4-D Sequential Restoration and Its Applications*

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Abstract

Restoration is defined as the operation that moves presently deformed rock units to their pre deformation position. 2D restoration of cross sections is common practice since many years. 3D restoration on volumes becomes now available, as 3D modelling capabilities of modern software increase (Dulac et al., 2011). 4D restoration aims at creating the full suite of restored 3D volumes of rock describing the evolution through geological times of a 3D faulted and folded structure, typically at basin or prospect scale.

The paper will start describing how 4D restoration is performed. 4D restoration extends the well-known backstripping method (Sclater & Christie, 1980) and is a sequence of 3D restoration steps. In backstripping, the only vertical movements are allowed. In 4D restoration, lateral movements in any direction are possible, because faults are taken into account. Layers move along faults through time, as fault throws are cancelled. The orientation of lateral movement might change through time, because of the structural complexity of fault patterns. As in backstripping, 4D restoration successively removes each stratigraphic unit in reverse order.

The possible applications of 4D restoration will then be described.

1. To quality control the present day interpretation of seismic picks (eg. a normal fault at present day should not be transformed into a reverse fault in the past in a pure extensional regime).

2. To provide inputs to petroleum system modelling, including maturity, pressure or migration modeling.
3. To provide inputs to sedimentary depositional modeling.
4. To compute the evolution of fault throw and fault related property through time.
5. To derive the strain evolution through time.

The strain changes are stepwise computed and may be related to reservoir fracturing at prospect or reservoir scale. At basin scale, the dilatancy might be used to select optimal fractured areas in tight reservoir rocks, or to avoid those areas when seal breaching is a risk.

References

Moretti, I., F. Lepage, and M. Guiton, 2006, KINE3D: a New 3d Restoration Method Based on a Mixed Approach Linking Geometry and Geomechanics: Oil & Gas Science and Technology, v. 61/2, p. 277. DOI: 10.2516/ogst:2006021.

Sclater, J.G., and P.A.F. Christie, 1980, Continental stretching; explanation of post-Mid-Cretaceous subsidence of central North Sea basin: AAPG Bulletin, v. 64/5, p. 781-782.

Website

Dulac-Arnold, G., L. Denoyer, P. Preux, and P. Gallinari, 2011, Datum-wise classification: A sequential approach to sparsity: In European Master's Program in Computational Logic (EMCL). Web accessed 26 August 2012. http://www.emcl-study.eu/

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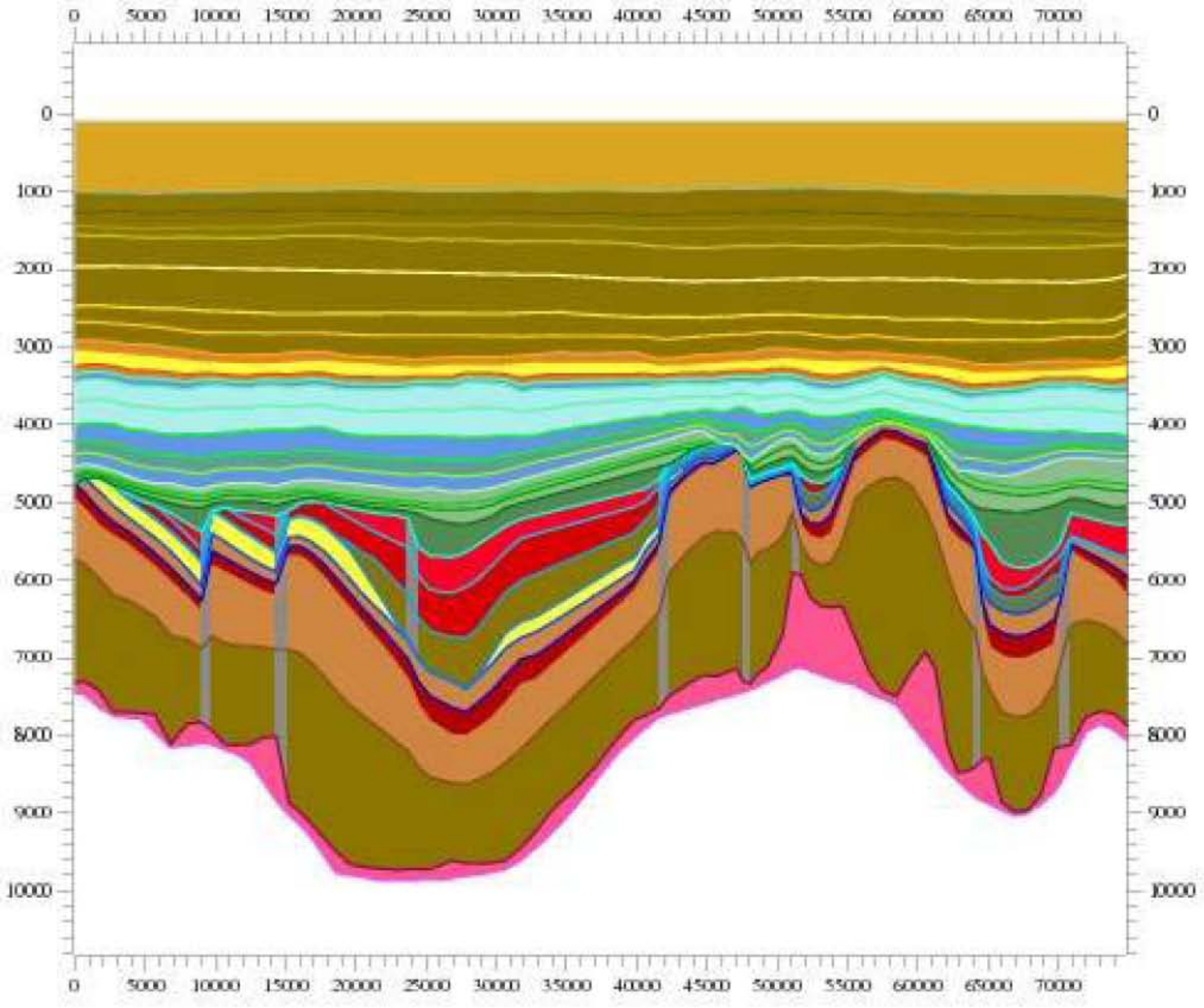
Outline

- What is 4D restoration ?
  - improved backstripping
  - successive 3D restorations through time (3D+time = 4D)
- Applications related to this session
  - quality control seismic interpretation or structural model
  - derive the strain evolution through time

Backstripping

- is the traditional way to restore basin geometry back in geological time
- assumes all deformation is along the vertical axis
- gives geometry in the past
- does not handle fault as discontinuity
- It is computed with minimum user efforts

