

Creating probability trend models for facies properties

Using multidisciplinary multiscale data to create nonstationary facies probability trend models



David Márquez
Product Analyst Petrel
Modeling

Product Analyst **David Márquez** and Global Geoscience Workflow Consultant **Didac Gese Jarque** show how to create probability trend models to constrain facies models in the Petrel E&P platform. **Data analysis** and **trend modeling** processes are used to create laterally and vertically nonstationary facies probability models from well logs and seismic-derived data.



Didac Gese Jarque
Global Geoscience Workflow
Consultant

Industry challenge

One of the main challenges in the upstream hydrocarbon industry is to build reservoir models that can be used to obtain reliable estimates of the original volume, spatial distribution, and dynamic behavior of hydrocarbon reservoirs, as well as the associated uncertainties. This information is paramount to assess the economic value of a reservoir, predict reservoir performance under different production scenarios, and optimize the development plans.

A critical step in the reservoir modeling workflow is to create a detailed and geologically sound facies model, primarily because the lithological characteristics of the reservoir rock and their spatial distribution affect the distribution (connectivity, range of variability, anisotropy, and degree of heterogeneity) of the petrophysical properties (porosity, permeability, and fluid saturation) that are required to compute the hydrocarbon in place and perform the numerical simulation of the reservoir.

Why model discrete property trends?

The lithological characteristics of the reservoir rock and their spatial distribution are the result of particular depositional and transport patterns as well as diagenetic changes. The facies model, therefore, provides the link to the sedimentological-depositional model of the reservoir, which ultimately characterizes the volume, spatial distribution, and dynamic behavior of hydrocarbon reservoirs. As with any natural phenomena caused by geological processes, reservoir facies may exhibit large-scale trends, i.e., slow, gradual changes in the spatial distribution and the direction of continuity over the area of interest. Such spatial trends must be accounted for to obtain geologically and statistically reliable facies models that are to be used to predict the fluid volumes and flow within the reservoir, and reduce the inherent uncertainty.

Different trend models can be created to analyze different depositional settings or geological scenarios. However, it is important to point out that the presence or not of a trend will depend on the scale of observation of the available data. It is the job of the modeler to determine when observed

trends are significant enough to be accounted for in the model. If there is not strong evidence of a trend in the available data, if the observed trend is not geologically meaningful, or if not enough data are available to build a reliable trend model, then it might be better to keep the modeling simple and not model an explicit trend.

One of the major questions faced in geostatistical property modeling is: *How can we use and optimally combine all the available geological and geophysical data to build a probability trend model for the discrete properties?* Once the probability models of the observed facies trends have been built, it is then straightforward to use them as constraints in any of the cell-based or object-based facies simulation algorithms available in property modeling in the Petrel[®] E&P platform. The resulting facies models will then honor the input well data and the spatial distribution induced by the trend models.

Of course, the choice of the simulation algorithms and their respective parameterizations, as well as the input data type including the trend models, will impact the spatial distribution of the facies in the 3D geological model. Selecting the appropriate facies models among the many possible geostatistical realizations is an iterative interpretation process that requires considering several project-dependent static and dynamic ranking criteria. Such analysis is beyond the scope of this article. The purpose of this article is to illustrate some of the tools available in Petrel property modeling that allow you to successfully integrate data from different sources and of different scale to build probability trend models. This article will focus on the use of the trend models to constrain the widely used stochastic facies modeling technique known as sequential indicator simulation (SIS). Details of how to correctly set up the SIS parameters such that the facies models fully honor all the input data are also discussed.

What are probability trend models?

To determine how much of each particular facies you should expect to see and how the facies should be distributed within the 3D grid, the target probability distribution of the various facies must be specified. In Petrel facies modeling, the target facies probability distribution is characterized by the facies global fraction parameter and trend models. The spatial distribution and resulting global proportions of the simulated facies within the 3D grid will then be determined by the combined information provided by the target global fraction, trend models, and the selected variogram models of spatial continuity for each facies.

In the simplest case, a constant value per facies (and per stratigraphic zone) might be used to define the target probability distribution of the facies within the 3D grid. This means that the probability of occurrence of a given facies code throughout the 3D grid will be the same constant value determined by the **Global fraction** parameter (see Fig 1). Usually, the constant global fractions are estimated from the input upscaled (or raw well) data. When additional supporting information is available (e.g., fractions estimate of targeted sands from an analogue reservoir), a constant global fraction can also be manually entered for selected facies codes.

[®] Mark of Schlumberger

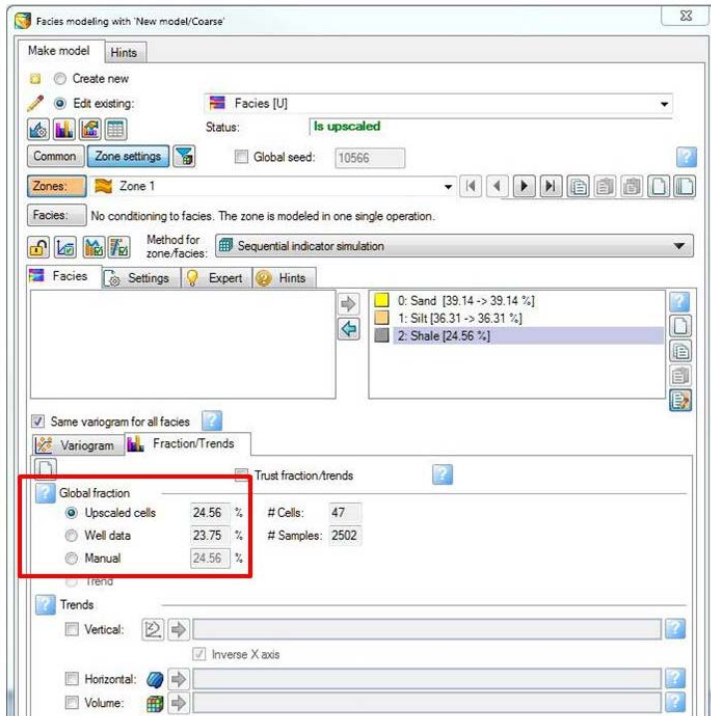


Fig 1. Global facies fractions, simplest case with constant proportion value per facies (and per zone)

As stated before, any observed trend in the spatial distribution and direction of continuity of the reservoir facies must be accounted for to obtain reliable predictive facies models. Furthermore, since the wells are usually preferentially drilled into the good parts of the reservoir, the facies proportions calculated from the upscaled data are generally not representative of the overall field probability distribution. In cases in which the facies proportions cannot be specified as constant (per zone), a probability trend model need to be created from available data and used as input in in facies modeling to guide the probability of occurrence of each facies throughout the 3D grid.

A probability trend is a model in which each cell value represents the probability or expected proportion of a particular facies. For a given facies type, a probability trend model should be created for each facies code value present in the property. That is, if M different facies codes are present in a given facies property, a probability trend model for the facies property will consist of M trend objects, each one defining the probability or expected proportion of a particular facies code. The trend models can be defined in the form of vertical proportion curves (1D trend), horizontal probability maps (2D trend), or probability volumes (3D trend). Fig 2 shows examples of 1D and 2D probability trend models, for a facies property containing three facies codes (sand, silt, and shale). In any case, the probability values of the facies trend models will usually be normalized such that the sum of the probability values of all existing facies models at the same cell location is equal to 1.

