Reservoir Modelling

1- Introduction

A reservoir model is a digital representation of the subsurface formation and its rock and petrophysical properties. It is geometrically defined by its area of interest and top and base bounding surfaces. It is a process of integrating geological, geophysical, and petrophysical data into a 3D description of a reservoir (Fig.1).

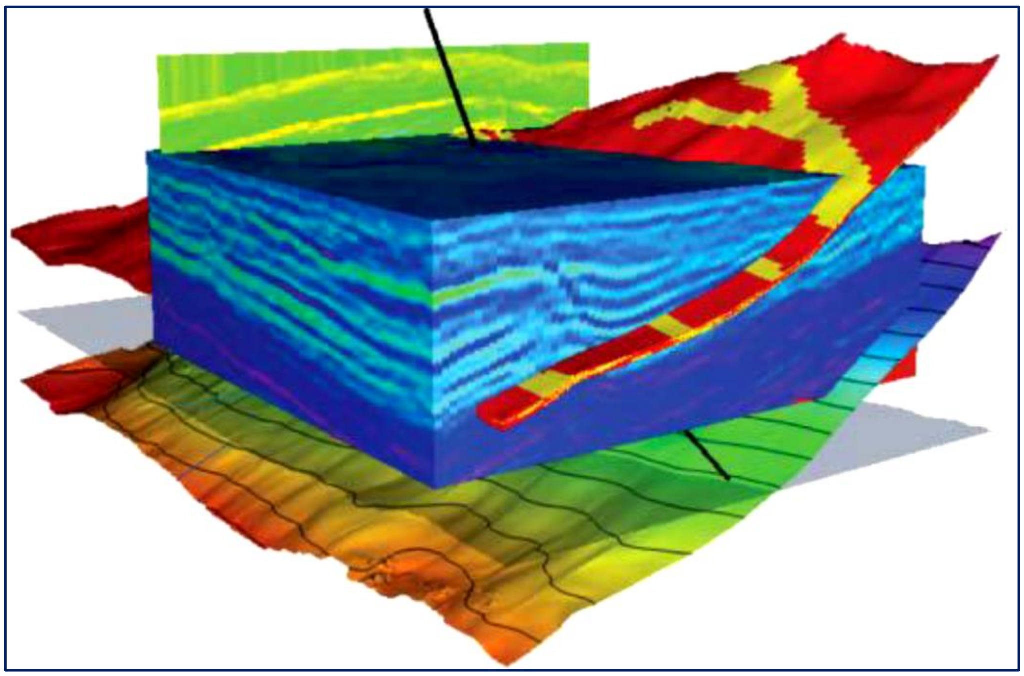

Fig-1: 3D reservoir model

Building a reservoir model includes the construction of ***a structural and stratigraphic model*** and determining the spatial distributions of facies and various petrophysical properties in the model. Therefore, when we build models of oil and gas resources in the subsurface we should never ignore the fact ***that the fluid resources are contained within rock formations***.

Constructing a good reservoir model requires multi- specialties analyses and integration of geological, geophysical, petrophysical, and reservoir engineering data using scientific and statistical inferences. So building a model of an oil and gas reservoir is complex ***because of the variety of data types involved as the many different steps required.*** Reservoir modelling is also a challenge ***because we are dealing with a mix of geological and spatial properties and the complex fluids present in the reservoir.***

2- The Uses of Reservoir Modelling:

1- Evaluation of rock volumes and the original hydrocarbons in place.
2- Representation of geological and petrophysical descriptions of the reservoir for input to reservoir simulation.
3- Increase profitability through better reservoir management, including development plans for new fields and depletion strategies for mature fields.
4- Prediction of the liquid volume (oil, gas, and water), decline analysis, secondary or tertiary recovery option injection strategies, and well and completion designs.
5- Observation of fluid movement contacts and pressures.
6- Analysis of fault seal and transmissibility in addition to calculating the displacement of the fault vertically and laterally.
7- Assessment of wells number and types that required to produce the reservoir economically (e.g. vertical, slant, horizontal, multilateral, etc.) and locations.

3- Reservoir Modeling According to the Stages the Reservoir Life Cycle:

3-1 Exploration Stage:

- Enhance depositional environment and conceptual model understanding.
- Refine stratigraphic model.
- Assess fault partition.
- Identify new prospects.
- Use the model as a data/information store.