  - example of a North Sea cross section in the Elgin/Franklin area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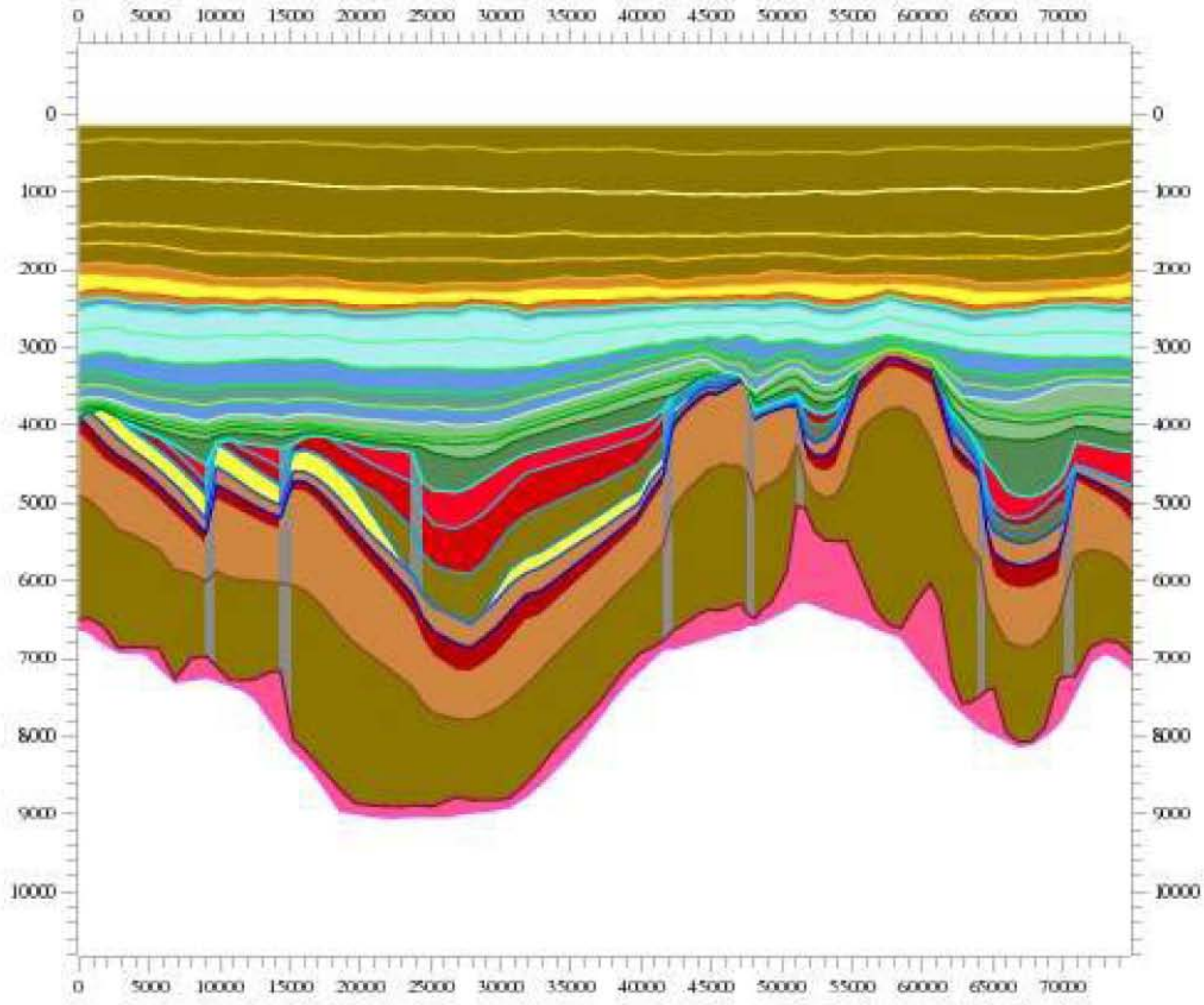
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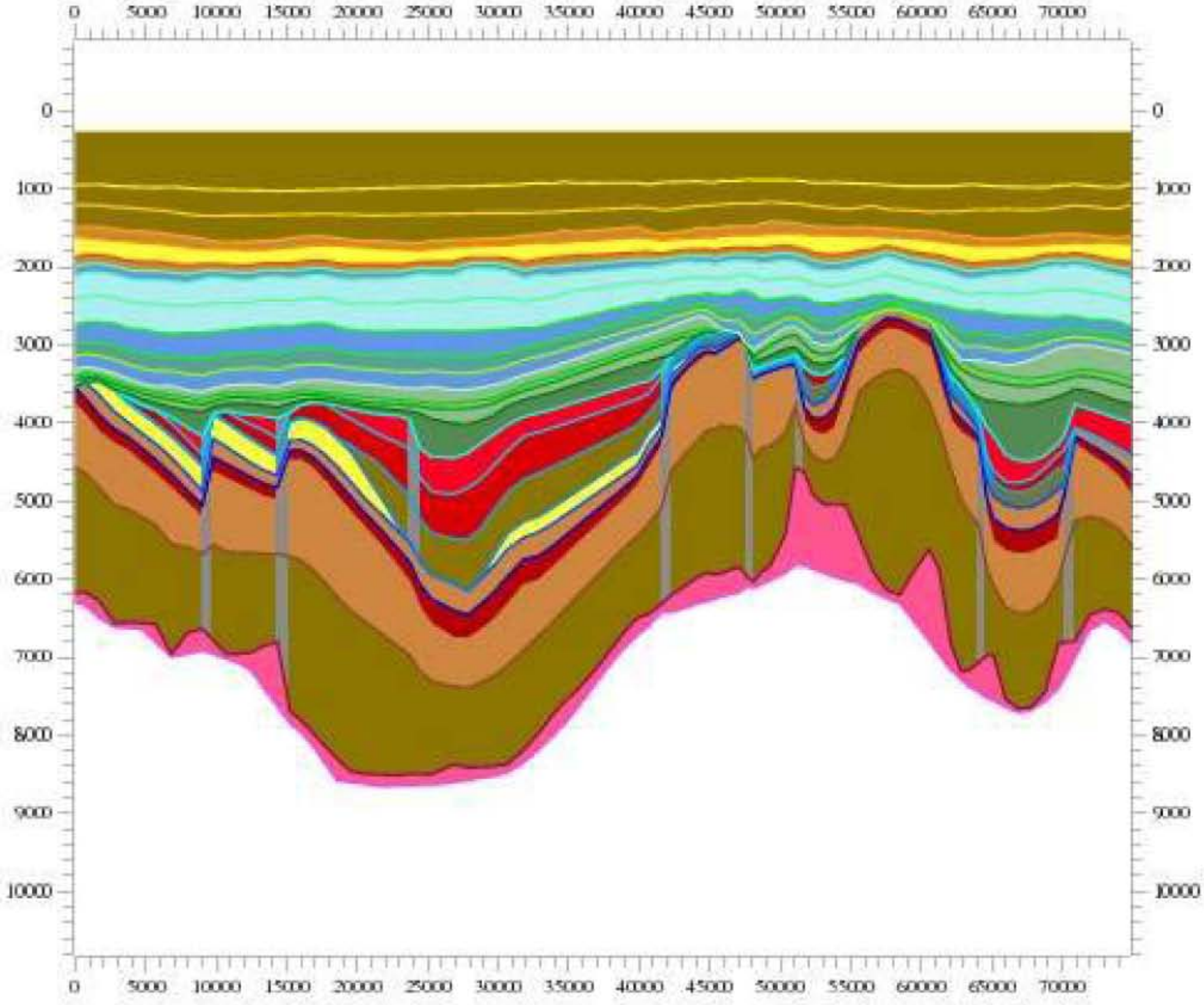
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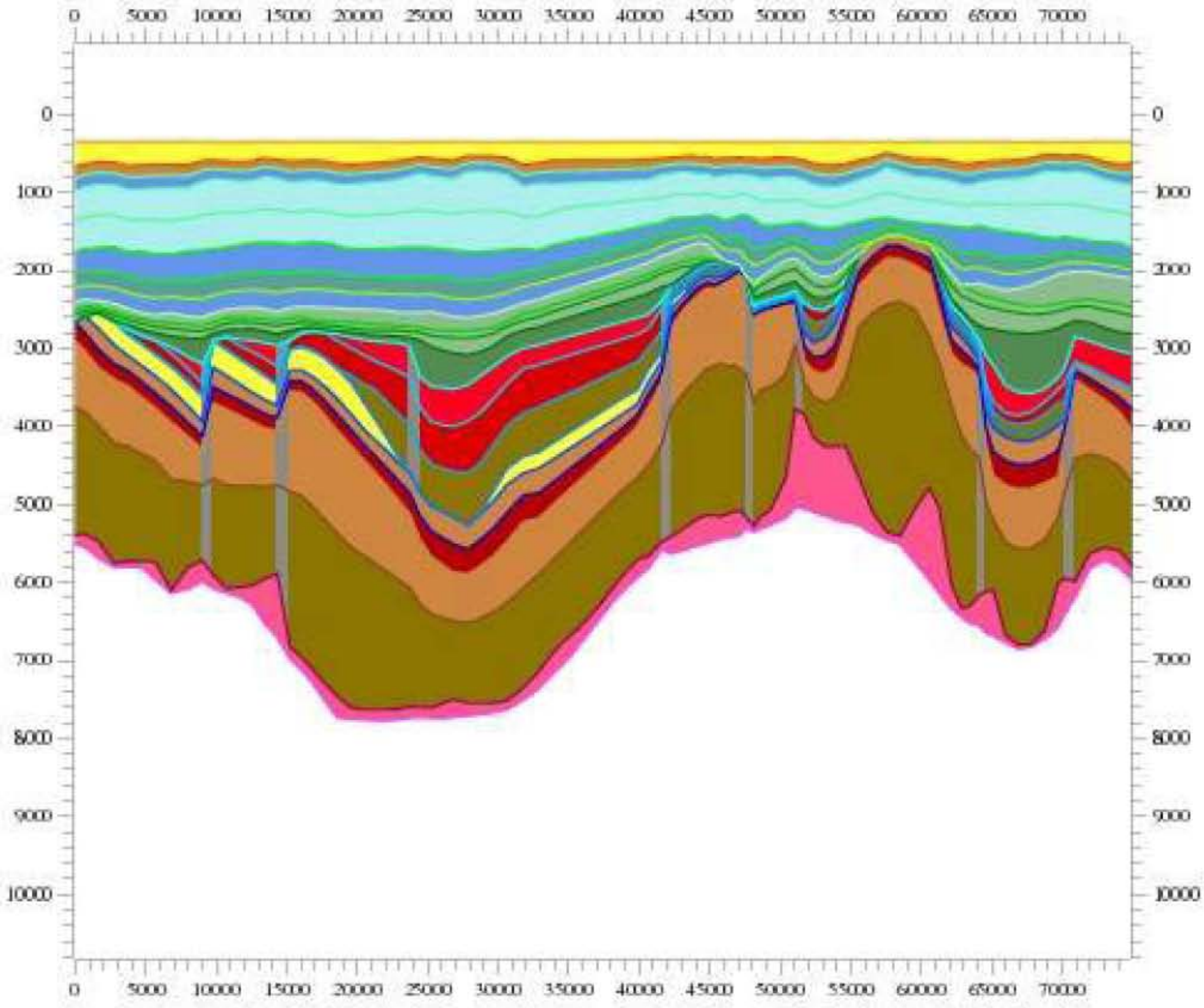
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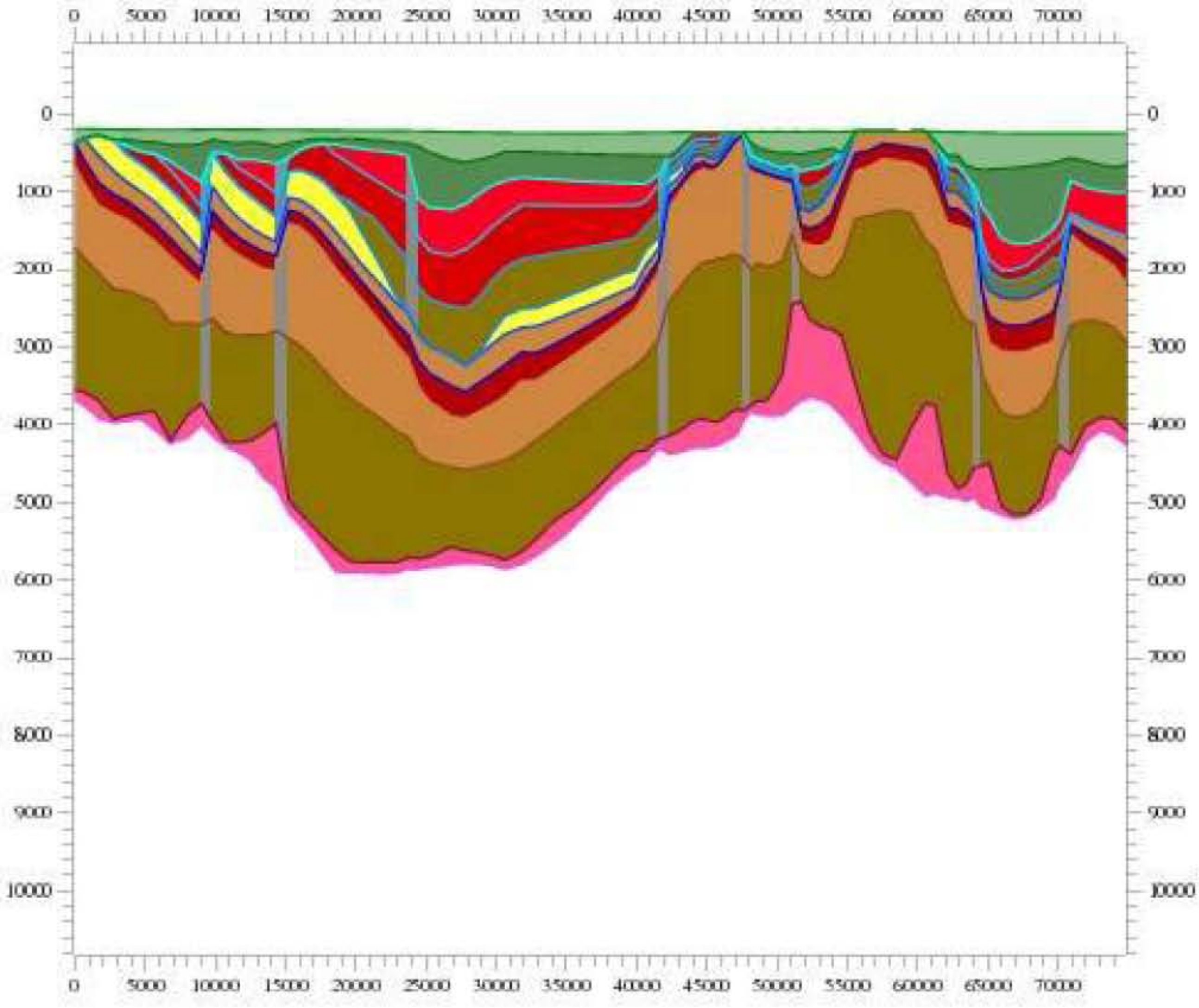
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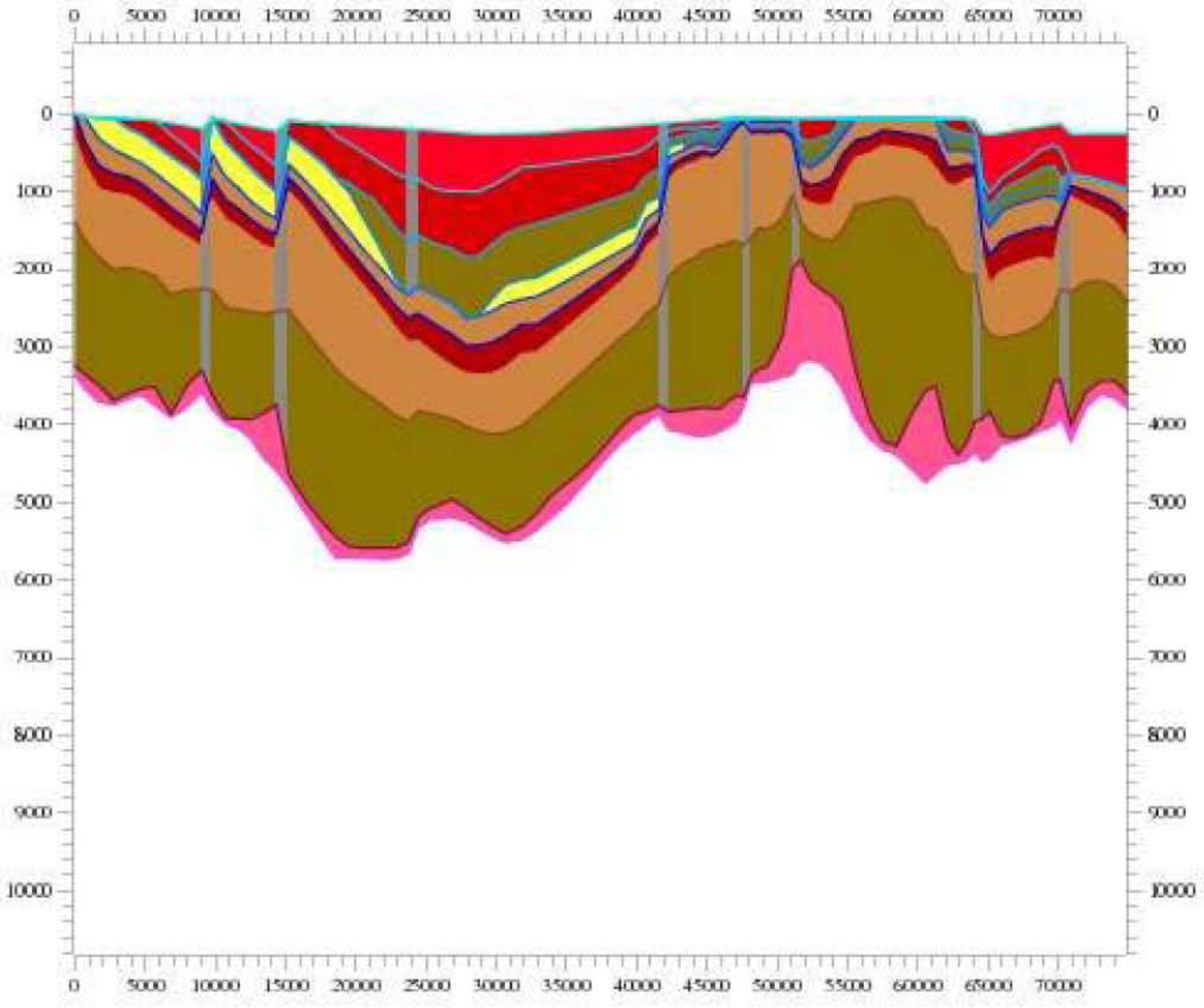
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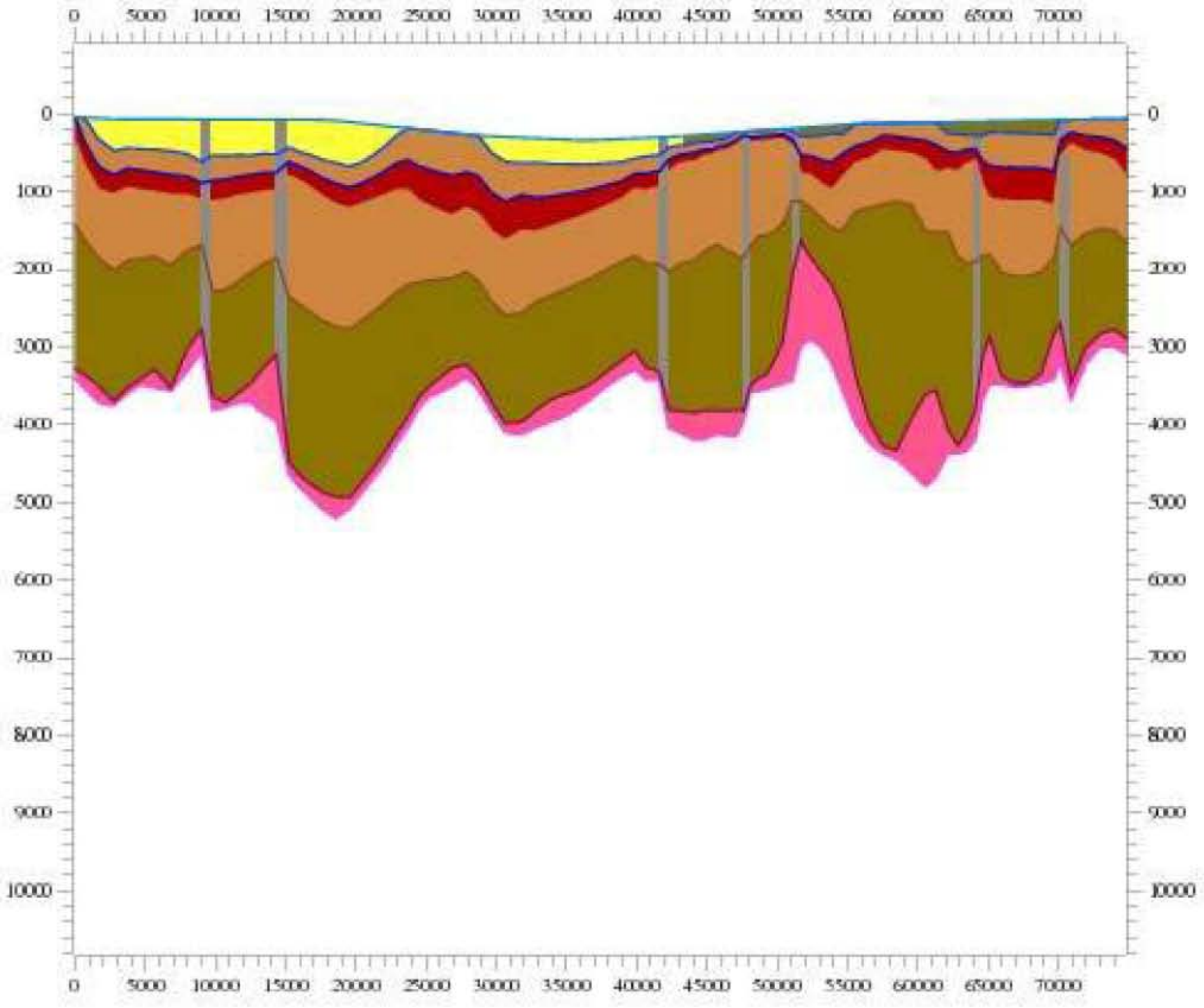
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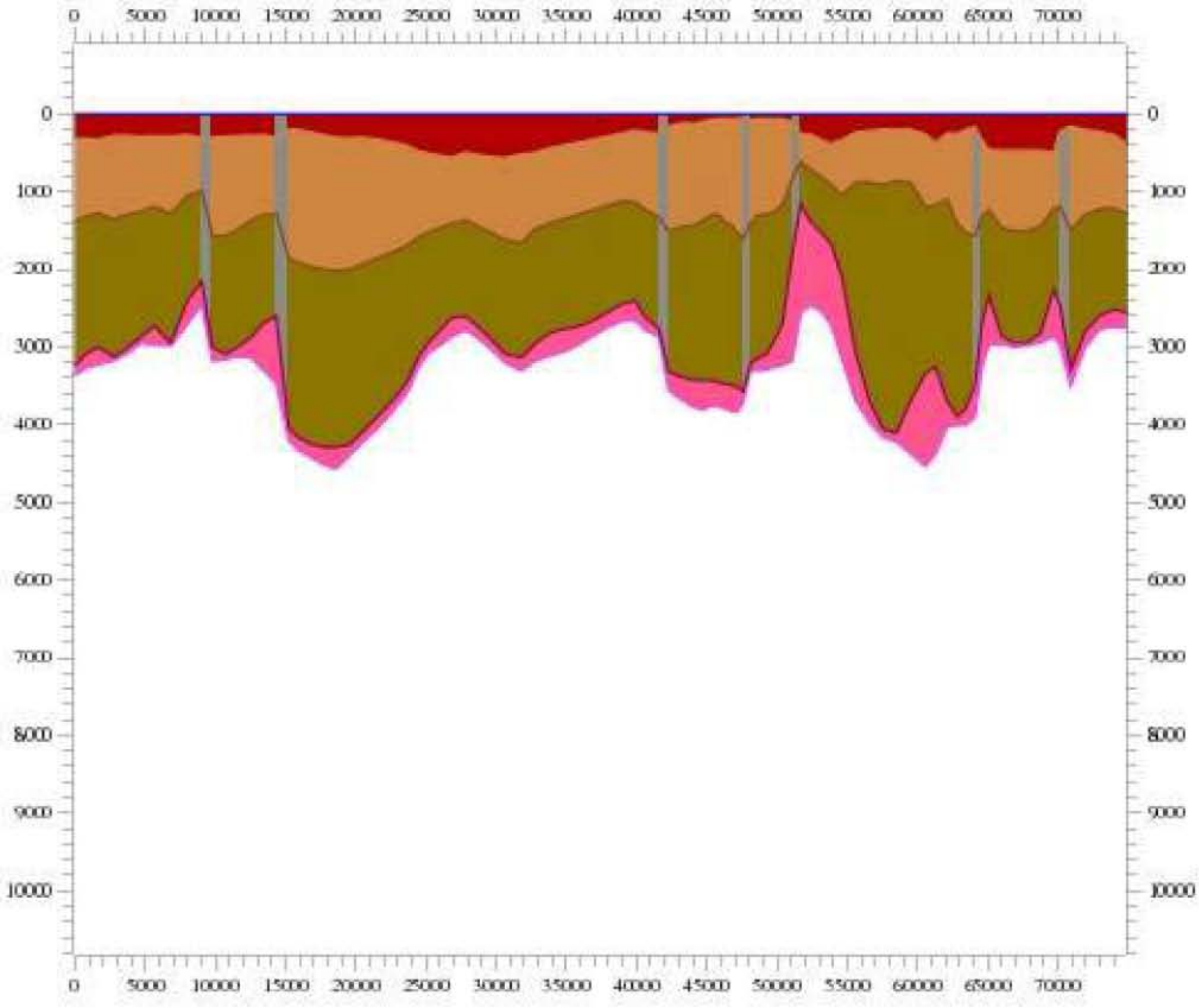
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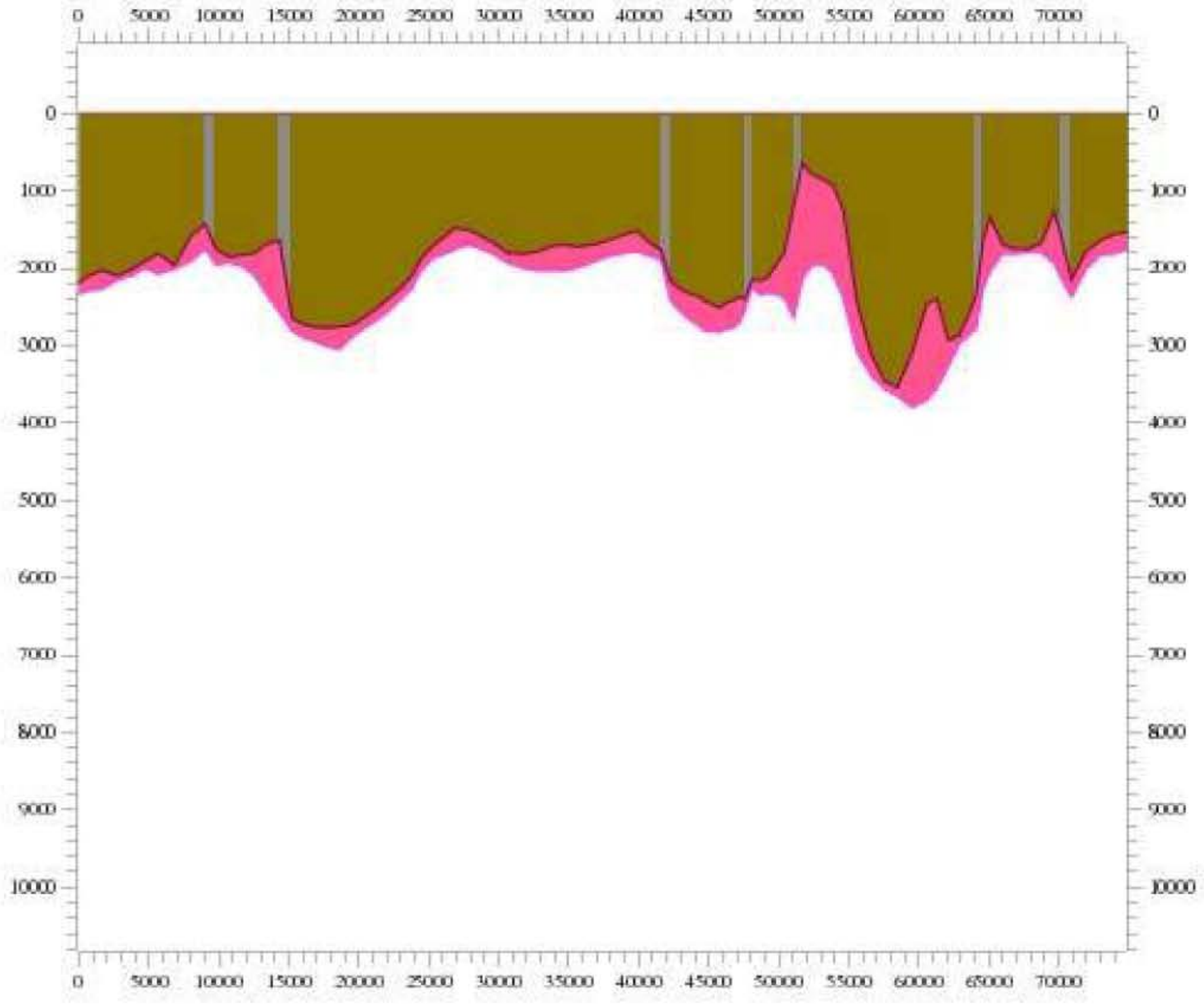
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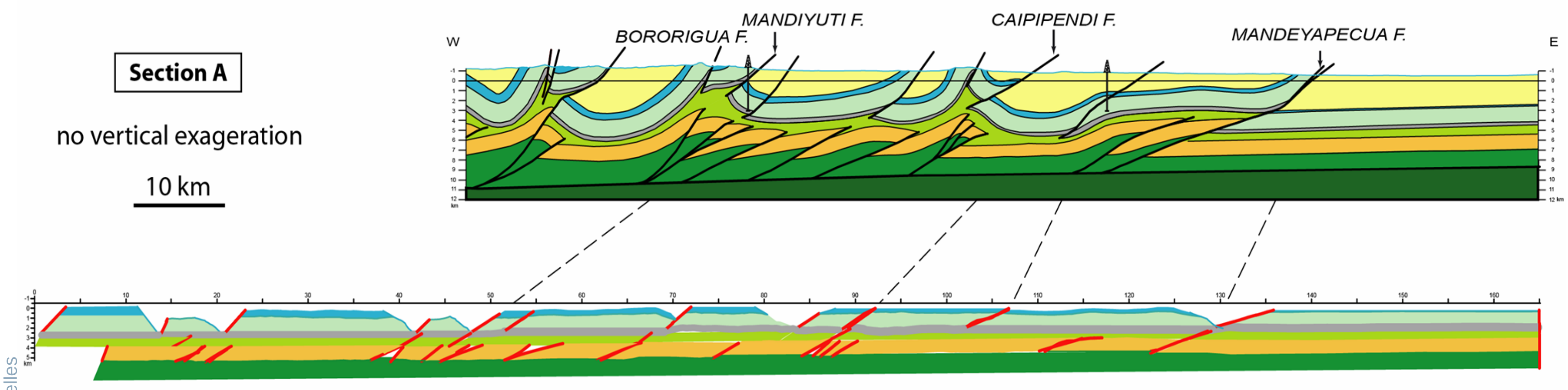
2D or 3D restoration

