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Impact of Geological Interpretation on Reservoir 3D Static Model: Workflow, Methodology Approach and Delivery Process

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Abstract

The traditional method of geologic modelling requires the interpretation of geological sections during digitization. But this traditional method has its limitations, the main limits are; it is usually time consuming and the model produced is unique to each individual geologist interpretation and may not be easily replicated by others. This study proposes an alternative workflow method for modelling, constructing and interpreting 3D geologic static model with multi-source data integration. The volume base method (VBM) was used to construct the 3D model. The combination of deterministic and probabilistic methods was used to model the facies workflow process to capture the geometrics of depositional environmental element. The truncated Gaussian simulation method was used with vertical trends option to obtain vertical transitional lithofacies in most of the reservoirs. Verification of results and detailed discussion of the proposed workflow and methodology is based on comparison with the conventional method. The saturation height function (SHF) equation applied to the water saturation model and permeability model improved the 3-D properties modelling workflow. The pillar gridding process was identified as the stage that increases the timeframe in 3-D modelling workflow. The results have proven to improve the overall timeframe and maximize the value of the field studies. The proposed method can be applied to a broad and complex geologic area. And is useful for marginal field development, by contributing economically and improving the deliverability of the entire project.

Keywords: 3D Static Model, Geologic Interpretation, Lithofacies, Model Workflow, Truncated Gaussian Simulation, Oil and Gas

Introduction

Geologic models are considered the main part of any field development in the oil and gas industries (Yusof et al., 2018). However, the main problem is how to accommodate the huge amount of data and consolidate it into a comprehensive geologic model. This demands high collaborations among teams from various disciplines within the industries personnel mainly geoscientist. Reservoir modelling is a complex process where different data types and technical discipline must be integrated to optimize reservoir management and decision making (Weber and Geuns, 1990). The technical integration and teamwork are essential and can be optimally achieved through planning and monitoring of a work process. A common understanding of the work process, its products and result is fundamental for successful project delivery. One of the importance of a model is to use it as a predictor and to make decisions. There are many different types of model based on the methodology involved, such as the deterministic, stochastic and other types of modelling methods. The choice of the algorithm to use is driven by the type of data, the density of the input data and the objectives (Scheidt et al., 2011).

Geological modelling where the term ‘geologic model’ usually refers to the geologic description of the reservoir, specifically the lithological and structural character. The internal spatial distribution of properties such as porosity, permeability and water saturation which determine the storage capacity, flow potential of the reservoir and fluid behaviours. In general, a theoretical model can be regarded as a collection of relationship between quantities describing some observed phenomenon (Debski, 2010). The quantities can be of numerical character for example, a porosity model of nominal character have names, level or the combination of both. Details of these models are only as useful as they are helpful to explain observation.

The geologic model is typically hierarchical containing a collection of sub-models such as structural model (with or without a fault model), a porosity model (Bai et al., 1994), permeability model (Mera et al., 2017) and water saturation model (Onuvughe and Sofolabo, 2016). There are several ways to characterise model but a scientific model consists of the following parts; a conceptual model, a mathematical model, the model parameters and realisation of the model. Understanding the spatial organisation of the subsurface is essential for quantitative modelling of geologic process. It is also vital for a wide spectrum of human activities ranging from hydrocarbon exploration and production to environmental engineering (Florinsky, 2012; Agi et al., 2017). Skilled geologist can translate 3D to 2D and vice versa, but no matter how experienced one can be this mental translation is bound to be qualitative hence, it is sometimes incorrect (Florinsky, 2012). Geologic models represented in 3D model building calls for a complex feedback between the interpretation of the data and the model. Such feedback can only be partial when viewing only the interpretation on a section plane (Florinsky, 2012).

In most application fields, 3D modelling is also a means of obtaining quantitative subsurface model from which information can be gathered. Such 3D geologic information system can be used in mineral potential mapping (An et al., 1994) and geo-hazard assessment (Culshaw, 2005). The distribution of petrophysical properties is mostly determined by rock types. Therefore, a clear understanding of how rocks are spatially laid out in 3D is paramount to any geostatistical study or simulation of a physical process. Traditionally, geologic models are presented by 2D cross section, but increasingly been visualized as digital 3D models (Artimo et al., 2003; Kassenaar et al., 2003; Hinsby and Abatzis, 2004). Today 3D geologic model is a crucial part of field development plan (FDP) and full field review (FFR). The technique selected at this stage will determine the outcome of the FDP and FFR studies. The project development plans are the major impact and relies mainly on the reservoir studies. The impact of these studies is not limited to the cost, but the compatibilities of the requirement and development designs are mostly impacted.

There are several methods to 3D surface generation problem; the use of contours on consecutive slices with triangle (Keppal, 1975; Fuchs et al., 1977); iteration method (Christiansen et al., 1978); Voxel (Herman et al., 1983; Meagher, 1982) and Ray casting (Farrel, 1983; Hohne et al., 1986). The marching cubes meshing algorithm (Loren and Cline, 1987), this method is effective in generating grade boundaries but, the resolution of the grade shell depends directly on the resolution of the voxels. The jagged nature of the marching cube meshes is not ideal for structural interpretation data and large dataset, which may slow down the interpolation process and might render the process impractical (Cowan et al., 2002). Other traditional method of geologic modelling requires the interpretation of geologic sections during digitization. The geological interpretation is therefore, written into the modelling and cannot be separated from the digitization process. A 3D model is then constructed using a tie-line between the section and a triangulation algorithm is then applied to generate a 3D shell from the tie sectional polylines. But these traditional methods have their limitations, the main limits are; it is usually time consuming and the model produced is unique to each individual geologist interpretation and may not be easily replicated by others. Therefore, this study is aimed at improving the project timeframe delivery, work process and final product. The study is modelled to coherently maximize the results of the study, and to come up with an alternative modelling workflow. This was done by compiling the modelling work processes from geologic interpretation into a complete interpretation to build a comprehensive geologic model.

