Geo-chronological 3-D Space Parameterization Based On Sequential Restoration

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Résumé

Defining distance is crucial for modeling geological properties with geostatistics. However, geological structures are generally deformed, making the usual Euclidean distance inappropriate for applying geostatistics. Considering this, the GeoChron theory maps geological models into a regular chronostratigraphic space, where deformations (especially those due to both faults and folds) have been removed [Mallet, 2004]. Three curvilinear coordinates are used for this mapping, among which a time parameter, inspired from H. E. Wheeler's work, and two paleogeographic coordinates corresponding to the location of each particle at deposition time.

To-date, the Geochron theory has been implemented by Moyen and Mallet [2004], Jayr et al. [2008], as a global optimization method which computes the three coordinates from chronostratigraphic interpretations. In this work, we propose instead to use sequential geomechanical restoration to compute paleogeographic coordinates. Geomechanical restoration is a way to infer the original position of a horizon taking rock physics into account. Each layer is restored into depositional state, which provides the paleogeographic coordinates of its hanging wall. These parameters are then propagated within the layer. Several methods, depending on the assumed hypotheses for deformation mode during syntectonic deposition were investigated. These methods are compared on a synthetic case.

Doing so, it is possible to capitalize on restoration efforts to build a geochron parameterization, not only dependent on geometric criteria but also on rock rheology and on the deformation path inferred from the sedimentary record.

Introduction

Modeling geological structures is by nature a challenging task. Indeed, field data, even obtained by feat of engineering, are generally incomplete or uncertain. Mathematical and geometrical theories certainly help to create geomodels honoring entry data. But how far are they representative of the reality they pretend to illustrate? Even if answering this question seems difficult, intuition suggests that integrating more geological concepts, gathering natural sciences knowledge like physics, chemistry or biology, sooner in the modeling approach should increase the representativity of the geomodels.

Modeling the geometry of geological structure is a crucial stage as it is conditioning all the following modeling steps and especially property modeling. Mallet [2004] proposes to simplify the representation of physical spaces used for geomodeling by using a 3-D curvilinear parameterization dedicated to geology. This method, called GeoChron, makes good use of the idea that choosing an appropriate curvilinear coordinate system reduces the complexity of many physical problems.

Another main idea associated with GeoChron is to separate the supports used to model geometry and properties. The modeling approach can be summarized in three successive steps :

- Volume discretization : in a preliminary phase, the volume occupied by the geological structures is discretized using a 3D mesh. This mesh represents the continuity of the media, separating sub-volumes bounded by discontinuities like faults or unconformities.
- Geometry implicit modeling : the geometry of geological structures is then modeled as a set of scalar fields.
- Property modeling in GeoChron space : geological properties are finally modeled in a dedicated space, which is mapped on the Cartesian space using a curvilinear coordinate system.

This curvilinear coordinates system is a key point of GeoChron (Section 1.1). Previous implementations of this theory are based on a global optimization honoring geometrical constrains deduced from stratigraphic and kinematic models [Moyen and Mallet, 2004, Jayr et al., 2008].

After a short presentation of restoration concepts, we propose an alternative method for computing GeoChron parameterization based on sequential geomechanical back-stripping.

1 Previous work : GeoChron, Time-Stratigraphy and Restoration

1.1 GeoChron, an extension of Time-Stratigraphy

The geo-chronological coordinate system used by GeoChron is constituted by three axis, which are chosen for simplifying the problems related to stratigraphic deposits. Indeed, heterogeneities in a sedimentary pileup generally highly depend on depositional conditions, hence call for a good characterization of layer geometry. The geometry of the stratigraphic layers thus appears as a key entry for property modeling. Besides, the notion of distance is also paramount, especially for geostatistical algorithms [Journel, 1986]. Then, the distance existing between two particles at deposition time is generally more adequate than present Euclidian distance for characterizing the spatial correlation between property values, because geological structures may have been deformed and faulted.

GeoChron theory considers a geological volume as a field of particles supporting some properties. These particles are deposited at a certain date. Particles that may be eroded and deposed at a new location are considered as new particles. In order to take the previously presented remarks concerning geometry and distance, a Geo-Chronological parameterization has to gather two types of information for each particle of the rock volume :

- The present layers' geometry, represented in GeoChron by the parameter τ.
- The location at deposition time, simplified into the two lateral paleo-geographic coordinates u and v.

The parameter τ comes from the Time-Stratigraphy notion, introduced by Wheeler [1958]. It exploits the fact that stratigraphic interfaces are isochronous, making the link between the stratigraphic layers stacking up and the age of deposition. However, the relation between stratigraphy and the actual age of particles may be biased by phenomena such as erosion, hiatus, variation of sedimentation rate and compaction. The parameter τ used in GeoChron is in fact an apparent time-stratigraphic parameter where these phenomenas have been simplified [Kedzierski and Royer, 2005]. τ is constructed to evolve continuously inside the stratigraphic layers except where discontinuities like faults or unconformities occur. This practical stratigraphic time is thus both convenient for representing the layer piles and easier to interpret from data than actual ages.

Furthermore, the parameter τ has to be distinguished from the actual time during which the rock volume has been deposited. Subsequently, the apparent time-stratigraphic parameter used for GeoChron will be referred as *stratigraphic parameter* s, this for avoiding confusion with actual *time coordinate* t.