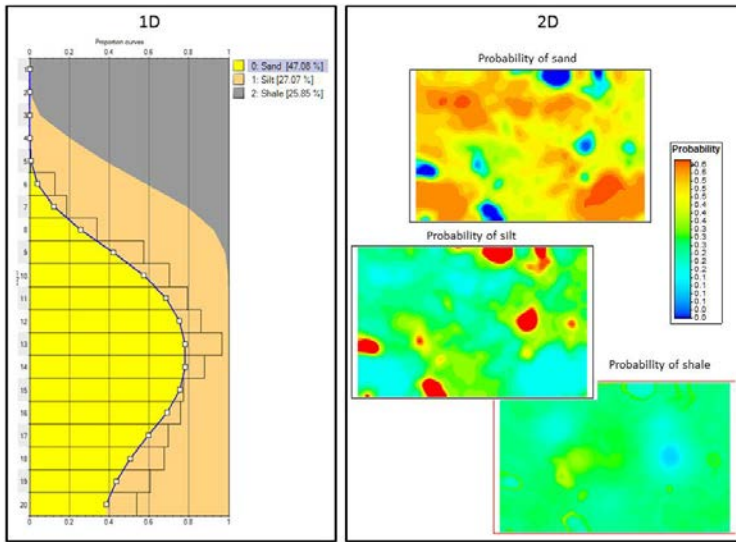


Fig 2. Examples of vertical (1D) and areal (2D) probability trend models

Note that the probability trend models represent soft constraints, in the sense that the algorithm does not use their values as a hard data to match, but as guidelines of how much of a given facies there should be and how, in a gross sense, the facies should be distributed within the 3D grid. Nonetheless, probability trends do have a strong impact on the results, so they should be used with caution.

Vertical proportion curves using well log data

When only a vertical (and not lateral) depositional or diagenetic trend is observed in the available data, 1D vertical probability trends can be used to constrain the vertical distribution of the facies property. The data analysis process in Petrel property modeling enables computing, displaying, and editing vertical proportion curves, based on estimates from the selected input data of the proportion of each facies for each layer of the selected stratigraphic model zone. The modeled vertical proportion curves can then be directly used as 1D trend models in facies modeling to control the vertical distribution of the facies proportions (see Fig 3):

- At each stratigraphic layer, the vertical proportion curve defines the probability of simulating the associated facies.
- The curves are stratigraphic in nature and follow the layering and vertical resolution defined by the 3D grid.

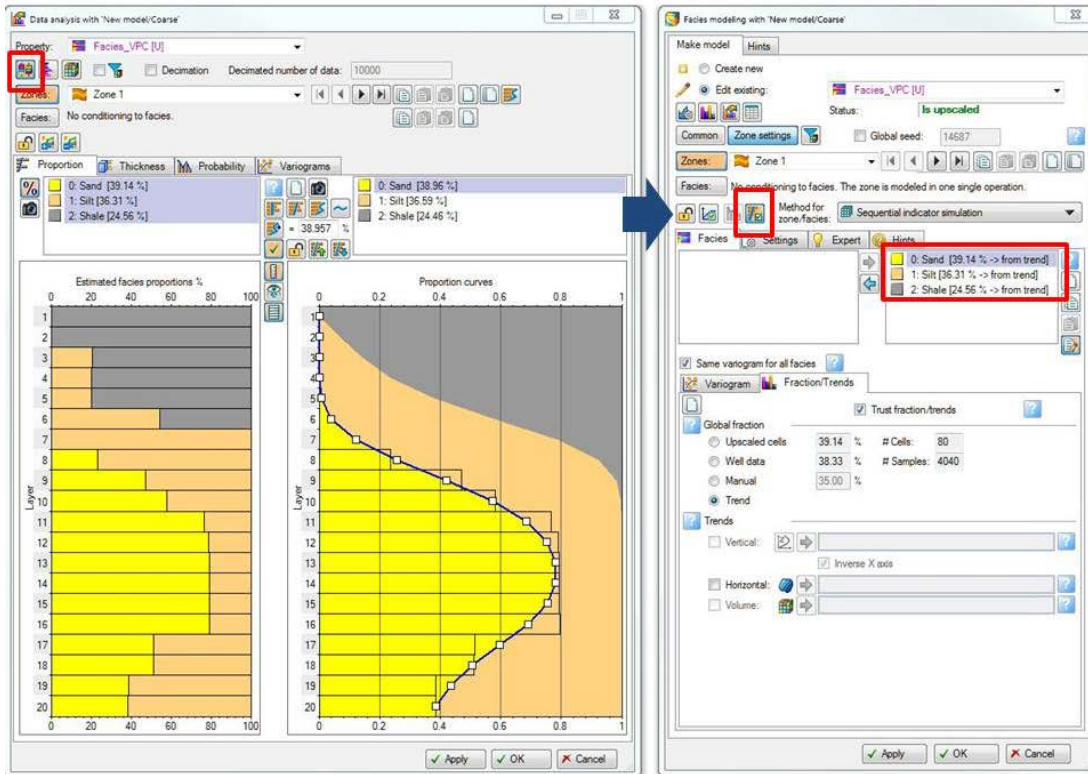


Fig 3. Vertical proportion curves (left) can be directly used as 1D trends for global facies proportions in facies modeling (right)

As stated before, the spatial distribution of the resulting simulated facies model will ultimately depend on the combined information provided by the target global fractions, the spatial distribution of the facies fractions (trend models), and the selected variogram model of continuity for the facies. For the SIS algorithm, a target fraction honoring parameter allows changing the weight that the simulation algorithm will give to honoring the input facies global fractions (Fig 4). The closer the target fraction honoring value is to 1, the more emphasis will be given to honor the input facies target global fractions and the lesser to honor the actual spatial distribution (trend) of the facies within the grid.

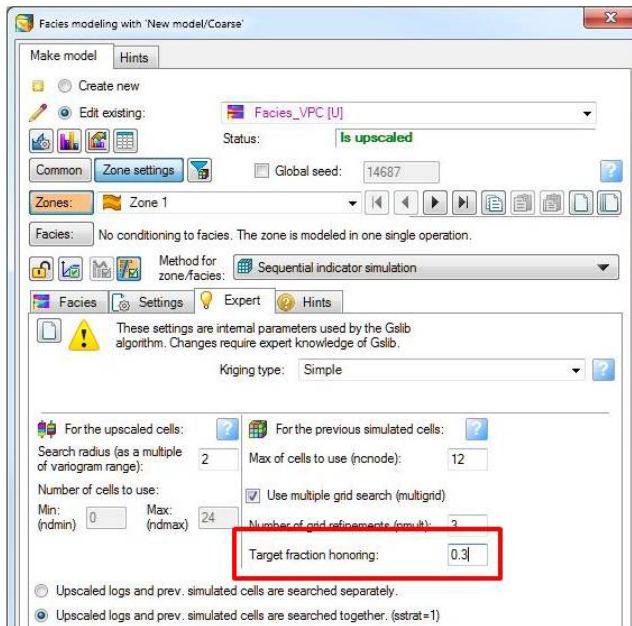


Fig 4. The target fraction honoring value determines how much weight is given to honor the target global fraction.

How well the simulated facies model will honor the input parameters (global fractions, trends, and variogram models) will therefore depend on both

- The consistency of the information provided by the input parameters
- The specified target fraction honoring value

The probability trend models generally work at a larger scale than the variogram models. When using vertical trend models for the facies, there will be a tradeoff between honoring the vertical distribution specified by the trend model and honoring the vertical continuity defined by the variogram model. Therefore, if the main priority is to obtain simulated facies models that fully honor the vertical facies distribution provided by the vertical trend model

- Set vertical ranges of the facies variogram models that do not exceed the vertical resolution (layering) defined by the 3D grid.
- Assign a target fraction honoring value close to zero.

Fig 5 shows three facies models created using a vertical proportion curve as a 1D trend and different settings for the vertical variogram range and the target fraction honoring value. Note that when the criteria described in the previous paragraph are not satisfied, the output facies models fail to fully honor the vertical facies distribution provided by the vertical trend model. Only when the vertical range of the variogram model does not exceed the 3D grid layering and the target fraction honoring value is close to zero, does the vertical distribution of the output facies model match the input vertical trend model.

