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Understanding The Uncertainties In Geomodeling Process, An Awareness for Risks Mitigation Case Study of Senoro Field, Senoro-Toili Block, East Sulawesi

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Abstract

The uncertainty is exist from subsurface to surface facililties, effecting a large element of decisions making. These uncertainties, without exception, exists across the workflow within all the process of Senoro field development plan. This paper is focus on describing the uncertainty in the 3-D static geomodeling process. The information from uncertainty analysis provides an understanding of the reservoir behaviour for accurate assessment and reservoir performance prediction. Uncertainty analysis, along with sensitivity quantification, could also be used to identify which area requires a detail consideration, or where more data collection is required.

The key uncertainty in Senoro 3-D geomodeling have been analized to map the risks that may encountered in the future. It includes seismic interpretation, time to depth conversion, porosity-permeability transform for a certain facies, facies prediction for un-cored intervals, facies/properties distribution based on geostatistics, water contact,and water saturation analysis from cappilary pressure/J-function analysis.

The uncertainty analysis was commenced by defining a base case model, represents the best estimation. Subsequently, uncertainty parameters were varied to quantify the effect of each variable toward OGIP and impact of sensitive variable on reservoir performance. The Monte Carlo technique was applied by certain distribution method. In Senoro case, a triangular distribution was selected. After a thousand realizations (runs), the representative P10,P50 and P90 of OGIP were plotted in a histogram.

In further process, uncertainty will also be analyzed in dynamic model (history matching and production forecasting) in accordance with fracture existence and the relative permability end point estimation. It is suspected that those two variables impact the cummulative gas production and water coning that imply on plataeu time (deliverability).

Introduction

Senoro field is belong to Senoro-Toili Block, located in the eastern arm of Sulawesi island (**Figure 1**). Senoro field was discovered by drilling Senoro-1 wildcat well in April 1999 and it was tested 13.7 MMSCFD of gas, with 2% CO2 and 600 ppm H2S. Since then, 5 (five) successful delineation wells have been drilled and tested in the Senoro structure in year 2000, 2001, 2005, 2007 and 2009, i.e SNR-2/2ST, SNR-3, SNR-4, SNR-5 and SNR-6 wells.

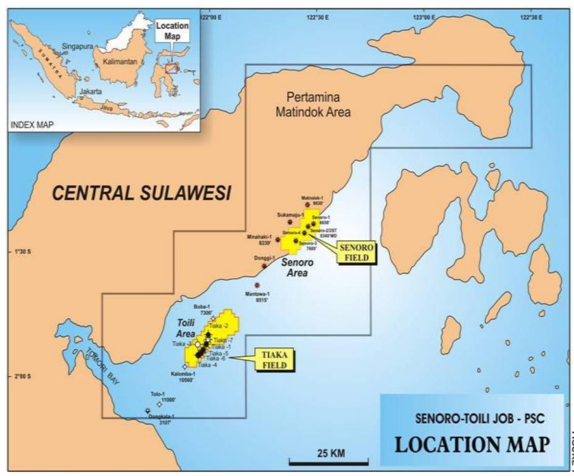


Figure 1. Senoro-Toili Block, Sulawesi Island

The Minahaki Formation represents the main reservoir target in the Senoro field and adjacent area of northern Tomori. It consists of platform facies carbonates (formerly referred to as the Upper Platform Limestone) and the reefal facies carbonate build-ups at the top, namely Mantawa Member. The Mantawa Reef Member at the top of Minahaki Formation generally provides excellent reservoirs in Senoro Field. **Figure 2** showing the depth structure map of Senoro field.

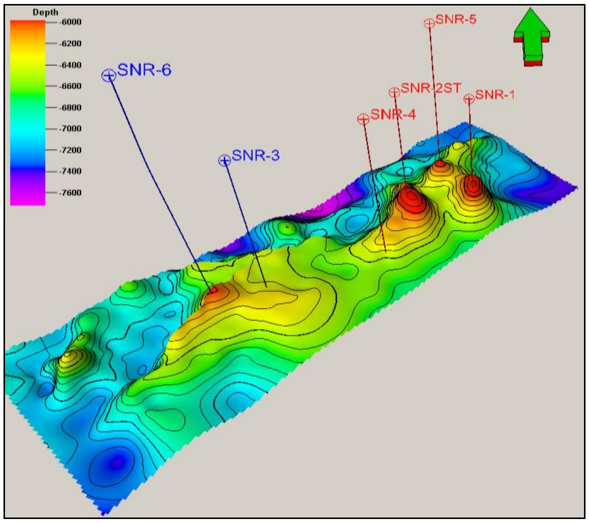


Figure 2. Depth structure map of Senoro field

Geologically, Senoro-Toili Block is located in a tectonically complex area at the eastern arm of Sulawesi, formed by a collision process between Banggai-Sula micro-continent and East Sulawesi Ophiolite Belt.

