SLOVAK - ASIAN
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SACC World GEOScan

GEOScan

AUTOMATED SURFACE ANALYSIS AND GEODATABASE CREATION

Introduction

Geophysical analysis is often dealing with curves, surfaces and volumes in many subdomains in digital form which creates a considerable challenge.

- Surface analysis started 200 years ago with main contributions by Euler and Gauss

  In their time the concept of a surface took the form of a smooth, continuous function.

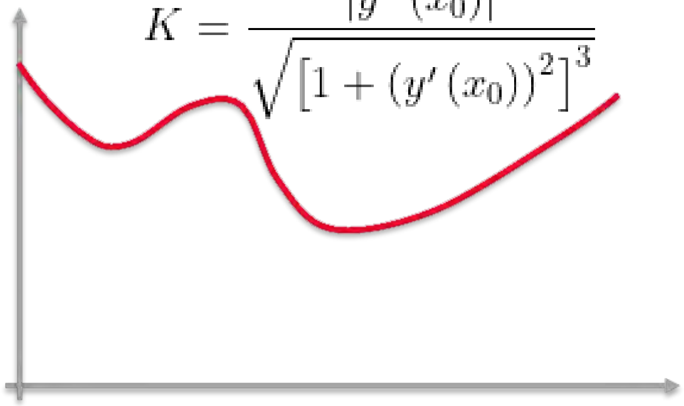
- **1970's - Digital**
  - No longer continuous function
  - Strict mathematical analysis is not applicable in the digital world
  - This creates a fundamental problem with analyzing data from the digital world

- To address the problem the industry used many simplifying assumptions (splines, operators, etc.) The industry and mathematicians have not succeed because they did not address the fundamental problem of applying differential geometry to digital data (which eliminates the reason for many of the other techniques)

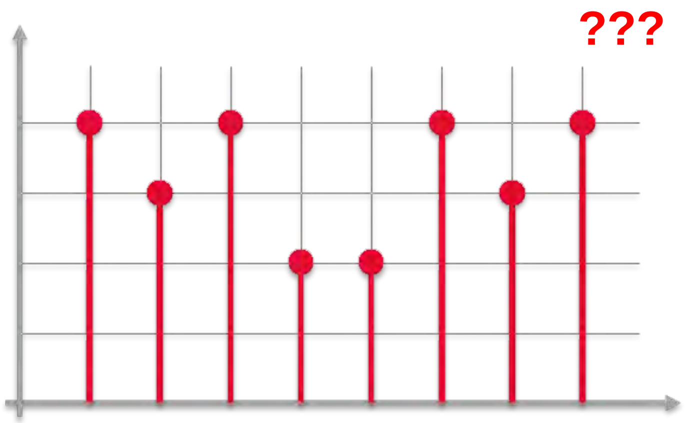
Problem is purely mathematical and before any application this has to be solved

Digital Space - Computations

$$K = \frac{|y''(x_0)|}{\sqrt{\left[1 + (y'(x_0))^2\right]^3}}$$



Digitization ↓ (+ noise)

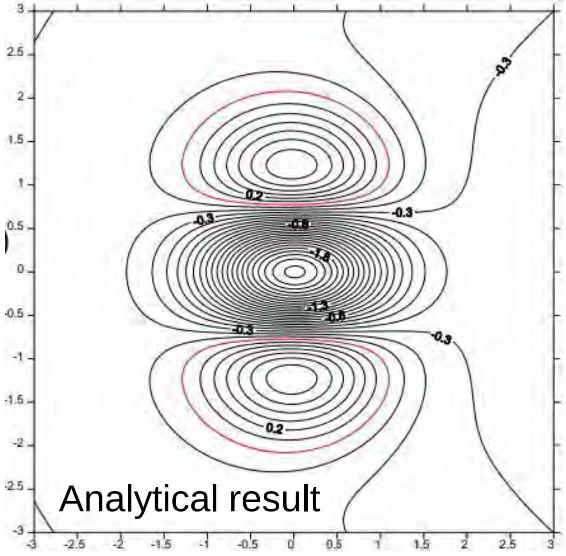


Continuous function exactly defined by formula
All properties can be calculated using mathematical analysis

Some of the classical problems in digital space include calculations such as the circumference of a circle, length of a curve, derivative calculations etc.
The solutions to these problems are trivial when dealing with continuous functions
However, these calculations become very complicated in the real digital space because of errors and noise in real data

Digital representation is no longer continuous
Standard mathematical analysis cannot be used anymore, one can apply through the points as many curves (splines) as he wants.

Example of using simplifying assumptions

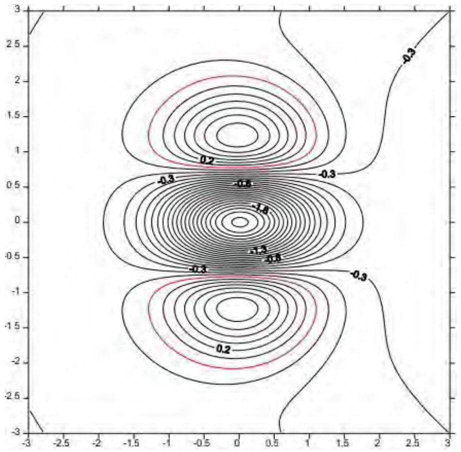


Analytical result

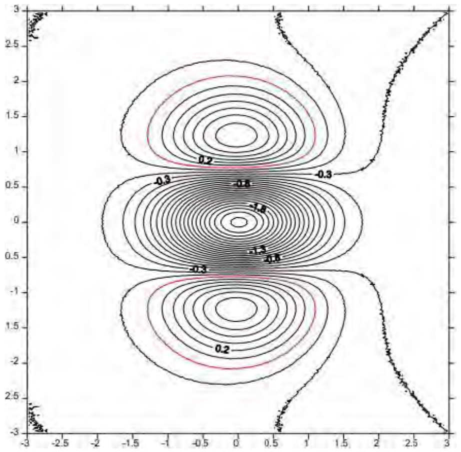
This group of contour maps demonstrates the effect of reduced precision on the accuracy of numerical derivatives

In this example the input was a mathematical function where a second order derivative is a precise and known derivative of the mathematical source function (named: Analytical result)

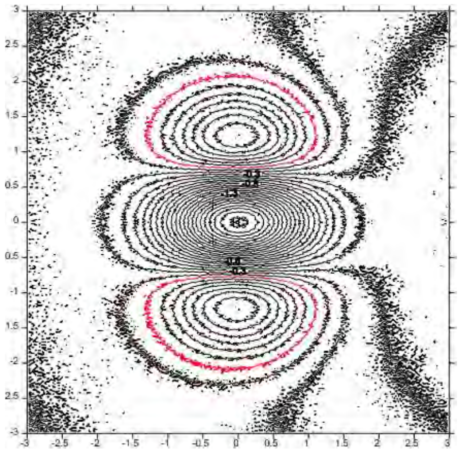
Functional values with different decimal precision were used for the numerical estimation of the same derivative. As the computational precision becomes less than 10 decimal places, more noise is noticeable in the result. In this example using less than 6 decimal place precision produces a result that is compromised by noise introduced by the analysis. Unfortunately, this computational noise is often interpreted as signal (i.e. useful information). Note that when only 4 decimal precision is used the result is mostly noise! Furthermore, with real datasets, the presence of noise is also detrimental to the quality of the result.



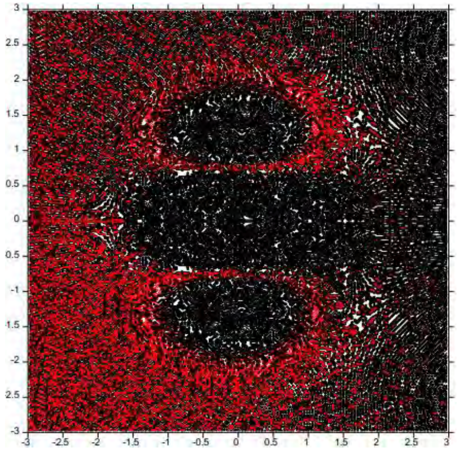
10 Decimal precision



6 Decimal precision



5 Decimal precision



4 Decimal precision

Our technology solves the problem of mathematical analysis in the digital space

The issue is purely mathematical and has to be solved in the first place

- After 10+ years of research addressing the fundamental mathematical problem we created GEOScan which allows automatic analysis of digital data by applying differential geometry
- The key component to the solution was the use of numerical mathematics and digital geometry. This branch of mathematics, rigorously developed by Russian, French and German mathematicians, gives very useful ways of dealing with non-continuous functions

Our approach to morphometric analysis of surface is equivalent to the differential geometry calculated on the basis of numerical mathematics

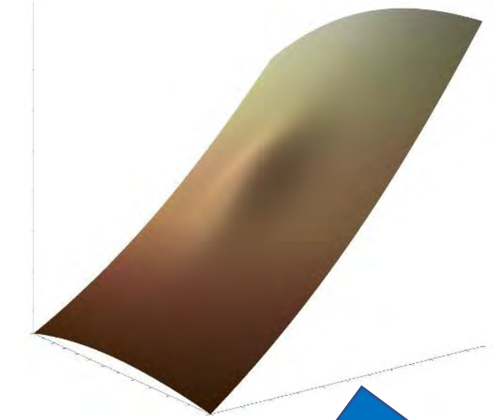
Unlike other existing technologies and approaches, our methods are not affected by the so-called ill-posed problem which makes direct calculation of derivatives unstable and can lead to unpredictable errors.

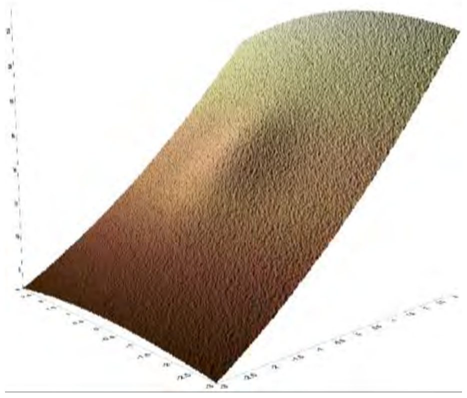
The result of our analysis is the complete set of morphometric parameters describing the surface, as it is defined by the differential geometry.
The whole process is fully automatic, without setting parameters for different types of surfaces separately. Thus it is not necessary to know the properties of the surface before it is calculated. This is an important feature, without which automation is not possible

We have comparred our results with exact analytical results, ad it shows that our solution is the most accurate

Object identification - Does the applied technique find the object of convex dip curvature?

$$e^{-x^2-y^2} + 45e^{-\left(0.008(x-12)^2+0.008y^2\right)}$$





Digital representation of model with additional random noise.

Convex dip curvature object calculated nalytically

This is 100% correct mathematical result

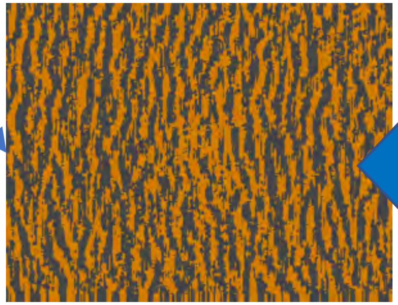
GEOScan technology automatically identifies objects, vectorizes their boundaries and creates a database of features

Greyscale representation of the model with noise.

Compare the output from each technique with the correct result!

Dip Curvature object calculated by GEOScan

Success: The object is identified reasonably well (without the introduction of significant artefacts)



Industry 'standard' Dip curvature object Wood 1996 algorithm.

Failure: Clearly the object is not identified. Moreover, artefacts dominate the result

Automated surface analysis **and Geodatabase** creation

- **GEOScan** is an extremely fast, complex proprietary technology linking several unique processes.

- This technology for morphometric analysis of surfaces can be described as a **global method**, working with the entire set of input values.

- The resulting vector form allows us to create a **database of objects with associated geometric and morphometric characteristics - attributes.**

- This is essential for working effectively with a large number of objects using selections based on the geometric attributes of objects.

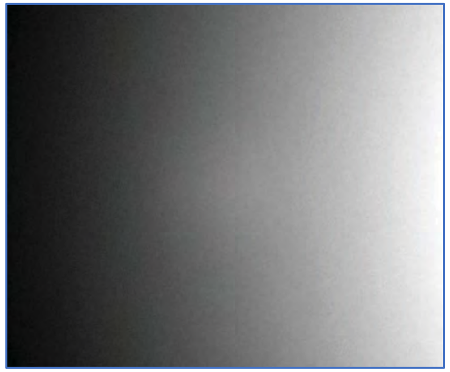
- The whole process is fully automated without parameterization for different surface types **Therefore, it is not necessary to know the properties of the surface before it is calculated.**

- This is an important aspect of the technology which is necessary to enable **automated processing of hundreds or thousands of surfaces.**

Mathematical model
(Surface analysis)

Step 1: Analytically defined surface allows exact calculations of all surface properties

Step 2: Extraction of values with an appropriate sampling rate and resolution



Step 3: Addition of specified level of noise e.g. Gaussian noise, to simulate natural measurement errors

Step 4: Application of specified surface property calculation algorithm (in this case Dip curvature by GEOScan)

Convex object of Dip curvature calculated by GEOScan. Note the feature has been defined without artefacts!

Comparison: to the mathematical result (see below).

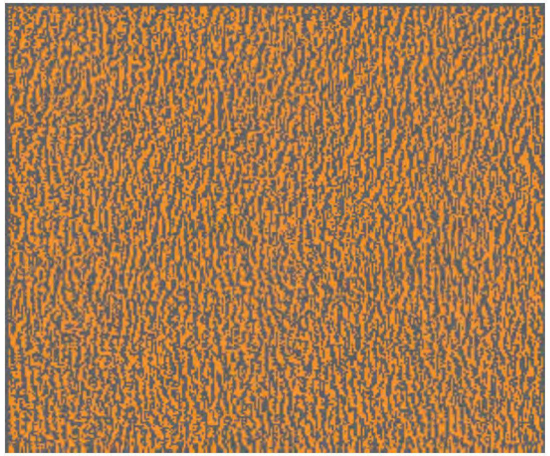
Method of comparative evaluation of surface analysis algorithm

Note that this approach is valid and recommended to understand the effectiveness of any algorithm evaluation

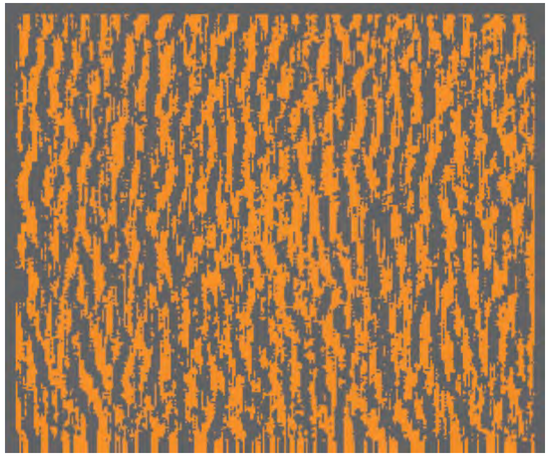
The analytically defined Convex object of Dip curvature embedded in the input data.
This object should be found by tested algorithm as closely as possible.

Results of widely used methods in geophysics

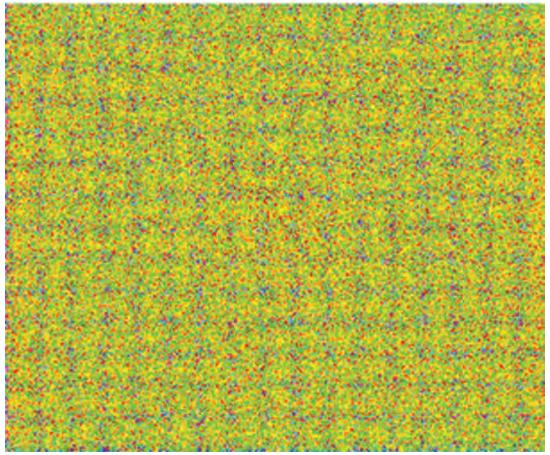
Analysis of mathematical surfaces seen above. Introduction of structured noise to existing data



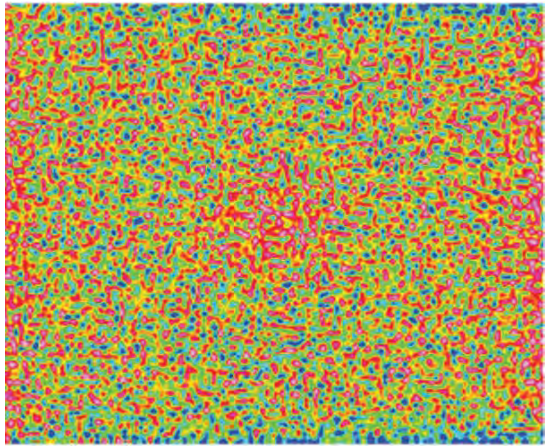
Dip curvature objects according to Roberts 2001



Dip curvature objects using r.param.scale 13x13 window according to Wood 1996

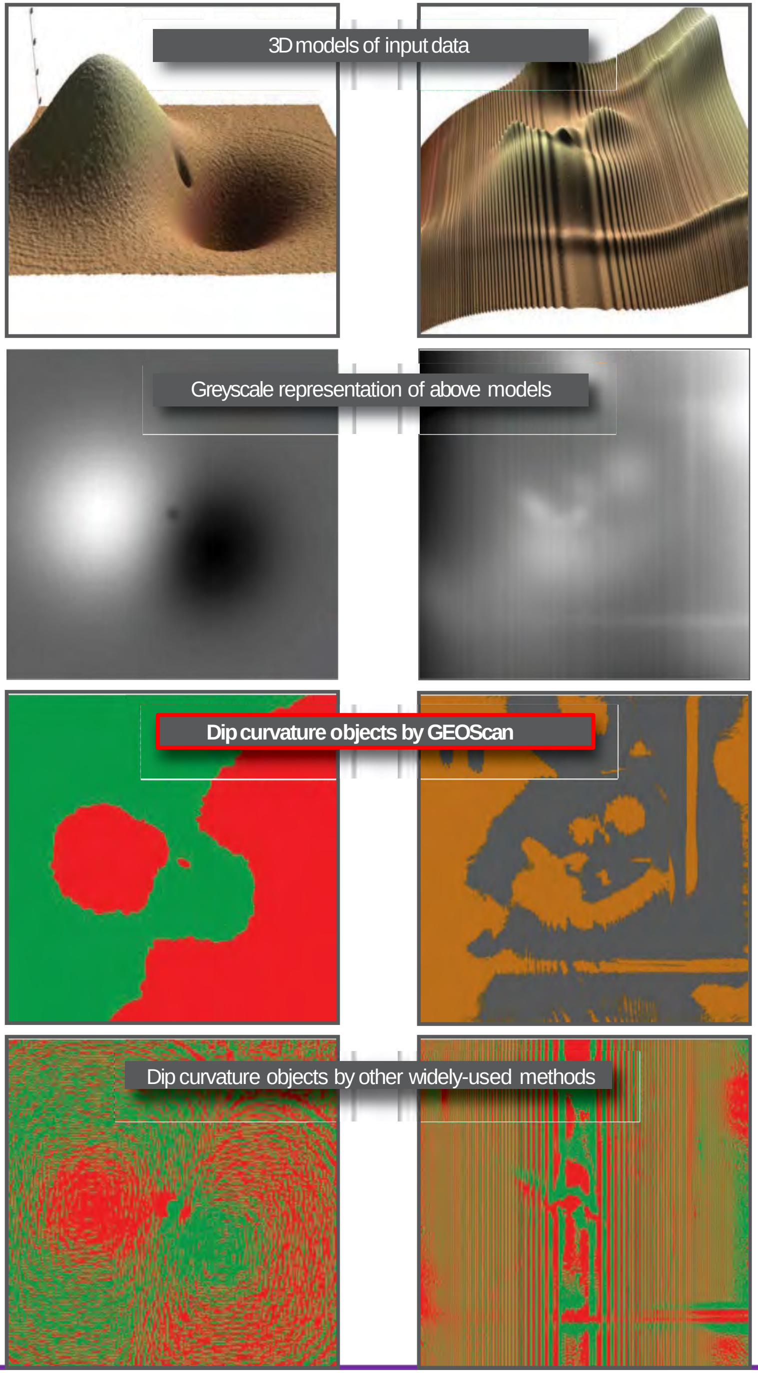


1st vertical derivative calculated by 10x10 operator is shown in false colours. It illustrates the result of lower order derivatives calculation by widely used software