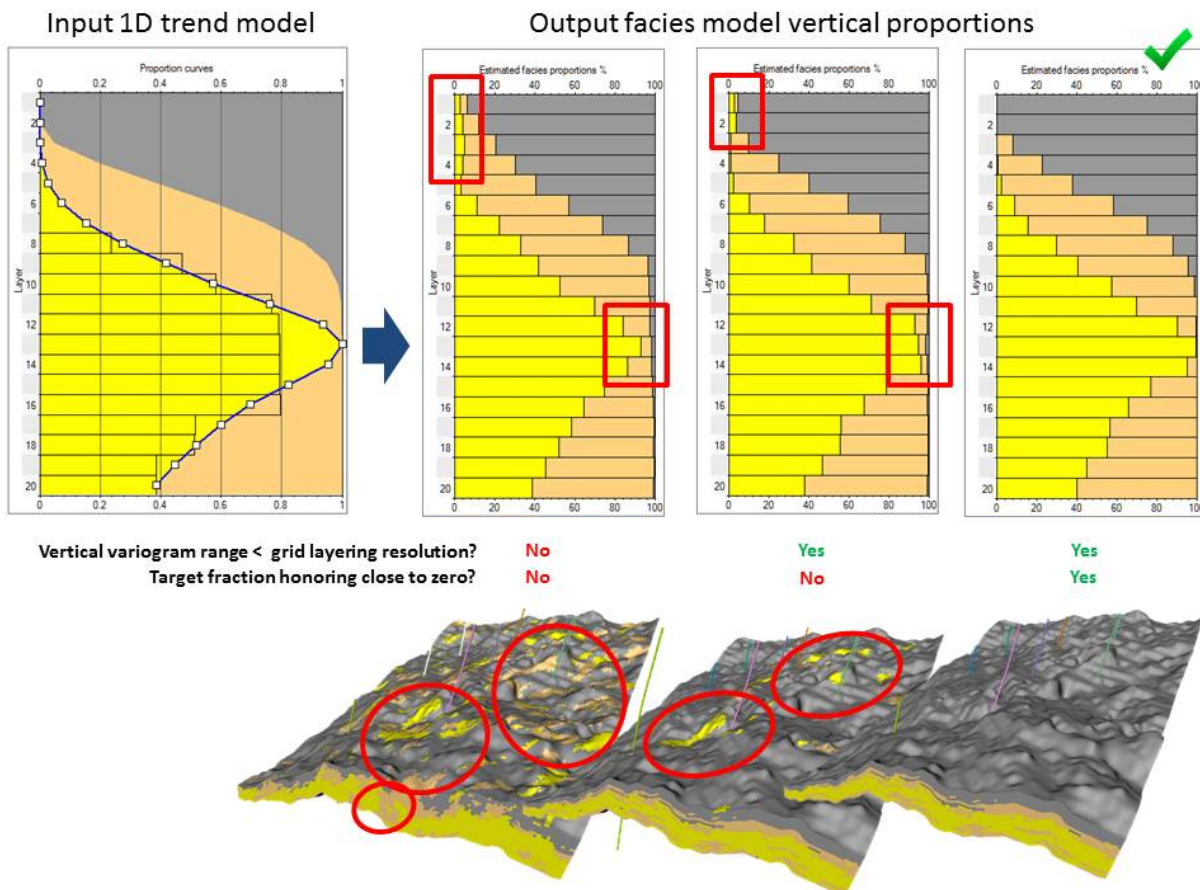


Fig 5. Honoring the vertical trend model (left) requires using a vertical variogram range below vertical grid resolution and a target fraction honoring value close to zero

It is important to point out that, when using vertical probability trends in Petrel facies modeling, these are laterally extended into the 3D grid by assigning the same trend value at each (x, y) position for each stratigraphic layer. The resulting laterally constant 3D probability models (one for

each facies code) are then used by the simulation algorithm to specify the probability or expected proportion for a particular facies to occur at each cell. Some guidelines for setting up the SIS parameters such that the resulting facies models fully honor all the input data are given below:

- By default, the target facies global fractions are given by the arithmetic average of the laterally constant 3D facies trend models. This is the recommended option as it guarantees consistency between the input spatial distribution and associated global proportions of the facies trend model.
- The facies modeling process also allows selecting as target facies global fractions the values estimated from the input (upscaled or raw) well data or even specifying the values manually. This enables controlling how much of each facies there should be in the resulting facies models (for example, if the estimated proportion of sand is too high due to preferential drilling), while still using the trend model to guide how the facies should be distributed within the 3D grid.
- When using a vertical trend model, if the global fraction for a particular facies code has been selected to be either estimated from well data or manually entered, then most probably the target global fractions for all facies will not add up to 100%. To make the input global proportions a valid probability distribution, the facies simulation algorithm will proportionally scale every facies fraction such that their sum equals to 100%.
- To prevent a manually entered or well log estimated facies global fraction from being rescaled, and thus preserve the desired value as the target global fraction for a given facies, check the **Trust fraction/trends** option for the selected facies.

Fig 6 shows two facies models created using a vertical proportion curve as a 1D trend. In the first model, the facies global fraction is computed from the trend model (default). Note that the resulting sand global fraction matches the sand fraction computed from the vertical proportion curves. In the second model, a manual global fraction value has been entered and the **Trust fraction/trends** option has been checked for the selected facies to prevent the manually entered value from being rescaled. As a result, the resulting sand global fraction matches the manually entered target global fraction.

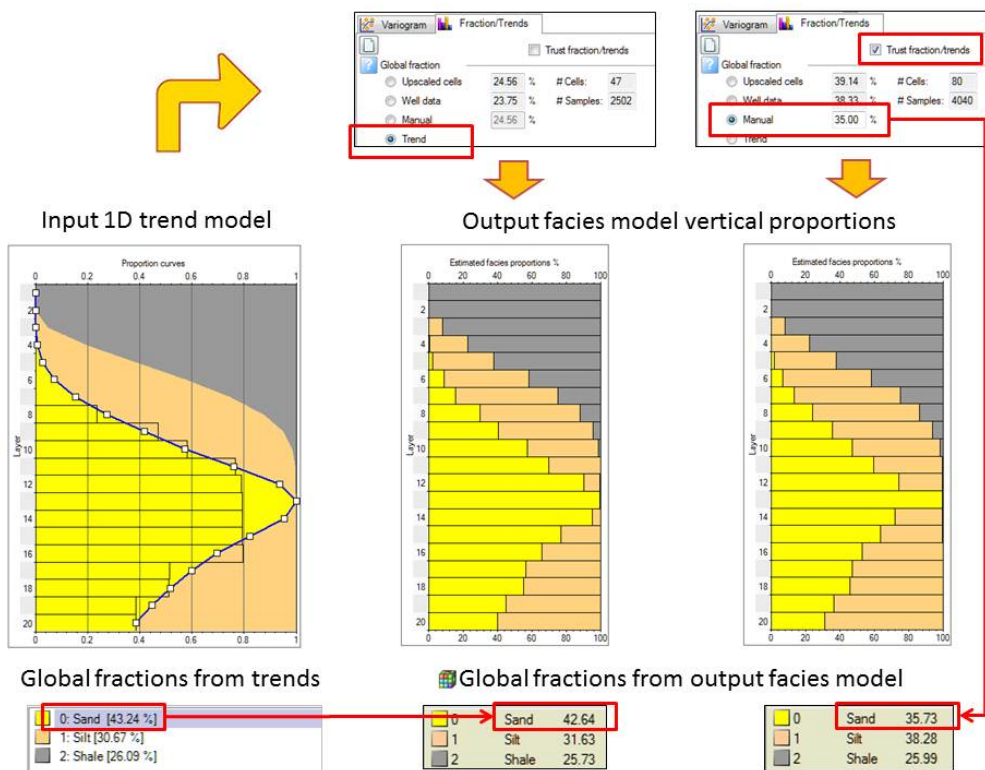


Fig 6. The facies target global fractions are estimated by default from the vertical trend model. Different global fractions can be entered from different source data (upscaled or raw well logs or values entered manually)

Although modeling and using vertical trends is relatively simple and straightforward, this is also the approach most likely to give problems away from well control, simply because there are no data to constrain the simulations/estimation in those areas. It is considered good practice to check that the values predicted away from well control still make physical and geological sense.