The Banggai-Sula micro-continent was originally a part of the major Australia-New Guinea Continental Plate, which itself had been formed during the Mesozoic break-up of Gondwanaland. Following the break-up, the Banggai-Sula micro-continent drifted westerly directed by the South Sula-Sorong Fault. As the micro-continent continued its westward drift, a really extensive Miocene carbonate shelf with localized reef growth was developed along the micro-continent margin.

During the Late Miocene - Early Pliocene time, the Banggai-Sula micro-continental shelf collided with the East Sulawesi Ophiolite Belt resulted in folding, thrusting and imbricating structures of micro-continent shelf section, coinciding with the uplift of abducted East Sulawesi Ophiolites.

In the Pliocene – Pleistocene period, following over-thrusting and uplifting of eastern Sulawesi, as a result, an easterly-directed deposition of post-tectonic flysch and molasse sediments occurred in the thrust front basin. The Micro-continental shelf sediments were buried deeply, allowing the maturity of the Miocene source rock sections.

The stratigraphy of eastern Sulawesi is related to two distinct depositional time periods. The first representing a continental margin rift/drift sequence of Banggai-Sula deposition prior to the collision, and the second representing a foreland basin flysh-molasse sequences, deposited in front of an easterly-migrating thrust front after collision had occurred. A generalized stratigraphic diagram of the Tomori-Banggai Basin is presented in **Figure 3**.

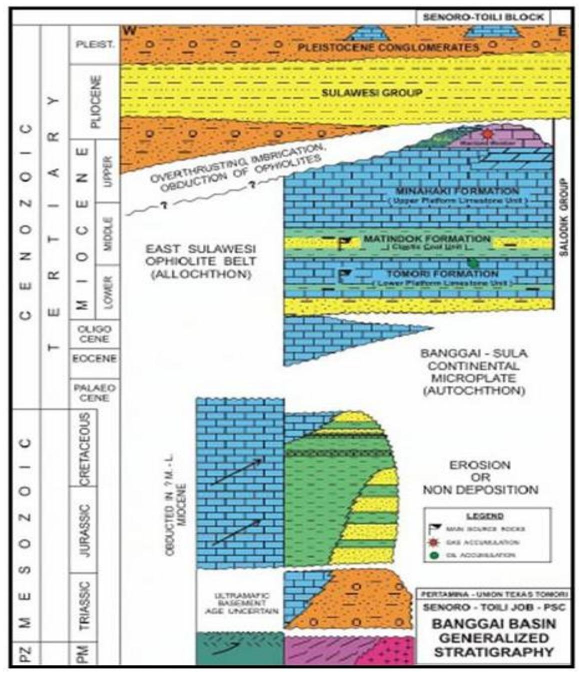


Figure 3. Stratigraphic column of Senoro-Toili Block

Two major reservoir types were identified based on seismic, log and core observations. Based on geometry of body recognized from seismic data, limestone in Senoro can be generalized into 2 types, namely build-up type and platform type. The platform type recognized as Minahaki Formation, which is widely developed in all areas. Meanwhile, the build-up type limestone (Mentawa) only developed in the northern part of Senoro Field. **Figure 4** showing the carbonate development across Senoro and adjacent fields (Minahaki and Cendanapura).

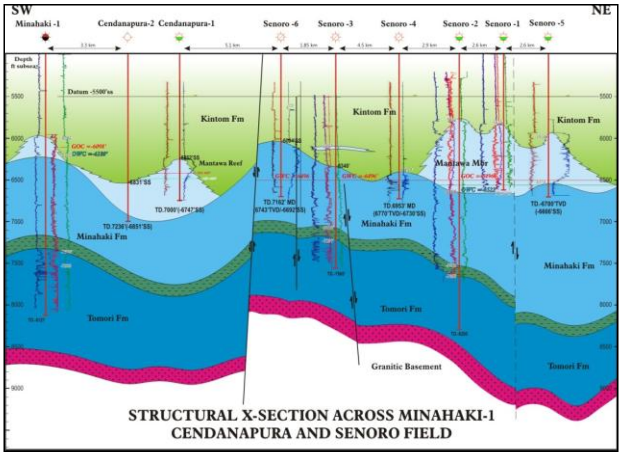


Figure 4. Structural cross section across Minahaki-1, Cendanapura and Senoro Field