Methodology

Modelling Workflow

The study was carried in three main stages; in the first stage the project was setup, the geological, geophysical, petrophysical and other data set were imported into the Analogue Project (study project). The data was interpreted and analysed in the second stage for geo-modelling construction. The static model was used to obtain results with the proposed workflow and methodology. The verification process and the analysis of the result from the alternative workflow and conventional workflow result were carried out in the third stage. The overall workflow and stages of this study are shown in Figure 1.

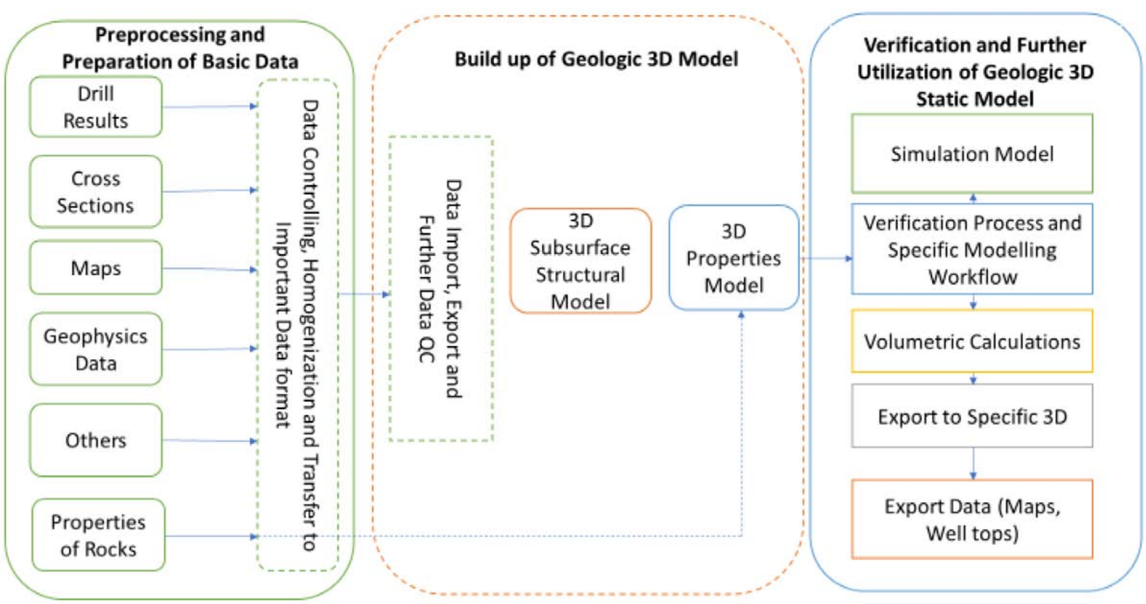

Figure 1—Main Stages of 3D Geologic Model Workflow

Facies and Property Model Workflow

The combination of deterministic and probabilistic methods was used to model the facies workflow process to capture the geometrics of depositional environment element. The truncated Gaussian simulation method was used with vertical trends option to obtain vertical transitional lithofacies in most of the reservoirs (Beucher and Renard, 2016). The facies model for conventional and this study workflow is presented in Figure 2, and is described as follows:

- The top reservoir is treated as a top conformable reservoir where sediments have accumulated within the basin study.
- The background lithofacies (representing floodplain, tidal were generated using TGSim in combination with the 'stack belts' option and pre-defined transitional boundary polygons.
- The channels and bar are modelled as 'flexible backbone' Boolean objects. A vector field following bar and channel depositional directions was initially created and implemented to control object direction.
- Based on the dynamic information, a narrow area of poor-quality reservoir was modelled from the main area.
- The above parameters were merged to produce the final lithofacies parameter.
- The results for the various method used were combined into a single lithofacies parameter for the entire reservoirs.

