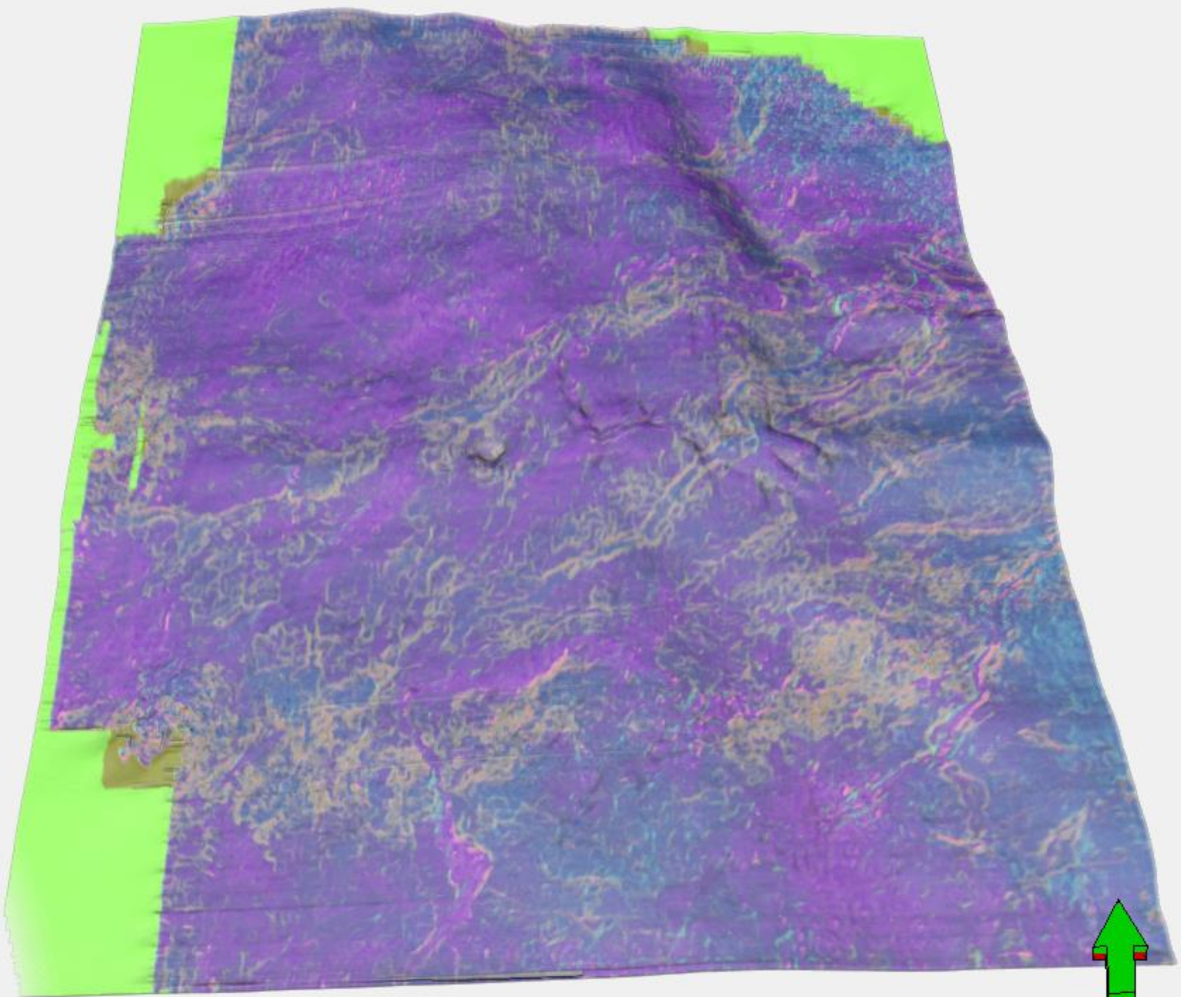


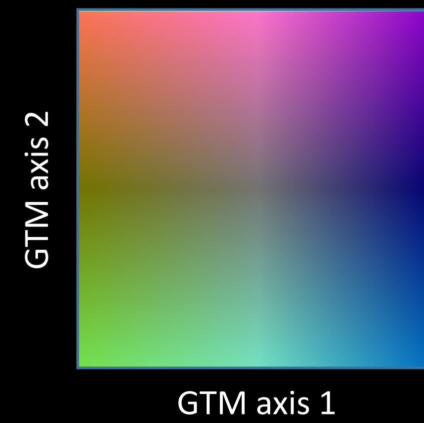
(Facebook communication on 10/18/2011. Origin unknown)


