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DeliveryMassager - Propagating Seismic Inversion Information into Reservoir Flow Models

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SUMMARY

We present a new open-source program for the integration of stochastic seismic inversion information generated from the freeware Bayesian seismic inversion tool Delivery (Gunning and Glinsky 2004) with reservoir simulation models commonly used in modeling and flow-simulation packages. This modeling tool is able to integrate the full range of complex knowledge inferable from probabilistic seismic inversion with auxiliary geological and petrophysical information to produce an integrated model; a process we call massaging. The major innovative achievement of this code is the synthesis of multi-layer multi-property correlations inferable by the inversion with the transverse correlations induced by geological processes. The massaged model(s) are then directly suitable for uncertainty studies of volumetrics, scenarios explorations, or fluid recovery risking.

Abstract

We present a new *open-source* program for the integration of stochastic seismic inversion information generated from the freeware Bayesian seismic inversion tool *Delivery* (Gunning and Glinsky 2004) with reservoir simulation models commonly used in modeling and flow-simulation packages. This modeling tool is able to integrate the full range of complex knowledge inferable from probabilistic seismic inversion with auxiliary geological and petrophysical information to produce an integrated model; a process we call *massaging*. The major innovative achievement of this code is the synthesis of multi-layer multi-property correlations inferable by the inversion with the transverse correlations induced by geological processes. The massaged model(s) are then directly suitable for uncertainty studies of volumetrics, scenarios explorations, or fluid recovery risking.

Introduction

At the time an oil or gas field is being appraised or developed, the development of a reservoir model usually centers on the task of building computer models suitable for forward flow simulation. Prior to this, much of the work will have focused on data acquisition and interpretation, and the construction of models suitable for simple volumetric calculations or drilling decisions. In particular, much of the interpretative work will be based on seismic data, and this is routinely fed into inversion routines which produce estimates of the properties of direct interest, such as layer horizons (in time), layer thicknesses, hydrocarbon content, net-to-gross (NG) etc.

In previous publications and EAGE meetings (Gunning and Glinsky, 2004; Gunning and Glinsky, 2005), we have introduced an open source tool *Delivery* that enables users to perform a fully probabilistic seismic inversion for a 'meso-scale' layer-based model of the reservoir. This is a trace-based inversion, so it produces an ensemble of realisations of the relevant reservoir parameters at each trace in the imaged seismic grid over a field. The 'meso-scale' layer resolution is usually around 5-20m. At each CMP location, the inversion provides a full joint-probability distribution of quantities like the layer thicknesses, fluid content, NG, layer times, and velocities. This data is directly suitable for answering the simple kind of questions mentioned above, such as point-wise histograms of layer thickness, maps of hydrocarbon probability etc, but is not directly suitable for flow calculations.

For the calculation of volumetric (not point-wise) uncertainties, and the task of flow simulation, it is necessary to carry these inversion calculations over to grid formats that are more directly useful in 3D volumetric calculations and flow calculations. We use cornerpoint grids, which are used in the ECLIPSE family of flow simulators and modeling packages like PETREL. Further, the effect of inter-trace correlations in the seismic data (which is deliberately neglected in *Delivery*) can be captured in this remapping calculation. The objective is to produce 3D models that capture both transverse correlations known from either well data or geological analogues, and the vertical inter-layer and inter-property correlations that seismic inversion can reveal. Since the inversion models are stochastic, it is natural for the remapped or `massaged' models to be stochastic as well. The objects of interest will then be the 'most likely' massaged model, as well as a suite of "realisation" models, which enable stochastic forward flow simulations to be performed for risking purposes.

The *DeliveryMassager* code has several modes of operation. It can produce "most-likely" reservoir models for flow evaluation or volumetric analysis, or ensembles of models for uncertainty studies. Another mode of operation produces fine scale facies simulations via a downscaling or "decoration" algorithm, which produces subseismic models that honour the bulk net-to-gross properties detectable at the seismic scale, whilst preserving the fine scale depositional and correlation structures which often influence flow behaviour at the subseismic scale. We briefly describe the algorithms and show an example.

Theory

Transverse and vertical correlation synthesis algorithms

The problem is one of merging spatial correlations which are prescribed with inter-property correlations which are inferred in the process of seismic inversion, while honoring hard well data. The theory we use is derived from the multi—Gaussian framework and is a kind of generalised *p*-field simulation.

We spatially smooth the means and covariances of the multi-property *Delivery* output ensembles to produce a smooth trend map for each property and a smooth between-properties trend covariance. The trend map may be allowed to have discontinuities at faults for certain properties. The property trends are then deformed by a kriging adjustment from well observations to produce a trend that passes through all hard observations. The kriging-variance maps produced in the kriging calculation are normalised and stored for each property, for later use. The maps may be truncated or clipped depending on consistency requirements for the properties (e.g. net--sand will be clipped to less than thickness). The trend maps then constitute the most-likely maps of properties. The uncertainty maps are defined by the diagonal entries of the smooth trend covariance multiplied by the kriging variance maps. The square root of the latter map is then a local standard deviation' for each property, which honours the inversion uncertainties and the well data.