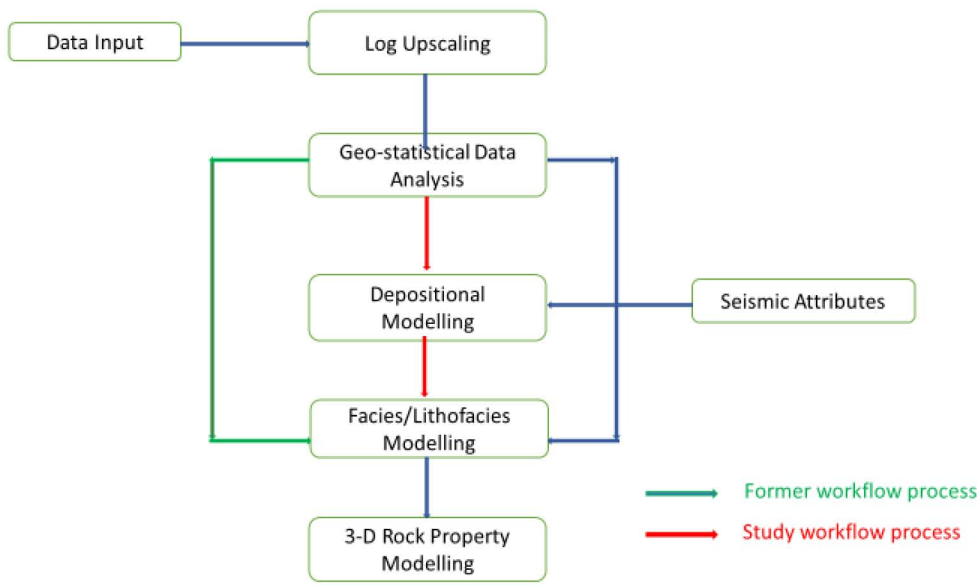

Figure 2—Facies Modelling Workflow; Conventional and Study Workflow

Results and Discussion

Structural Framework Workflow

The structural framework is part of the first stage in construction of a 3-D geologic static model. The structural framework is used to denote all geometric distribution of the reservoir, including horizons, faults planes, geo-grid or cells and simulation grid. The structural framework builds from interpreted faults stick and structural depth which is the most basic need of the framework construction. The comparison between the conventional method and this study method is shown in Figure 3 and the corresponding results are shown in Figures 4 and 5.