Dealing with its reservoir heterogeneity, an integrated reservoir study was then conducted to obtain a better understanding of the reservoir behaviour for an optimum development plan by formulating a reliable geologic model of producing formations in Senoro field (Mentawa and Minahaki). A multidiciplinary team of geophysicist, petrophysicist, geologist and engineers works closely to integrate various data, tools and skills from subsurface to engineering aspects. Petrophysical analysis and reservoir characterization combined with the geologic model was described to study the degree of reservoir heterogeneity at several scales, develop numerical techniques to predict facies and property distribution. The final reservoir distribution will be used to determine the optimum number, type and locations of producing wells and their drilling schedule for various development scenarios. General reservoir characterization workflow is shown in **Figure 5**.

Along with that, the nature of collaborative works and various data integration allow the associated element of uncertainty in the decisions making process. Accordingly, understanding the uncertainties in geological modeling is imperative.
This paper emphasizes on uncertainty quantification of OGIP and EUR, identification of the most influential parameters contributing to uncertainties in OGIP, and further mitigation of the probable risks.

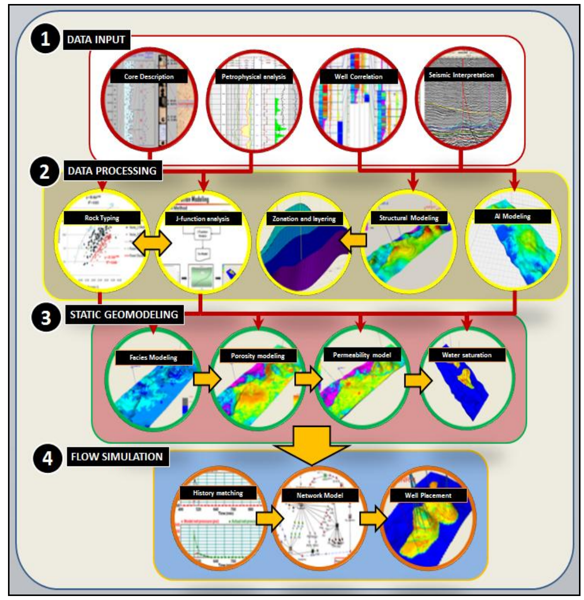


Figure 5. General workflow of Senoro static geologic modeling

Data and Method

Uncertainty analysis was commenced by gathering the most possible influential reservoir parameters for hydrocarbon volume. The most likely parameter/values from the existing data are used to calculate hydrocarbon volume. This volume is called a base case, that will be used as the reference value.
The most influential parameters were determined throughout the integrated reservoir study and reservoir geomodeling process of Senoro field. The large number of reservoir uncertainties can generally be grouped into 4 categories :

1. Geophysical uncertainties (for examples: data interpretation, time to depth conversion method, horizon picking, fault interpretation, well ties etc).

2. Geological uncertainties (for examples: definition of sedimentary depositional environments, rock type/facies prediction, variogram analysis and spatial distribution method etc.

3. Petrophysical uncertainties (for examples: petrophysical parameter for Vshale, porosity, permeability, water saturation, fluid contact,

permeability transforms, J-function analysis, cut off criterion etc.)

4. Dynamic uncertainties that have a great impact on the reserves and production profile (for examples: absolute and relative permeabilities, fault transmissibilities, well skin, end point scaling etc.)

In this paper, key uncertainty parameter will be focused on seismic interpretation, time to depth conversion, porosity-permeability transform for a certain facies, facies prediction at un-cored intervals, facies/property distribution using geostatistics method, fluid contact, and water saturation analysis derived from J-function and cappilary presure analysis.

Seismic Interpretation Uncertainties

Seismic interpretation is a key element in a modeling workflow, because it defines the structural configuration of 3D geomodel. However, the uncertainty in a geological model resulted from a seismic interpretation is not systematically assessed as part of a normal geomodeling workflow. Sharing interpretations, knowledge and analogue information, is important for understanding this range of conceptual uncertainty for a given seismic datasets. Knowing the geologic and tectonic setting of Senoro field, the uncertainty is arise from horizon picking and fault interpretation. In order to achieve best fit of top and base model, seismic horizon picking was refine by taking acoustic impedance into account.

