# Integrated Reservoir Characterization and Modeling of the Umm Gudair Minagish Oolite Reservoir, Kuwait*

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## Abstract

For optimal development of a large oil field, a reservoir characterization that integrates all the available geoscience and engineering data is very important. An example of this is the prolific Umm Gudair field, Kuwait, which produces from the early Cretaceous Minagish formation. The main reservoirs are oolitic grainstones and packstones interbedded with tighter wackestones, which act as baffles and barriers to fluid flow. A better description of the reservoir geology, in particular lithofacies, and petrophysical property heterogeneity was necessary for an accurate static model. The model needed to be robust enough to guide reservoir management for optimal depletion. This was achieved through an understanding of the various lithofacies, their distribution and relationship with the petrophysical properties (porosity, permeability and water saturation). These data, observations and interpretations guided the construction of a lithofacies model that could constrain petrophysical property distribution. Core descriptions of the Minagish provided data on the vertical distribution of the lithofacies and their petrophysical properties from special core analysis. Integration of the core with depositional analogs allowed for the development of a conceptual depositional model. Lithofacies probability maps and models were constructed that were consistent with this geological understanding of the Minagish. These maps and models were utilized to model the lithofacies throughout the field with the geostatistical truncated Gaussian method. Petrophysical properties were modeled by stratigraphic zone and guided by the lithofacies model. Tying the petrophysical property distribution to the lithofacies ensured a static model that was consistent with the geologic understanding of the reservoir.

## Modeling Workflow

In the static modelling for the Umm Gudair field, a structural framework and stratigraphic model were first built by incorporating the stratigraphic surfaces to represent the various reservoir units, and a fine-grid geocellular model was created that allowed description of the reservoir heterogeneity. Second, lithofacies were populated in the fine-grid geologic (static) model. This included several steps, including analysis of interpreted cored lithofacies, depositional facies analysis to help understanding of the reservoir facies, and lithofacies modeling using geostatistical truncated Gaussian method. Third, the lithofacies model was used as a guide to populate the petrophysical properties, including porosity, permeability, which in turn were used to guide distribution of the reservoir rock types and water saturation.

## Lithofacies Modeling

Thirty-four wells have cored lithofacies data. Eight lithofacies were interpreted from the cores, including mudstone, wackestone, packstone, floatstone, pack-grainstone, fine grainstone, grainstone and rudstone. Many of these lithofacies, however, have a very small presence, and they were merged with other lithofacies. The final composite lithofacies after the merge include four types: wackestone, packstone, pack-grainstone, and grainstone.

The differences in depositional characteristics between the various stratigraphic packages in the overall depositional environment are quite large. Figure 1 shows the lithofacies vertical profile from the 34 cored-wells' lithofacies data. Some major zone boundaries are marked by significant changes in lithofacies compositions. In particular, Zone A, composed of A0 to A5, has more wackestone than the other zones and is eroded in the western part of Umm Gudair. Zone B, composed of B1 to B7, is characterized by a fining-upwards cycle, in which grainstone decreases upwards while wackestone and packstone generally increase. Zone C, composed of C1 to C6 is another fining-upwards cycle, but with several smaller aggradational or fining-upwards cycles. Zones D and E appear to be one fining-upwards cycle, with abundant grainstone in E. Zone F is dominantly packstone deposits.

With the large difference in lithofacies composition, and the geological understanding of conceptual depositional models, it was clear that lithofacies were better modeled separately for each stratigraphic unit. To address this, lithofacies probability maps were first made to ensure that the final model honors both the depositional characteristics and lithofacies data at the wells (Ma, et. al, 2009).

A probability map was made for each lithofacies in each stratigraphic zone. The method and procedure for making facies probability maps can be quite complex, especially when three or more facies are modeled for a given stratigraphic unit. Initially, lithofacies probability maps were gridded with the proportional data at the well. These maps were then quality-controlled in order to honor both the lithofacies proportions from the well data and the conceptual depositional model. Notice that with limited data, especially outside of the well-control area, uncertainty is quite high. The lithofacies probability maps required a number of iterations to ensure that the maps represent a reasonable geological interpretation of the depositional environment.

