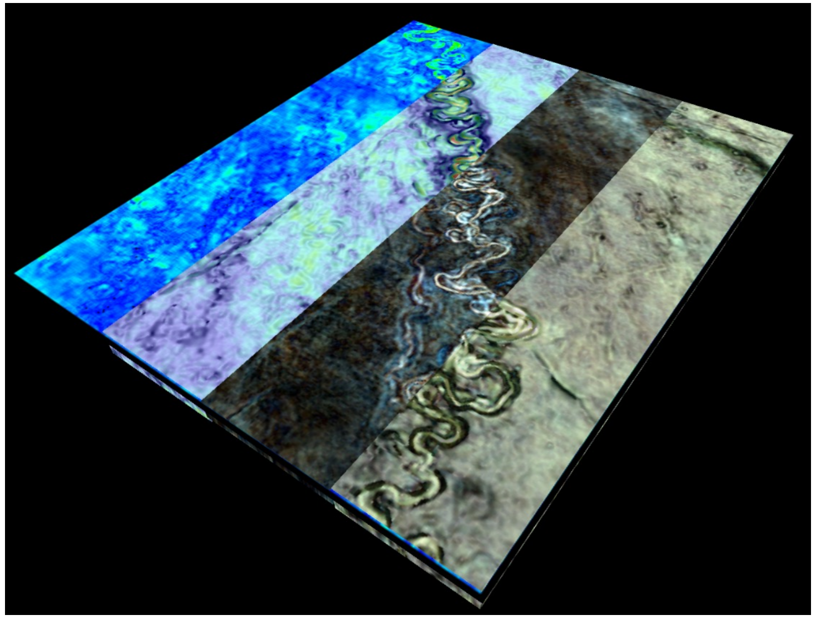
Seismic imaging
Lecture 6



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Module outline

Day 2 morning- Visualising and interpreting seismic data

Lecture 4: The SEGY data convention and where to find data

Lecture 5: How to interpret seismic data

Lecture 6: Seismic attribute analysis and machine learning (future outlook)

Day 2 afternoon- Exercises

Exercise 3: Reading SEGY data and visualizing 3D data

Exercise 4: Calculating seismic attributes

Lecture outline

Objective of lecture 6:

Post-stack seismic attributes and the future of seismic interpretation

1) Grid-based post-stack seismic attributes

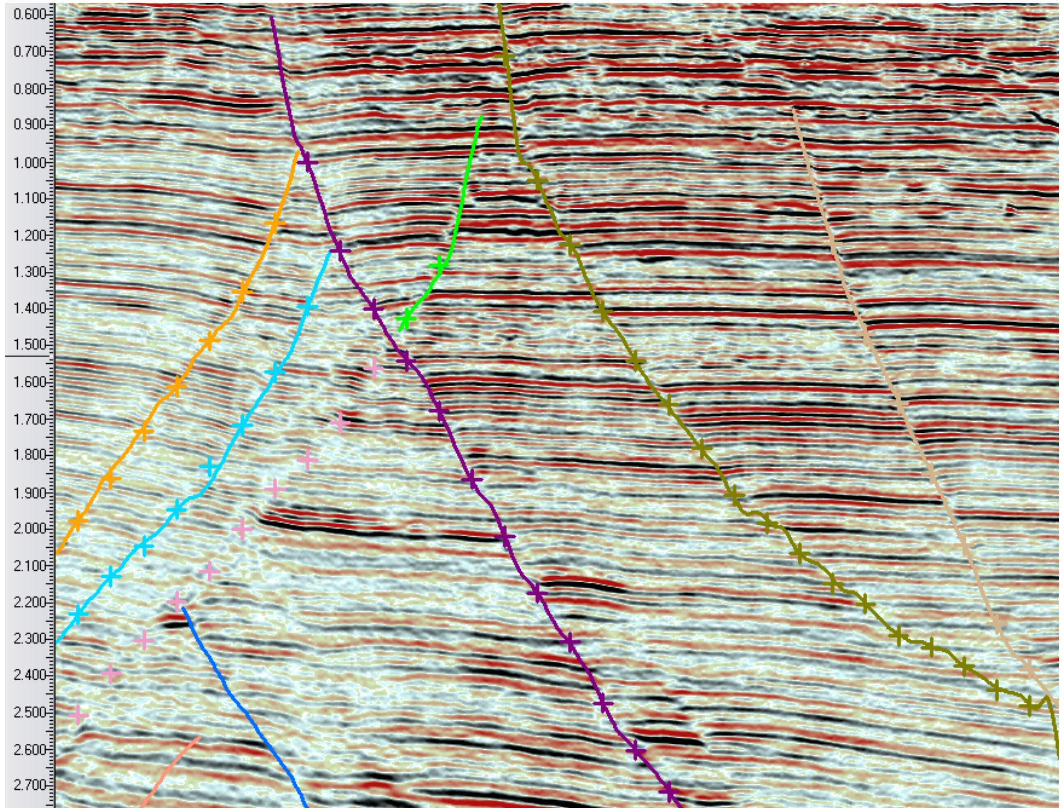
2) Volume-based post-stack seismic attributes

3) Potential for automation

This lecture directly links to Exercise 4:
Seismic attributes

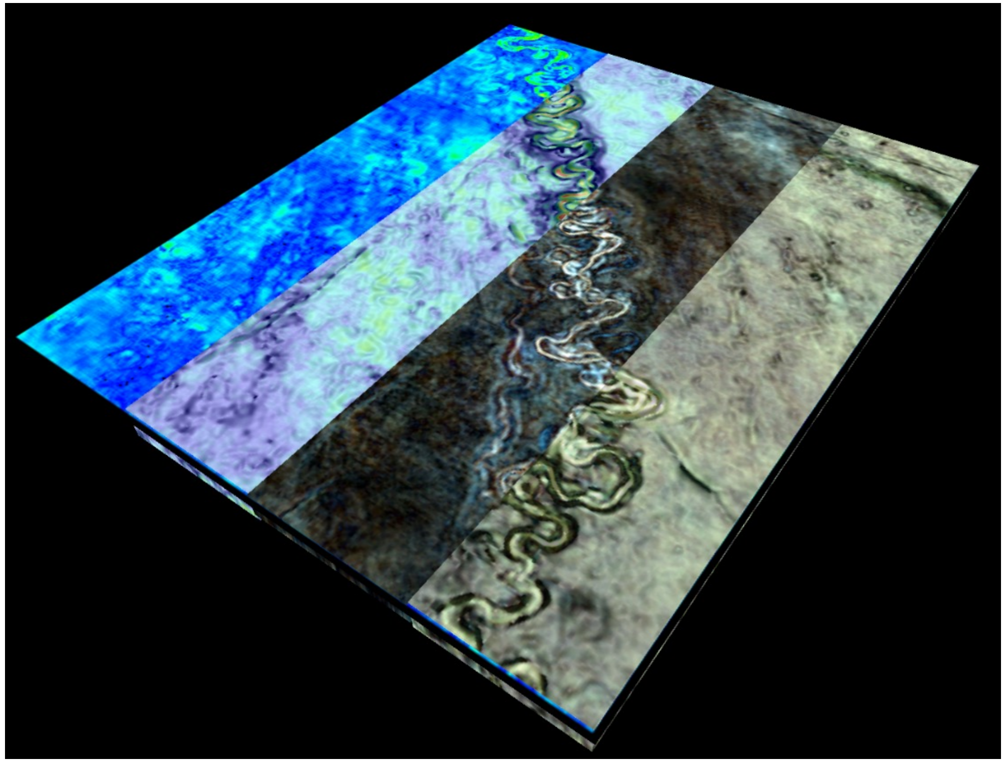
Conventional vs ‘cognitive’ interpretation

Conventional interpretation



Mapping to reveal geological features

Cognitive interpretation



Computing seismic attributes to reveal geological features before mapping

Definitions

- What is an attribute?