GeoChron links the Cartesian space with the geo-chronological space in a injective way (fig. 1). The three geo-chronological coordinates are expressed as three scalar fields u, v and s defined in $\mathcal{D}_t$, the whole geological volume available at a given time t.

$$\left\{\begin{array}{cccccc} u & : & \mathcal{R}^3 & \longmapsto & \mathcal{R} \\ & & \{x,y,z\} & \longmapsto & u(x,y,z) \\ \\ v & : & \mathcal{R}^3 & \longmapsto & \mathcal{R} \\ & & \{x,y,z\} & \longmapsto & v(x,y,z) \\ \\ s & : & \mathcal{R}^3 & \longmapsto & \mathcal{R} \\ & & \{x,y,z\} & \longmapsto & s(x,y,z) \end{array}\right. \quad (1)$$

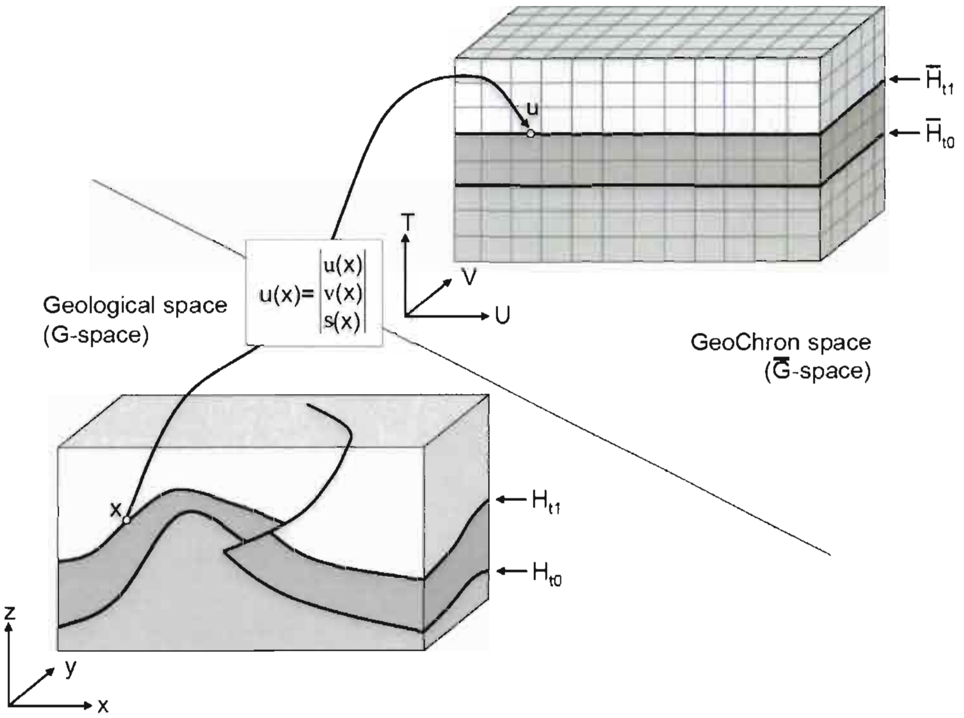

FIGURE 1: *Representation of the mapping between geological space (G-space) and chronostratigraphic space ($\overline{G}$-space). The GeoChron parameterization u maps each point X from the G-space to a triplet of coordinate u, v and s in $\overline{G}$-space. From [Frank, 2006] modified from [Mallet, 2004]*

1.2 Classical approach for computing GeoChron parameters

Previous implementations of GeoChron rely either on iso-paleo-geographic line tracking [Moyen and Mallet, 2004] or on global optimizations. In both cases, the entry data is a set of horizons, obtained from chrono-stratigraphic interpretation. In the first step of the process, the stratigraphic parameter s is interpolated between the stratigraphic horizons using Discrete Smooth Interpolation algorithm (D.S.I.) [Mallet, 2002] with a constraint allowing to keep its gradient orthogonal to stratigraphic horizons.

The paleo-geographic parameters u and v are computed in a second time. Moyen [2005] proposes to initialize the process by parameterizing a first given horizon, using Least Square Conformal Mapping [Lévy et al., 2002]. The paleo-geographic parameters are then propagated either by tracking the IPG-lines following the gradient of the time-stratigraphic parameter s or by a global optimization. Different assumptions can be made while performing the global optimization, depending on the considered kinematic model :

- Pure bending : gradients of u, v and s are kept orthogonal one to another :

$$\forall \underline{x} \in D_t, \begin{cases} grad\, u \perp grad\, v \\ grad\, u \perp grad\, t \\ grad\, v \perp grad\, t \end{cases} \tag{2}$$

- Flexural slip : the projection of the gradients of u and v on the horizontal, respectively $grad_H\, u$ and $grad_H\, v$, stay orthogonal one to another and are unitary vectors :

$$\forall \underline{x} \in D_t, \begin{cases} grad_H\, u \perp grad_H\, v \\ \| grad_H\, u \| = \| grad_H\, t \| \end{cases} \tag{3}$$

Figure 2 presents an example of parameterization in pure bending style.

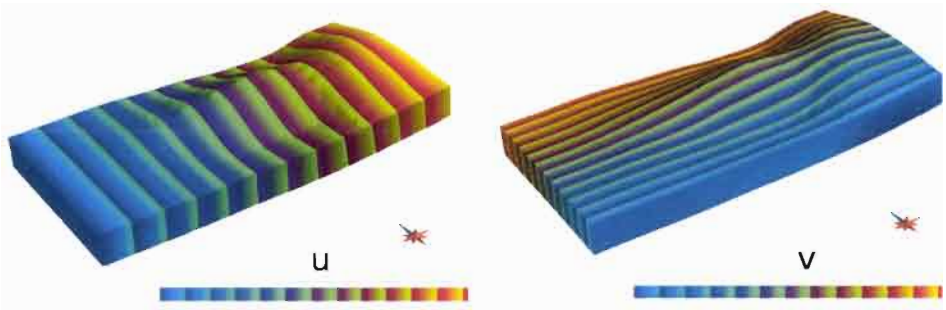

FIGURE 2: *this two models are painted respectively with parameter u, on the left, and v, on the right. This parameters were computed by a global optimization under pure bending constrain (eq. 2). Modified from [Moyen, 2005].*

1.3 3-D sequential restoration

The term restoration gathers different techniques to retrieve the effects of deformation phases from geological structures. The goals of these methods are to estimate the strain associated with the formation of the structure, to infer the paleo-geometries and possibly to invalidate inconsistent models.