Time to Depth Conversion Methods

Time to depth conversion of interpreted seismic horizon is an important step in the geomodeling workflow. Multiple velocity models were employed to provide a linkage between time and depth. It allows the quantitative assessment of uncertainty in uncertainty in velocity, and therefore depth. Available well velocity (well checkshot, VSP and/or synthetic seismograms), well markers, stacking velocity were analized to give an insight about velocity trends and layers. In Senoro, time depth conversion was attempted using 5 (five) different methods, those are: T-D conversion using 4 velocity layers, T-D conversion using 2 velocity layers, T-D conversion using average velocity, T-D conversion using stacking velocity gridded to fit the average velocity at each well marker, and T-D conversion using well checkshot gridding, using Top Carbonate TWT map as a trend.

Each method gives a significant impact on gross rock volume calculation, such that the correct handling of the structure and contact is often the key to realistic uncertainty assessment. Currently, 3D PSDM seismic data has been processed for the entire Senoro field. Hence, It is expected to reduce the uncertainty on time-depth conversion.

Porosity-Permeability Transform

Permeability (k) transform is the tool for predicting permeability based on the theoretical realtionship between porosity, facies/rock type and permeability. Practically, It used to be resulted from core porosity vs. permeability cross-plot for each rock type/facies. A consistency of transform achieved after each rock type/facies is splitted, inline with porosity-permeability classes. Rock type class 1 is dominated by Packestone-Grainstone facies with vuggy porosity, rock type class 2 is composed by Wackestone-Packestone with chalky characteristics, meanwhile rock type class 3 is predominantly composed by mudstone facies. Figure 6 showing the poro-perm transform for each rock type class.

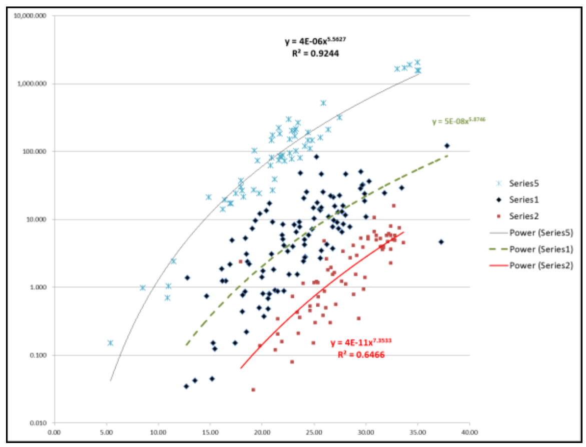


Figure 6. Poro-perm transform for each rock type

A linear regression was then estimated, and it will be used for transforming porosity, and inherent rock type into permeability to the entire 3D model. Applying this approach, uncertainty is associated since cloud of data was represented by a linear regression. Such that many data will be force to fit with regression line. Dealing with such linearization, uncertainty analysis is needed to honor the high and low limit of the cloud data.

Facies Prediction at Un-cored Intervals

Facies/Rock type classification is part of reservoir characterization process that defines the reservoir distribution. It was carried out based on integration process between quantitative porosity-permeability relationships and qualitative core description from SCAL and routine core. This classification is usually done visually on cores and then extended to wireline logs from the cored wells. The challenge is how to apply this classification to un-cored wells based on relationships observed at the cored wells. In Senoro, facies/rock type prediction was based on an approach on Adaptive Neuro - Fuzzy Inference Systems (ANFIS) techniques.

The ANFIS is trained on facies of cored wells based on gamma ray, density, neutron, and sonic logs. The lithofacies selected for training the ANFIS are grouped into 3 lithofacies representing lithological and diagenetic information, namely Packestone- Grainstone with vuggy porosity (lithofacies 1), Wackestone-Packstone with chalky characteristic (lithofacies 2), and mudstone with chalky characteristic (lithofacies 3). The approach of this work can be applied to fields where quantitative classification of a large number of logs by visual observation can be time-consuming and tedious. This approach can also be used to determine which logs are the most crucial for determining different types of facies. The lithofacies grouping is the main source of uncertainty. ANN works based on a training data that related to certain classification. Inappropriate clasification will lead for a mistake on a prediction results, because ANN will learn from any available datasets. Furthermore, in carbonate rock, a similar log characters may have a significant different on lithofacies/rock type.