Same 1st vertical derivative calculated after application of 5x5 convolution filter to minimize noise

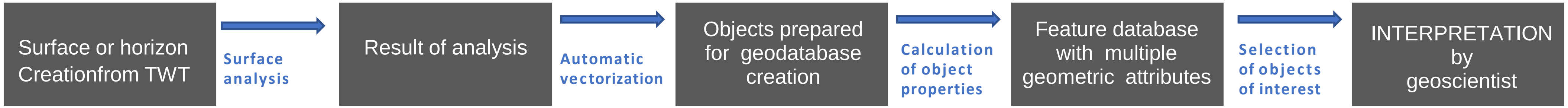
Testing surface of any complexity can be analytically defined. This way the quality of the result can be correctly compared



SEISMIC SURVEY REFERENCES & EXAMPLES

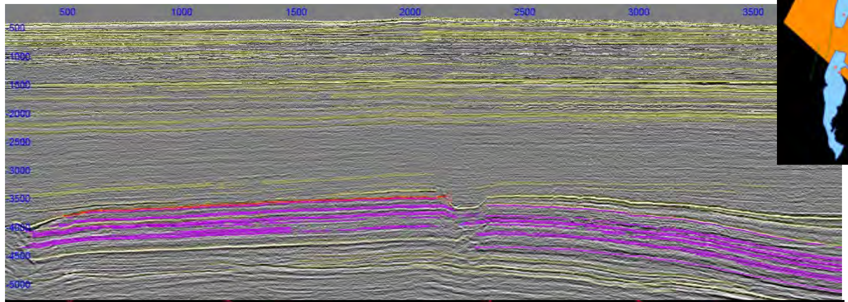
Creation of Horizons from TWT data
Identification of Faults and Linear features

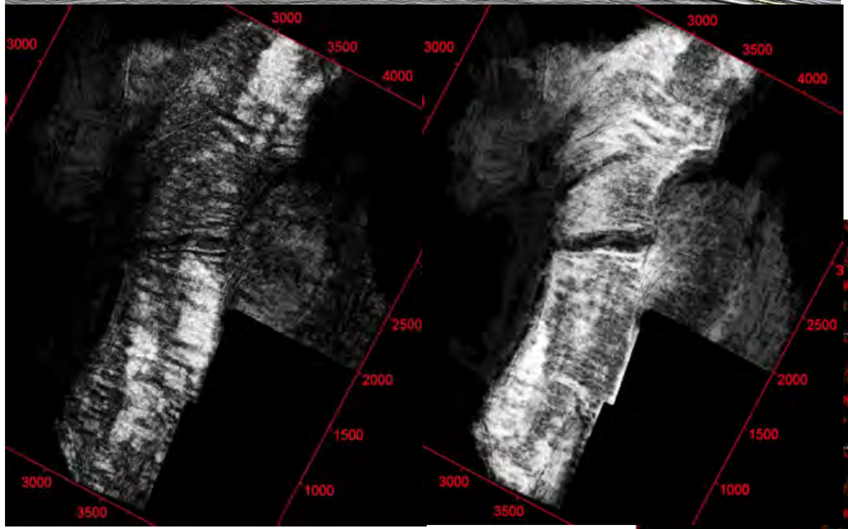
- Calculations are based on differential geometry
- Analysis and parameterization is automated and unbiased yielding robust results
- Variable error and noise is automatically taken into consideration
- The higher the data density, the better the result, no need for data reduction, smoothing
- The automatically created objects and their properties are stored into a database for further analysis

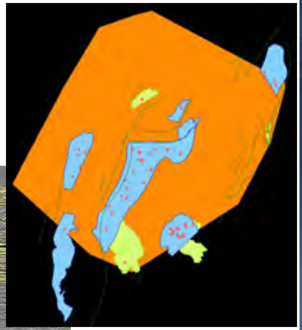


Reference – Norwegian sea seismic data

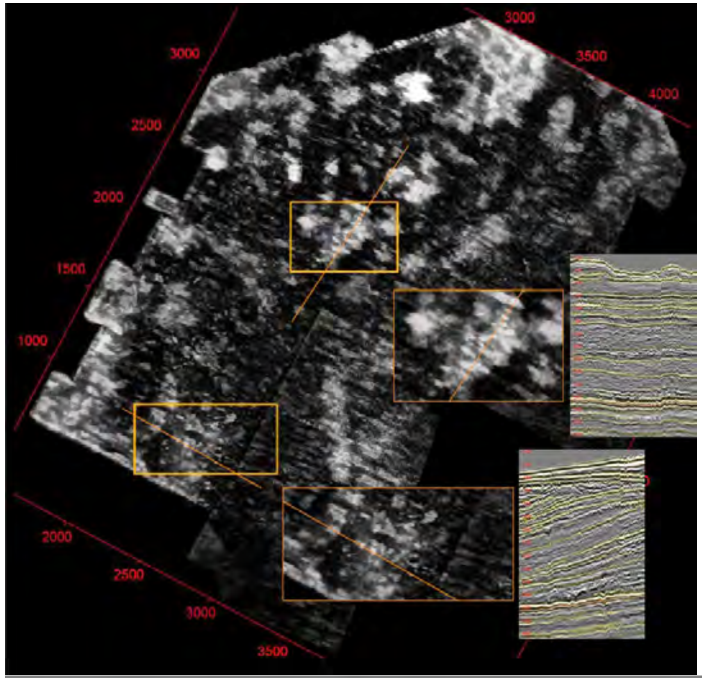
Interpretation of features
on large number of seismic surfaces

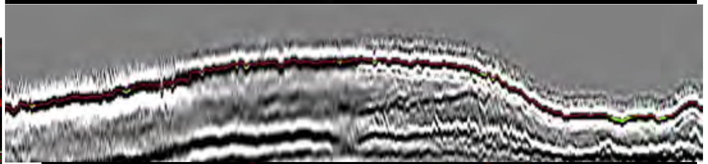


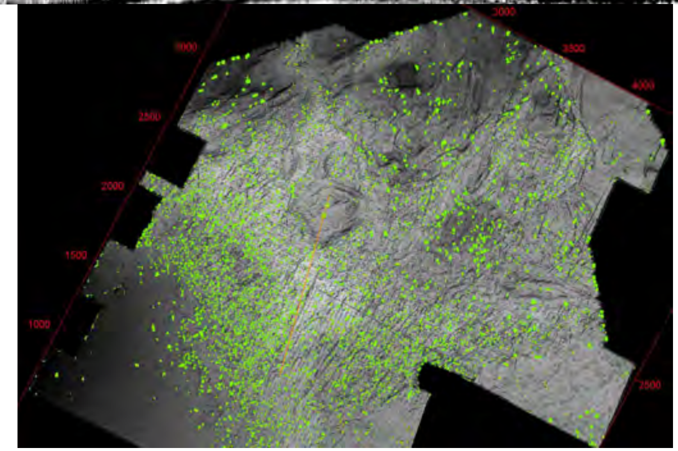


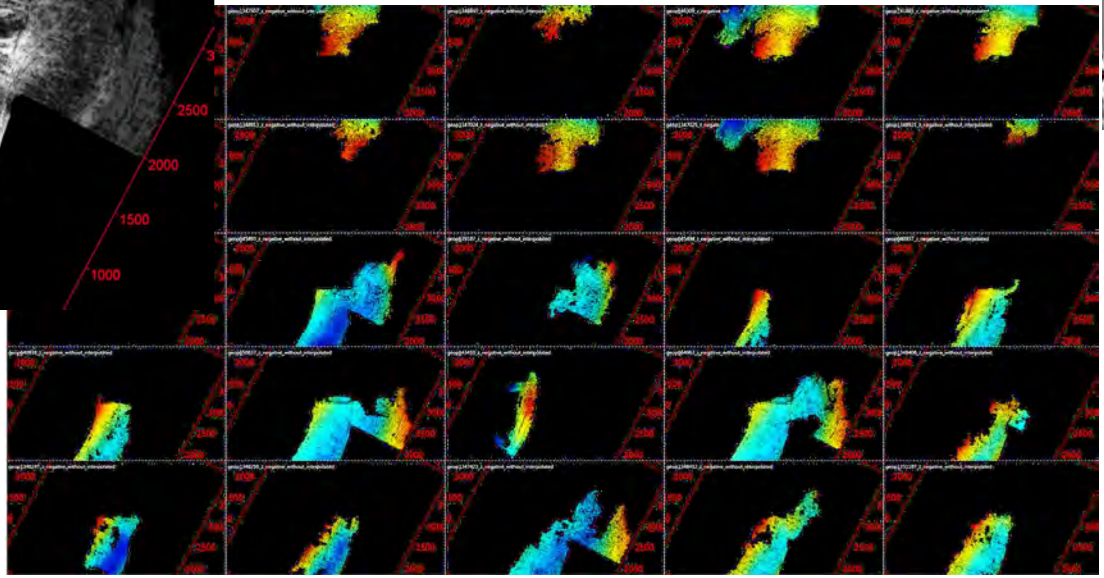


Pockmarks and
Collapse features
Extract and select
from noisy
seismic data

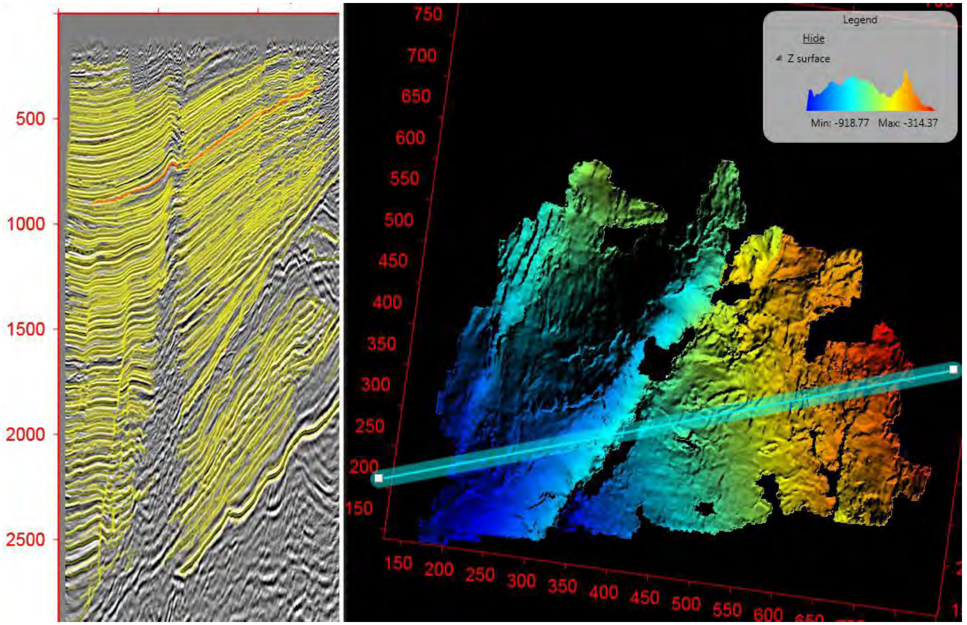


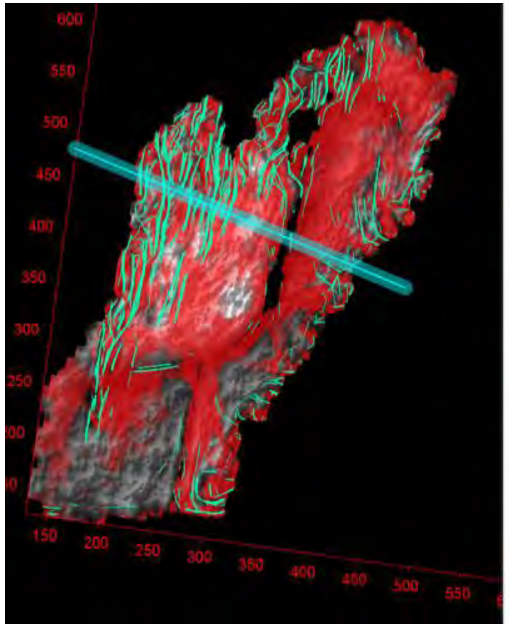


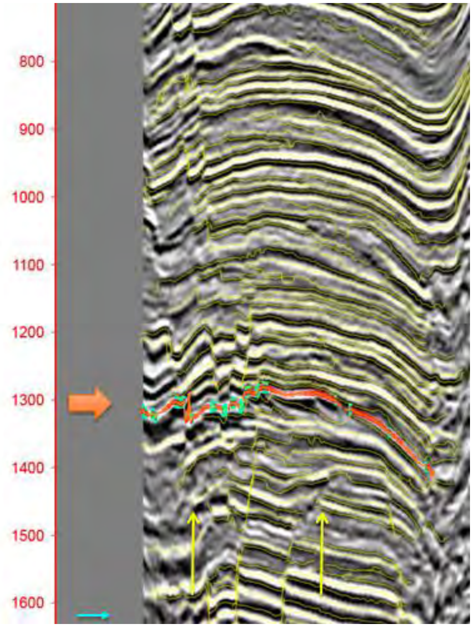




Reference – Vienna basin seismic data

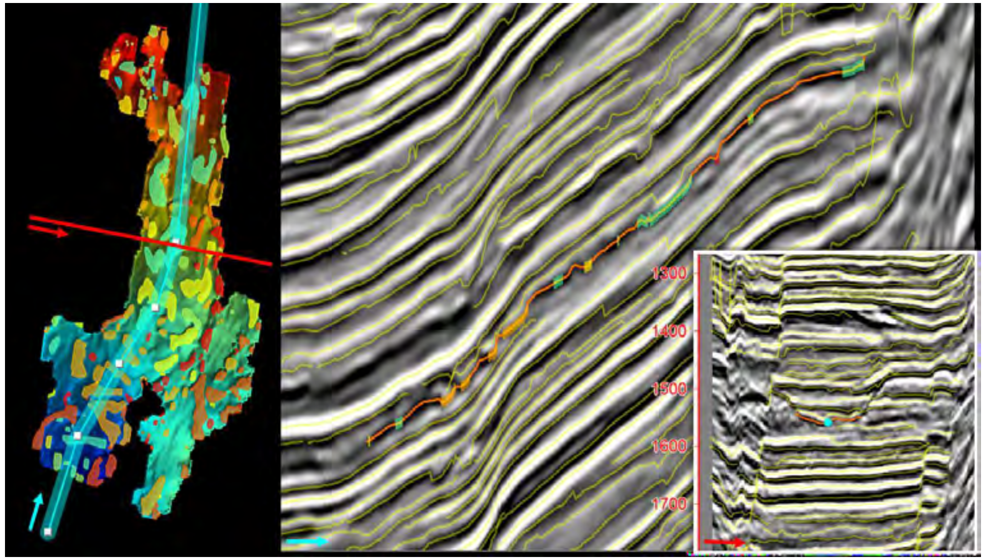






Morphometric features are automatically extracted. Fault features are located within north-west part of the displayed seismic horizon. Areas of slope line convexities (red) are covering large parts of the surface suggesting that the surface is rather convex than concave. All features are marked on seismic section as well. Yellow arrows are highlighting channel feature on seismic section which is located below central part of shown seismic horizon

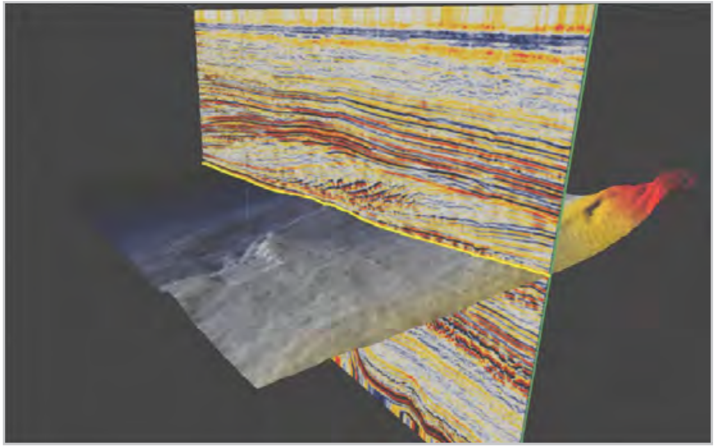
3D Seismic data
Seismic section showing large seismic surfaces (left)
Largest seismic surface with marked position of seismic section (right) is located within upper part of seismic section (marked by red line)



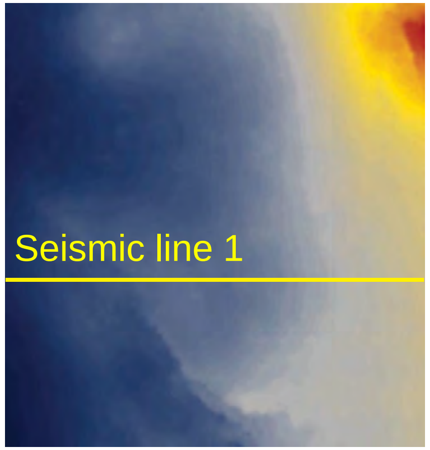
Seismic horizon with large number of automatically extracted concave features possibly related to depositional structures within larger channel feature.
Perpendicular seismic section (red) is showing location of interpreted seismic horizon between wing-like reflections
Extracted concave features are highlighting morphological variability of the seismic surface along seismic profile following channel structure (blue)

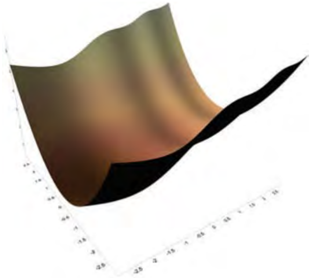
Example – TWT

As an example surface a Two-Way-Time (TWT) horizon is extracted from a 3D seismic dataset. This surface was used as input for minimum curvature calculation



Seismic horizon Two-Way-Time attribute map shown with false colour. False colors result in the loss of much visual detail

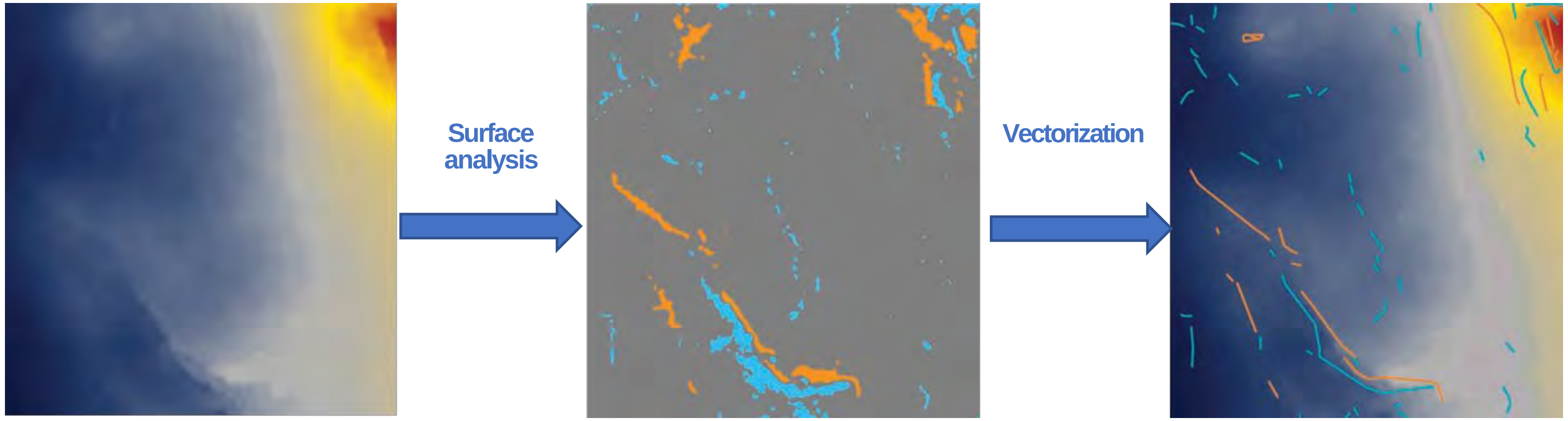




A simple model of the fault feature was created with know mathematical properties to assess the validity for this type of feature detection.