Historically, the first approaches aimed at restoring cross-section under geometric assumption [Chamberlin, 1910], whose technique was formalized under the term *balanced cross-section* by Dahlstrom [1969]. However, these techniques encounter limitations when modeling natural complex structures, first, because they are unable to capture displacements occurring out of the cross-section's plane, but also because exclusively geometric techniques are not appropriated for reflecting mechanical property variations inside the rock volume [Guzofski et al., 2009].

More recently, 3-D kinematic restoration methods have been developed, based on continuous media concepts [Mallet, 2002, Massot, 2002]. But these methods only consider the problem in its geometrical aspect, using kinematic models, without taking geo-mechanical behavior of rocks into account. As Fletcher and Pollard [1999] highlight, "the efforts to simulate geometry alone often forces incomplete and physically implausible interpretations of kinematics and process". This remark expresses the reason of being of mechanical approaches. When a complete mechanical model can be proposed, they use constitutive model for linking stress and strain, producing results closer to rock behavior. Different formulations using finite elements methods [Zienkiewicz and Taylor, 2000a,b] have been proposed [de Santi et al., 2003, Maerten and Maerten, 2004, Moretti et al., 2006, Muron, 2005]. In case of growth structures, sedimentation phases are associated with the tectonic evolution of the geological structures. It is then possible to restore step by step each layer, going backward trough the tectonic evolution [Griffiths et al., 2002, Muron, 2005, Durand-Riard et al., 2010]. In these sequential restoration methods, also called backstripping, each layer is in turn restore and then removed from the model as it does not participate to the deformation before its deposition. As input of backstripping, a set of isochronous stratigraphic surfaces are interpreted from geological data. Each surface is associated to its time of formation t and are thus denoted S_t. Each stratigraphic layer $\mathcal{L}_t$ in the model is bounded by an interpreted stratigraphic surface, S_t, at its top and an other one, S_{t+1} at its bottom.

Other geological contexts or phenomena can be considered such as salt tectonic [Titeux, 2009, Titeux and Gray, 2009] or compaction [Basier et al., 2009] and parameterization computed from restoration results would benefit from their integration.

2 Backstripping as a way of computing paleo-geographic coordinates

Restoring a layer to its undeformed state is a way to infer the location of particles at the deposition time. We propose therefore to compute the GeoChron paleo-geographical parameters from the displacement obtained from the restoration. Meanwhile, the stratigraphic parameter s remains interpolated from the interpreted chrono-stratigraphic horizons, like in previously proposed methods [Moyen, 2005].

The deformation induced by restoring the top surface S_t of a given layer $\mathcal{L}_t$ is expressed as a field of restoration vector, which ideally brings each point of the layer to its location of deposition. As a consequence, equation 4 expresses the paleo-geographic parameters as the sum of the current location and restoration vectors. Denoting r_x and r_y the coordinates of restoration vectors respectively in x and y axis, we have :

$$\forall \{x, y, z\} \in \mathcal{L}_t, \begin{cases} u(x,y,z) = x + r_x(x,y,z) \\ v(x,y,z) = y + r_y(x,y,z) \end{cases} \tag{4}$$

Actually, this relation is true in as much no deformation occurs within the layer during its deposition. When a stratigraphic surface of the model is restored, computing its paleo-geographic parameters is straightforward (fig. 3a). Indeed, equation 4 can be applied to all the points of the surface. In some cases, this remark also holds for the complete layer under the restored surface (see section 2.1).

In general, the parameters can not be computed directly from the restoration vector. For example, if the newly deposited particles are deformed or displaced during the remaining layer deposition, restoration vectors do not bring the particles in their exact deposition location (fig. 3b). Section 2.2 presents some approaches for extrapolating the parameters u and v from the restored surface into the layer.

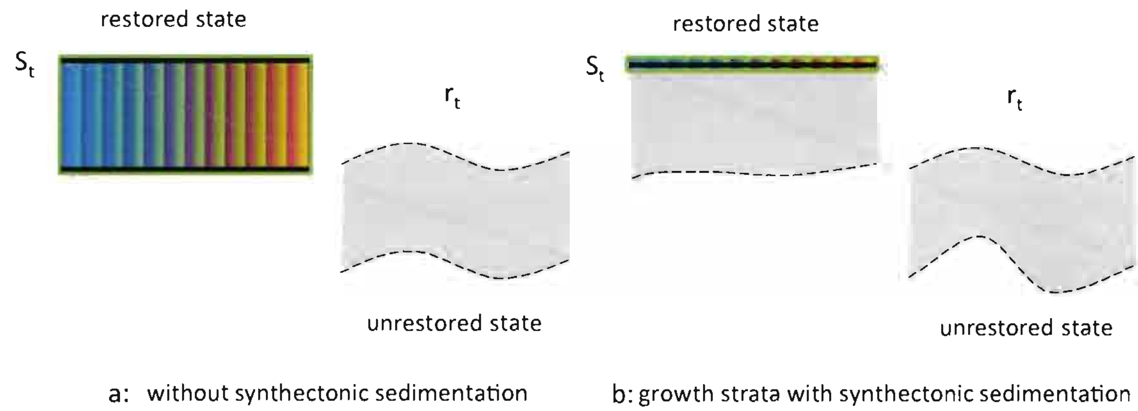

FIGURE 3: *comparison of the parameterization of a layer with or without synthectonic sedimentation. In figure a, layers sediment were deposited without deformation until the top surface S_t. All the layer is thus in place when S_t is restored (green box). Parameterization can be computed in the whole layer (colored zone). In figure b, in contrary, restoring S_t does not retrieve the complete deformation for particles within the layer. Indeed, they have been displaced during the period of time between their deposit and the deposit of S_t. Parameters computed with equation 4 is only valid for S_t.*

