A041 GEOLOGICAL LEAST-SQUARES CRITERIA FOR IMPROVING MACRO-MODEL ESTIMATES

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SUMMARY — Geological knowledge will help traveltime inversion to determine the shape of geological structures quantitatively. We consider various least-squares criteria: parallelism, developability and smoothness of folded interfaces, borehole dip measurements, and a new criterion related to the direction of fold axes. Numerical results demonstrate the feasibility of our approach. This work aims at integrating geology and geophysics quantitatively via multicriteria optimization.

INTRODUCTION — To introduce geological knowledge into the tomographic process, we follow the usual inversion approach which consists of three main steps: first, define the unknowns, second, find the data and build criteria, and, finally, optimize.

GEOMETRICAL MODELING — We model a geological structure locally with the geometrical concept of foliation, which is a pile of disjointed surfaces, called leaves, which represent deposition isochrons. We define a geological model globally as a set of jointed foliations since a single foliation would be inadequate where faults and unconformities occur. Physical properties like velocity or density could be assigned to each point for geophysical purposes. Numerical application requires parametric representation of these foliations which we discretize using B-spline tensor-products (Léger et al., 1991a). However, one foliation only is involved in the following.

GEOLOGICAL DATA — We now consider geological information. To obtain geological least-squares criteria we answer four questions. *Which properties can be assigned to a likely structure?* This yields the "observed" data. *How deviation from such properties can be defined?* This yields the data space. *To which extent such deviations are acceptable?* This defines the uncertainty in data space. *How can geological structure unlikeliness be measured using these properties and using acceptable deviations?* This results in geological objective functions.

Parallelism Deposition isochrons are almost parallel. We measure deviation from parallelism at any point of a foliation using the concept of convergence vector Γ (Léger et al., 1991a). We measure structure unlikeliness by the objective function $Q_\Gamma = C_\Gamma \int \|\Gamma\|^2 d\mathcal{F}$, where C_Γ is related to the uncertainty about parallelism.

Developability Deposition isochrons are almost developable (i.e. locally isometric to plane surfaces). We measure deviation from developability by the total curvature K of the foliation leaves and this results in $Q_K = C_K \int |K|^2 d\mathcal{F}$.

Smoothness Folding is not intense. We measure folding intensity of developable surfaces by the mean curvature H and this results in the objective function $Q_H = C_H \int |H|^2 d\mathcal{F}$.

Axial curvature In many areas, the axis direction of folds is known. Therefore, a vertical plane that contains this (horizontal) direction should cross any leaf of the foliation along a straight line. We measure the deviation of the actual axis direction from the known axis direction by the curvature Σ of that line and this results in the objective function $Q_\Sigma = C_\Sigma \int \|\Sigma\|^2 d\mathcal{F}$.

Wells Borehole trajectories and borehole correlations can be accurately known. For this reason, we formulate well information in terms of equality constraints, $C'p = c$, where p is the vector of the B-spline parameters and where c is the vector of the coordinates of the given points along the well(s).

Dip Dip measurements are often available along wells. We represent dip by the unit vector tangent to the local leaf of the foliation, and we define the objective function as $Q_N = C_N \int \|N - N_0\|^2 du^3$, where N_0 is known dip and where u^3 parameterizes each well.

INVERSION — The inverse problem finally consists in optimizing $Q_\varphi = Q_\gamma + Q_K + Q_H + Q_\Sigma + Q_N$ under the constraints $Cp = c$ using the Gauss-Newton procedure and the modified additional criterion method (Léger et al., 1991b).

NUMERICAL RESULTS — We present now numerical results that illustrate the positive effect of the axial curvature and dip criteria.