- handles 2D or 3D geometry of fault and horizons
- flattens one horizon and cancels the fault movement



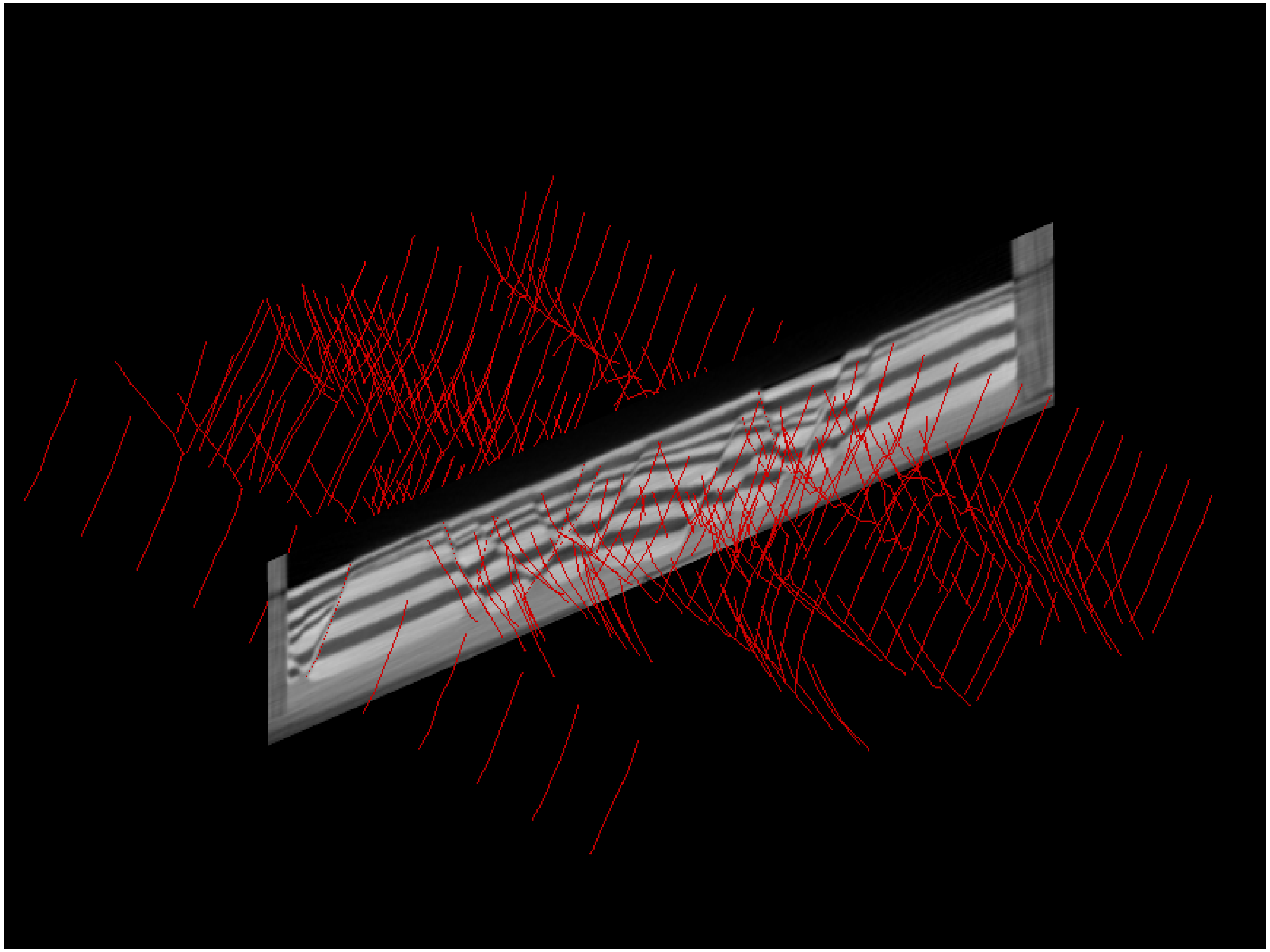
(data from Moretti et al, 2006)

4D restoration

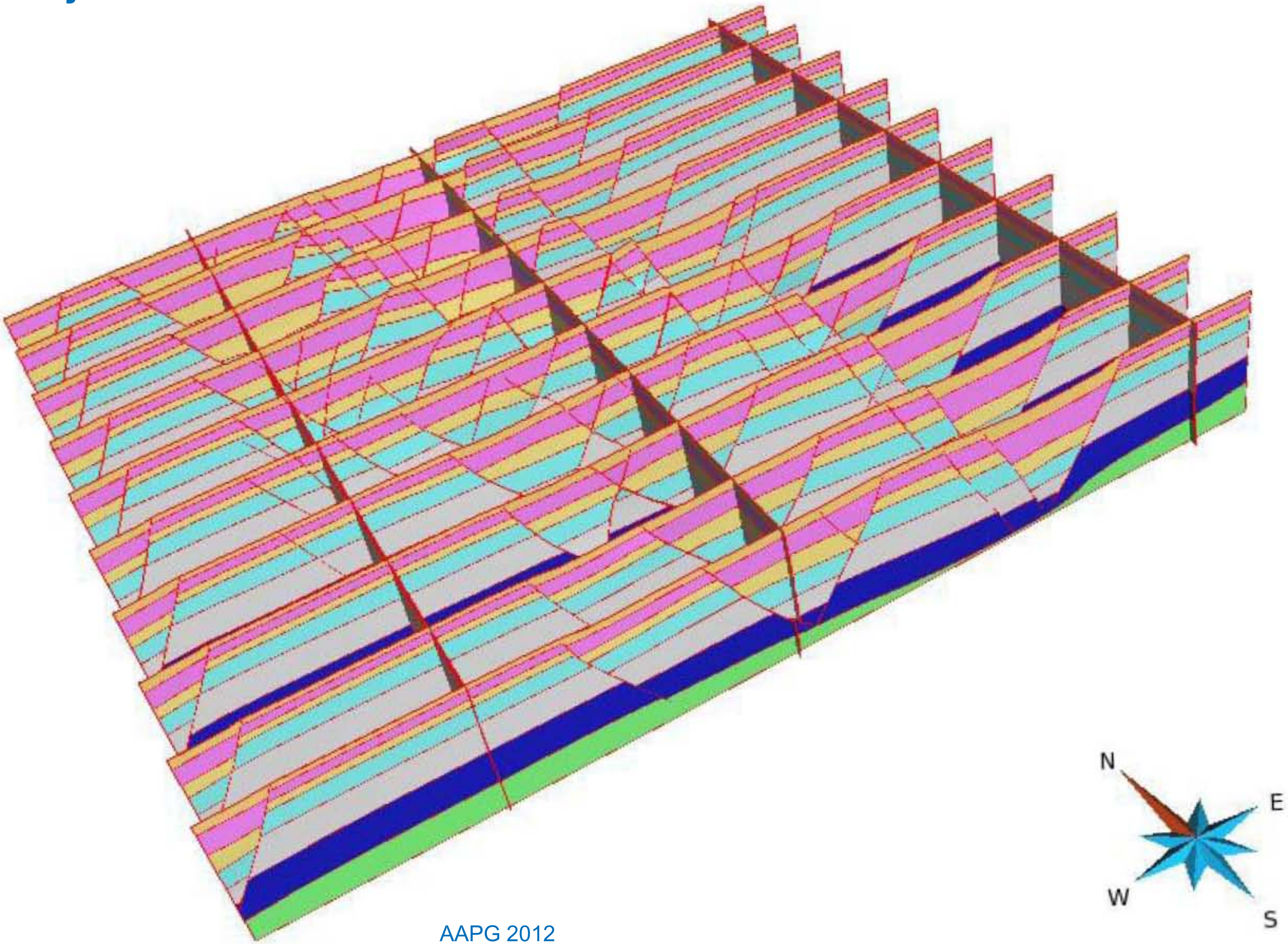
- is 3D restoration, taking into fault geometry and movements along faults
- coupled with layer removal
- results in successive images of a basin through time

- Example of a complex faulted setting
  - extensional setting
  - gliding on a mobile substratum

