Multi-Layer Reservoir Modeling

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Introduction

When developing an oil field, it is of prime importance to minimise the uncertainty associated with the volume estimations by using the most up to date well and seismic information. The objective of the study presented here is to develop a general methodology for modeling a multi-layer field that can be applied each time new data becomes available so as to continually update the volume calculations. The main sources of uncertainty come from the reservoir's geological structure, the variability of petrophysical properties and the OWC and GOC locations. Within the geostatistical framework it is possible to generate several simulations of the unknown reality that are completely consistent with the observed distribution and the spatial behaviour of the structural and petrophysical parameters. The probabilistic distribution of GRV, HCPV and STOIIP can then be obtained and used to get unbiased volume estimates and to quantify the risk associated with them.

The methodology is developed in order to best reflect geological structure of the field, that can be considered as a faulted layer cake system. It is applied to calculate a base case model by using estimation techniques, based on kriging. This allows us to visualize the general shape of the modeled reservoirs and verify the suitability of the model from a geological point of view. The final step is to apply the same concepts by means of simulation techniques so as to obtain reliable distribution curves of the volumes. Three main steps are involved in the study:

1. Modeling the geological structure.
2. Modeling the petrophysical parameters.
3. Volume calculations according to different OWC whose uncertainty can be characterised by a given probability distribution.

Field & data description

The technique will be illustrated on an oil field located in the North Sea. The field is composed of 11 reservoirs that constitute a large anticline structure that is oriented North-East South-West. The reservoirs are located below the base cretaceous unconformity (BCU) which has eroded the entire structure over the field. On the eastern side a major failure splits the field into two areas with quite different structural characteristics, making the depth conversion and the reservoir structural modeling even more complex. The presence of a large number of normal faults, clearly visible on seismic sections, has to be integrated in the modeling approach as they are important in the delineation of hydrocarbon contact domains. Finally each reservoir has a different OWC resulting from the production history.

The data available is comprised of a 3D interpreted seismic survey and approximately 180 wells, most of which are deviated. When modeling a reservoir, the limits between the geological units are defined through geological interpretation and seismic time picking. The seismic input to the proposed technique is 2D time maps of the picked seismic markers. From these 2D maps, a fully consistent 3D reservoir model will be built. Due to seismic vertical resolution, the seismic markers are not available for all the reservoirs. The layers where no seismic data is available are called geological zones and processed separately.

Concerning the normal faults, fault polygons for each seismic marker were used to build a geologically consistent model.

For STOIIP calculation, petrophysical parameters are needed to complete the reservoir model. Average Net to Gross and porosity at the mid-point of the intercepts between wells and layers are also provided.

Modeling the geological structure

When dealing with a layer cake type field, it is possible to go further than standard sequential techniques, by considering the spatial correlation between all the layers simultaneously using a multivariate variogram model. The standard approach when dealing with such a field is to sequentially krige the individual layers from the top down. This approach, that treats the layers independently, has some important drawbacks:

- The smoothing effect of kriging is even more accentuated when going deeper into the layer cake system, as this approach cumulates the errors made in the preceding layers.
- The interaction between the different layers, that is the correlation between interval velocities is ignored.
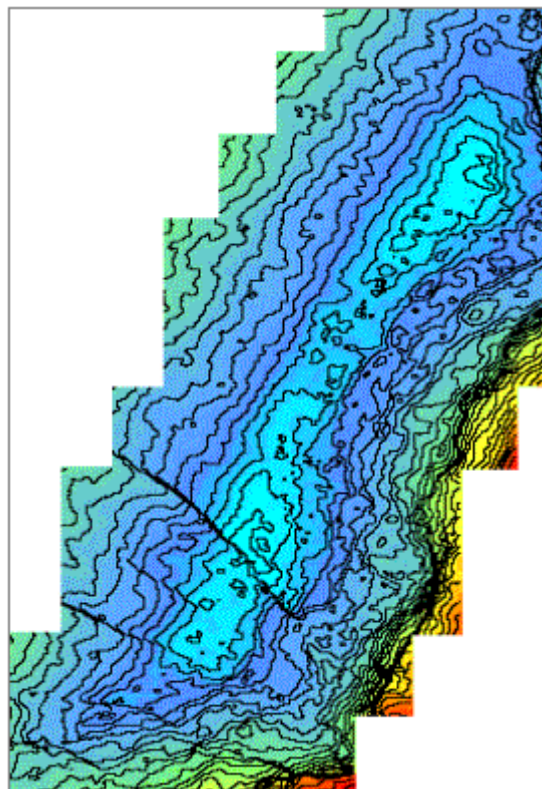