  - *"...A quality ascribed to any person or thing" (Oxford Dictionary)*

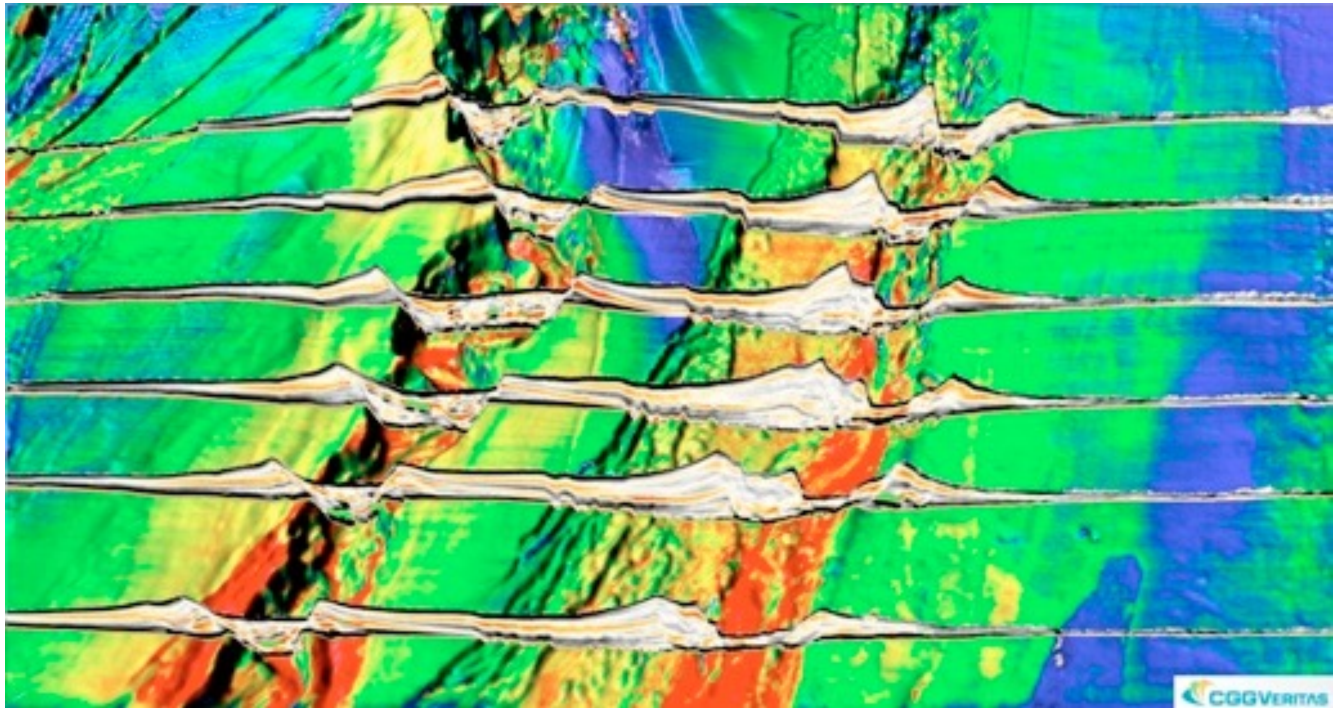
- What is a seismic attribute?

  – *"...a quantitative derivative of a basic seismic measurement that may be extracted along a seismic trace, extracted along a horizon, or summed over a time window" (see Brown 2003; Hart & Chen, 2004)*

- What types of seismic attributes are available?

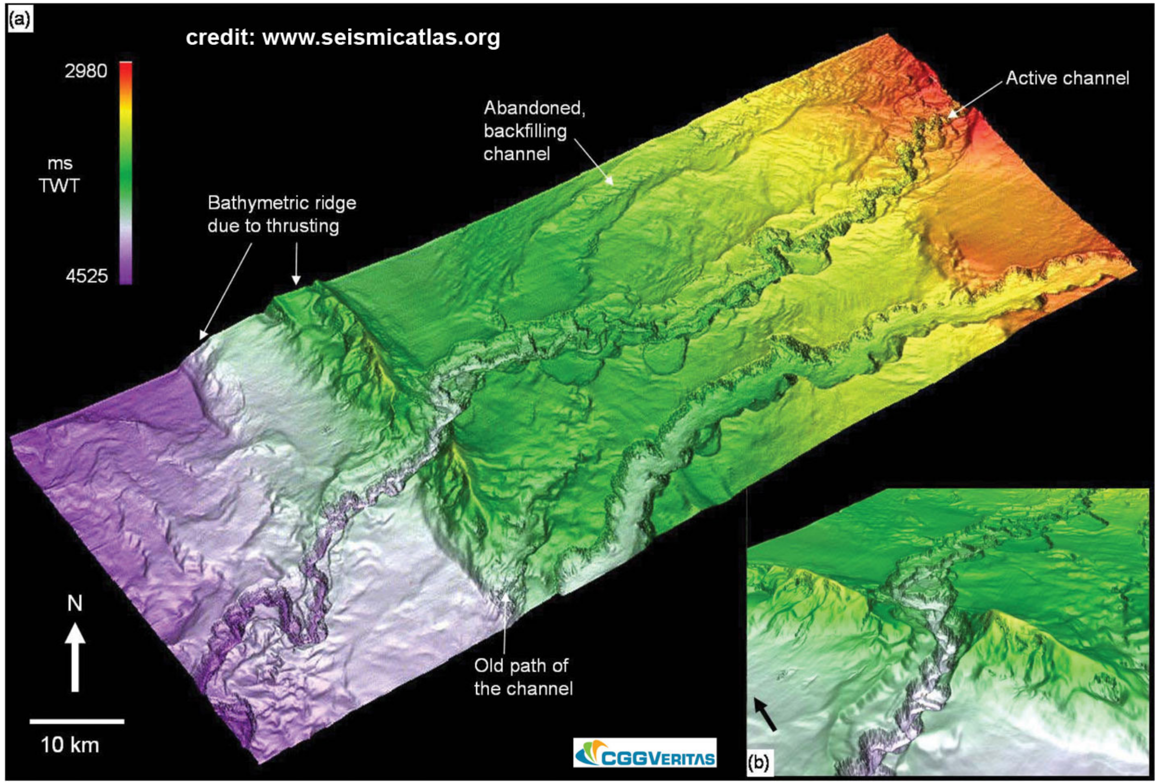
  – Grid-based attribute analysis
  – Volume-based attribute analysis

Grid-based seismic attributes



Time/depth-structure maps

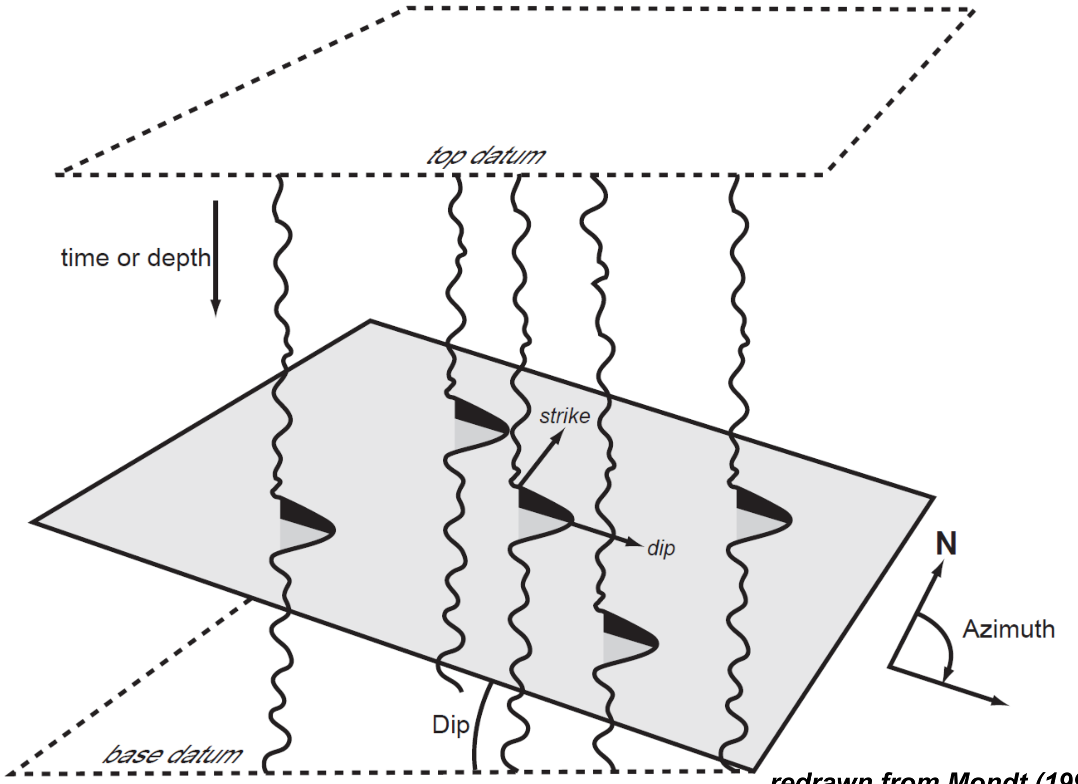
- Time/depth to a particular interpreted reflection (ie geological boundary)
- we can illuminate (hill shade) these diagrams to highlight features



- Grid-based seismic attributes can be used to examine the morphology of these surfaces in more detail

- Like working with a satellite-derived Digital Elevation Model (but underground!)