Horizontal nonstationary vertical proportion curves using well log data + geological information

In the previous section, the vertical proportion curves were computed assuming that the reservoir was laterally stationary. That is, it was assumed that the vertical proportion of facies was laterally constant throughout the reservoir. In most cases however, the vertical proportions of facies vary from one region to another within the reservoir (e.g., because of changes of the depositional environment) and therefore it is necessary to compute the vertical proportion curves conditioned on individual regions in the selected stratigraphic zone. The lateral extension of each region should be delineated first, for example based on geological knowledge and/or seismic facies analysis (i.e., mapping groups of seismic reflections to particular sedimentary environments according to the position, configuration, and character of the reflections within sequences). Different settings and upscaled data can then be used on the different regions, so the resulting vertical proportion curves will be different per region (Fig 7).

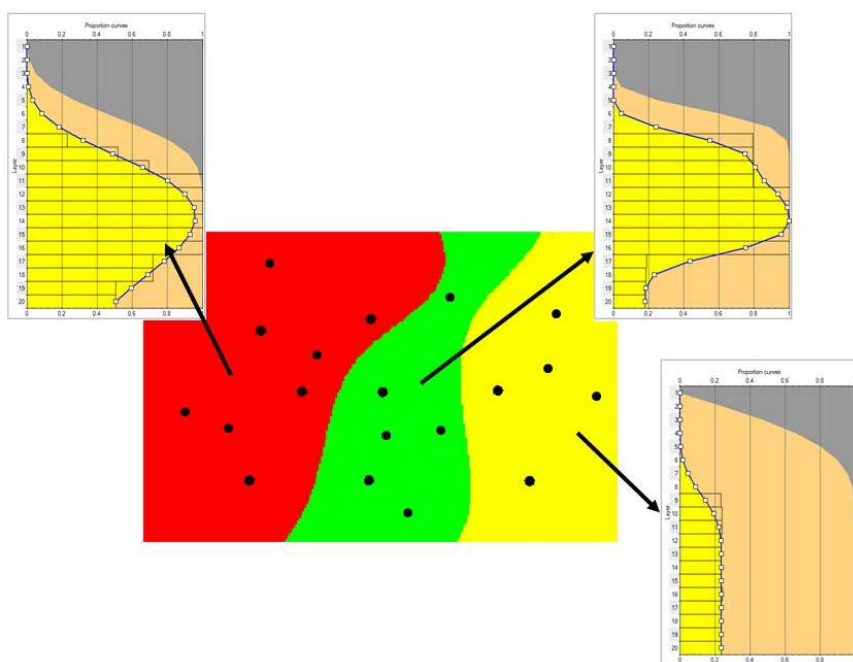
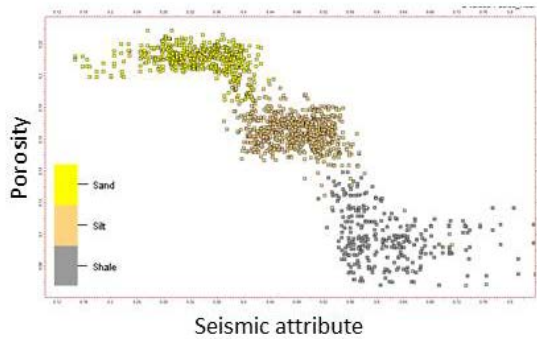
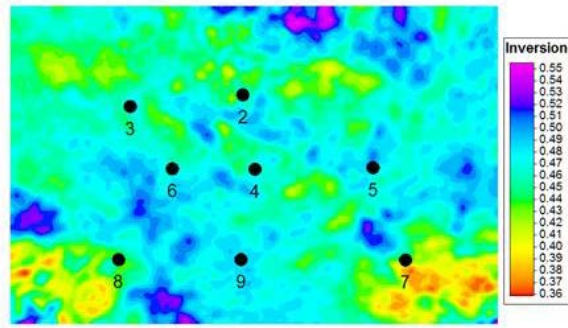


Fig 7. Different 1D models (vertical proportion curves) are computed for each region using different groups of wells

Facies attribute probability cubes using well log data + seismic-derived properties

When well coverage is limited, it is recommended to use laterally dense secondary data to build the trend model. Seismic-derived properties often provide valuable information regarding the lateral variability of the facies distribution. Of course, if seismic-derived data will be used to constrain the spatial distribution (connectivity and degree of heterogeneity) of facies models that are to be used for fluid flow reservoir simulations, the selected seismic attribute must be qualitatively, and more importantly, quantitatively, related to the geological facies of interest (Fig 8).

Map of seismic attribute



Seismic attribute, porosity and facies logs

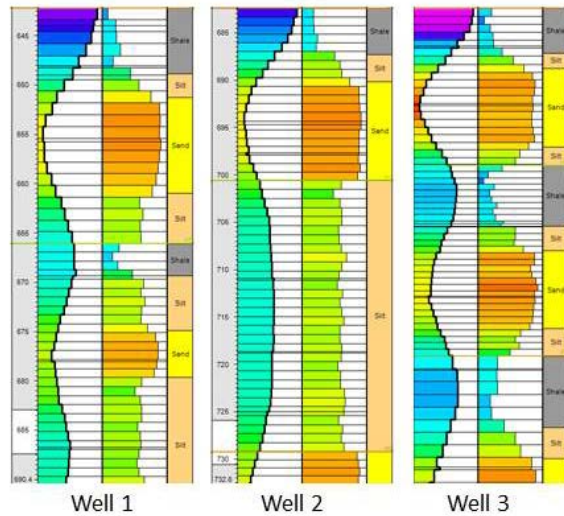


Fig 8. Map of seismic attribute (top left) might provide useful lateral information of facies distribution. Crossplot of seismic-derived data versus porosity data color coded by facies at the well locations (bottom right). Clear facies groups can be identified from seismic attribute only. Seismic attribute also shows good correlation with the facies in the wells (right).

Facies attribute probabilities can be computed and edited in the data analysis tool by calibrating the volume of the seismic attribute to the facies proportions at the well locations. Specifically, the range of the resampled seismic attribute variability is divided into a series of intervals, and the probabilities of finding each facies at a particular interval of the seismic attribute values are computed at the well locations. The resulting facies attribute probabilities can then be directly used as 3D probability trend models (one per discrete property type) in facies modeling to constrain the 3D spatial distribution of the target proportion of the facies property (Fig 9).