Figure 1: Depth map of the layer-cake reference surface (top layer of the layer-cake reservoir)

The proposed new methodology, based on a multi-layer approach, treats all layers simultaneously while taking the interaction between them into account. Thus it provides an optimal estimate of the interval velocities or thickness for the whole layer cake system.
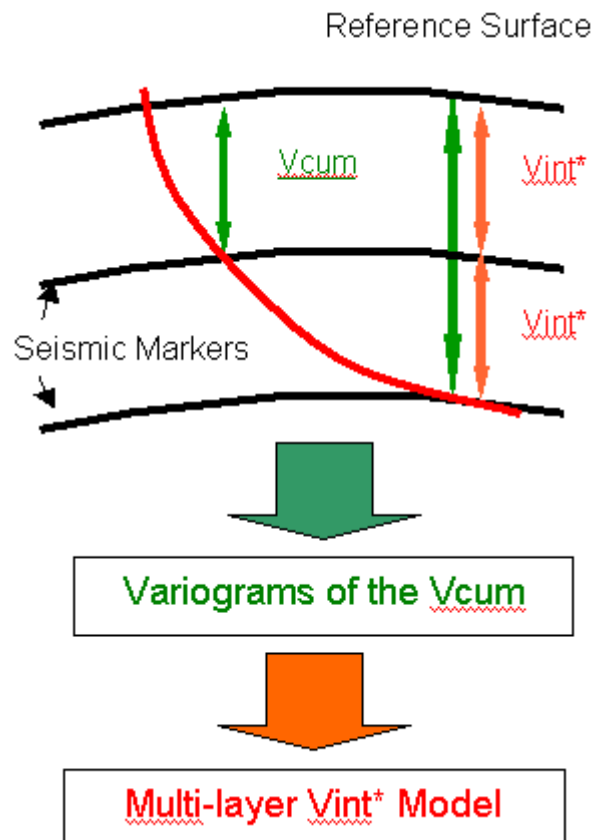
Figure 2: Workflow for deriving the interval velocity model from the cumulated velocity in the presence of deviated wells

The methodology is applied in four steps:

1. The reference surface of the whole layer cake system, the unconformity and the erosion surfaces are calculated from wells and seismic data using standard kriging techniques. These latter surfaces will just be applied afterwards for truncating the layer cake model itself.
2. The surfaces that correspond to seismic markers are calculated using this global multivariate time to depth conversion method. The interval velocities (Vint*) are cokriged from cumulated velocities (Vcum) at the wells intercepts using the respective time maps as external drifts (see Figure 2).
3. The previously obtained seismic surfaces will be considered as known. The surfaces of the intermediate layers (geological zones) are then calculated using a collocated cokriging method. The thickness of each intermediate layer is cokriged from cumulated thickness at the wells intercepts. A collocated cokriging is performed using the total thickness between two successive seismic markers as the collocated variable. This ensures that the intermediate layers respect both the well and seismic data.
4. To obtain a structurally realistic model, the faults are taken into account. To do so the fault surfaces are interpolated between the digitized fault polygons of two successive seismic markers. They are then applied to constrain the intermediate zones and reproduce the observed throws.
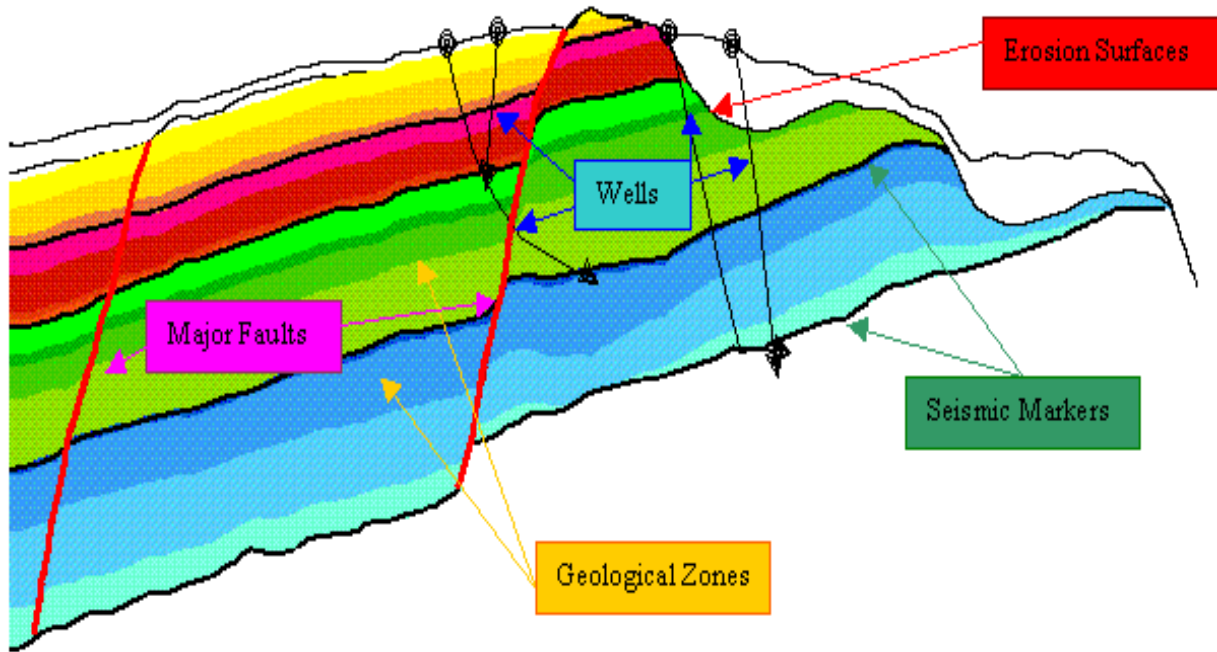
**Figure 3: Final structural reservoir model cross-section
where normal faults, deviated wells, erosion surfaces can be seen**

This new multi-layer modeling technique presents major improvements over existing techniques for the following reasons:

- Existing methods, based on variograms, cannot be used because of the highly heterotopic nature of the data. When the wells are deviated the intercepts with the different layers are at different locations in the (X,Y) plane. So any variogram calculation is effectively restricted to only the vertical wells. All data coming from deviated wells can only be taken into account via the use and modeling of multivariate simple and cross covariances.
- Existing methods require an empirical re-scaling "post-processing"of the estimated intermediate layer thicknesses so that their sum matches the total thickness between the seismic markers. This constraint is automatically fulfilled by the use of collocated cokriging.
- Applying the methodology to produce multi-layer simulations is straightforward, and as such it represents a powerful tool for characterizing the uncertainties on oil volumes.
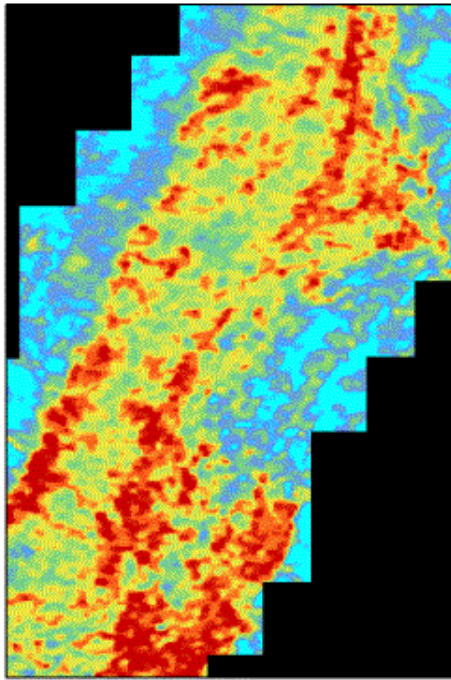
Figure 4: Porosity map of a particular geological zone derived from well porosities and seismic acoustic.