Minimum curvature can serve as a good descriptor of faults. Convex forms are orange and concave are grey

Automated identification and extraction of objects from surface data

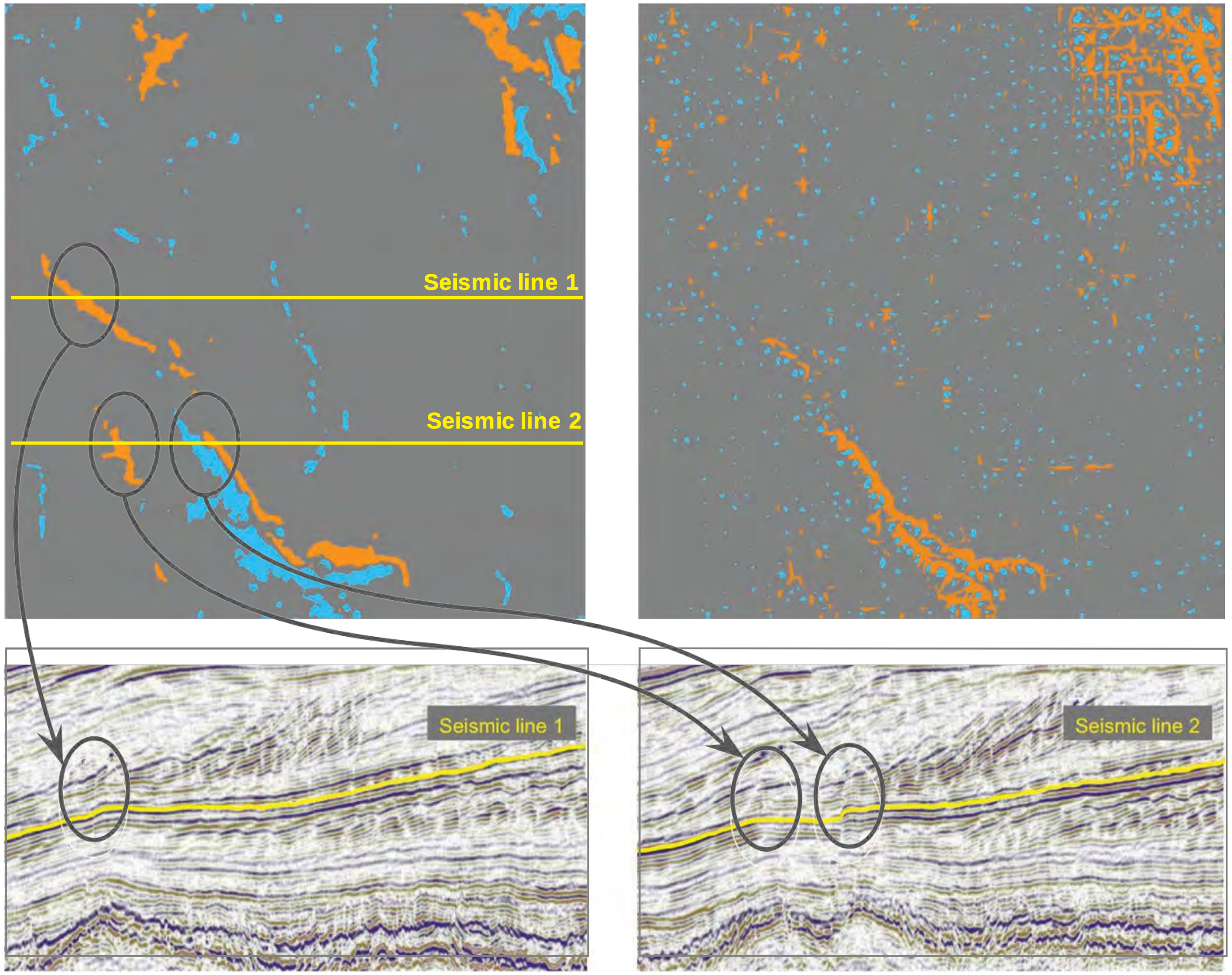


Resulting maximum curvature objects are automatically vectorized by GEOScan

Vectorized features can be directly stored in a database or geodatabase

Automatically calculated minimum curvature using the GEOScan technology

Most technologies calculate curvature using a user-defined window (e.g. 3x3, 7x7, etc.)



Convex

Concave

Geologically convex (orange) areas correspond to anticlinal features and concave (blue) to synclinal.

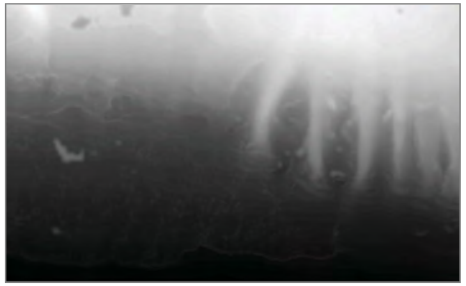
Close proximity between parallel orange and blue areas indicates a fault (as validated by viewing the seismic data).

Comparison of results with widely used methods

Confirmation of identified features validity on original seismic data

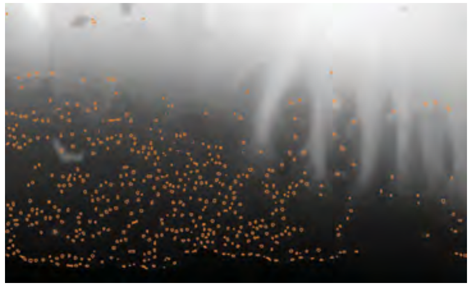
Example – Sea floor pockmarks

- **These pockmarks are important indicators of upward fluid flow**
- **They are often difficult to visualize on false colour images**



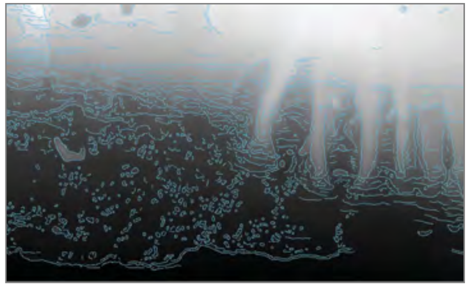
Sea floor TWT surface across Australian Gorgon Gas Field used as input. Displayed here in greyscale.

Surface analysis and vectorization of objects

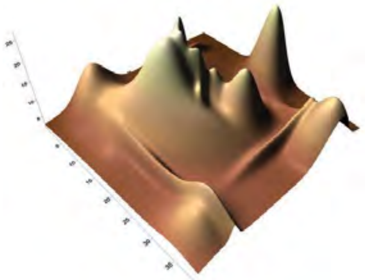


Automatically vectorised boundaries of potential pockmarks by GEOScan

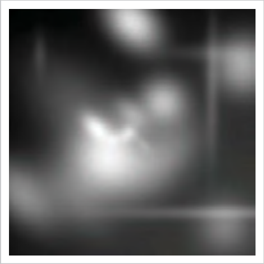
Comparison of results with widely used methods



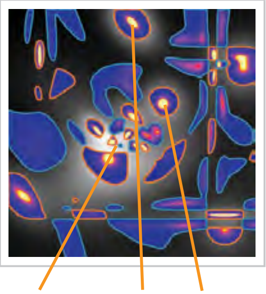
Pockmarks candidates found using one of the "best" results of Canny operator application shows inaccurate shapes and many linear artefacts. Moreover it is not automatically vectorized



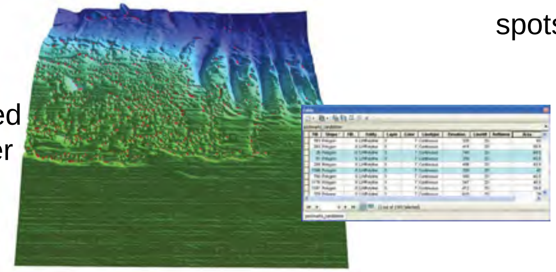
Mathematical model shown in 3D, was created to investigate which mathematical properties would best describe pockmark-like features



Greyscale 2D image of model



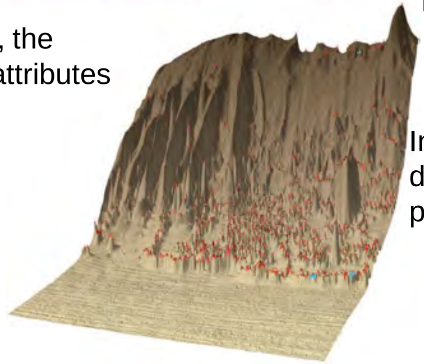
Sharp Peaks or Lows are characterised by high Gaussian curvature values and are visible as bright spots (yellow within blue)



3D top view with overlayed potential pockmarks layer (orange)

Automatic vectorization of objects and calculation of their geometric properties is essential for the creation of features database

As required by the interpreting geoscientist, the processed database of GEOScan surface attributes can be queried to enable feature extraction



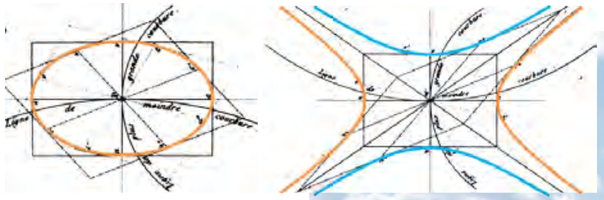
Inverted 3D display of previous dataset

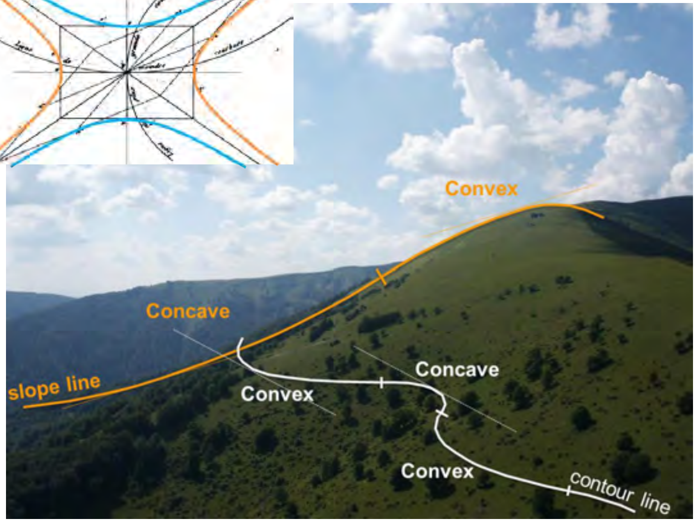
Reference – Automating fault characterization and features extraction

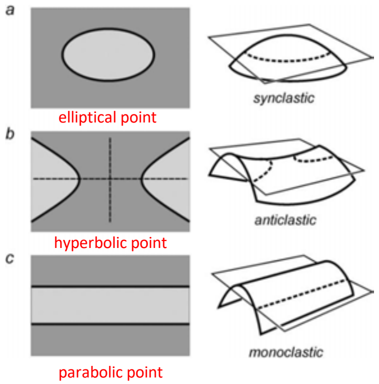
The objective of the data collected at a mine-site is to help with the development of a more realistic geological models. These models provide a perception of reality upon which critical decisions are made. Since the amount, density and detail of the data collected has increased dramatically over the last decade or so, this volume of data creates technical challenges for traditional interpretation methods. Regardless of whether these decisions relate to initial commerciality or day to day operations, efficient, effective and unbiased methods of analyzing these detailed datasets is fundamental. The methodology discussed and demonstrate ed in this poster incorporates a breakthrough in mathematical analysis with respect to the analysis of digital data. This technique enables the automated analysis of any digital surface creating a query able spatial database of geometric properties. Validated geometric properties can then be used to support the estimation of a geological resource and the support of modifying factors in the conversion of a resource to a reserve. As a consequence, the distribution of these geometric properties can also help with assessing the reliability of the interpretation.

In differential geometry, the **Dupin indicatrix (D.I.)** is a tool for characterising the local shape of a surface, based on the **intersection of a parallel plane** to the tangent plane (in an infinitesimal small distance).

The indicatrix was described by Charles Dupin (1784-1873).







Picture illustrating **convex** and **concave** shapes of a slope line and a contour line.

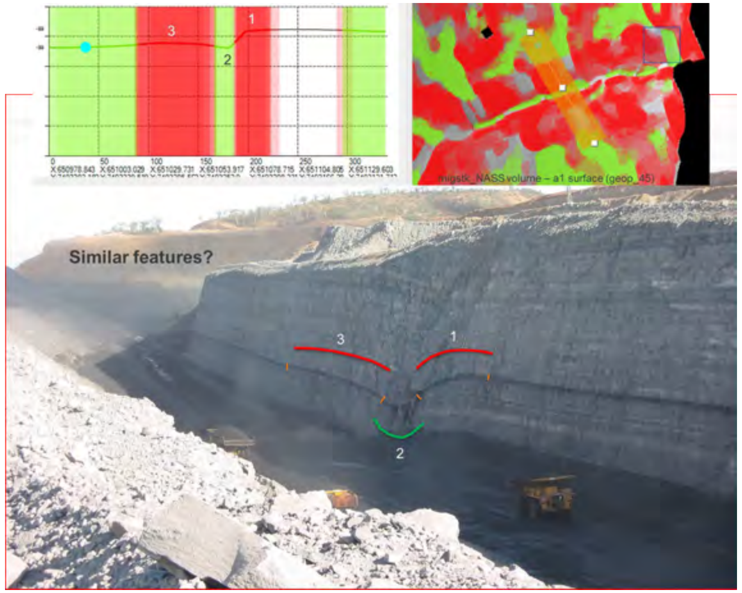
Inflection points locate transition from one shape into another. Dashed lines are tangent to slope line and contour line.

We use the term of **Local curvature** in order to classify surface according to the shape of the Dupin indicatrix.
Areas of the surface which are strictly Convex or Concave in all directions have points with **Elliptic** Dupin indicatrix.
Meanwhile areas with some directions being concave and some being convex have **Hyperbolic** points.

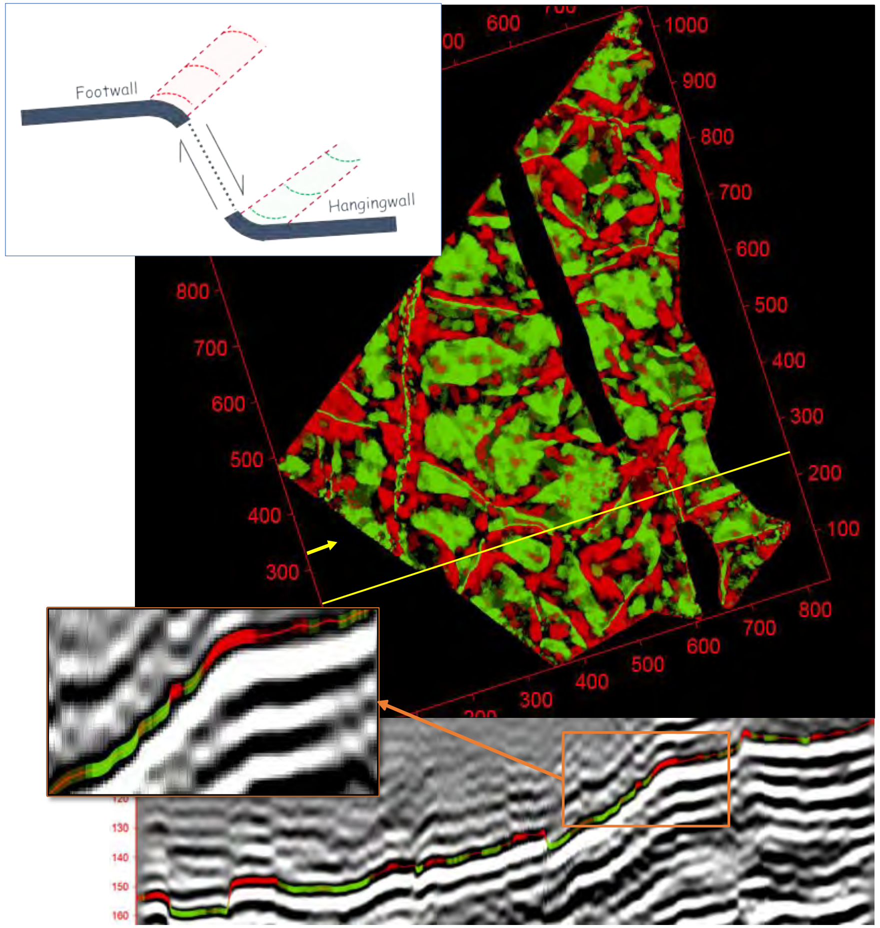
Methodology

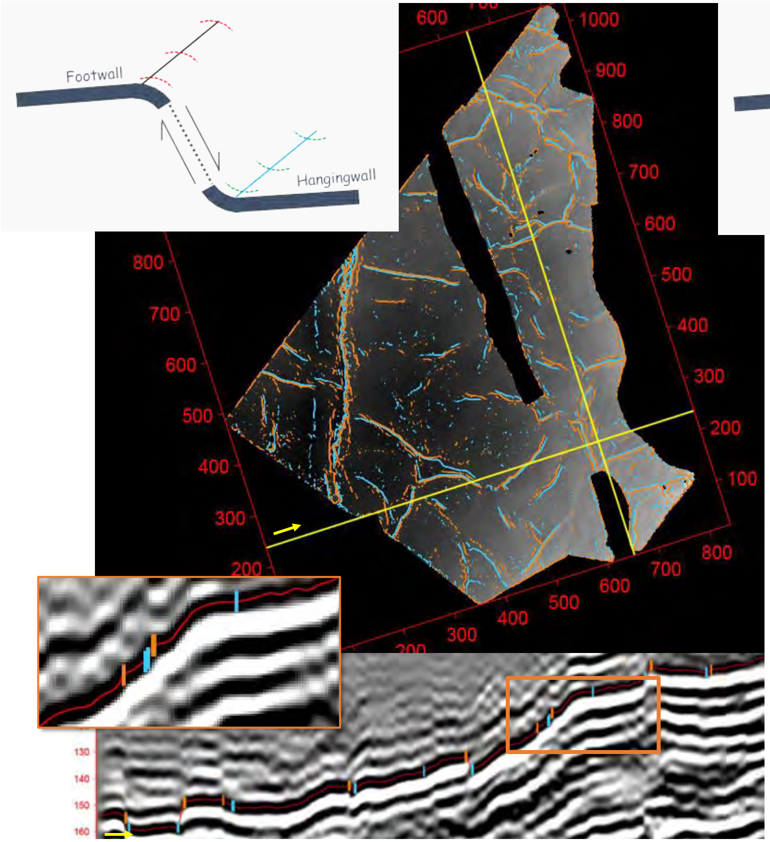
- Automatically calculate and catalogue the geometric properties of any surface (e.g. TWT surface from the working coal seam)
- Query spatial database of surface geometric properties
- Identify/Extract/Export features affecting mine planning and mine operation (exported as Shape files)
- Incorporate into geological a model