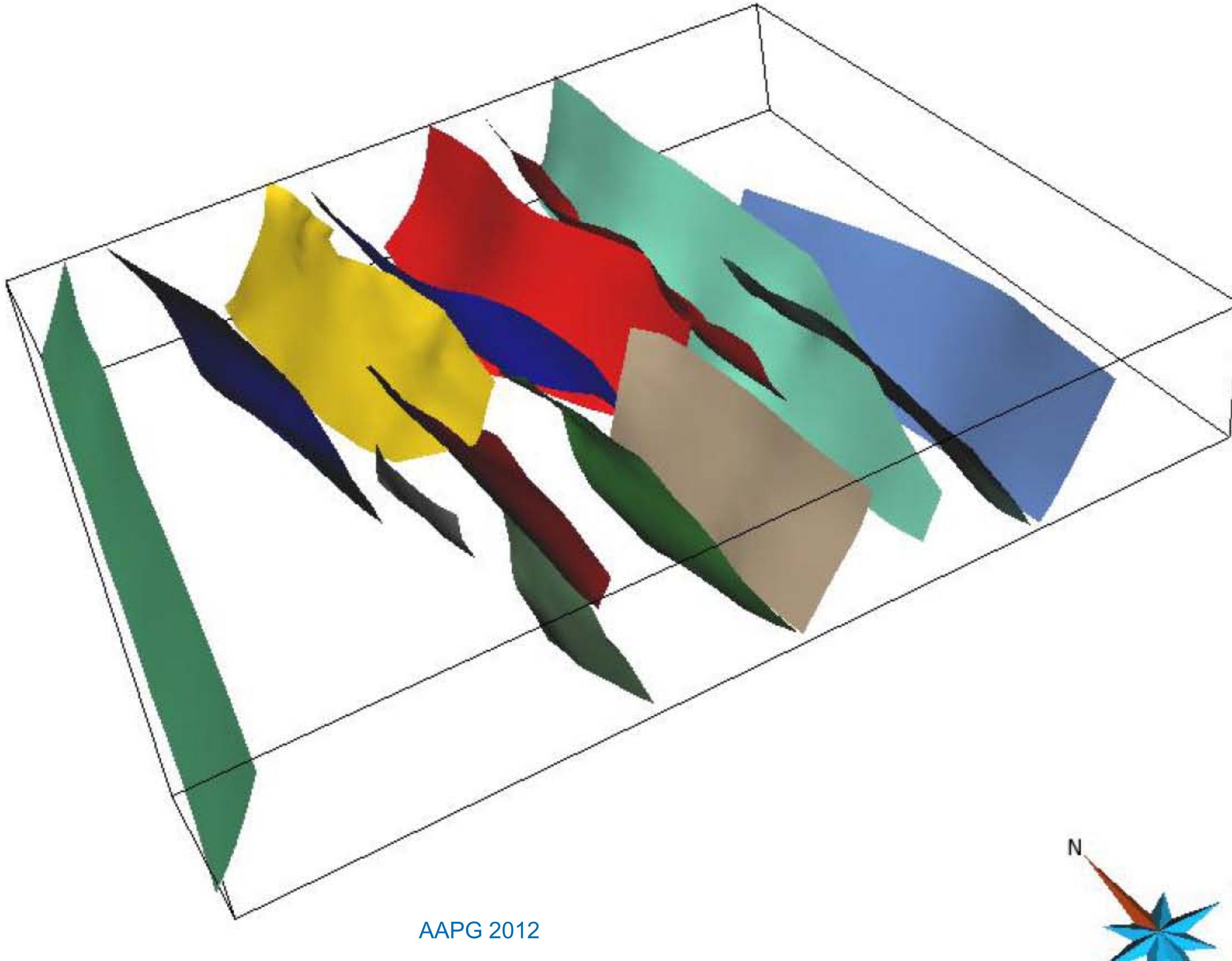
Data set from a 3D voxet of analogue sand box experiment, mimics 3D seismic



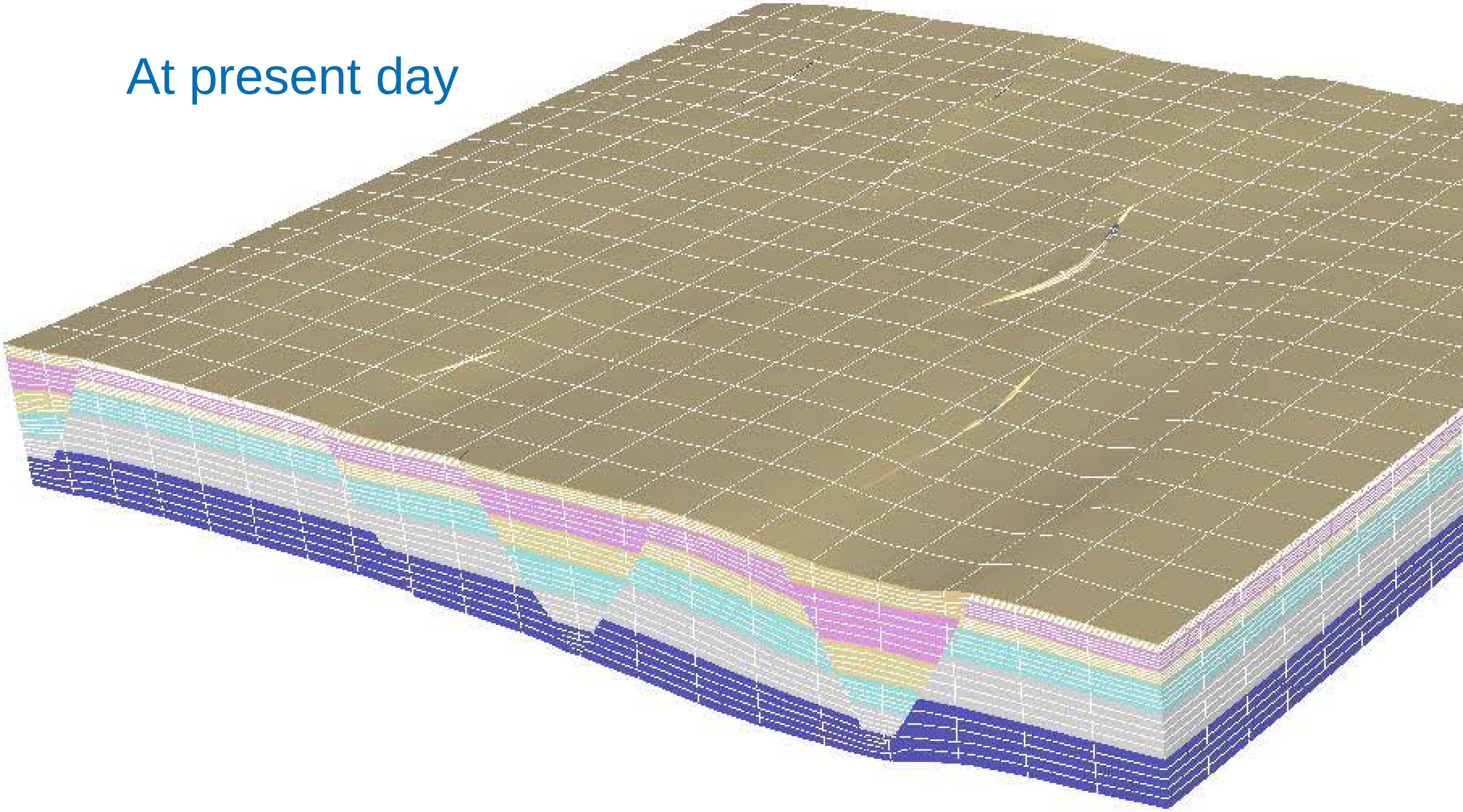
6 major horizons



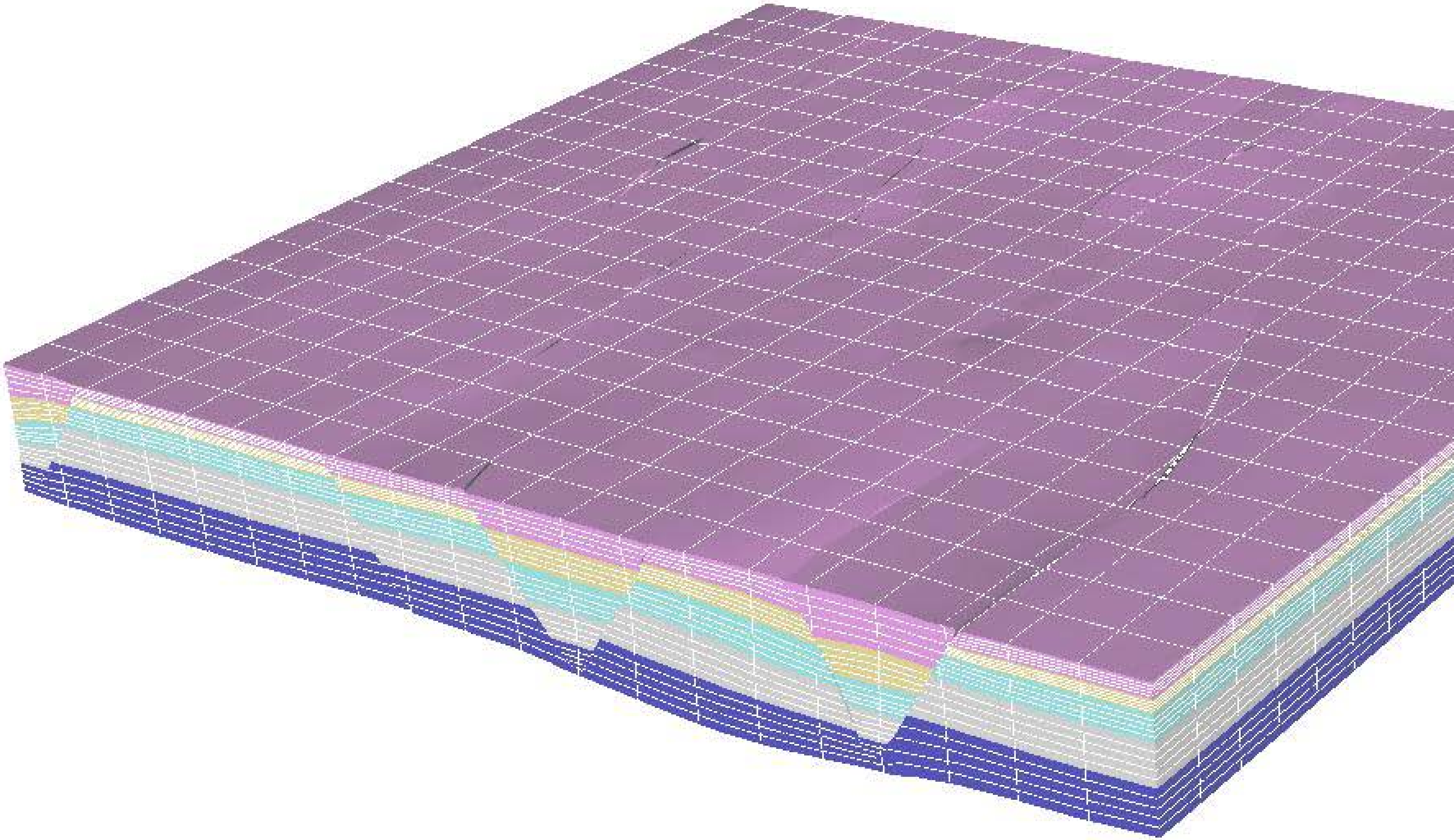
17 normal faults, with various configurations



