

3D Pore Pressure Prediction Model in Bentu Block – Central Sumatra Basin*

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Abstract

Pore Pressure Prediction is crucial to prepare a safe drilling program especially if the well will potentially intersect shallow gas zones. It influences casing design, drilling mud weight, and mitigation of overpressure as a drilling hazard. In the Bentu PSC and Korinci Baru PSC, several wells have experienced blow-outs: Baru-1 (1951), Baru-2 (1967), Korinci-1 (1983), and Segat-1 (1965). These blow-outs led us to conduct a pore pressure study ahead of future drilling. The work emphasized the technique on how to create 3D pore pressure model.

The study used as input data from wireline logs, pressure tests, 2D Seismic, and drilling.

The Eaton method is an empirical method to estimate pore pressures from sonic, resistivity, and density logs which are calibrated to measured pore pressures from RFT and DST. In the Bentu PSC, the resistivity data did not reliably characterize pore pressure, and density data was incomplete, so the sonic log proved to be the most appropriate source data.

Reliable 3D pore pressure distribution required an empirical relationship between pore pressure and velocity.

The Bentu PSC 3D model created in this study allowed us to predict pore pressure throughout the block, and was used to design a drilling program especially for delineation wells, especially for casing design, drilling mud weight, and overpressure prediction to prevent drilling hazards.

Introduction

Formation pore pressures estimates incorporated into the drilling program (casing design, drilling mud weight, and mitigation of overpressure as a drilling hazard) can significantly improve drilling performance to successfully reach the drilling objectives and reduce costly drilling problems, especially if shallow over pressured gas zones exist.

In the Bentu PSC and Korinci Baru PSC, several wells have experienced blow-outs: Baru-1 (1951), Baru-2 (1967), Korinci-1 (1983), and Segat-1 (1965) (Table 1). These blow-outs led us to conduct a pore pressure study ahead of future drilling. The work emphasizes the technique on how to create 3D pore pressure model.

This study predicted formation pore pressures at existing wells using Eaton's Method from velocity from sonic logs. Then pore pressures were distributed away from well control in the 3D reservoir static model, guided by an empirical relationship between the pore pressure and velocity.

Origin of Over Pressure

All blow-outs in the Bentu PSC occurred in over-pressured Binio Formation sands. This formation conformably overlies the Telisa Formation, a Middle Miocene-aged sequence of claystones and sandstones with minor coals and limestones. These sediments were deposited in a variably fluvial, coastal or shallow marine environment that reflects the onset of a marine regression directed to the northwest and southeast (Figure 1).

Overpressure can be caused by rapid sedimentation (disequilibrium compaction), clay dehydration, hydrocarbon maturation, tectonic, aquathermal pressure, and biogenic gas.

Overpressure in the Binio sands is thought to be caused by disequilibrium compaction and to have been exacerbated by recent uplift and erosion that further imbalanced pore pressure. Hydrocarbon charging could be as additional factor. Overpressure implies that the sands have limited regional lateral continuity and were charged locally. Uplift then displaced the sands from a normal pressure regime to an overpressure regime. The excess pressure would dissipate over time, but equilibrium has not yet occurred owing to the relatively recent age of the uplift.

Methodology

Data

The study is based on data from wireline logs (gamma ray, sonic, density, and resistivity), pressure tests (DST and RFT), 2D Seismic, and drilling.

The Eaton method is an empirical method used to estimate pore pressure from sonic, resistivity, and density logs that have been calibrated to measured pore pressures from RFT and DST. This log data (as well as some others) can give clues as to the presence of over-pressure or under-pressure. For this study, the resistivity data did not reliably characterize the pressure data in this area, and density data was incomplete, so the sonic log was the most appropriate source data (Figure 3)

The sonic log output is the interval transit time (ITT), the time taken for a sound wave to travel through the formation and back to a receiver. Sonic log analysis for pore pressure prediction is developed around the concept for normal compaction with depth, porosity decreases and density increases, and the rock becomes a much more efficient sonic conductor. The ITT will decrease with depth and so the sonic velocity will increase with depth. Conversely, if under-compaction exists, ITT will increase and sonic velocity will decrease. Intervals with higher ITT than the normal compaction trend are likely to have abnormal pore pressure.

Eaton's Method

Most over-pressure discrepancies can be observed in seismic velocity and sonic log velocity as deviations from the normal compaction trend. So definition of the normal compaction trend is vital role for reliable pore pressure prediction.

The Eaton Ratio Method is typically applied to seismic or acoustic velocity data, and to resistivity data. The procedure is to examine "porosity" vs. depth data and to make a ratio comparison between the measured value (obs) and the expected value if the pore pressure was hydrostatic (norm). The form of the Eaton equation is:

$$P_p = S_v - (S_v - P_n) (A_{obs}/A_{norm})^X$$

Where P_p is the pore pressure; S_v is the total vertical stress (overburden/lithostatic pressure); P_n is the normal or hydrostatic pressure; A_{obs} is the observed attribute (sonic, resistivity etc); A_{norm} is the attribute when pore pressure is normal, and "X" is an empirical constant. Eaton developed empirical constants for velocity data ($x = 3$) and resistivity data ($x = 1.2$) (Swarbrick, 2002).

Pore Pressure Analysis from Well Logs

The Workflow of this study in [Figure 2](#) shows the first step is to determine the shale interval and lithology curve with guidance from core and log data. Shale sections are best for analysis of logs for abnormal pore pressure. Because of their low permeabilities, shales do not equilibrate pressure with the mud column in the well bore. Selection of only the purest shales minimizes the effects of mineral variation, multiple phases, fluid composition, and fluid distribution. This leaves porosity as the major variable within shale sections. Because porosity is related to compaction, porosity measurements from well logs can be calibrated to fluid pressure in the pore systems. These shale intervals are then used to determine corresponding readings in the shale intervals on the porosity-indicating dataset.

Next, Wyllie's equation is used to translate shale base lines into a porosity-indicating dataset. This is then used to make a shale-filtered or "shale points" dataset. The sonic log is used for porosity estimation:

$$\Delta t = \Phi \Delta t_f + (1 - \Phi) \Delta t_{ma}$$

where Δt is the zone transit time, Φ is the porosity, Δt_{ma} is the matrix transit time, and Δt_f is the pore fluid transit time.

A filter is applied to the raw shale points to create a filtered (for noise) porosity-indicating dataset that will have a line connecting all the points. This refined porosity-indicating dataset will be used in the pore pressure prediction.

The next step is to calculate the Overburden Gradient (OBG). This requires a density log (or a synthetic density log) to estimate the overburden pressure. The OBG is simply the density log integrated from the surface down.

The normal-pressured shale compaction trend uses the ITT of compressional sonic waves through the shale. In zones of normal hydrostatic pressure, an ITT curve versus depth is linear on a semi-log plot. If the ITT is above the trend, the zone is likely to have abnormal pore pressure.

Having completed the previous analyses, pore pressure is calculated by Eaton's Method and compared to RFT and DST data. If the calculation fits with DST or RFT test, then the pore pressure estimate is considered to be reliable (Figure 3)

Then the workflow is applied to others wells (Figure 4). The pore pressure can be reliably estimated for all wells with the same chronostratigraphy order.