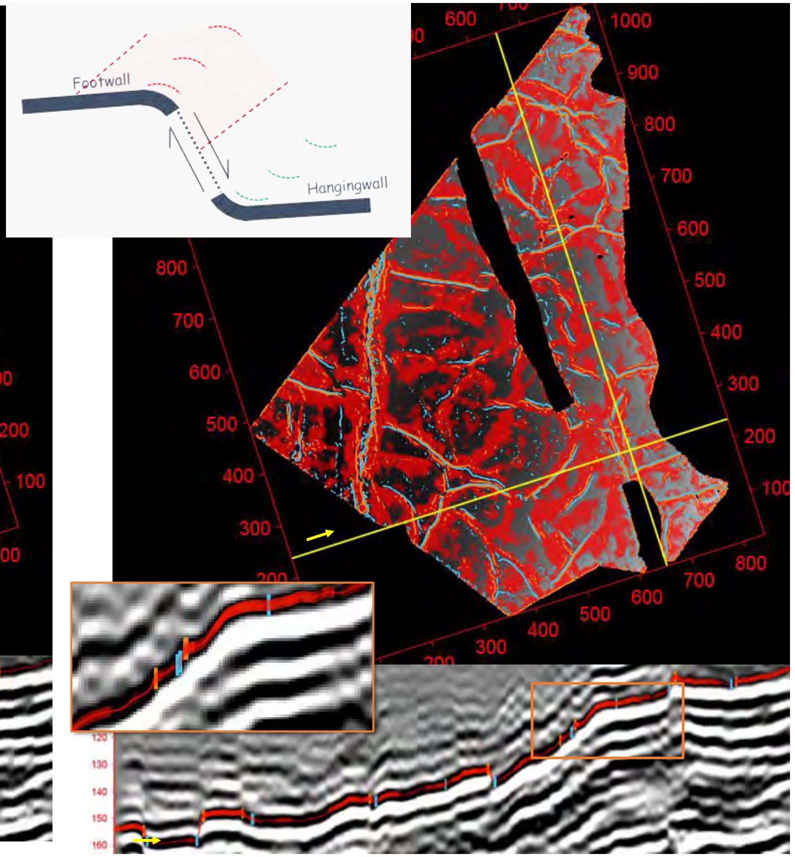
Since the surface analysis is automated, consistent and unbiased, the process is very time efficient



Morphometric properties of the seismic horizon representing roof of a coal seam







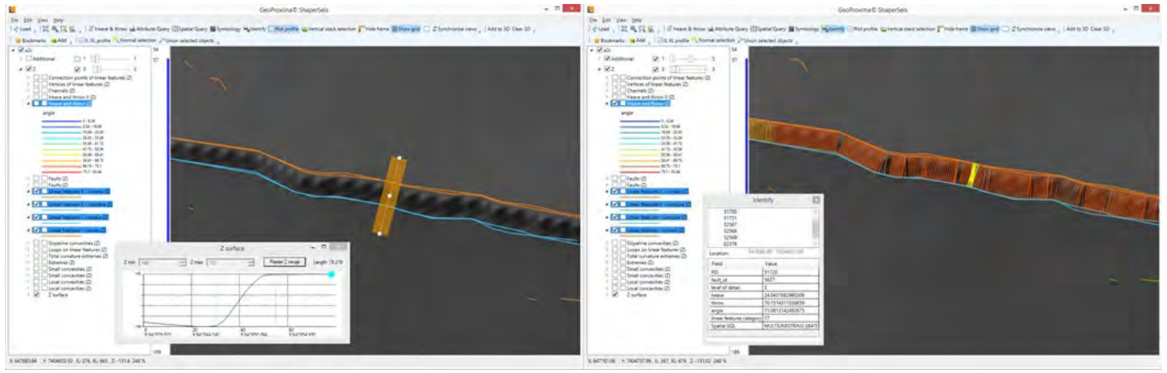
- Locally convex (red) and locally concave (green) features providing essential information about surface morphometry

- Coal TWT horizon is marked on the seismic panels. The zones of convexity and concavity corresponding to the map are highlighted along the TWT marker

- Extreme convex (orange) and concave (blue) points are automatically vectorized features in the database. -- Each vector is made of hundreds of measurements (one per surface data point). Concave Convex parallel vectors often identify footwall-hanging wall pairs

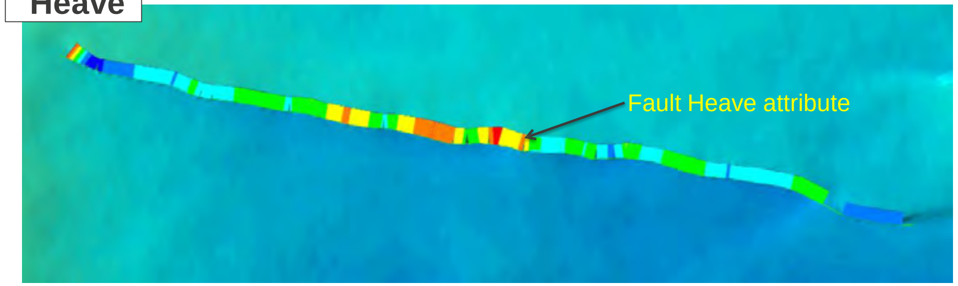
- Slopeline convexities are used delineate steepest parts of possible fault features and show areas of “roll” into faults

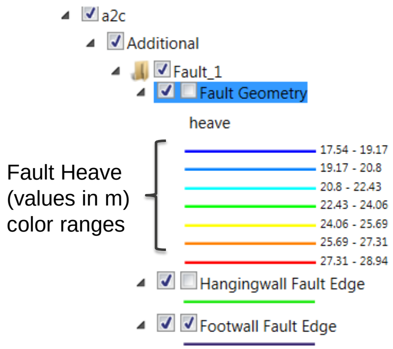
Automating fault characterization



Detailed view on a major fault with extracted convex and concave linear features marking hangingwall and footwall space of the fault. Heave, throw[i], angle[i] or orientation attributes were automatically calculated for all major faults. According to interpreter's requirements features can be selected from the database using query tools or manual selection and used for additional calculations. ([i] If geometric analysis is of a TWT surface, throw and angle are relative)

Heave



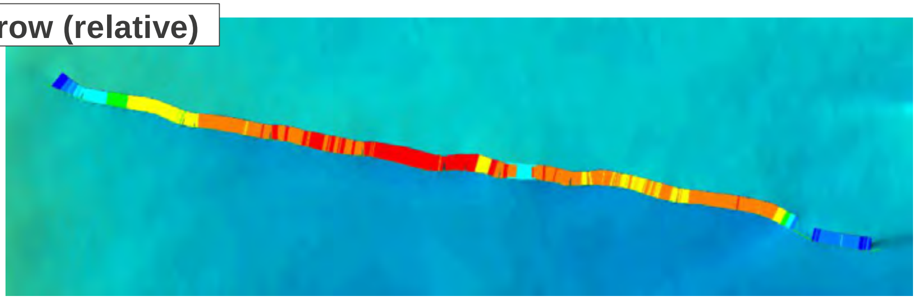


Using the symbology tools the faults heave attribute can be color based on its magnitude.

In this example the fault heave has been assigned a colour over equal intervals, where hot colours (yellow, orange and red) show the widest portions of the fault and cold colours (blues and purples) show the thinnest portion.

The faults could be assigned different thresholds manually based on other mining considerations

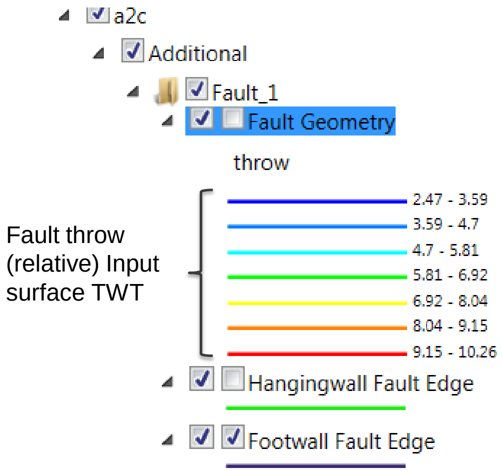
Throw (relative)

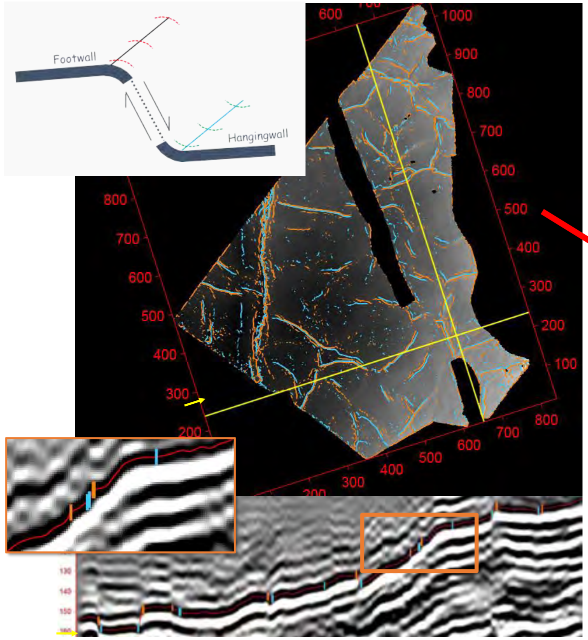


Using the symbology tools the faults throw attribute can be color based on its magnitude.

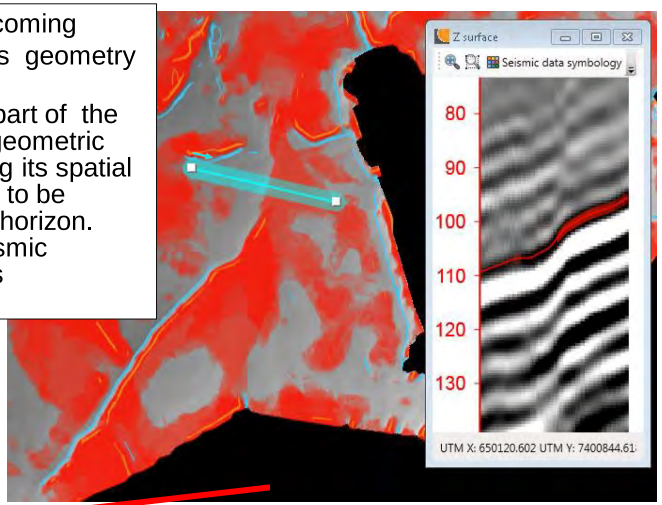
In this example the fault throw has been assigned a color over equal intervals, where hot colors (yellow, orange and red) show the largest vertical offset portions of the fault and cold colors (blues and purples) show the smallest vertical offset portions

The faults could be assigned different thresholds manually based on other mining considerations



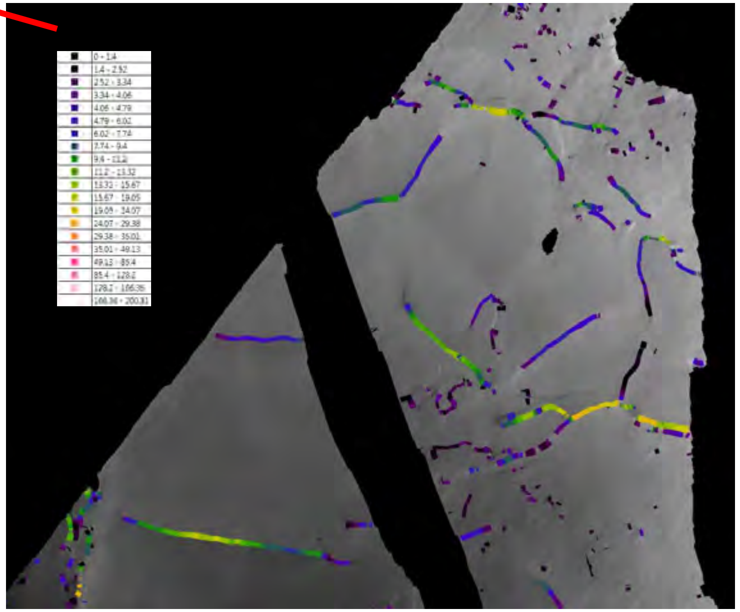


As the major fault is becoming spatially more subtle, it’s geometry is changing.
However, the steepest part of the fault is still tracked by geometric inflection points allowing its spatial location (and character) to be tracked on the seismic horizon.
Verification with the seismic section display confirms presence of a fault

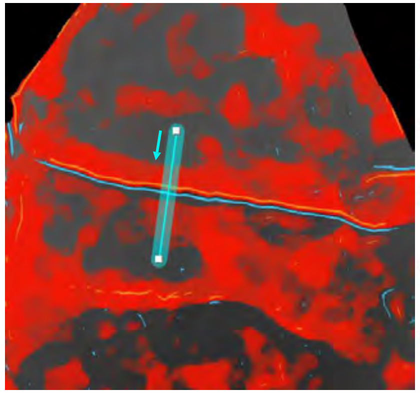


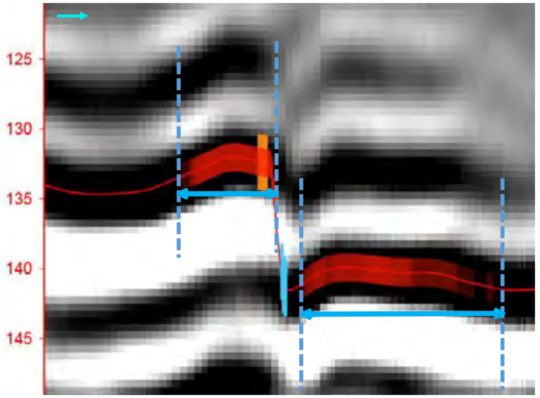
All extracted features are stored in a spatial database that can be queried, used for interpretation, or for additional processing

Large numbers of automated heave and throw measurements with assigned numerical attributes were created for each and every major fault. This unbiased and time efficient methodology dramatically improves the consistency and accuracy of quantitative interpretation for the creation of subsurface models



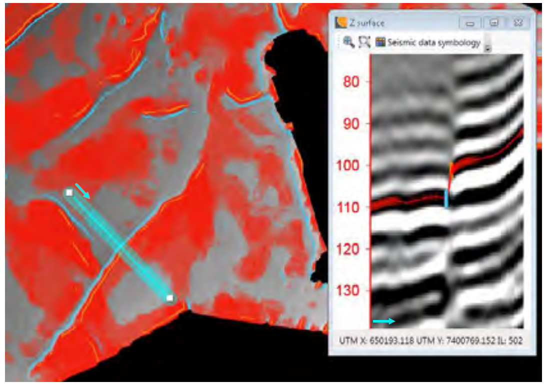
Possible continuation of a major fault is marked by clear spatial correlation of boundaries of extracted convex features



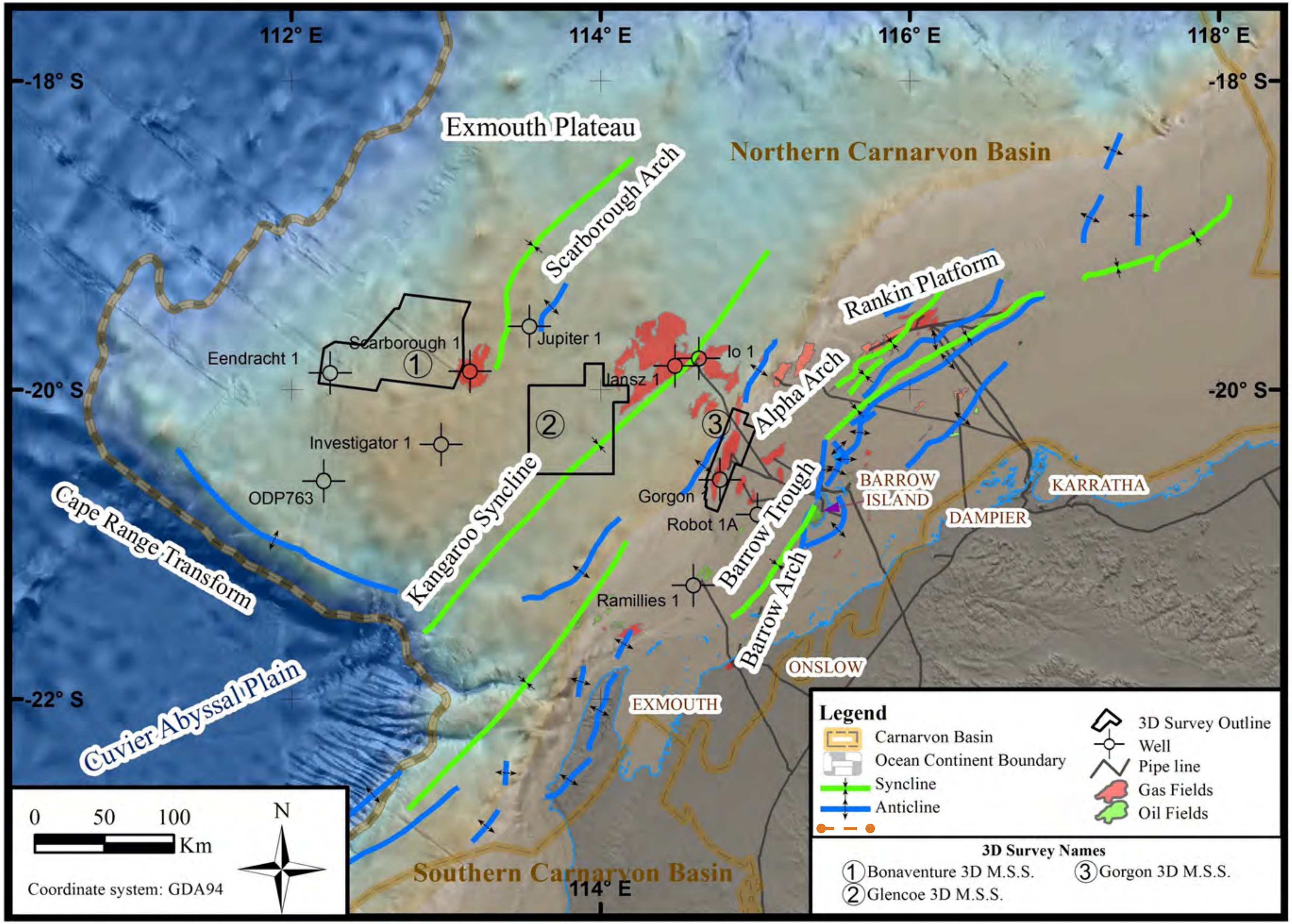


Boundaries of extracted morphometric features enable an interpreter to effectively measure fault-related properties such as roll or normal and reverse drag

