4-D Sequential Restoration and Its Applications*

J.L. Rudkiewicz¹, J.F. Lecomte¹, J.M Daniel¹, C. Borgese³, M. Latourrette⁴, M. Guiton¹, Wan-Chiu Li³, and S. Jayr²

Search and Discovery Article #41013 (2012)**
Posted August 31, 2012

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Long Beach, California, April 22-25, 2012
**AAPG©2012 Serial rights given by author. For all other rights contact author directly.

¹IFP Energies Nouvelles, Rueil-Malmaison, France (Jean-Luc.Rudkiewicz@ifpen.fr)
²Paradigm, Houston, TX
³Paradigm, Nancy, France
⁴Paradigm, Paris, France

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


Website

4D sequential restoration and its applications


IFP Energies nouvelles   Paradigm
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
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 voxel
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 being 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

\[ \forall N_i \in S_k, \exists F_j \in S'_k, \overrightarrow{d}(N_i, F_j) = 0 \]