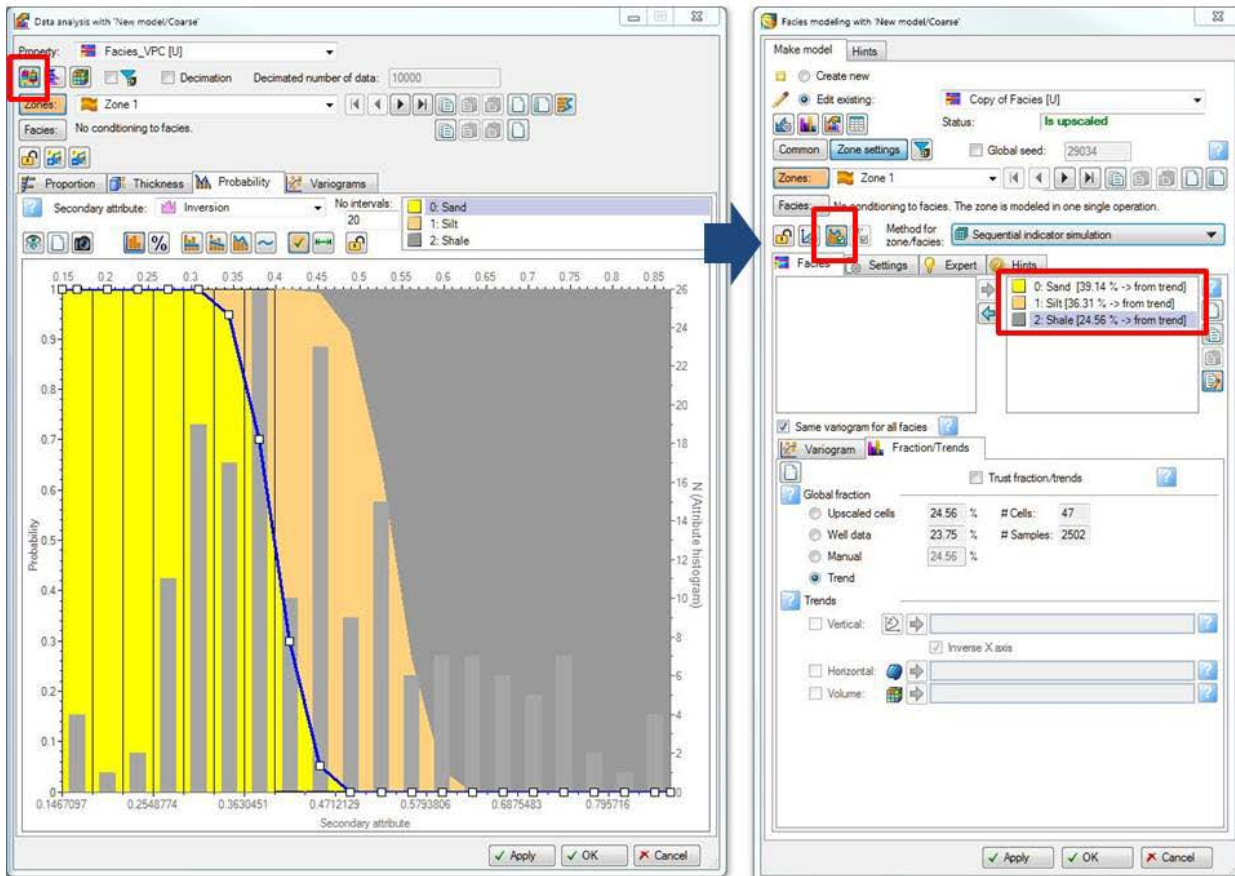


Fig 9. Facies attribute probabilities relative to the value of acoustic impedance in the upscaled cells (left). The outlined histogram represents the distribution of the secondary attribute in the upscaled cells of the selected facies. The gray histogram represents the distribution of the secondary attribute in all upscaled cells/well log points. The facies attribute probability curves can be directly used as 3D trends for global facies proportions in facies modeling (right).

The closer the facies attribute probabilities (outlined histogram in Fig 9) are to 1 and 0 at each interval of seismic attribute values, the better is the selected seismic attribute at predicting the geological facies. However, this is generally not the case due to

- Small scale variations of geological facies, and
- Variability of the seismic derived properties within the same facies.

Here again, there will be a trade-off between honoring the spatial distribution specified by the 3D trend model and honoring the spatial continuity specified by the ranges of the 3D variogram model. To obtain simulated facies models that fully honor the 3D spatial distribution provided by seismic-derived attribute probability curves (Fig 10), use the methods below:

- For the facies codes whose distributions are to be entirely specified by seismic-derived attribute probability curves, set vertical and lateral variogram ranges that do not exceed the lateral (cell sizes) and vertical (layering) resolution defined by the 3D grid. Larger variogram ranges can be used for background facies.
- If necessary, edit the facies attribute probability values to remove small-scale artifacts from seismic attribute intervals.
- Assign a target fraction honoring value close to zero.
- If necessary, check the **Smooth result** option in the **Facies modelling** dialog box. This will remove geologically unrealistic small-scale variations in the simulated facies model due to short ranges in the variogram models.

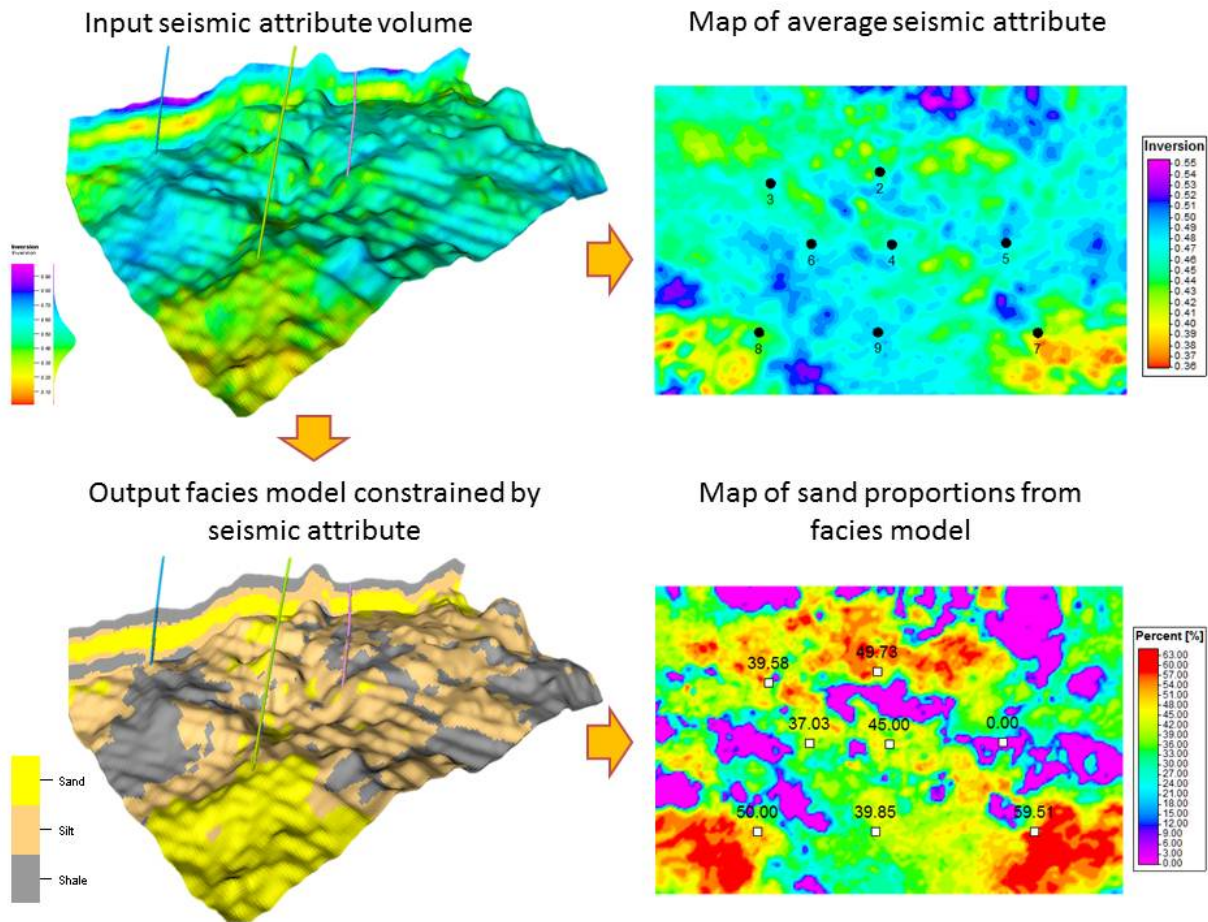


Fig 10. Stratigraphic slices and cross sections extracted from 3D seismic attribute (top left) used to compute the facies attribute probabilities. These were used to constrain the SIS facies model (bottom left). The simulated facies model fully honors the 3D spatial distribution provided by seismic-derived attributes. In particular, the map of sand proportions (bottom right) computed from the facies model in the zone of interest shows similar trends to the map of the average seismic attribute over the same zone.