Facies and Property Distribution Based on Geostatistics Method

Facies and property modeling (porosity, permeability, water saturation) is an important step of the 3D geomodeling process. The common method of propagating the facies/properties to the whole field is using geostatistics procedure since its versatility to be used for several purposes related to reservoir description. Stochastic modeling provides the quantitative relationship describing the spatial variablility of a reservoir property. This includes the used of variogram analysis and primary/secondary variables. In Senoro, since facies/property data is only available in 6 wells, it is useful to use the sample data from another extensively seismic data as long as there is a spatial relationship exists among them. Depending on the availability of the sampled data, the uncertainties with respect to the estimate can vary significantly. In addition to provide the estimated values, geostatistical procedures also provide associated uncertainty in the estimation. Geostatistics, similar to any other statistical procedures, involve subjective decision making. For instance, subjective decision of variogram range and direction, zonation/layering concept, data analysis (vertical proportion curve, input/output truncation), value of correlation coefficient between porosity and AI, seed number and so on. Those parameters will be a subject to uncertainty analysis in further process.

Fluid Contact Uncertainty

A range of fluid contacts (Gas Water Contact and Oil Water Contacts) was picked based on limited well test data, RFT, and combined log interpretation. The plot of pressure versus depth for the subject reservoir zone is illustrated as below figure. Fluid contact identification has resulted different fluid rezim between north cluster (Mentawa) and south cluster (Minahaki). In northern structure, fluid contact was indicated by GOC and OWC at -6496 ft-ss and -6522.34 ft-ss respectively. Whereas in the southern structure, gas is directly in contact with water at depth -6496 ftss.

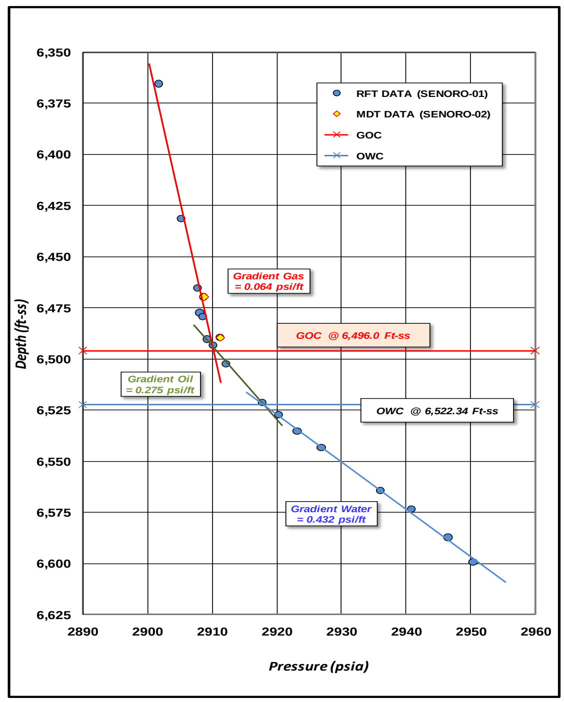


Figure 7. Fluid Contact Determination

However, DST 2 in Senoro-2 well at depth 6510-6520 ft TVD-ss resulted in 6.41 MMSCFD, 24.5 BCPD, and 123 bwpd. This result yield another interpretation that the GOC might be around 6520 ft TVD-ss. In this analysis, GOC at depth 6520 ft TVD-ss is considered as high estimate, meanwhile, GOC at depth 6508 ft TVD-ss (halfway between 6496 and 6520 ft TVD-ss) is considered as best estimate. GOC at depth 6496 ft-ss is considered as low estimate. This nature of fluid contact determination is the subject for uncertainty analysis. Figure 7 showing the base case determination of fluid contact.

Water Saturation Analysis

Oil and gas reservoirs exhibit water saturation transition zones above the water contact. The extent and shape of this zone vary from one reservoir to another and also related to the drainage capillary pressure curve of the reservoir rock. The relationship between saturation transition zone and drainage capillary pressure for gas-water contact can be obtained from capillary-gravity equilibrium. Various plots are then included in uncertainty parameter subject, for instance Sw vs depth and Sw vs capillary pressure. As indicated on Figure 8, water saturation trend from petrophysical analysis (purple) shows an optimistic values compared to those derived from core (Sw trend then normalized using Swc measurement from core, orange). Therefore, uncertainty on that particular plot should be address to avoid tremendous impact on reserve calculation.