3-2 Development Stage:

- Build more-detailed structural and stratigraphic model.
- Plan and design wells, including well path.
- Computing the production profiles (oil, gas, and water).
- Estimating the oil and gas technical reserves.
- Assess intermediate-scale reservoir heterogeneities and connectivity.

3-3 Production Stage:

- Assess small-scale heterogeneities, including flow units modeling.
- Use for reservoir management.
- Matching of the past production history (fluid rates, GOR, WC, pressures, etc).
- Optimize production in the field.
- Perform enhanced oil recovery (EOR)

4- The Modelling Workflow:

There are five major steps in the modelling workflow as follows (Fig-2):

1- Data collection, analysis and loading.

- Collect the input data
- Undertake qualitative and quantitative sedimentological and stratigraphic studies.

2- Build the reservoir framework.

- Structural Model
- Stratigraphic Model
- Geocellular Model

3- Build the facies model.

- Facies Model

4- Build the property model.

- Property Model
- Volumetric Model.

5- Build the dynamic simulation model.

- Simulation Model
- Uncertainty Model

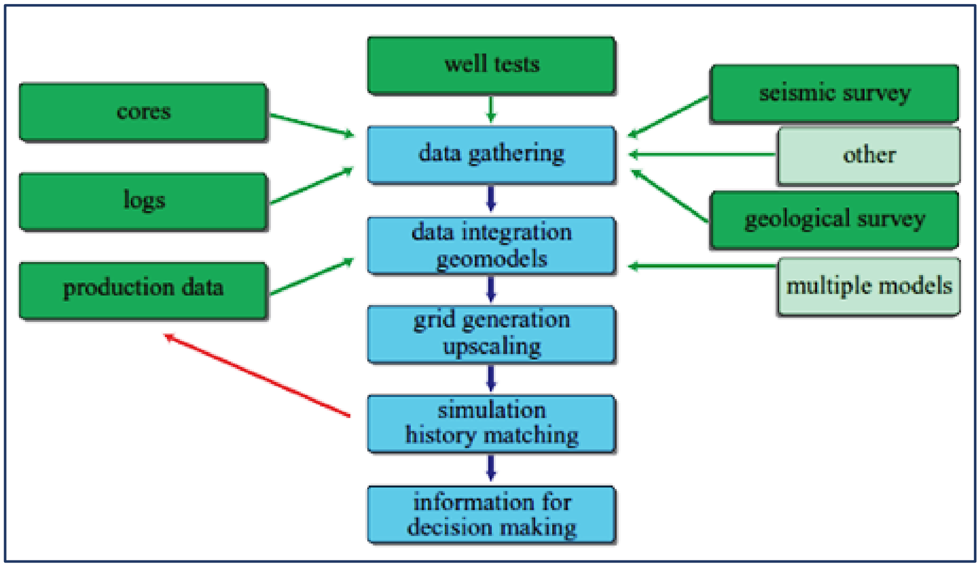

Fig-2 Reservoir modelling workflow elements

Heterogeneities in Reservoir Geology

Heterogeneity is one of the most complex problems in subsurface formations. ***The fluid storage and flow in porous media are governed by a variety of geological and petrophysical variables, including structure, stratigraphy, facies, lithology, porosity, and permeability. These variables all contribute to subsurface heterogeneities and have different scales***.

Many geological parameters affect subsurface fluids but control them differently, partly because of ***the different physical nature*** of these variables and partly because of their ***scale differences*** (table).

- **Large-scale parameters**, such as depositional environment, structural, and stratigraphic variables, are often dominant in controlling hydrocarbon storage.
- **Small-to-medium scale parameters**, such as lithofacies, porosity, and permeability, play leading roles in governing fluid flow for hydrocarbon production. Exceptions exist, such as the case of some large conductive faults controlling fluid flow.