How reliable the 3D seismic-derived property is to constrain the 3D spatial distribution of the facies model depends largely on the quality of the seismic-derived data and the degree of information the data carry regarding the geological facies. We must be particularly careful when using low-resolution data to constrain a highly detailed reservoir model as the difference in support and scale between the seismic and geological facies might mask the information value of the seismic data. This can lead to erroneous interpretations regarding the spatial distribution (connectivity and degree of heterogeneity) of the facies bodies, as well as the associated uncertainties.

In particular, the vertical resolution of seismic data is generally much coarser than the layering of the 3D grid. Therefore, a common approach to integrate the seismic data into the probability trend model is to use 2D maps of the averaged seismic attribute over the area of interest, as opposed to the full 3D seismic attribute cube, to constrain the lateral (and no vertical) distribution of the simulated facies model. Within this approach

- The vertical variation of the facies model is guided by vertical proportion curves
- The horizontal variation of the facies model is guided by seismic-constrained facies probability maps

The next sections describe some of the approaches available in the Petrel platform to create seismic-constrained facies probability maps and different options for using facies probability maps as 2D probability trend models in facies modeling.

How to create seismic-constrained facies probability maps using well log data + averaged seismic attribute maps

Facies proportion maps constrained by an averaged seismic attribute correlated to the proportions can be created, for example, by collocated cokriging interpolation of the well log facies proportions over the reservoir zone using the averaged seismic attribute map as the secondary variable. Geostatistically speaking, this requires both of the following:

- A model of the spatial continuity (variogram) for the facies proportions
- The correlation coefficient between the facies proportions and the averaged seismic attribute (computed at well locations)

In Petrel property modeling, the following procedure can be used to create, for each facies code, seismic-constrained facies probability maps (Fig 11):

1. From the **Well tops** folder, insert a new attribute and compute the proportions of the selected facies well log data (as a well tops attribute) over the zones of interest.
2. Drop the zone in the **Well tops** folder as input into making a surface, and select the newly created well tops proportion attributes.
3. In **Make/edit surface dialog**, for each facies code
 - a. Use the well log proportions points as main input and select **Kriging** as interpolation algorithm.
 - b. Select the desired ranges for the variogram. The longer the lateral ranges, the longer the ratio of influence of the well proportions on the resulting maps.
 - c. Check the **Do normal score transform** box. This will result in a Gaussian global distribution of the kriging interpolated values. Estimate the minimum and maximum from the input data.
 - d. Select **Collocated co-kriging** using the correlated averaged seismic attribute map as the secondary variable. Estimate the correlation coefficient between the averaged seismic attribute and facies proportions at the well locations.
4. Use the **Surface calculator** to normalize the resulting facies proportions maps such that they have values between 0 and 1 and the sum of all the facies probability maps is equal to 1.

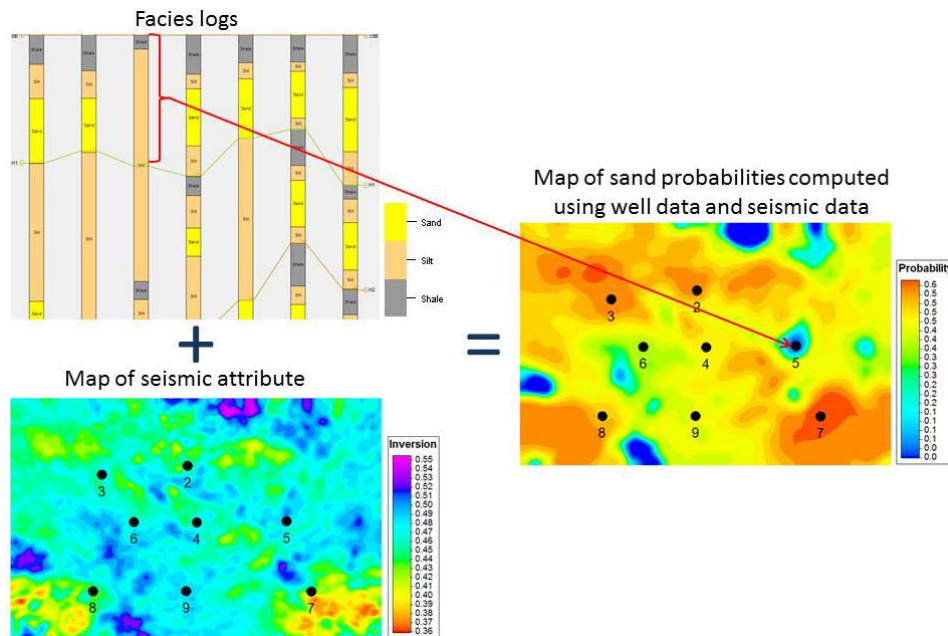


Fig 11. Example of facies probability map driven by a seismic attribute. The resulting probability map for the sand facies (right) takes into account the facies well data, the variogram parameters, and the average acoustic impedance map (bottom left). Notice the zero probability of sand around well 5, as indicated by the well data, and the zero probability of sand areas at the reservoir boundaries, as indicated by seismic attribute values.

Using vertical proportion curves and facies probability maps in facies modeling

In prospecting stages, when well data are scarce, seismic-constrained facies probability maps can be used as 2D trends for the lateral variability of the facies model. Of course, the extent to which this lateral constraint is reliable depends largely on the quality of the seismic-derived data and the degree of information these data carry regarding the geological facies. When probability maps are used as trends in facies modeling, the probability maps are extended vertically to create (vertically stationary) 3D probability trend models (one for each facies code).

On the other hand, in production stages, when, in addition to the seismic data, more well logs and geological data are available to build reliable (maybe regionally nonstationary) vertical proportion curves, both 1D (vertical proportion curves) and 2D (probability maps) trend models can be jointly used in facies modeling. The vertical proportion curves and proportion maps are multiplied to create horizontally and vertically nonstationary 3D probability trend models (one for each facies code).

The resulting 3D probability trend models are then used by the simulation algorithm to specify how much of each particular facies you can expect to see and how they should be distributed within the 3D grid. The target global fractions are determined either by the arithmetic average of the 3D probability trend models (default), or estimated from the input (upscaled or raw) well data, or manually specified. How the facies are distributed within the 3D grid by the simulation algorithm will be guided by the trend models. The resulting facies models will then honor the input well data as well as vertical and lateral distribution induced by the trend models (Fig 12).