Dip and azimuth attributes



redrawn from Mondt (1993)

- **Dip** - calculates the dip at each point on an horizon. The resultant map (termed a 'dip map') displays variations in the ***magnitude of dip***. The map contains no information on dip direction or magnitude of offset across a structure (e.g. total displacement or displacement direction in the case of a fault). Typically used to delineate structural features (i.e. faults and folds)

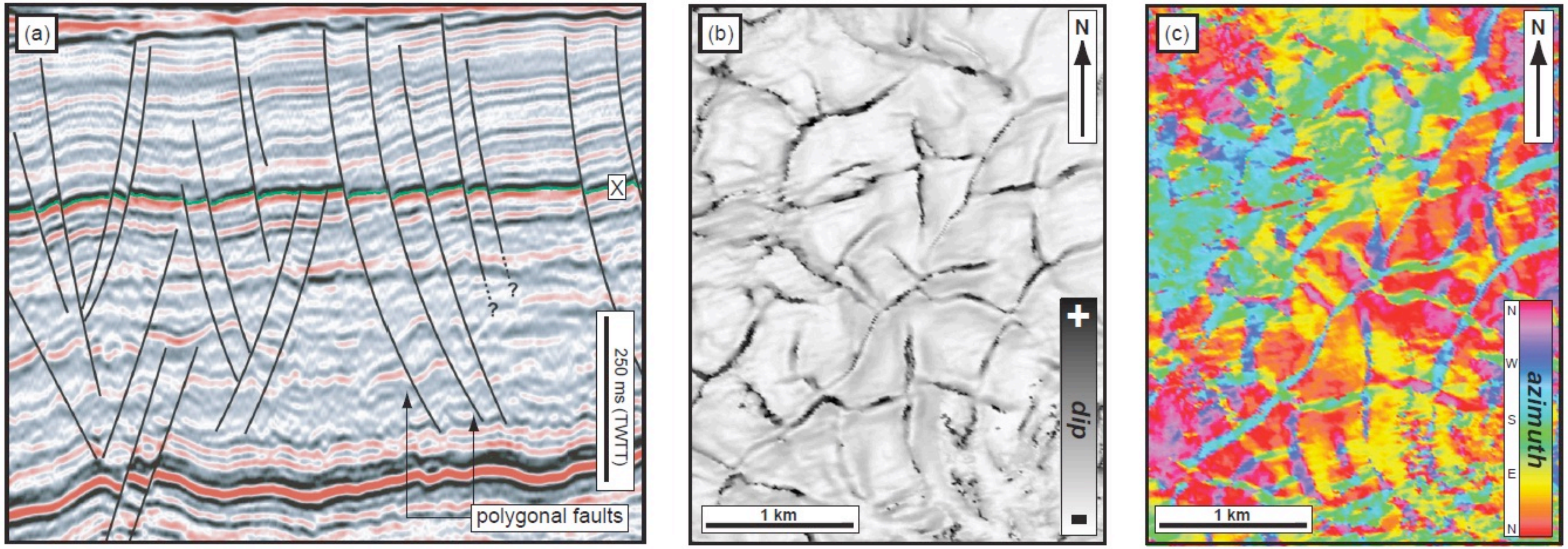
- **Azimuth** - calculates the azimuth at each point in degrees (˚) away from north and displays variations in the ***direction of dip***. The map contains no information regarding the dip magnitude of a structure (e.g. total amount of displacement on a fault). Typically used to delineate large-scale structural trends within sedimentary basins.

Direction of max dip

Dip and azimuth attributes

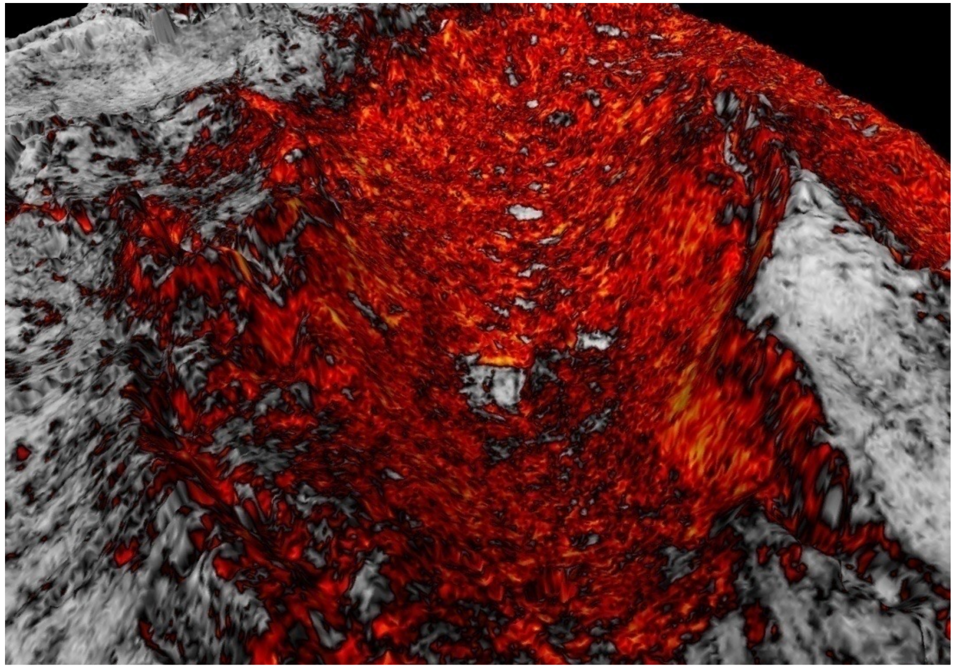
detecting faults using dips. Dips will have high gradient / dip

Images are not of the same faults



- **A** - Seismic section from the North Sea Basin illustrating the presence of small faults. Note the mapped reflection event marked X (in green)
- **B** - Dip map of reflection event X illustrates the polygonal pattern of the fault array
- **C** - Azimuth map of reflection event X illustrating the polygonal pattern of the fault array in addition to the variable dip direction of individual faults

Volume-based attribute analysis



Volume-based seismic attributes

- Volume-based attributes are derived directly from the seismic reflectivity volume

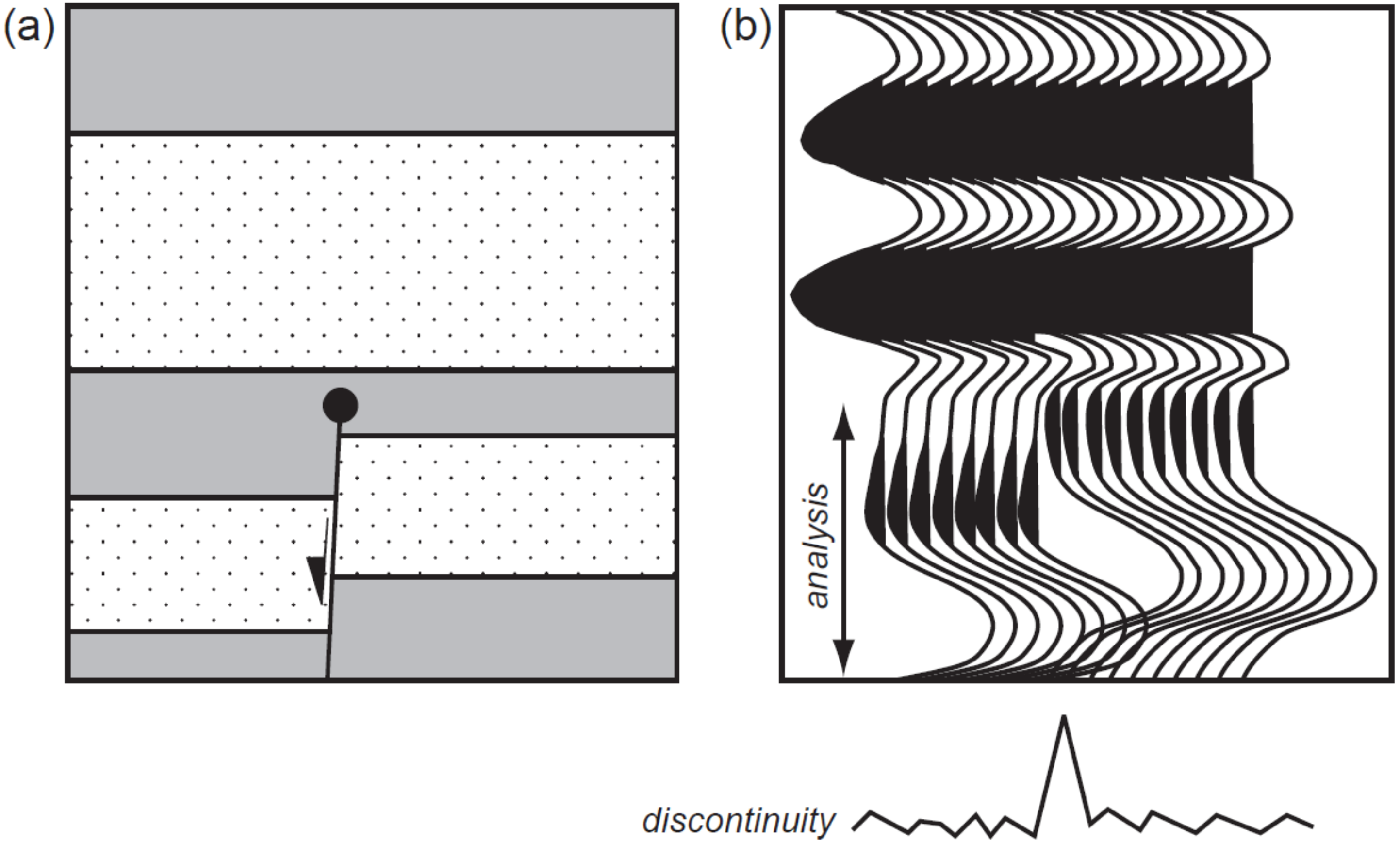
- Volume-based attributes can be affected by noise in the initial input volume; caution should be exercised when interpreting geological features...