+40 ms

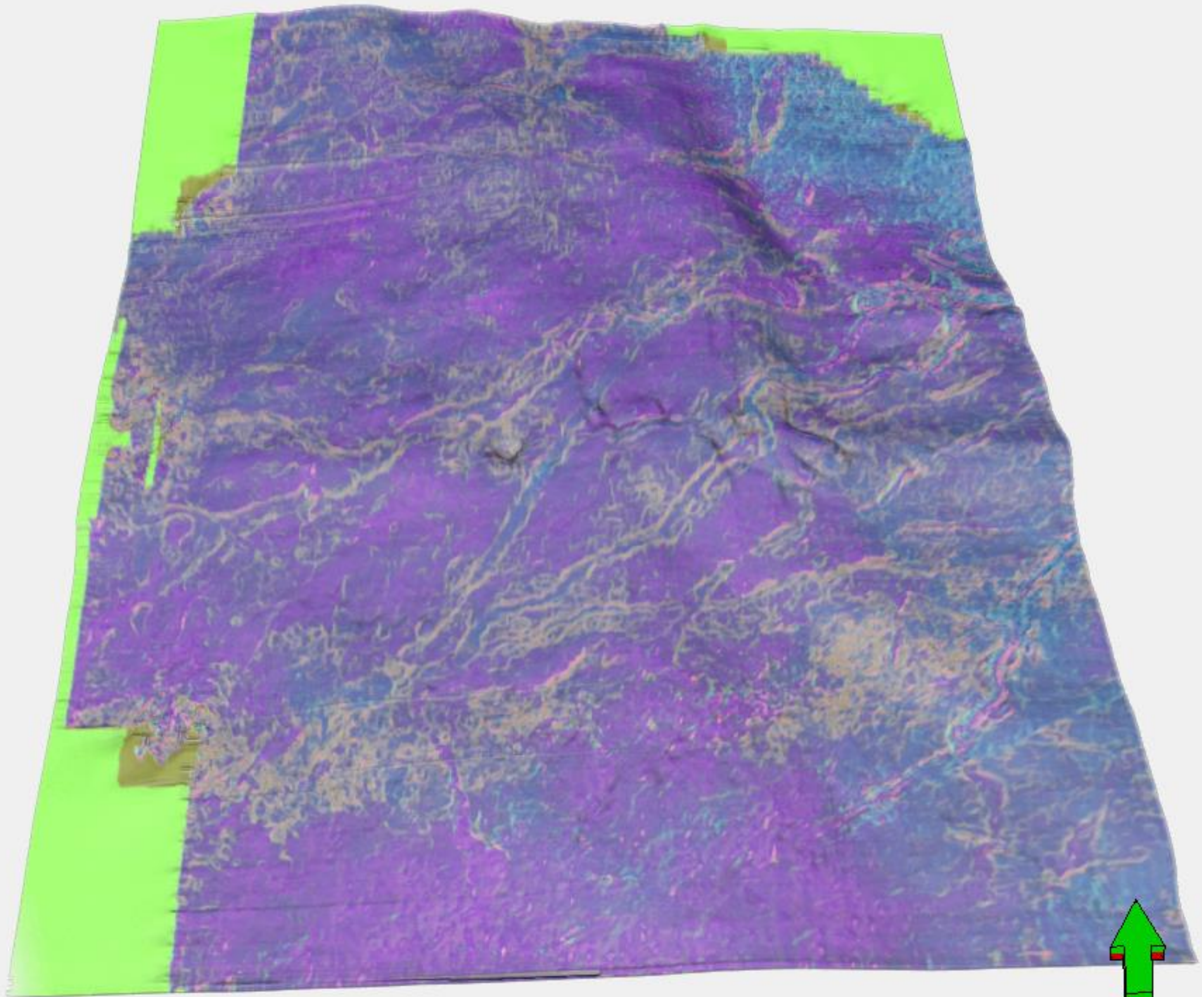

GTM axis 2
GTM axis 1

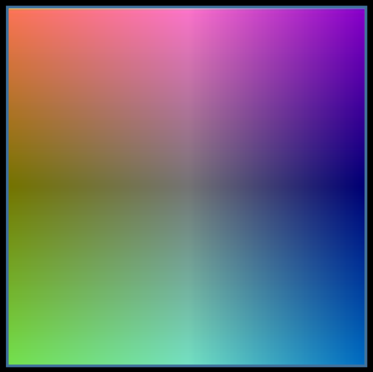
+35 ms



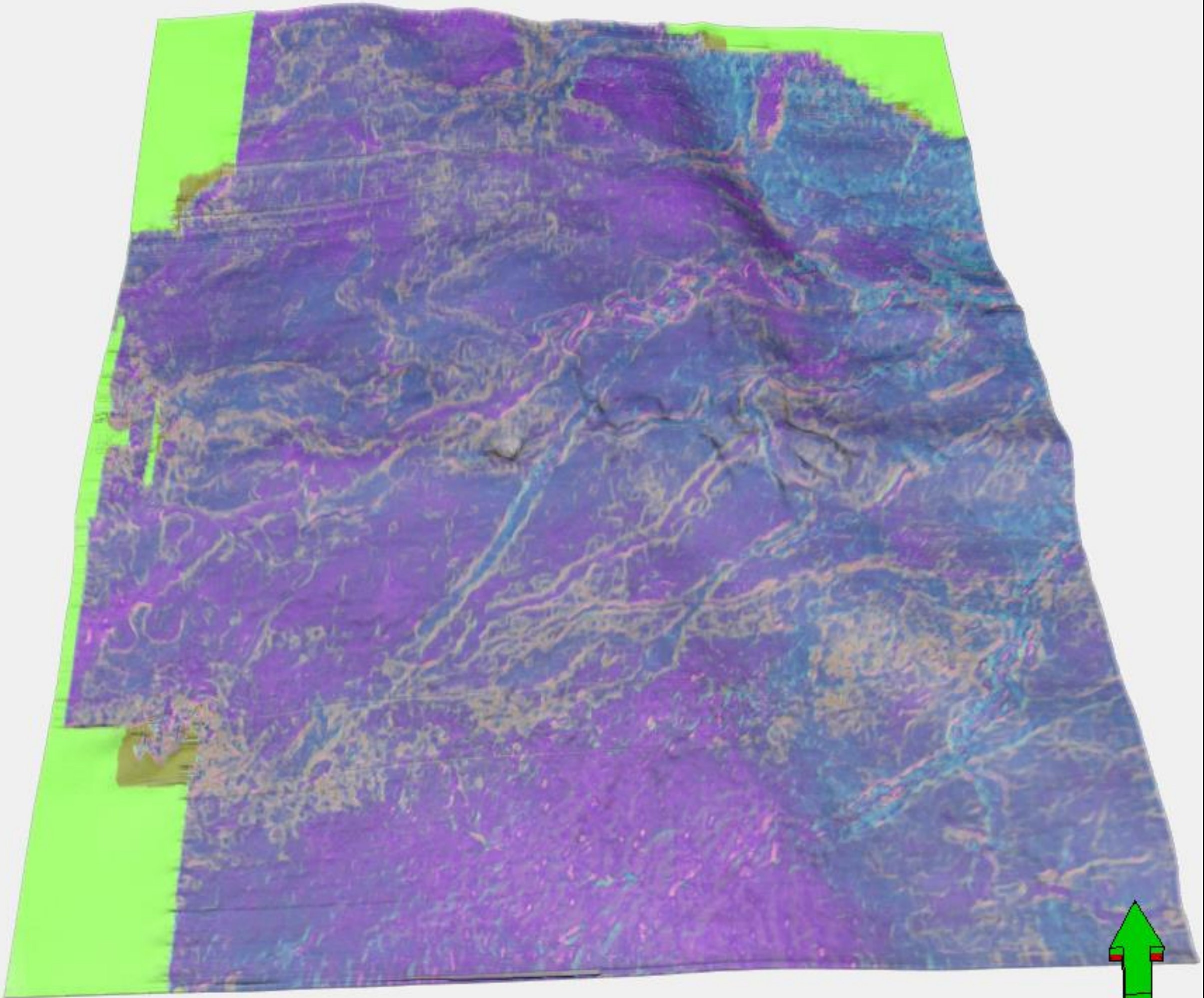


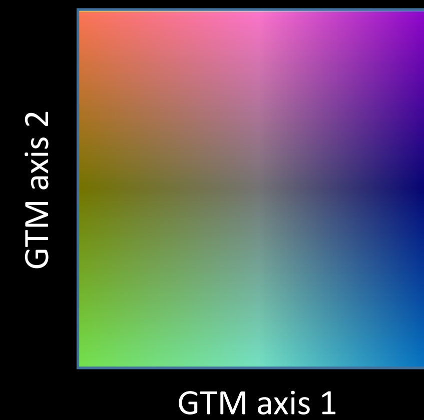
+30 ms



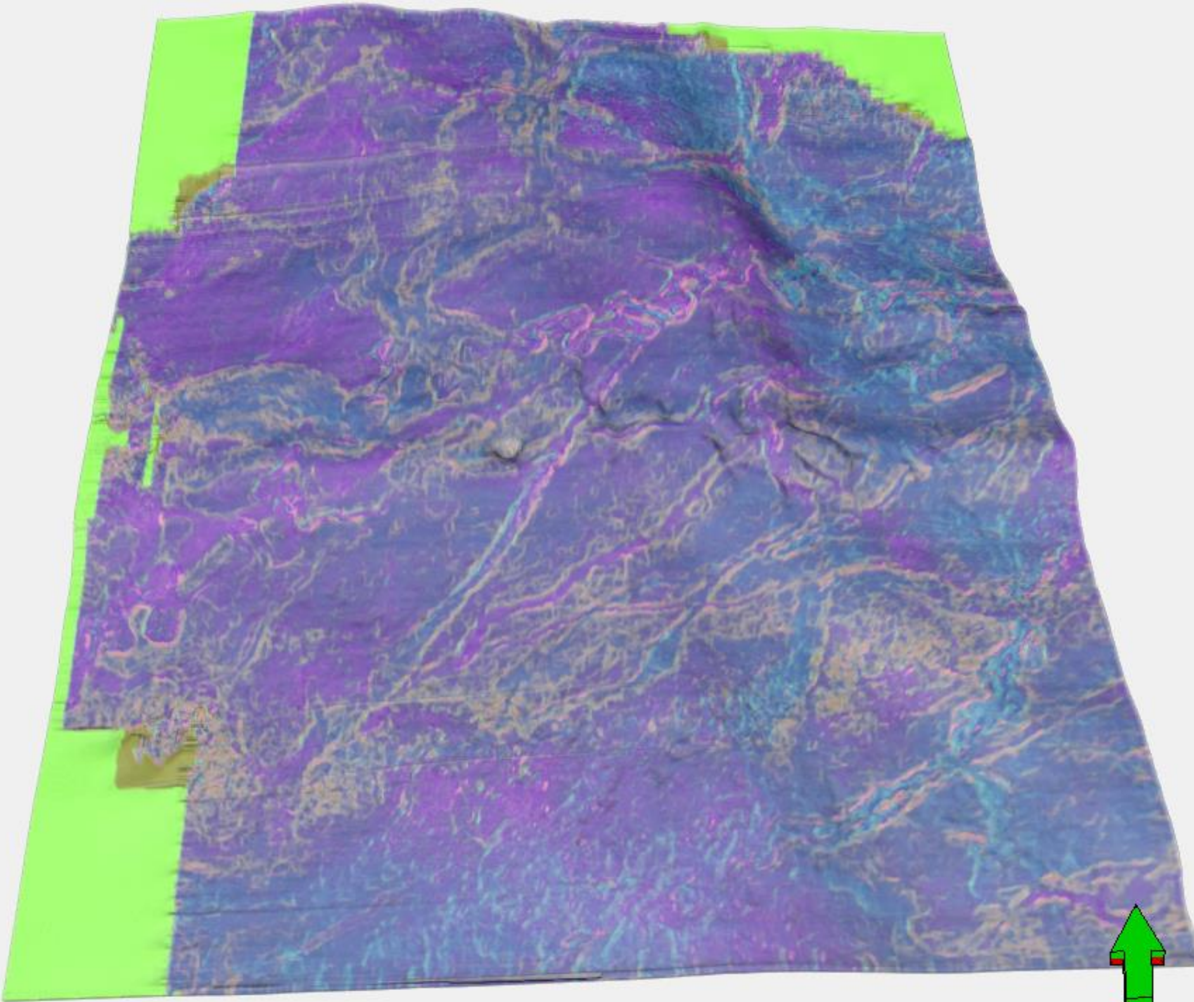


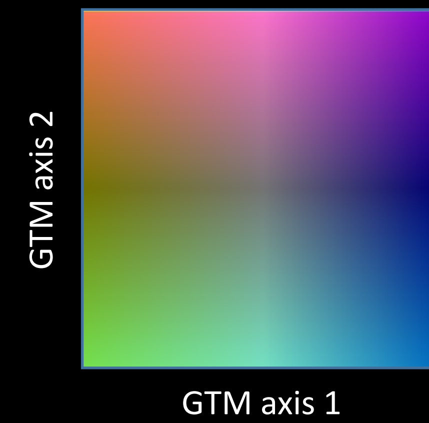
+25 ms



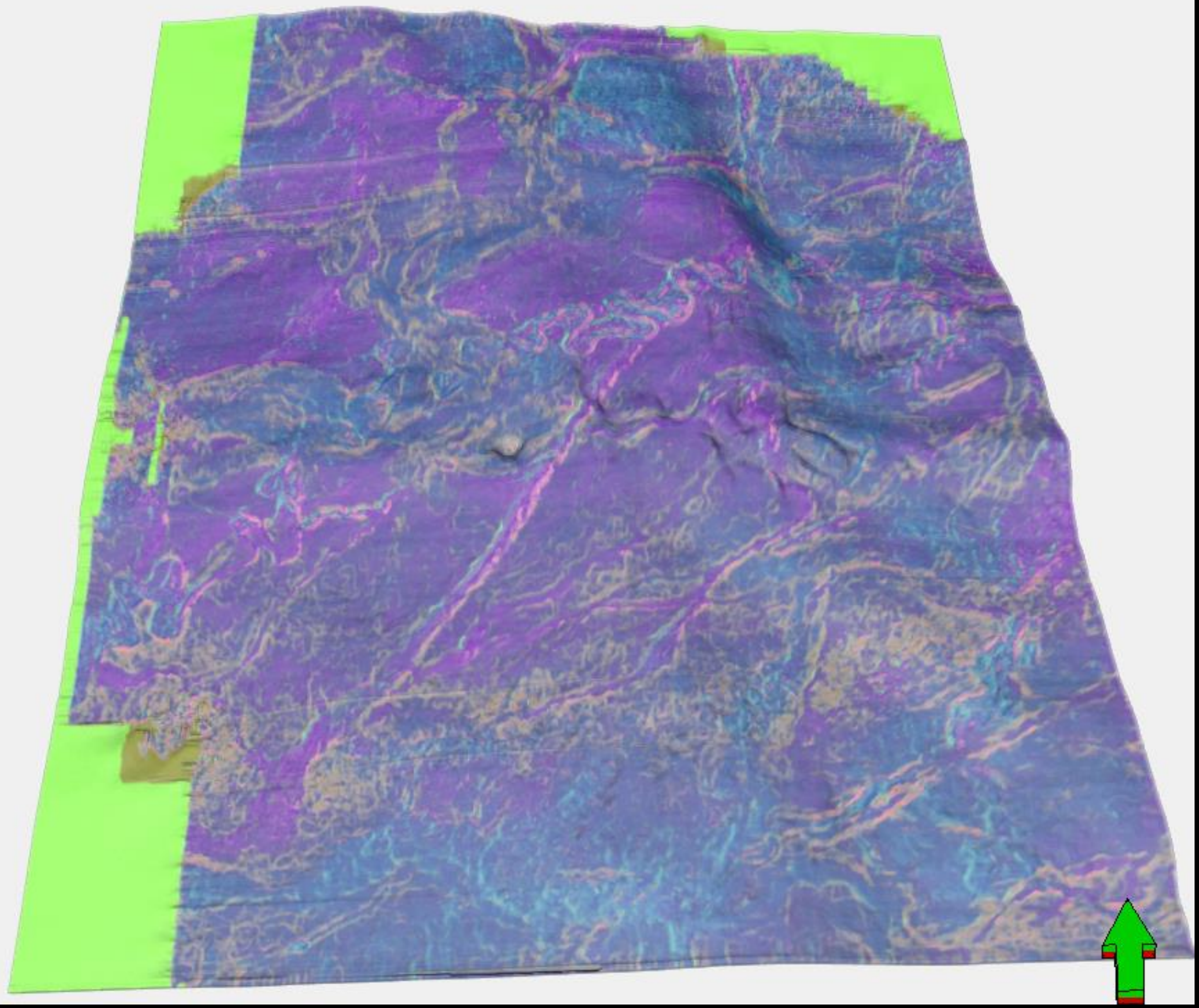


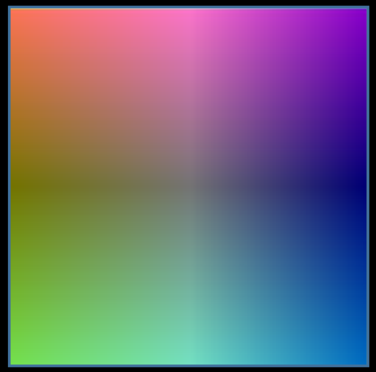
+20 ms

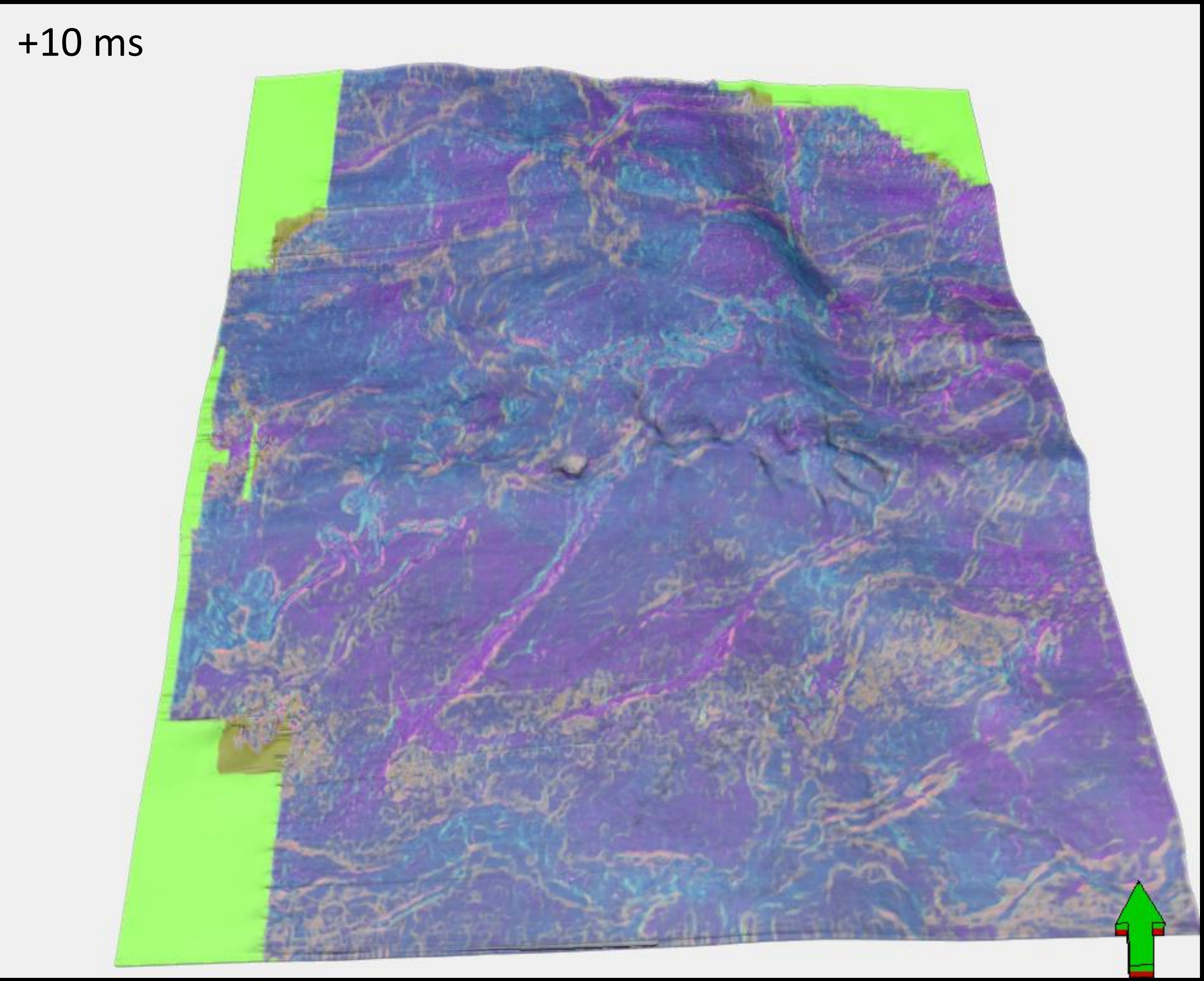


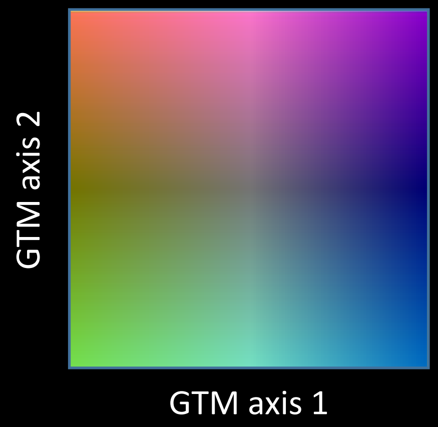


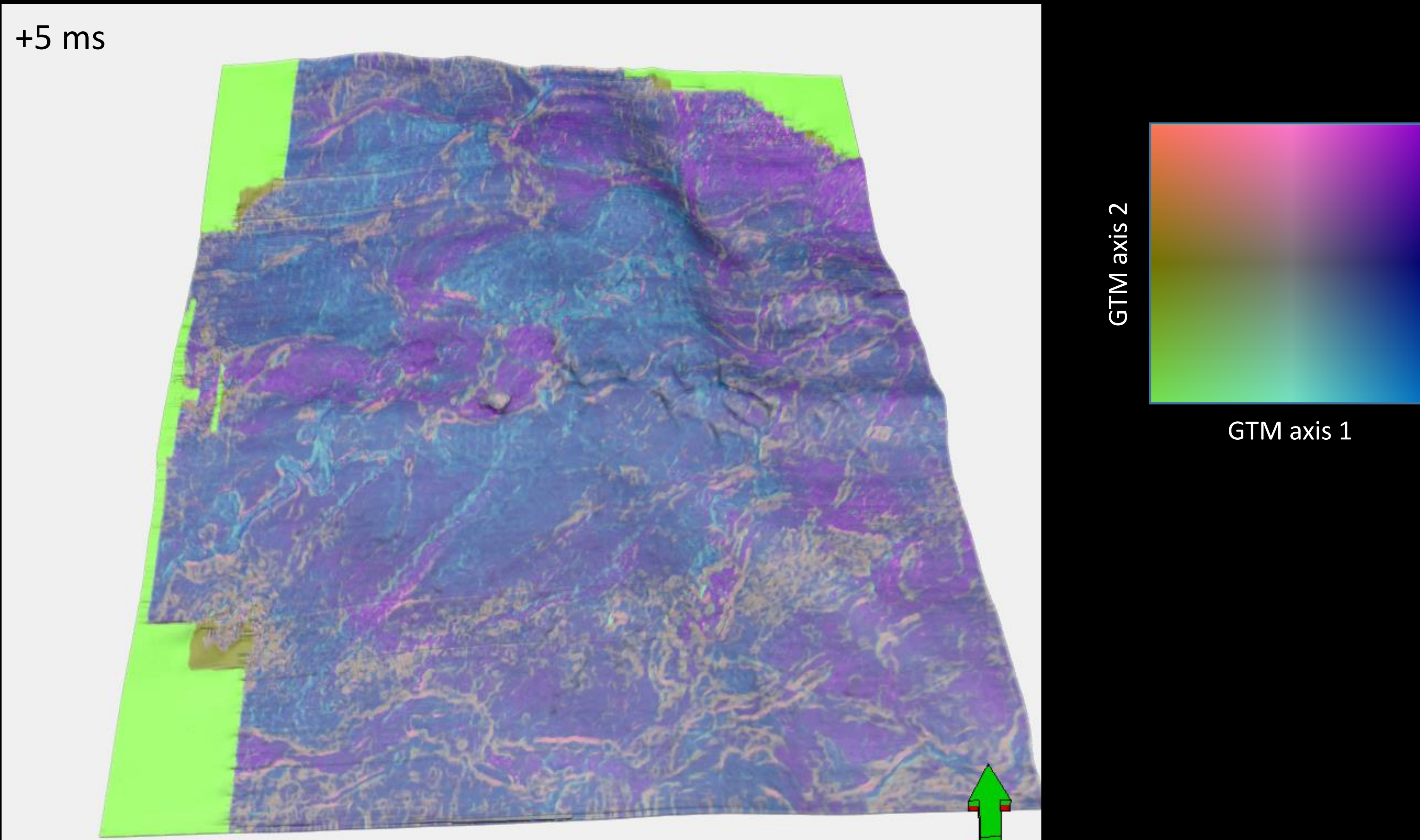
+15 ms

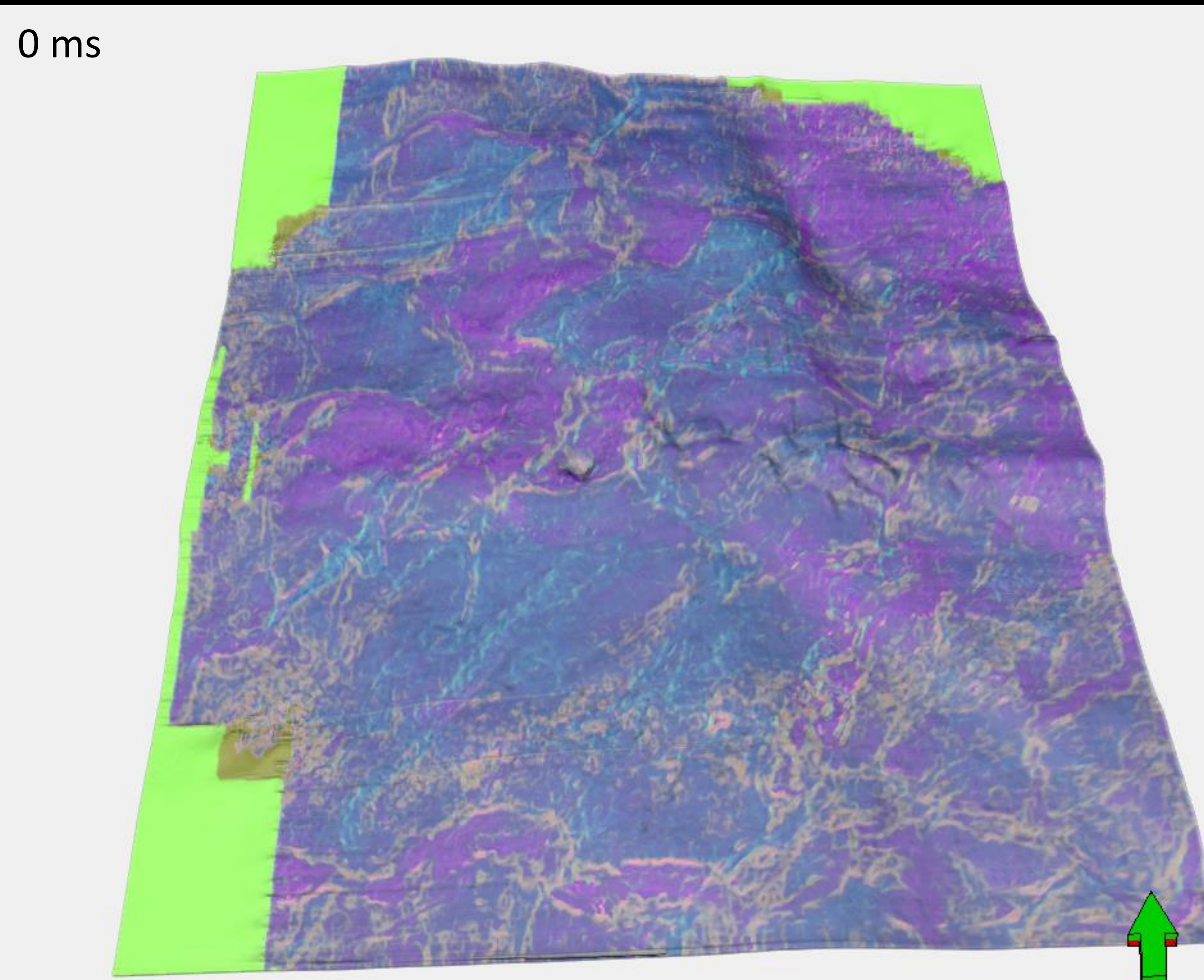





+10 ms

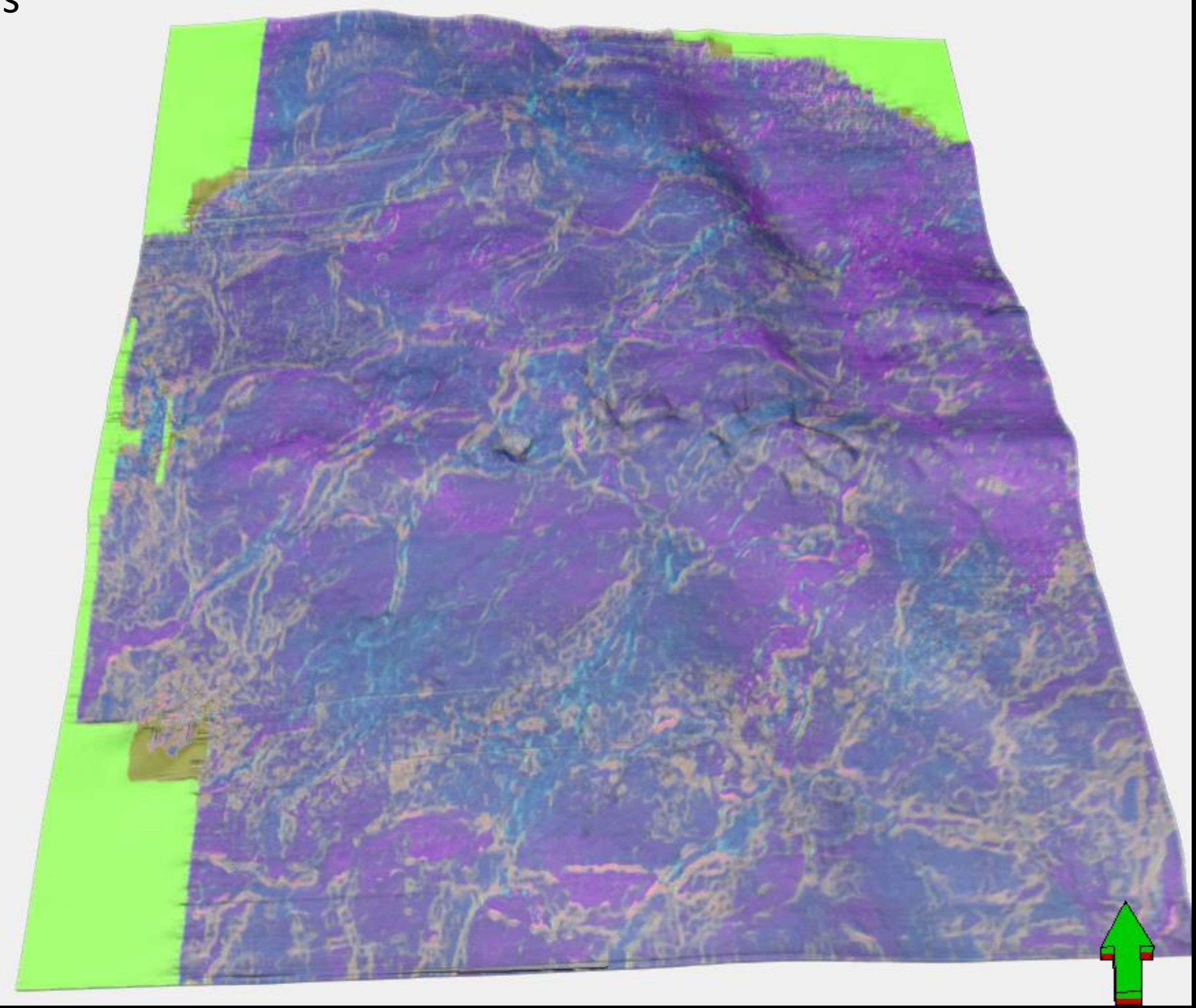

GTM axis 2
GTM axis 1

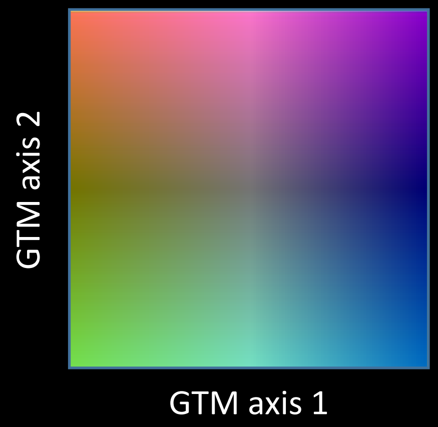

+5 ms
GTM axis 2
GTM axis 1

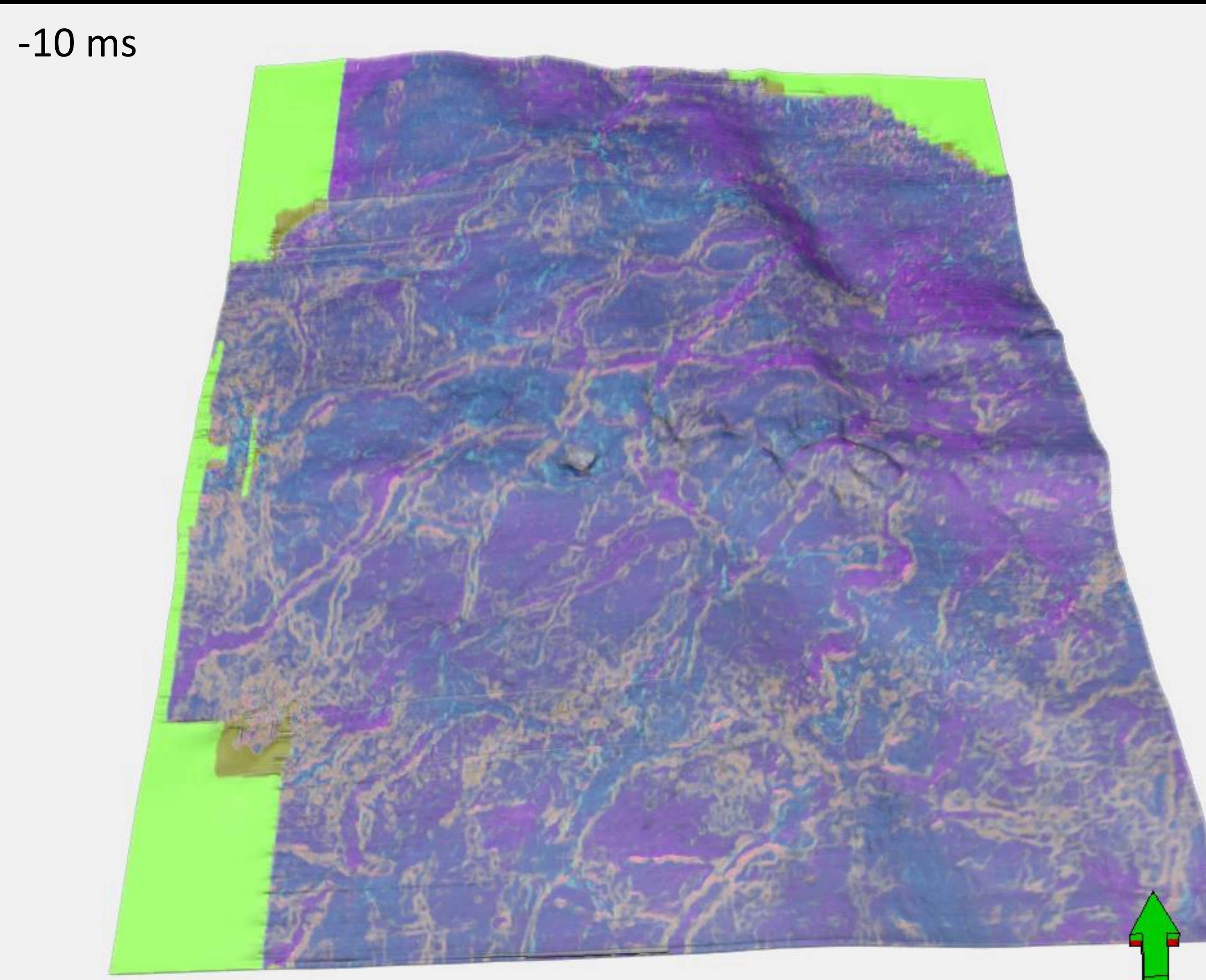

0 ms

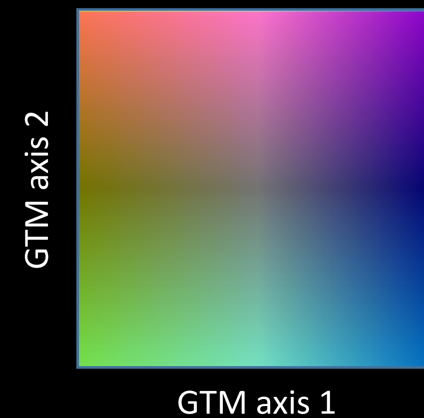