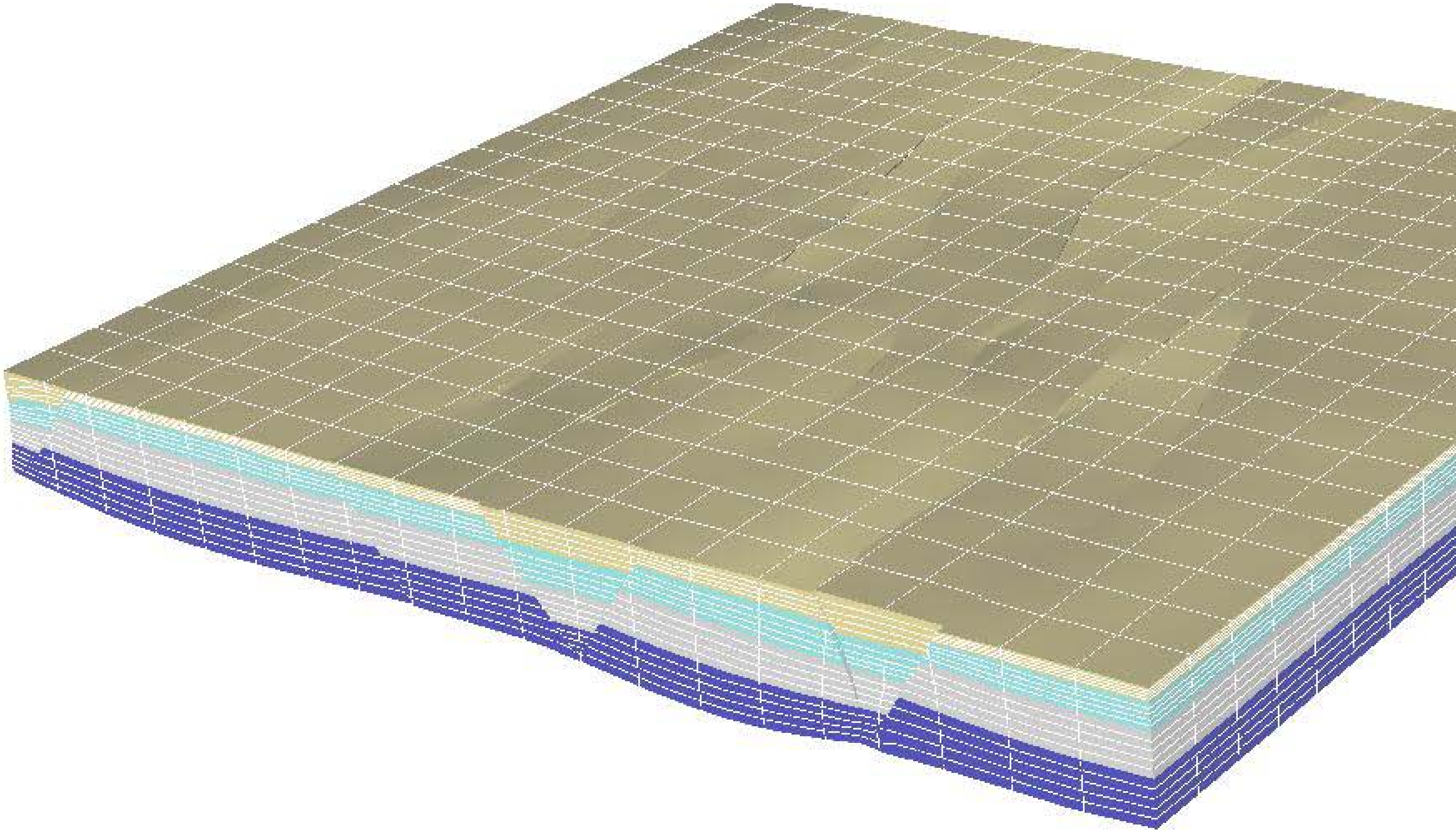
At present day



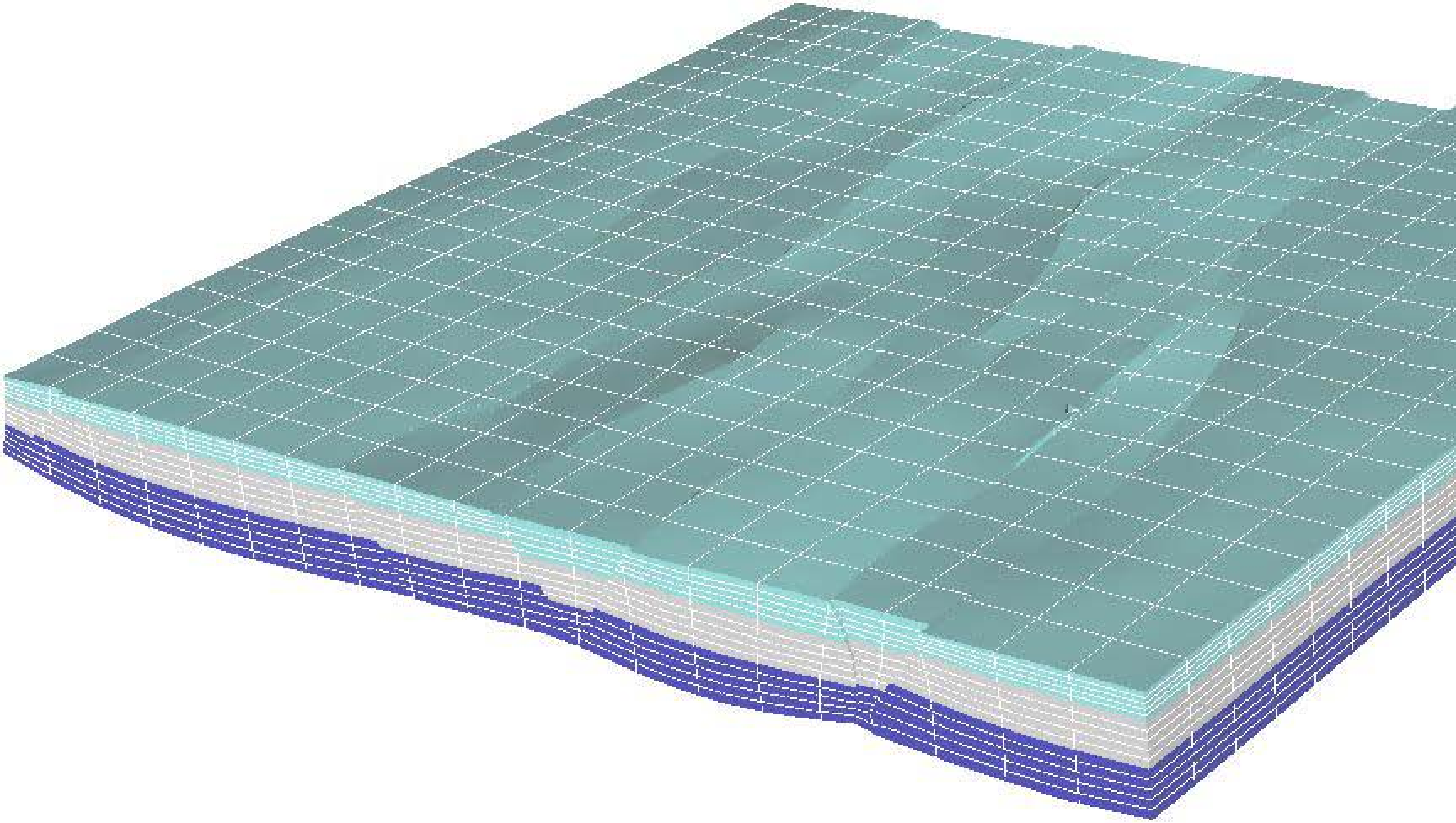
At pink layer



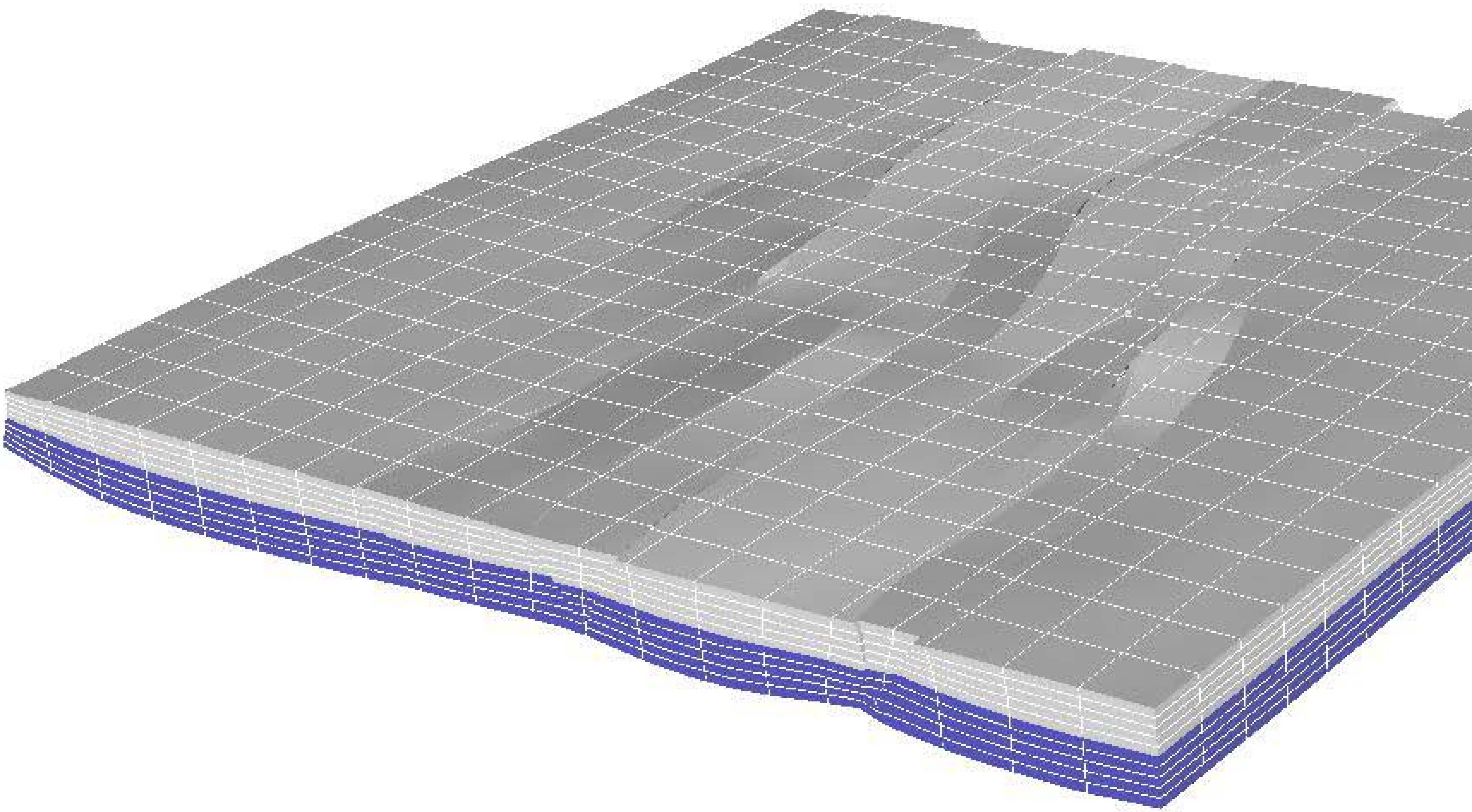
At yellow layer



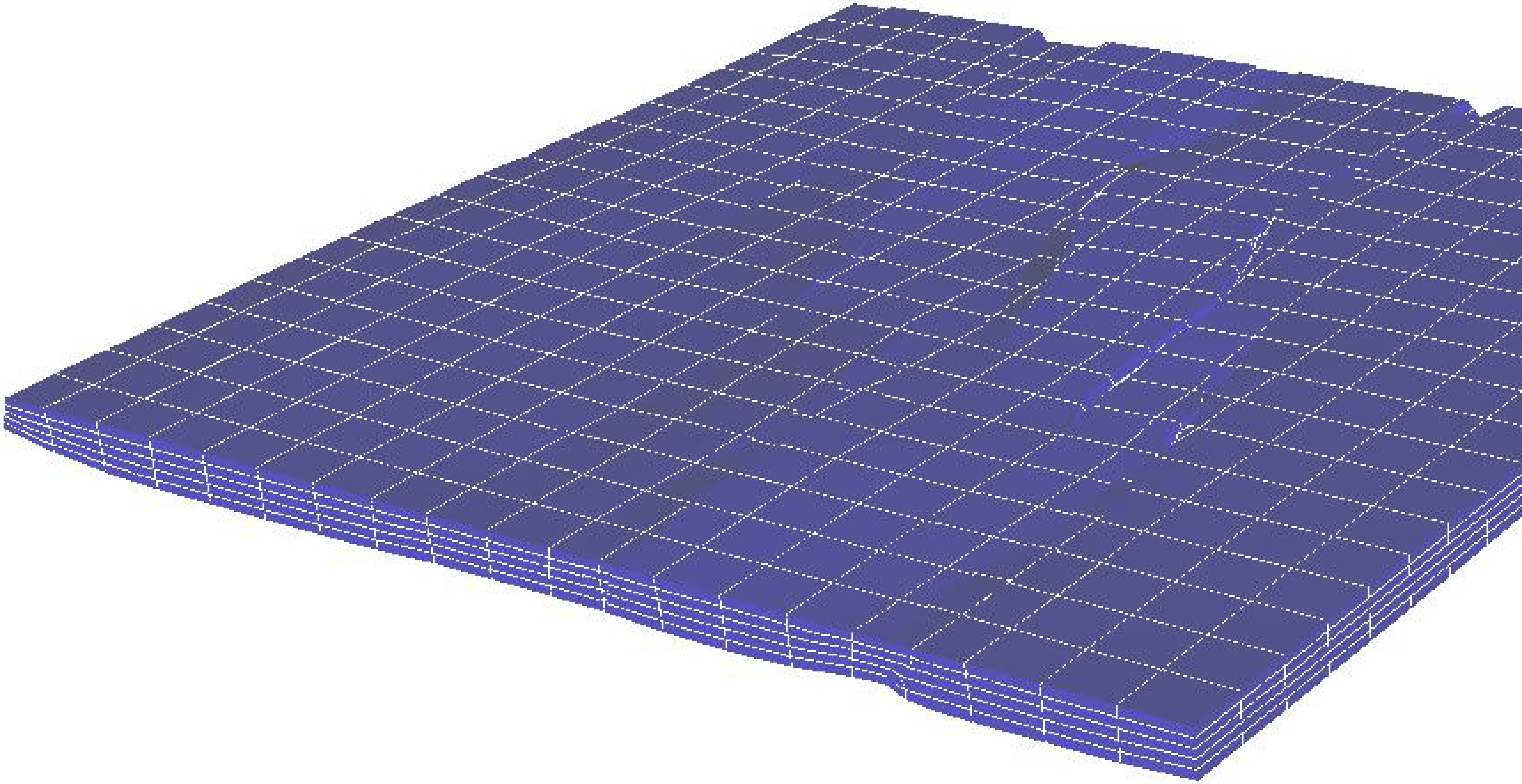
At green layer



At grey layer



At violet layer



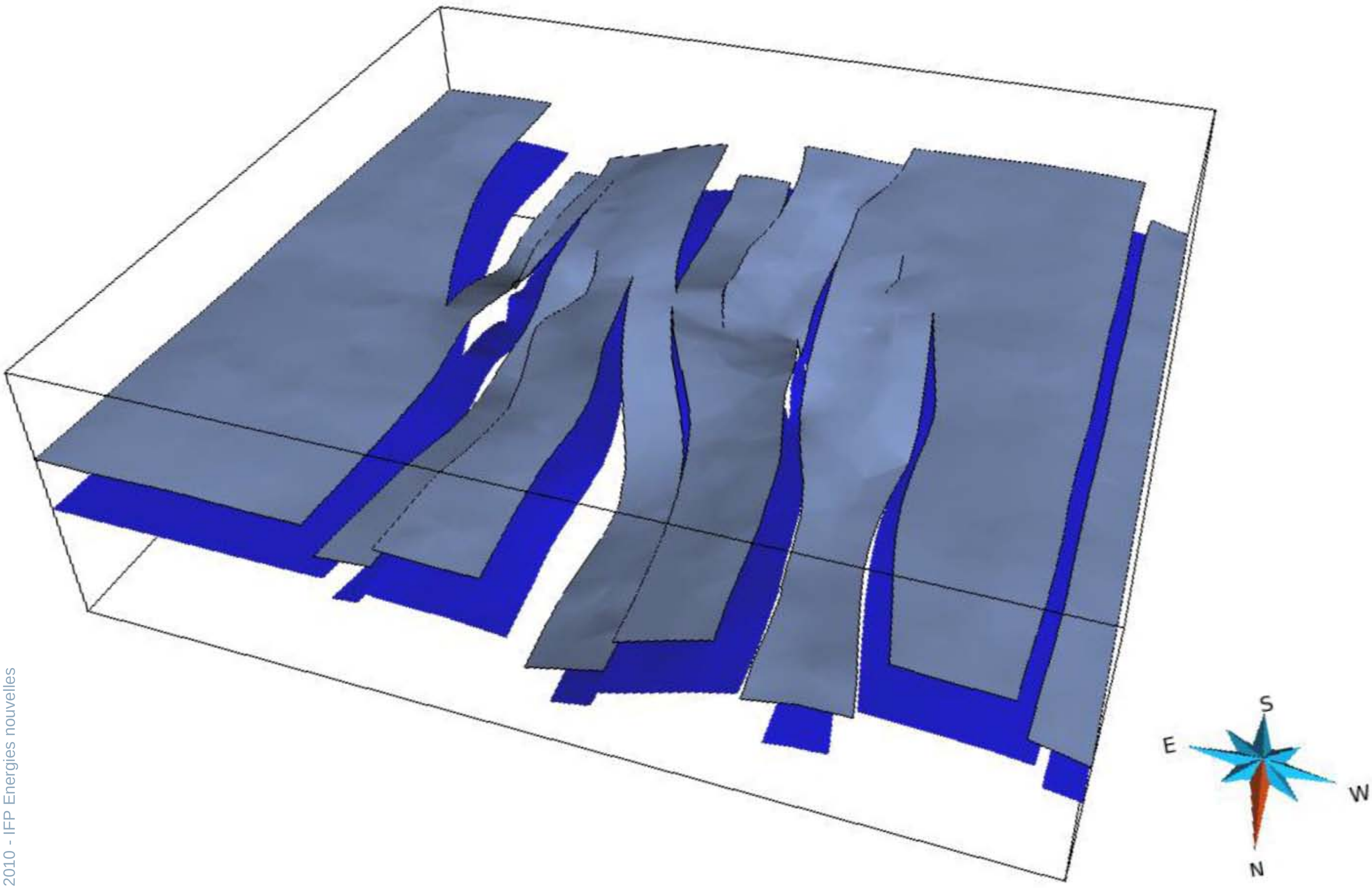
How does it work ?

- needs a consistent present day model of horizons and faults
- full 3D restoration is solved as a mechanical problem with three constraints :
  - minimize internal deformation
  - flattens the top horizon
  - makes sure both faults compartments are kept in contact during movement
- is not a simple geometric flattening
- embedded in a workflow that allows for automatic computation of all restoration steps, as it is done in classical backstripping

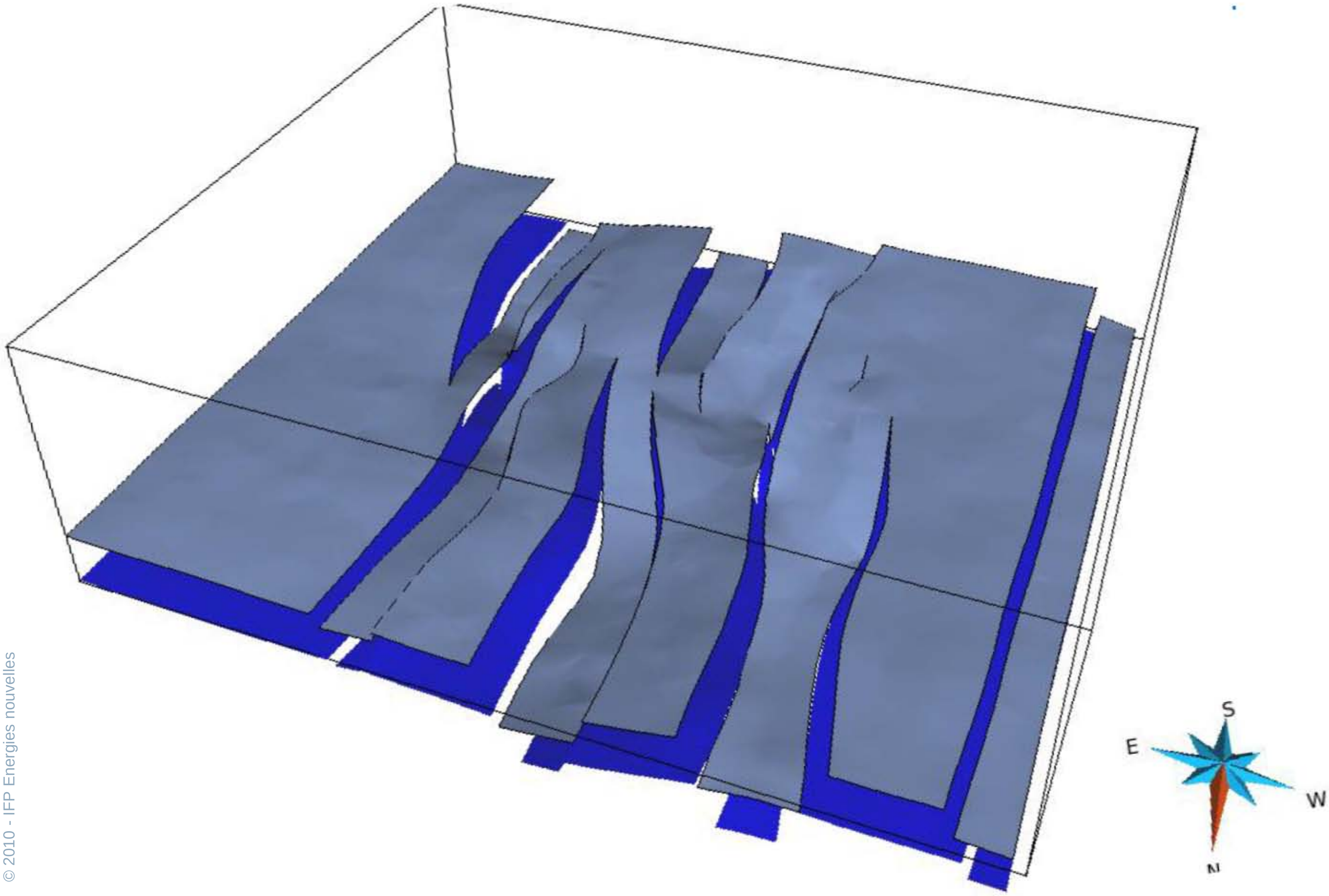
What do we get ?