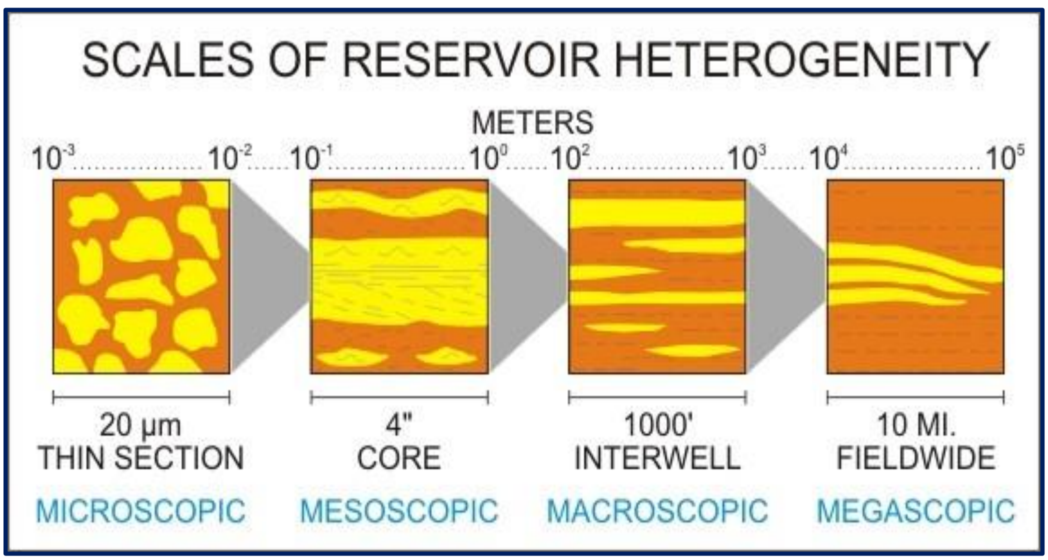

Fig.23 Scales of Reservoir Heterogeneity

Categories	Entities/Variables[a]	Hydrocarbon storage[b]	Hydrocarbon flow[c]
Structural	Anticlines	Dominant	Weak-moderate
	Domes		
	Faults	Moderate-dominant	Moderate-dominant
	Fractures	Weak-moderate	Strong
Stratigraphic	Composite sequences	Strong	Moderate-strong
	Sequences	Strong	Moderate-strong
	Sequence sets		
	System tracts	Dominant	Moderate-strong
	Parasequences stacking patterns	Moderate	Moderate-strong
	Layers Pinchouts truncations	Moderate	Strong
	Bedsets bedding	Moderate-strong	Strong
Depositional environment and facies	Depositional facies	Moderate – dominant	Moderate – dominant
Lithofacies	Mineral compositions	Small scale	Dominant
Petrophysical properties	Porosity S_w, Permeability	Small scale	Dominant

Types of Heterogeneities: (Figure-25)

1- Structural Heterogeneities:

Large-scale tectonic settings have significant impacts on the characteristics of subsurface formations.

- **Anticlines**: Anticlines provide one of the most common closed reservoirs. Many reservoirs in the world have an anticlinal closure for hydrocarbon accumulations. These include both small and large oil fields.
- **Faults**: Fault analysis is often critical for reservoir characterization and modeling because faults are present in many subsurface formations and they can create favorable structures for hydrocarbon storage. Faults can be very large or small and the size, quantity, geometry, and orientation of

faults are all important characteristics that influence on the heterogeneities of the reservoir.

- **Fractures:** Fractures are small to microscopic cracks, and their quantity can be much greater than faults. Faults and fractures are good examples of multiscale structural heterogeneities.

  Sealing and semi-sealing faults can have a great impact on both reservoir connectivity and sweep efficiency.