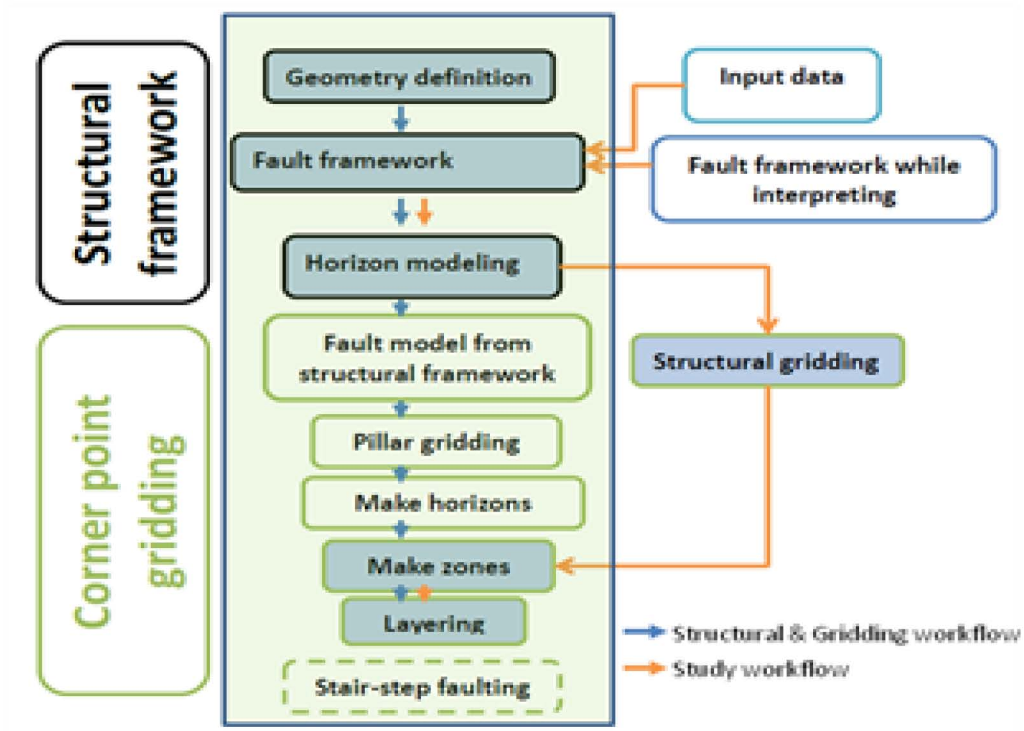

Figure 3—Structural and Gridding Workflow, Comparison of Normal and Study Method

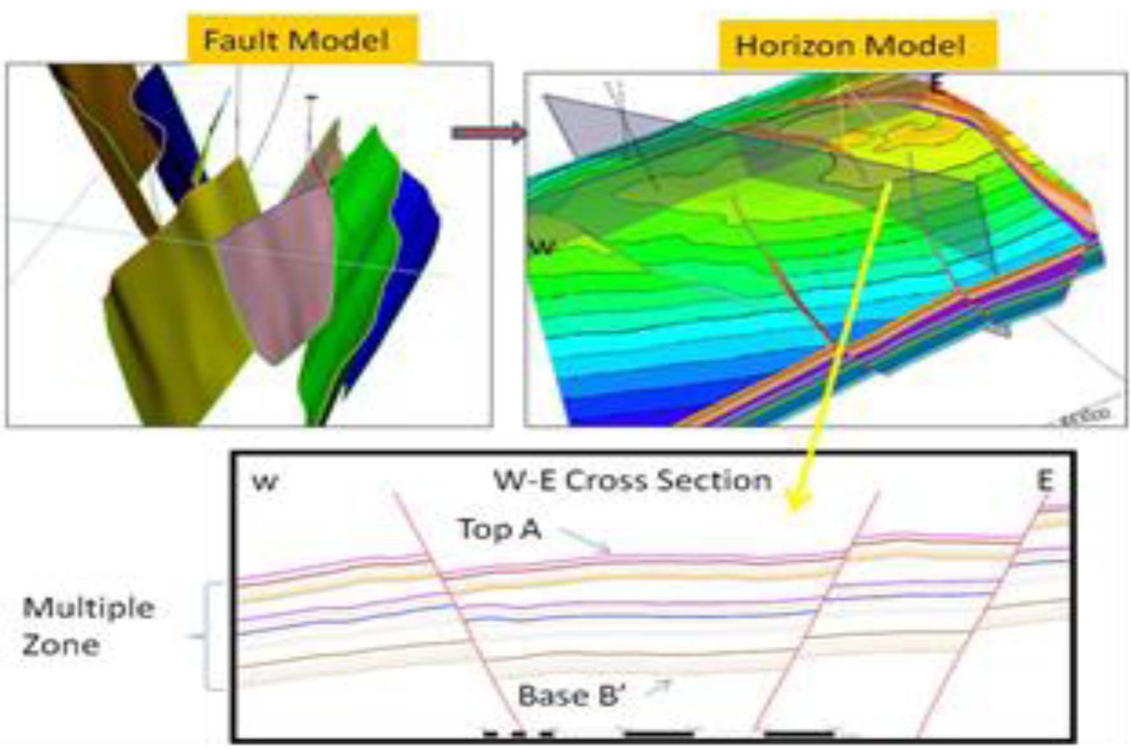

Figure 4—Structural Modelling

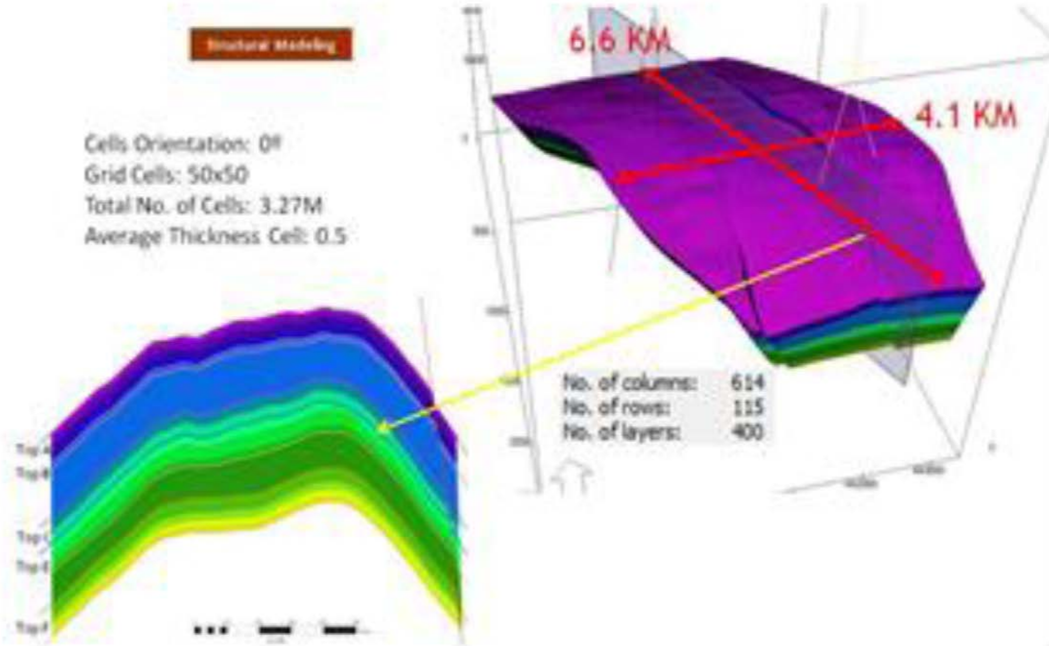

Figure 5—Structure Model Gridding and Layering

The results show that general steps and stages of workflow in 3-D structural framework construction can be combined into a single step making modelling simpler and faster. By reducing the timeline of geologic modelling, it creates new opportunity for testing multiple working hypothesis (Cowan et al., 2002). The grid resolution, geologic concept used for the interpretation (faulting and folding) can be easily modified. Individual management of each region and grid enable parallel processing and management of more complex structure (Suter et al., 2012).

Facies and Properties Modelling Workflow

Depositional environment, lithofacies, and property modelling are very diverse and complex task involving all discipline in the work process. In the general context of the workflow, it is the populating of the structural framework with lithological information and reservoir information. In this study, two main stages were applied; the depositional environment and facies 3-D modelling are grouped into a single stage. The second stage models the reservoir properties such as porosity, permeability, and water saturation model. These properties were modelled separately and divided into sub-group. The lithology and reservoir properties will be dependent on the reservoir under investigation and will include elements of depositional environment and facies association. The facies model will control the outcome of the reservoir property model. The properties of the reservoir such as porosity, permeability, and fluid saturation play a major role to determine the reservoir qualities and development of the fields.

(a) Geologic Element (Depositional, Diagenetic) and Facies Modelling

Figure 6 shows the interpretational workflow for depositional environment model. The conventional methods of workflow need to capture the depositional or architectural element of the depositional settings. The depositional environmental model needs to define and capture the history of the basin environment (Maliva, 2016). The depositional model will determine the facies definition for modelling steps to be carried out and the interpretational workflow. However, in this study, the workflow for facies modelling process are not virtually modelled to the depositional architecture but the depositional element will depend on the facies modelling process.