The Fracture Gradient calculation is based upon the calculated Overburden Gradient and the calculated Formation Pressure. In this study, Eaton's Method is applied.

3 Dimensional Pore Pressure Prediction Modeling

The existing 3D geological model, complete with structural framework, reservoir zonation, and petrophysical analysis were utilized to model the anticipated abnormal pressure.

Geological Static Model

The reservoir static model has the zone of interest (Binio Formation) as a layer cake (Figure 5). This model is supported by regional tectonostratigraphy work in central Sumatra that concluded that the Binio Formation is a post-rift sequence where sand thickness is likely similar laterally). The implication for pore pressure prediction is the interval velocity profile (and so pore pressure profile) is likely consistent across the block in areas with the same chronostratigraphic order.

Grid Construction

The grid was built as one zone with no sub-divisions; however, once the grids were constructed, reservoir intervals were subdivided into internal layers. The grids were rotated by 45 degrees to best align the grid along direction of the primary structural grain (Figure 6).

Structural Framework Building

The 3D structural framework was constrained by four faults; one major fault which is interpreted as strike slip fault with trend NW-SE, and three normal faults which are second-order faults from the major fault with a NE-SW trend (Figure 7).

Reservoir Zonation

The study target area is a post rift sequence; in which layer cake geology can be applied to the reservoir zonation. Given poor seismic data quality with uncertainty in the structure map; and the reservoir distribution of multilayered sandstone, specific treatment must be applied for reservoir zonation. This study used the well top zonation in the grid, and used the conformable zonation method to build a conceptual layer cake geology model. Figure 8a and Figure 8b compares results from all available structure maps as references for reservoir zonation and well tops as reference zonation.

Pore Pressure Prediction Model

The pore pressure model was built along the 3D structural grid, using the empirical relationship between pore pressure and velocity. Pore pressure data is treated as a property, upscaled and distributed along the 3D structural grid based on interval velocity from the sonic (distributed with a geostatistical approach) as seen in Figure 9a, Figure 9b, Figure 10a, and Figure 10b. Fracture gradient is treated as per pore pressure. An example of pore pressure prediction is shown in Figure 11, where four delineation wells are inserted. The model pore pressure profile can be used for mud weight determination.

Discussion

The sediments in the study area are formed during the post-rift stage, hence the structures were not growth rapid or complex. This is one of the conditions where the velocity interval derived from sonic log could be distributed geostatistically in this area study.

The Eaton Method in unconsolidated sands in Binio Formation still needs further study, usually the Eaton Method is used in compacted formations.

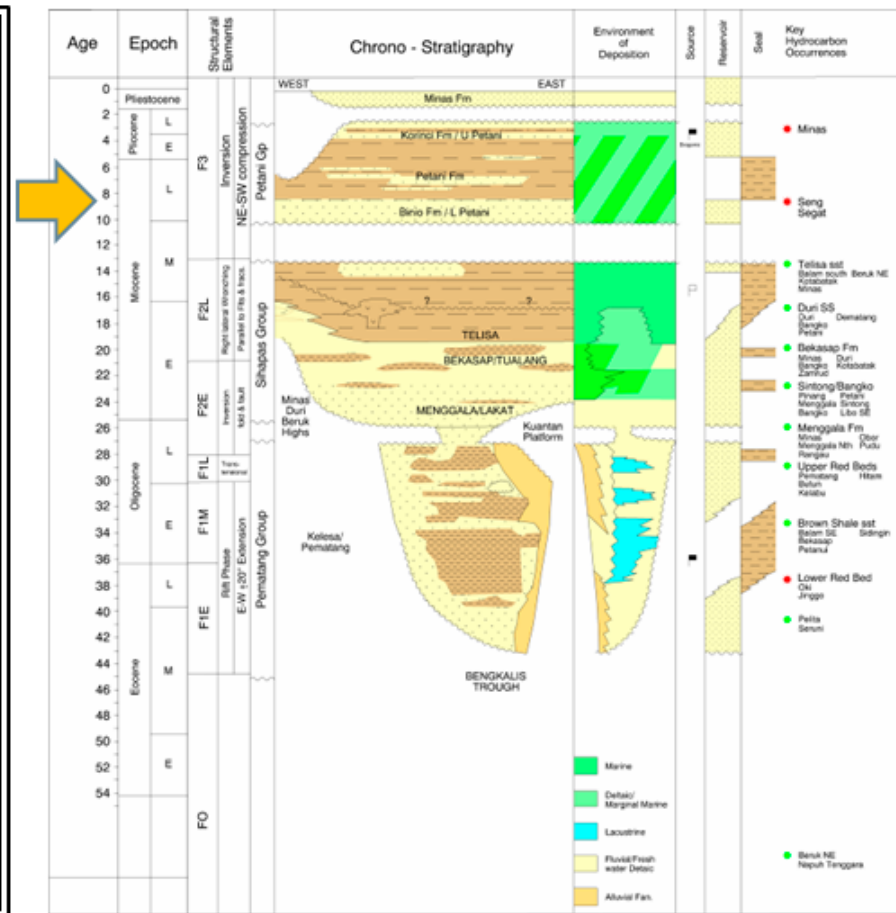
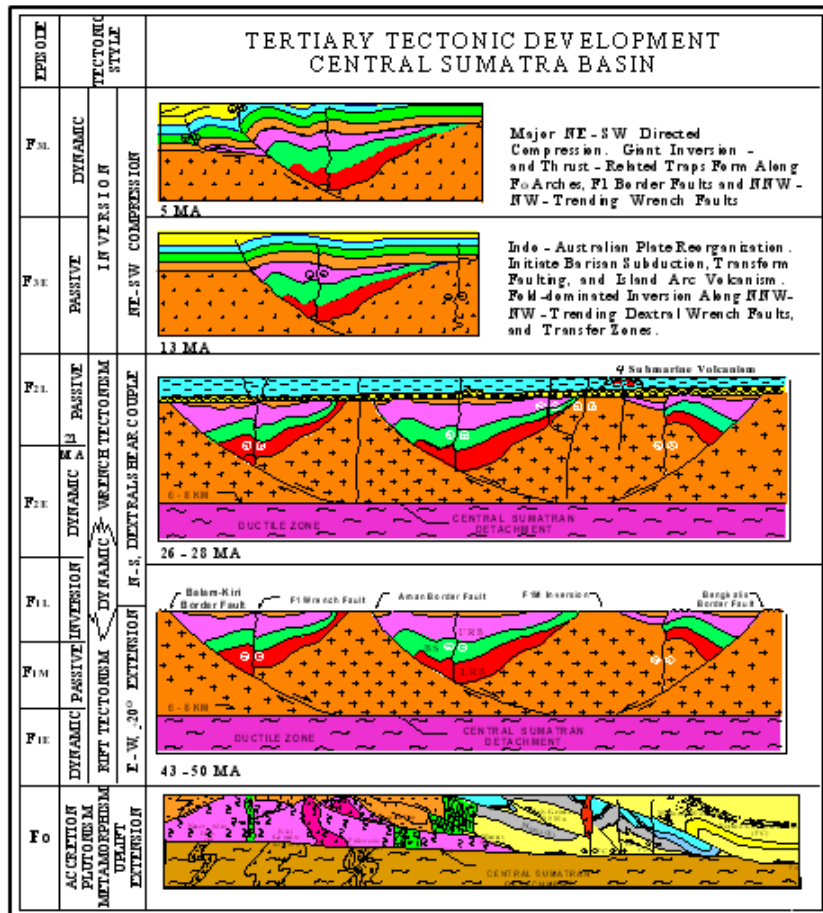
Conclusion

The fundamental aspect in 3D pore pressure distribution is an empirical relationship between the pore pressure and velocity. This relationship enables the pore pressure prediction to be distributed in 3D model that follow the trend of the velocity.