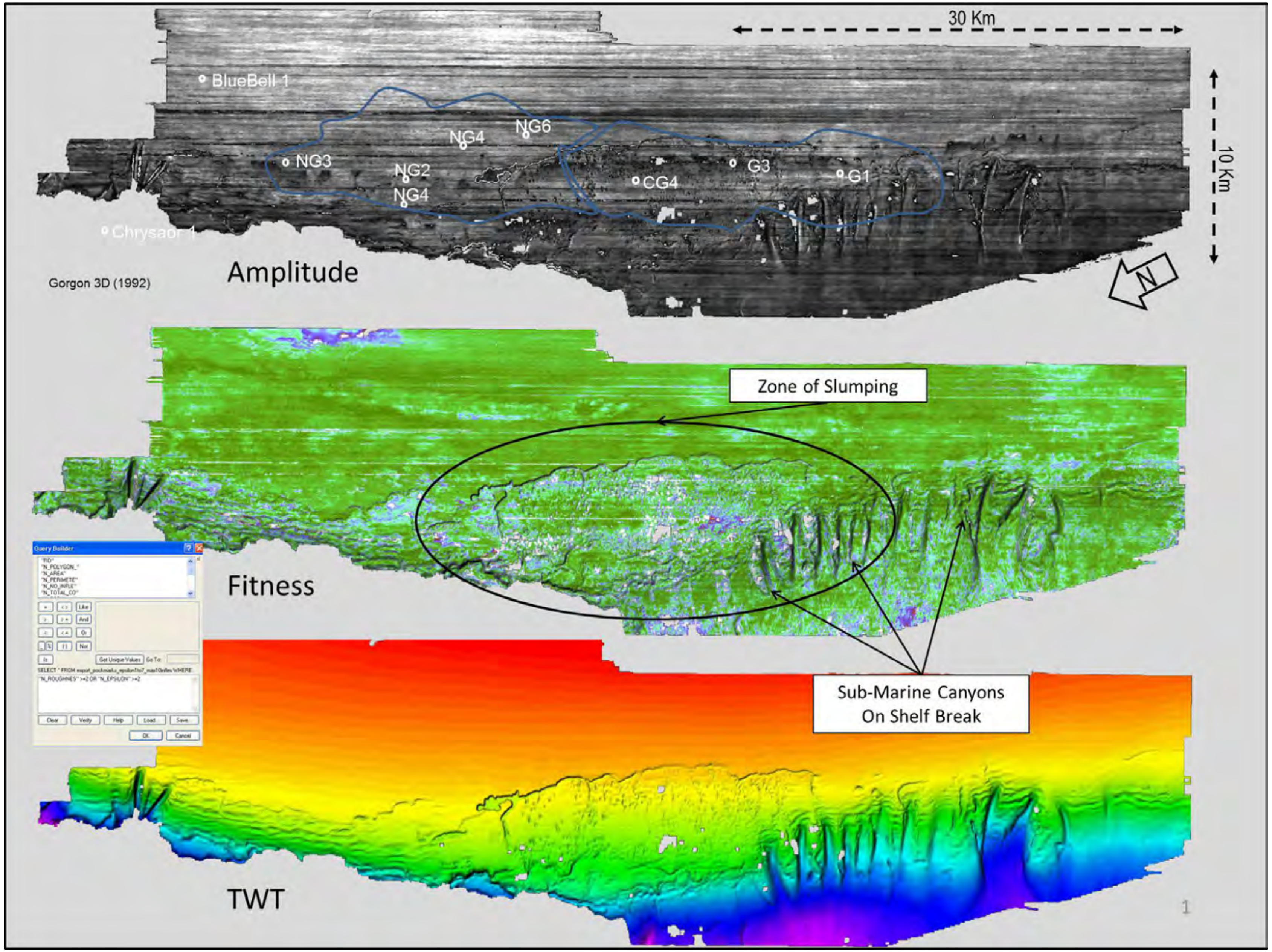
Possible continuation of a major fault is marked by clear spatial correlation of boundaries of extracted convex features



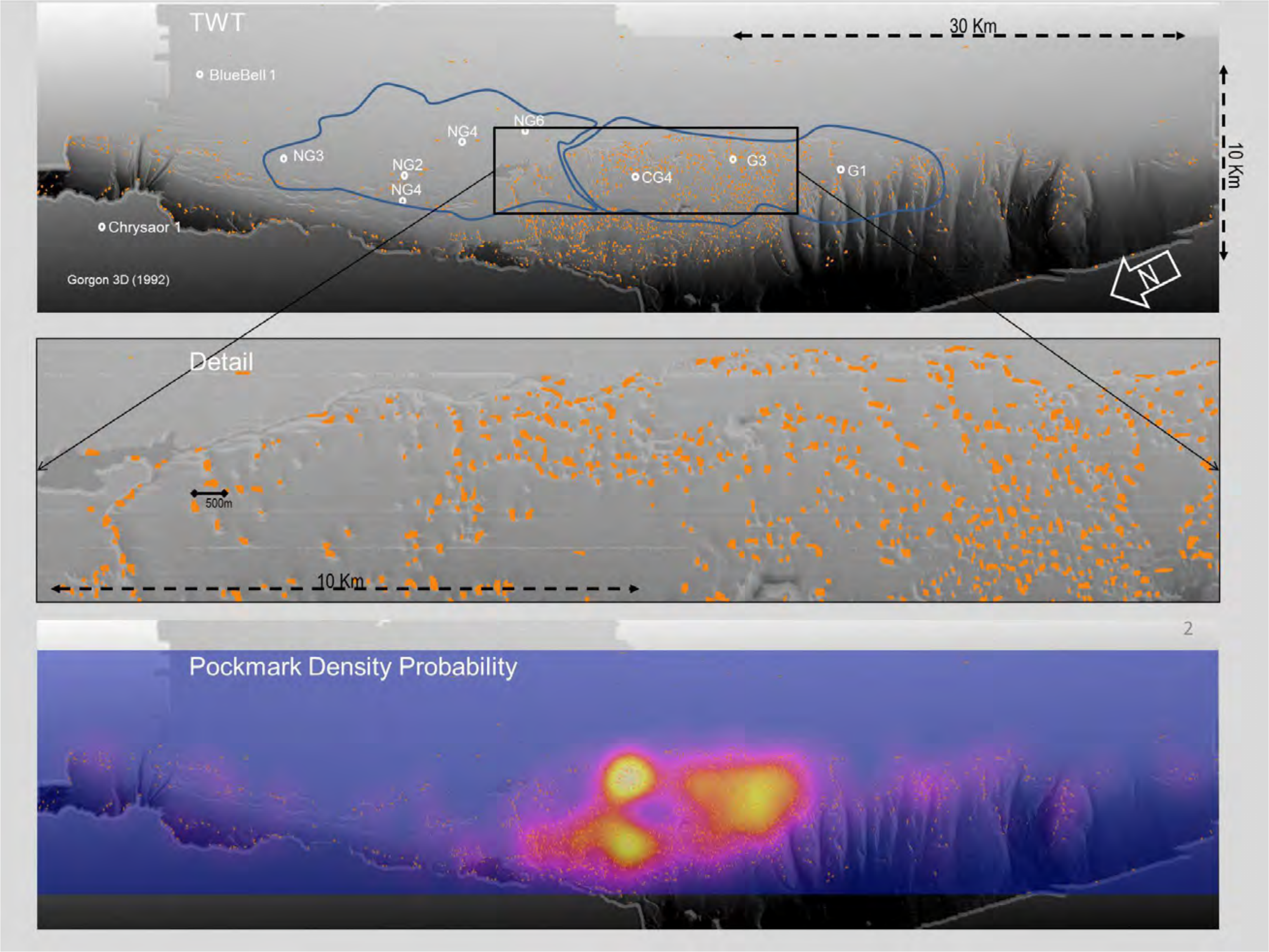
Examples: Carnarvon Basin Pockmarks (Gorgon)



Examples: Carnarvon Basin Pockmarks (Gorgon)

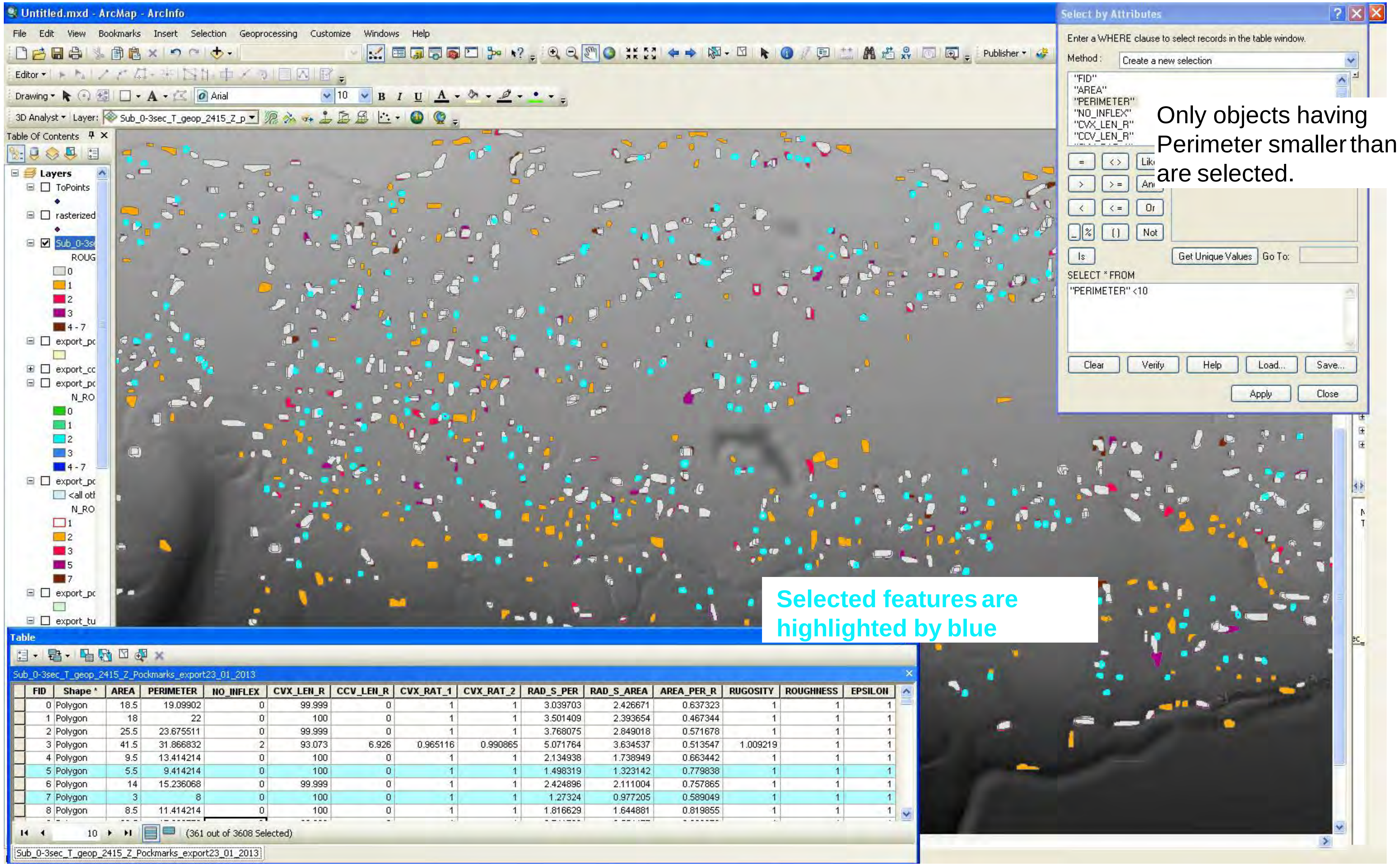


Examples: Carnarvon Basin Pockmarks (Gorgon)



Examples: Carnarvon Basin Pockmarks (Gorgon)

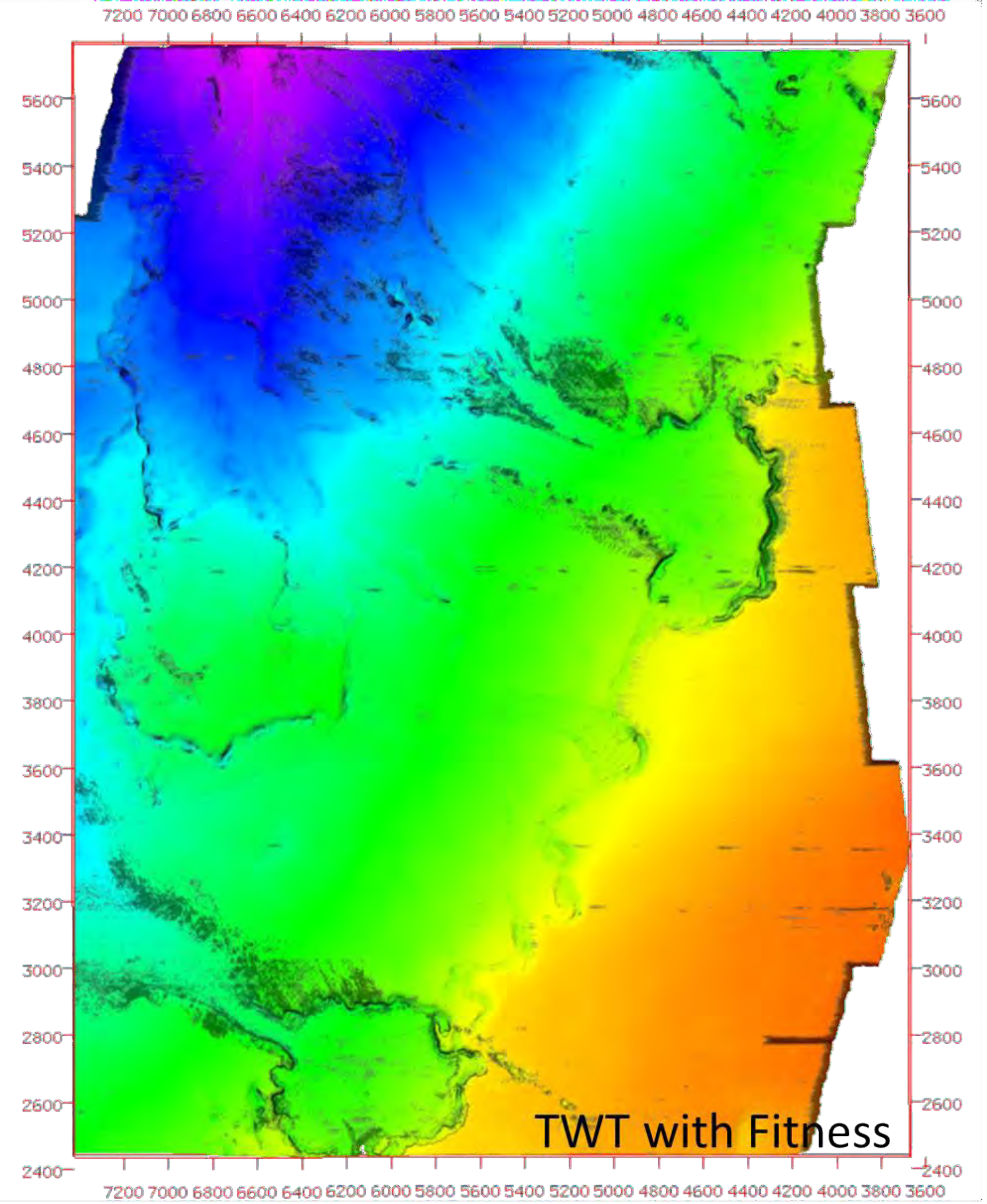
Sub-selection based on geometric attributes

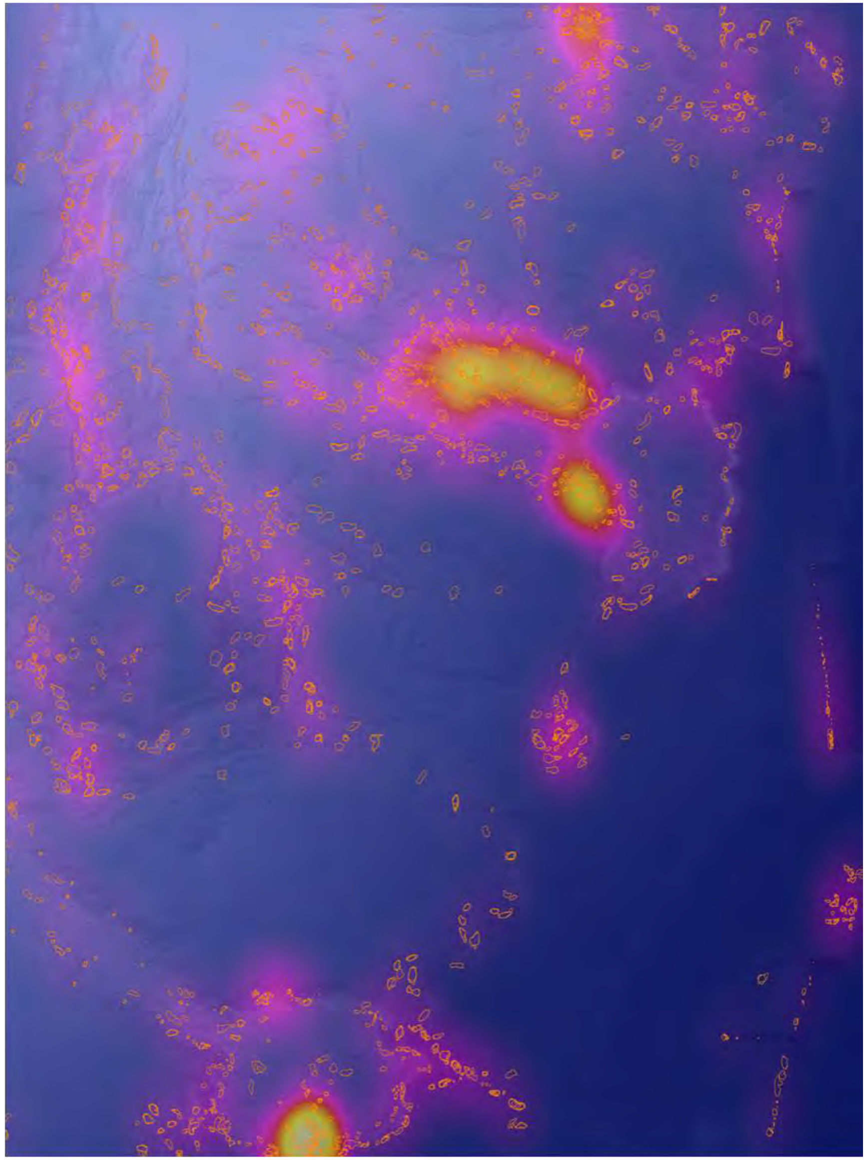


Only objects having Perimeter smaller than 10 are selected.