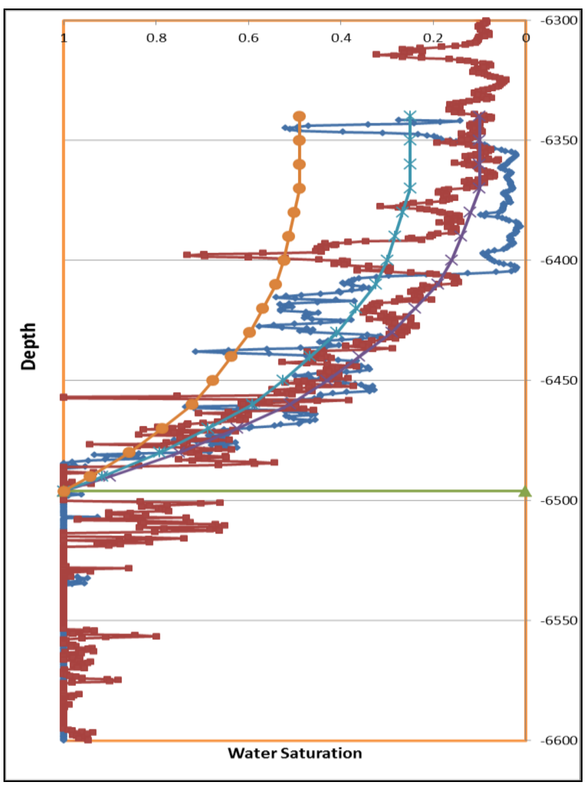


Figure 8. Estimation of Sw trend based on petrophysical analysis

Water Saturation for each trend were then cross-ploted with cappilary pressure on transition zone depth to obtain the relationship. Its equation will be used to estimate water saturation (as shown in Figure 9). As indicated, applying different Swc will impact on Pc-Sw relationship, and in turn, will be impacted on gas volumetric (OGIP).

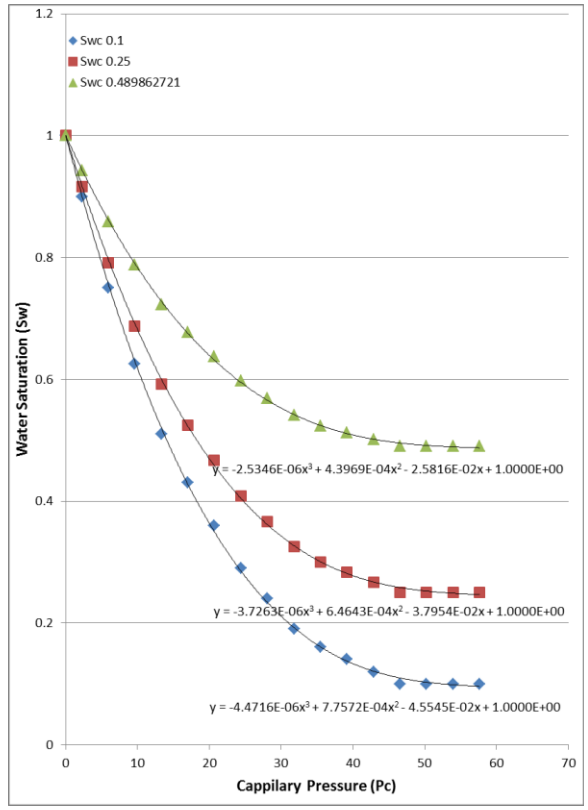


Figure 9. Cross Plot of Water saturation vs Cappilary Pressure

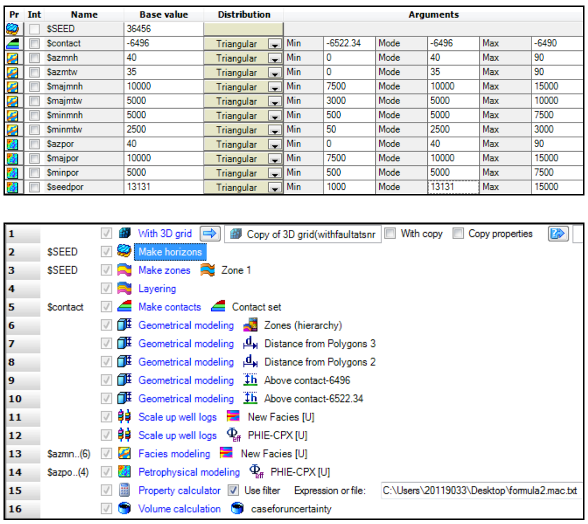
Result and Discussion

Uncertainty analysis was conducted to evaluate the effect of various uncertain variables (mentioned above) toward gas volume (OGIP). Combination of uncertain variables were built together into multiple realizations (run).
The base case of volume calculation has been generated using below constraint:

- Top and base model was interpreted based on 3D seismic (PSTM), refined by Acoustic Impedance.
- Time to depth conversion using 4 velocity layers
- Poro-perm transforms were defined for 3 rock types
- Water contact was set @-6496 ftss for south structure, and -6522.34 ftss for north structure

- Variogram input for Mentawa were set by major/minor/azimuth of 5000/2500/40, meanwhile for Minahaki were set as 10000/5000/40 respectively.
- Porosity distribution was guided by AI trend, correlation coefficient was set by -0.8
- Water saturation was calculated using cappilary pressure

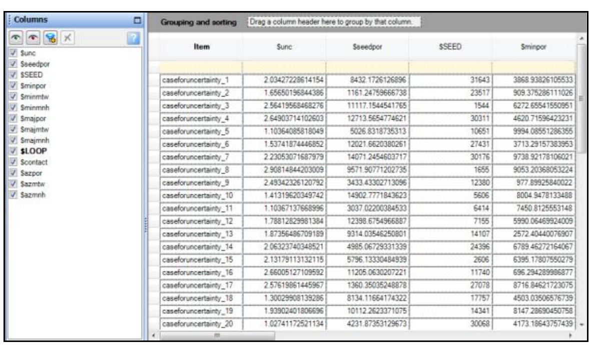
Uncertainty workflow was subsequently arranged using base case input. Due to software limitation, uncertainty parameters could only be applied limited to fluid contact, variogram range/azimuth, and seed number. While uncertainty represented by equation, such as poro-perm transform and Sw-Pc relationship will be run in seperate model/deterministic scenario. Variables and workflow editor for uncertainty analysis are shown in Figure 10 :



Pr	Int	Name	Base value	Distribution	Arguments					
		$SEED	36456							
		$contact	-6496	Triangular	Min	-6522.34	Mode	-6496	Max	-6490
		$azmnh	40	Triangular	Min	0	Mode	40	Max	90
		$azmtw	35	Triangular	Min	0	Mode	35	Max	90
		$majmnh	10000	Triangular	Min	7500	Mode	10000	Max	15000
		$majmtw	5000	Triangular	Min	3000	Mode	5000	Max	10000
		$minmnh	5000	Triangular	Min	500	Mode	5000	Max	7500
		$minmtw	2500	Triangular	Min	50	Mode	2500	Max	3000
		$azpor	40	Triangular	Min	0	Mode	40	Max	90
		$majpor	10000	Triangular	Min	7500	Mode	10000	Max	15000
		$minpor	5000	Triangular	Min	500	Mode	5000	Max	7500
		$seedpor	13131	Triangular	Min	1000	Mode	13131	Max	15000

Figure 10. Uncertainty workflow and variables

A total 50 number of realizations were run to generate large number of random distribution. Results from case folder can be shown as variable spreadsheet (Figure 11)



Item	$unc	$seedpor	$SEED	$minpor
caseforuncertainty_1	2.03427228614154	8432.1726126896	31643	3868.93826105533
caseforuncertainty_2	1.65650196844386	1161.24759666738	23517	909.375286111026
caseforuncertainty_3	2.56419568468276	11117.1544541765	1544	6272.65541550951
caseforuncertainty_4	2.64903714102603	12713.5654774621	30311	4620.71596423231
caseforuncertainty_5	1.10364085818049	5026.8318735313	10651	9994.08551286355
caseforuncertainty_6	1.53741874446852	12021.6620380261	27431	3713.29157383953
caseforuncertainty_7	2.23053071687979	14071.2454603717	30176	9738.92178106021
caseforuncertainty_8	2.90814844203009	9571.90771202735	1655	9053.20368053224
caseforuncertainty_9	2.49342326120792	3433.43302713096	12380	977.89925840022
caseforuncertainty_10	1.41319620349742	14902.7771843623	5606	8004.9478133488
caseforuncertainty_11	1.10367137668996	3037.02200384533	6414	7450.8125553148
caseforuncertainty_12	1.78812829981384	12398.6754966887	7155	5990.06469924009
caseforuncertainty_13	1.87356486709189	9314.03546250801	14107	2572.40440076907
caseforuncertainty_14	2.06323740348521	4985.06729331339	24396	6789.46272164067
caseforuncertainty_15	2.13179113132115	5796.13330484939	2606	6395.17807550279
caseforuncertainty_16	2.66005127109592	11205.0630207221	11740	696.294289986877
caseforuncertainty_17	2.57619861445967	1360.35035248878	27078	8716.84621723075
caseforuncertainty_18	1.30029908139286	8134.11664174322	17757	4503.03506576739
caseforuncertainty_19	1.93902401806696	10112.2623371075	14341	8147.28690450758
caseforuncertainty_20	1.02741172521134	4231.87353129673	30068	4173.18643757439