- geometry of faults and layers during time
- possibility to mark and locate wrong picked areas
- deformation patterns due to fault and top horizon flattening induced movement

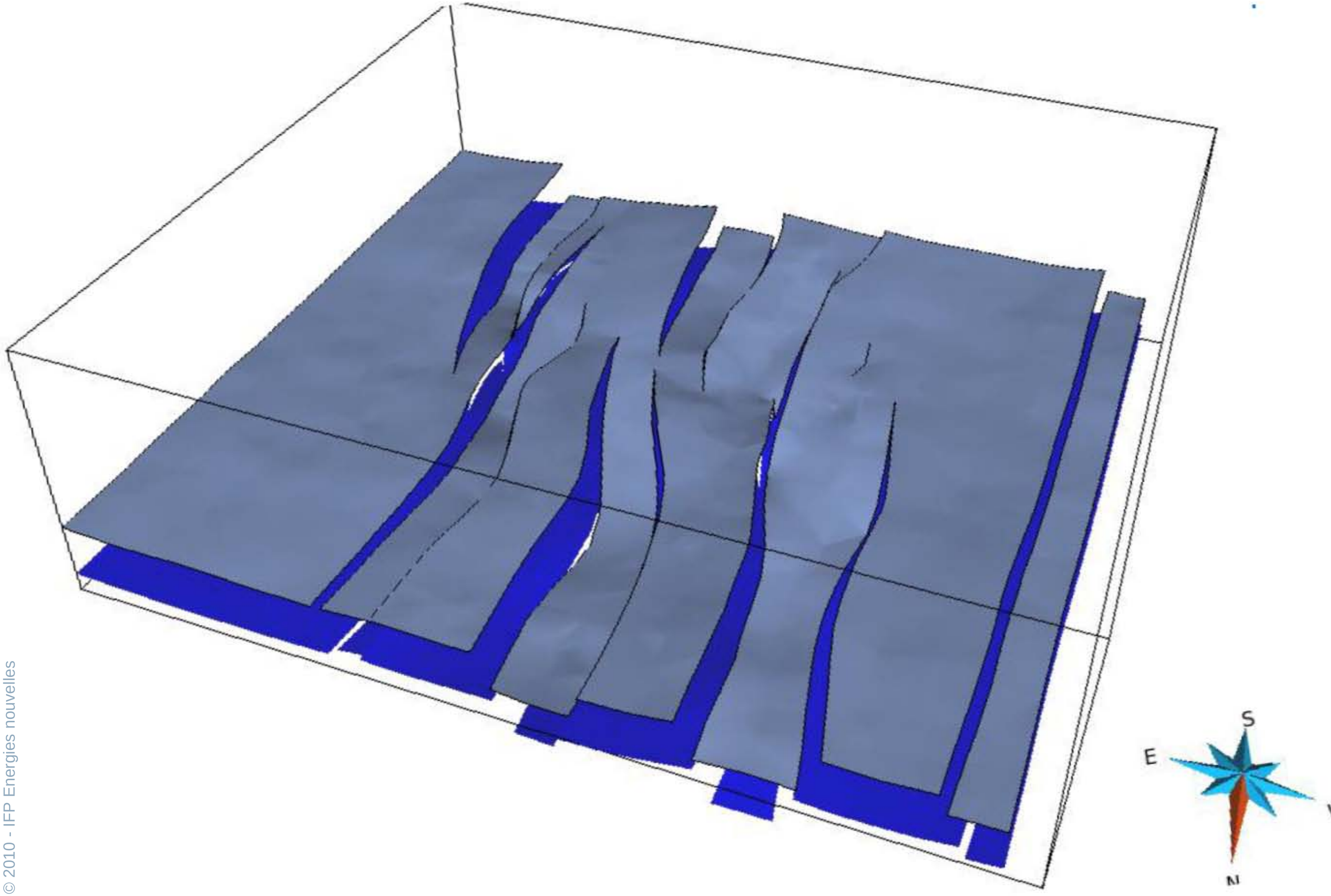
Blue layers at present



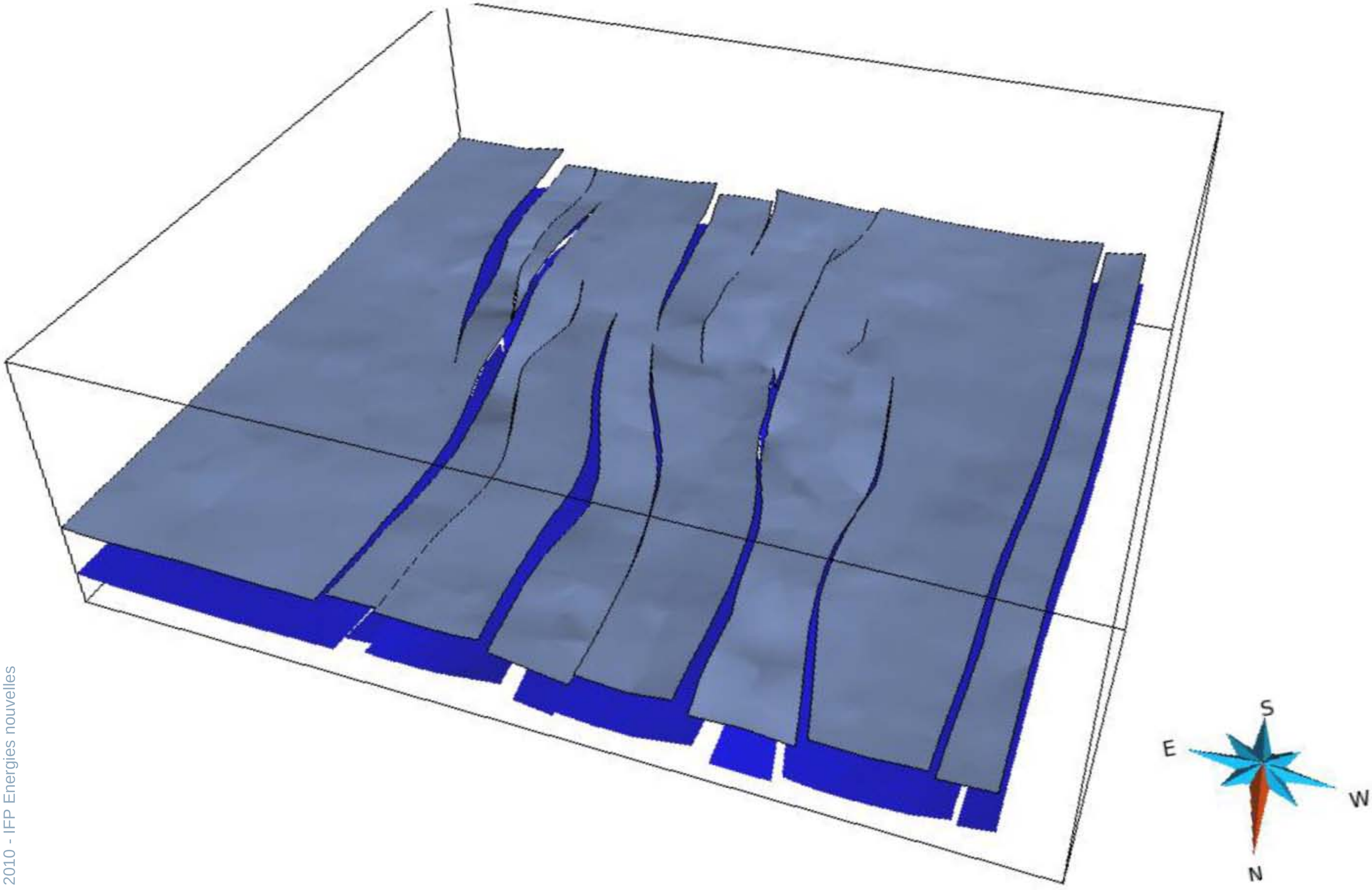
Blue layers at pink layer time



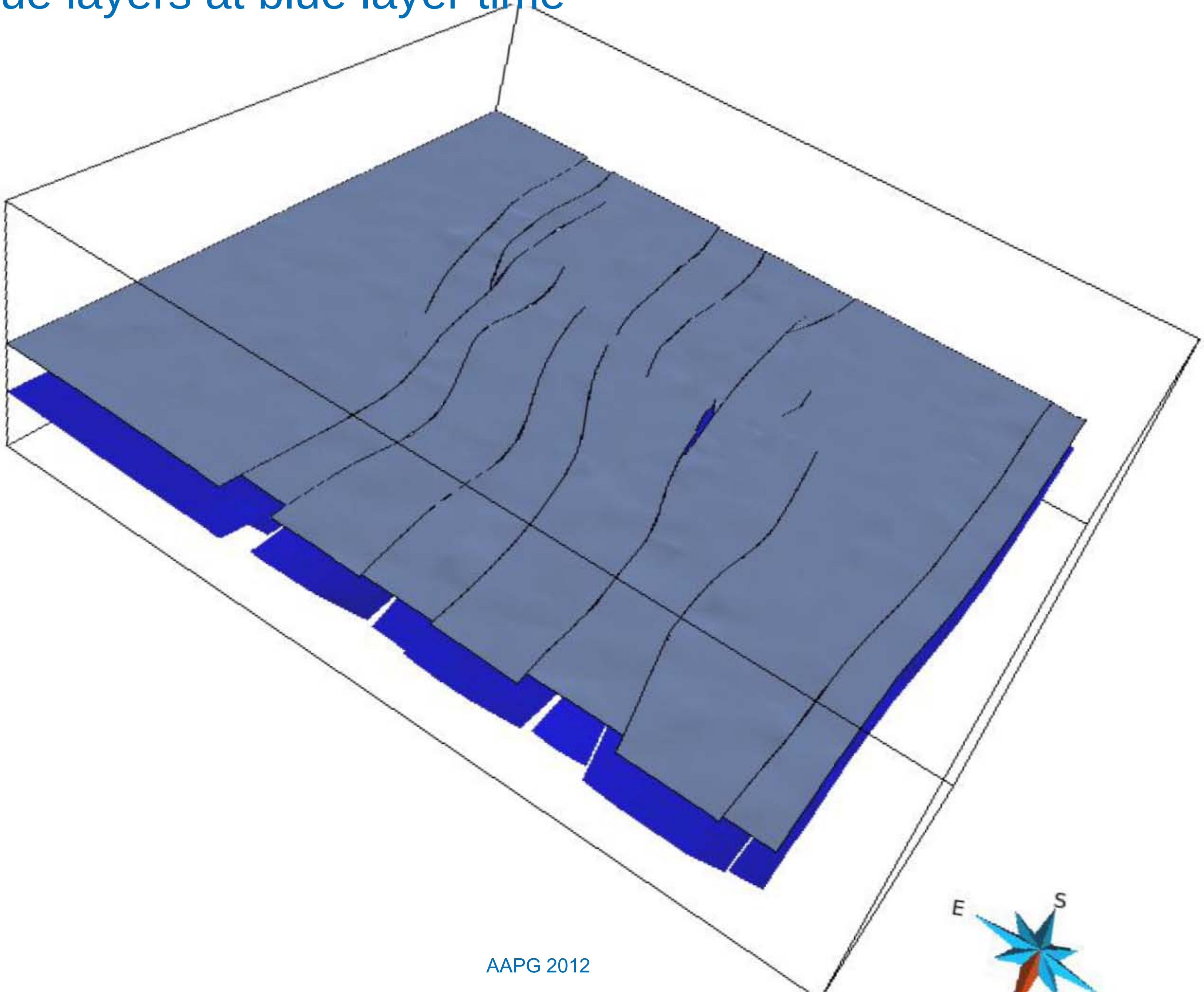
Blue layers at yellow layer time



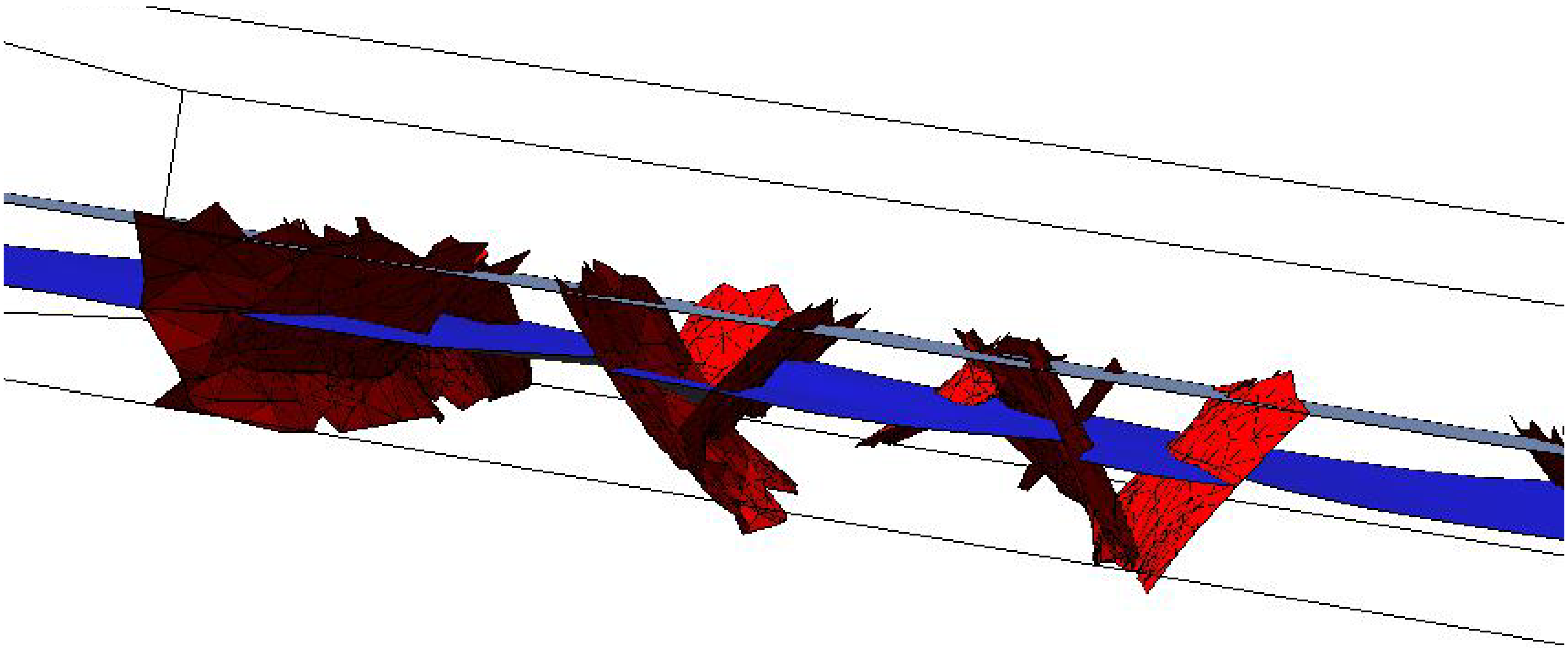
Blue layers at green layer time