GTM axis 2
GTM axis 1

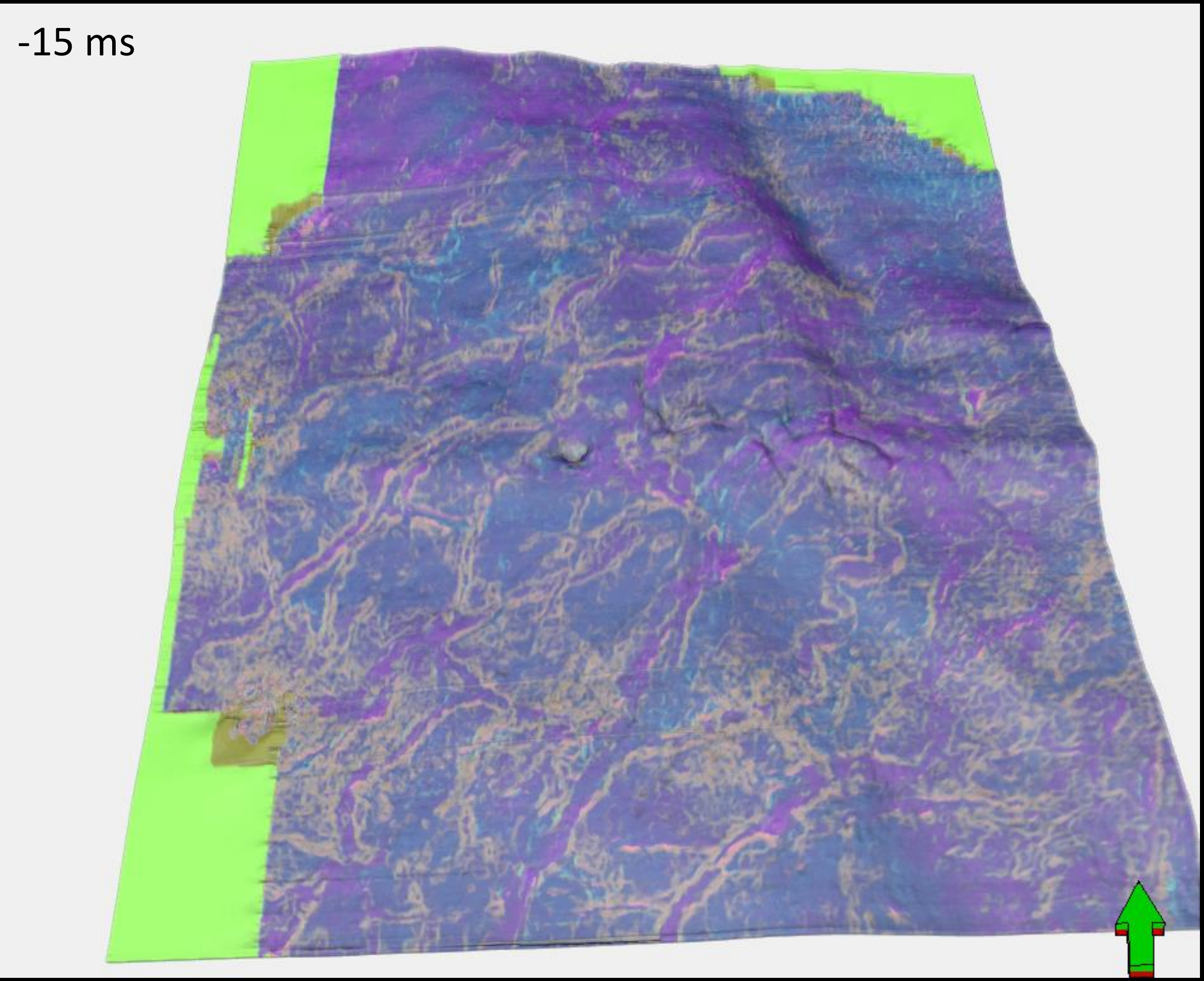
-5 ms

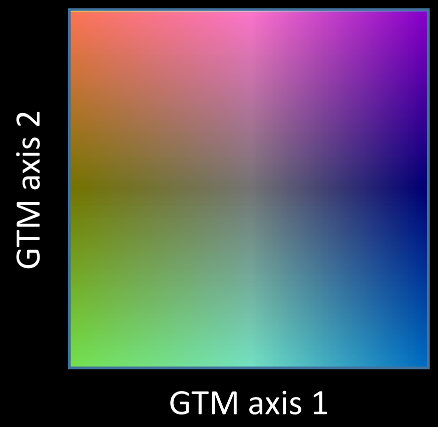




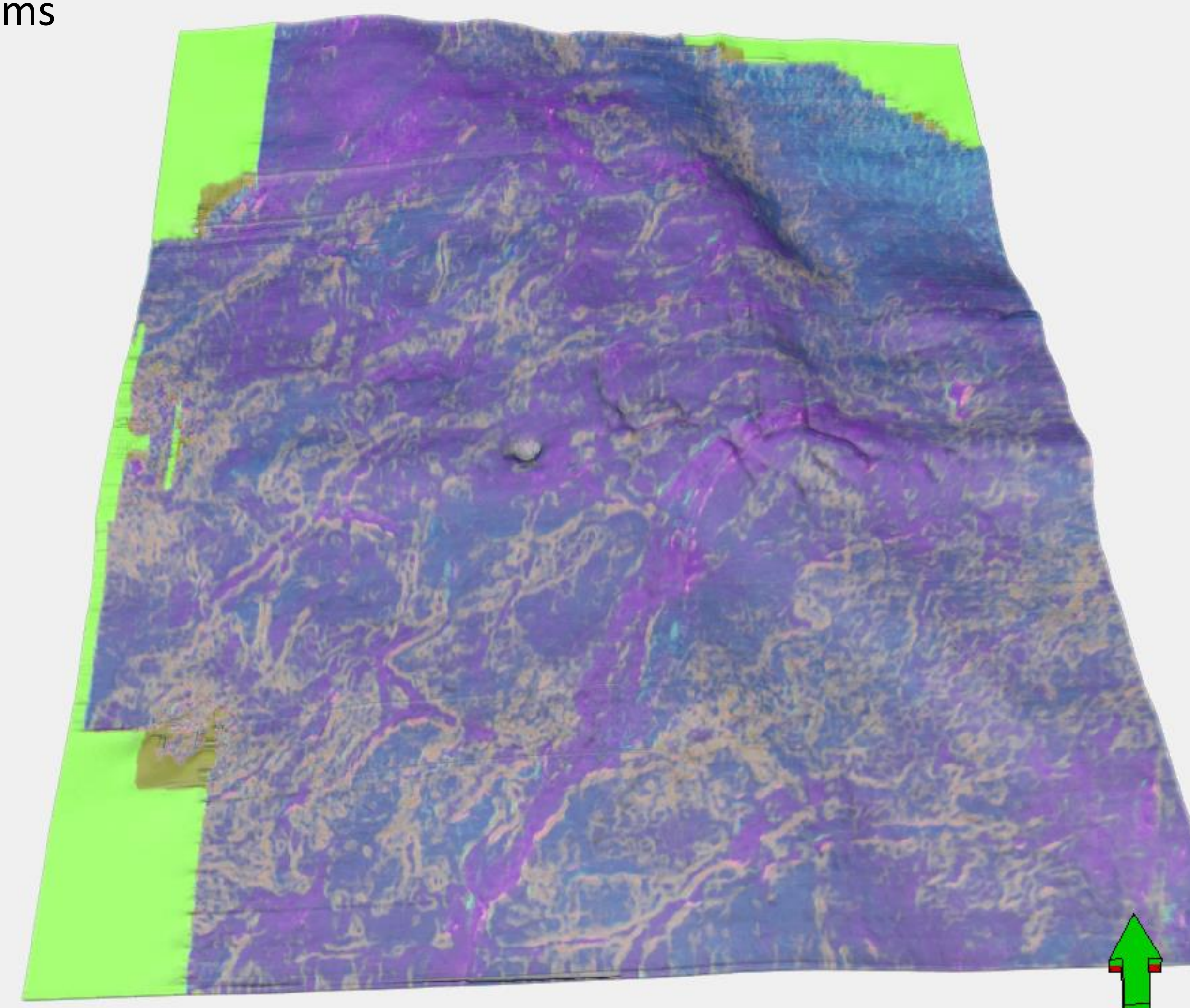

-10 ms

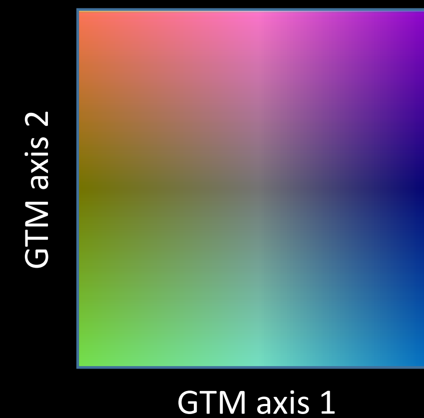

GTM axis 2
GTM axis 1

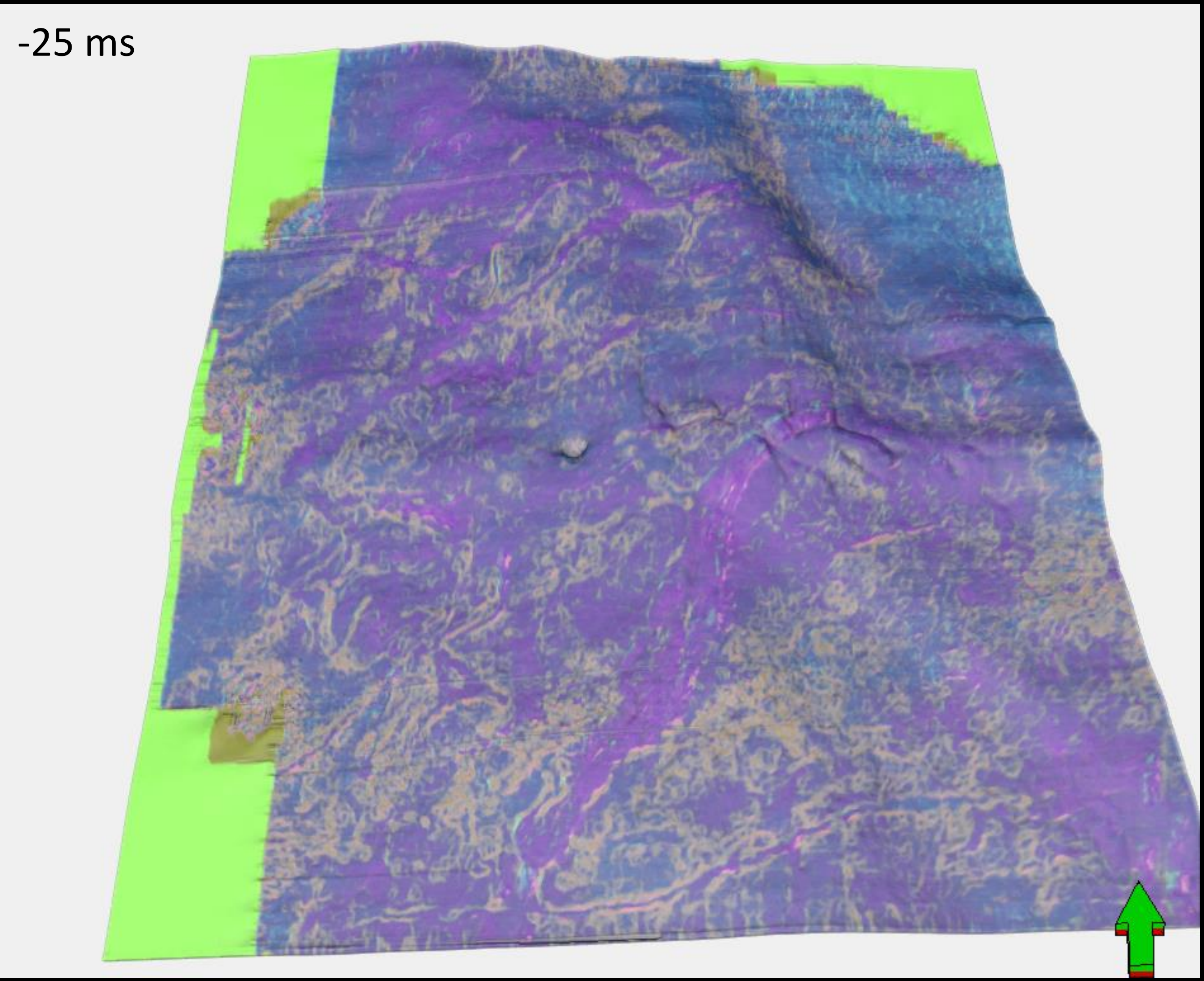

-15 ms

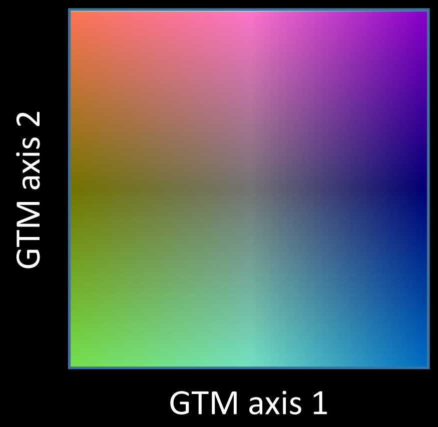

GTM axis 2
GTM axis 1

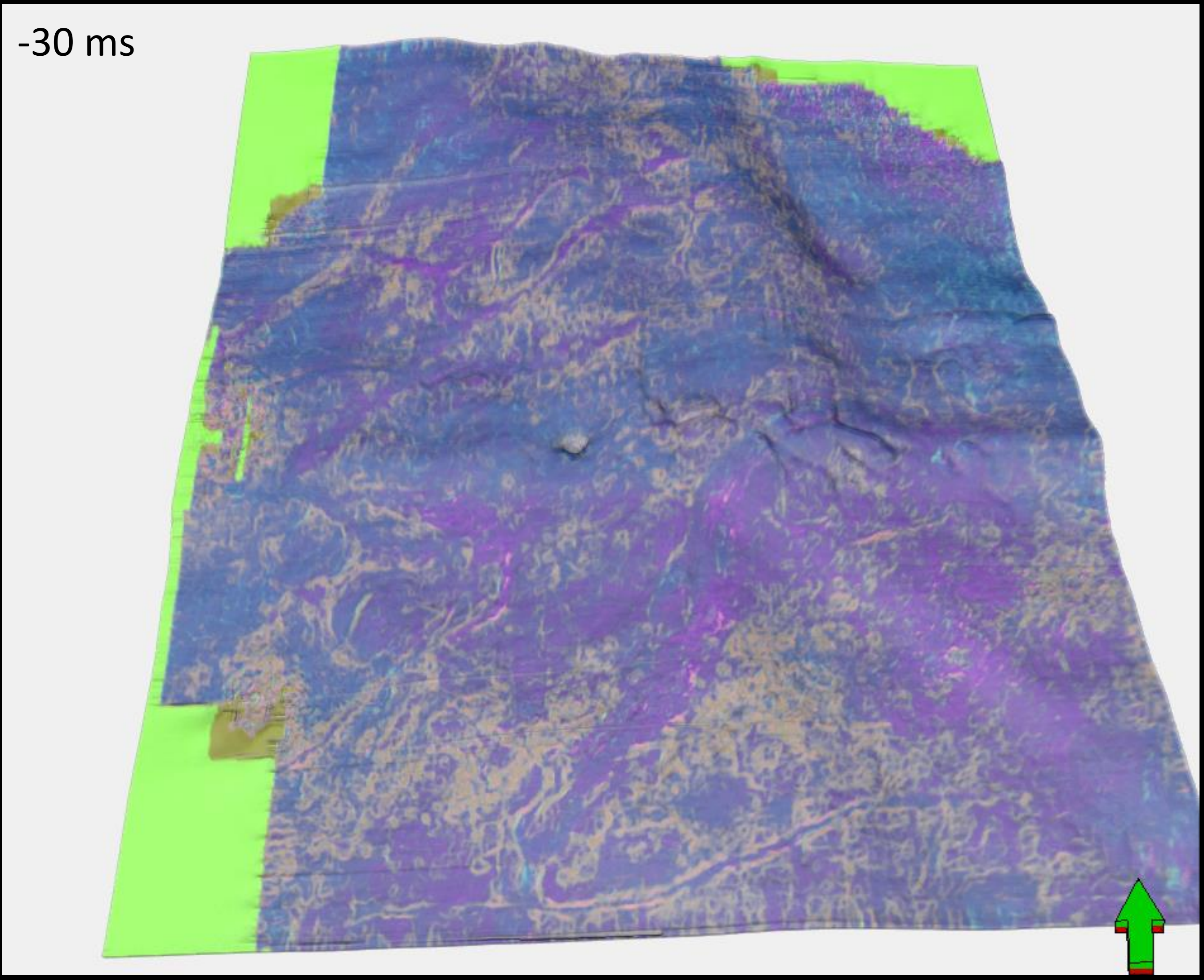
-20 ms

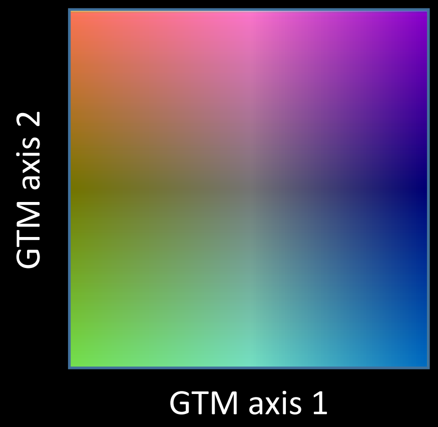


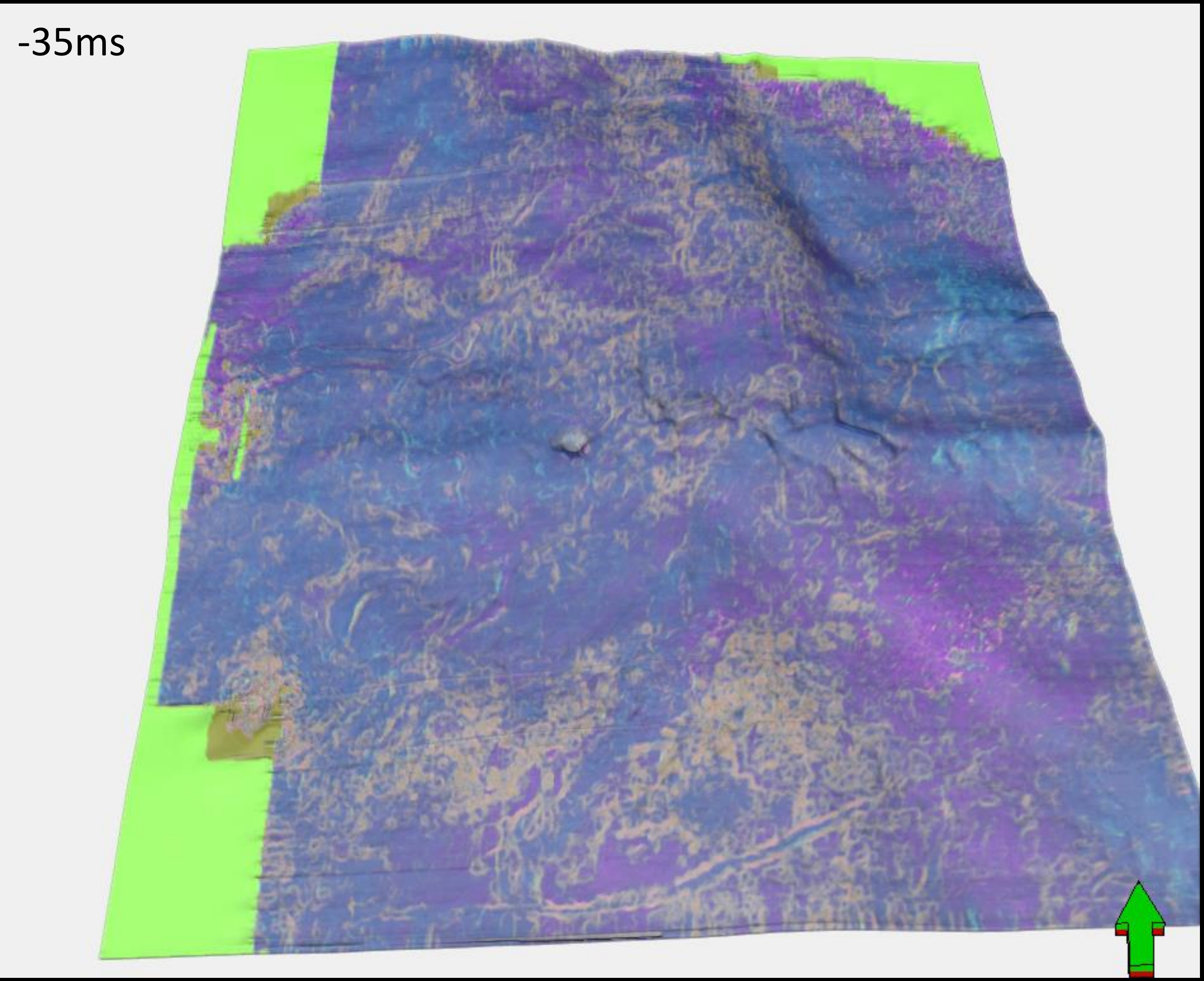



-25 ms

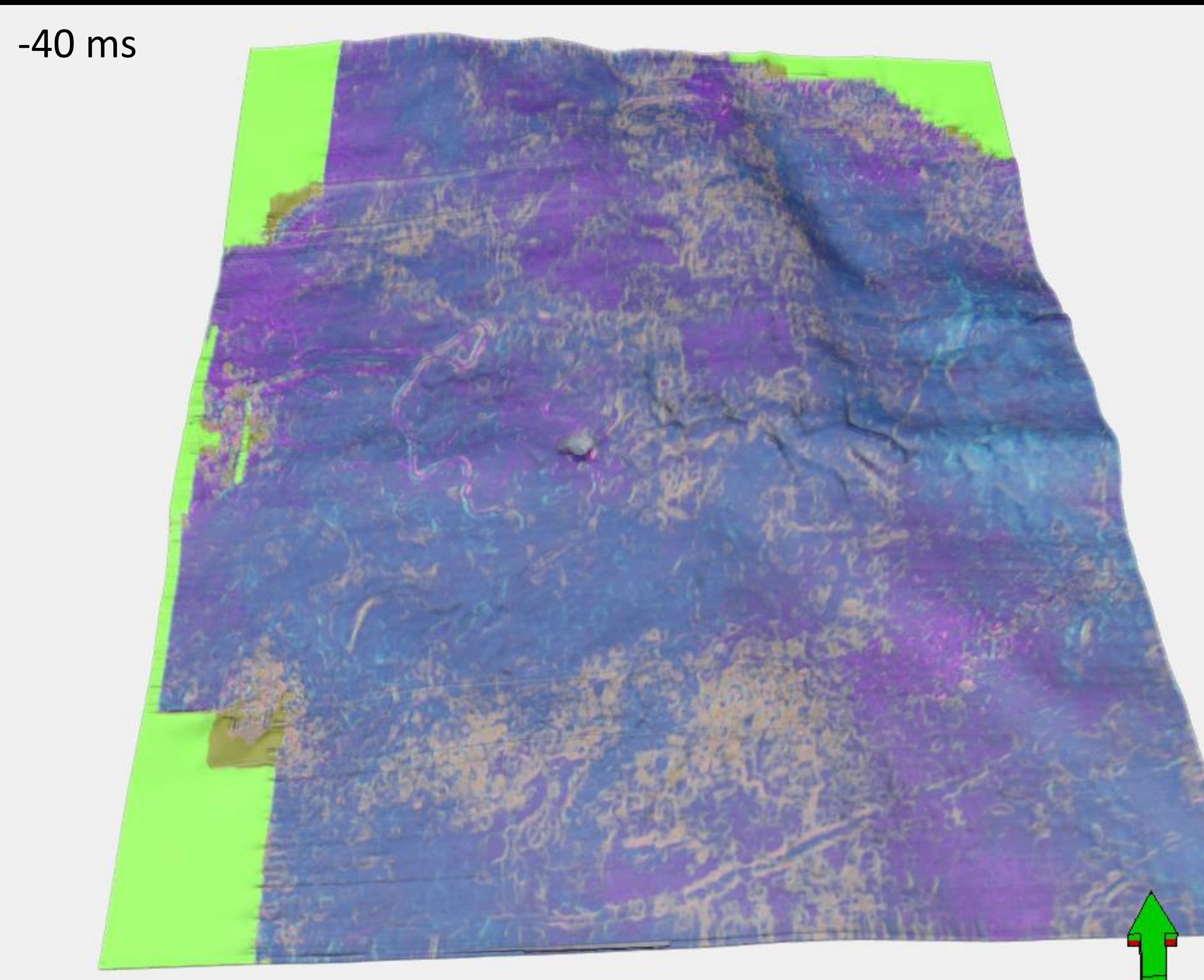

GTM axis 2
GTM axis 1


-30 ms


GTM axis 2
GTM axis 1

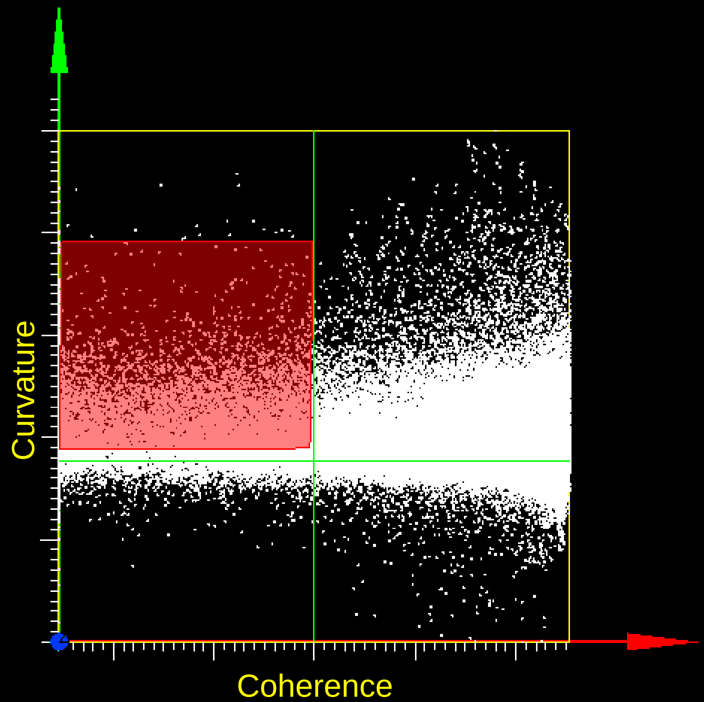

-35ms


GTM axis 2
GTM axis 1

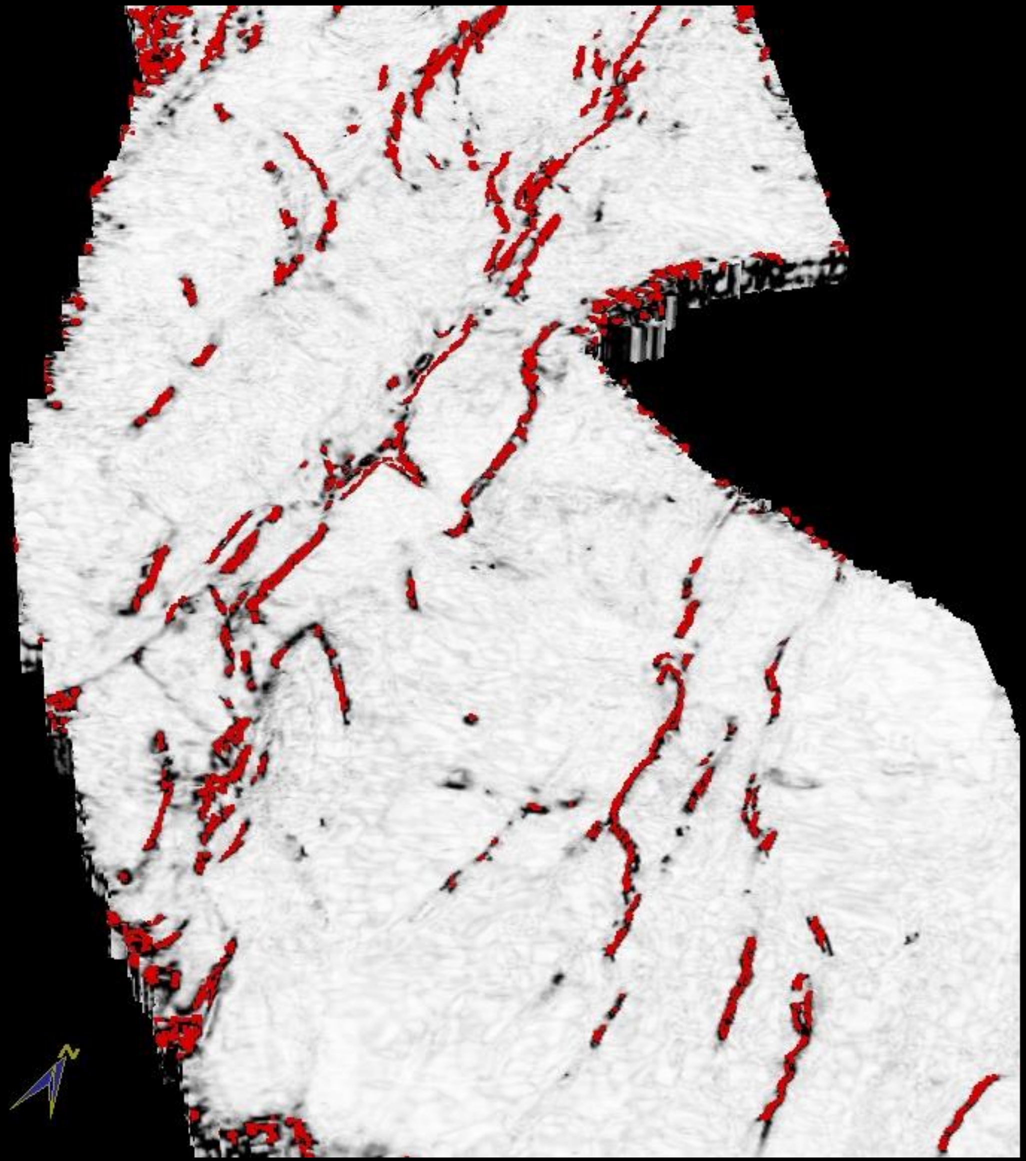

-40 ms


GTM axis 2
GTM axis 1

Crossplotting discontinuity attributes