The lithofacies data from the wells showed abundant high-quality rocks, including oolitic grainstones and packstones because most wells are clustered on or near the crest of the structure. As such, low-quality rocks, such as mudstone, wackestone, are under-represented by the lithofacies data from the wells. Outside of the well-control area, there was likely not a significant presence of grainstones and packstone, but mostly wackestone and wackestone-packstone. This means that the lithofacies model should have more of these lithofacies compared to the well log data. As such, the lithofacies model generally does not reproduce the lithofacies histograms from the well data.

The general lithofacies modeling workflow is illustrated in Figure 2. Truncated Gaussian method was used to populate the lithofacies in each stratigraphic zone separately, honoring the well-log data, debiased lithofacies frequencies, probability maps and indicator variogram. By modeling lithofacies for each stratigraphic zone separately, sequence stratigraphic interpretations were better honored in the model. Well-log lithofacies, after upscaled into the 3-D grid, were used as conditioning data and hence are honored by default. Global frequencies of lithofacies determine the relative presence of each lithofacies. When there is no preferential sampling, the lithofacies model honors the global frequencies of the lithofacies data from the well logs (Ma et. al, 2009). When sampling preference is present, the model should discount the sampling bias. Often, however, it is not clear how to discount the sampling bias because of the lack of a precise understanding of the conceptual model. In the case of the Umm Gudair field, the interpreted cored lithofacies data are all located in the center of the model; sampling bias is quite obvious. This bias, however, is largely mitigated by the lithofacies probability maps that account for the conceptual depositional models for each stratigraphic zone.

In the truncated Gaussian method, indicator variogram ranges determine the lithofacies object size or spatial patterns, and probability maps constrain the model to honor lithofacies spatial positioning in the model. A variogram with a greater continuity in NNE direction was generally used because of depositional orientation in the geological interpretation and indicator variogram analysis. Lithofacies modeling examples for four stratigraphic zones are shown in Figure 3.

## Modeling Petrophysical Properties (Porosity and Permeability)

Similar to indicator variograms for the lithofacies, variograms for porosity show anisotropy in continuity, with the major variogram range approximately in NNE25°, and minor range in NWW (Figure 4). Thus, a variogram with a greater continuity in the NNE direction was typically used for porosity modeling because that was the main depositional orientation in the geological interpretation.

In the 3-D porosity modeling workflow used in the project (Figure 5), the lithofacies model is used as a constraint of the spatial distribution of porosity using Gaussian random function simulation (GRFS), in addition to utilizing the detailed stratigraphic definitions.

One concern in using geostatistical methods for modeling petrophysical properties is the non-stationarity because most geostatistical simulation methods assume the second-order stationarity (Ma, et. al, 2008). When the reservoir model is constructed vertically with stratigraphic zonations, however, vertical variations of petrophysical properties within each zone are generally moderate.

One of the objectives was to integrate the inverted seismic data in porosity modelling. An effort was made to analyze the correlation between the seismic porosity from the inversion and well-log porosity. In general, their correlation is weak to moderate; however, the seismic data was useful in areas where well–log data are not available.

Collocated co-simulation (Ma, et. al, 2008; Cao et al., 2014) was utilized to honor the relationship between the permeability and porosity. This allowed for modeling the spatial continuity of permeability based on the variogram analysis, and porosity-permeability relationship derived from the petrophysical analysis of the well logs.

The water saturation (Sw) has a high correlation to porosity. The Sw model was distributed utilizing collocated co-simulation, which honored the Sw data at the wells, the correlation between porosity and Sw while incorporating the capillary pressure effect.

## Conclusions

An integrated static modeling was carried out for the early Cretaceous Minagish carbonate formation in the Umm Gudair field. The lithofacies were modeled by honoring the depositional interpretation by stratigraphic zone. Petrophysical properties, including porosity, permeability and water saturation, were modeled using geostatistical methods that were constrained to the stratigraphic interpretation and the lithofacies model. The integrated model is currently undergoing dynamic simulation with the goal being reservoir management and field development planning.