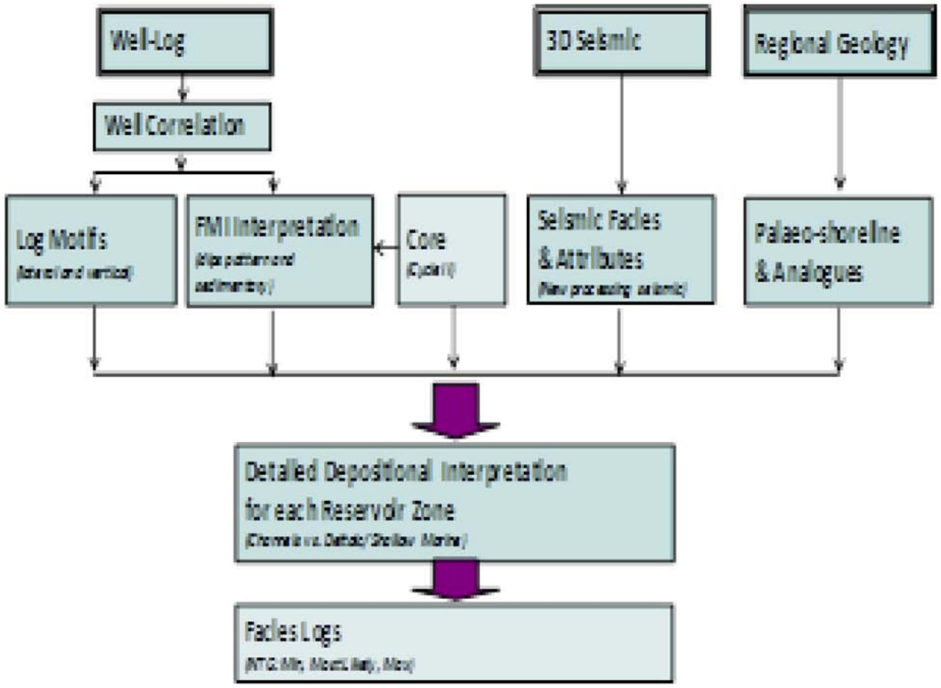

Figure 6—Depositional Interpretational Workflow

The final results (Figure 7) are similar in the overall output. The net to gross (NTG) are close to each other. The details of the volumetric from both methods are close enough with small range of uncertainties. This could be due to the complexity of the heterogeneity and the subjective nature of the geologic interpretation (Fogg, 1989). Facies model characteristics and distribution are a complex function of the interaction of numerous variables within the depositional environment. Multiple factors control sediment deposition, which can result in a great variation in the physical character of the sediment. Also, fragmentary preservation and variability, transportation, erosion, subsequent diagenesis and degree of deposition are contributing factors, as considerable uncertainty exist about the appropriateness of the analogs used for each specific case (Miall, 2006). There can be a great difference in modern facies assemblages and facies distribution and what is preserved in geologic record. Earlier depositional sediment is subject to late partial or complete erosion and redeposition. Despite its limitation, facies modelling has been demonstrated to be a valuable tool for analysis of sedimentary deposit and ultimately aquifer characteristics (Maliva, 2016).

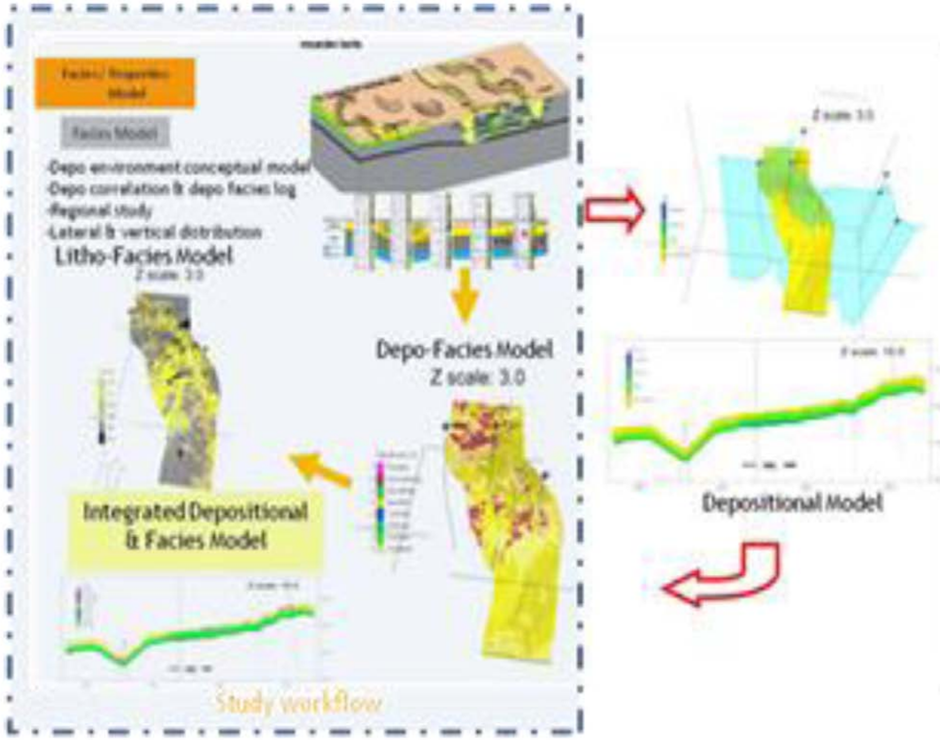

Figure 7—Depositional Facies Model and Lithofacies Modelling Workflow

(b) Porosity Modelling

Porosity modelling workflow for this study is similar to the standard process, although the data interpretation process and data analysis differs. It comprises of the total porosity (PHIT) or effective porosity (PHIE), depending on what is suitable to reflect the eventual fluid flow in the rock. In the Malay Basin, PHIT is modelled whereas, in Mexico PHIE is captures the reservoir properties in a suitable manner (Madon, 1994, 1997). In either case we must always model PHIT during log analysis. It is the total porosity which is either calibrated using core analysis data whereas, PHIT is an interpretation used by the petrophyscist. Both variables should be co-located together with volume of shale (VSH) to give a better interpretation of the surface. The porosity workflow for this study and results are shown in Figure 8.