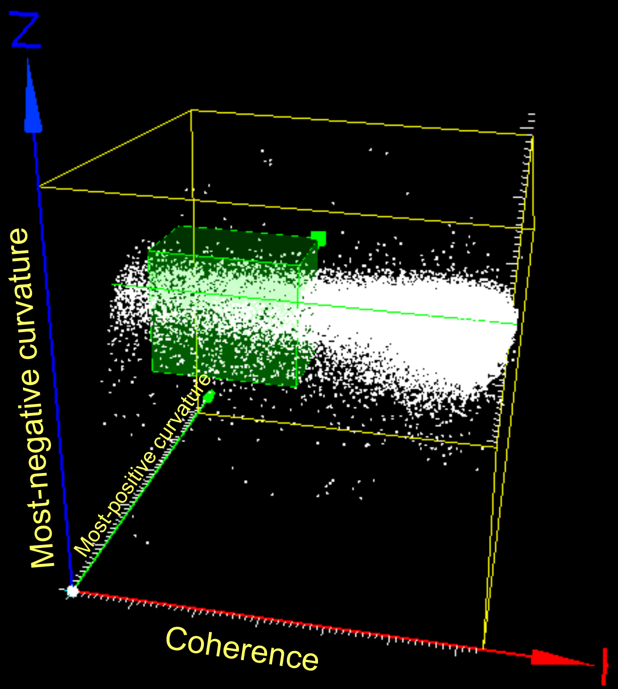


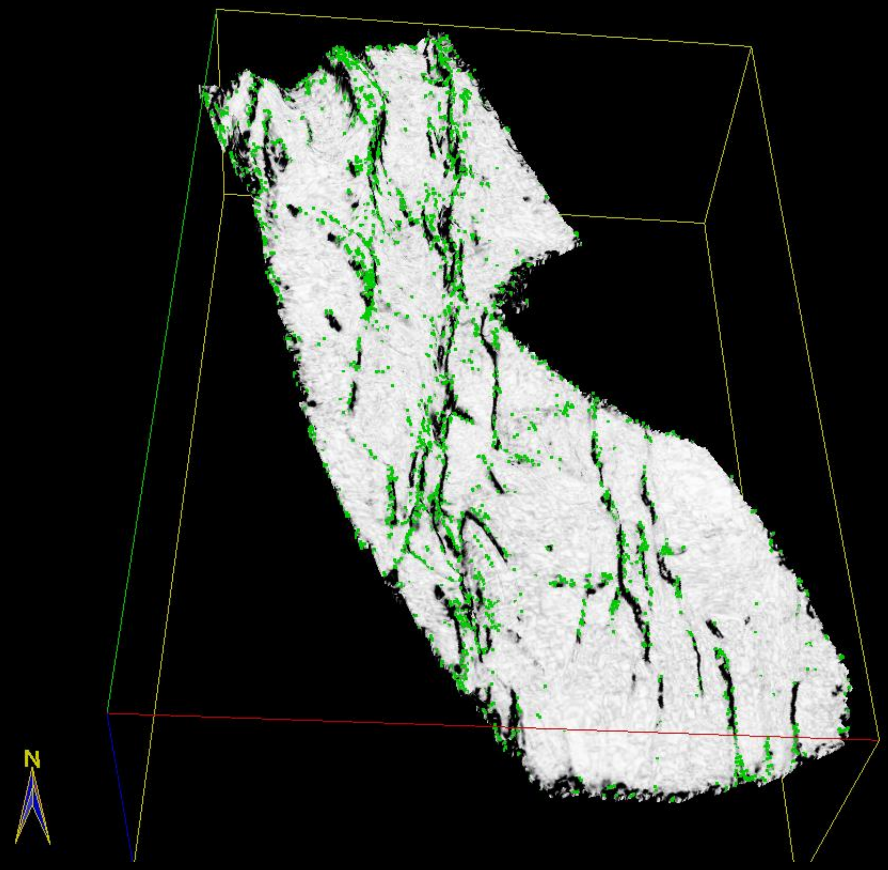
Crossplot of coherence versus most-positive curvature



Overlay of the cluster of points enclosed in a polygon on the crossplot of coherence versus most-positive curvature, on the coherence strat-slice. The red lineaments align with the faults that one would interpret on the coherence strat-slice

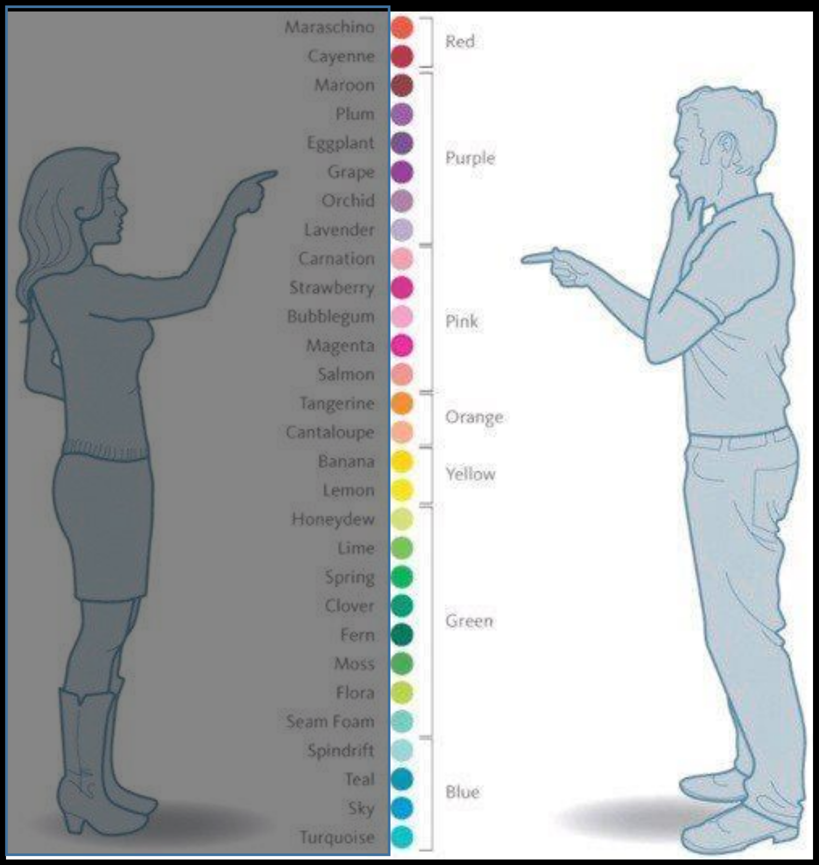
3D Crossplotting of discontinuity attributes





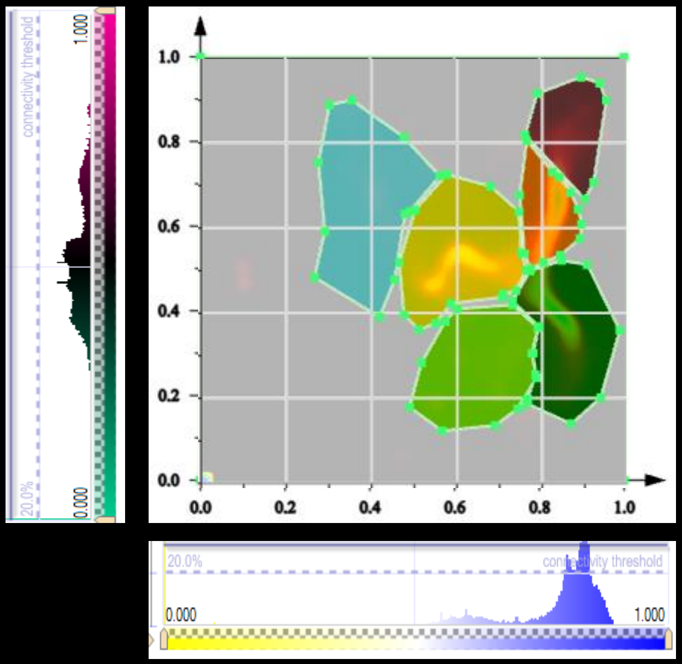
Coherence strata-cube

Color perception: Men vs. women.



Interactive cluster definition

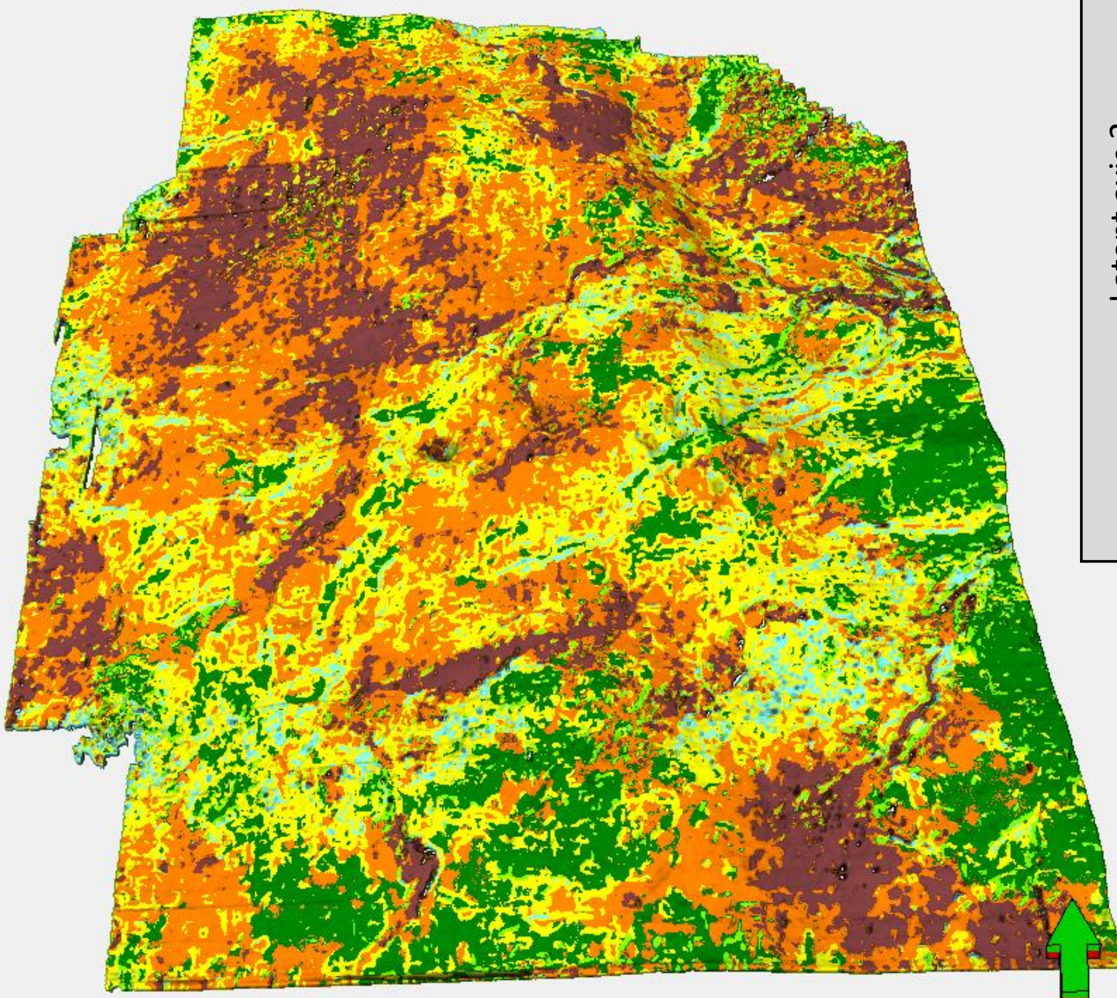
GTM axis 2

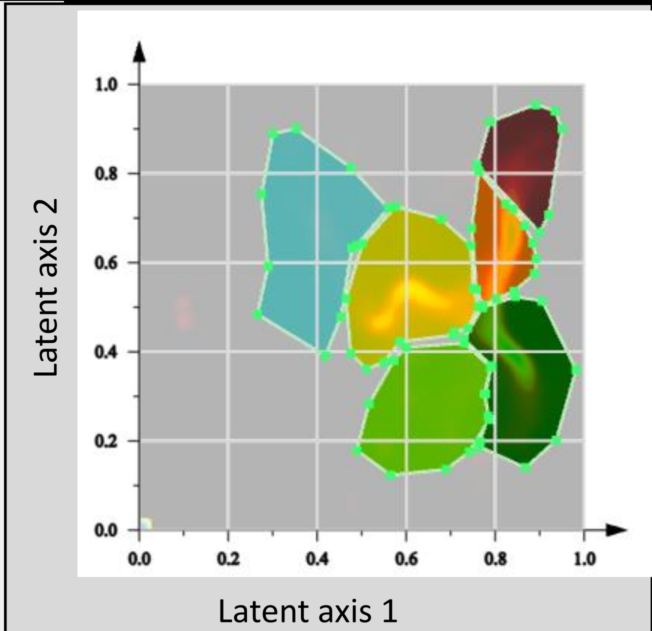


GTM axis 1

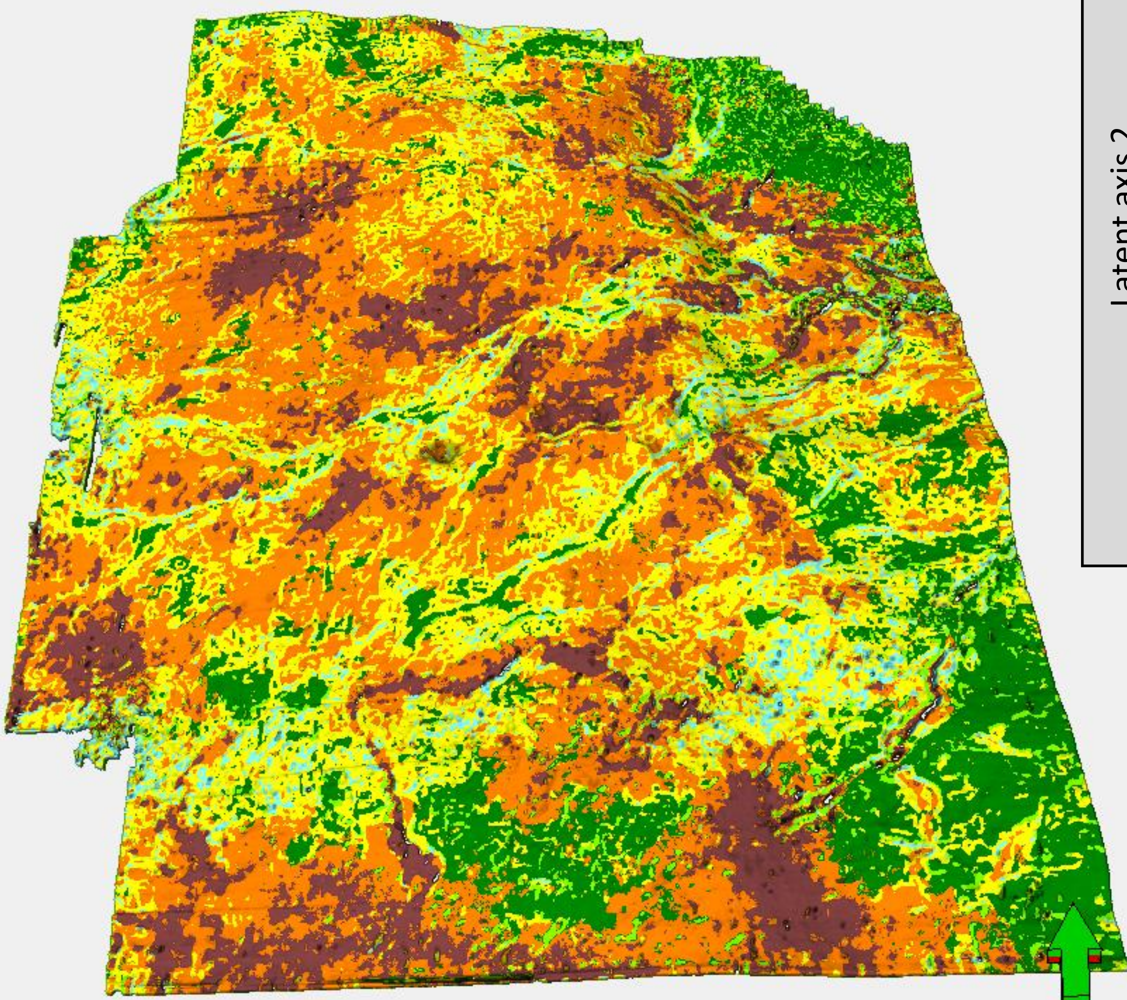
(Facebook communication on 10/18/2011. Origin unknown)