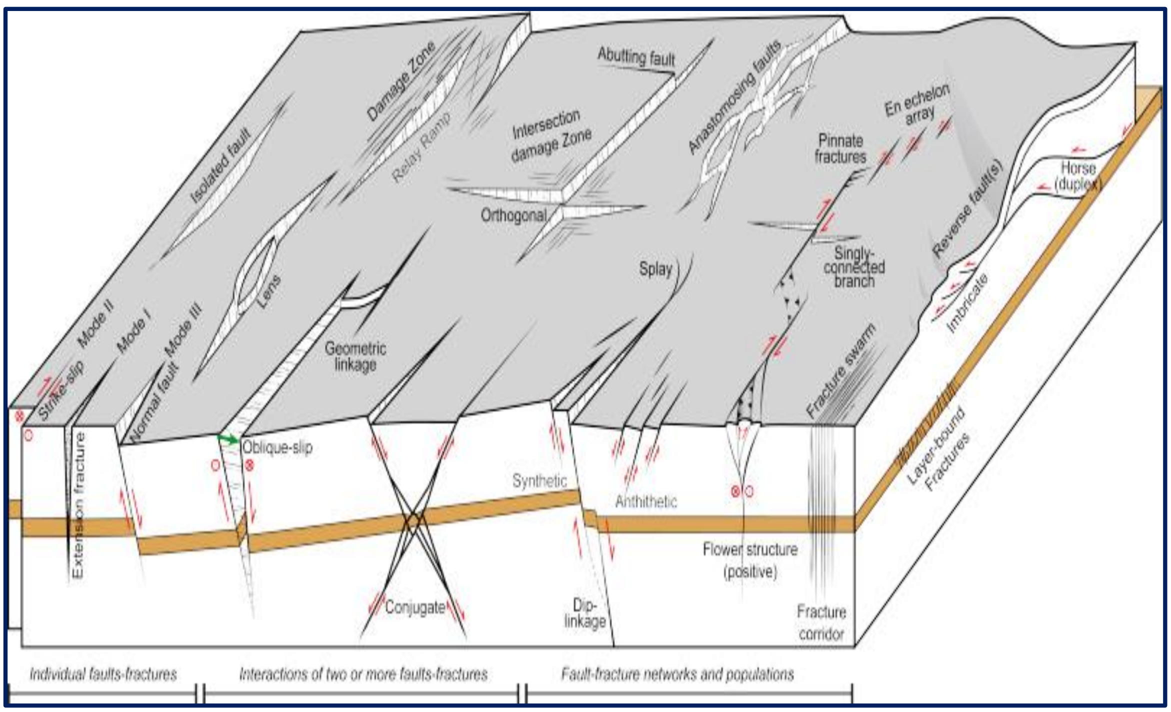

Fig.24 faults and fractures

2- Facies and Lithology:

Sedimentary facies often exhibit lateral and vertical spatial trends. This is a type of heterogeneity.

- **Facies Lateral and Vertical Trends:** As a function of water-depth (or sea-level) change and other factors, sediments can exhibit several types of depositional facies. These lead to a type of heterogeneity—the spatial trend.

Facies boundaries can act as barriers to flow when the permeability contrast is significant, the change between a channel body and the floodplain.

- **Lithology Compositional Trends:** Facies are typically made of a variety of lithologies. This is highly related to multiple scales of heterogeneities and statistical correlation analysis.

3- Heterogeneities in Petrophysical Properties:

Porosity, fluid saturation, and permeability are some of the most important petrophysical variables in natural-resource geosciences because they directly control storage and flow of subsurface fluids and are used to determine the hydrocarbon resources, productivity, recovery, and field development plans.

The descriptions of these petrophysical parameters include the characterization of their heterogeneities. There are several ways for evaluating heterogeneities of these parameters, including ***statistical descriptions, geospatial descriptions, and dynamic descriptions***.

Data and Measurements for Describing Heterogeneities:

Several types of data can be used for characterizing heterogeneities of subsurface formations, including core, well logs, well test and seismic data. These data represent different scales vertically and have different coverages laterally.

- **Vertically**, core and well-log data have much higher resolutions than seismic data and can provide information for descriptions of high-frequency heterogeneities.

- **Laterally**, core and well logs have limited coverage by individual vertical wells and they are generally sparse between different wells.

Impact of Heterogeneities on Subsurface Fluid Flow and Production:

Heterogeneities in structure, stratigraphy, depositional facies, lithology, and petrophysical properties affect fluid distributions in subsurface formations, including zonations of oil and gas. The most of those heterogeneities are more related to static reservoir properties and fluid storage. Many of these heterogeneities also have a significant impact on fluid flow. **For example:**

- **Stratigraphy and spatial distributions of lithofacies** can have a significant impact on the productivity of hydrocarbon.
- **Spatial variations in permeability and other reservoir properties** are ubiquitous in all permeable media and are among the most influential factors to fluid flow, hydrocarbon production, and recovery rate.

Summary:

- Heterogeneities in various scale of geological and petrophysical variables impact both storage and flow. Large-scale variables tend to control fluid storage and are very important in delineation and description of a reservoir. Characterization of small-scale variables is important because they control both storage and flow.

- The continuity and heterogeneity of these variables determine how the hydrocarbons are stored, and how they flow or inhibit the flow of fluids in porous media.