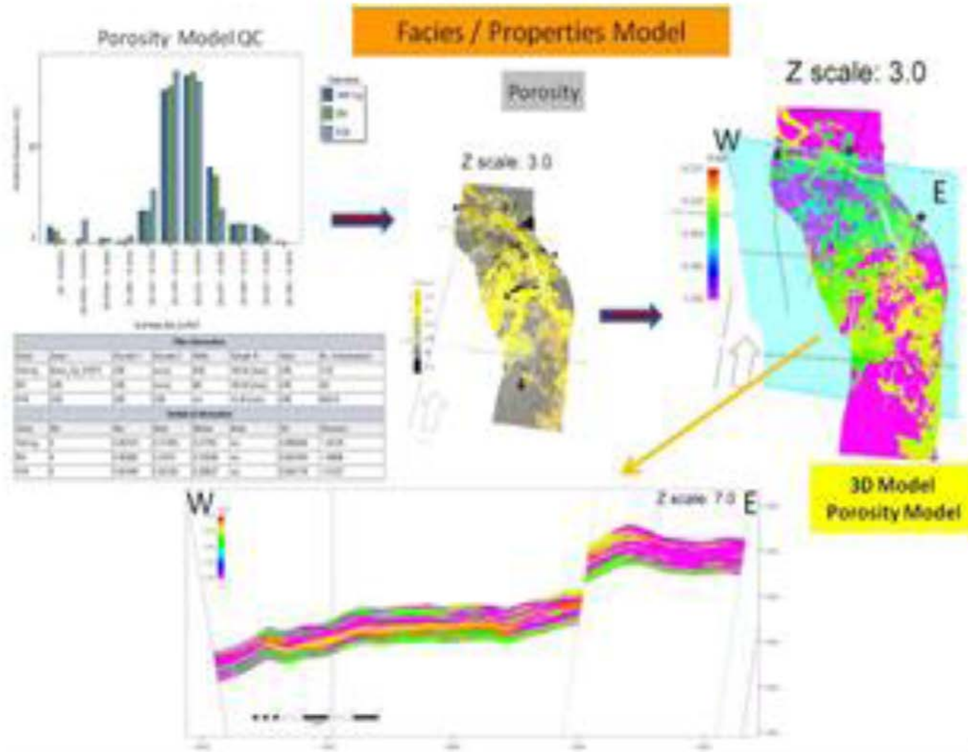

Figure 8—Porosity Modelling Workflow. The Facies Model as a Trend of Porosity Distribution.

(c) Permeability Model (Horizontal and Vertical) Workflow

The function method was used in the permeability modelling workflow. The relations porosity and permeability curve are derived, and relationship equation recorded. The permeability may come from core or derived from NMR logs or similar. Often the permeability parameters may form part of the water saturation (S_w) function. Thus, one must be careful about dependencies, especially when edits are made to one parameter. The collaboration between the petrophysicist and reservoir engineer is key at this point. Figure 8 shows the permeability model workflow, direct poro-perm function. The difference between this workflow and the conventional is the methodology approach. In the conventional methods, the permeability is modelled using a similar approach with porosity modelling and the cloud transform. There is no direct relationship between porosity and permeability model in this method.

From the 3-D permeability model results from function method and following the study workflow, given the function relationship between the porosity and permeability 3-D models (Figure 8). Both function and 3-D model results show the same pattern with define value. The values are direct calculations and the results of the uncertainties are very minimal. The permeability uncertainties have a direct relationship with porosity 3-D model uncertainties. The relationship may be partly due to their true correlation, and partly due to measurement inaccuracy (Moore et al., 2011).

(d) Fluid Saturation Model (Water, Oil or Gas)

Total water saturation (SWT) or effective water saturation (SWE) was modelled based on the relationship between the fluid contact and free water level (FWL) using the saturation height function equation. 3D modelling saturation method is not the preferred modelling method, this is because it over estimates the S_w across the reservoir as contacts are usually not considered. Therefore, the use of saturation height function equation (Figure 9) is preferable (Harrison and Jing, 2001). This is because the feedback from the detailed data analysis of all well and core data shows good results. Also, there are availability data and it can depict the reservoir heterogeneity. The saturation height function can be derived from either SWT or SWE log curve and by a combination of logs and capillary pressure data, if available.