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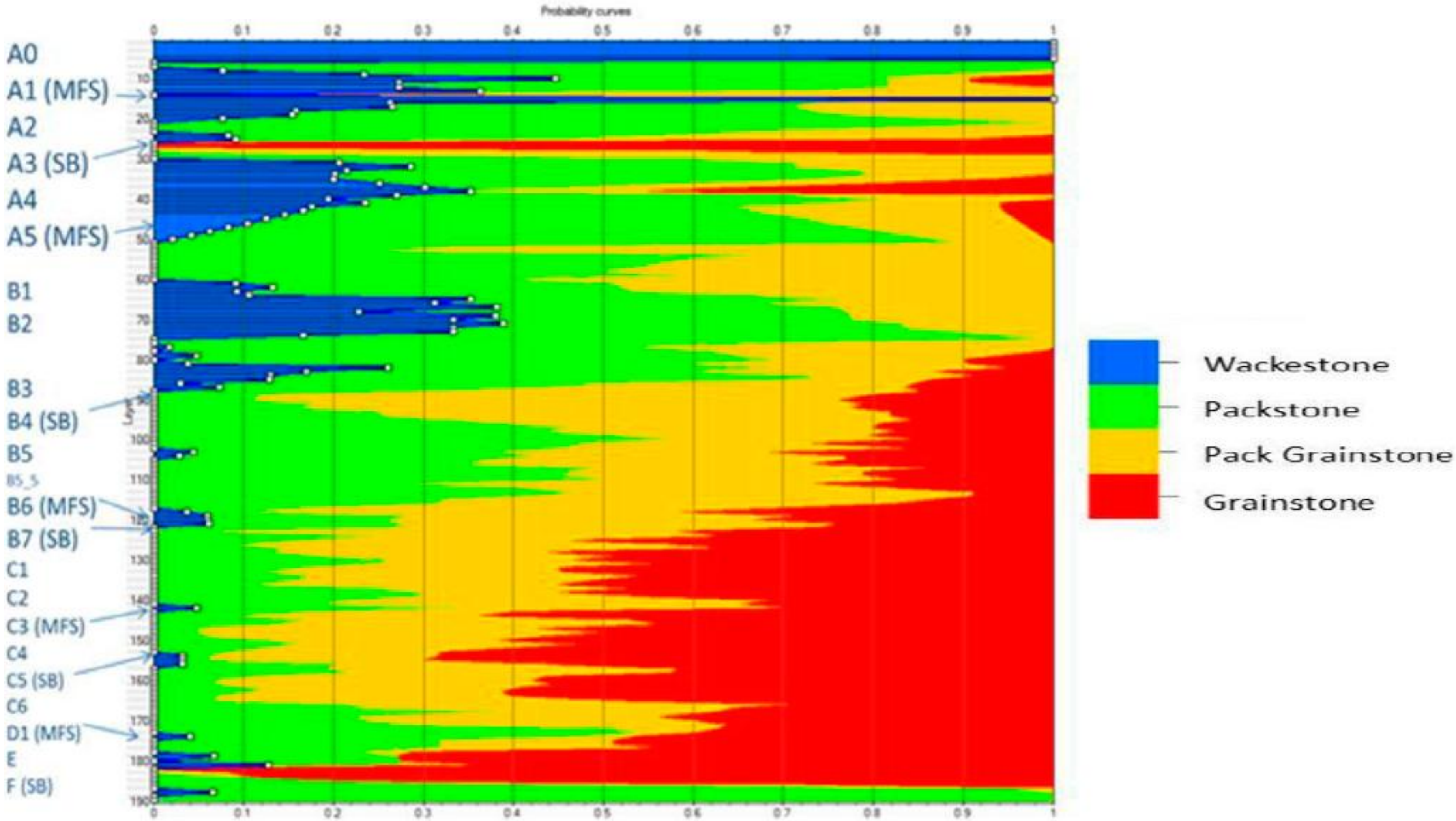



Figure 1. Lithofacies vertical profile.