2.1 Discontinuous parameterization

The most simple assumption consists in considering sedimentation and deformation periods separated in time. The sedimentation is therefore discontinuous at this scale of time and occurring without synchronous deformation. In this case, each stratigraphic surface appears as an unconformity. Paleo-geographic parameters are thus discontinuous across this surface, either due to folding during non-deposition, or post-sedimentary deformation and flexural slip at layer boundaries (Figure 4).

The absence of deformations during the deposition implies that the whole layer is restored when its top is restored. In other terms, equation 4 can be applied to the whole layer.

Under this assumption, the parameterization can be computed for each layer as follows :

- compute the vectors restoring the layer ;

– compute the parameters u and v by applying equation 4 to each point of the layer.

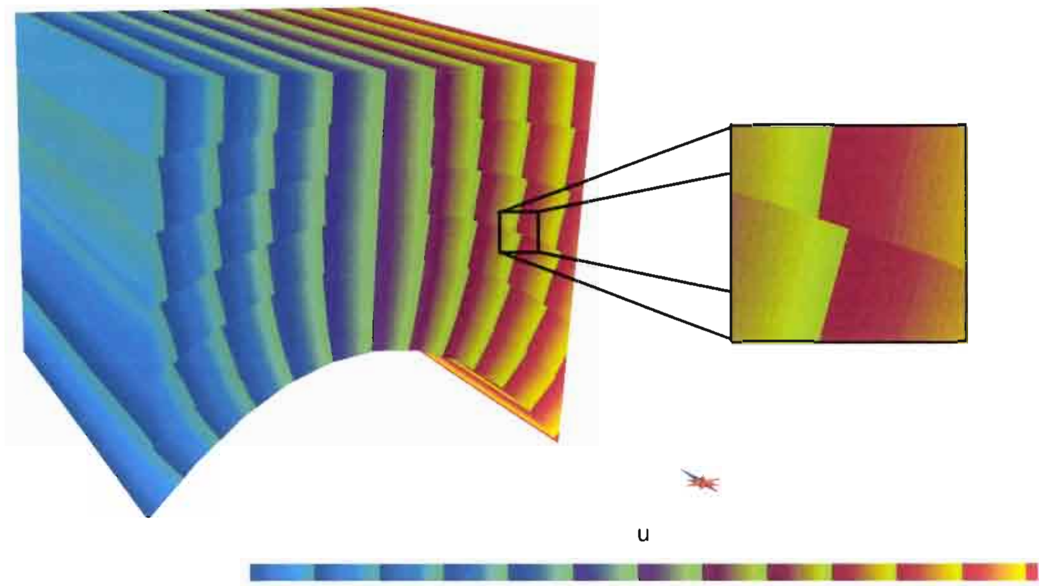

FIGURE 4: *This figure illustrates a paleo-geographic parameter computed in an synthetic antiform growth structure under the assumption that each layer has been deposit without deformation. Deformation stages occurred between the deposition of each layer producing the observed structure. The detail image highlights the discontinuity of the parameter. Nevertheless, continuity is present along the axial surface.*

In this situation, the paleo-geographic parameters are simple to compute as restoration vectors give the location of deposition for each point in the volume. However, in many cases the input stratigraphic horizons do not correspond to sedimentation discontinuities. For example, it is generally not the case for maximum flooding surfaces.

In a nutshell, unconformities introduce a discontinuity in the parameter scalar fields. In this case, each side of the surface has to be parameterized separately after restoration. One consequence is that it multiplies the number of property to be stored in the model or forces to cut the mesh along the discontinuity. Indeed, each parameter has to be stored for both side of the discontinuity.

The assumption that no deformation occurs during the deposition of the strata above or under the unconformity may be inappropriate, in which case parameters have to be computed following section 2.2. Note that Durand-Riard et al. [2010] proposes a method for restoring eroded portions. Using this restoration approach eroded parts of the strata could be parameterized as well.

2.2 Paleo-geographic parameters extrapolation

Considering the sedimentation as continuous during the deformation phases implies that the sedimentation floor may be continually deformed during the deposition and newly deposited sediments as well. Consequently, the paleo-geographic parameters u and v cannot be directly deduced from the vectors restoring the surface S_t. Parameters computed this way are only valid for the restored surface (Figure 3b).

However, computing an approximation of the paleo-geographic parameters value remains possible. Three approaches are proposed :

– Geometrical extrapolation from the restored surfaces (section 2.2.1).
– Restoration displacements extrapolation (section 2.2.4).

– Fine backstripping, performing series of fine restoration between the major stratigraphic horizon (section 2.2.5).