The result of this 3D pore pressure prediction model can image the pressure profile of surrounding area with limited data and provide drilling engineers and operation geologists to reduce drilling hazard, in this case abnormal pressure from hydrocarbon or shale.

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**Tertiary Tectonic Development Central Sumatra Basin
(Heidrick and Aulia, 1993)**

Regional Stratigraphy

Figure 1. Tectonostratigraphy Study Area.

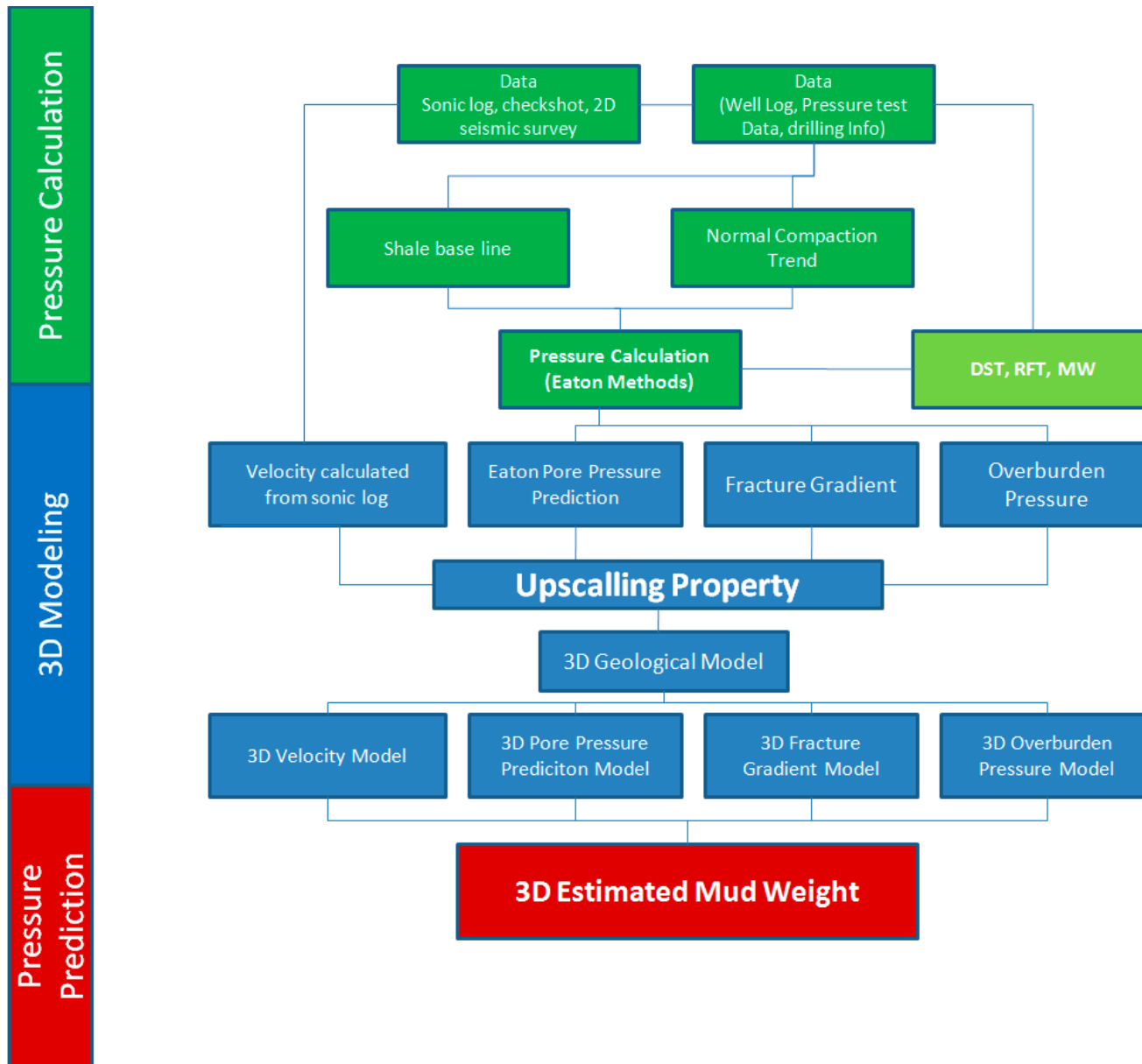


Figure 2. The Workflow of 3D Pore Pressure Modeling Study.