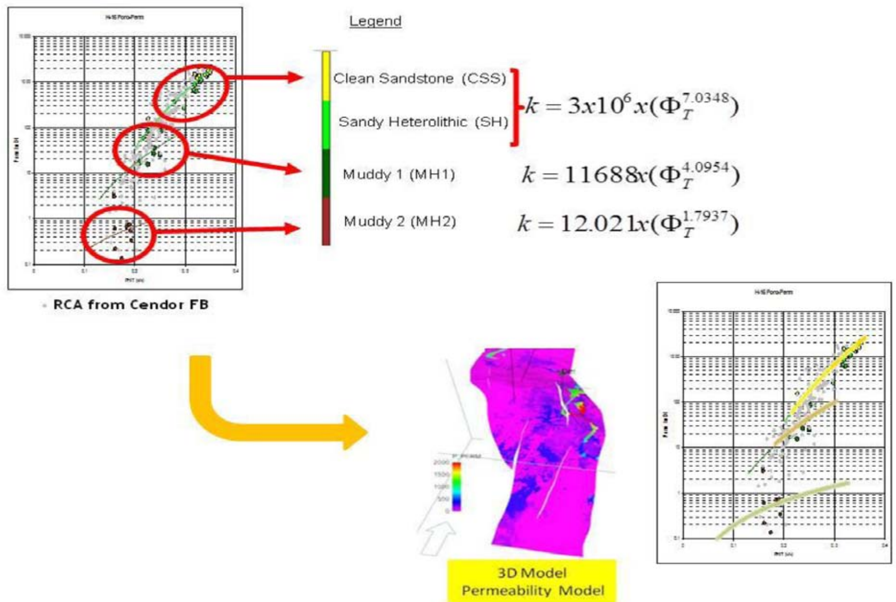

Figure 9—Permeability Modelling Workflow: Direct Poro-Perm Function

Core studies and analogue data from surrounding field were used to determine SHF equation relationship with rock properties. This helped in reducing the uncertainties of the SWT/SWE 3D models that was created from the direct SHF equation. The irreducible water saturation (S_{wirr}) and the fluid contact were used in estimating the water saturation of the reservoirs.

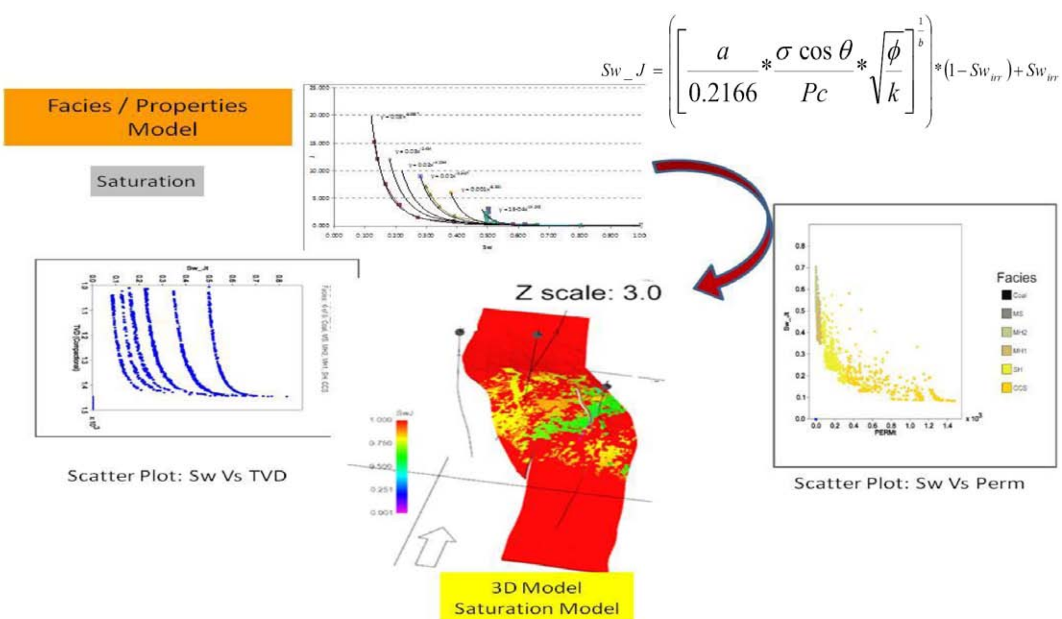

Figure 10—Fluid Properties Modelling Using Saturation Height Function (J-Function Transform) Method.

Conclusions

The 3-D geological model is very important stage in the development of the field. To carry out proper study and maximize result, time and value for money, the proper design of workflow process and project design are crucial. Based on the construction of the 3-D static modelling workflow and the result of this study, the following conclusions can be made;

1. The total timeframe to build a 3-D geologic static model can be reduced significantly with this method compared to the conventional method. The construction of the 3-D model improved significantly by using the Volume Base Method (VBM). The VBM workflow avoids some stages or process that cannot be avoided in the conventional workflow. The pillar gridding process was identified as the stage that increases the timeframe in 3-D modelling workflow.
2. The depositional modelling and lithofacies modelling process on a single run method can improve the efficiency of the overall output of a 3-D facies model. The construction of the depositional and lithofacies 3-D models in separate process can be avoided.
3. SHF equation was applied for the water saturation model and permeability model which improved the 3-D properties modelling workflow. It also saved a lot of time compared to the statistical method in the conventional workflow.
4. The study is useful for marginal field development, by contributing economically and improving the deliverability of the entire project.

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References

Agi A., Junin R., Gbonhinbor J.R., Onyekonwu M.O., 2017. Exploitation of Thin Oil Rims with Large Associated Gas Cap, *Int. J. Petroleum Engineering*, **3** (1): 14–48.

An, P., Moon, W.M., Bonham-Carter, G.F., 1994. Uncertainty Management in Integration of exploration Data Using the Belief Function. *Nonrenewable Resources*, **3**, 1, 60–71.

Artimo, A., Makinen, J., Berg, R.C., Albert, C.C., Salonen, V.P., 2003. Three-Dimentional Geologic Modelling of the Virttaaakangas Aquifer, Southwestern Finland. *Hydrogeology Journal*, **11**, 3, 378–386.

Bai, M., Ma, Q., Roegiers, J., 1994. Nonlinear Dual-Porosity Model. *Applied Mathematical Modelling*, **18**, 11, 602–610.

Beucher, H., Renard, D., 2016. Truncated Gaussian and Derived Method. *C.R. Geoscience*, **348**, 510–519.

Christiansen, H.N., Sederberg, T.W., 1978. Conversion of Complex Contour Lines Definitions into Polygonal Element Meshes. *Computer Graphics*, **12**, 3, 187–192.