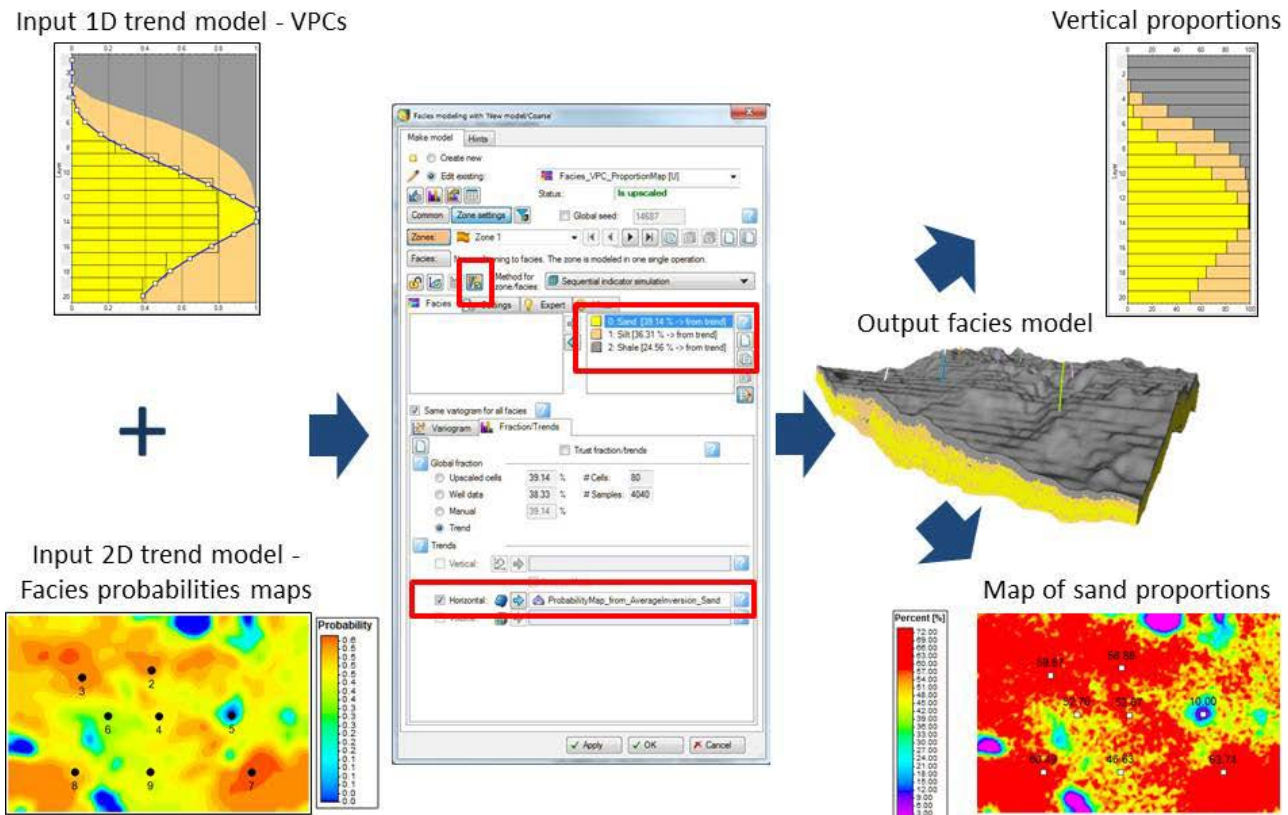


Fig 12. Vertical proportion curves computed in data analysis (top left) and facies probability maps (bottom left) can be jointly used in facies modeling as 1D and 2D trends, respectively. The resulting facies models will honor the vertical proportion variability (top right) and lateral distribution (bottom right) induced by the trend models.

Using trend modeling to create proportion volumes: Combine all available data to build probability trend models

In the previous sections, we discussed different options to build probability trend models (namely, vertical proportion curves, facies attribute probabilities curves, and seismic-constrained probability maps), and we showed how to use them directly in facies modeling to specify the target global fractions and to guide how the facies should be distributed within the 3D grid. In a nutshell, when the probability trend models are used directly as input in facies modeling,

- 3D probability trends models are first created according to the following rules:
 - If only vertical trends are used, these are extended laterally to create (laterally stationary) 3D probability models.
 - If only horizontal trends are used, these are extended vertically to create (vertically stationary) 3D probability trend models.
 - If both vertical and horizontal trends are used, these are multiplied to create horizontally and vertically nonstationary 3D probability trend models.
- The target global fractions are then determined by the arithmetic average of the respective 3D probability trend model (rescaled to the estimated fractions from the input well data or the manually specified value, if necessary).

Then, if the adequate parameterization is set up in facies modeling, as shown in the previous sections, the resulting facies models will honor the target global fractions and the spatial distribution induced by the trend models. However, there are some limitations when using probability trend models directly as input in facies modeling:

- It is not possible to visualize and therefore QC a priori the internally created 3D probability trend models.
- It not possible to know a priori the target facies global fractions determined from the 3D probability trends.
- The methods used to extend and combine the input 1D and 2D trend models into 3D trend models are simple arithmetic operations suitable to create (nonstationary) facies trend models for simple geological settings.

The trend modeling tool available in Petrel property modeling provides a flexible way of combining multiple data types of different scales and spatial coverage to create complex 3D probability trend volumes for each facies. The trend modeling algorithm for discrete properties uses a sophisticated technique that combines interpolation by kriging and block averaging of input upscaled facies data to estimate, on each cell of the geocellular grid, the probability of each facies to occur. An outline of the general method is as follows:

1. Transform data from each input upscaled facies log into facies probability values.
2. For each cell of the geocellular grid, and for each facies code, estimate a probability value using simple or ordinary kriging.
3. Finally, remove small-scale variations, averaging the probability values within a block defined by a selected block radius in the I , J , and K directions.

Several options are available to define the mean of the inherent kriging algorithm. Either a global or a locally varying kriging mean can be assumed:

- By default, a simple kriging algorithm will be used. When using the simple kriging algorithm
 - A global kriging mean is defined using the percentages for each facies, either estimated from the input upscaled or raw well data or manually specified.
 - The global kriging mean can also be defined from any available input trend model. When a trend model is used to define the global kriging mean for the simple kriging algorithm, the targeted global mean for the resulting trend model for each facies will be given by the arithmetic mean of the respective input facies trend model. At the same time, the input trend models will guide how the facies will be distributed within the 3D grid.
- An option is available to select ordinary kriging. When using the ordinary kriging algorithm
 - The kriging mean of the selected facies is assumed to vary locally and is re-estimated at each location. This option is useful in production stages when significant well log data are available.
 - The local kriging mean of the selected facies code will be defined by the input trend models. Specifically, the trend value at each node (horizontal), stratigraphic layer (vertical), or cell (volume), defines the local kriging mean of the current facies.

- Toggling the **Trust global/local kriging mean** option on will prevent the selected local kriging mean from being rescaled if the percentages for all facies do not add up to 100%.

Vertical proportion curves, facies attribute probabilities curves, seismic-constrained probability maps, and probability volumes can be used to constrain the global/local kriging mean in the trend modeling tool (Figure 13). Note that, when using trend models as input in the trend modeling process, if any influence from the upscaled well data is removed in trend modeling (e.g., by using variogram ranges close to zero and removing block averaging), using the output trend volumes as trend volumes in facies modeling would give similar results as using the trend models directly as input in facies modeling.