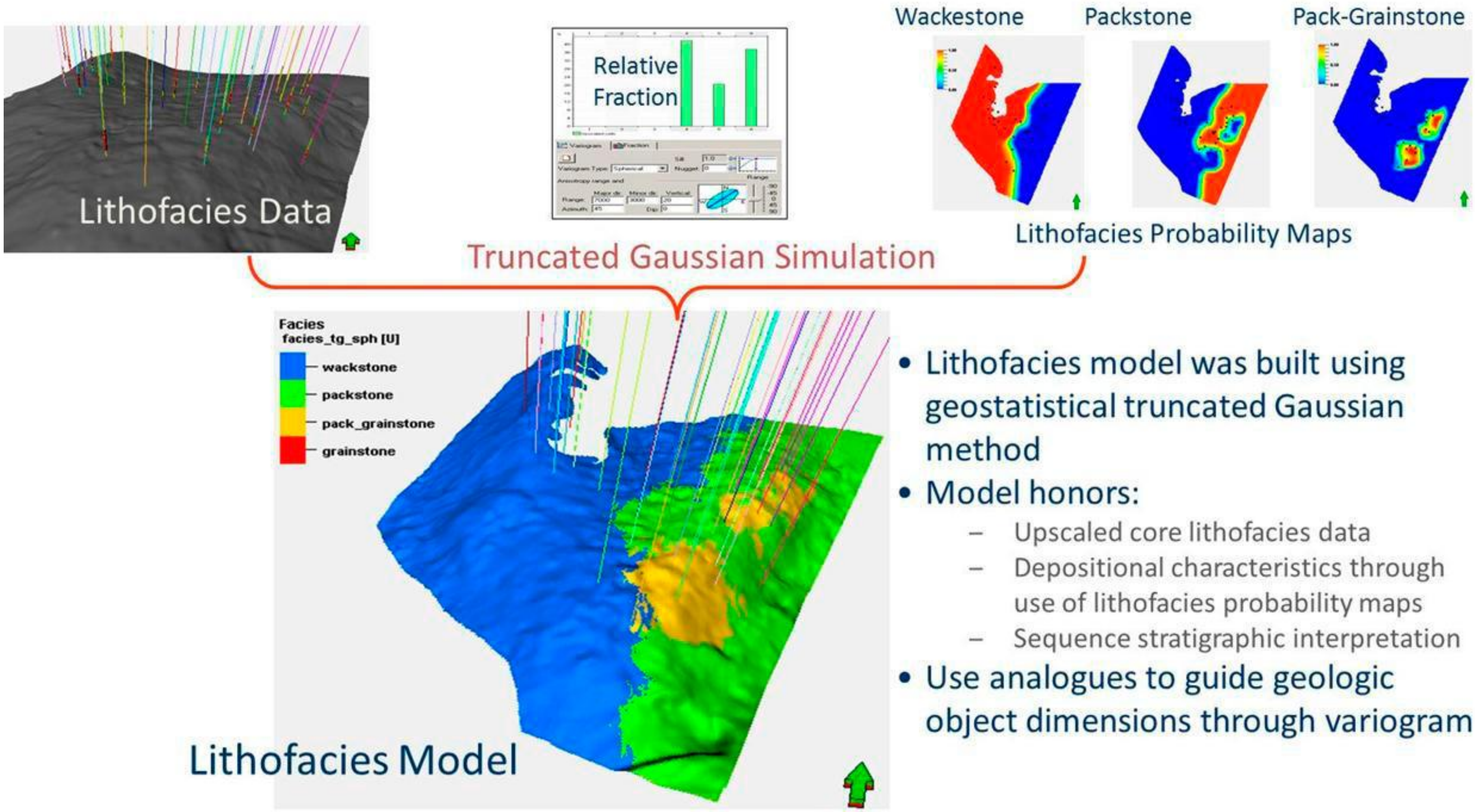



Figure 2. Lithofacies modeling workflow (example for A5).