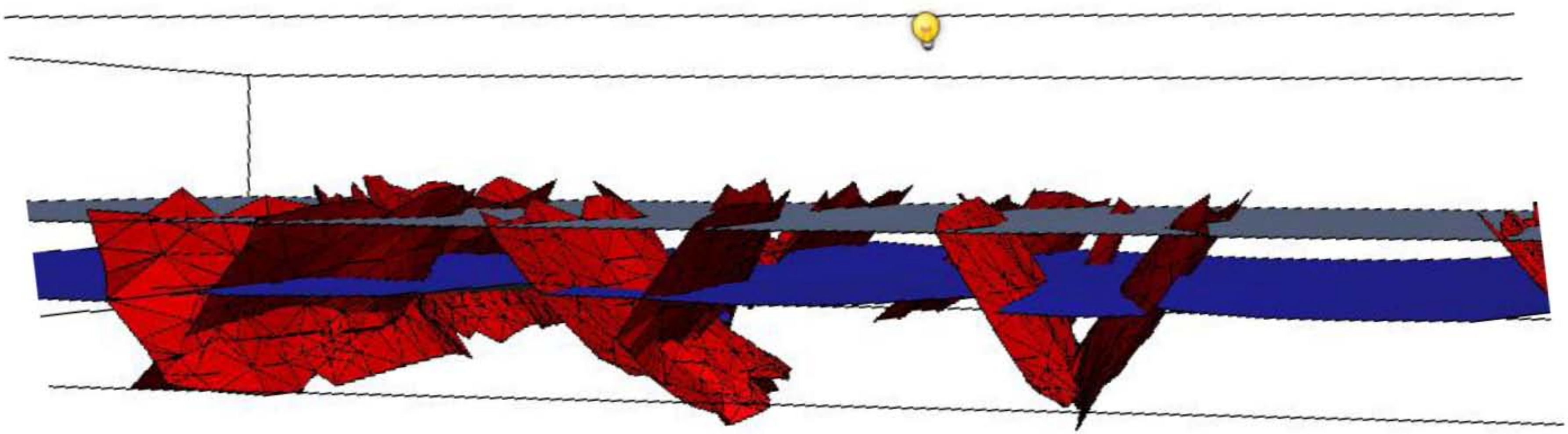


Blue layers at blue layer time

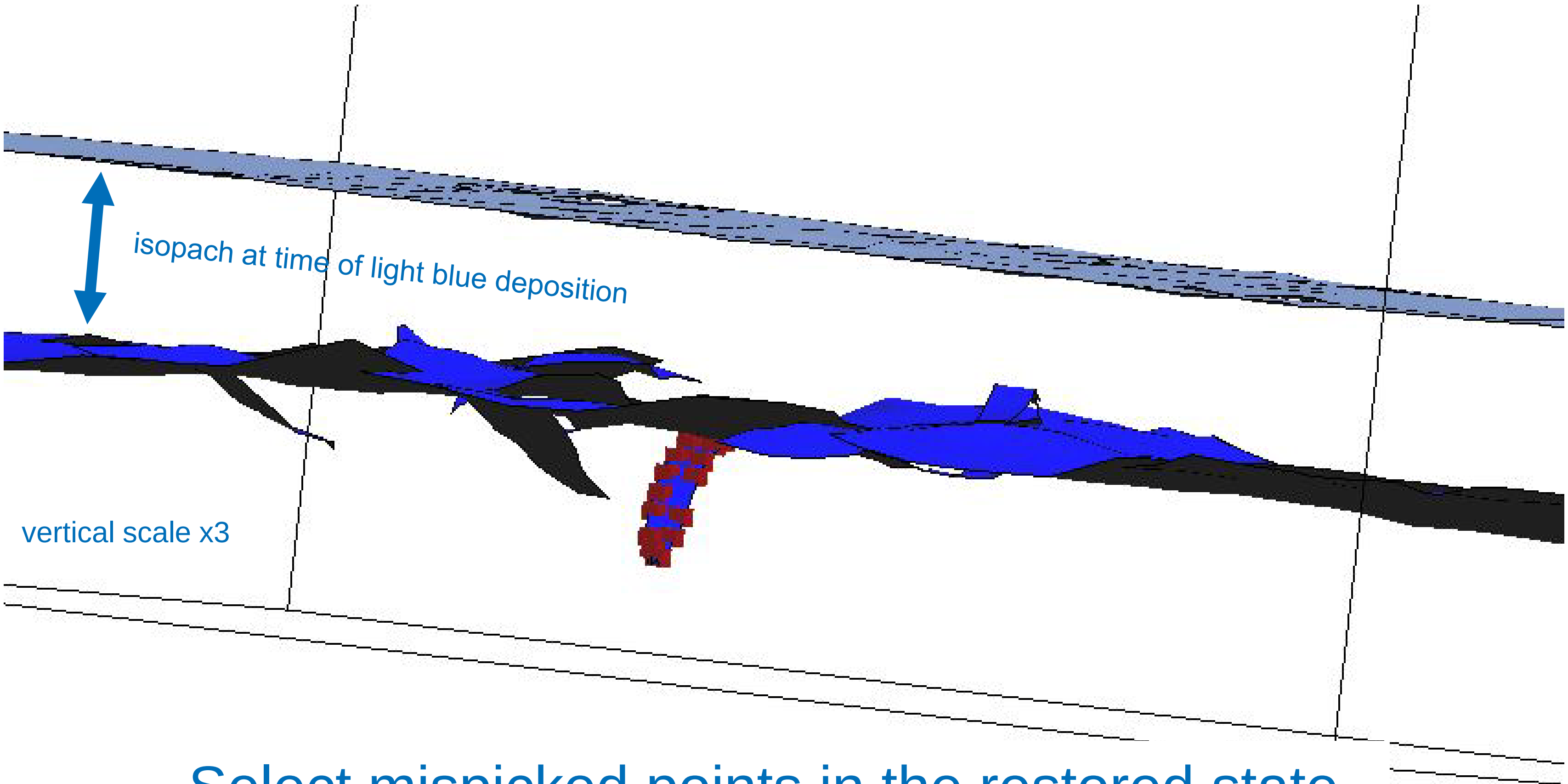


Faults are also restored back in time

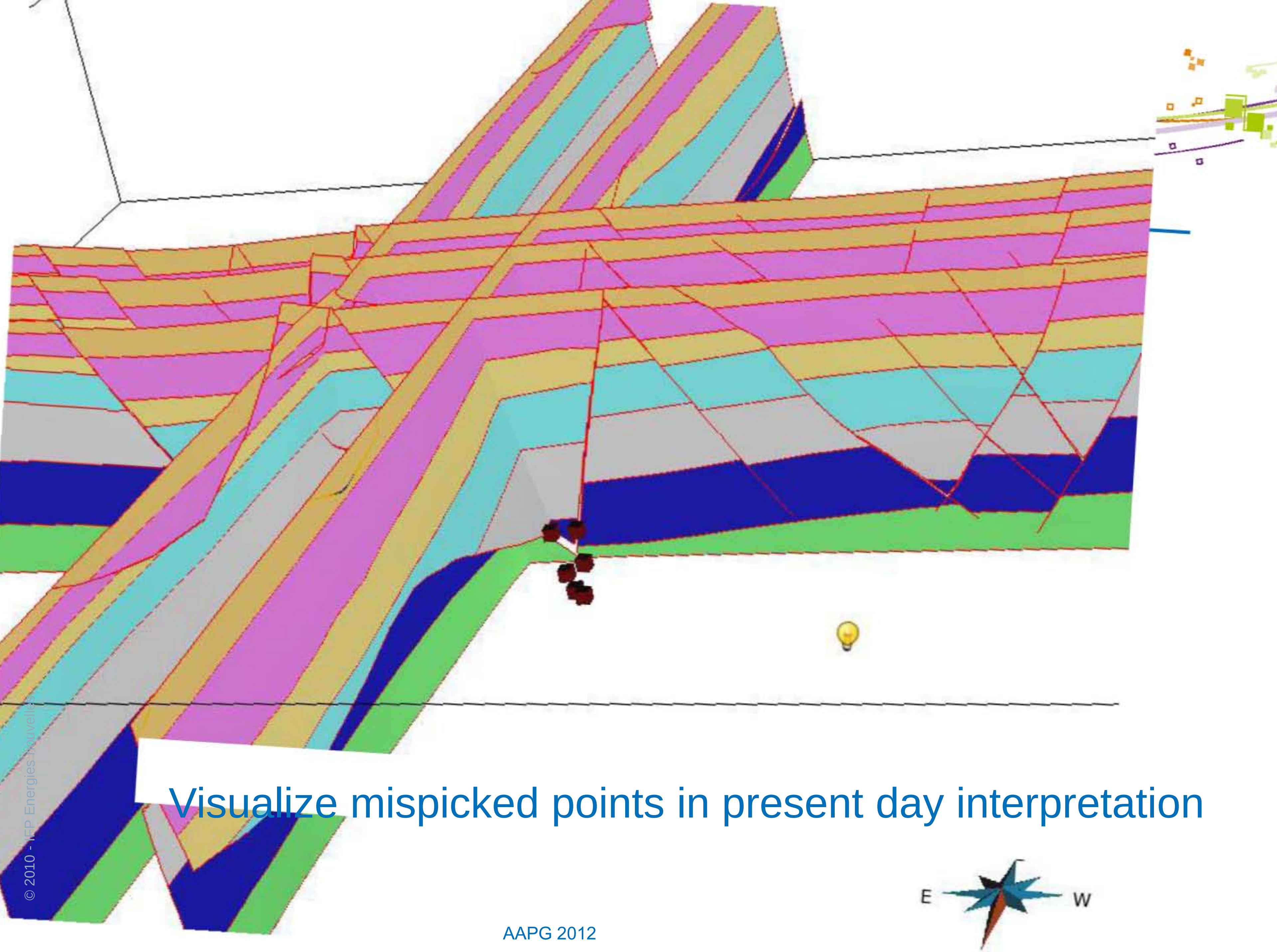




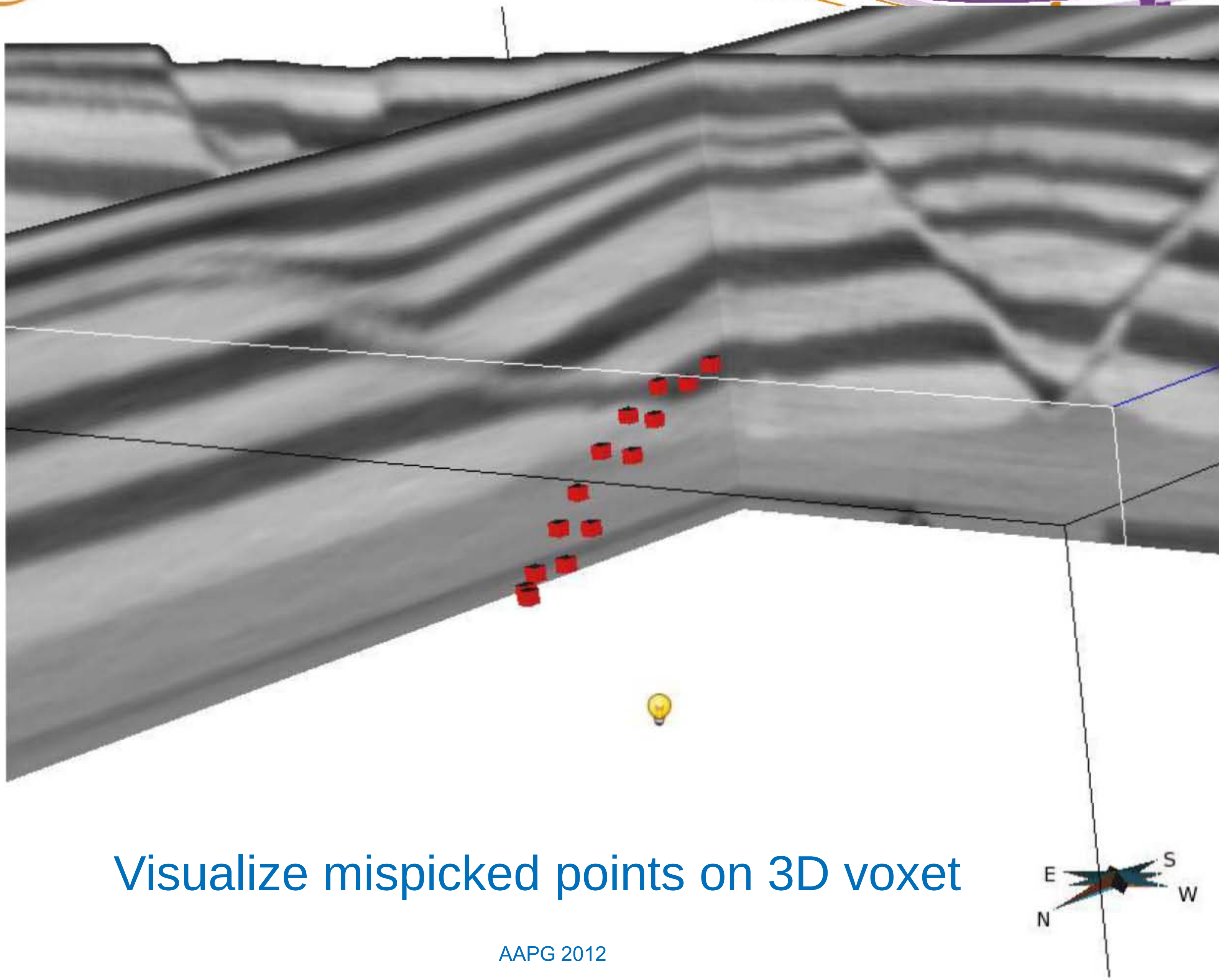
Applications: QC interpretation



Select mispicked points in the restored state, according to an isopach assumption



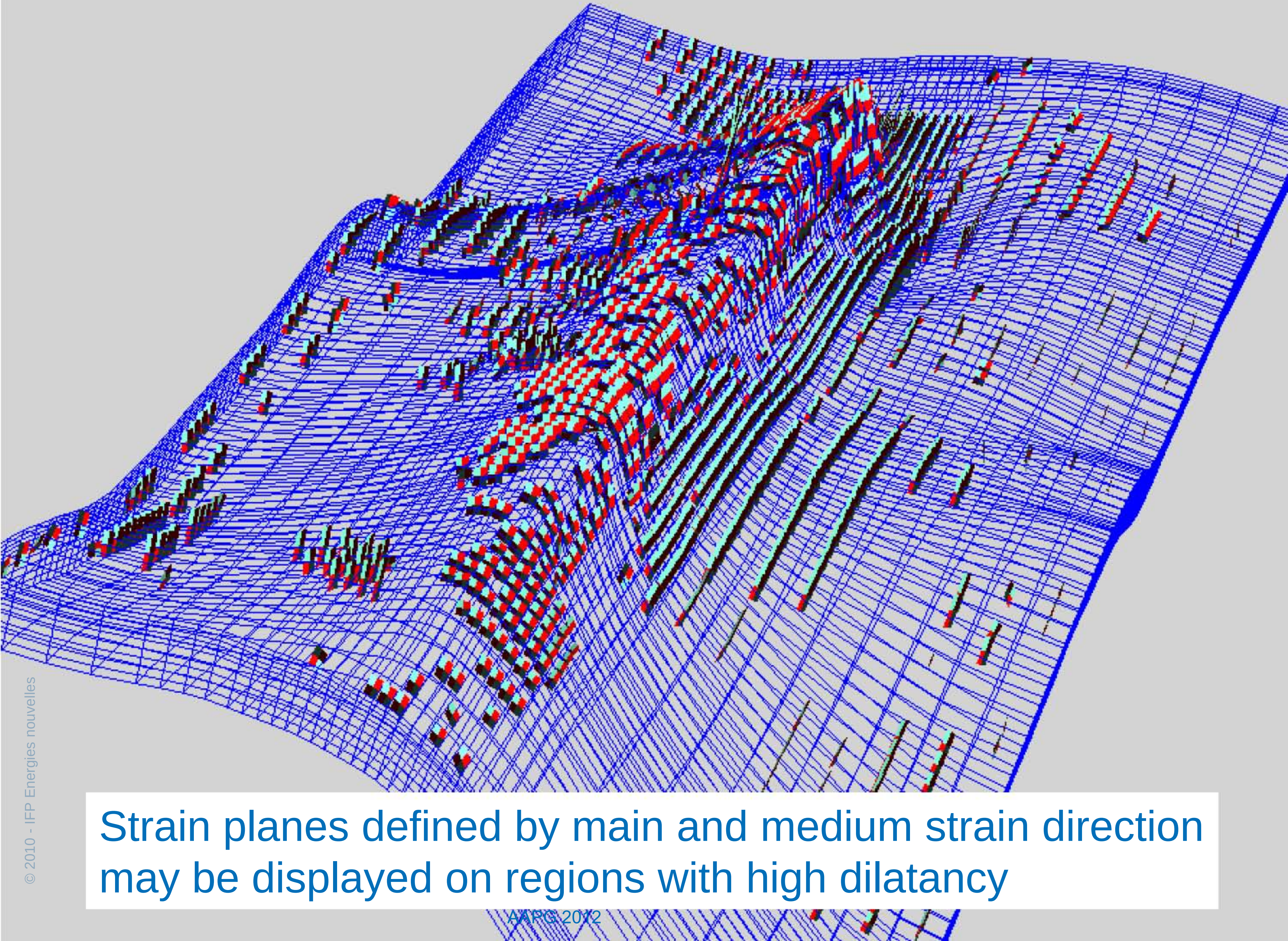
Visualize mispicked points in present day interpretation