Modeling the petrophysics

The petrophysical parameters treated here (N/G and F) are assumed to be independent from one geological zone to the next. They are kriged or simulated using a gaussian based technique, which allows us to take into account geographical or vertical trends. In order to reproduce the disymmetric distribution observed for most layers, the data are firstly transformed into normal scores. After simulating the normal variable, the simulated values are back transformed to respect the original distribution.
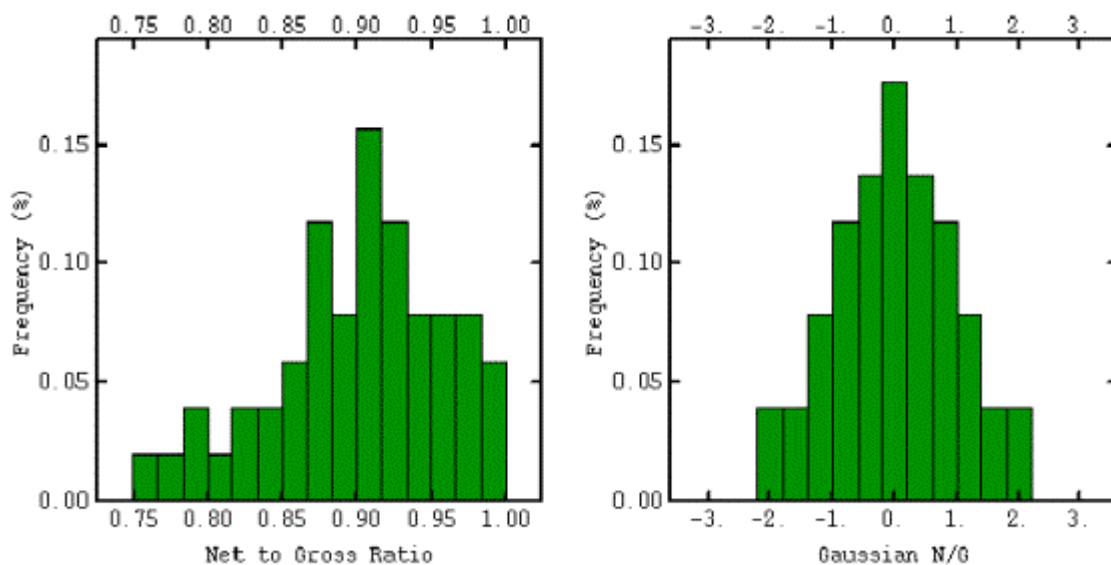

Figure 5: An example of a normal score transformation of Net to Gross data.

Volumes calculation

The geological structure and the petrophysical parameters are simulated within predefined polygonal areas to 0calculate volumes and perform risk analysis. The interaction between the variables is taken into account by performing the simulations within nested loops on the following categories:

- erosion surfaces
- reference surface
- surfaces of the seismic layers
- surfaces of the geological zones
- petrophysics (N/G and F).

The water saturation is algebraically derived from the other parameters, height above the oil-water contact (OWC) and porosity.

The result is a combination of the different sets of simulations. An OWC is applied to each element of that combination in order to calculate the volumes. The OWC is drawn at random from a distribution (constant, uniform, gaussian or triangular) defined by means of its statistical parameters. The field can be partitioned into many segments so as to apply a changing OWC throughout the field. When looking at all the simulations together, the distribution of possible volumes can be derived. One can then calculate P10, P50 and P90 for each layer individually or for a set of layers as shown in the figure 6. In addition at each grid node we can obtain the average value and the standard deviation for the following quantities:

- layer depth.
- height above contact.
- GRV, HCPV or STOIIP.
- probability of the height above contact being above a set of threshold values.
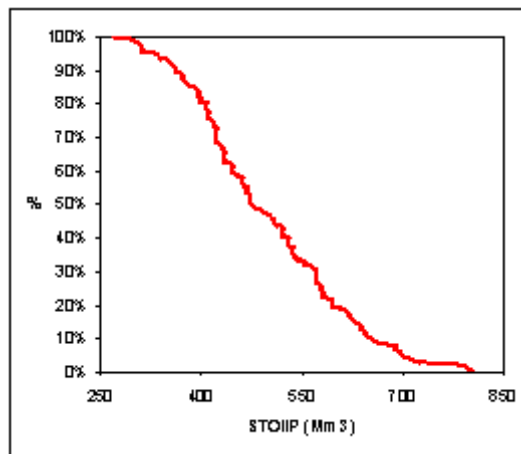- quantiles of the depth values for a set of frequency values.