To generate realisations, a set of normalised, spatially correlated random fields (p-fields) are simulated for each property. At each spatial location these fields are then mixed in a linear combination described by the Cholesky factor of the smooth between-properties trend covariance. The final set of fields are then scaled by the normalised kriging-variance maps and added to the trend maps to produce a series of realisations.

Downscaling, or `decoration' algorithms

In most realistic applications, fluid flow will be sensitive to the manner in which impermeable material (usually "shale") is spatially dispersed within the `mesoscopic' reservoir layers used for the inversion. Capturing this effect will then require subdivision of the vertical gridding and suitable categorical simulation of the shales within a mesoscopic layer.

This categorical simulation must be consistent with the vertical average of the shale content obtained from the seismic inversion: the inversion forward model uses an effective-medium approximation based on a separation of length scales between the vertical spatial scales characterising the shale distribution and the seismic wavelength. In this regime, the effect of the shale on the seismic response is then captured by an effective macroscopic parameter, the layer NG, via the Backus average. The model also assumes a laminated distribution of shale, which is a respectable assumption for reservoirs where internal shales are usually gently dipping.

The categorical simulation must then yield an internal layer shale distribution that honours the mesoscopic NG, which is a vertically averaged fraction of permeable-rock thickness to overall thickness. We use an adapted "greedy truncated-Gaussian" algorithm for the decoration problem, on account of the efficiency of simulation of the underlying continuous field (le Loc'h and Galli, 1996). Other categorical techniques like Markov Random Fields or indicator simulation could be equally adapted. Users are expected to furnish a 3D variogram describing the spatial continuity of the underlying Gaussian field. The algorithm we describe is somewhat heuristic, but very efficient, and strikes a good compromise between the connectivity embedded in the variogram and the coarse-scale inversion constraints. The algorithm runs roughly as follows, conditional on some known realisation of NG on the coarser grid:

The layers are subgridded to the desired vertical resolution. A multigrid traversal of the fine-scale grid is generated, visiting entire columns of gridblocks at a time, with widely spaced blocks visited earliest. The sequential-Gaussian conditional kriging weights for an entire column are computed and stored, enabled rapid repeated simulation of the Gaussian field for the column. The truncated Gaussian threshold is computed from the coarse-scale NG, and multiple realizations are drawn of the column. The realization with the best fit to the NG is (greedily) chosen, and the algorithm proceeds to the next column. Categorical models within a fine-scale gridblock's resolution of the target NG can usually be drawn with this method.

Field Example

The Stybarrow field off Western Australia has been subjected to the full gamut of *Delivery* style workflow. A more comprehensive overview is given in Glinsky (2005). The field is an early Cretaceous turbidite sandstone, whose structure comprises a narrow, wedge-like NE-to-SW tilted fault block, with normal faults providing closure to the SW.

The seismic inversion was calibrated by a four well simultaneous wavelet extraction. The well ties and bandwidth are good enough to yield respectable fluid detection and net-to-gross inversion. Inversion uncertainties increase in the brine leg to the NE where the reflections dim with additional pinchouts.

Figure 1 shows the effect of the massaging on the most likely model. Various realizations of the meso-scale model may be drawn for volumetric uncertainty studies (Fig. 2). Fig. 3 illustrates how the decoration algorithms can yield a variety of subscale facies maps consistent with the inversion data.