- A key part of the seismic interpreter's toolkit, they are applicable in a wide variety of structural and stratigraphic settings and across a range of scales

- Two types of volume-based attributes are defined; (i) geometric; and (ii) amplitude

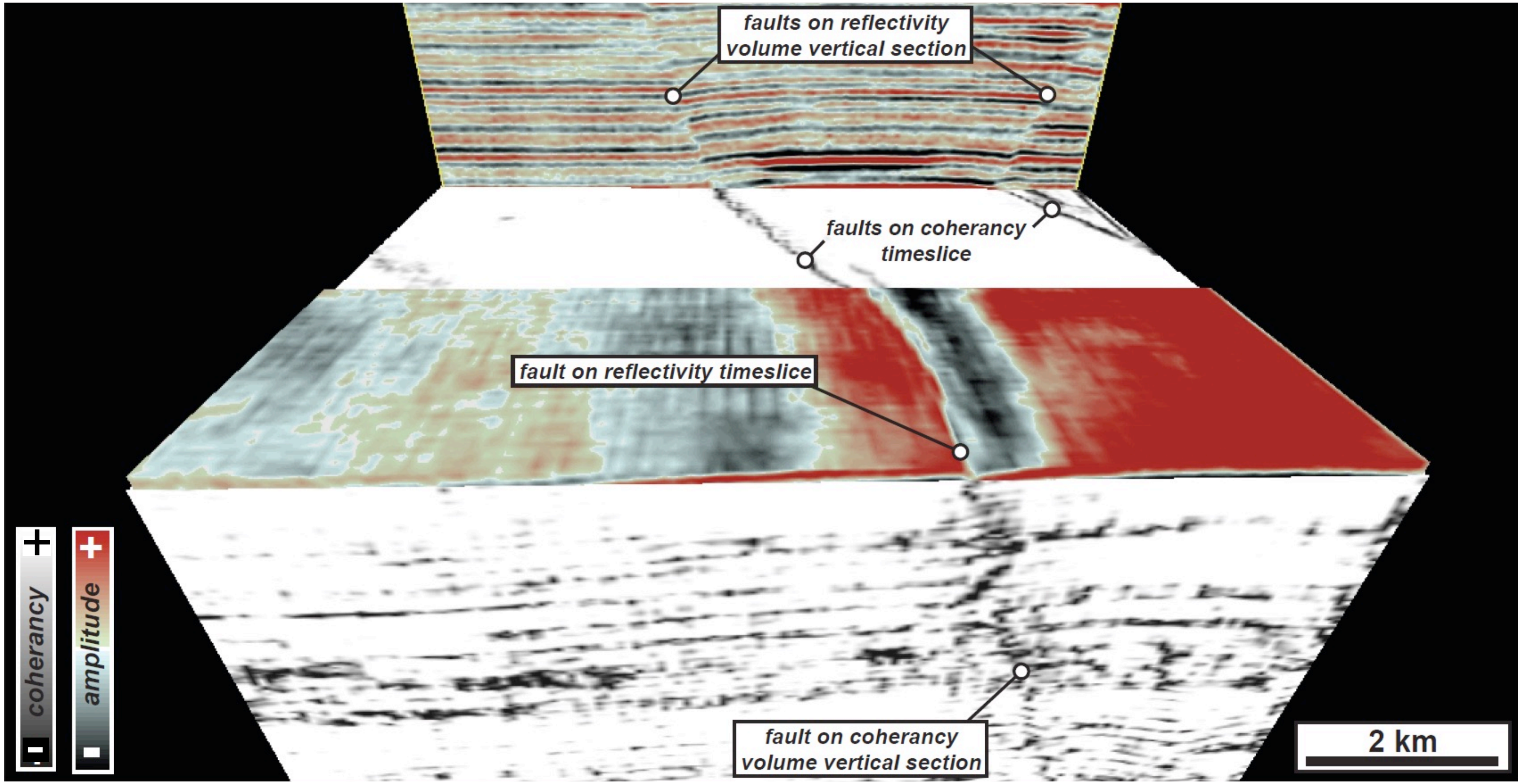
- **Hundreds of volume-based seismic attributes exist… you may be able to design your own (basically, any calculation you do on the seismic data reveals a seismic attribute, which may or may not be useful for resolving environmental/geological features)**

Geometric attributes- Coherency/discontinuity/semblance



- Coherency, discontinuity, variance and semblance-type volumes is one of the most commonly-used volume-based geometric attributes used by seismic interpreters
- (a) illustrates a simple geological cross-section characterised by a normal-faulted sand (stippled)-shale (grey) sequence; (b) is a schematic sketch of how the coherence attribute ‘sees’ these lithological variations and the fault
- Note the discontinuity ‘spike’ (or decrease in coherence) at the location of the normal fault due to an abrupt change in the spatial seismic character of reflection events

Coherency/discontinuity/semblance



- Combination of vertical and timeslice displays from a standard reflectivity volume and a coherence cube illustrating the application of coherency to imaging normal faults
- Note the clear expression of the normal faults on the vertical reflectivity slice and the coherency timeslice. The left-hand fault is more poorly-imaged on the reflectivity timeslice and the vertical coherency slice. Better imaging on timeslices rather than vertical slices is typical for coherency-type volumes