Cowan, E.J., Beatson, R.K., Fright, W.R., McLennan, T.J., Mitchell, T.J., 2002. Rapid Geologic Modelling. Applied Structural Geology for Mineral Exploration and Mining, International Symposium, Kalgoorlie, Australia, 22-25 September.

Culshaw, M.G., 2005. From Concept Towards Reality: Developing the Attributed 3D Geologic Model of the Shallow Subsurface. *Quarterly Journal of Engineering Geology and Hydrogeology*, **38**, 231–284.

Debski, W., 2010. In: *Advances in Geophysics*, Academic Press, **52**, London.

Farrel, E.J., 1983. Colour Display and Interactive Interpretation of Three-Dimensional Data. *IBM J. Res. Develop* **27**, 4, 356–366.

Fogg, G.E., 1989. Emergence of Geological and Stochastic Approaches for Characterisation of Heterogenous Aquifer. In Proceedings R.S Kerr Environmental Research Lab (EPA) Conference on New Field Techniques for Quantifying the Physical and Chemical Properties of Heterogenous Aquifers.

Florinsky, I.V., 2012. *Digital Terrain Analysis in Soil Science and Geology*. Academic Press, USA.

Fuchs, H., Kedem, Z.M., Uselton, S.P., 1977. Optimal Surface Reconstruction from planar Contours. *Comm. of the ACM*, **20**, 693–702.

Harrison, B., Jing, X.D., 2001. Saturation Height Methods and Their Impact on Volumetric Hydrocarbon in Place Estimates. Paper SPE-71326, presented at the SPE Annual Technical Conference held in New Orleans, Louisiana, USA, 30 September – 3 October.

Herman, G.T., Udupa, J.K., 1983. Display of 3D Digital Images: Computational Foundation and Medical Applications. *IEEE Computer Graphics and Applications*, **3**, 5,39–46.

Hinsby, K., Abatzis, I., 2004. Petroleum Geology Modelling Tools of Relevance to Ground Water Investigations. *Geologisk Tidsskrift*, **2**, 10–11.

Hohne, K.H., Bernstein, R., 1986. Shading 3D-Images from CT using Grey-Level Gradient. *IEEE Trans, on Medical Imaging, M1-5*, **1**, 45–47.

Kassenaar, D., Holysh, S., Gerber, R., 2003. An Integrated 3D Hydrostratigraphic Interpretation Methodology for Complex Aquifer Systems. In: Poeter, Zheng, Hill and Doherty (eds.): Proceedings, MODFLOW and More, Understanding through Modelling, Colarado School of Mines, Golden Co. pp. 661–665, 16-19 September.

Keppal, E., 1975. Approximating Complex Surface by Triangulation of Contour Lines. *IBM J. Res. Develop*, **19**, 1, 2–11.

Lorensen, W., Cline, H.E., 1987. Marching Cubes: A High-Resolution 3D Surface Construction Algorithm. *Computer Graphics*, **21**, 4, 163–169.

Maliva, R.G., 2016. Aquifer Characterisation Techniques, Schlumberger Methods in Water Resource Evaluation. *Springer International Publishing Switzerland*.

Madon, M., 1994. Depositional and Diagenetic histories of reservoir sandstone in the Jerneh Field, Central Malay Basin: *Geol. Soc. Malaysia, Bull.* **36**, 31–53.

Madon, M., 1997. Kinematics of extension and Inversion in the Malay Basin, Offshore Peninsular Malaysia: *Geol. Soc. Malaysia, Bull.* **41**, 127–138.

Meagher, D.J., 1982. Geometric Modelling Using Octree Encoding. *Computer Graphics and Image Processing*, **19**, 2, 129–147.

Mera, J.P., Chiamulera, M.E., Mantelli, M.B., 2017. Permeability Model of Sintered Porous Media: Analysis and Experiments. *Heat and Mass Transfer*, **53**, 11, 3277–3285.

Miall, A.D., 2006. *The Geology of Stratigraphic Sequences* (2nd Ed.) Heidelberg: Springer.

Moore, W.R., Ma, Y.Z., Urdea, J., Bratton, T., 2011. Uncertainty Analysis in Well Log and Petrophysical Interpretation. *AAPG Memoirs*. DOI: 10.1306/13301405M963478

Onovughe, E., Sofolabo, A., 2016. Saturation Modelling: Using the Maxman-Smits Model/Equation in Saturation Determination in Dispersed Shaly Sands. *JMEST*, **3**, 6, 4985–4992.

Scheidt, C., Caers, J., Chen, Y., 2011. A Multi-Resolution Workflow to Generate High-Resolution Models Constrained to Dynamic Data. *Computer Geoscience*, **15**, 545–563.

Suter, E., Cayeux, E., Escalona, A., Karstad, T., Vefring, E., 2012. A Strategy for Effective Local Updates of the Geological Structures in an Earth Model During Drilling, 74th EAGE Conference and Exhibition, 2012.

Webber, K.J., Guens, L.C., 1990. Framework for Constructing Clastic Reservoir Simulation Models. *Journal of Petroleum Technology*, **42**, 10, 1248–1297.

Yusof, M.A., Agi, A., Gbadamosi, A., Junin, R., Abbas, A., (2018). Uncertainty analysis of hydrocarbon in place calculation using 3D seismic and well data during appraisal stage – Case study of Goldie Field, offshore Sarawak. *Journal of Natural Gas Science and Engineering*, **58**, 238–265.