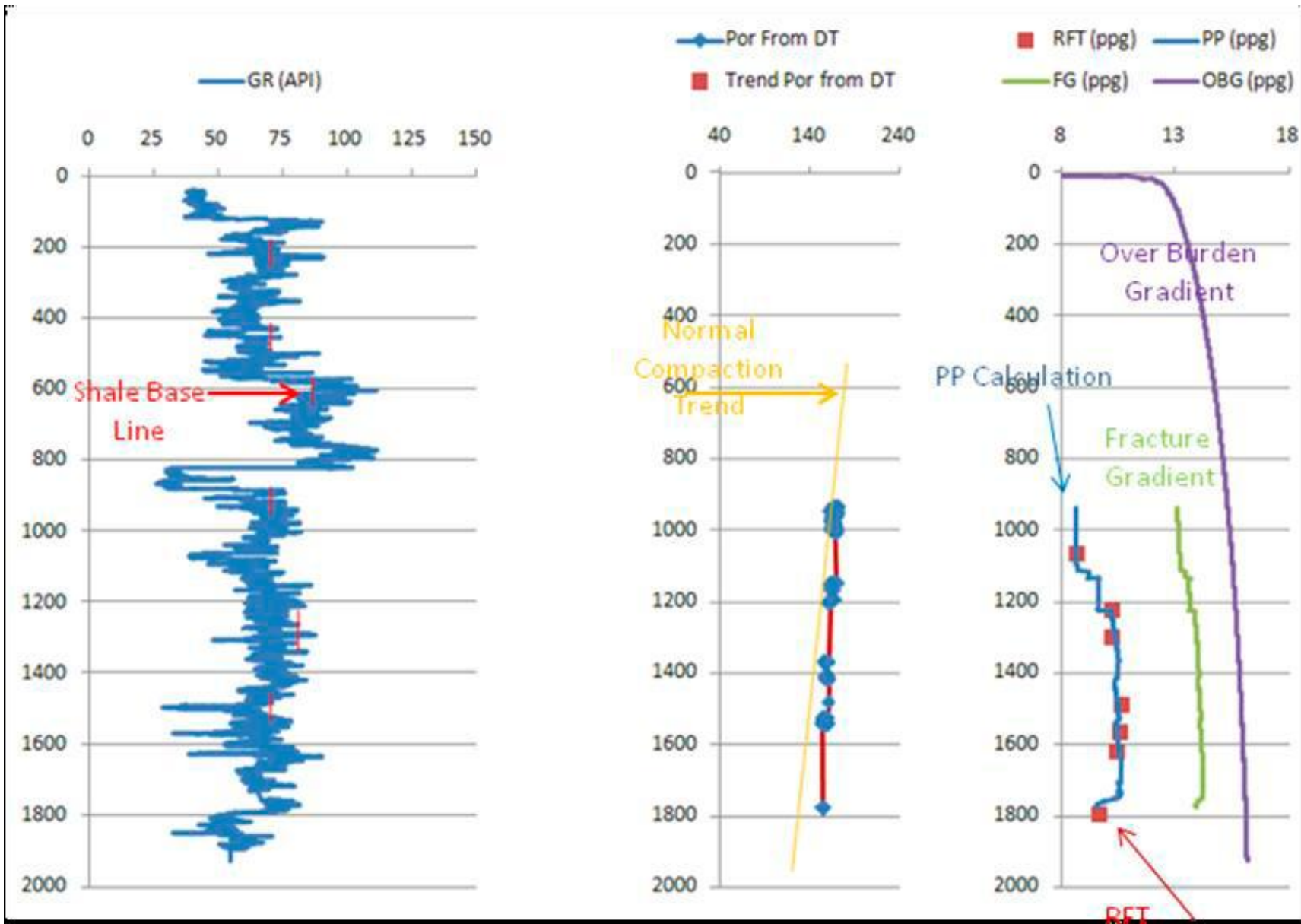


Figure 3. Pore pressure estimation from well logs compare with RFT data (SEGAT 3 Well).

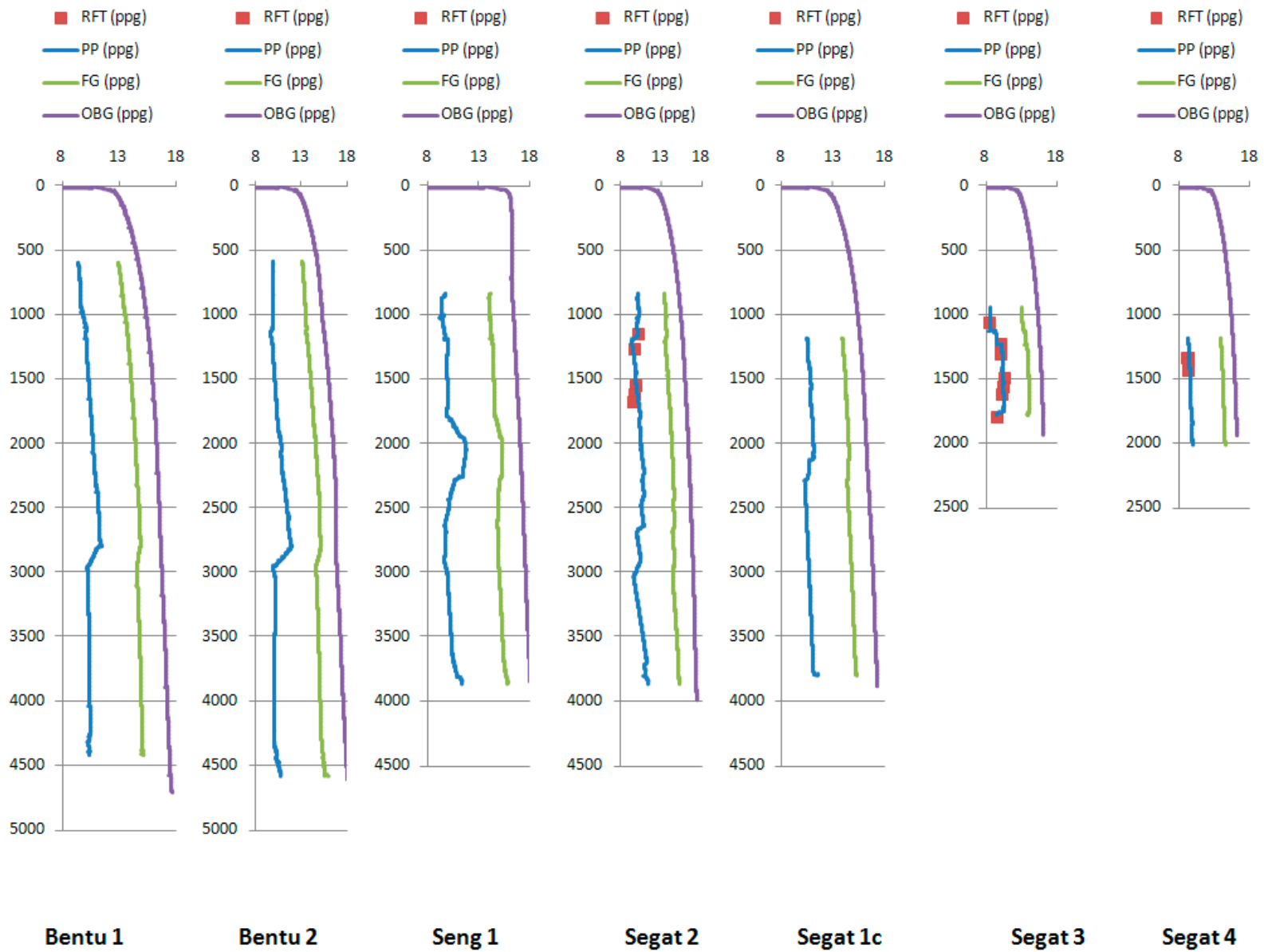


Figure 4. Pore pressure estimation result from well logs compare with RFT data (Other Wells).