Coherency/discontinuity/semblance

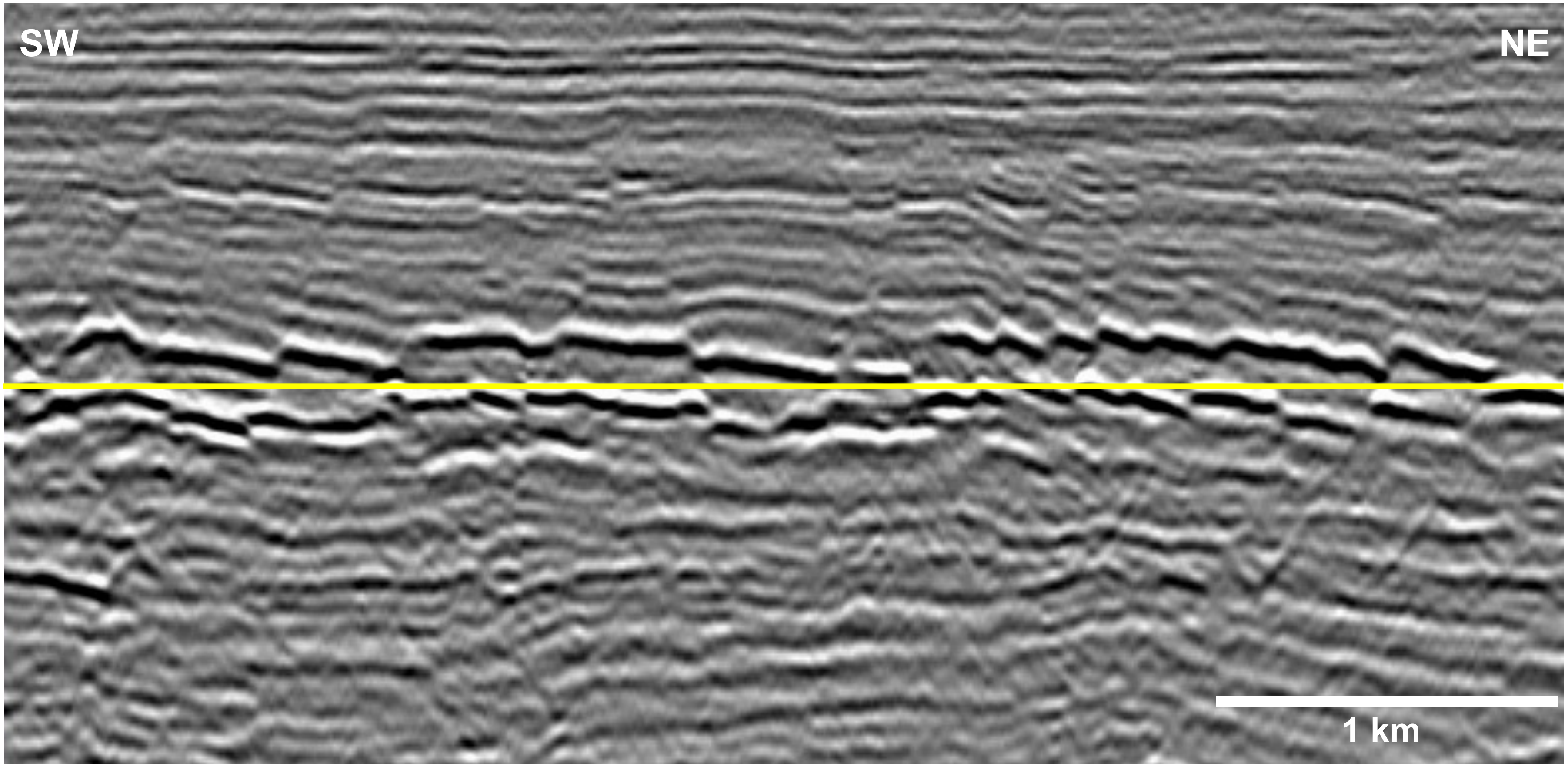
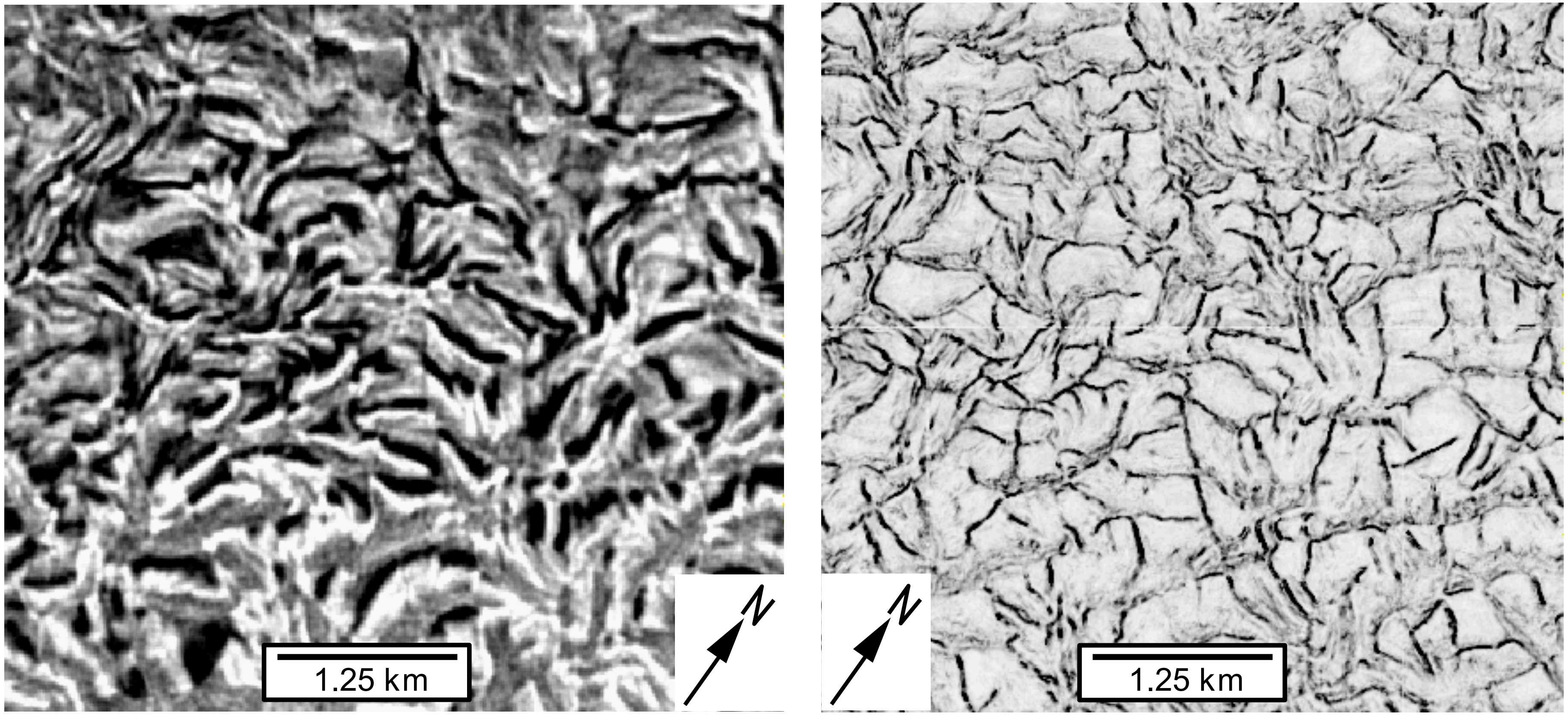


Image courtesy of Lidia Lonergan

- Seismic section from the northern North Sea
- Note the development of a series of low-displacement faults
- A timeslice (yellow line) is extracted from both the reflectivity volume and corresponding coherency volume (see next slide)

Coherency/discontinuity/semblance



Images courtesy of Lidia Lonergan

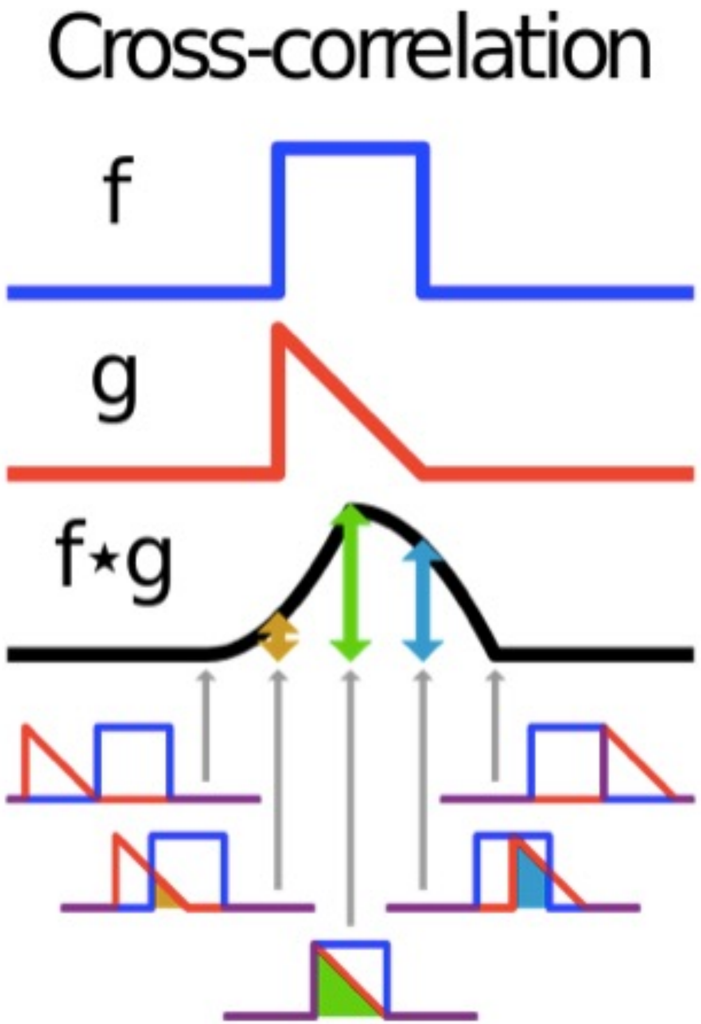
- **Above-left** – Timeslice through reflectivity volume. Faults are poorly-imaged due to structural 'interference' with shallowly-dipping reflection events (see previous slide)
- **Above-right** – Timeslice at the same structural level through a coherency volume. The faults are very clearly-imaged

• Discontinuity algorithms

Take a look at the following tutorial on Github from Joe Kington. There is a nice introduction to the use of discontinuity attributes and calculating them yourself

- We are focusing here on attributes that compare the local similarity/variance of traces. In image processing these would be considered like a type of “3D edge filter”
- The attributes are referred to as ‘semblance’, ’coherence’, ‘similarity’, ‘discontinuity’, ‘chaos’ and many other terms. We are using the term “discontinuity” for this whole family of terms
- Most discontinuity attribute algorithms are trade-secrets within seismic interpretation packages- and the vast majority of interpreters just use them as a ”black-box”
- The earliest discontinuity algorithm uses the **maximum cross correlation value of traces**. The entirety of each trace is correlated within a moving-window subset of two neighboring traces.