2.2.1 Geometrical extrapolation

2.2.2 *extrapolation methods*

This method proposes to extrapolate the paleo-geographic parameters computed on a surface S_t. These extrapolations are purely geometric. However, they allow to honor the parameterization computed on the restored surfaces, which are considering the geomechanical behavior of the rock. Parameters defined in the whole volume can be computed following this steps :

- Restore each surface S_t with a backstripping approach (see section 1.3).
- Parameterize each surface S_t using equation 4 with their restoration vectors.
- Extrapolate the parameter of each surface in the volume honoring one of the following constrains :
  - Constant gradient constrain, corresponding to the classical roughness criterion in D.S.I. [Mallet, 2002].
  - Paleo-geographic parameters gradients orthogonal to the gradient of the stratigraphic parameter. This constrain allows to better integrate the variation of the stratigraphic parameter.

The constrain of orthogonality to stratigraphy allows to honor specific situation, when the sedimentation floor is animated by rigid body motion and no deformation occurs in the newly deposited sediments as well (fig. 5) :

- Pure vertical displacement : where the floor presents no lateral displacement or deformation during the sedimentation. The stratigraphic surfaces stay horizontal during the burial.
- Simple rotation : the floor surface rotates around an horizontal axis, angular speed may vary during the sedimentation. The stratigraphic surfaces stay horizontal during the burial.

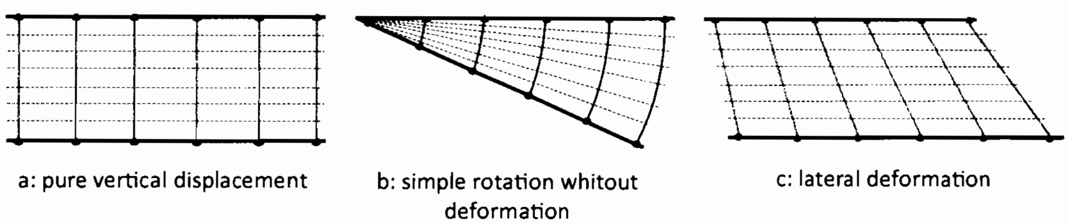

FIGURE 5: *simple models of floor displacement during sedimentation. In each model, the blue dashed lines represent some iso-values of the stratigraphic parameter inside a layer while it is being deposed. The shape of the IPG-lines (in green) depends on the deformation of the sedimentation floor (gray arrows). The curves are vertical in case of pure vertical movement (a) and orthogonal to stratigraphy when the floor rotates without deformation (b). When lateral deformation or displacement occurs, the IPG-lines are no more orthogonal to stratigraphy (c).*

A pure vertical displacement implies no lateral movement inside a layer during its deposition. The horizontal components of the vectors actually restoring its particles are thus equal to those computed for restoring the top surface S_t. Consequently, equation 4 can be applied for parameterizing the layer. If the deformations stays purely vertical from a restoration step to another, the continuity of the parameter should be strictly respected by using this equation.

Besides, in simple rotation model, the particles stay at the same distance of the rotation axis during the sedimentation of the layer. In restored state of the top S_t, an IPG-line is thus an arc of a circle centered on the rotation axis (fig. ??b). Consequently, IPG-lines are orthogonal to the stratigraphic parameter iso-surfaces in each point of the layer. For this reason, u and v parameters can be computed so that their gradient are orthogonal to the gradient of stratigraphy.

Nevertheless, these constrains may not be sufficient in more complex contexts, such as when lateral deformation occur (fig. ??c). A shift between the parameters extrapolated from the top surface S_t and the bottom surface S_{t+1} will occur at the location of these surfaces. Indeed, geometrical constrains on the parameters gradients cannot completely recreate the actual mechanical deformations.

2.2.3 *parameter interpolation*

In general case, the method presented in the precedent paragraph will produce unlikely discontinuous parameters. But, for a given layer $\mathcal{L}_t$, parameter extrapolated from the top and bottom surfaces can be combined for producing a continuous parameter. Extrapolated parameters are denoted respectively u_{top} and u_{bottom} for the parameter u and v_{top} and v_{bottom} for the parameter v. For each layer $\mathcal{L}_t$, u_{top} and u_{bottom} are blended using stratigraphic parameter as reference :

$$\forall \{x, y, z\} \in \mathcal{L}_t, \left\{ \begin{array}{lcl} \alpha & = & \frac{s(x,y,z) - s_{bottom}}{s_{top} - s_{bottom}} \\ u(x,y,z) & = & \alpha \cdot u_{top}(x,y,z) + (1-\alpha) \cdot u_{bottom}(x,y,z) \\ v(x,y,z) & = & \alpha \cdot v_{top}(x,y,z) + (1-\alpha) \cdot v_{bottom}(x,y,z) \end{array} \right. \quad (5)$$

An other solution would be to compute the paleo-geographic parameter trough a global optimization honoring both the entirety of the parameters computed on the restored horizons and a constrain on the gradient, either classical roughness criterion or orthogonality to stratigraphy criterion.

2.2.4 Restoration displacement extrapolation

This method aims at approximating the restoration vectors that actually bring inner-layer particles in their location of deposition (equation 6). The restored position of a particle is taken as the intersection of the straight line following the restoration vector direction and the horizontal surface at the depth of deposition z_h. As this depth may vary from one layer to another during the sedimentation, the Two approaches are investigated (fig. 6) :

- Extrapolation of top surface restoration movement.
- Restoration of the bottom surface without removing the restored layer.

$$\forall \{x, y, z\} \in \mathcal{L}_t, \left\{ \begin{array}{lclcl} z_h & = & z_{top} & + & (z_{bottom} - z_{top}) \cdot \frac{s(x,y,z) - s_{bottom}}{s_{top} - s_{bottom}} \\ u(x,y,z) & = & x & + & r_x \cdot \frac{z_h - z}{r_z} \\ v(x,y,z) & = & y & + & r_y \cdot \frac{z_h - z}{r_z} \end{array} \right. \quad (6)$$

2.2.5 Fine back-stripping parameterization

Even if actual stratigraphy is only interpreted on some horizons, an approximation is estimated by interpolating within the volume in between. It is thus possible to compute small increments of restoration producing a fine scale discretization of the model particles position. Doing so, an estimation of the restoration vector r of each particle is computed and can be directly used in equation 4.