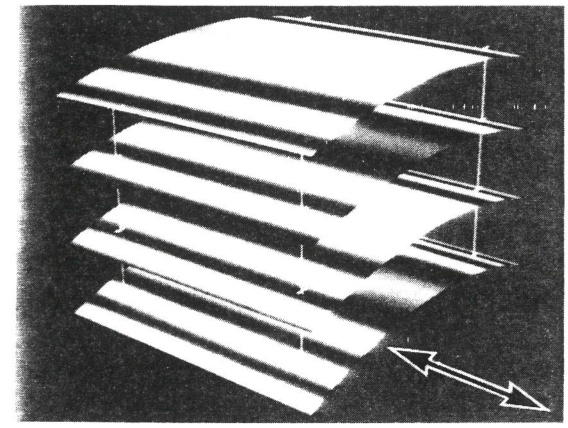

Figure 1. *Four wells and a point on the top surface are fixed. $Q_\varphi = Q_\Gamma + Q_H + Q_\Sigma$ is optimized. The arrow denotes the given direction of fold axes in Fig. 1 and 2.*

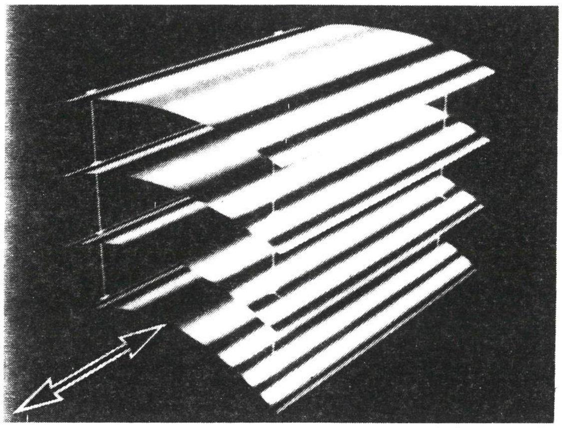

Figure 2. *Fig. 1 and 2 display distinct local minima of $Q_\Gamma + Q_H$. Using Q_Σ, this model as initial one may lead to the result displayed in Fig. 1, and conversely.*

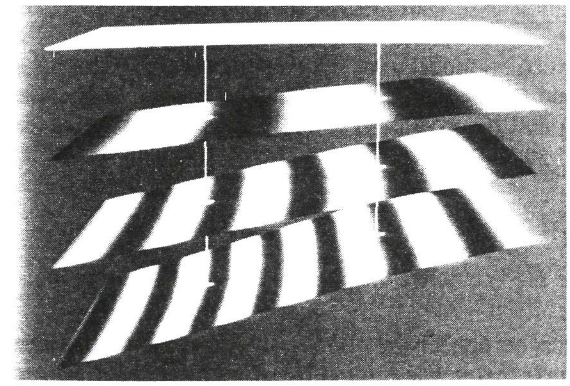

Figure 3. *The top surface and two wells are given. $Q_\varphi = Q_\Gamma + Q_K + Q_H$ is optimized. The constraints, and hence the result, are symmetrical.*

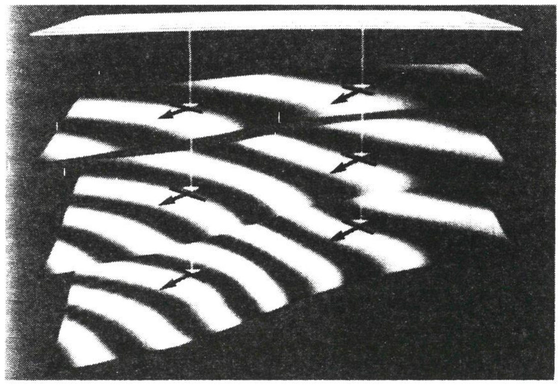

Figure 4. *Dip measurements along the wells are introduced. Hence, the result changes a lot. It is expected to be much better.*

CONCLUSIONS — Geological least-squares criteria substantially improve the result of macro-model inversion. The axial curvature criterion is particularly useful to "choose" between the different local minima that are due to the strong non-linearity of the total curvature. In this approach, traveltimes could be used instead of the well constraints. A lot of work remains to be done, first to model realistic complex structures made of several jointed parametrically represented foliations, second, to find other geological criteria that could constrain the shape of the faults, and third to develop tomography in these media so as to integrate structural geology and kinematical seismics.

REFERENCES

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