You will explore discontinuity attributes in Ex 4



http://www.ceri.memphis.edu/people/egdaub/datanotes/_build/html/sac5.html

Amplitude-based attributes derived from grids and volumes

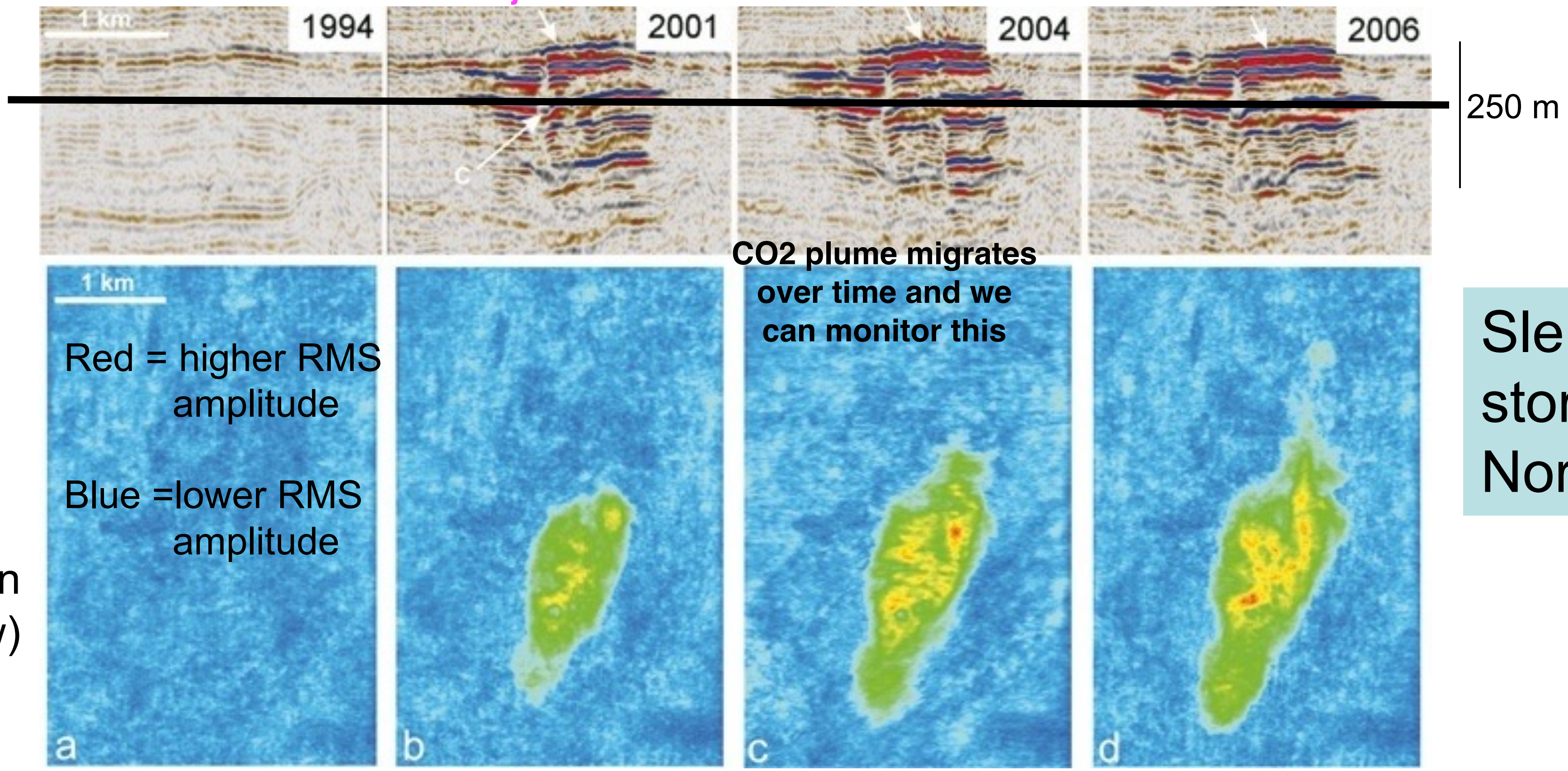
- Amplitude algorithm extraction methods aim to delineate map-view distributions of amplitude anomalies (ie areas where the wiggles of the seismic trace have abnormally high or low amplitude)

- There are an almost indefinable number of amplitude extraction algorithms.... (maximum positive or negative amplitude, reflection intensity, total energy, average amplitude etc etc...)

- We can extract amplitude along or in a window around a mapped horizon or along a time/depth slice or within a time/depth volume

4D seismic and RMS amplitude

CO2 injected ~ 2000



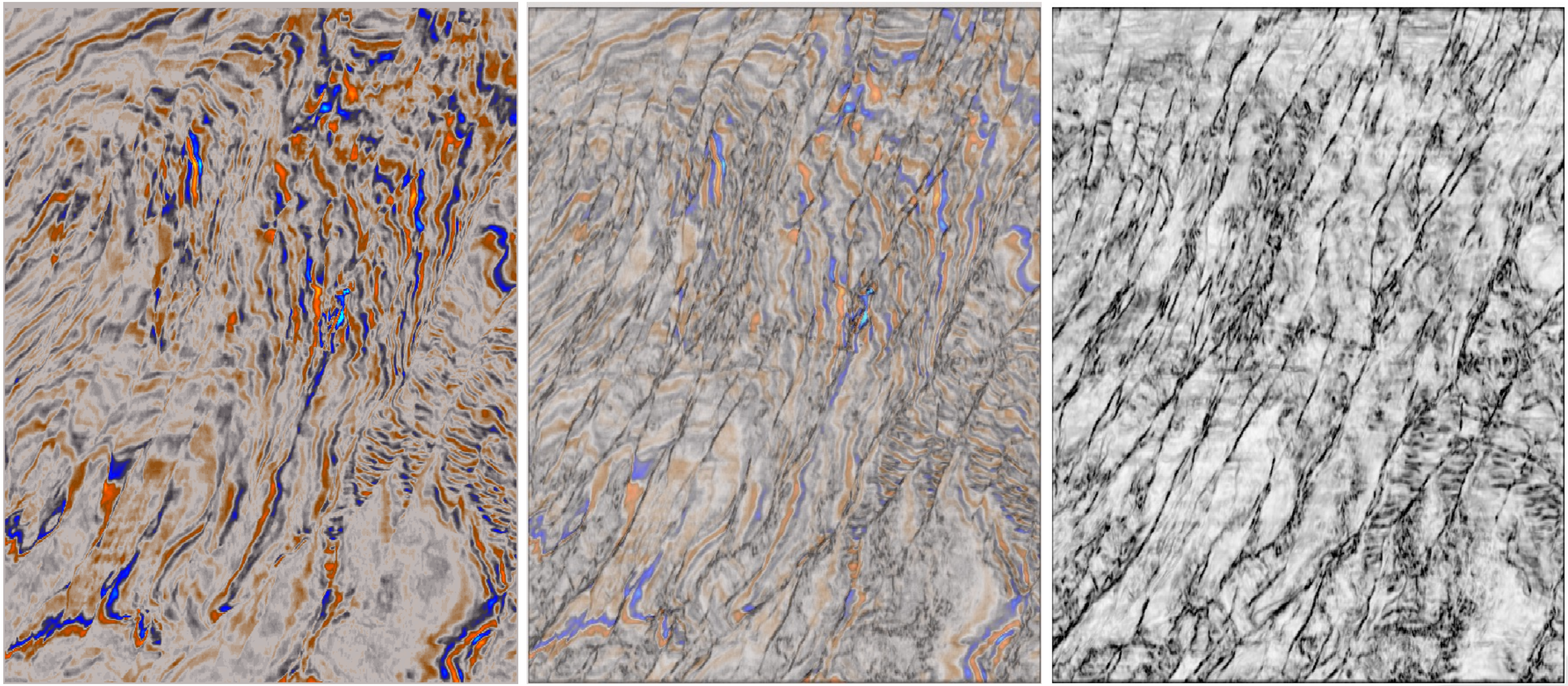
RMS amplitude (calculated over a window 125 m above the horizon and 125 m below)