Figure 6: Example of the distribution of volume obtained from simulations.

Potential applications

Sensitivity Analysis

Quantifying the uncertainty on volumes or structural model is an important objective, but the characterisation of the impact on the uncertainty of a few key parameters is equally important either at the exploration, appraisal or production stage.

An interesting application of these nested simulations consists of performing simulations on only one of the above sources of uncertainty (structural or petrophysics), the other ones being considered as known (base case). This allows us to study the sensitivity and hence quantify the influence of just one particular group of parameters on the volumes. This can help in defining the main sources of uncertainty and hence in managing new data acquisition.

Depth Conversion

The proposed technique presented above can be used as a depth conversion tool. It compares favourably with other techniques like linear velocity modeling
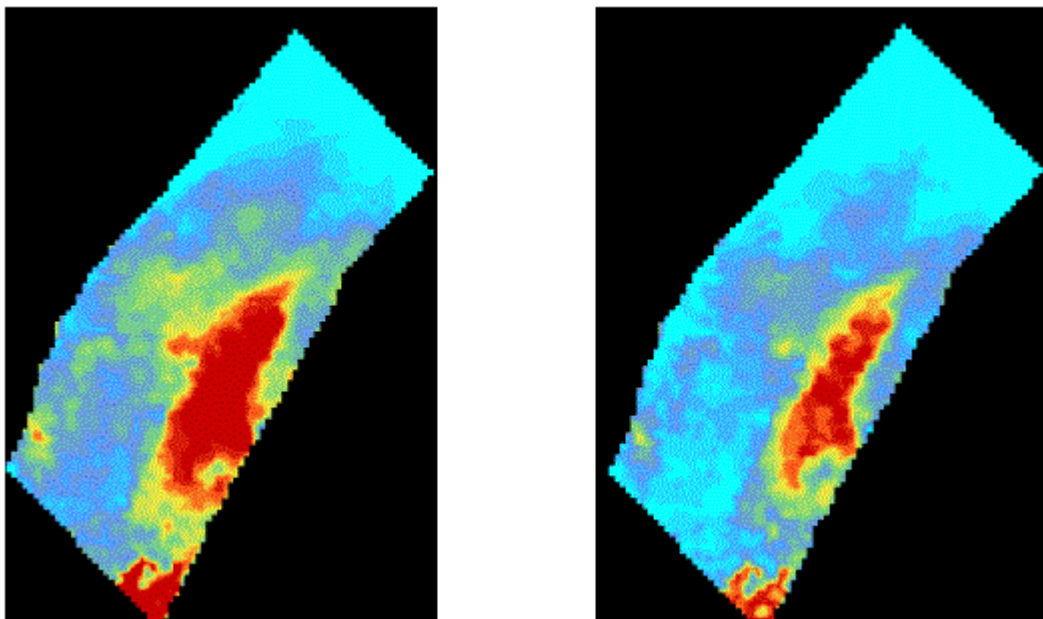

Figure 7: Probability of the height above contact being above two threshold values (10m left, 20 m right) for a portion of one geological zone.

Conclusions

This methodology, based on 2D modeling techniques, is particularly attractive because it can produce a model of layer cake type reservoirs that is fully consistent in 3D. The method has been applied successfully on a North Sea field and the results have been obtained using *Isatis and Isatoil packages*. The whole procedure can be run in batch mode, thus allowing volumes to be updated, as new wells or new seismic interpretations become available. This procedure makes possible to correctly follow the risk evaluation throughout the development of an oil and gas field, thus making its management more efficient.