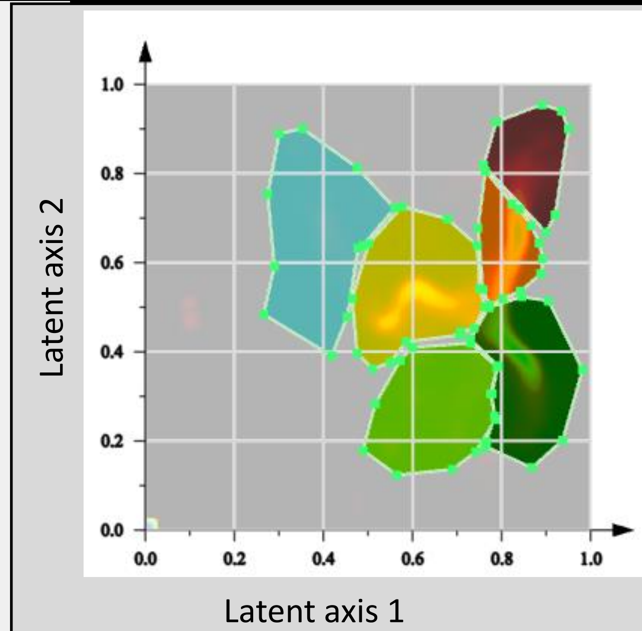
+40 ms



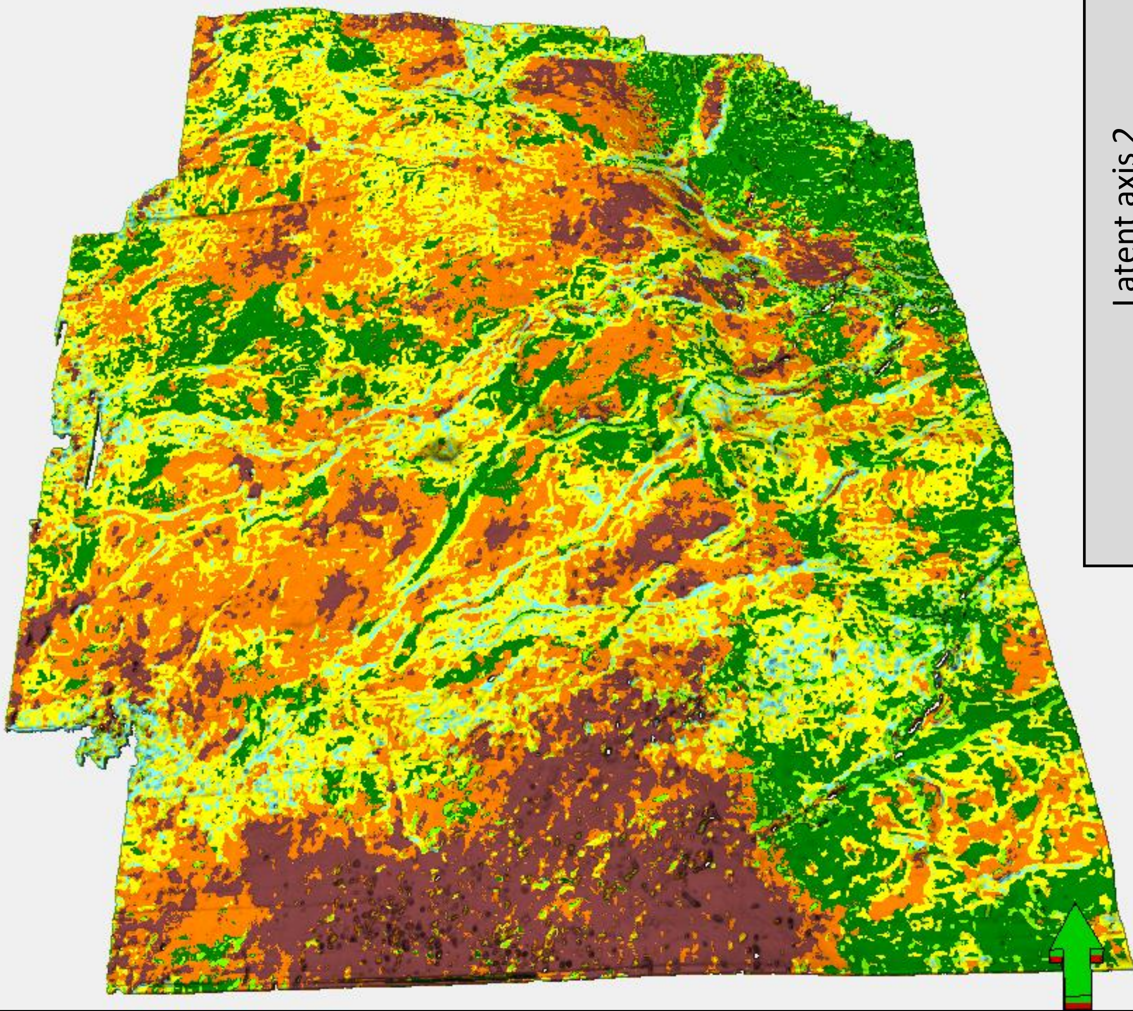


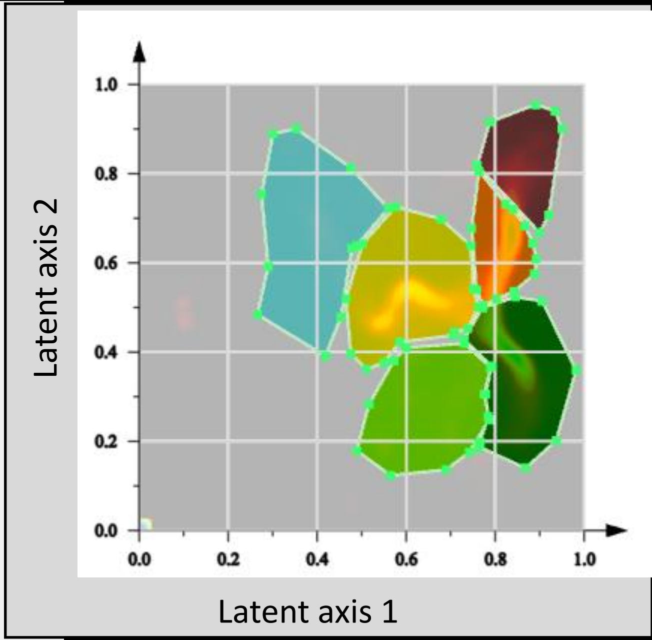
+35 ms



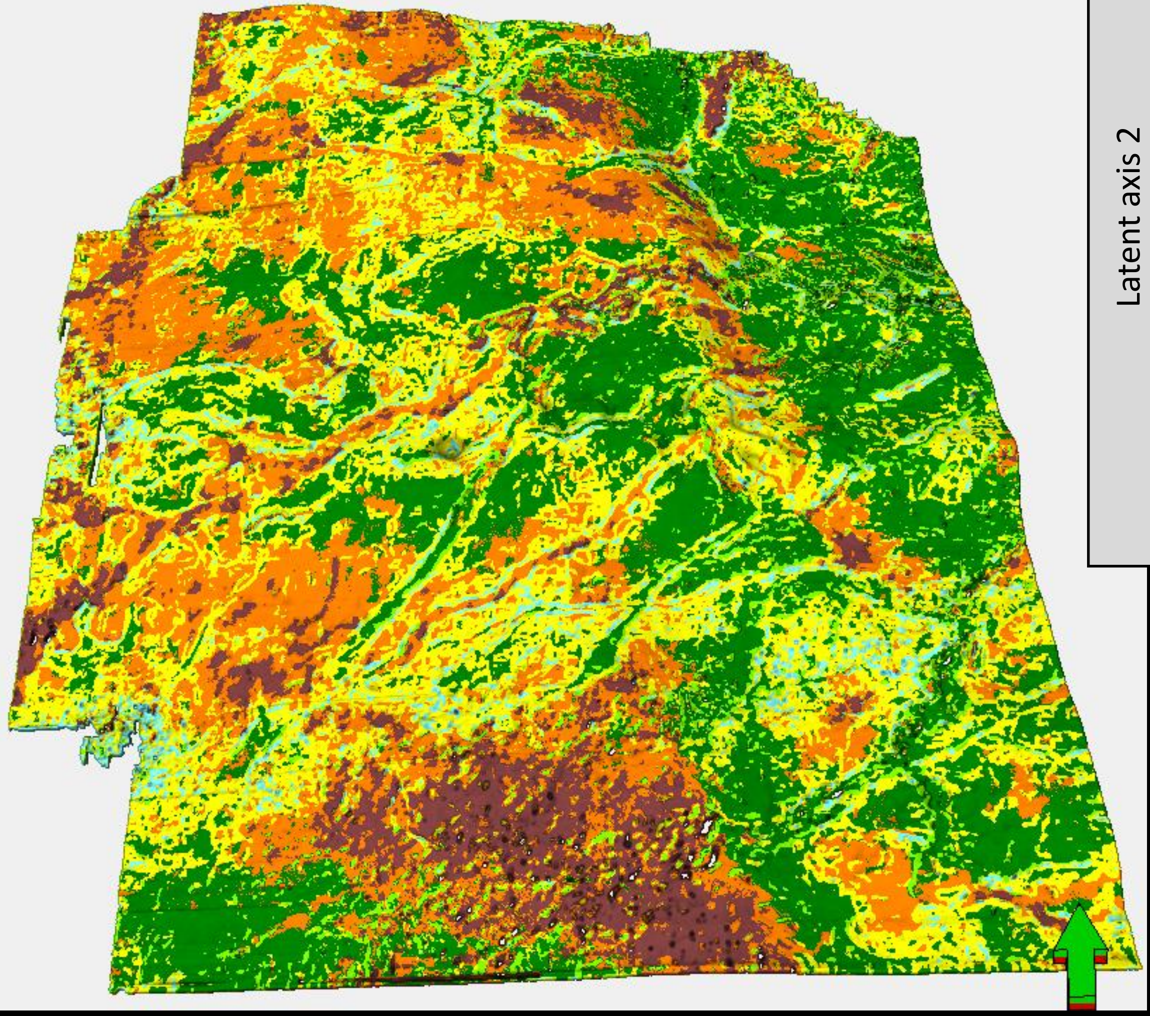


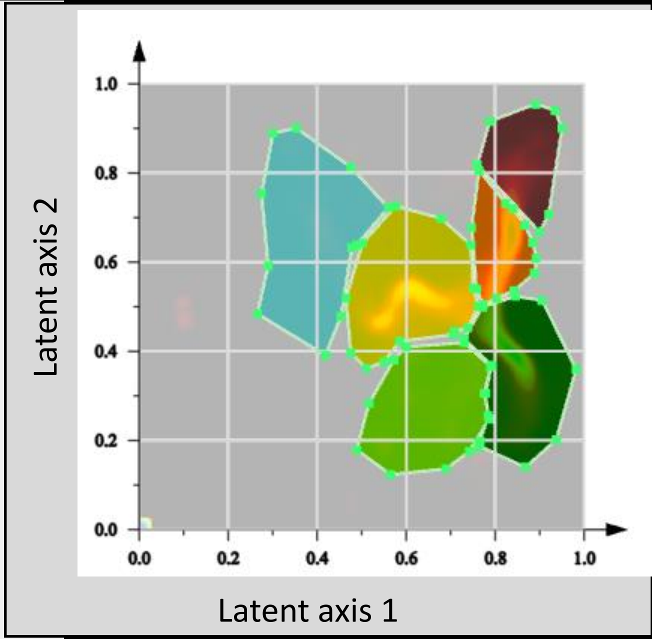
+30 ms



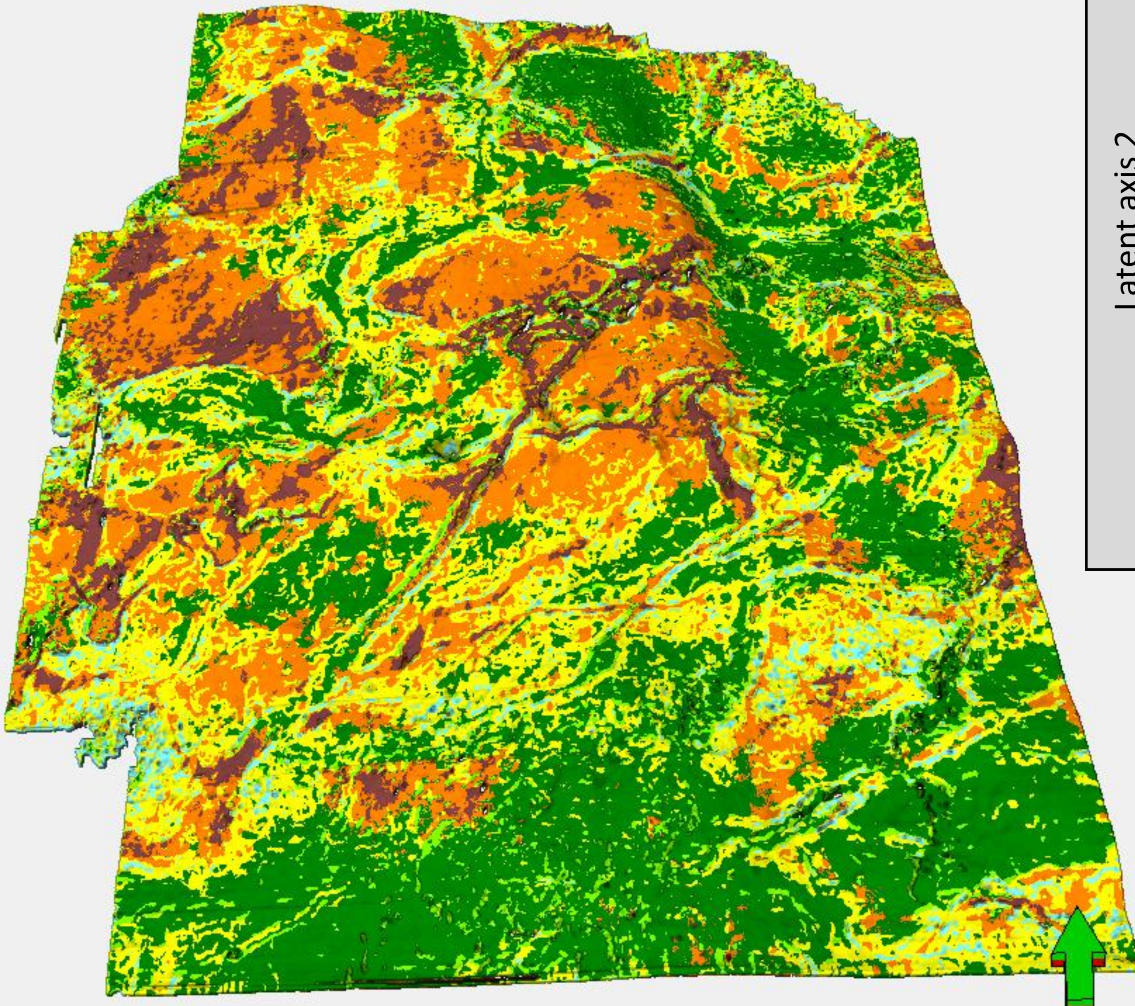


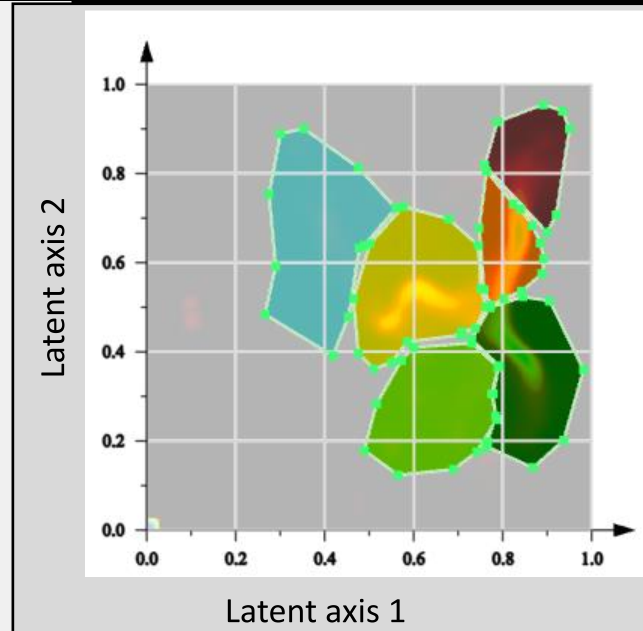
+25 ms



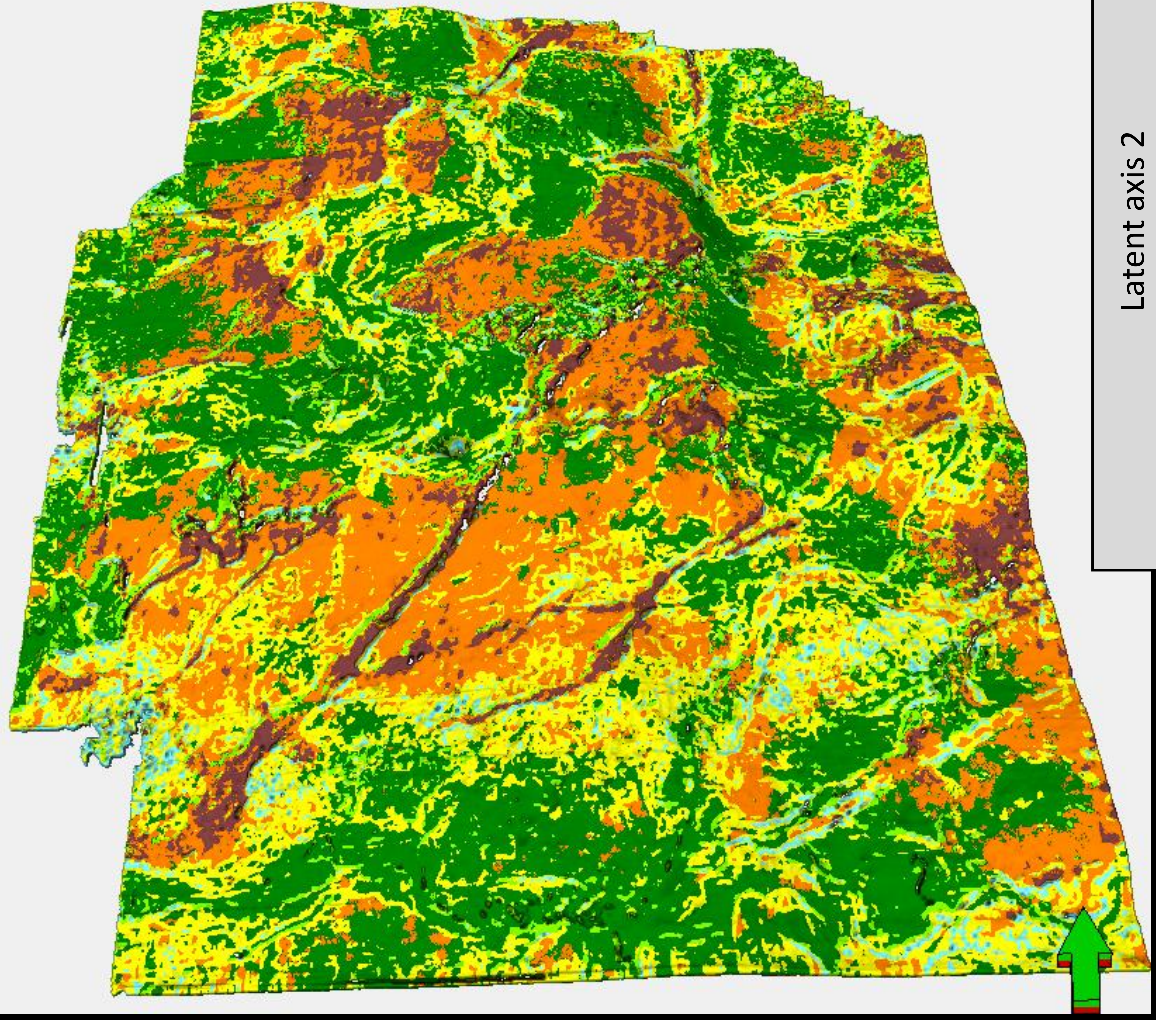


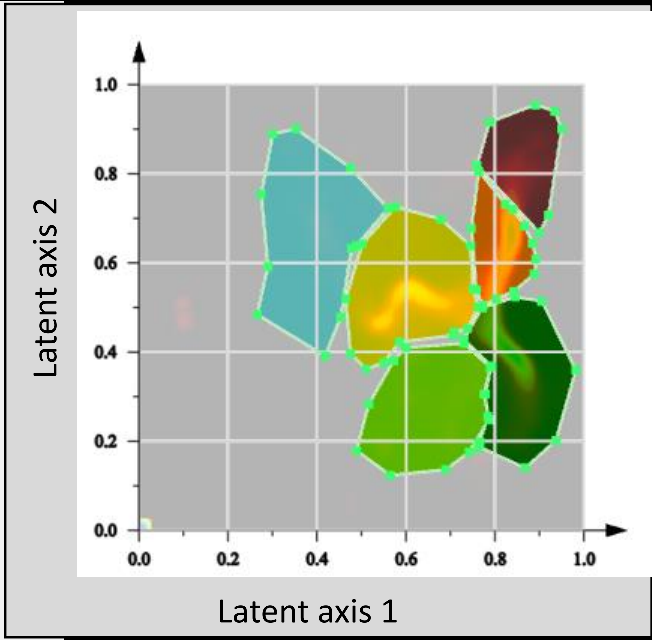
+20 ms



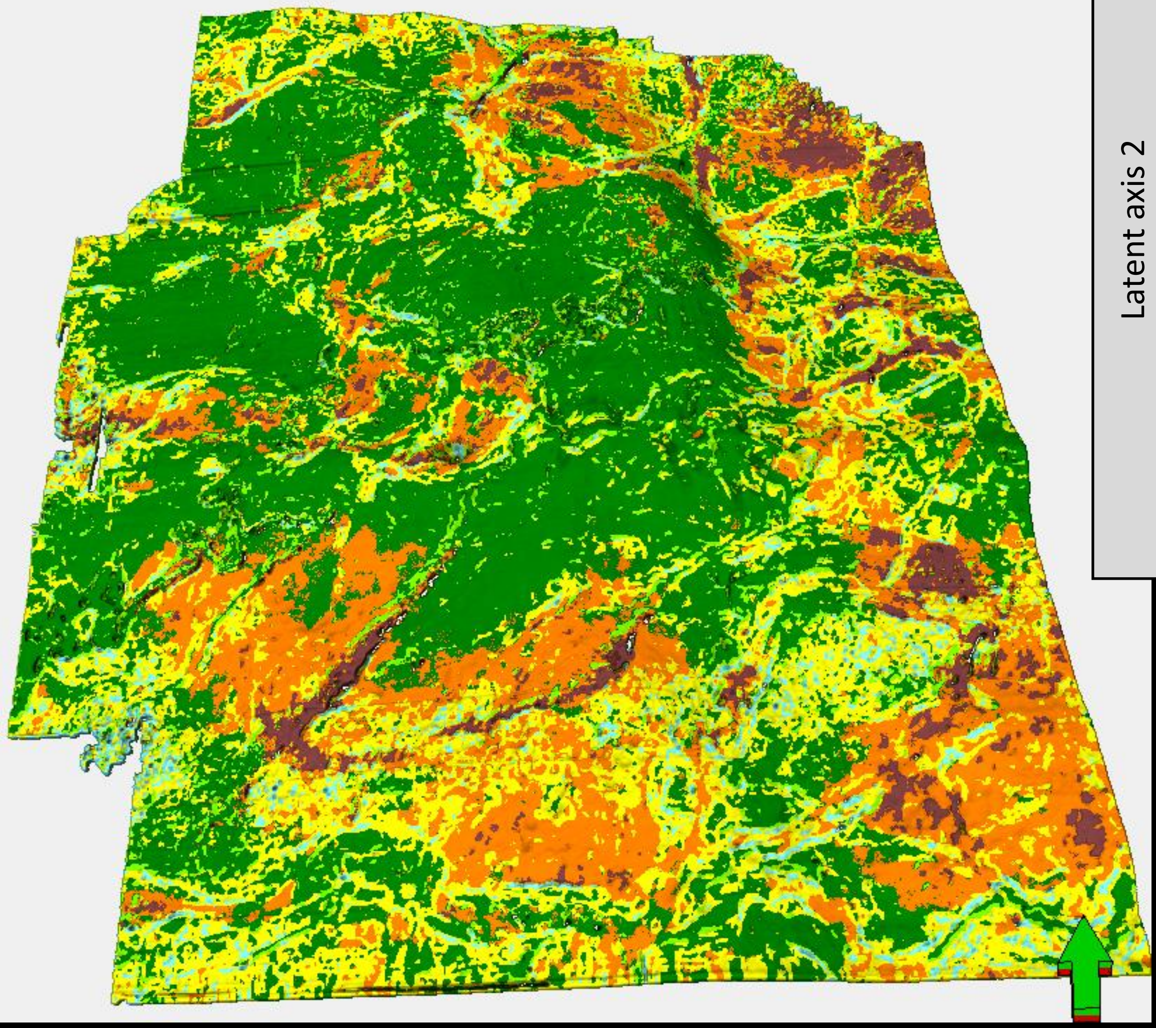


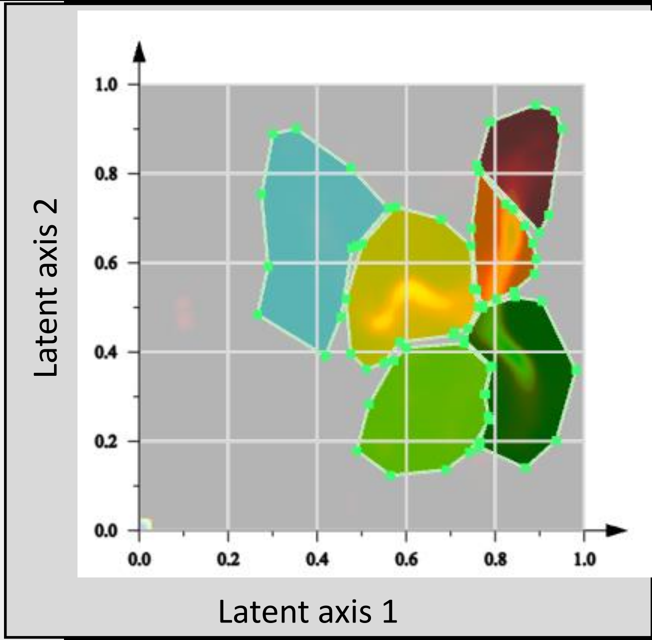
+15 ms

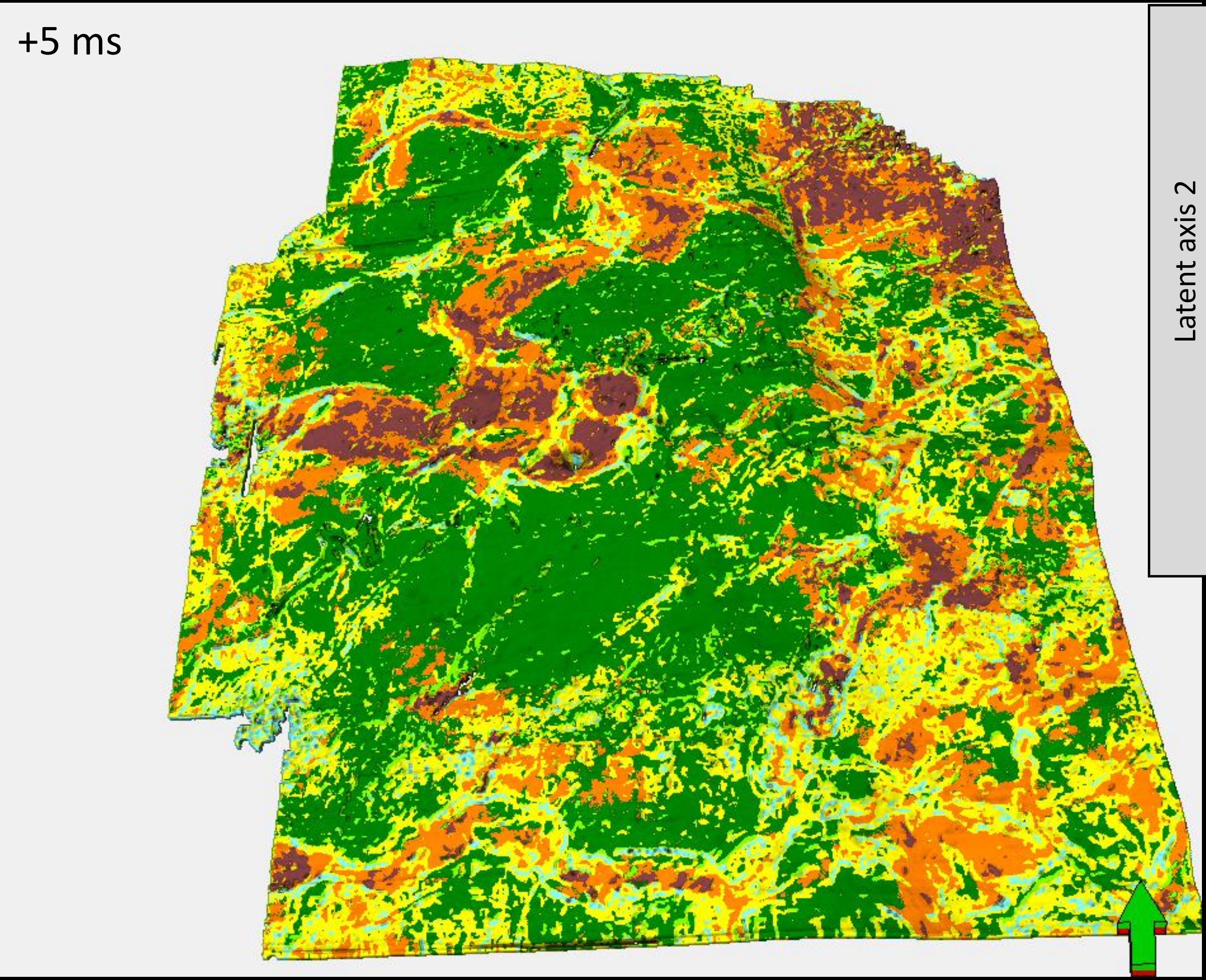