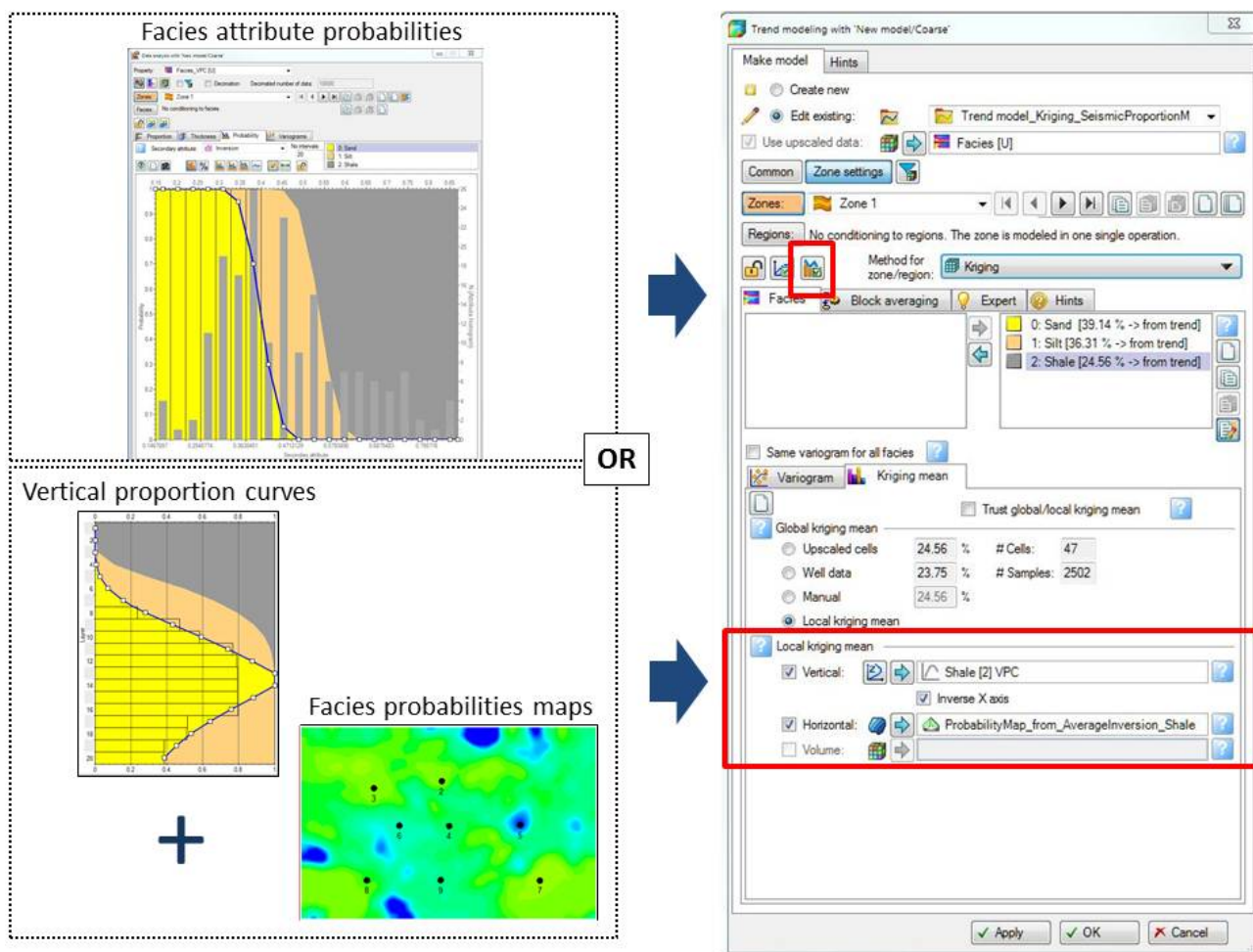


Fig 13. Facies attribute probabilities computed in data analysis (top left) or vertical proportion curves together with facies probability maps (bottom left) can be used constrain the global/local kriging mean in trend modeling (right).

The advantages of using the trend modeling process to build a priori the trend volumes are as follows:

1. Different setting options can be used (e.g., variogram for the kriging interpolation, simple versus ordinary kriging) to further locally constrain the output trend volumes with information from wells (assuming you have enough and reliable well data or any other geological information regarding the spatial variation of the trend).
2. The trend modeling process for a discrete property creates and stores in the 3D grid tree a 3D probability property for each facies. The resulting 3D probability volumes can then be visualized in any suitable window, iteratively QC'ed and, if necessary, edited, before they are used as input trend volumes in facies modeling.

The resulting nonstationary facies probability trend volumes for the different facies will then honor

- The upscaled facies well data (transformed into local vertical proportion curves)
- The anisotropy range and orientation given by the variogram parameters
- The large-scale variability defined by the input trend models (facies attribute probabilities, vertical proportion curves, probability maps, etc.)

Fig 14 shows stratigraphic slices of trend models constrained by facies attribute probabilities from data analysis (top) and vertical proportion curves combined with probability maps (bottom). As can be observed, in the former case, the sand probability distribution of the trend model is strongly influenced by the lateral and vertical variations observed in the correlated seismic attribute cube. In the latter case, the sand probability distribution of the trend model shows the same lateral imprint of the facies probability maps whereas the sand probabilities are consistent with the proportions indicated by the vertical proportion curves for the corresponding layer.

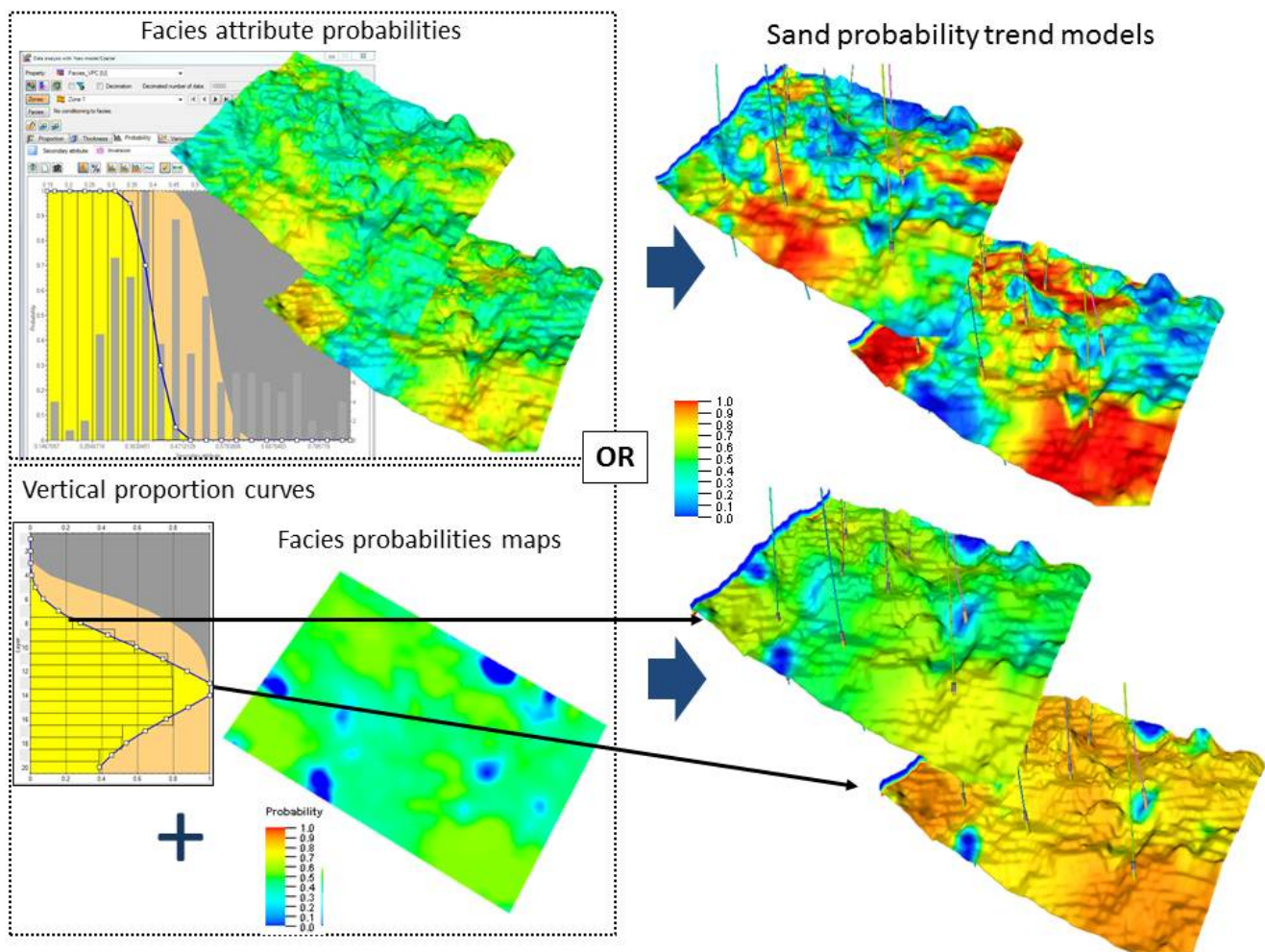


Fig 14. The input probability trend models (facies attribute probabilities, vertical proportion curves, probability maps), together with the kriging parameters (variogram model) in trend modelling will guide the kriging of the upscaled facies profiles. The well data, trend models, and variogram models are therefore taken into account to create horizontally and vertically nonstationary facies proportion volumes (one for each facies code), which can then be used as trends in facies modeling.