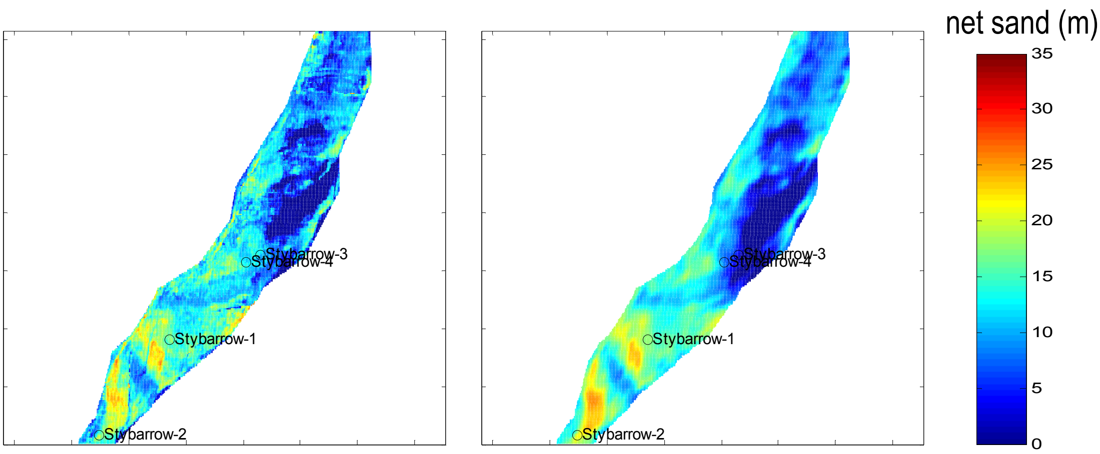

Figure 1: Most –likely reservoir net-sand before and after applying massager step. The effect of imposed correlations on suppressing the seismic and inversion noise is obvious.

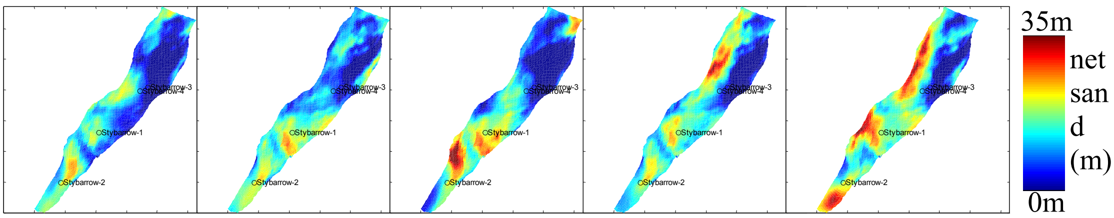

Figure 2: Net-sand realizations for main reservoir. All images are consistent with the seismic inversion and the specified transverse variograms.

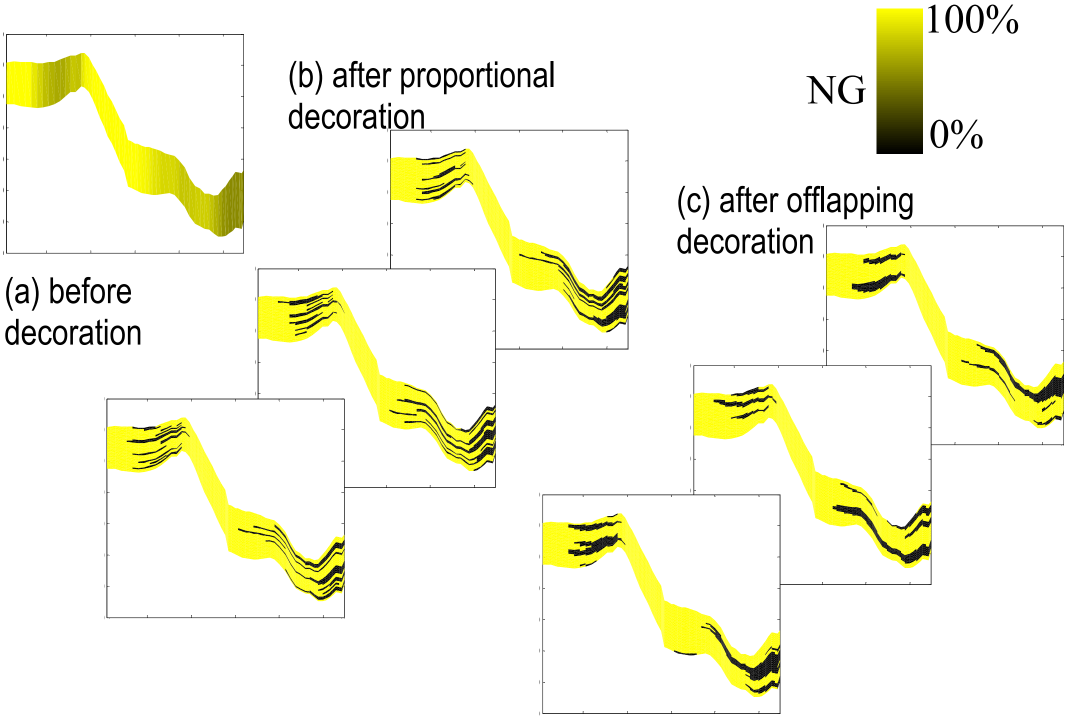

Figure 3: Decorated facies realizations consistent with the net-to-gross realization (a) constrained by the seismic inversion. Possible realizations for both (b) proportional and (c) offlapping systems are shown.

Conclusions

The *DeliveryMassager* code is essential for the task of propagating the complex information available from seismic inversion further into reservoir engineering models. Reservoir models honouring the full multi-layer, inter-property constraints available from seismic inversion with well data and geological continuity requirements will yield greatly improved estimates of reservoir architecture and uncertainty.

References

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