Selected features are highlighted by blue

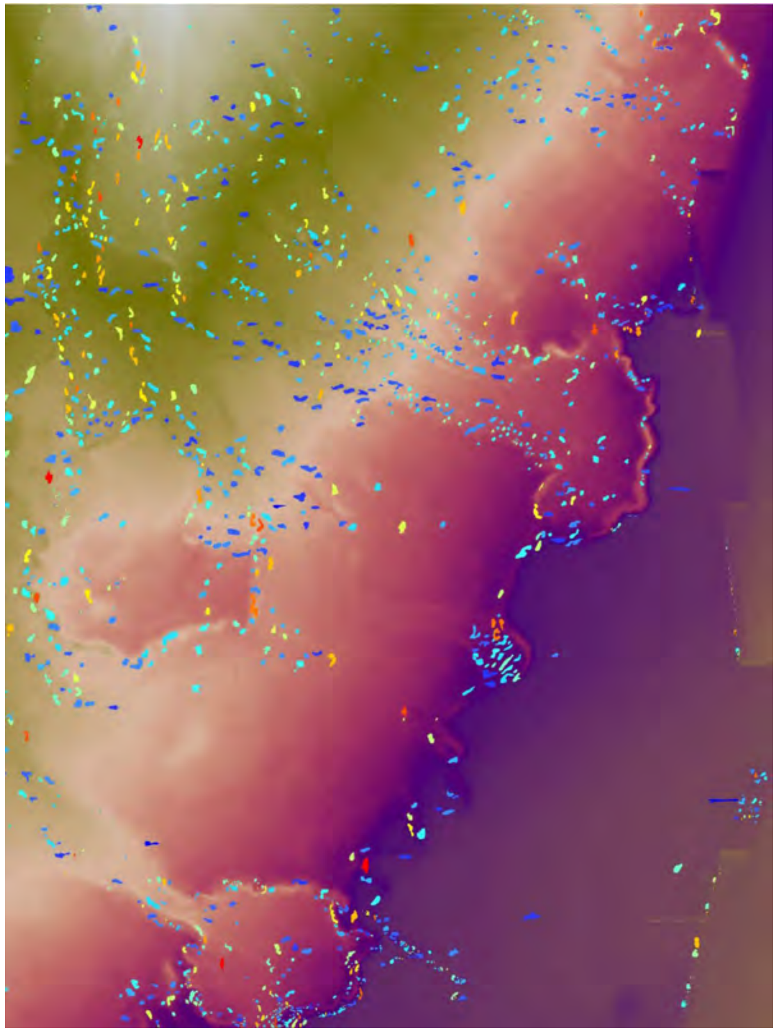
Examples: Carnarvon Basin Pockmarks (Bonaventure 3D)



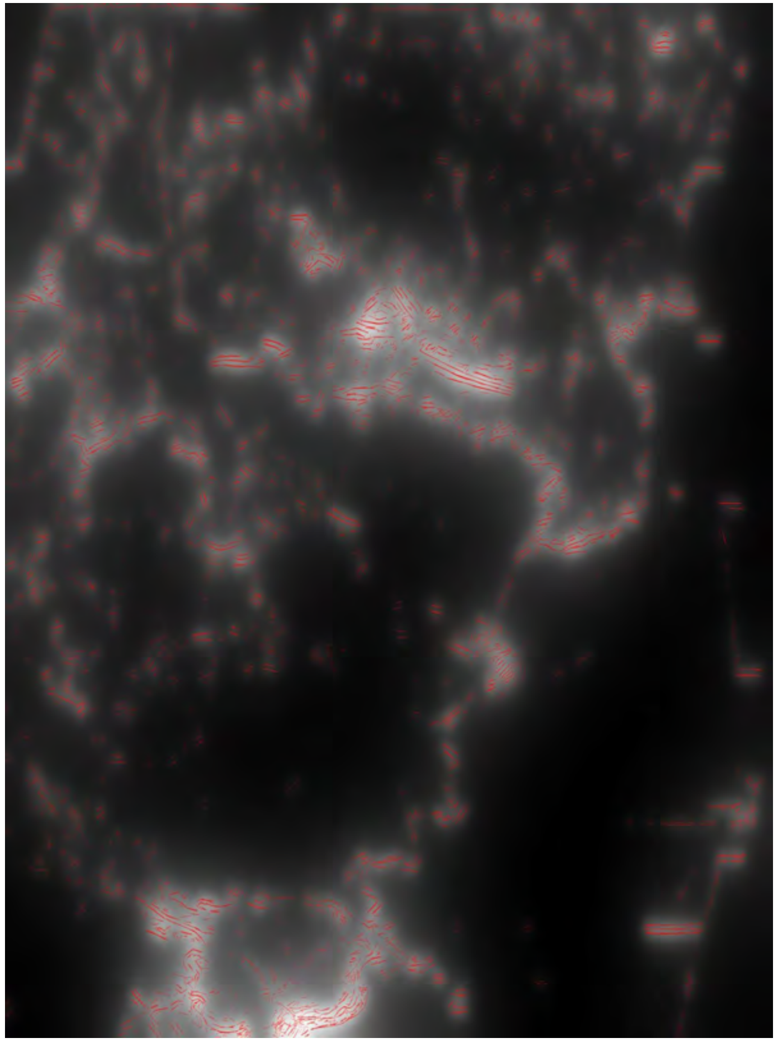


Pockmark Density Probability

Examples: Carnarvon Basin Pockmarks (Bonaventure 3D)

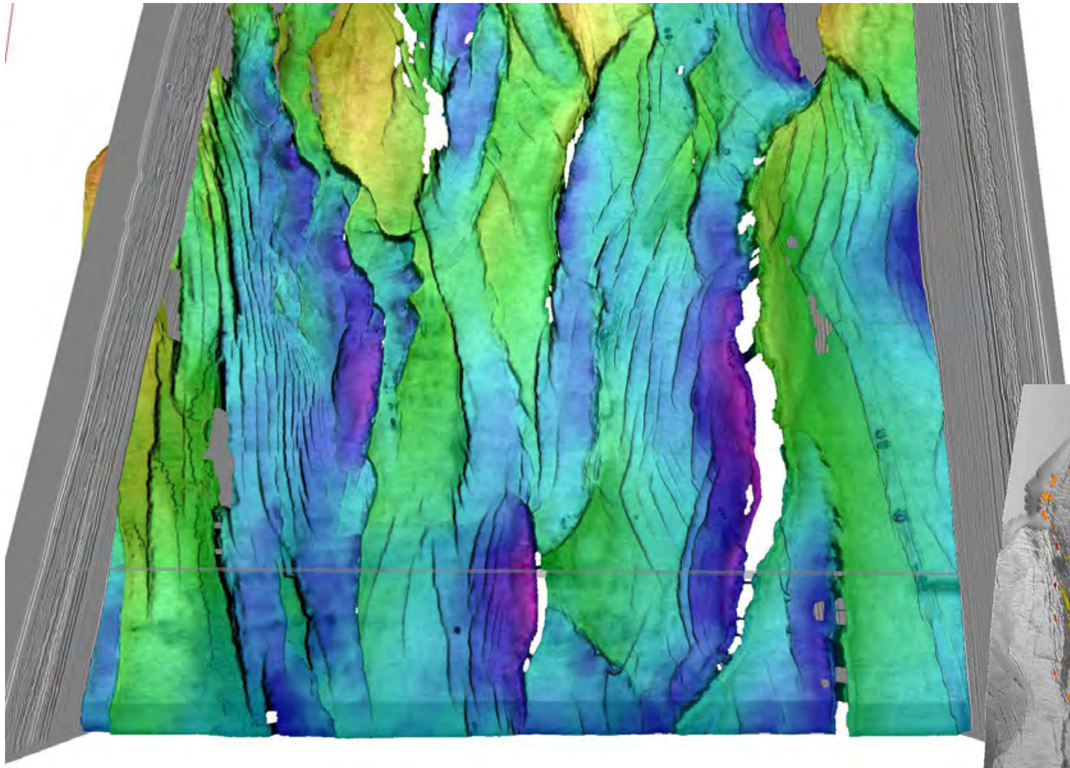


Vectorized localized concave objects coloured by the direction of their long axis



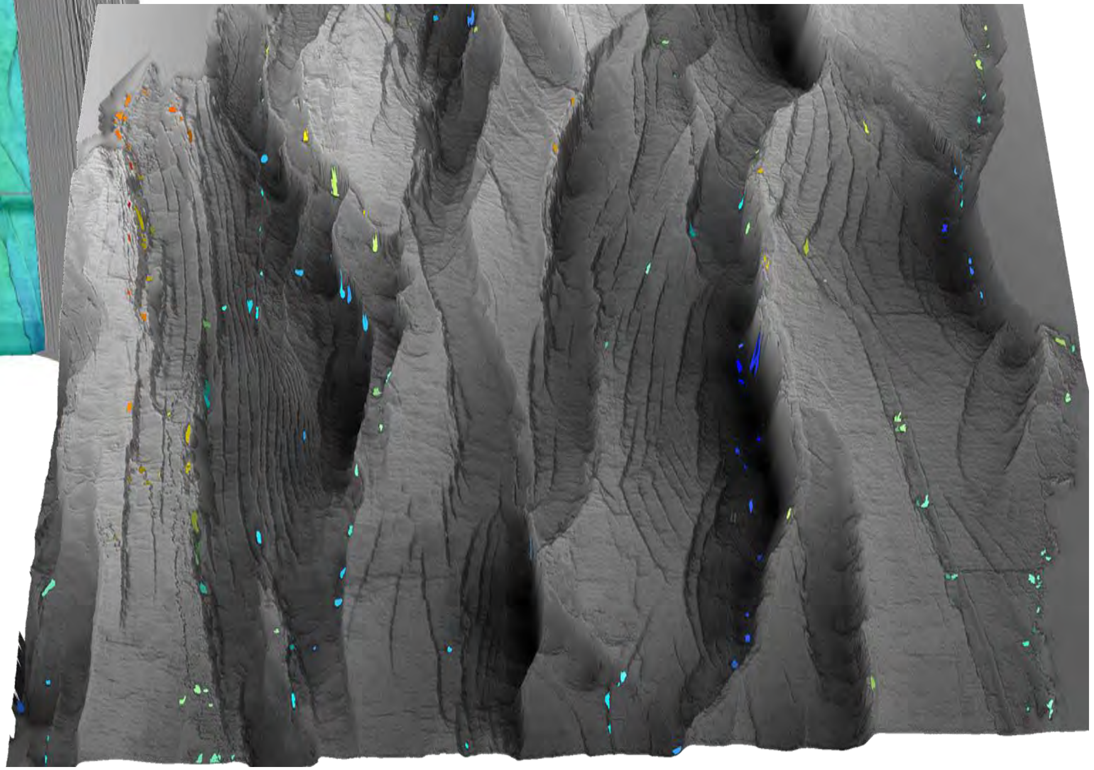
Vectorized linear features and their density probability

Examples: Carnarvon Basin Pockmarks (Bonaventure 3D)



TWT surface which has been rendered

Vectorized locally concave objects coloured by the direction of their long axis. Focused just on certain size.

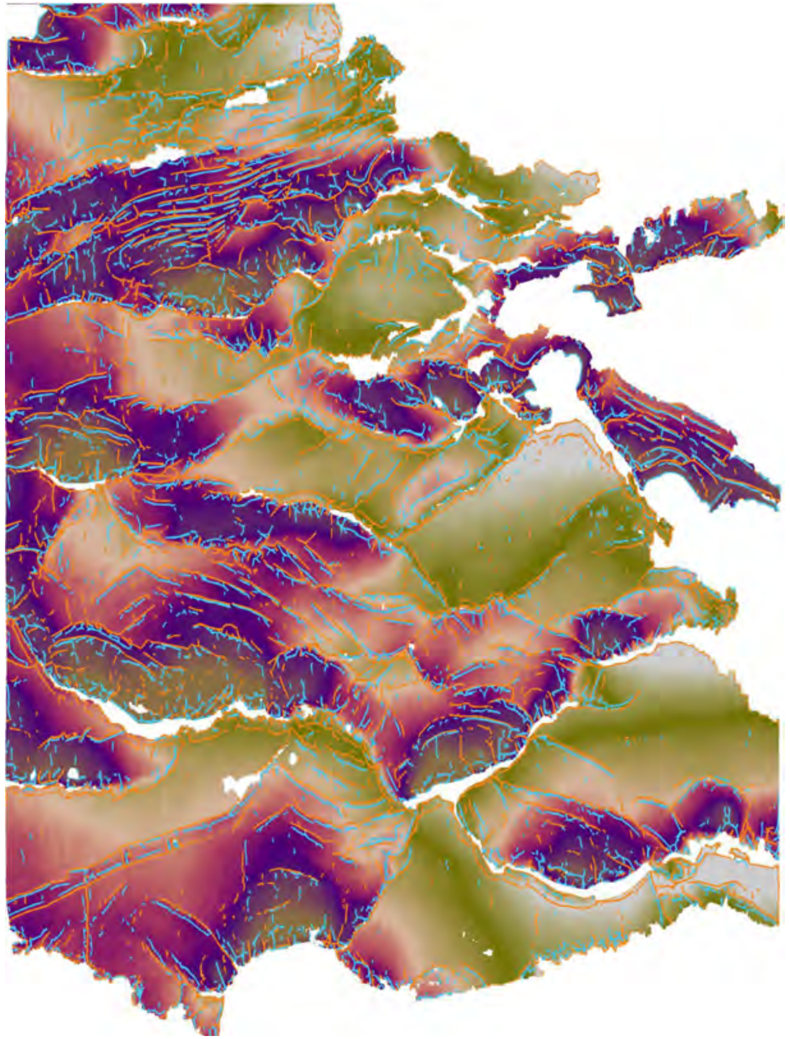


AUTOMATED DATA MINING AND FEATURES EXTRACTION

Linear features and Faults

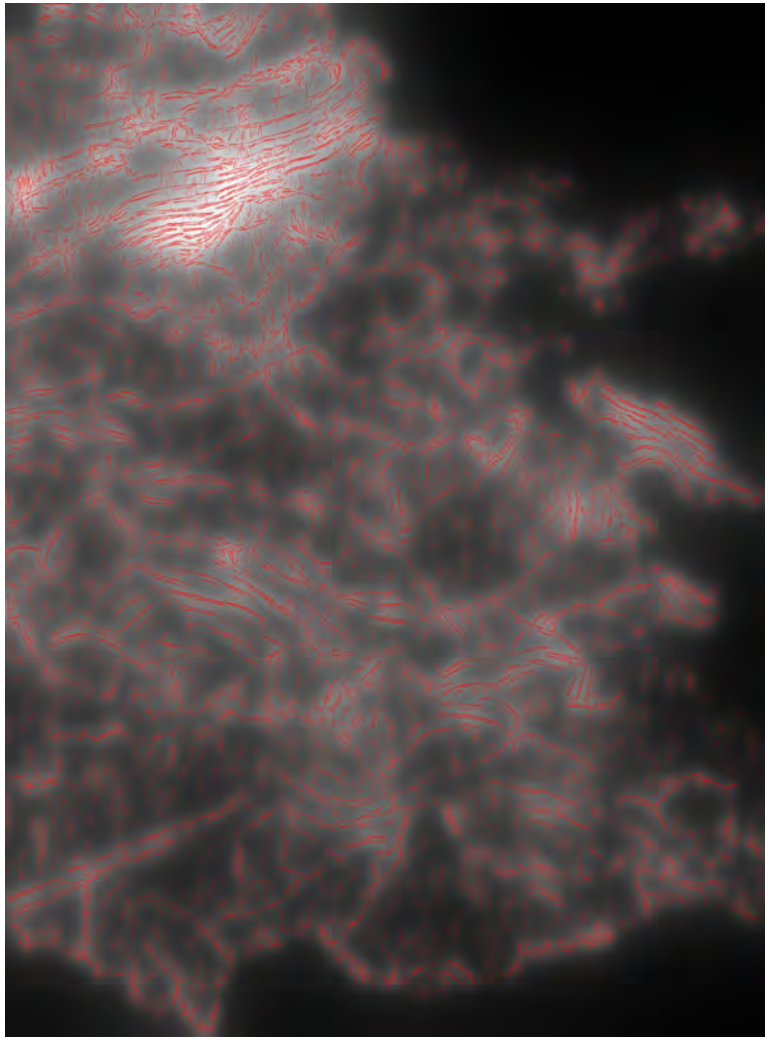
Examples: Carnarvon Basin (Bonaventure_T_merge_8)

Rendered TWT surface in grayscale

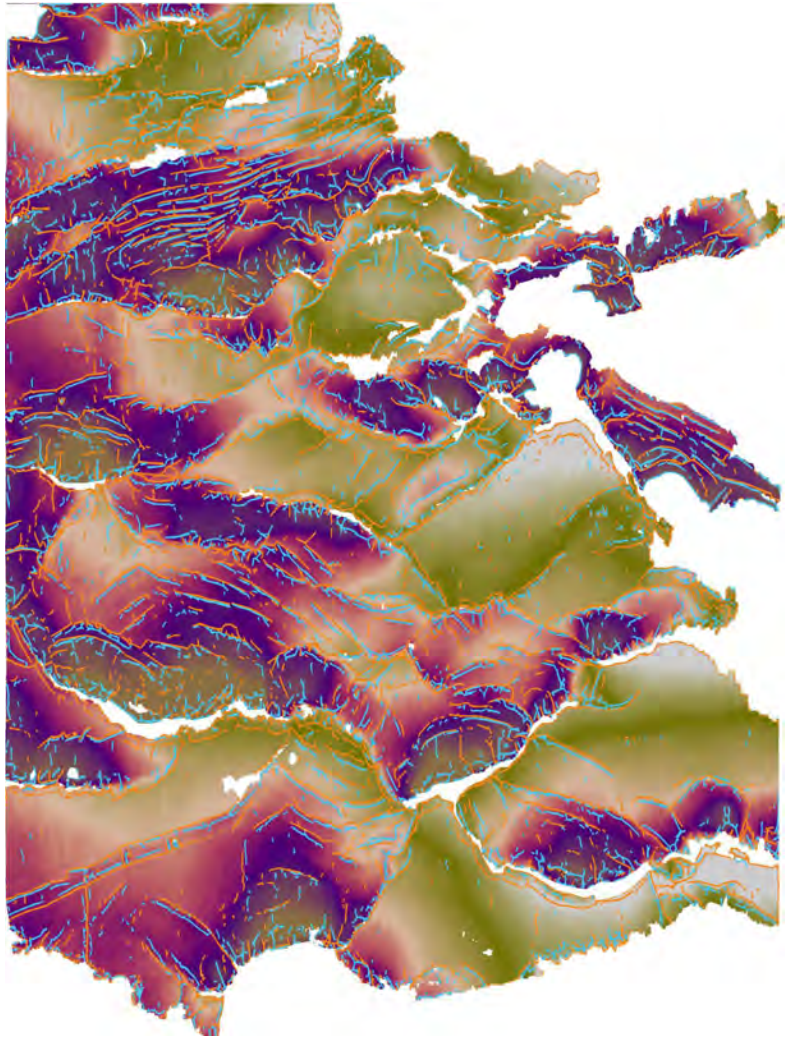


Vectorized linear features: convex (orange), concave (blue)

Examples: Carnarvon Basin (Bonaventure_T_merge_8)