Sleipner CO_2 storage site, North Sea

http://www.bgs.ac.uk/science/CO2/home.html

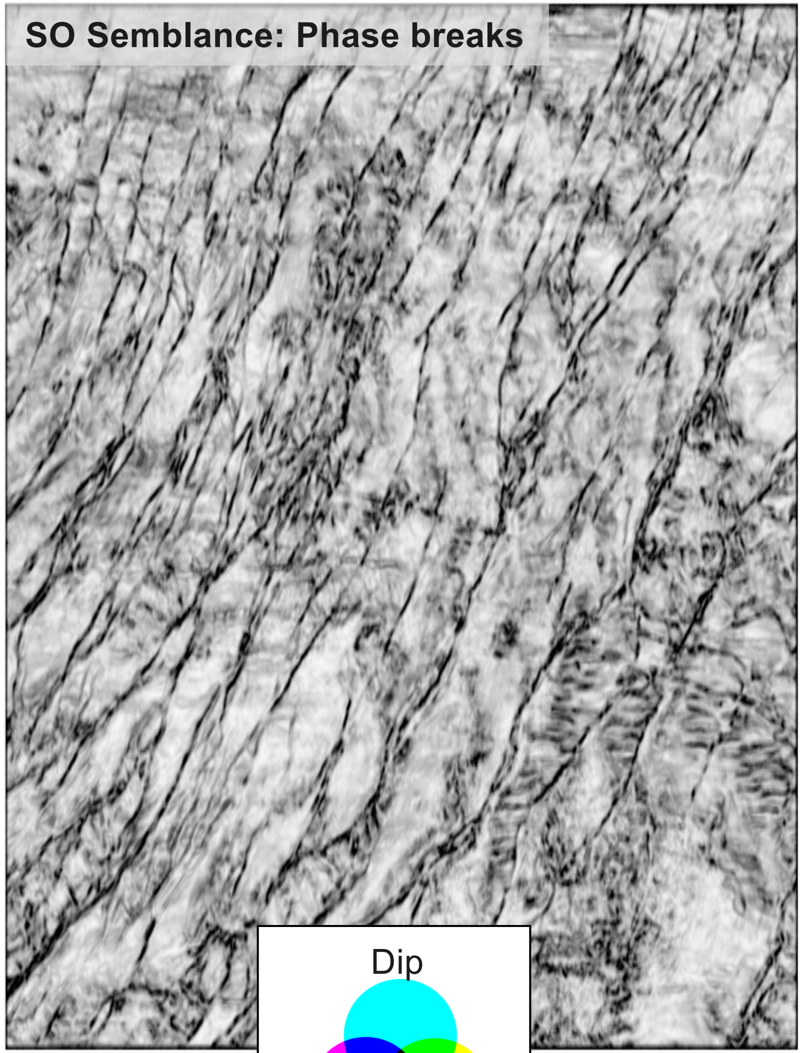
- 3D seismic data acquired at different times over the same area (time-lapse)
- Require exactly the same source, receiver and survey configuration
- Used to asses monitor CO2 storage
- http://www.bgs.ac.uk/science/CO2/home.html

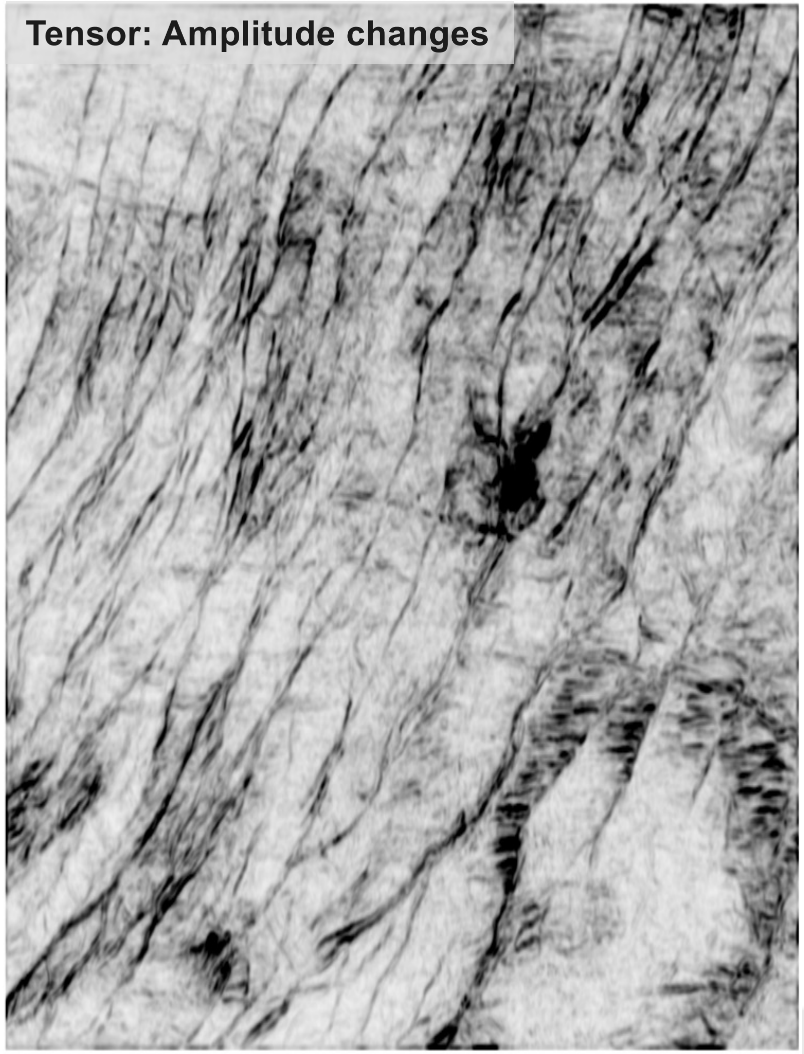
Multi-attribute analysis- superposition

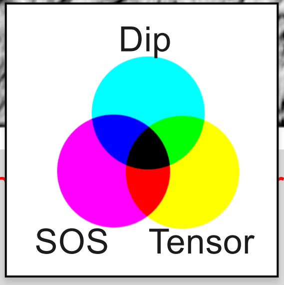


Reveals the relationship between two images.