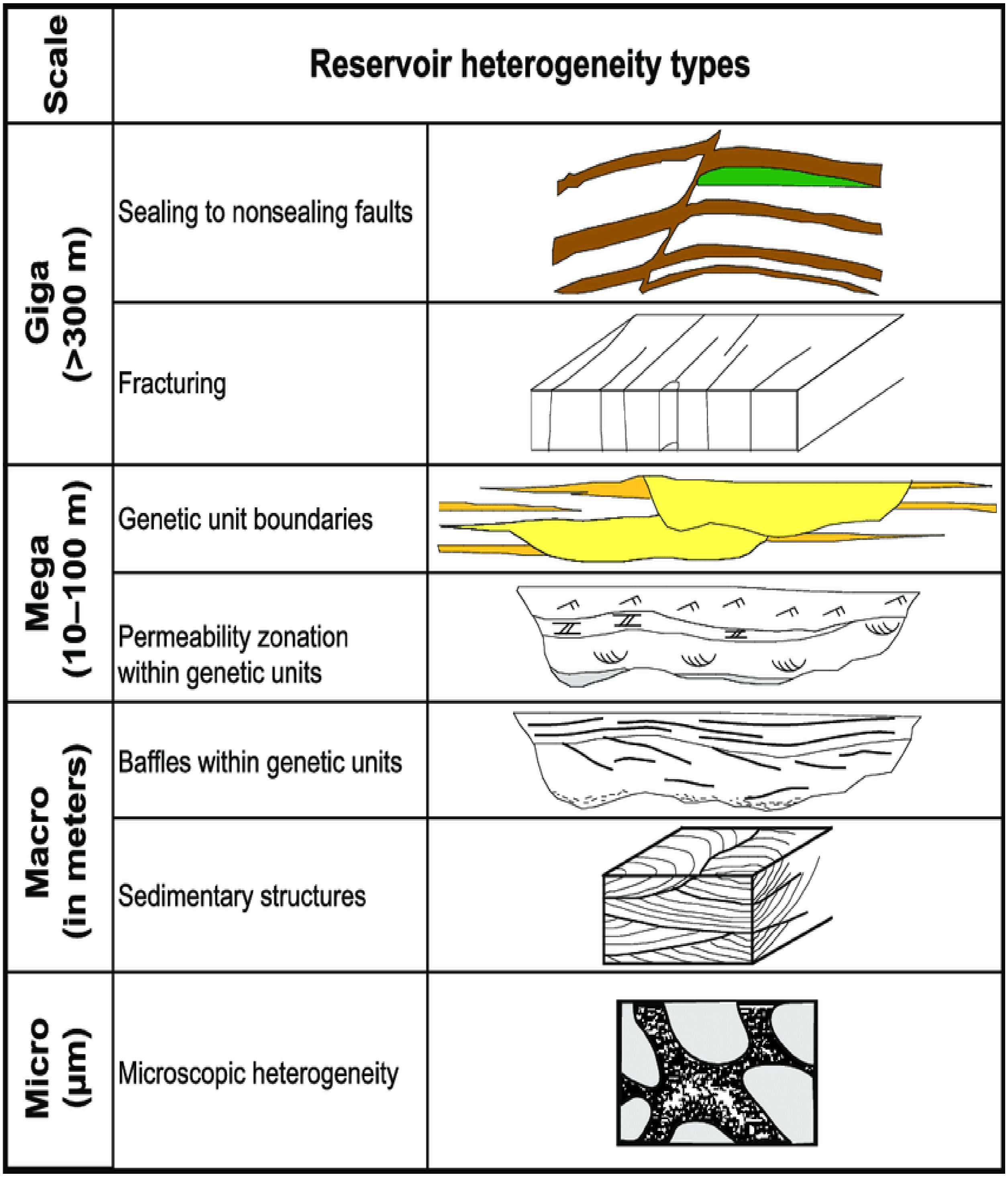

Fig.25: Types of heterogeneity at different scales from the microscopic to basin

3- Facies Model:

The three-dimensional distribution of bodies of rock and sediments with different sedimentological properties and associated properties is controlled to varying degrees by ***the depositional history of the strata of interest***. Primary (depositional) variations in sediment textures and fabrics are modified by ***diagenetic processes, such as compaction, dissolution, and cement precipitation.***

The facies: ***is defined as a body of sedimentary rock with specified characteristics, which may include lithology and rock properties.***

Reservoirs are commonly be as ***siliciclastic*** or ***carbonate***. Siliciclastic reservoirs are dominated ***by eroded and transported rock detritus***, while carbonate reservoirs are ***dominated by carbonate materials that are grown in place and/or transported to the basin***.