Figure 11. Variable spreadsheet for each realization

The histogram of the results can be displayed using histogram map window to visualize the range of P10,P50 and P90. Scale CDF was plotted to display the cummulative distribution (Figure 12). In order to obtain a smooth histogram plot, it is recommended to have much more realizations. But it used with caution, because running a huge amount of realization will be time consuming.

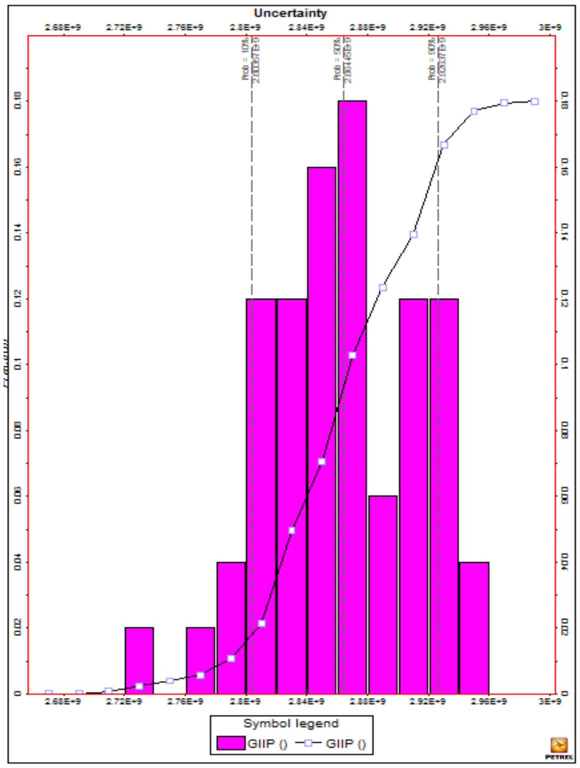


Figure 12. Histogram and CDF plot to define P10, P50 and P90

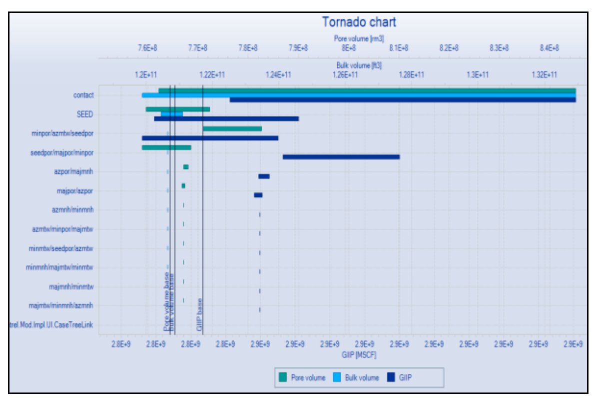


Figure 13. Tornado chart for sensitivity analysis

Furthermore, to understand the influence of each parameter toward OGIP, the sensitivity analysis can be run separately. The realization results were then plotted in a tornado chart, as shown in Figure 13. As indicated, 60 sensitivity run was unable to cover all combination of sensitivity run. In such case, a deterministic sensitivity run should be implemented to obtain a sensitivity distribution representing lowest and highest range.

Conclusions

- Uncertainty and sensitivity analysis is an important step of assessing the impact of each parameter incorporated in 3D Geomodeling process. Understanding the degree of uncertainty/sensitivity will give an insight about the inherent risks and further mitigation plan.
- After conducting a series of uncertainty analysis in Senoro 3D model, based on 50 uncertainty runs and 60 sensitivity runs, the most influential parameter impacting OGIP were :
  - Fluid contact
  - Water saturation vs, Cappilary pressure equation
  - Permeability transforms
  - Seed number (random pattern)
  - Variogram analysis
- In addition, parameters that suspected to cause tremendous impact on static/dynamic model are also need to be considered, those are :
  - Cut offs
  - AI vs. Porosity correlative coefficient
  - Permeability multiplier (Kv/Kh)
  - Aquifer size
  - Relative Permeability end point
- Uncertainty issues in geomodeling process can not be avoid, but the degree of uncertainty will be reduced as additional data has been acquired.

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