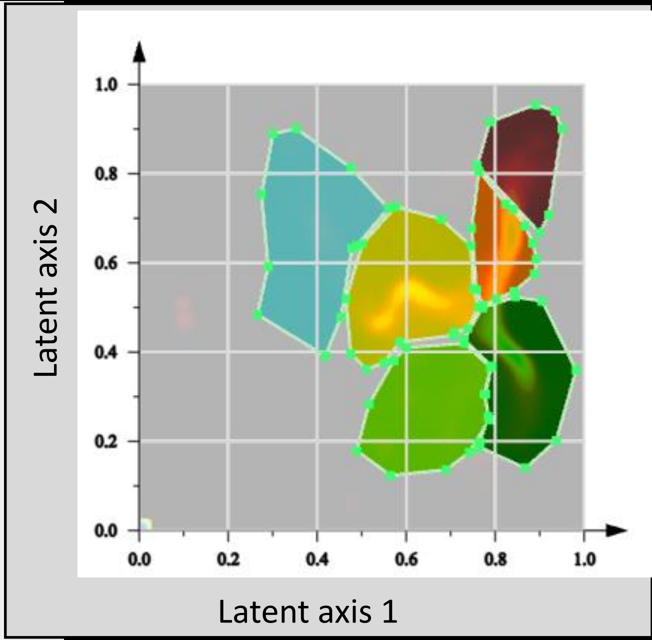


+10ms

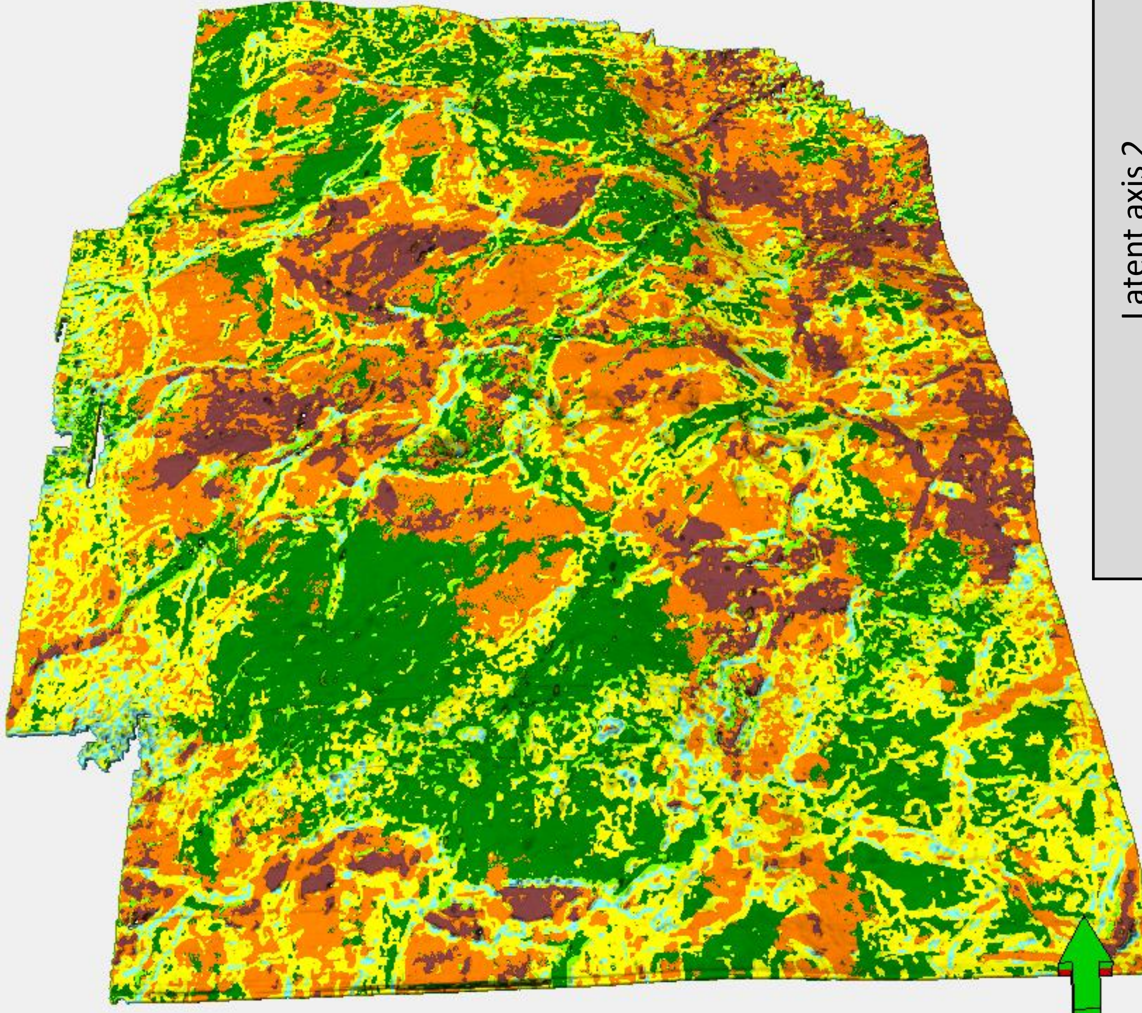


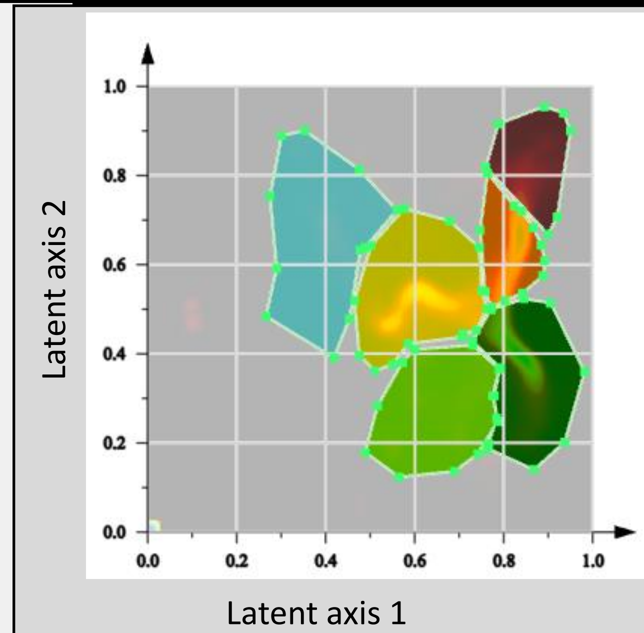



+5 ms

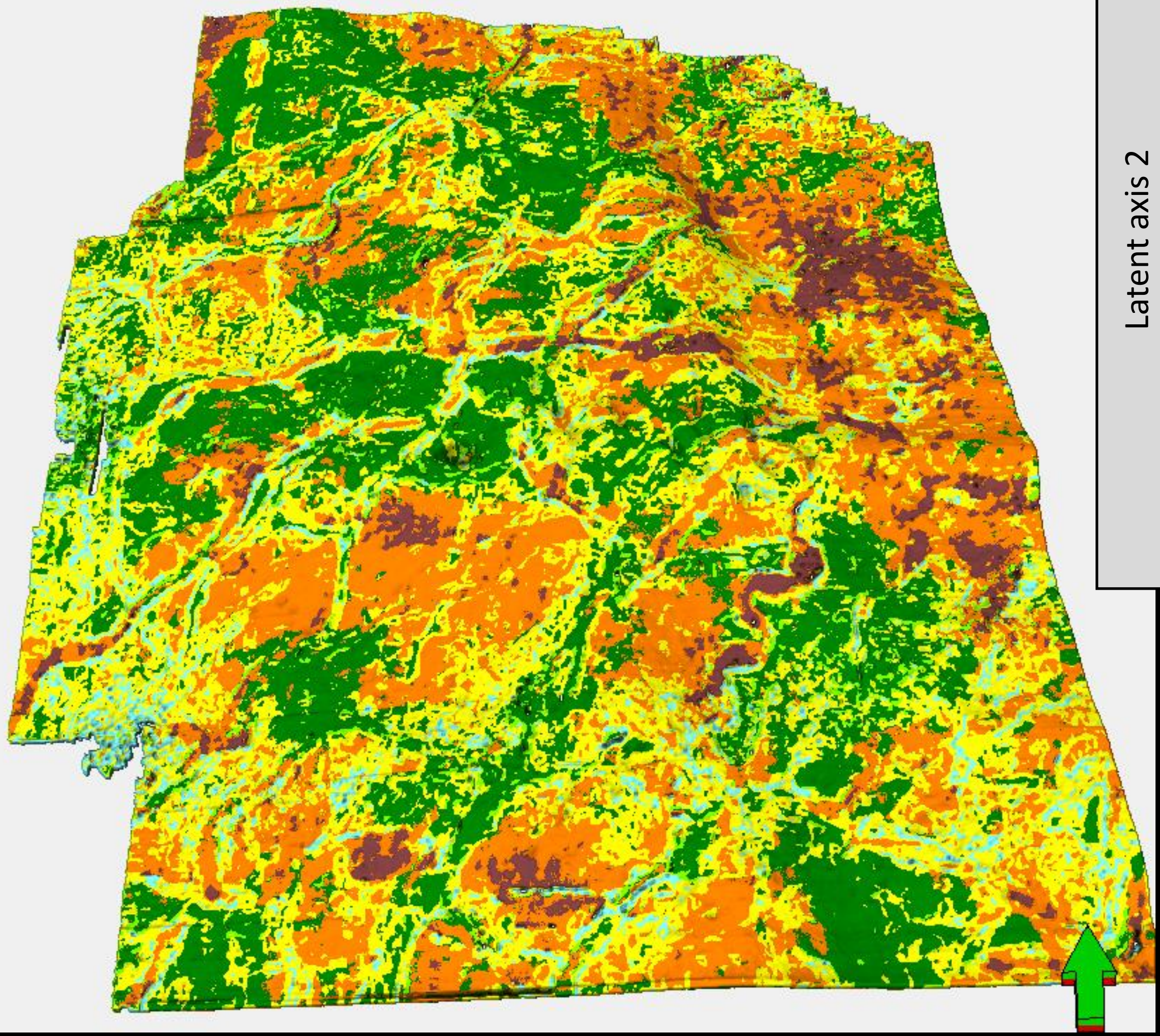

Latent axis 2
Latent axis 1
0.0
0.2
0.4
0.6
0.8
1.0

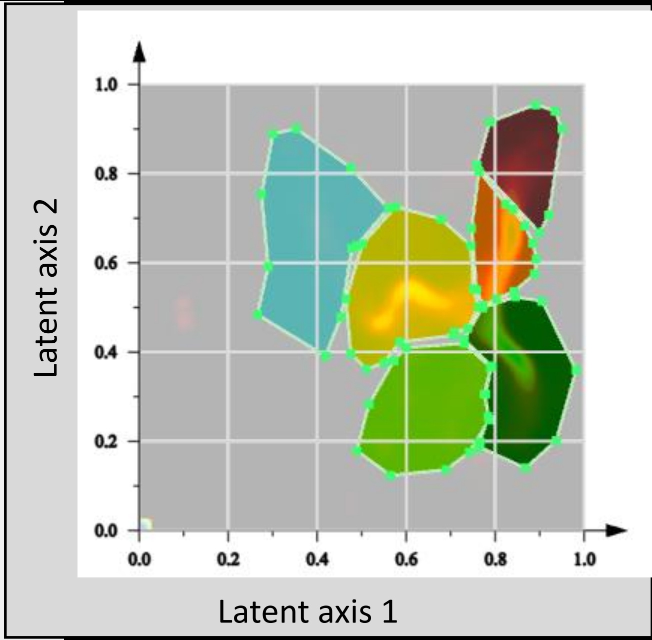
0 ms



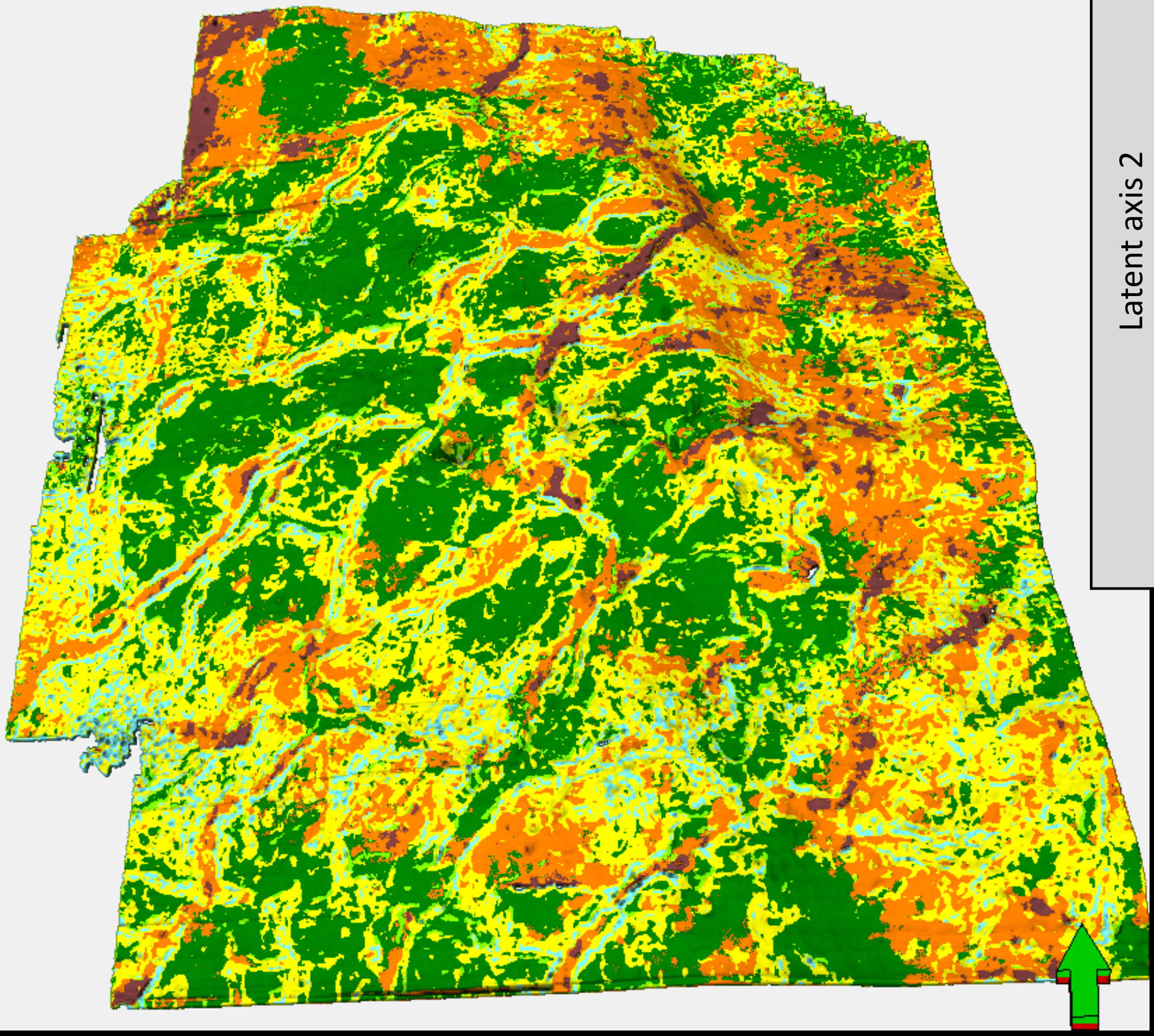


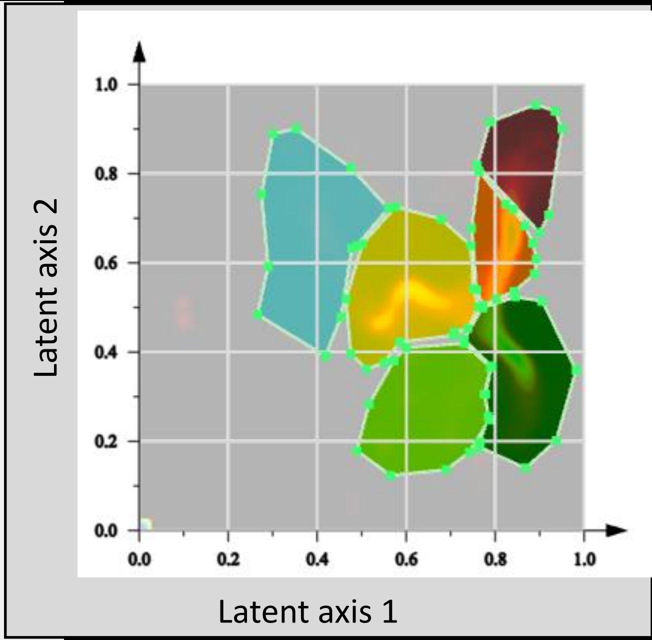
-5ms



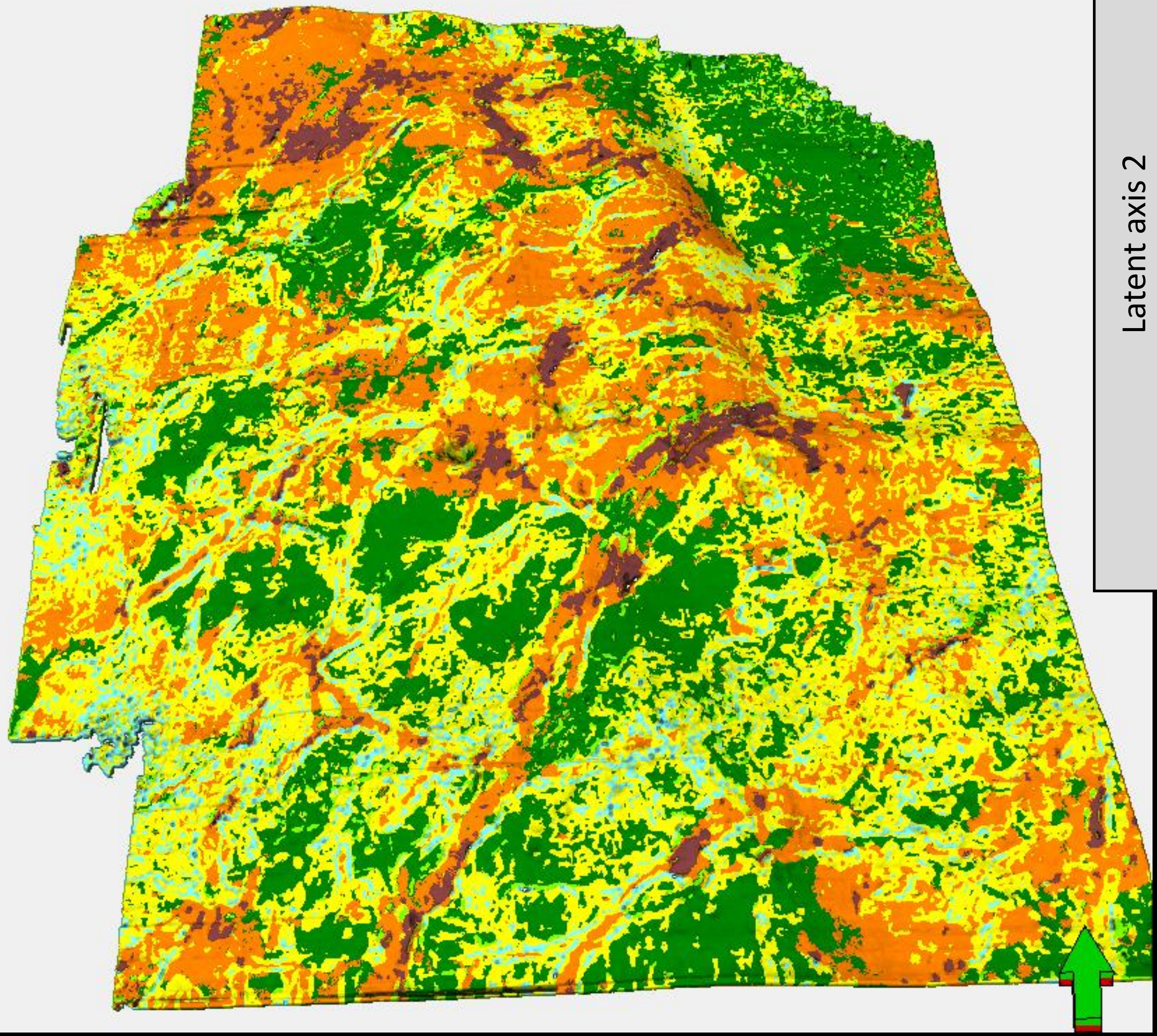


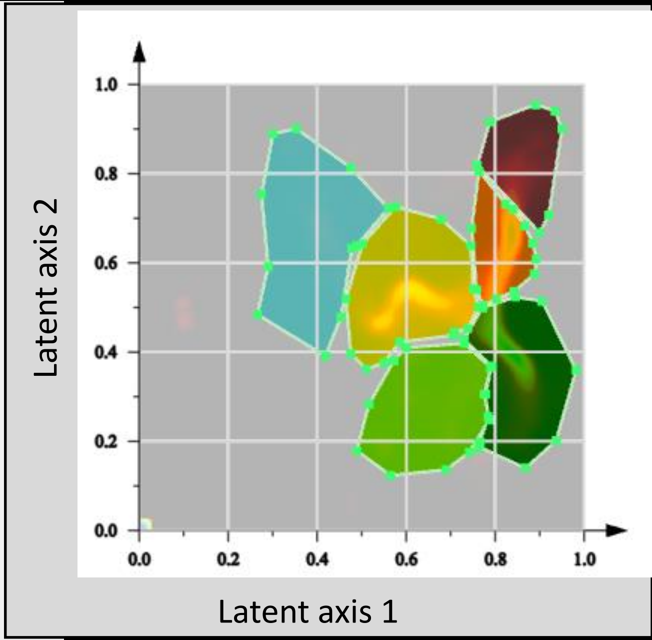
-10 ms



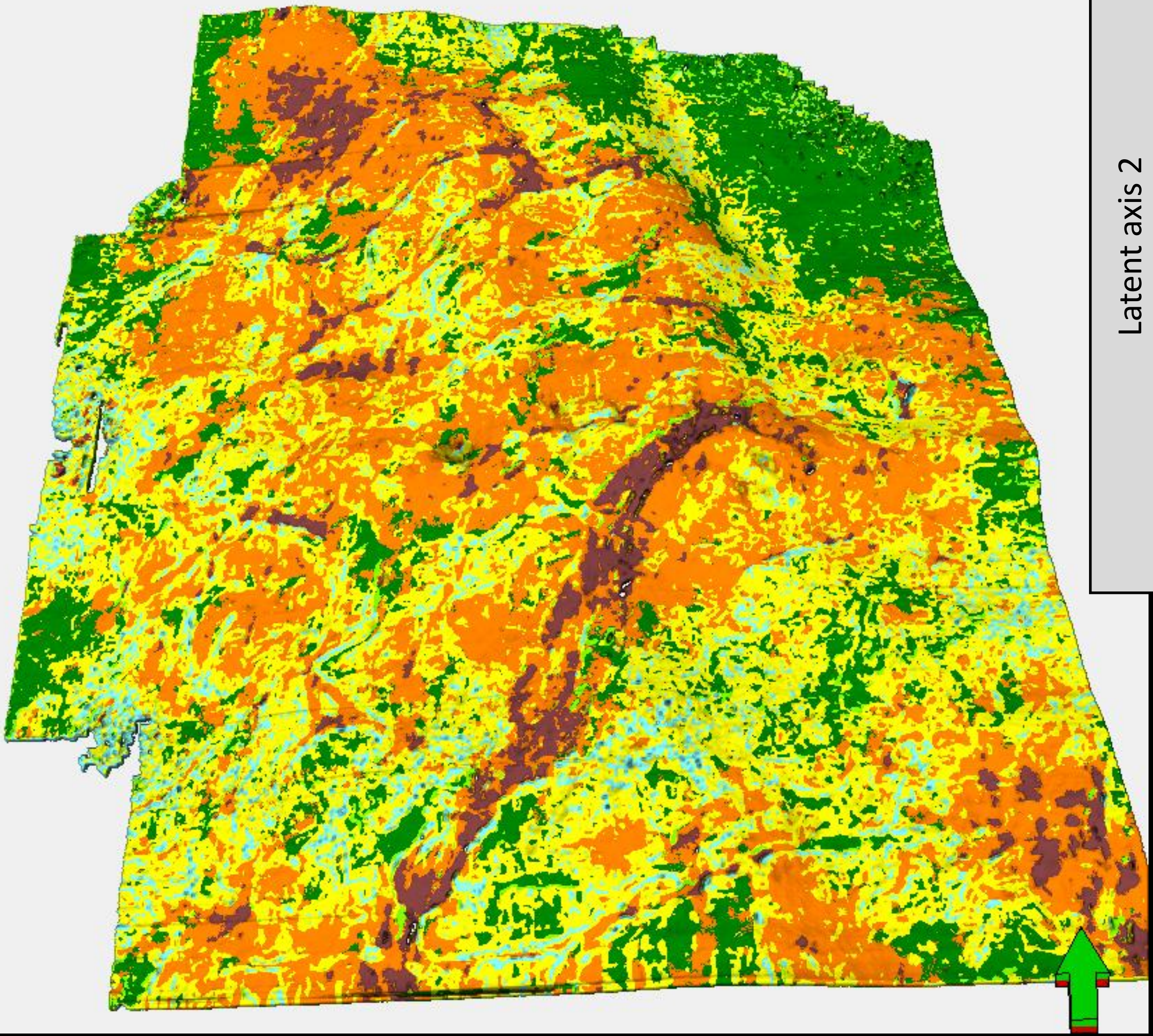


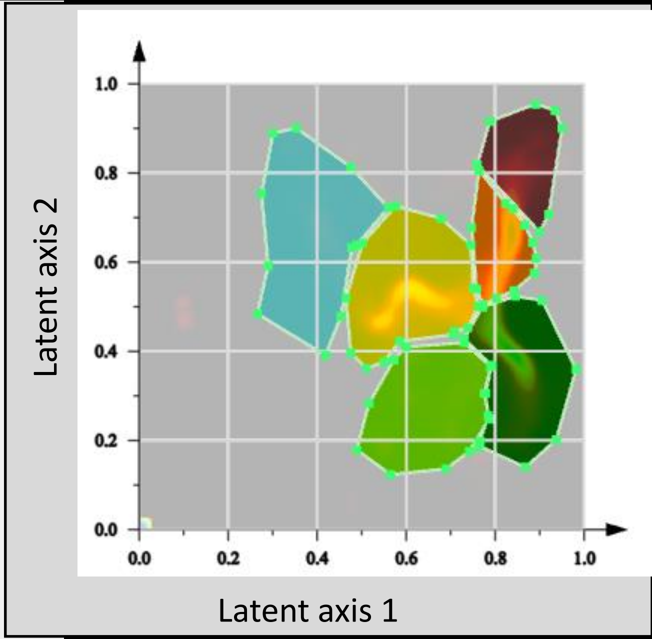