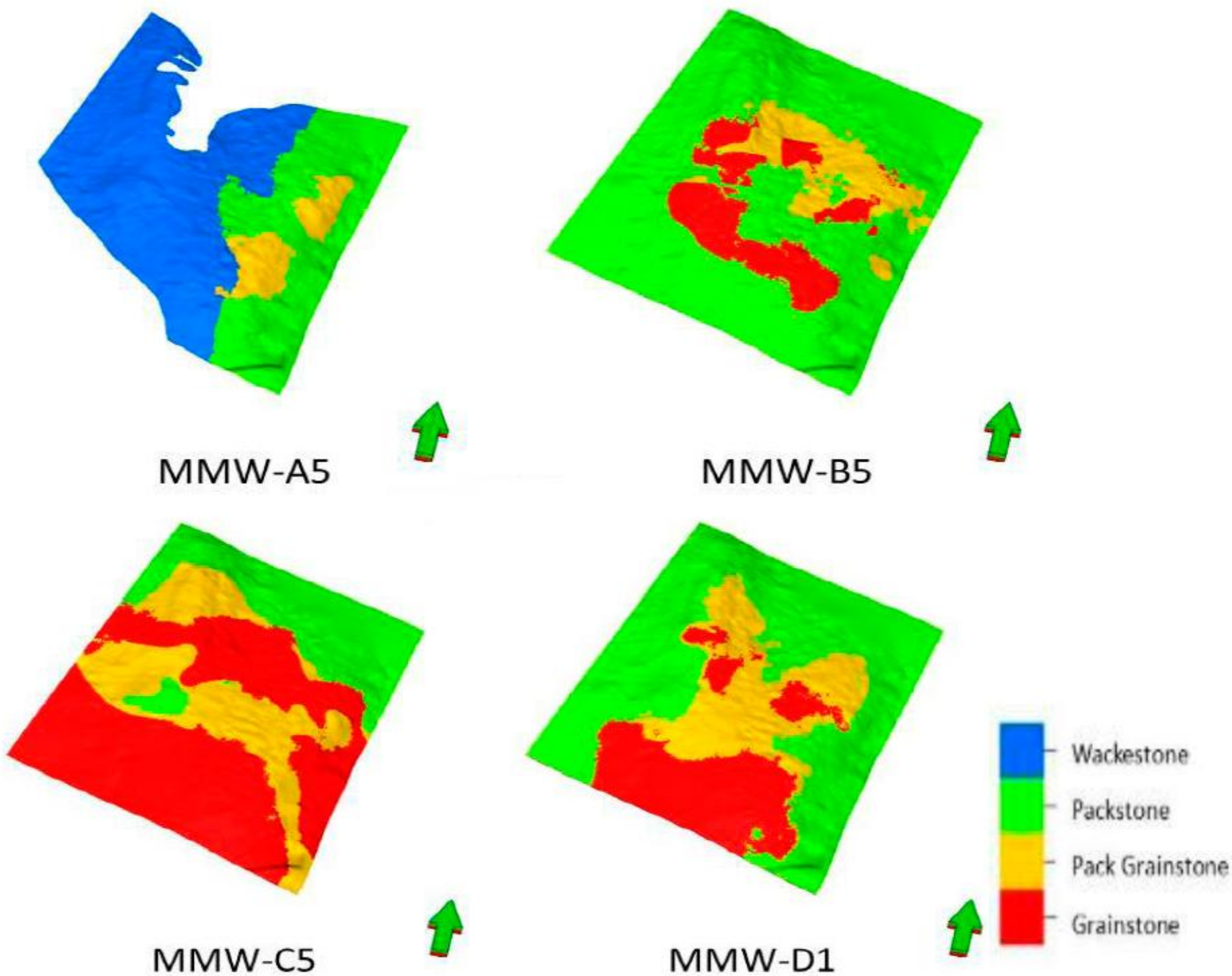
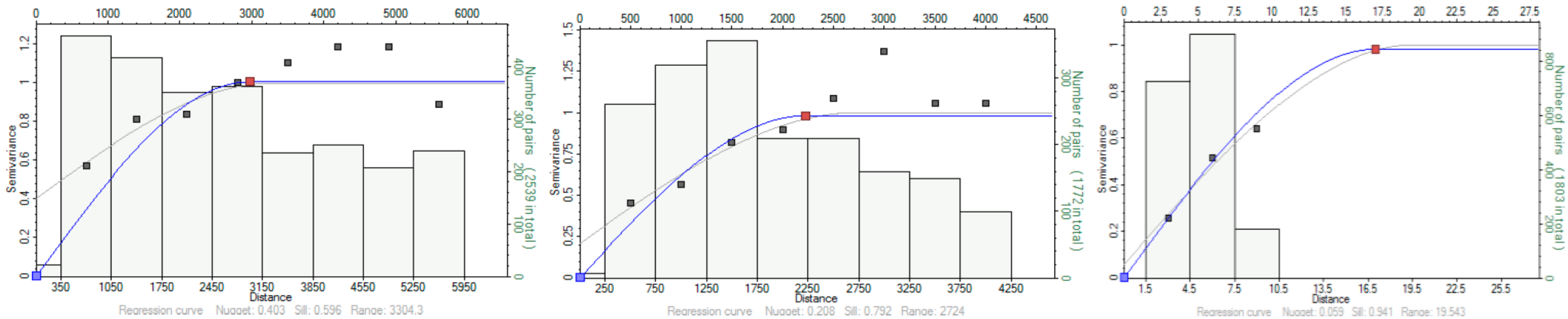



Figure 3. Lithofacies examples for 4 different stratigraphic zones.