Several shades of grey



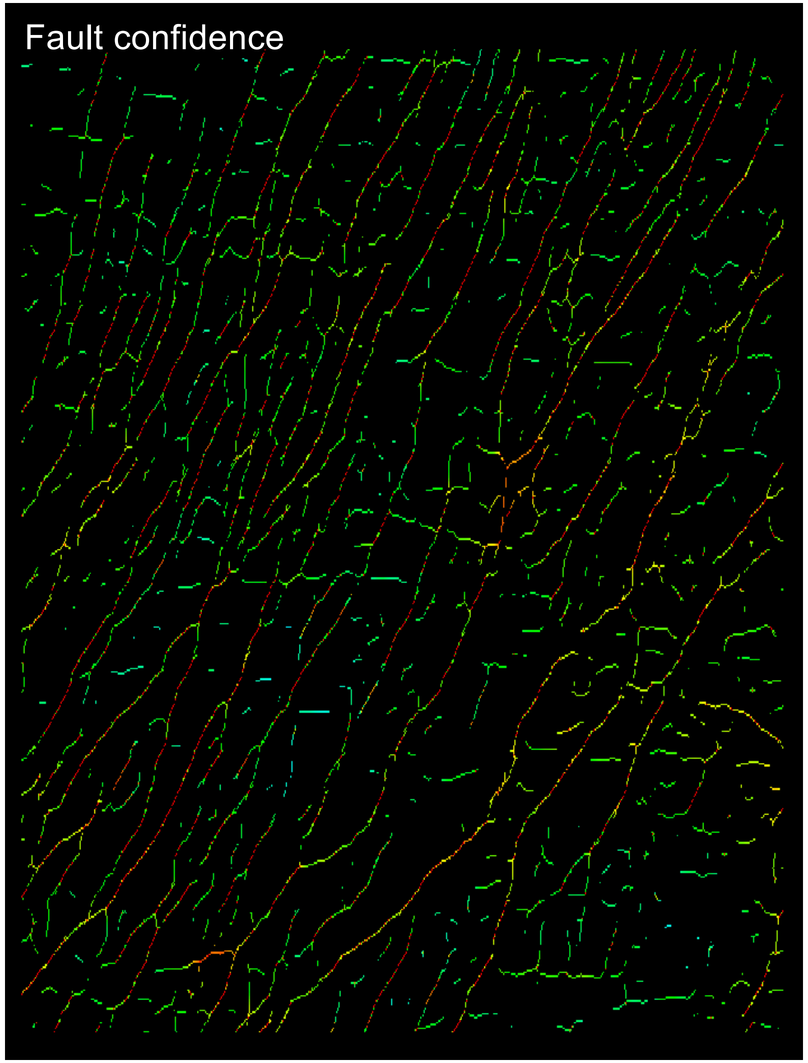


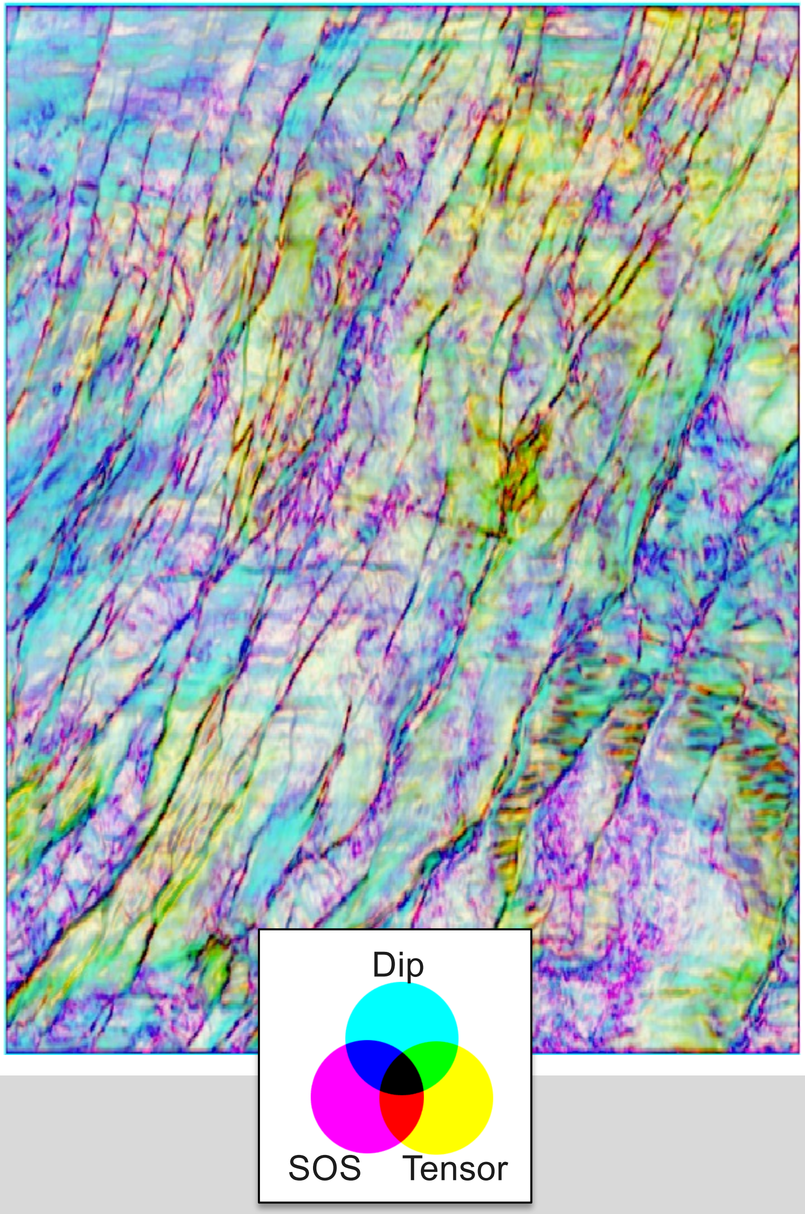


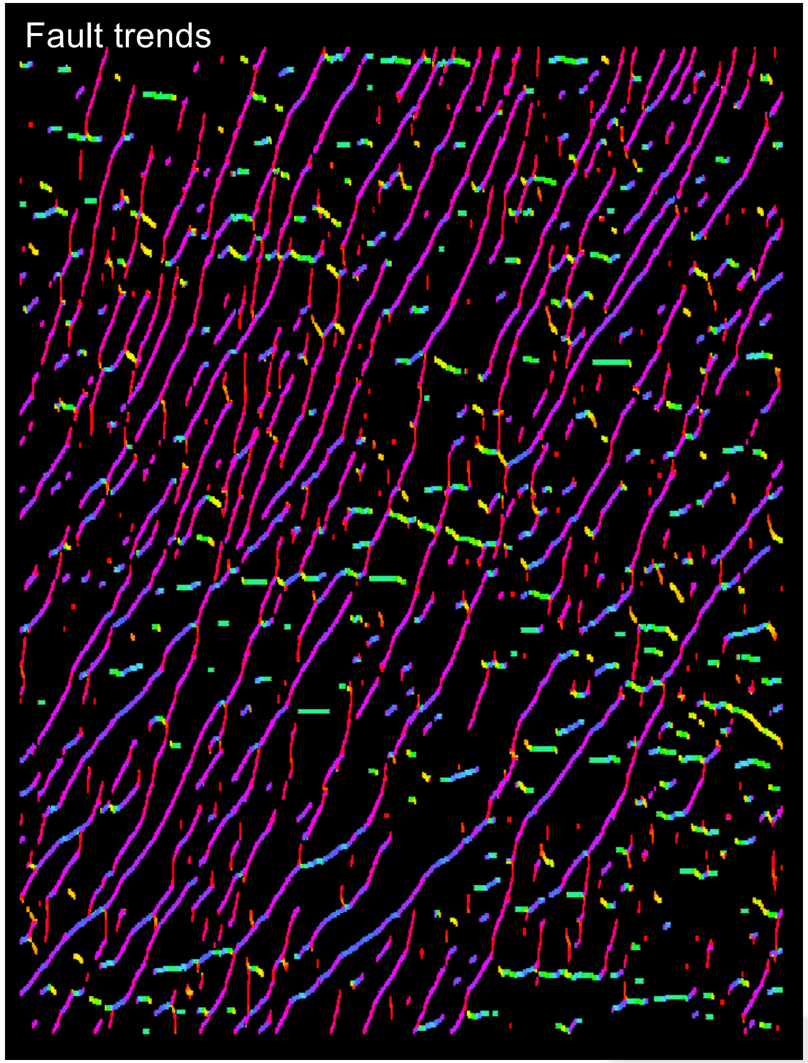
feature imaged by all 3 attributes will show as black in colour blending

Faults h ressions.

Colour blending







A question for you…

Go to **www.menti.com** and use the code **5445 8699**

In your view, how might data science and ML contribute to seismic interpretation?

Mentimeter

Key points

- Understand the importance of post-stack seismic attributes (both grid-based and volume-based)

- After Ex 4 appreciate how some basic post-stack attributes can be calculated using real data

- Begin to think about the potential role of data science and machine learning in revolutionizing the field of seismic data interpretation

Introduction to Exercise 3 and 4

- In Exercise 3 and 4 you will load two/three different SEGY volumes, visualize them and have a look at the geological features and compute some simple post-stack attributes to reveal geological features even further

- In the EDSML group project you can expect to load a new SEGY file and conduct similar analysis, so make sure you are happy with all steps of Ex 3 and 4

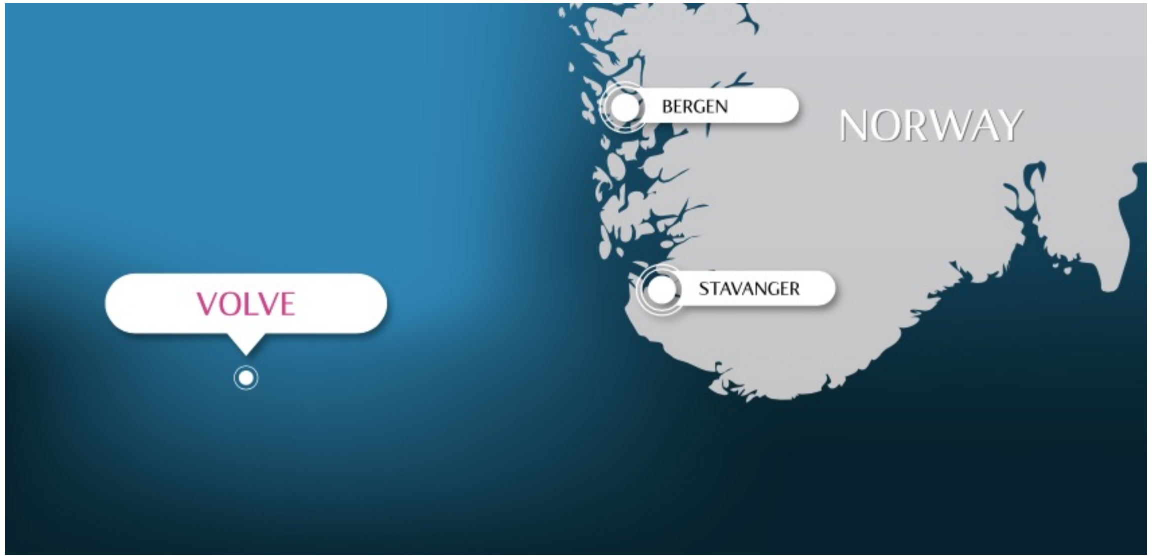
Data volume 1- Exercise 3/4

- TNW 3D Ultra-high resolution seismic (UHRS) (TNW_small2.segy)
- **Sparker** source **depth** dataset collected to develop a ground model for an offshore wind development at Ten noorden van de Waddeneilanden, north coast Netherlands
- Netherlands Enterprise Agency (RVO) have released the data and geophysical reports
- SAND Geophysics now developing a ground model from the data
- We will look at just a subset of the data containing modern channels and evidence of past glaciations

TNW 3D UHRS geophysical report

Data volume 2 – Exercise 3 Bonus

- Volve dataset (ST0202.segy)
- **Airgun** array source **time** dataset 200 km west of Stavanger, Norway
- Equinor have released the full-dataset (40,000 files) for the 2016 decommissioned Volve oil field. Dataset includes seismic, wells, interpreted horizons and faults etc and is a great dataset for data scientists to explore
- Old oil fields like this are now being re-considered as sites of CO_2 storage- see for example the CO2 storage atlas from the Barents Sea



This dataset is not a perfect rectangle… therefore when you load it you need to add some padding to make it a complete rectangle. It is useful to know how to do this when you download your own data sets

Data volume 3 – Exercise 4

- Thebe 3D seismic (Thebe_rift_faults.segy)
- **Airgun** array source **time** dataset
- Gas field located in Exmouth Plateau of NW Shelf Australia. Data open source from Geoscience Australia
- Spectacular crustal-scale imaging of fault systems makes this an important dataset for research into faults and earthquakes hazards eg. [Pan, Bell et al. 2021]()
- The dataset shows older Jurassic rifts and younger ’polygonal’ faults. We are going to look at the Jurassic faults