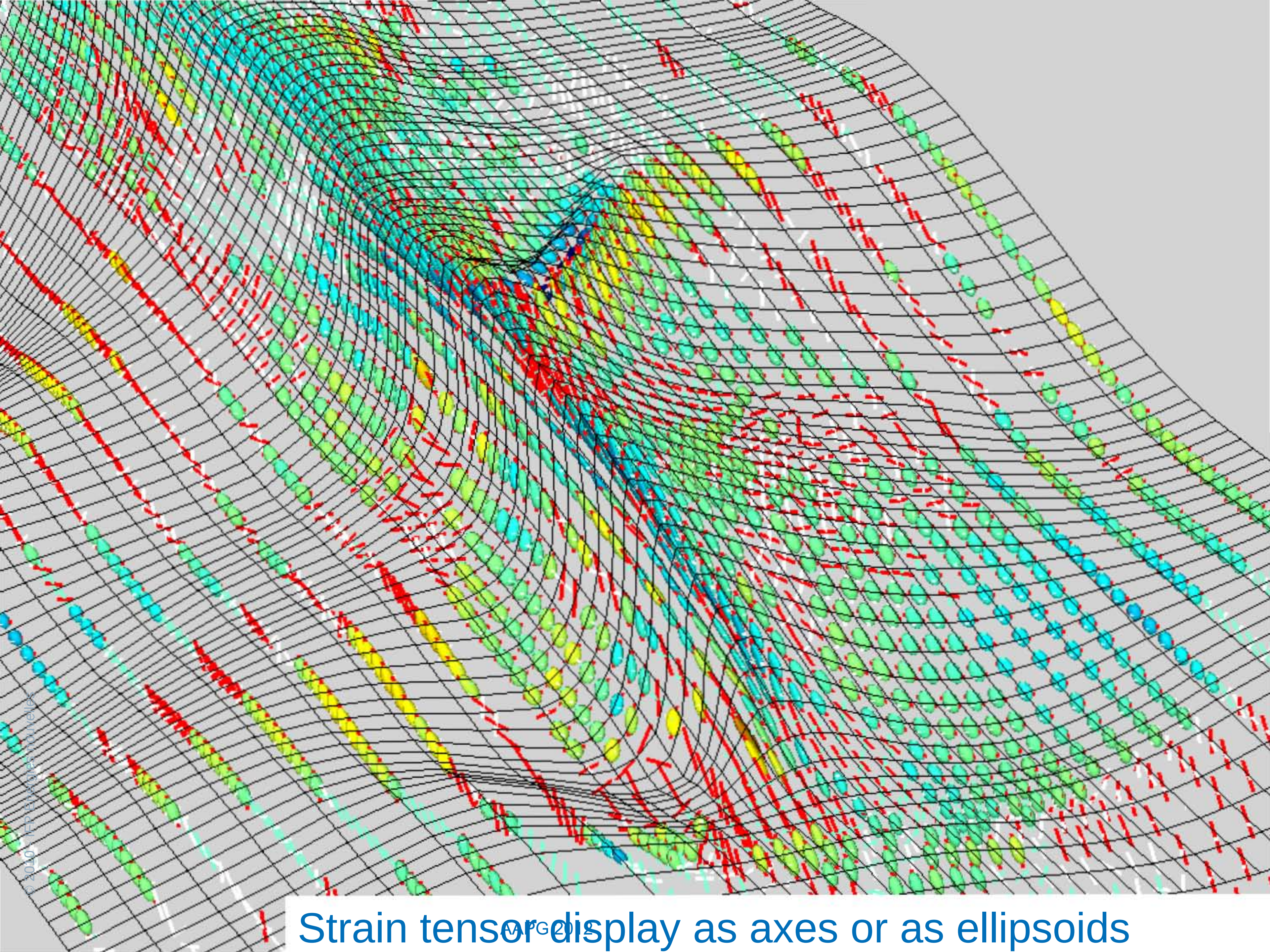
Visualize mispicked points on 3D voxet

Deformations can be computed

- Incremental deformation tensor between two successive geometry can be computed
- Could be used as external constraints on fracture identification or interpretation
- Could be related to velocity anisotropy for improved rock typing
- Deformation eigen vectors and magnitudes are displayed

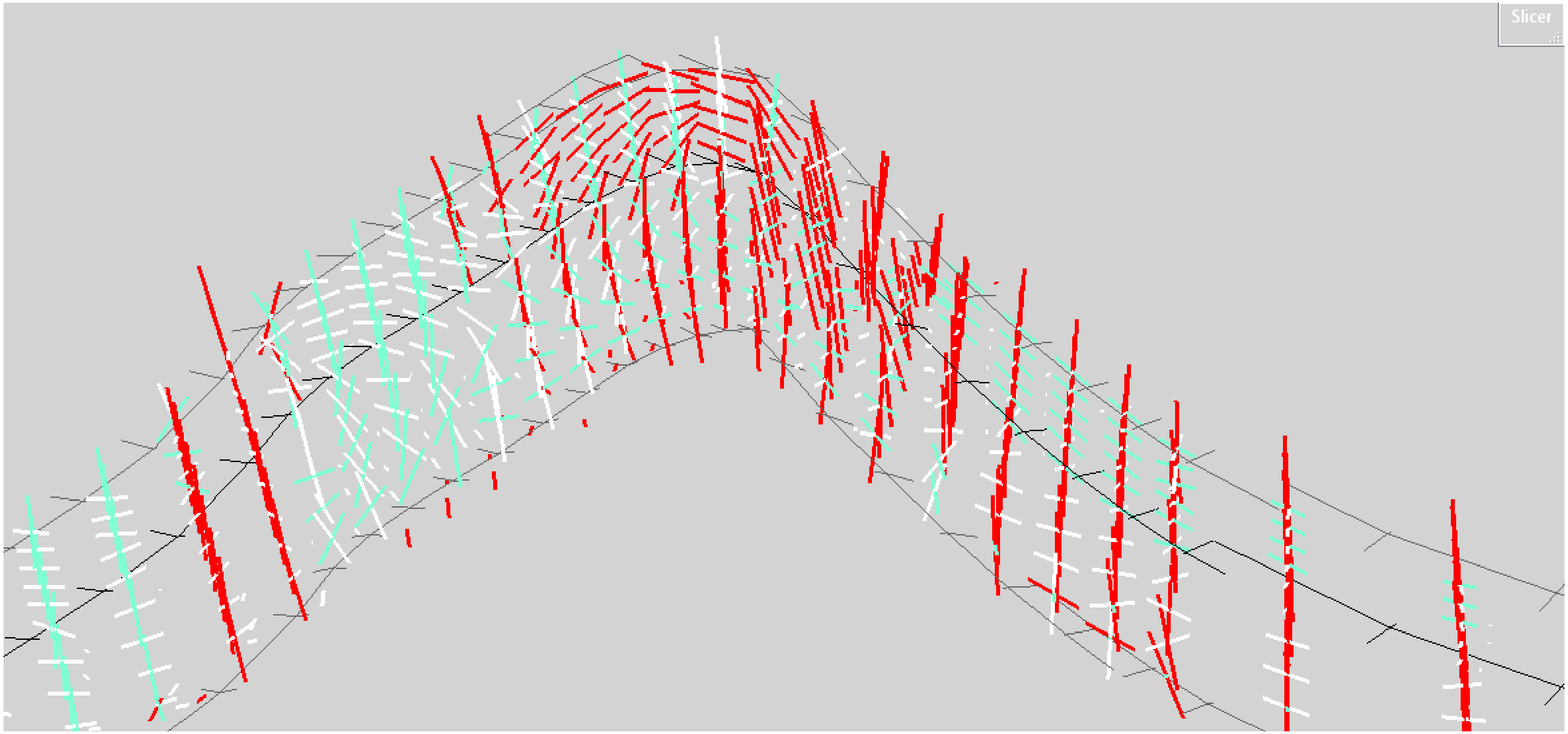


Strain planes defined by main and medium strain direction may be displayed on regions with high dilatancy



Strain tensor display as axes or as ellipsoids

Deformations can be computed



Conclusions (1)

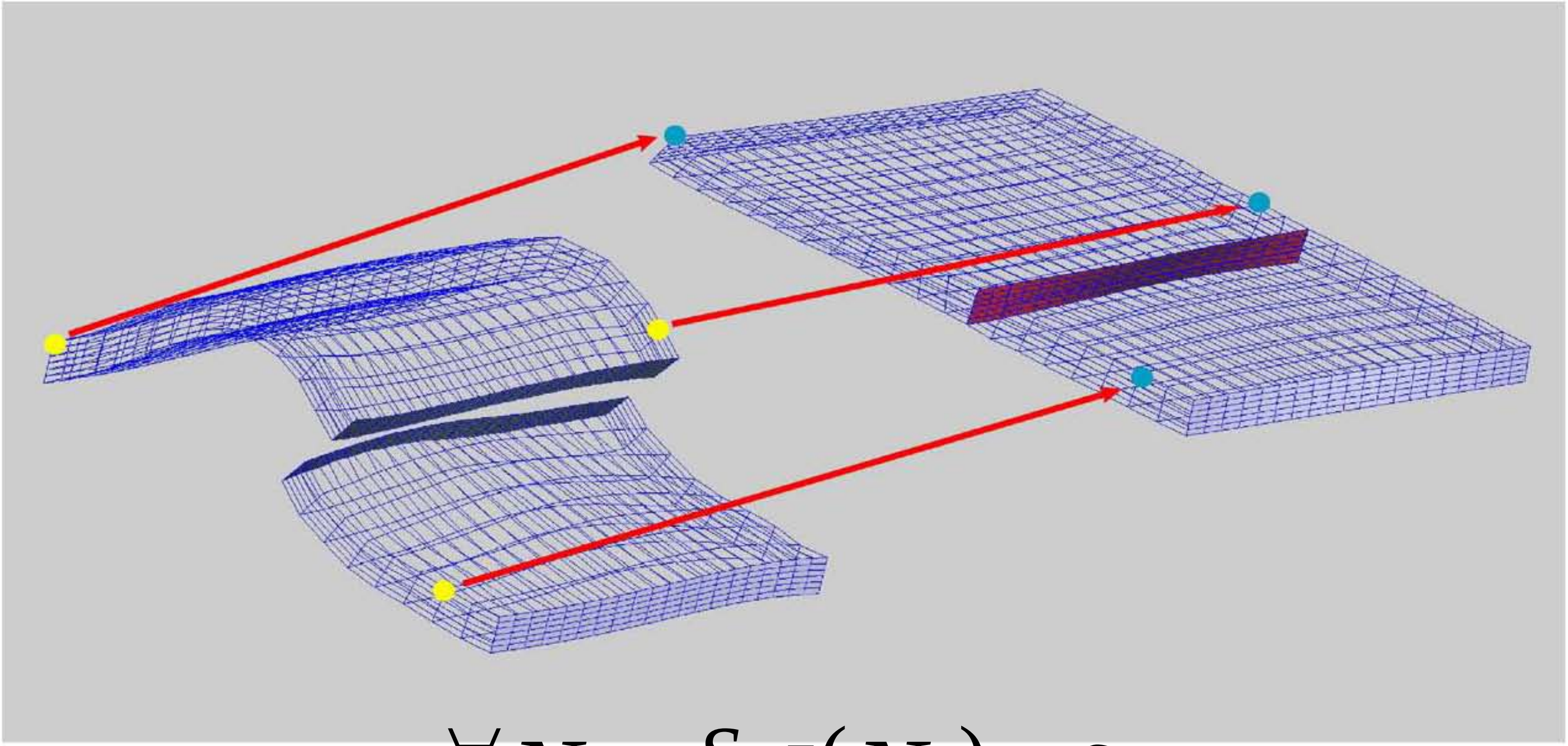
- 4D restoration is backstripping v2.0
- it combines the advantages :
  - of backstripping : it is automatic
  - of 3D restoration: it takes faults into account
- it requires a topologically valid 3D model (faults and horizons)

Conclusions (2)

- its main domain of application
  - QC and correct seismic interpretation
  - derivation of incremental strain related attributes
    - This attributes are worth beeing compared to seismic anisotropy measurements
  - generates structurally consistent geometry in the past that may be used for all paleo geometry applications
    - Stratigraphic modeling,
      - sandstone sinks for turbidite deposition for example
    - petroleum system modelling
  - compute the evolution of fault throw and fault related property through time

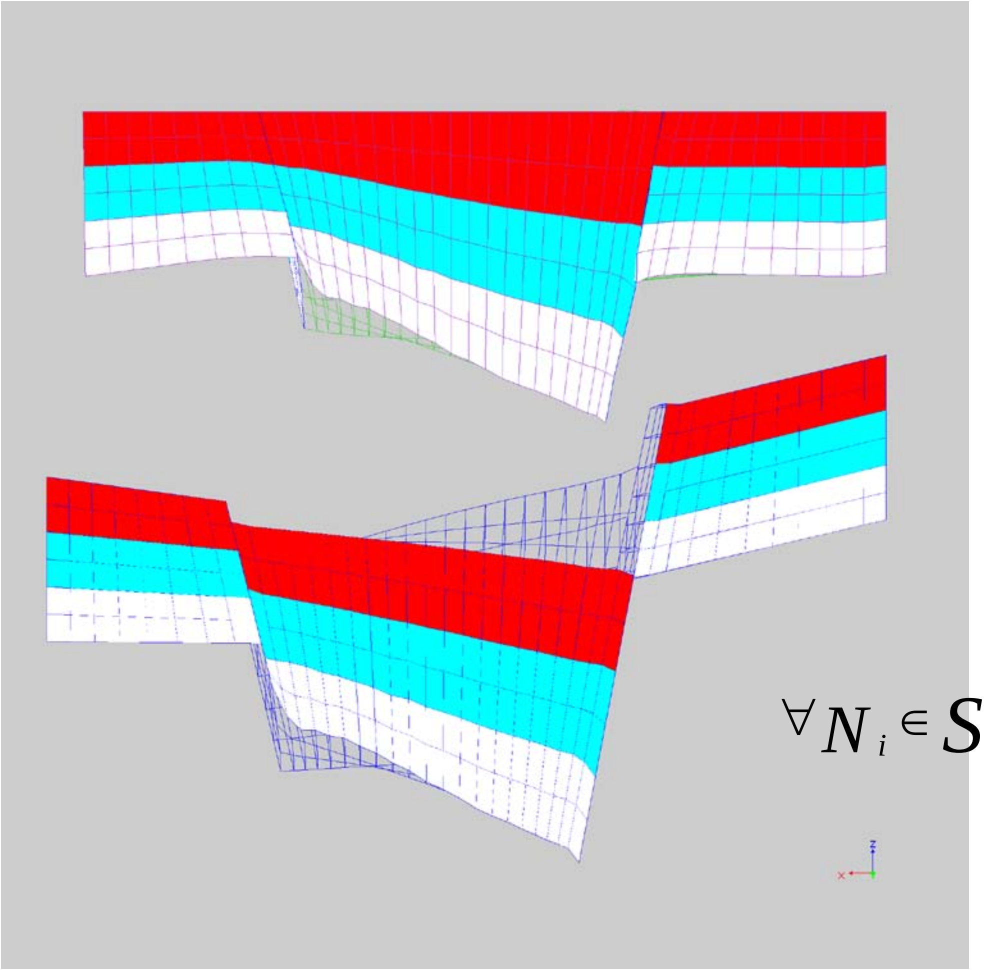
Thank you for your attention

Flattening



$$\forall N_i \in S, z(N_i) = c$$

Fault Gliding Contact



$$\forall N_i \in S_k, \exists F_j \in S'_k, \vec{d}(N_i, F_j) = 0$$