Compared to other methods, fine scale back-stripping is the technique introducing the most geomechanics in the parameterization. However, a large amount of restoration computation is needed which may dramatically increase computation time and accumulate approximation which finally becomes sizeable.

3 Application of interpolation and observations

This section aims at comparing the different interpolation methods we proposed. They have been tested on a synthetic model (fig. 7).

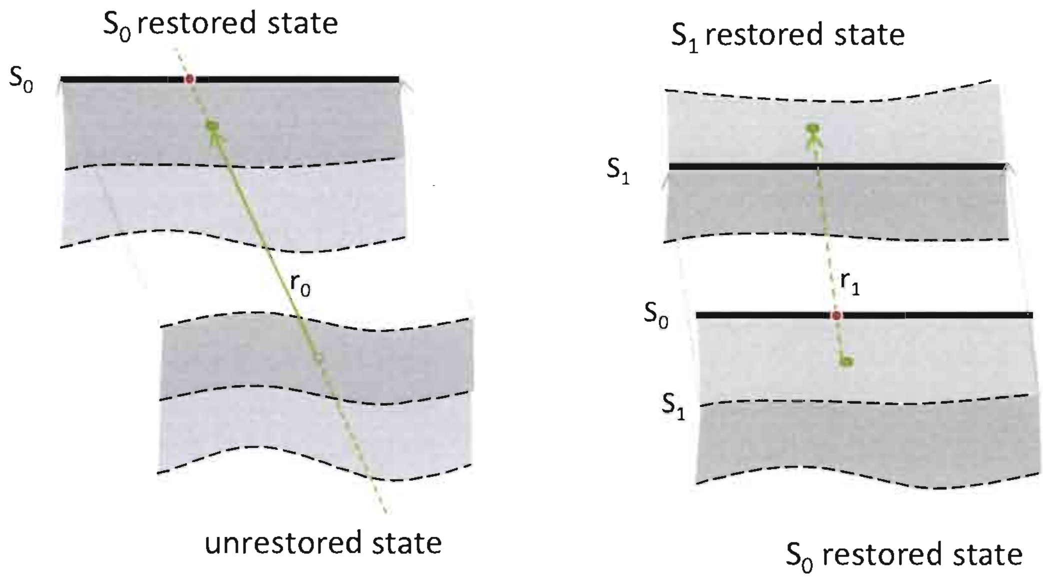

FIGURE 6: *this figure illustrates two possible approaches for computing the paleo-geographic parameters from extrapolating the displacement computed for restoring the top or bottom surface of a layer. On the left, the vector r_0 computed for restoring S_0 is propagated until to reach S_0 deposition depth. On the right, the layer S_1 has been restored without removing the layer at its top. Restoration vectors r_1 are also computed in the layer between S_0 and S_1.*

3.1 Synthetic reference model and fine scale parameterization

In a first stage, this model has been restored step by step with small increments for producing a fine back-stripping parameterization (fig. 8). This parameterization constitutes a reference for comparing with other interpolation methods.

The intensity of the deformation is null on the West border of the model and increasing to the East. This allows us to keep the same boundary conditions, no lateral displacement on West boundary, for all the restoration steps. This done for limiting the impact of boundary conditions on the parameterization. The model is constituted of two principal layers both subdivided into ten sub-layers. The top of the model is called S_0, the bottom of the first main layer S_1 and the bottom of the second main layer S_2. The intensity of the deformation is increasing with the depth, which simulates synthectonic sedimentation. The stratigraphy is modeled implicitly in order to simplify the meshing task. So we used techniques presented in [Durand-Riard et al., 2010] for the restoration as they allow to take implicit geometry into account.

Fine scale back-stripping is performed on the sub-layers using small deformations assumptions. For avoiding the restoration hypothesis to bias the comparison between the methods, the macro-scale restoration vectors are produced by stacking those of fine back-stripping.

3.2 Restoration-based methods compared to classical approach

Compared with classical methods used for computing GeoChron parameterization, restoration based parameterization allows to take geomechanics into account. In our example, this is particularly visible on the parameter v, which presents deformations related to Poisson's ratio (fig 9). This illustrates how accounting for mechanical processes can impact the parameterization.