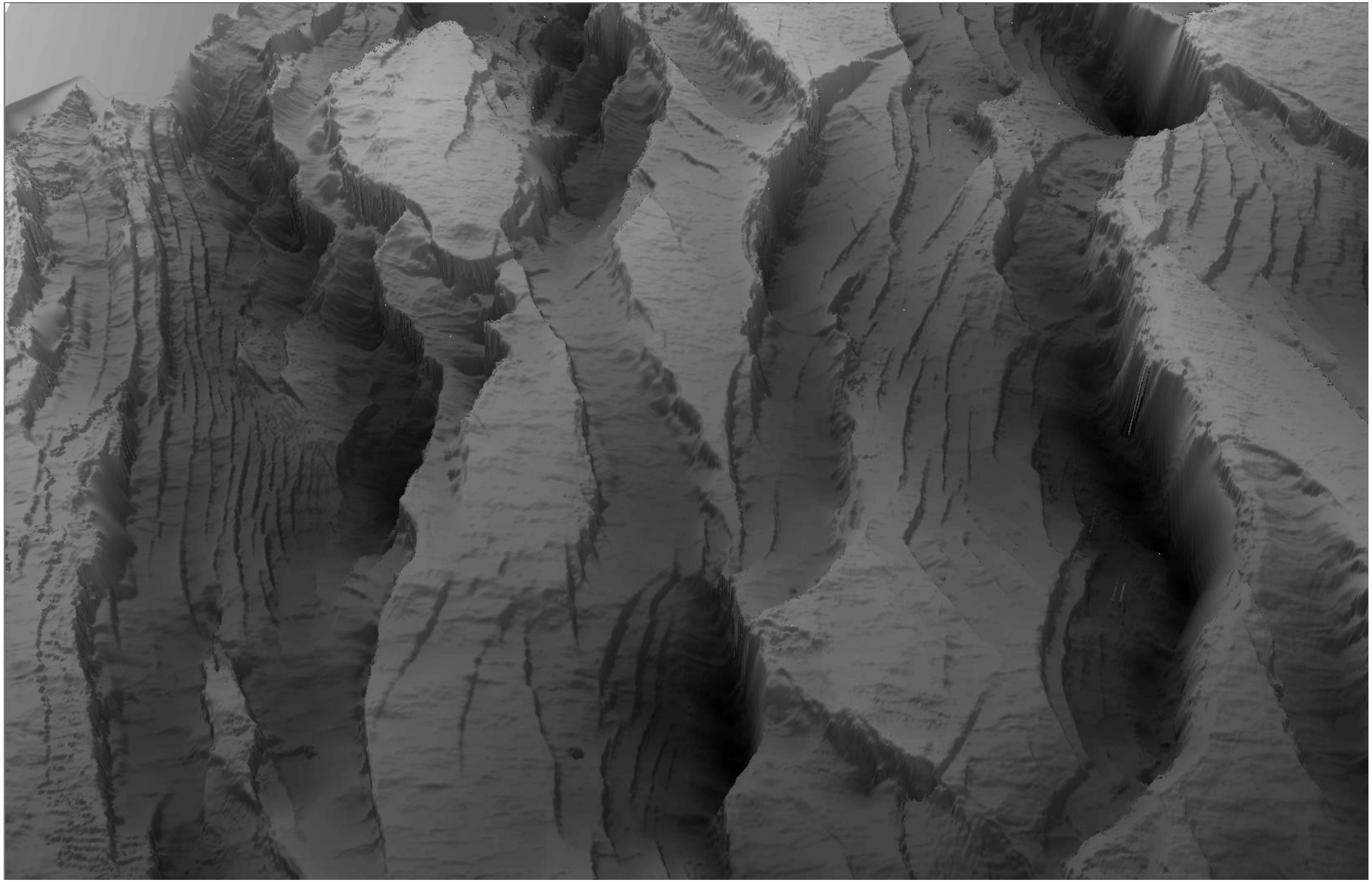


Vectorized linear features and their density probability

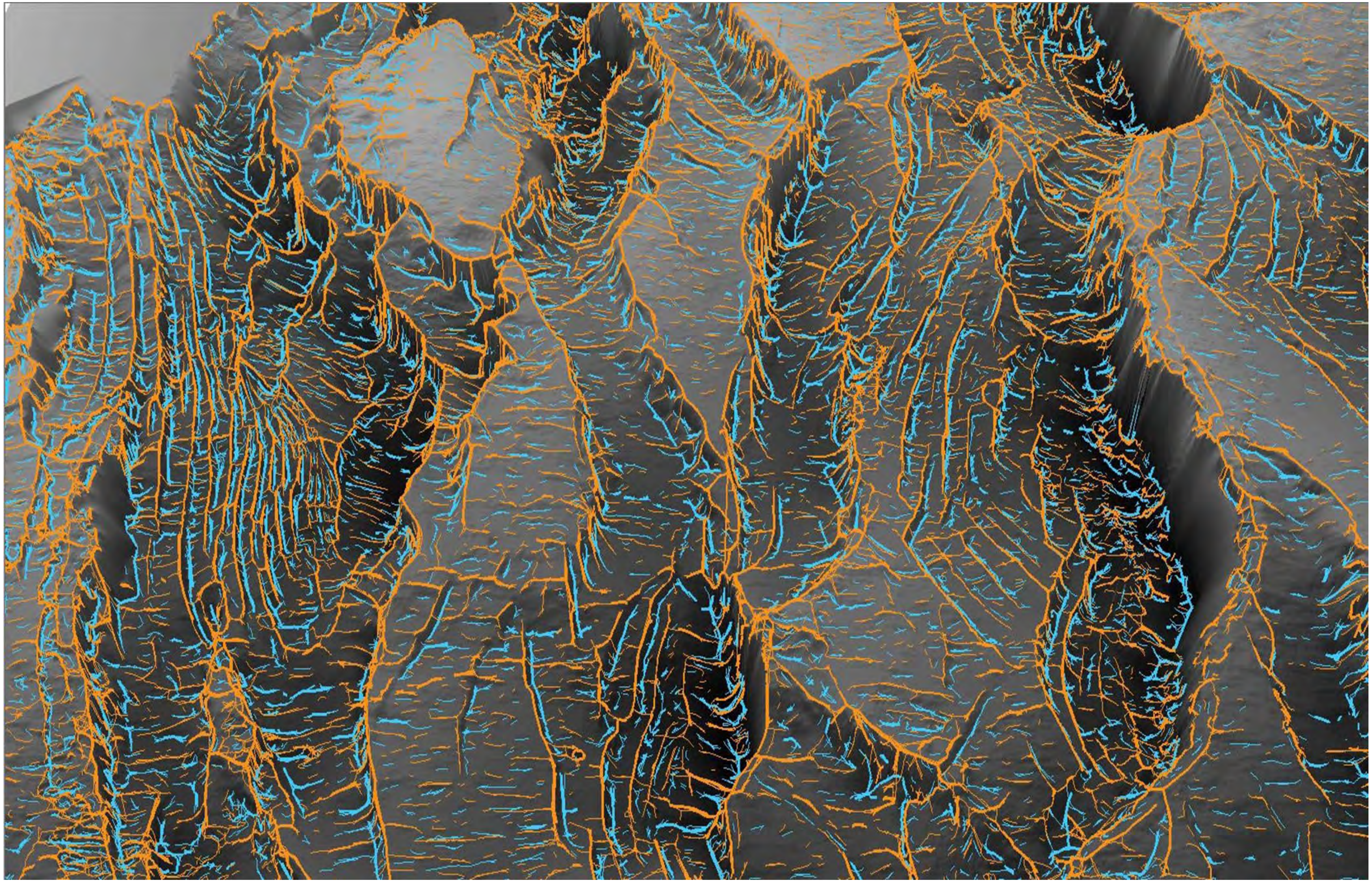


Vectorized linear features: convex (orange), concave (blue)

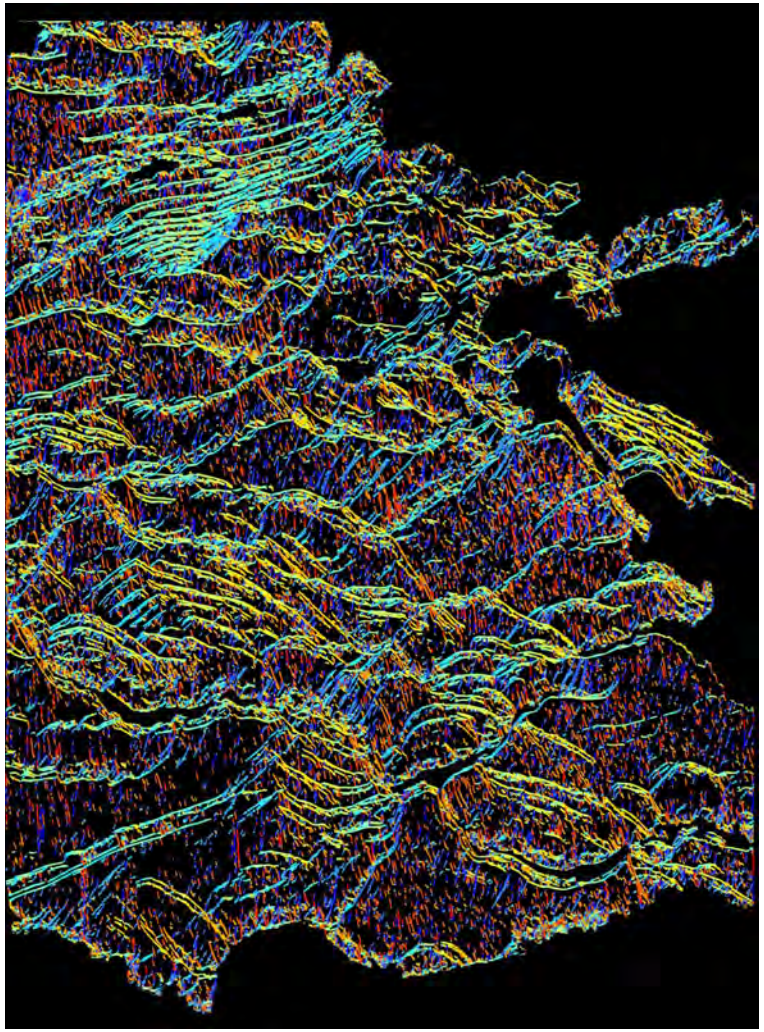
Examples: Carnarvon Basin (Bonaventure_T_merge_8)



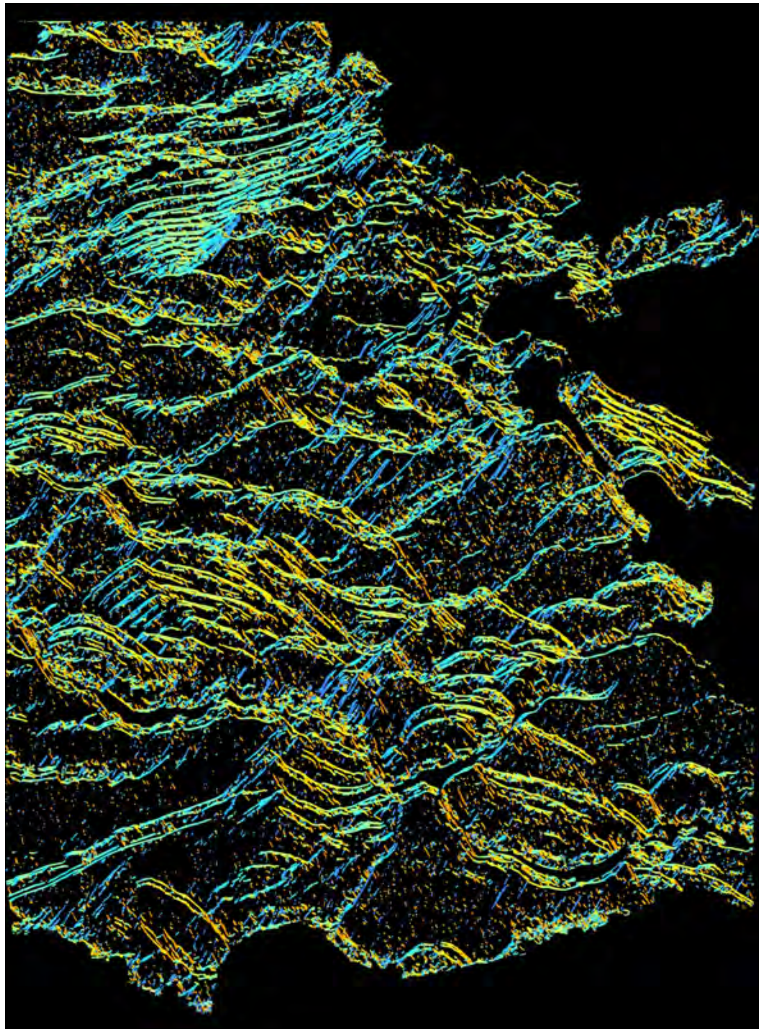
Examples: Carnarvon Basin (Bonaventure_T_merge_8)



Examples: Carnarvon Basin (Bonaventure_T_merge_8)



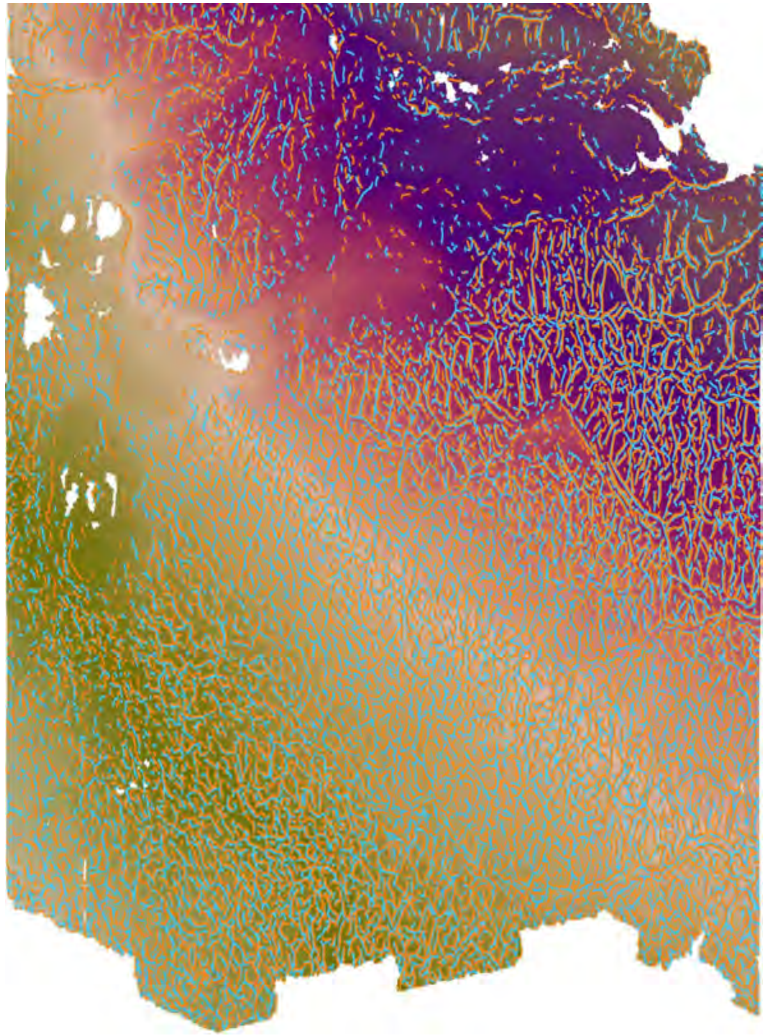
Vectorized linear features coloured by their orientation



Sub-selection: all features outside of +-30 degrees are filtered out

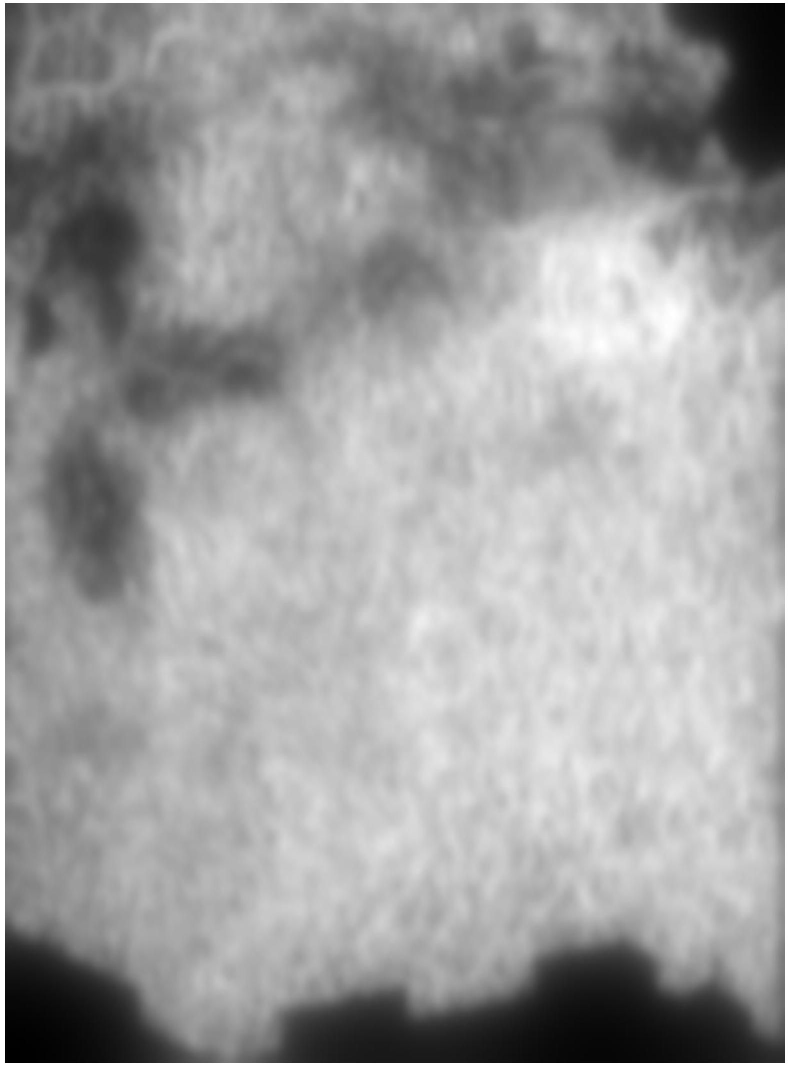
Examples: Carnarvon Basin (geop_2182)

False coloured TWT image

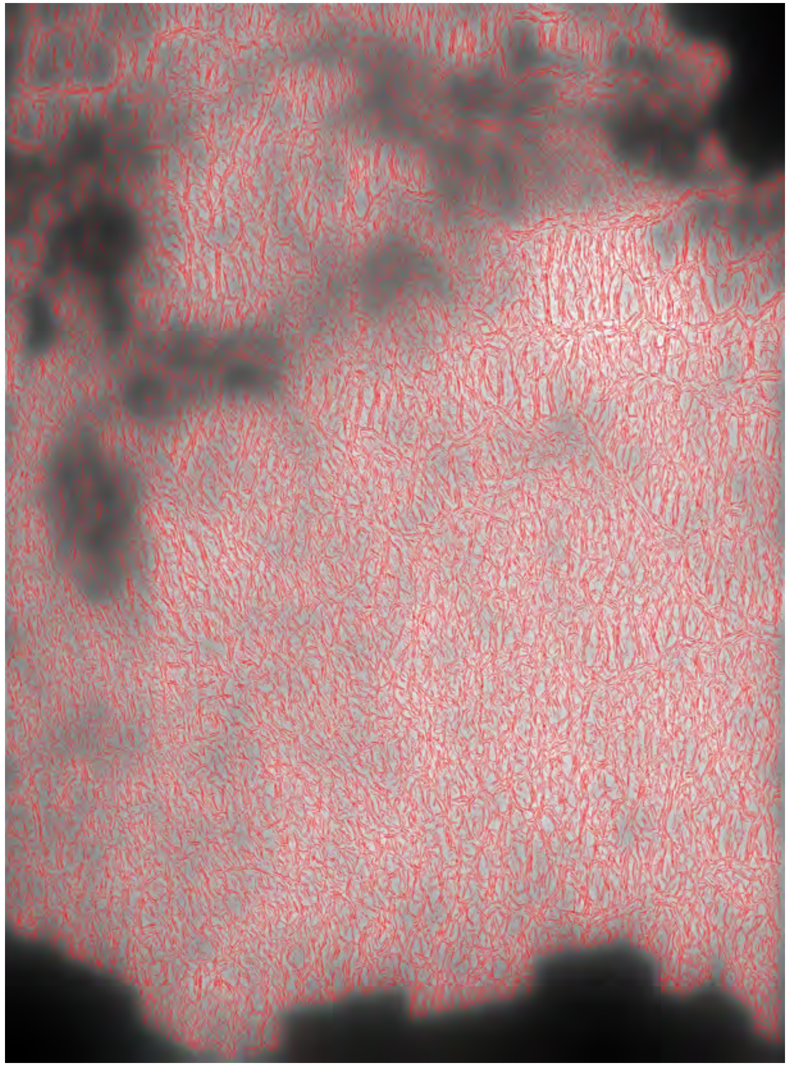


Thousands of automatically vectorized linear features: convex (orange), concave (blue)

Examples: Carnarvon Basin (Kentish Knock)



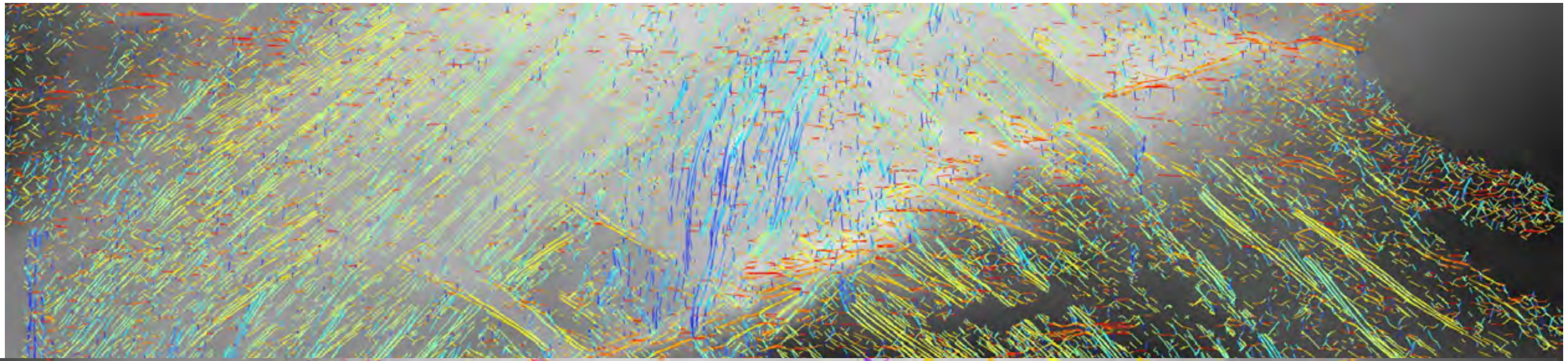
Grayscale image of density probability of linear features



Thousands of automatically vectorized linear features overlayed on their density probability

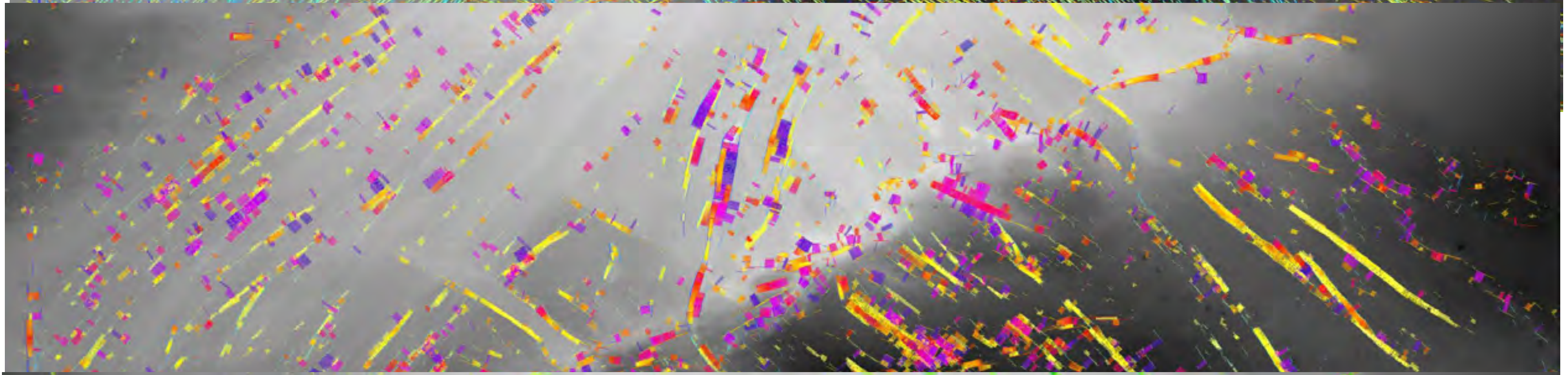
Examples: Willem 1070

Vectorized linear features coloured by their orientation.