Facies Model: ***A facies model captures the reservoir variability based on the sedimentological analysis of the core and wireline data, combined into a conceptual model of the reservoir depositional environment.***

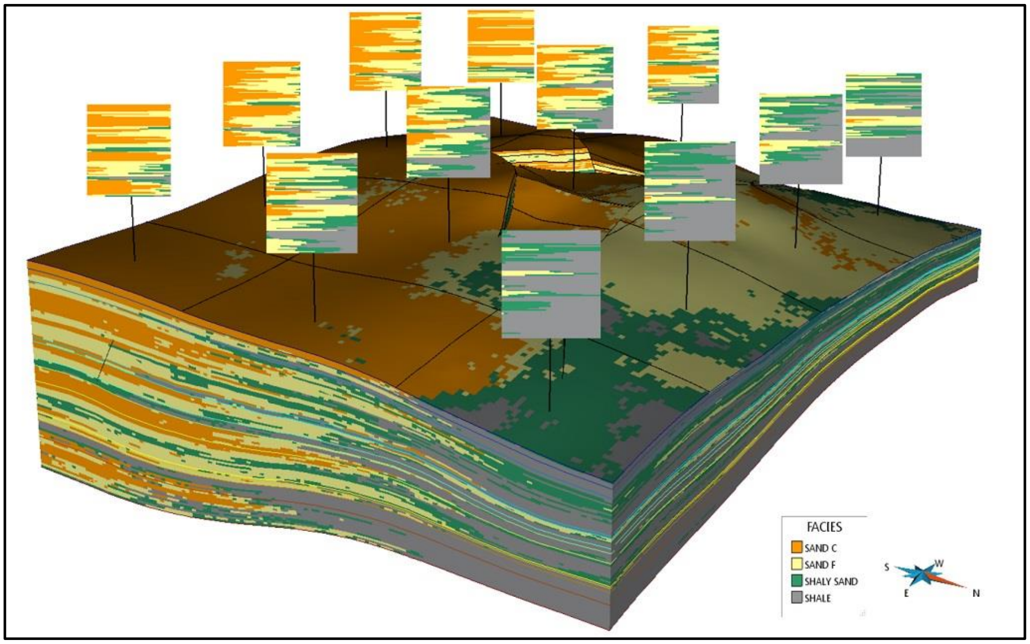

Fig.26 Facies Modelling

The main reason to build a facies model is to condition the subsequent property model; each facies should have a porosity and permeability distribution that is different from the other facies.

Facies Modelling Methods:

Depending on the distribution of facies, there are different methods are used in facies modelling. These methods fall into two categories: **pixel-based and object-based modelling methods.** Pixel-based models are built using correlation methods based on the variogram. It is more suitable for carbonate environments as the facies may have a more random pattern. Object-based modelling allows to build realistic representations of large-scale geological units such as channels, dunes, sand bars and reefs.

1- Pixel-Based Methods:

Pixel-based models are built using correlation methods based on the **variogram**: a measure of spatial variation of a property in three orientations, vertical, and maximum and minimum horizontal directions.

The variogram captures the relationship between the difference in value between pairs of data points, and the distance separating those two points. Numerically, this is expressed as the averaged squared differences between the pairs of data in the data set, given by the empirical variogram function, which is most simply expressed as:

$$2\gamma = (1/N)\Sigma(z_i - z_j)^2$$

Where Z_i and Z_j are pairs of points in the dataset

For convenience we generally use the semivariogram function:

$$\gamma = (1/2N)\Sigma(z_i - z_j)^2$$

The semivariogram function can be calculated for all pairs of points in a data set, whether or not they are regularly spaced, and can therefore be used to describe the relationship between data points from, for example, irregulary scattered wells.

The results of variogram calculations can be represented graphically to establish the relationship between the separation distance (known as the lag) and the average γ value for pairs of points which are that distance apart (Fig.27).

A more formal definition of semi-variance is given by:

$$\gamma(h) = \frac{1}{2}E\left\{[Z(x+h) - Z(x)]^2\right\}$$

Where:
E = the expectation (or mean), **Z(x)** = the value at a point in space
Z(x + h) = the value at a separation distance, **h** = (the lag).