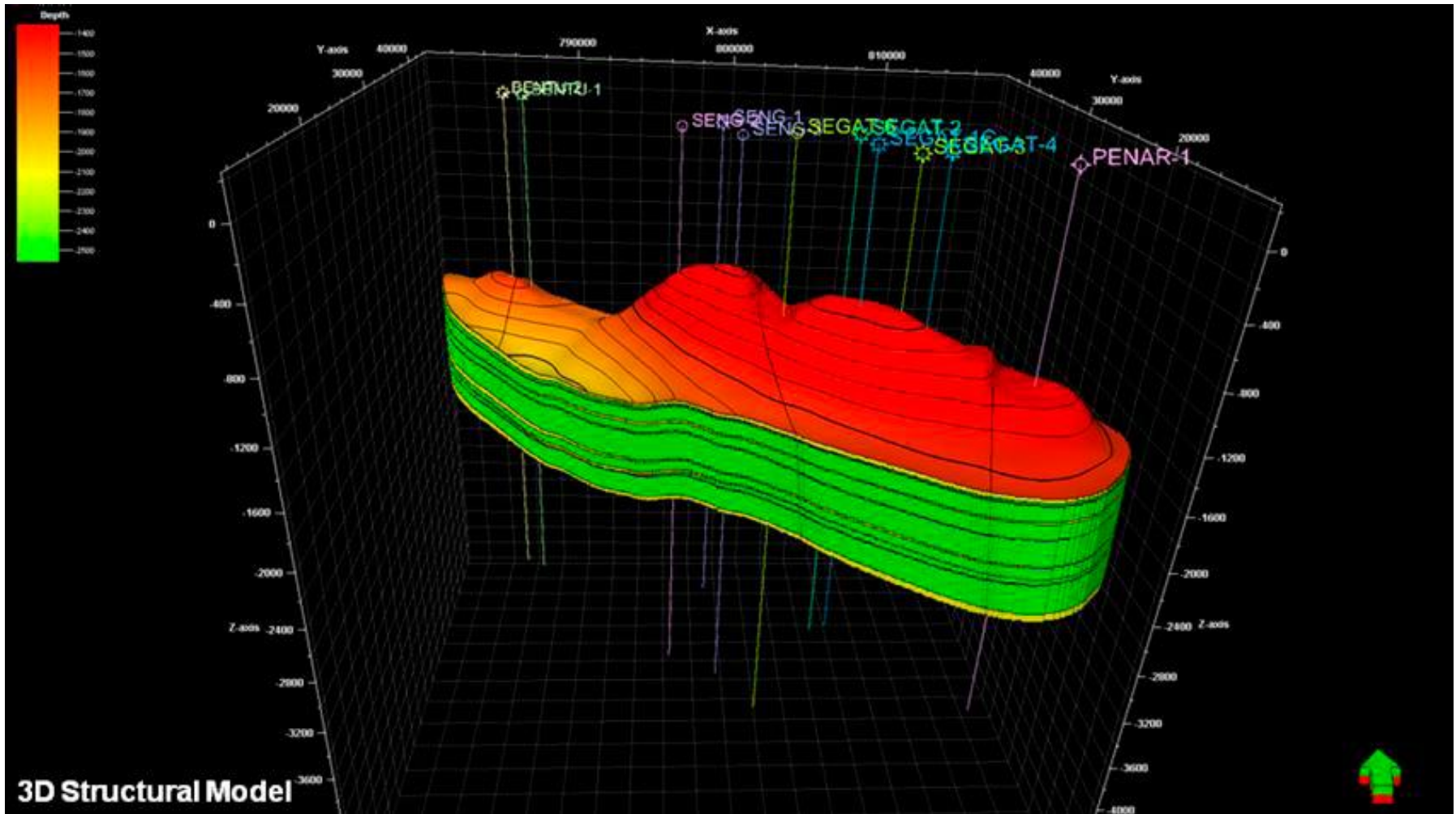


Figure 5. 3D Structural Model of Bentu-Seng-Segat Field.

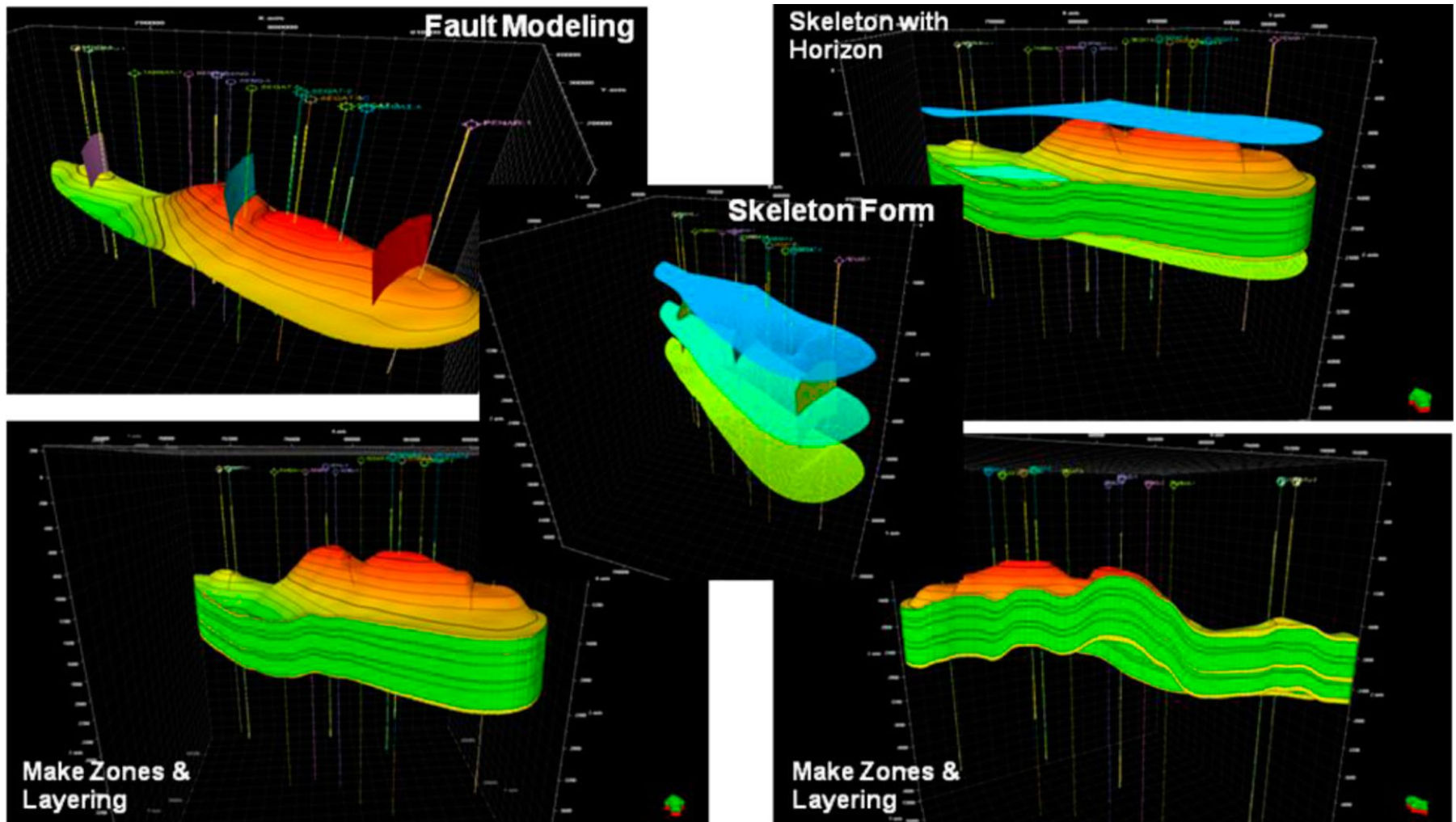


Figure 6. Grid Construction, fault modeling, and structural framework building.