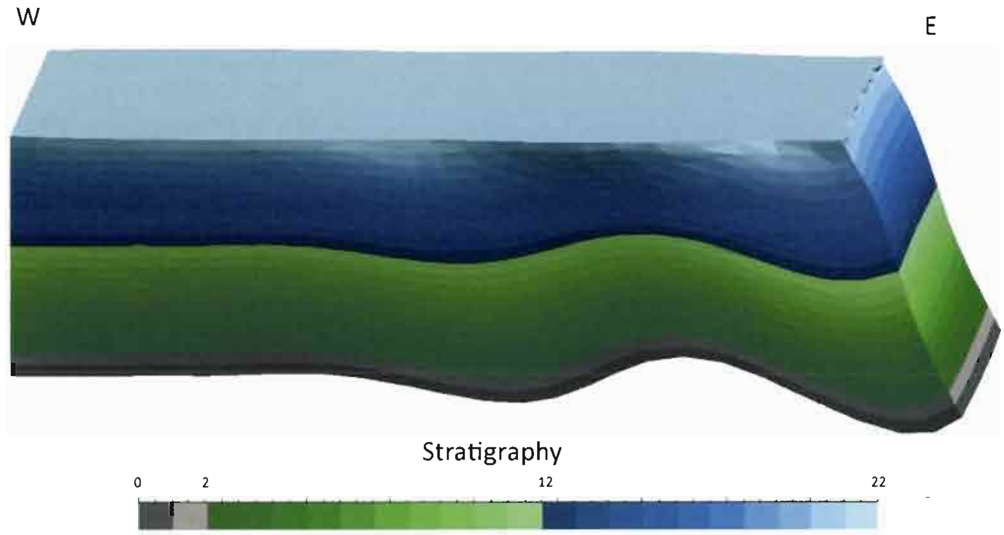

FIGURE 7: *the synthetic model used for the restoration painted with its stratigraphy. The model is presented in the restored state of the top layer.*

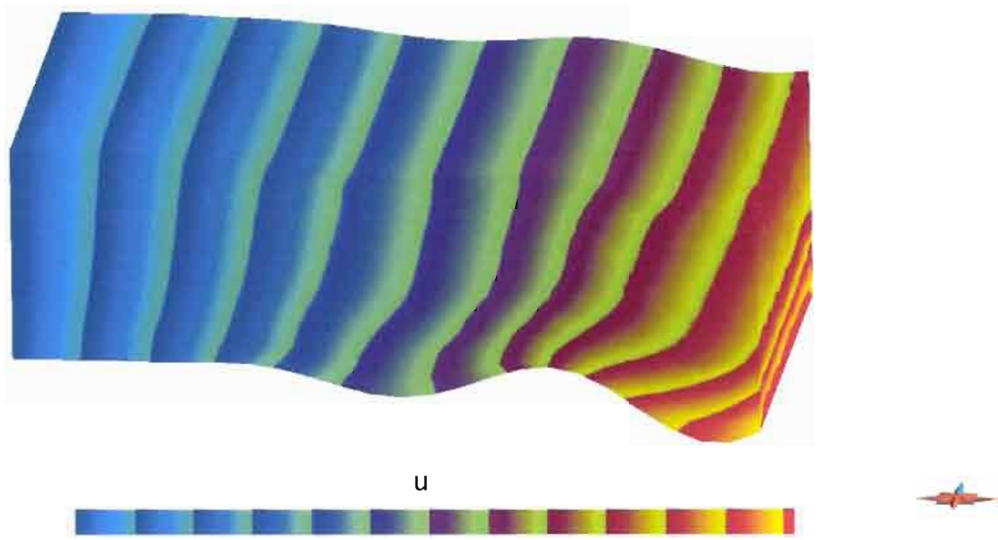

FIGURE 8: *the model is painted with one of the paleo-geographic parameter computed with the fine-backstripping approach presented section 2.2.5.*

3.3 Observations about interpolation methods

The geometric interpolation methods proposed in this paper have been designed for honoring the paleo-geographic parameters computed on the restored surfaces. This appears to be sufficient for giving a good first order approximation of the parameters computed with a fine scale back-stripping (fig. 10). Practically, a shift is observed far from the restored surfaces, in the areas with strong deformation parallel to stratigraphy. Indeed, this kind of deformation is more complicated to take into account because stratigraphy is used as a reference for the interpolation.

The methods based on restoration displacements extrapolation produce good general results as well. However, a lack of robustness has been observed were very small displacements occur. In fact, only

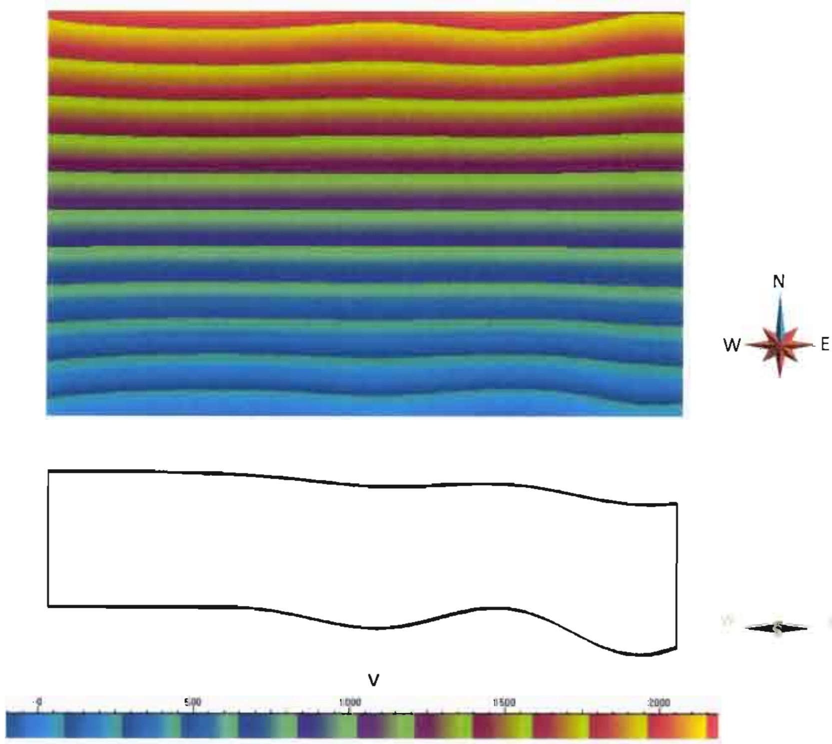

FIGURE 9: *parameter v computed from geomechanical restoration vectors, extrapolated orthogonally to stratigraphy and visualized from the top. The outline of the volume observed from south is represented at the bottom of the figure for comparing the parameter distortion with the folding localization. v shows contraction at intrados and dilatations at extrados parallel to fold axial direction. This is a typical behavior due to Poisson's ratio.*

the direction of the displacement vectors are considered and problems of precision appear, especially when the vectors are nearly horizontal. As this problem is principally concentrated near the restored surfaces, the solution of blending the resulting parameter with parameter geometrically extrapolated from the surface has been explored. Nevertheless, this reduces the interest of restoration displacement based method compared with geometric interpolation methods.