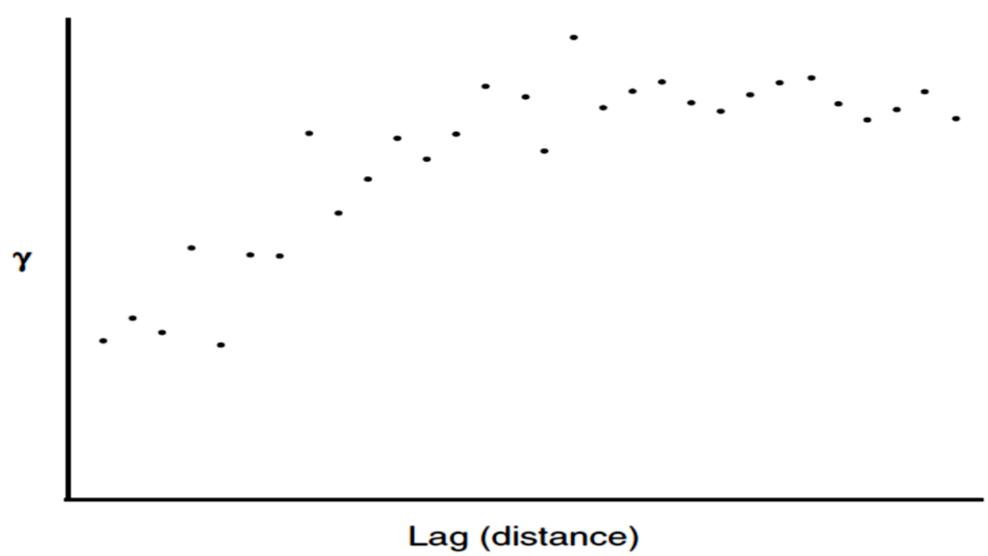

Figure 27: The raw data for a variogram model

Generally, γ increases as a function of separation distance. Finding a trend line through the points on a semivariogram plot yields a ***semivariogram model*** (Fig. 28).

A semivariogram model has 3 defining features:

- ***The Sill***, which is a constant γ value that may be approximates for widely-spaced pairs and approximates the variance.
- ***The Range,*** which is the distance at which the sill is reached.
- ***The Nugget,*** which is the extrapolated γ value at zero separation

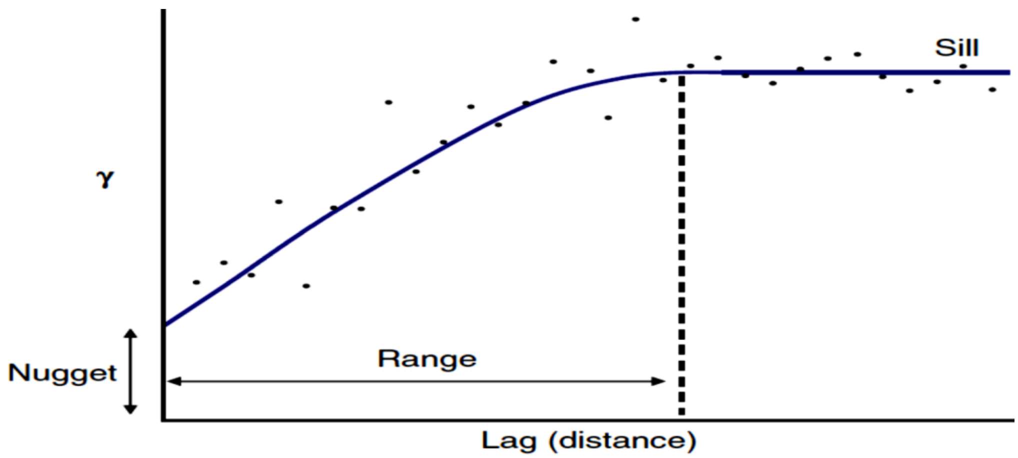

Fig.28: A semivariogram model fitted to the points in the figure above.

2- Object-Based Modelling

OBM is a facies modeling technique that accounts for geometry of geological objects. The geometry of facies bodies is analyzed using sedimentary principles and field data, and then it is characterized by probabilistic distributions.

Users describe these probabilistic distributions using statistical parameters, such as minimum, mean and maximum values. Depending on the shapes of facies bodies, such as channels and bars, OBM uses some predefined mathematical functions to approximate the facies body shapes.