(a) (b) (c)

Figure 4. Variograms for porosity in B5, (a) NNE25, (b) NWW, (c) vertical

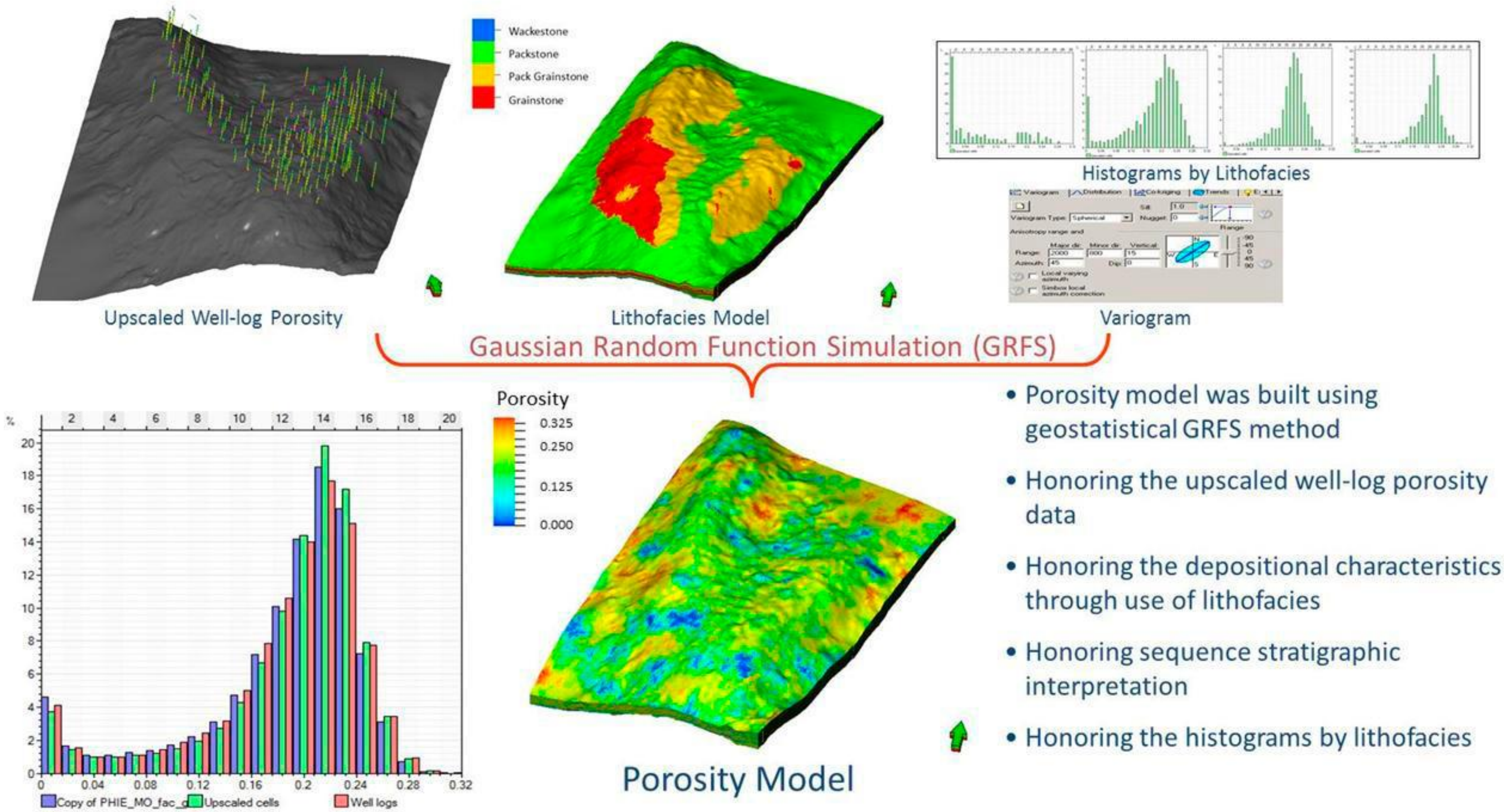



Figure 5. Porosity modeling workflow.