-15 ms



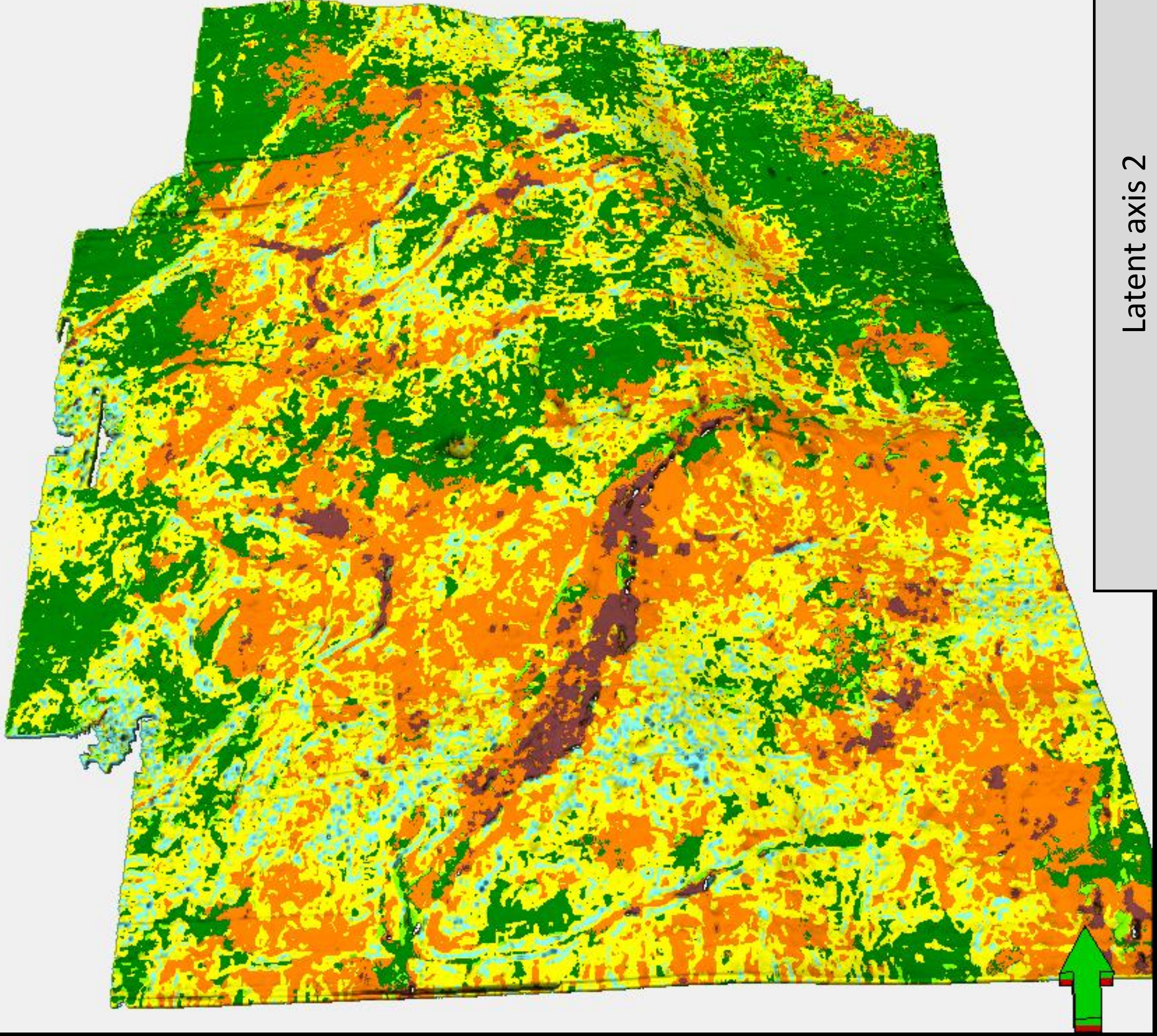


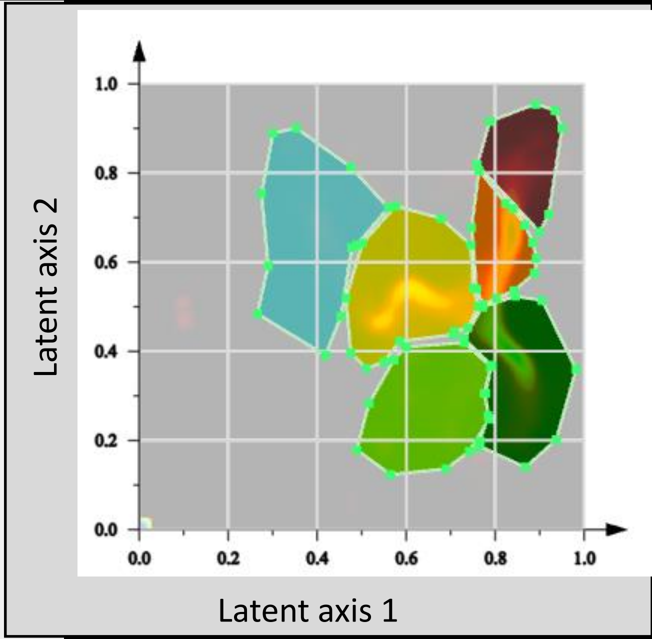
-20 ms



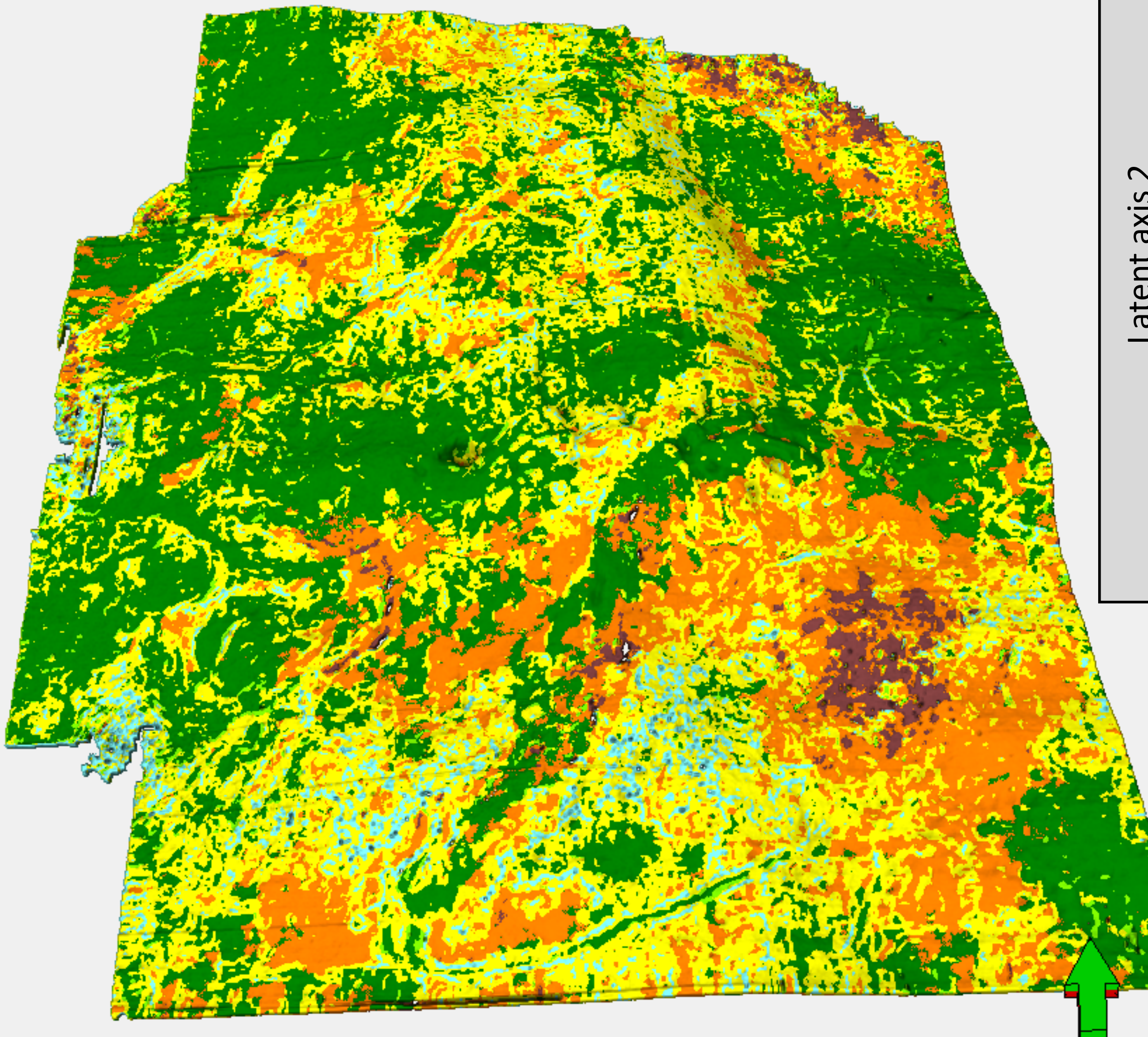


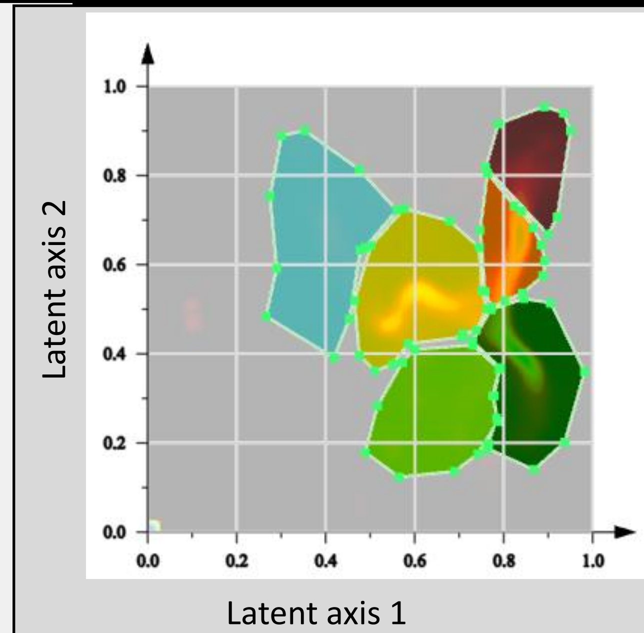
-25 ms



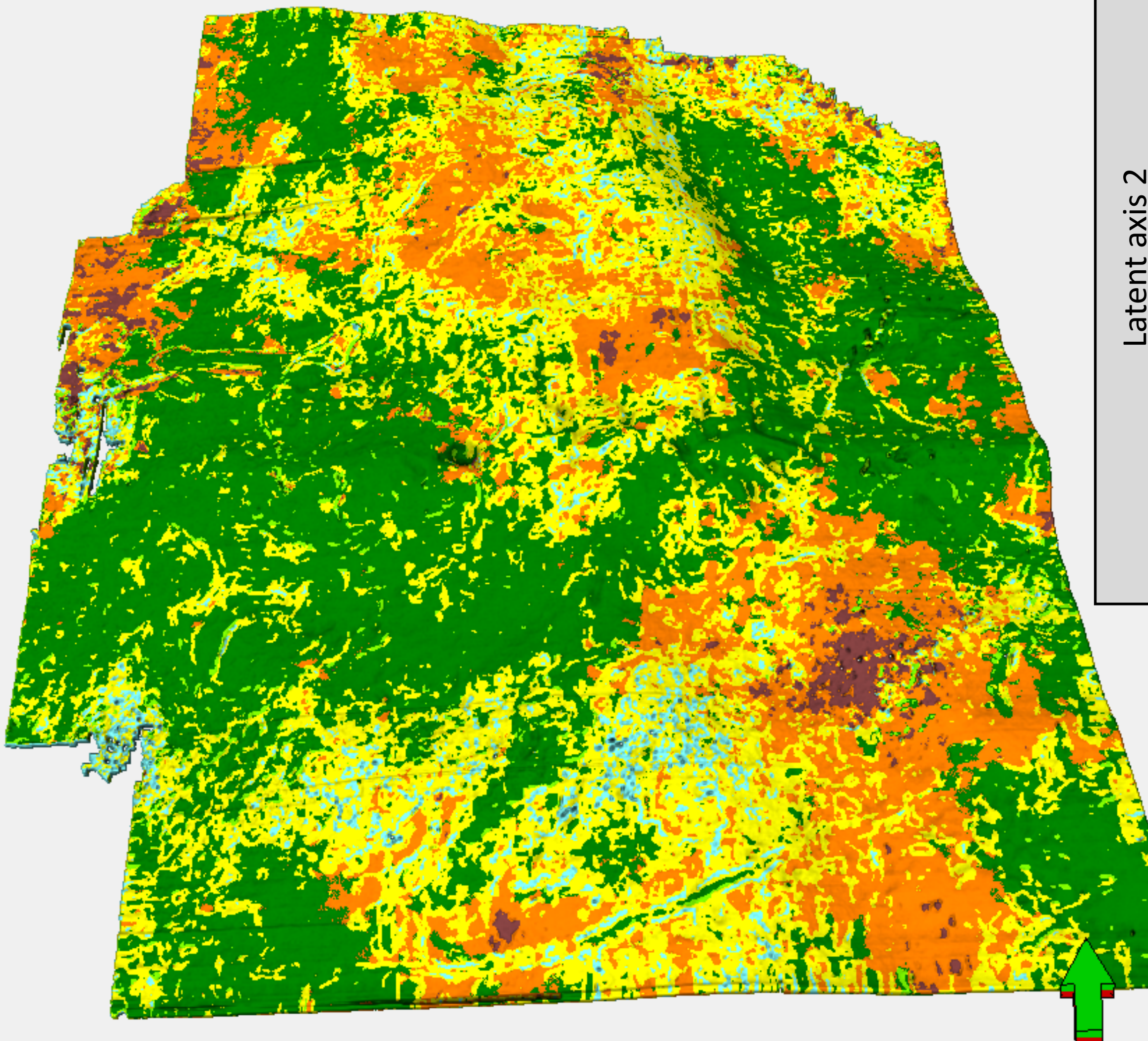


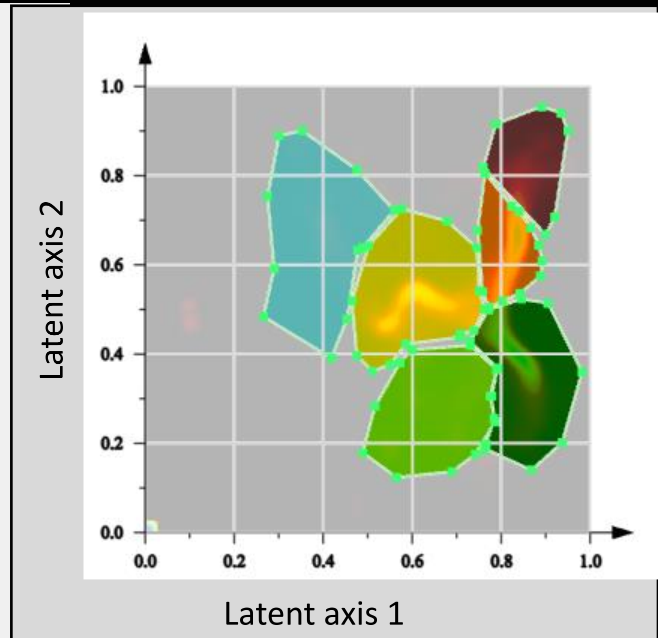
-30 ms



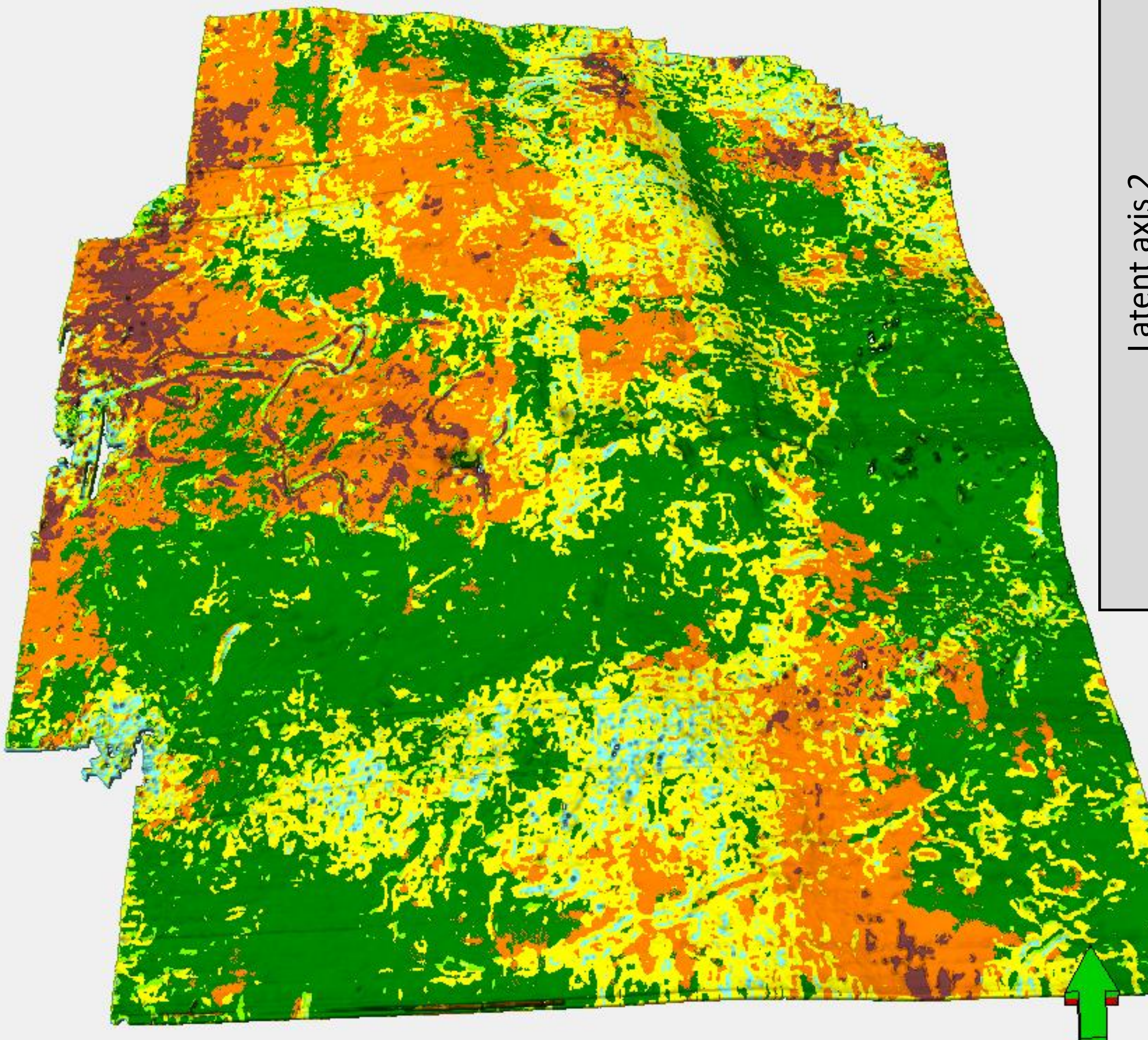


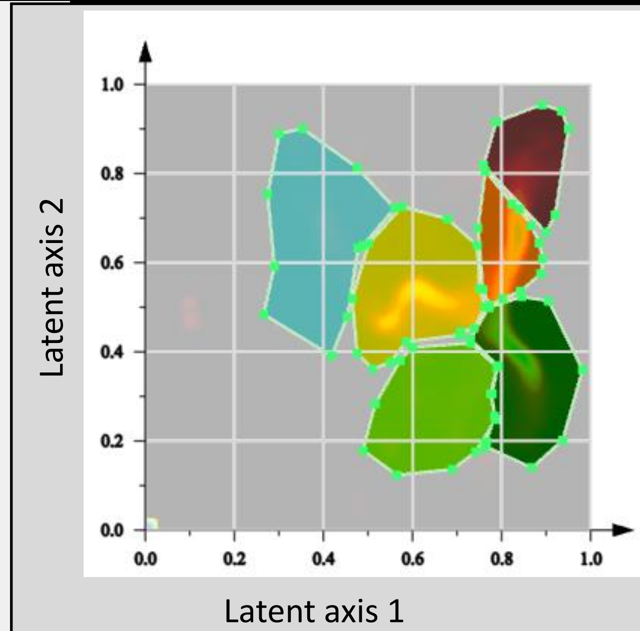
-35 ms



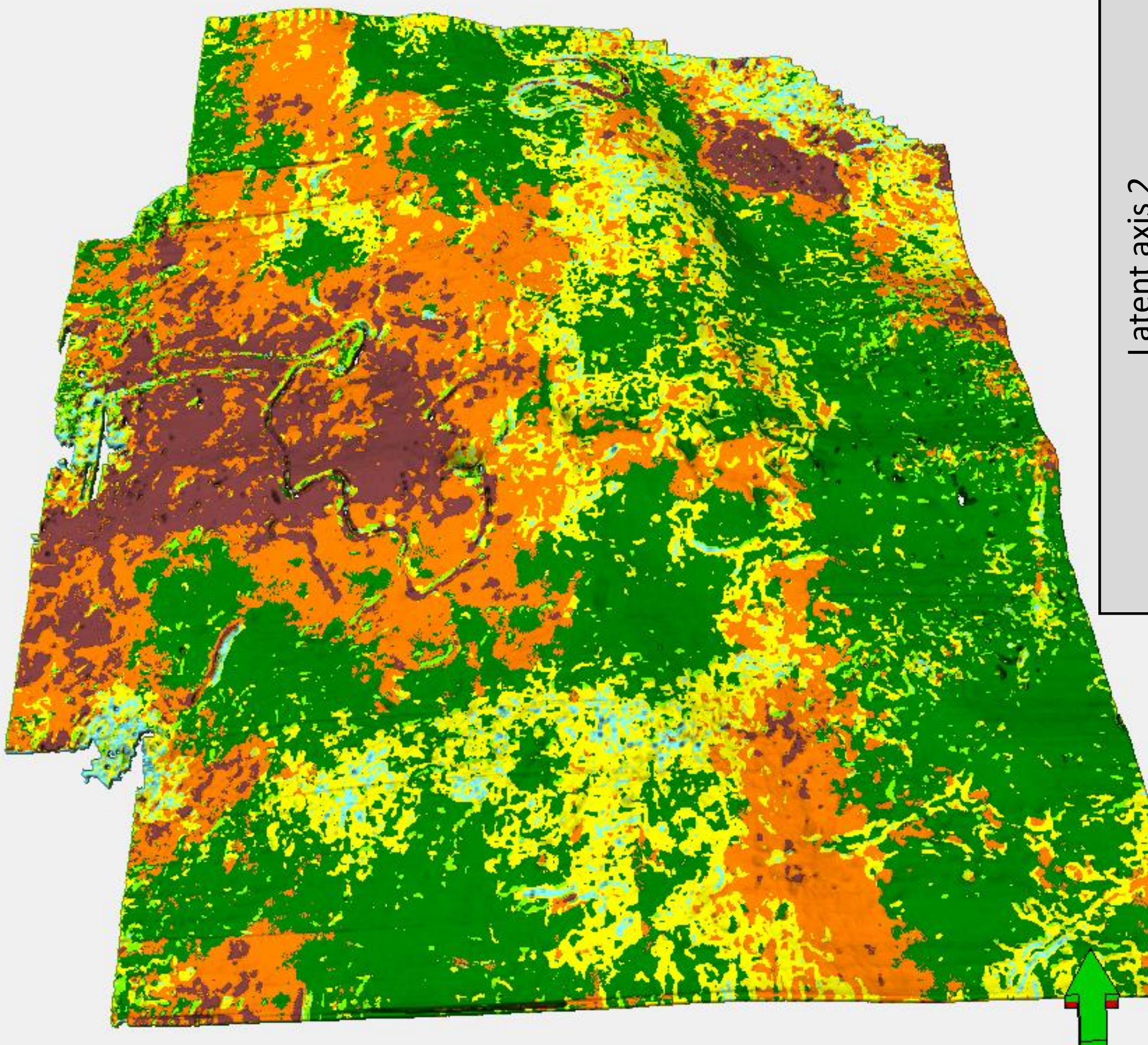


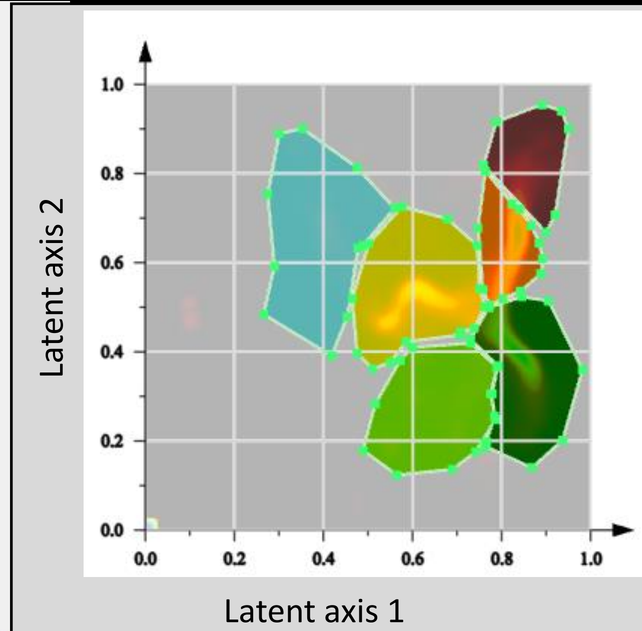
-40 ms



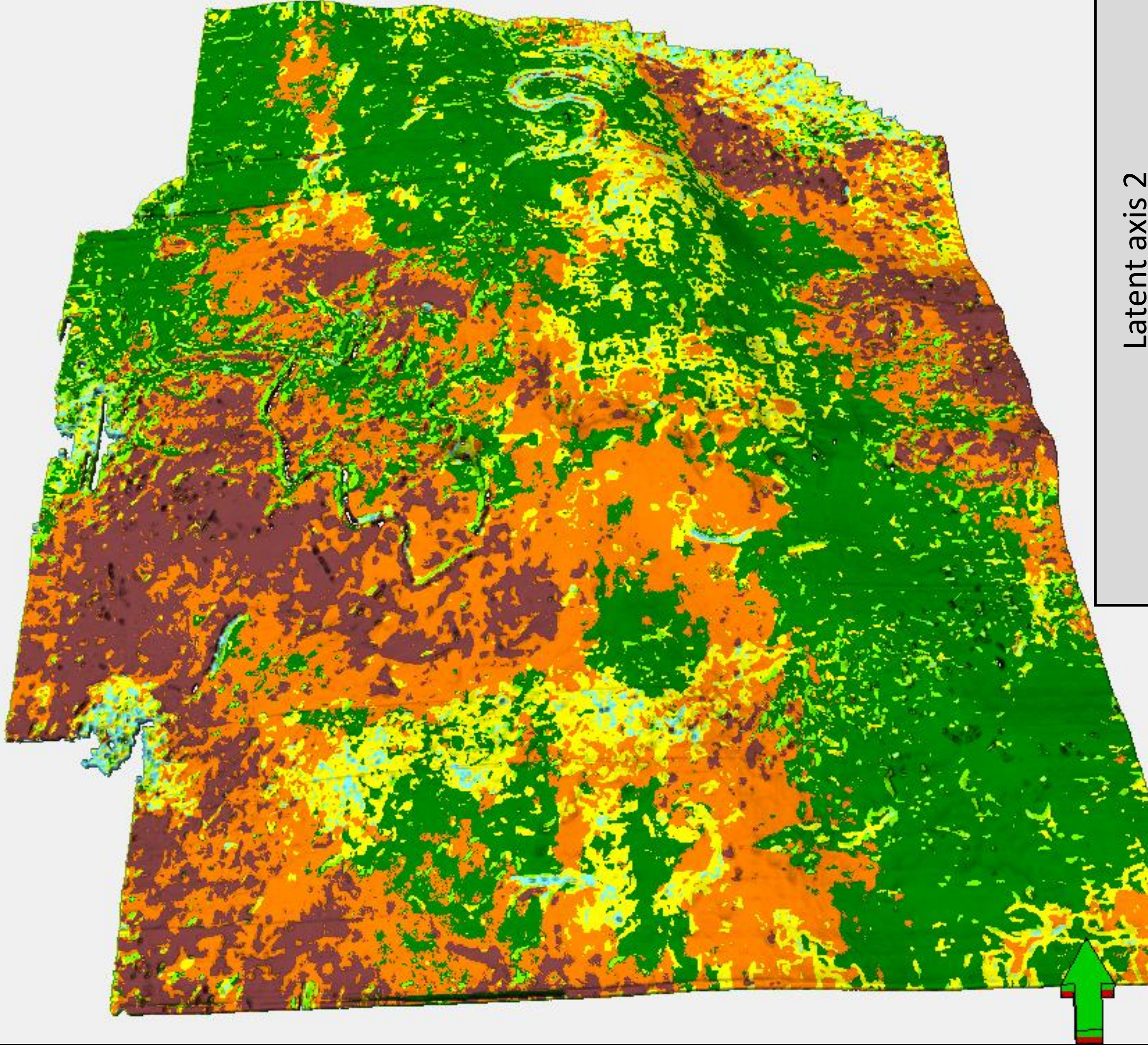


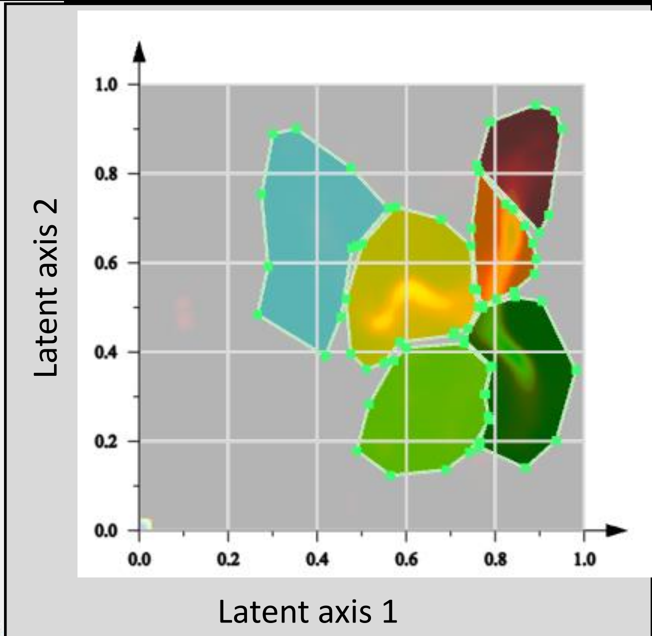