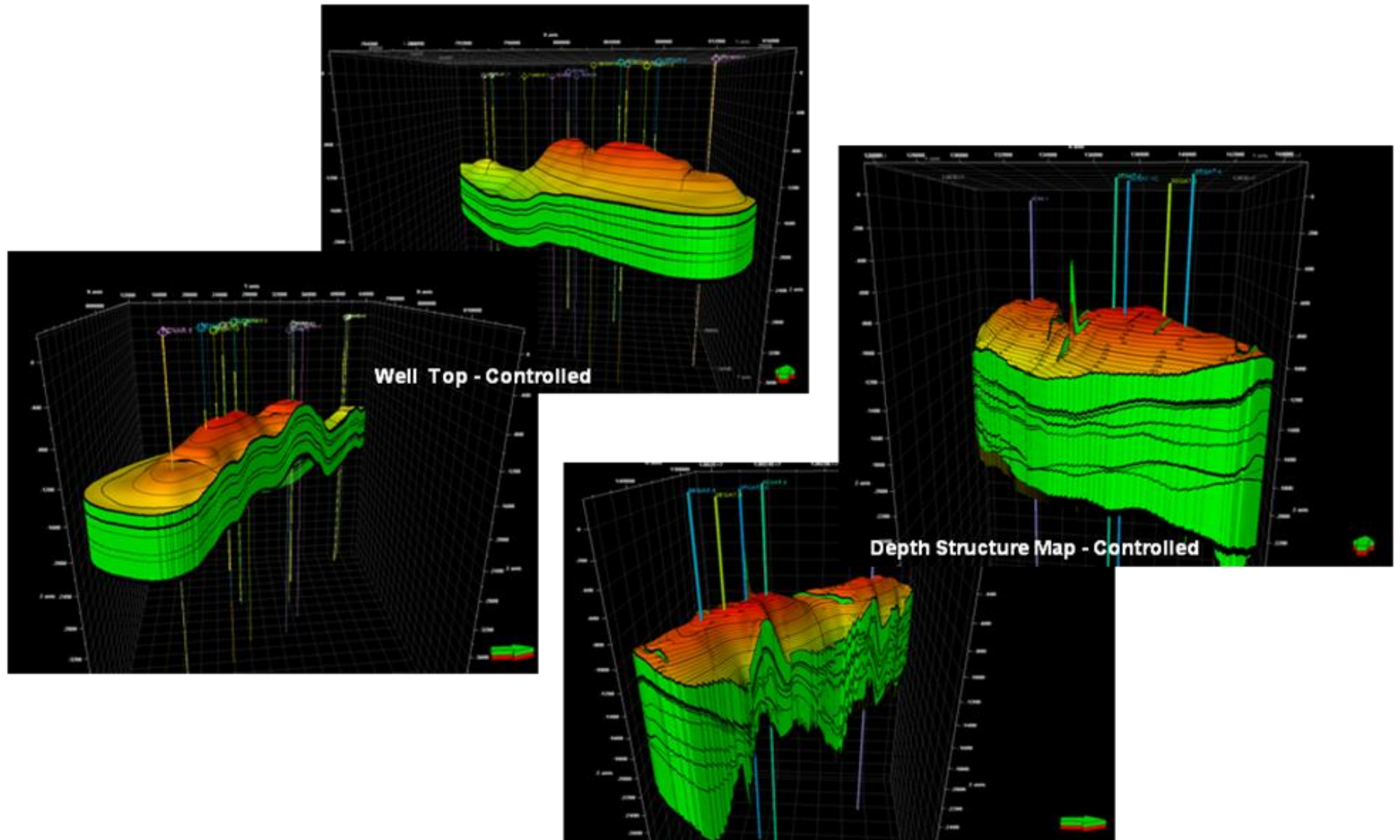


Figure 7. Reservoir Zonation Building.

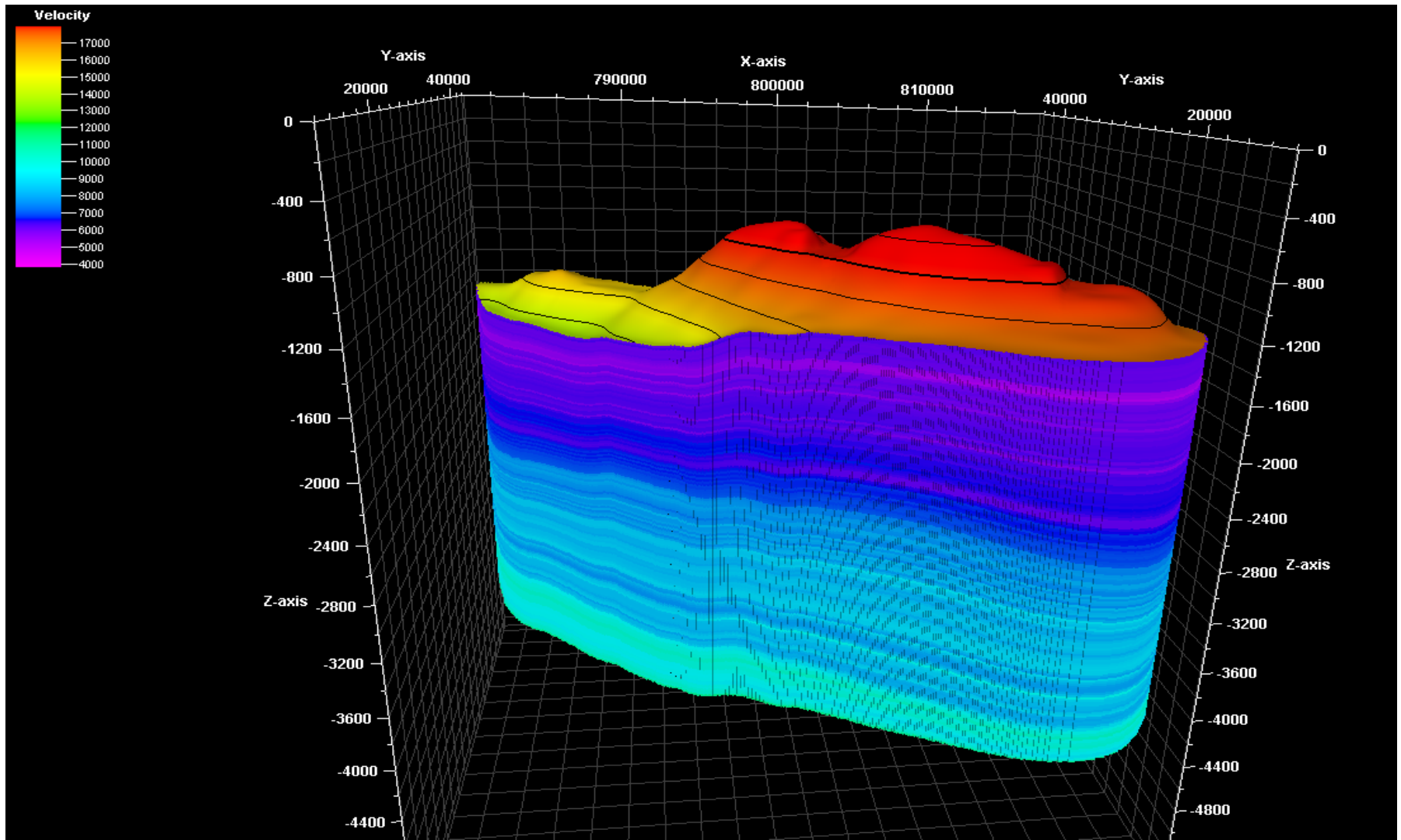


Figure 8a. Interval Velocity (sonic) Model.