Conclusions and perspectives

To conclude, the first results presented in this article show how mechanical processes, which only are able to represent the complexity of geological deformations, can be integrated in the task of geometric modeling. The fine scale back-stripping approach is only capable of producing a purely geomechanical parameterization. However, because informations about stratigraphy are actually too sparse, this method seems to remain inapplicable or at the price of major approximations. It will also certainly turn to be dramatically time consuming in actual modeling. For these reasons, interpolations methods have been proposed allowing to compute paleo-geographic parameters from the parameterization obtained on a set of restored surfaces. The geometrical interpolation are the most promising methods. Indeed, they allow to honor the restored surfaces parameterizations while providing a relatively light and robust way of interpolating the parameters, either with constrain of constant gradient or orthogonality to stratigraphy.

This concept of parameterizing has now to be tested and validated. It would be particularly in-

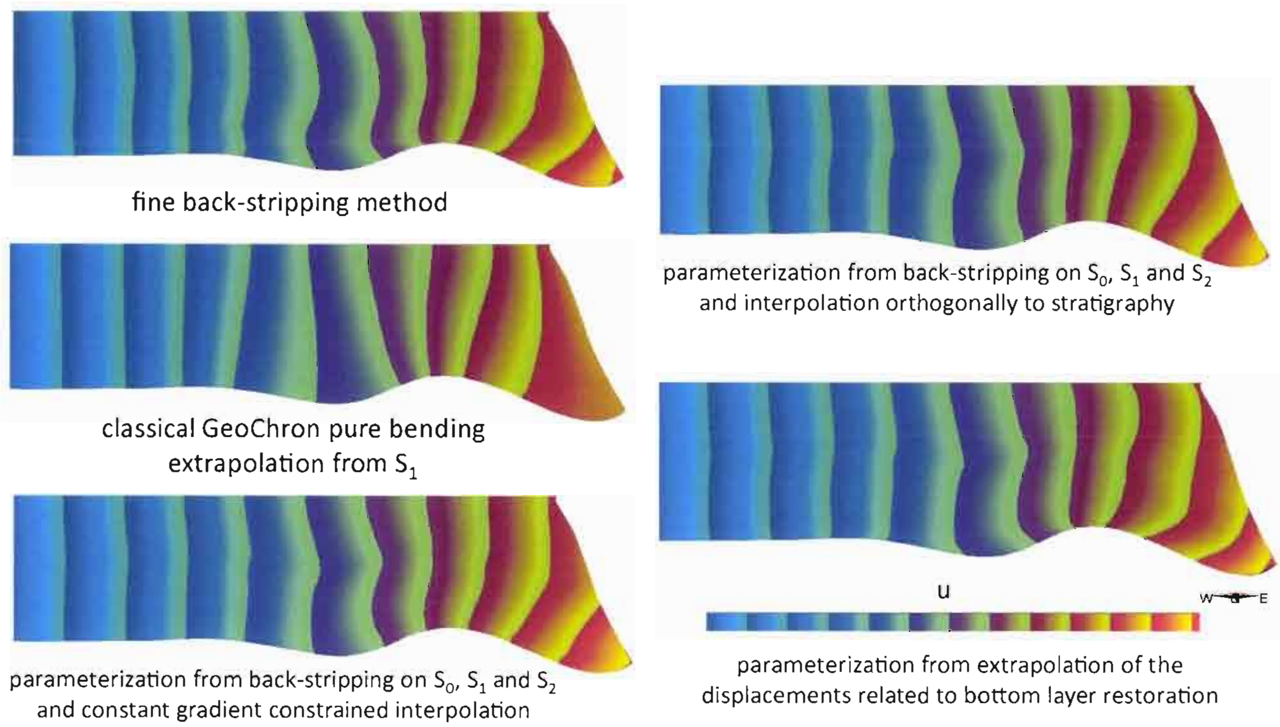

FIGURE 10: *parameter u computed with different methods.*

teresting to parameterize analog sand box forward models with this method. As they allow to record the complete deformations, computed parameters could be compared with actual initial positions. In the short term, observing the strain implied by the interpolated parameters could also be a way to validate the interpolation methods.

Nevertheless, the goal of restoration based GeoChron parameterization is not to replace classical geometrical approach. In fact, restoration uses a complete geomechanical model, which ideally implies to model some mechanical properties first and modeling properties properly needs a correct GeoChron parameterization. Parameterizing a geological model seems to be like a "chicken or the egg" causality dilemna. Two solutions are proposed among which a progressive parameterizing approach. This last would consists in firstly using a purely geometrical parameterization for modeling mechanical properties and then to perform a more precise geomechanical parameterization. An other solution would be to propose a coarse geomechanical model in input, which could be subsequently refined.

More generally, restoration based parameterization can also be seen as a way of analyzing sequential restoration results. One of the objectives would also be to better understand the influence of mechanical properties on the process of property modeling and how it impacts reservoir modeling and flow simulations.

Acknowledgments

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