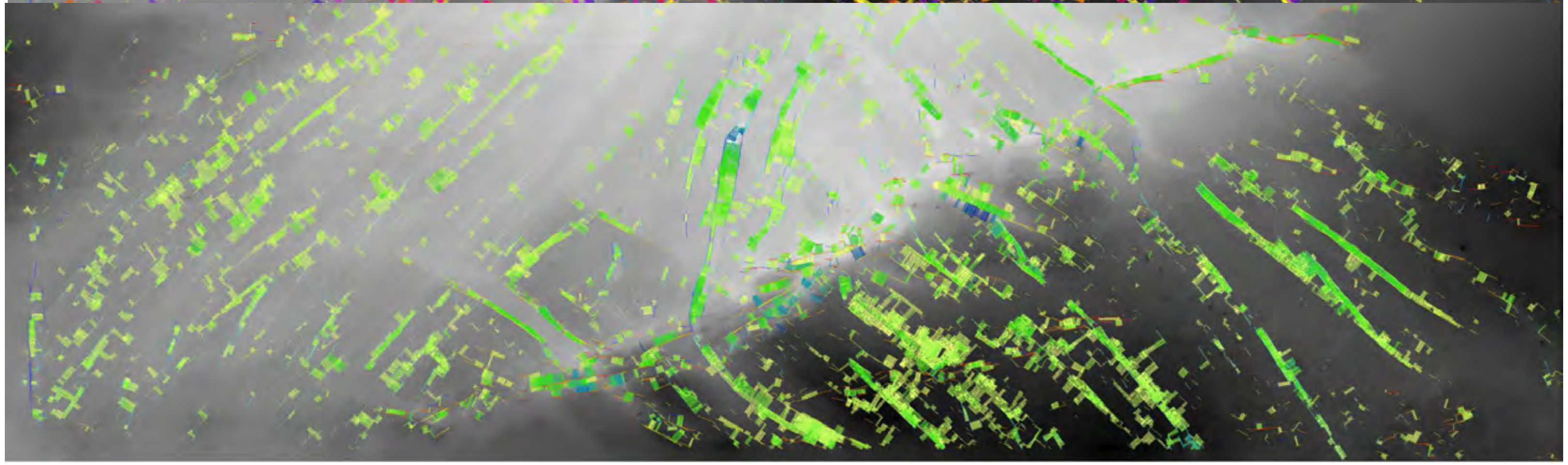


Using standard methods this is unavailable

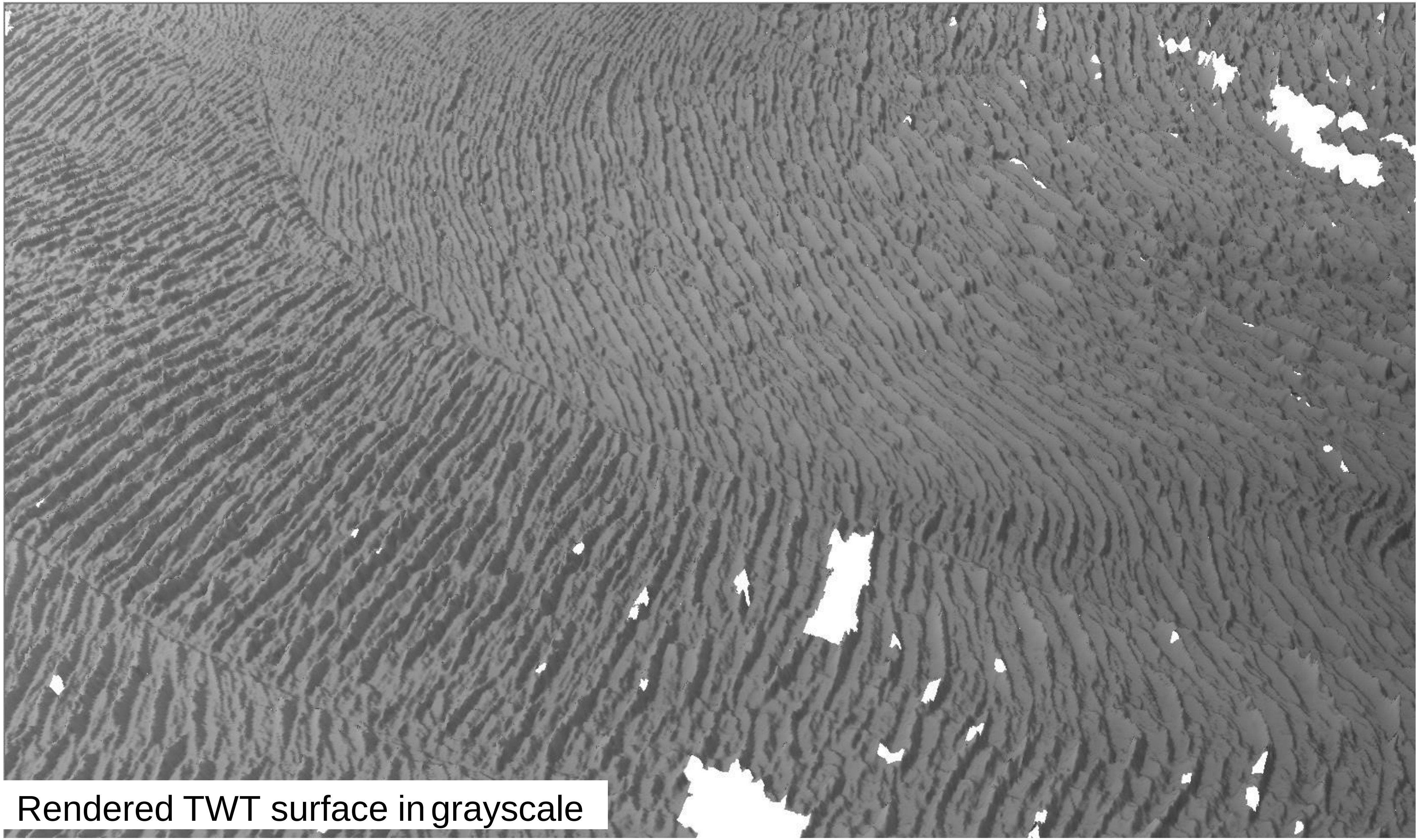
Heave of parallel linear features.



Throw of parallel linear features

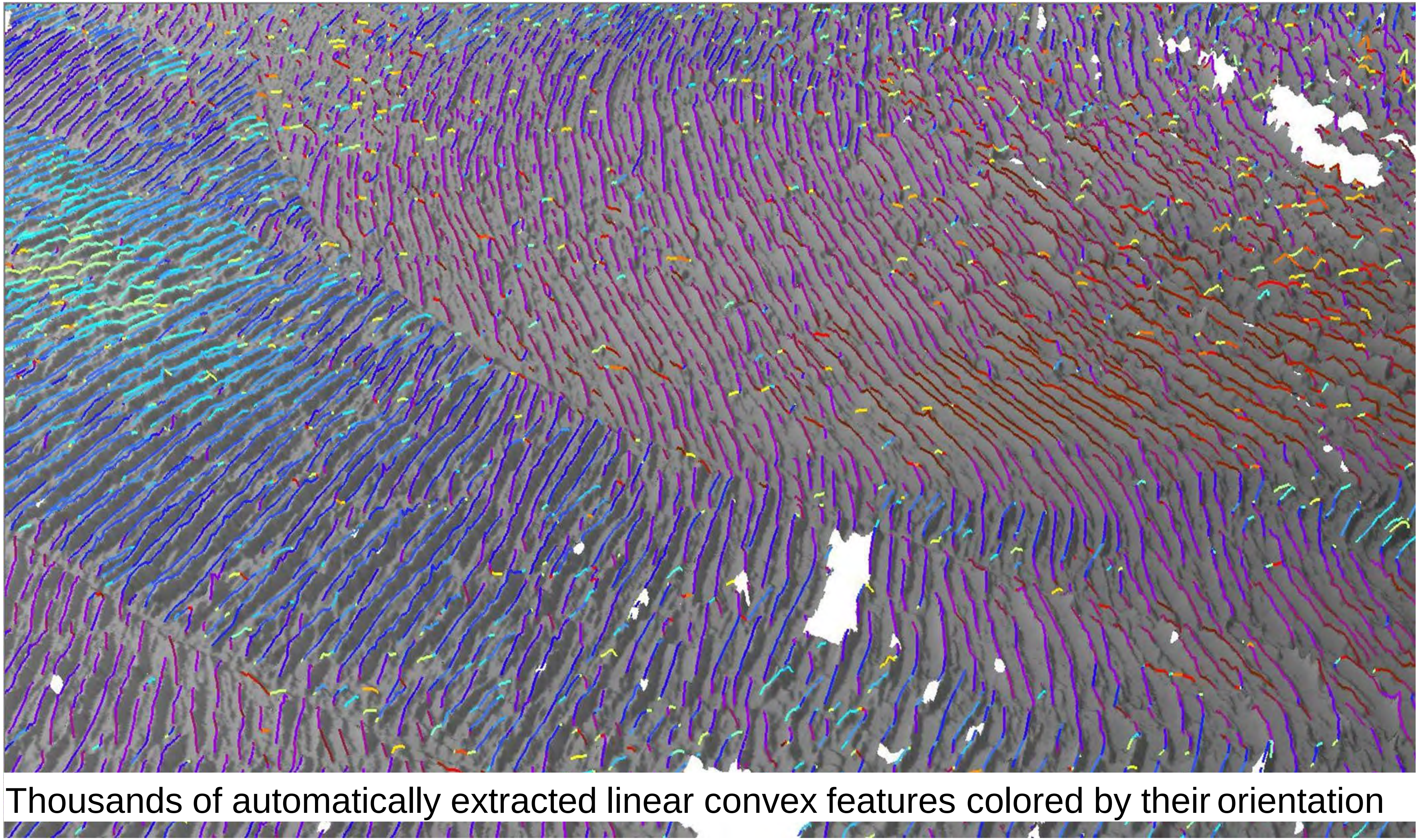


Examples: Carnarvon Basin (Glencoe – geop_389)



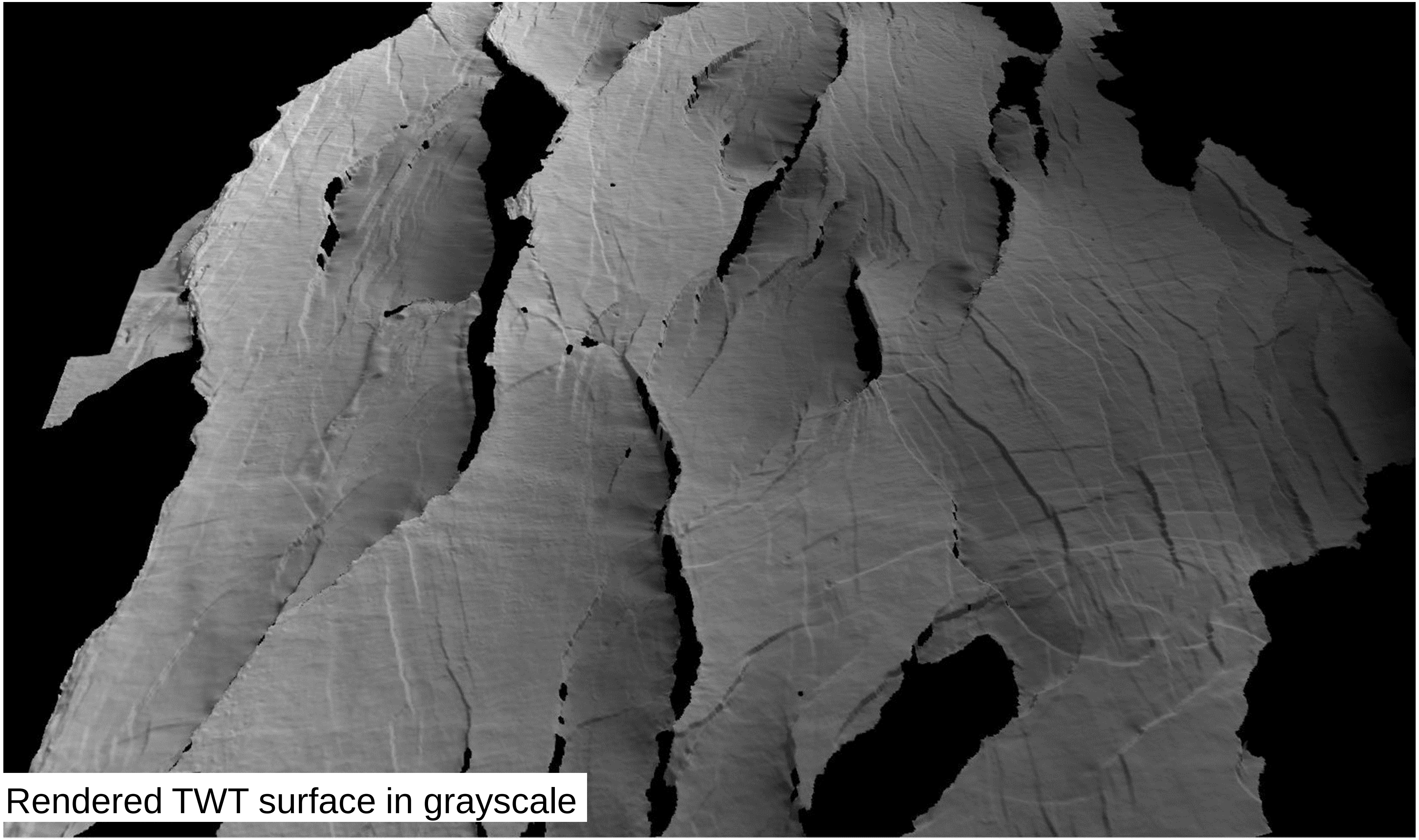
Rendered TWT surface in grayscale

Examples: Carnarvon Basin (Glencoe – geop_389)



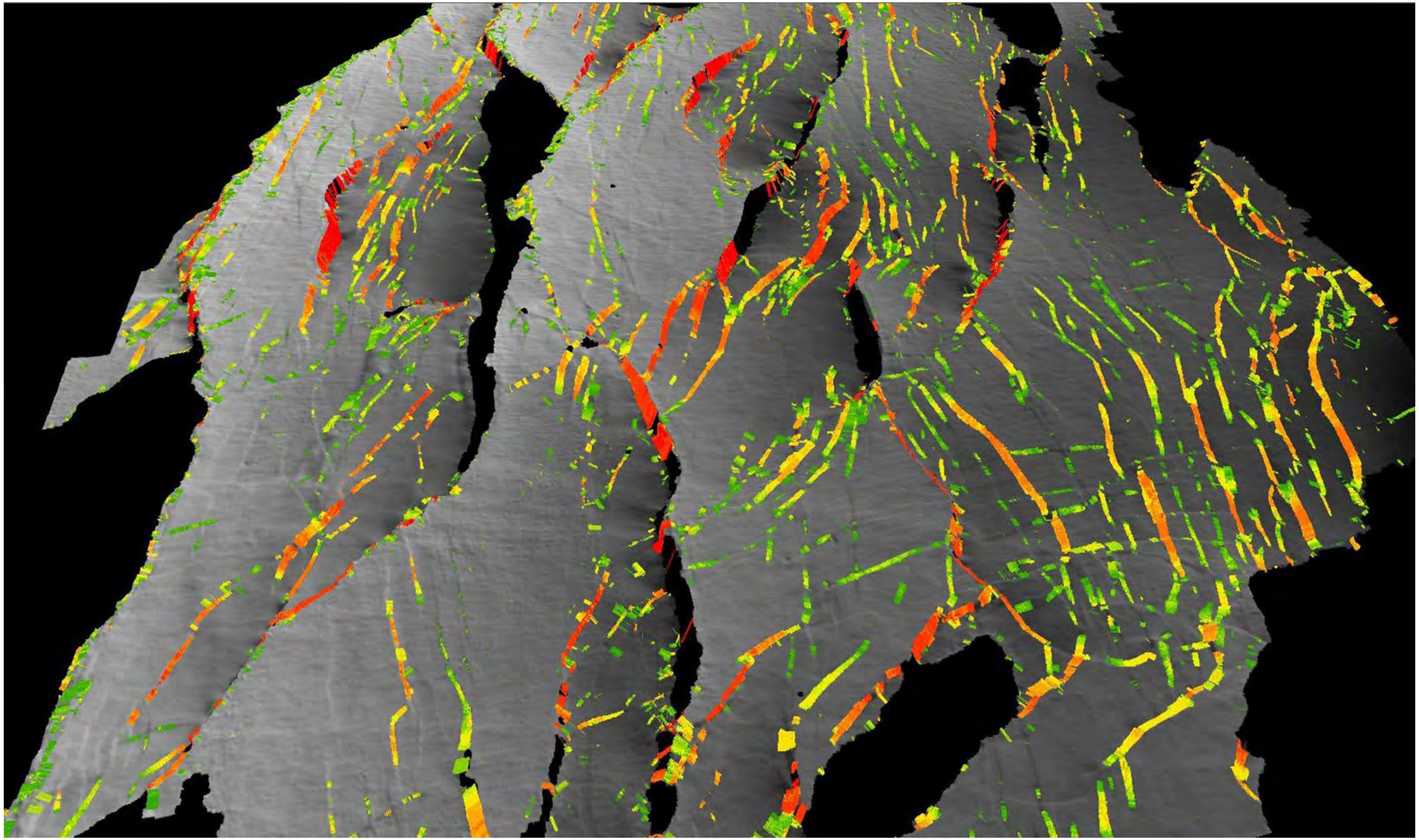
Thousands of automatically extracted linear convex features colored by their orientation

Examples: Carnarvon Basin (Glencoe – merge5)



Rendered TWT surface in grayscale

Examples: Carnarvon Basin (Glencoe – merge5)



Tens of thousands of automated measurements of fault angle
Red highlights very steep faults