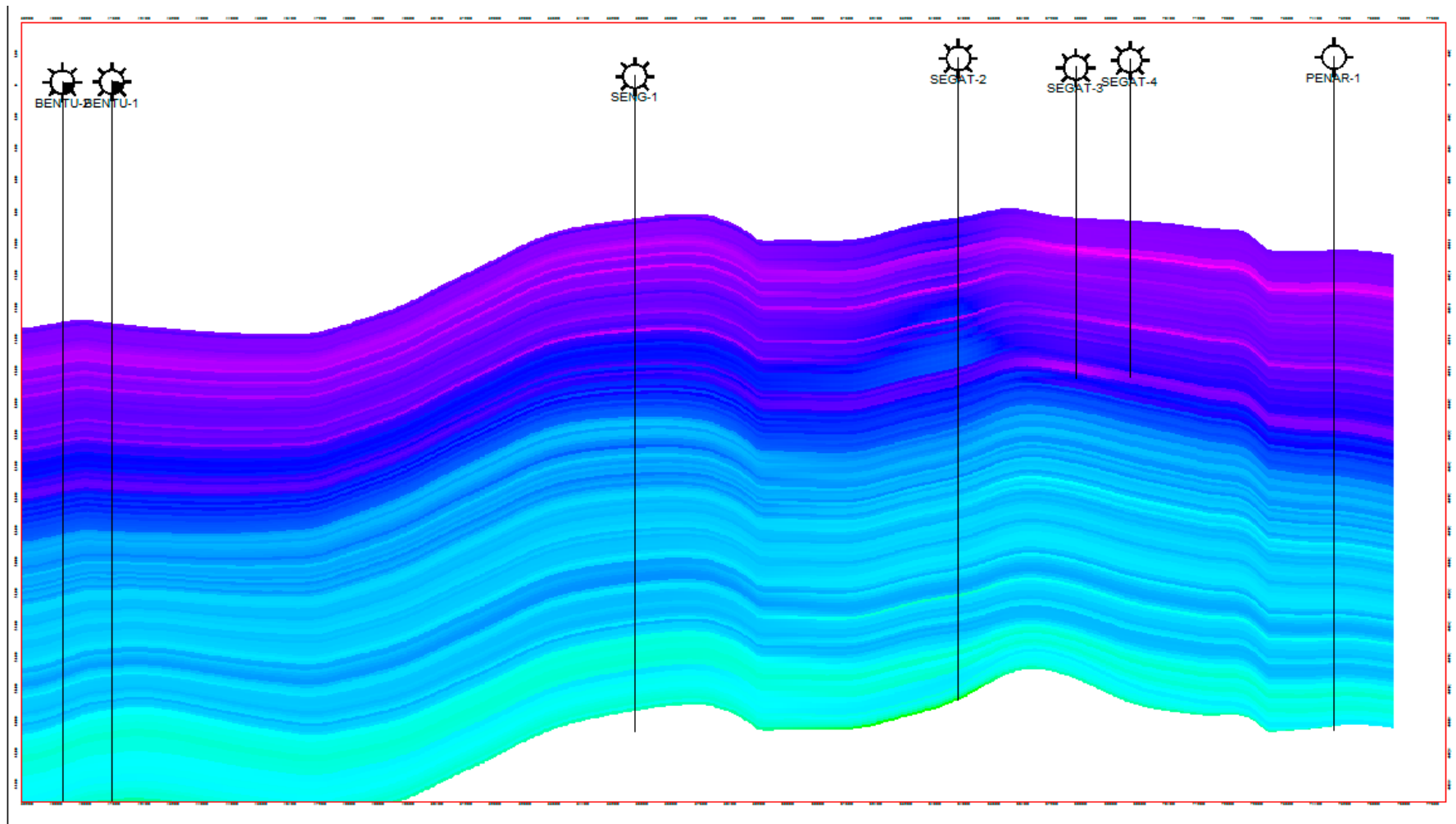


Figure 8b. Cross section of Interval Velocity (sonic).

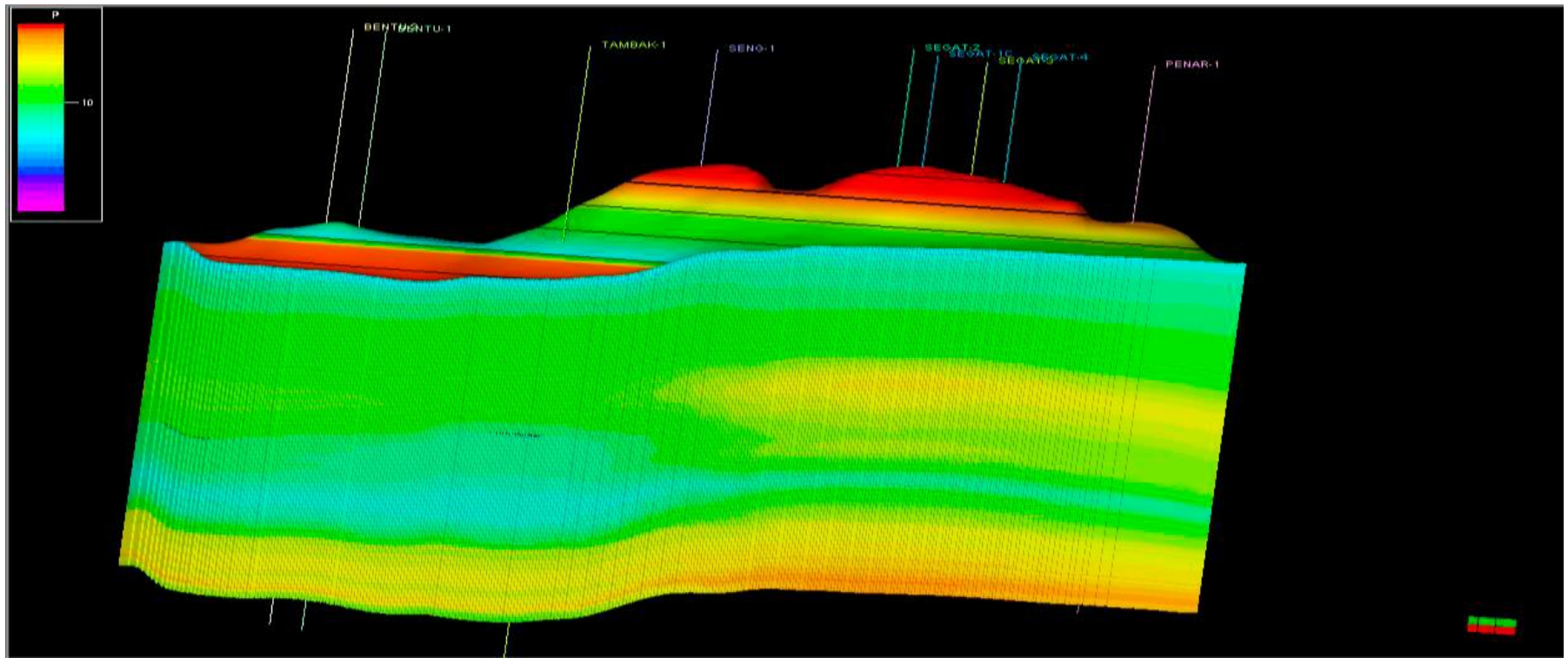


Figure 9a. Pore pressure prediction Model.