-45 ms



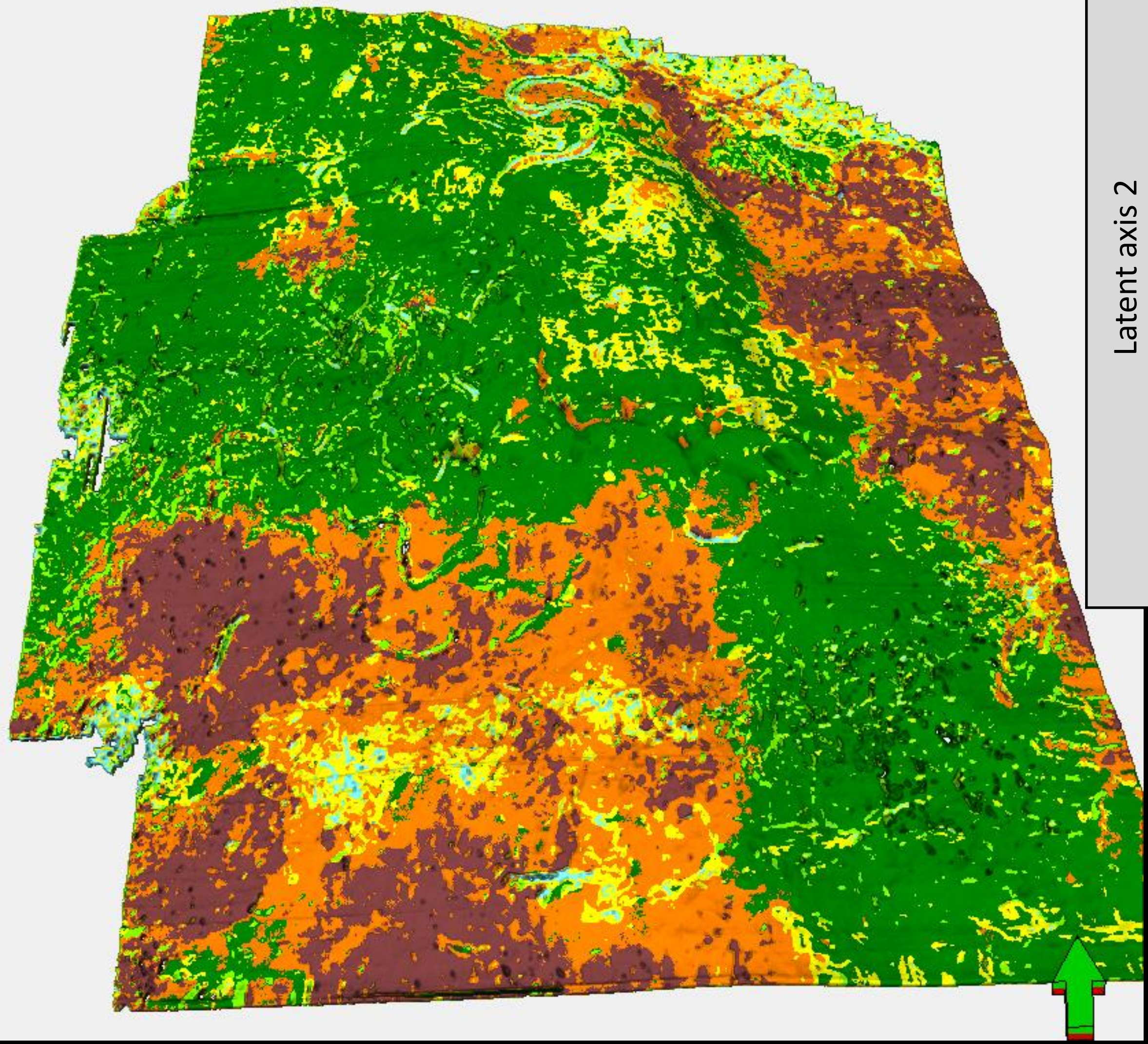


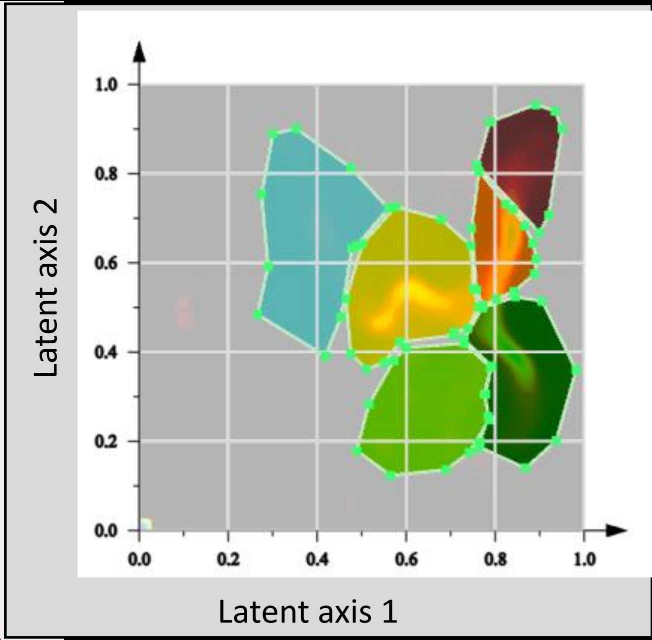
-50 ms





-55 ms





Conclusions

1. GTM and SOM provide excellent tools to extract patterns seen in seismic data.
2. Input seismic attributes need to measure the facies characteristics we wish to differentiate.
3. 2D latent spaces provide a better representation of the high dimensional data than 1D latent spaces.
4. 2D latent spaces can be interactively explored using modern interactive color tools or polygonal definition of the 2D histogram.