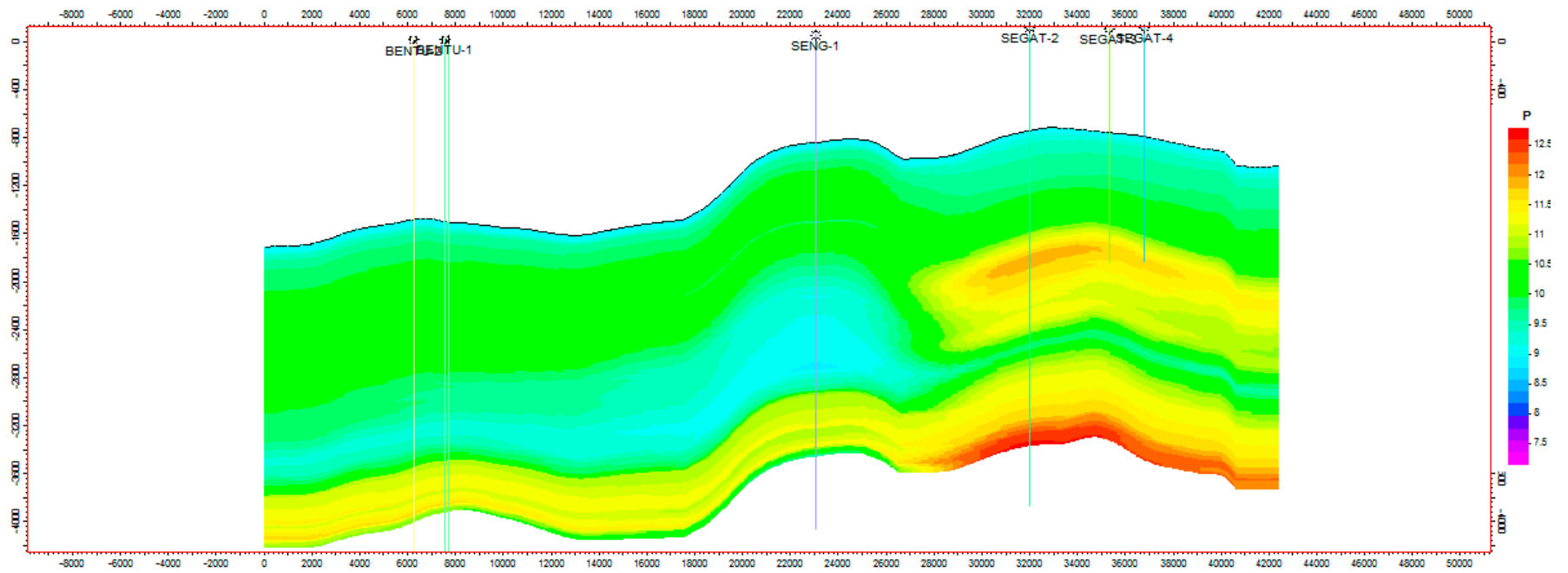


Figure 9b. Pore pressure prediction cross-section result.

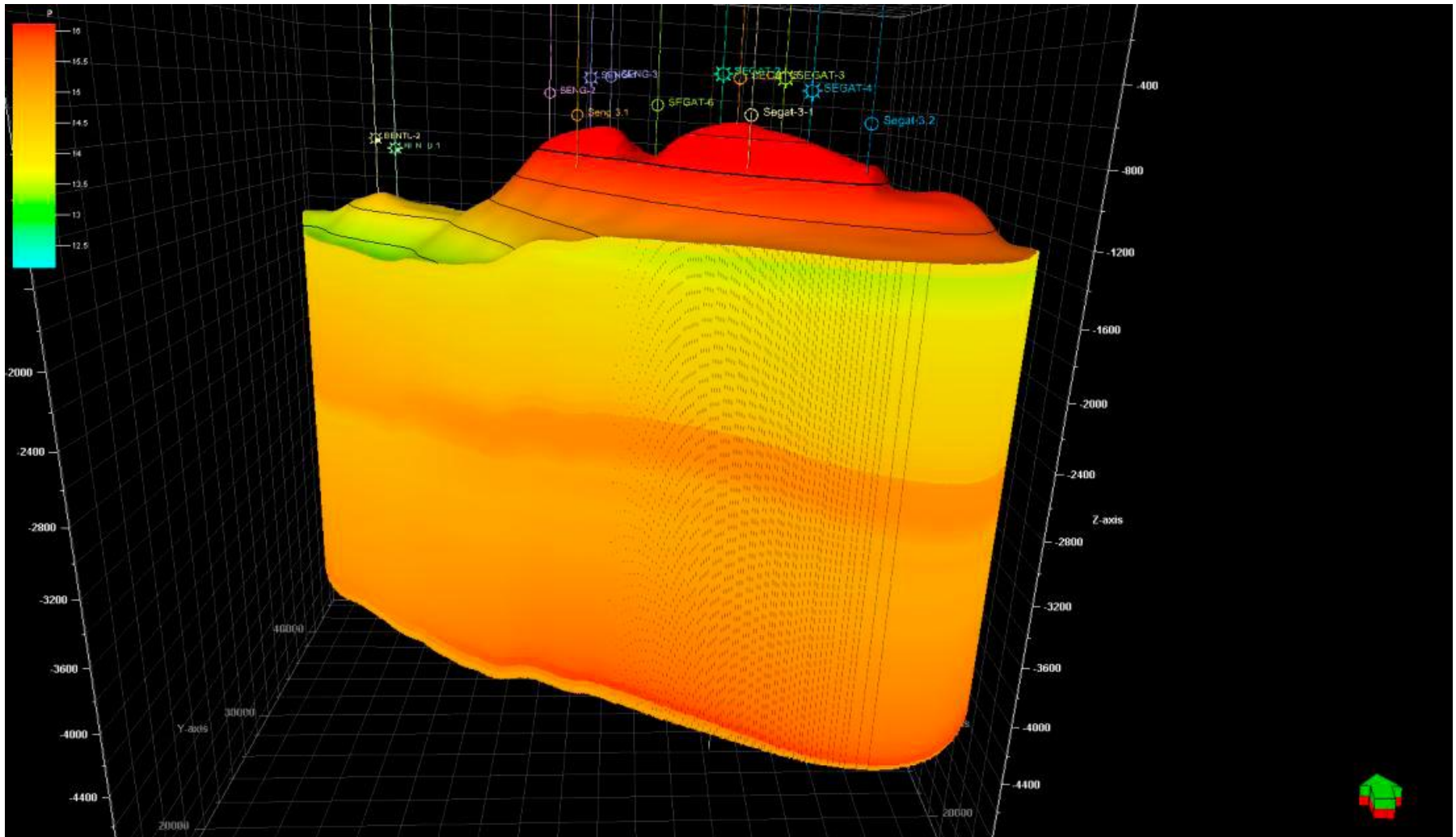


Figure 10a. Fracture gradient prediction Model.

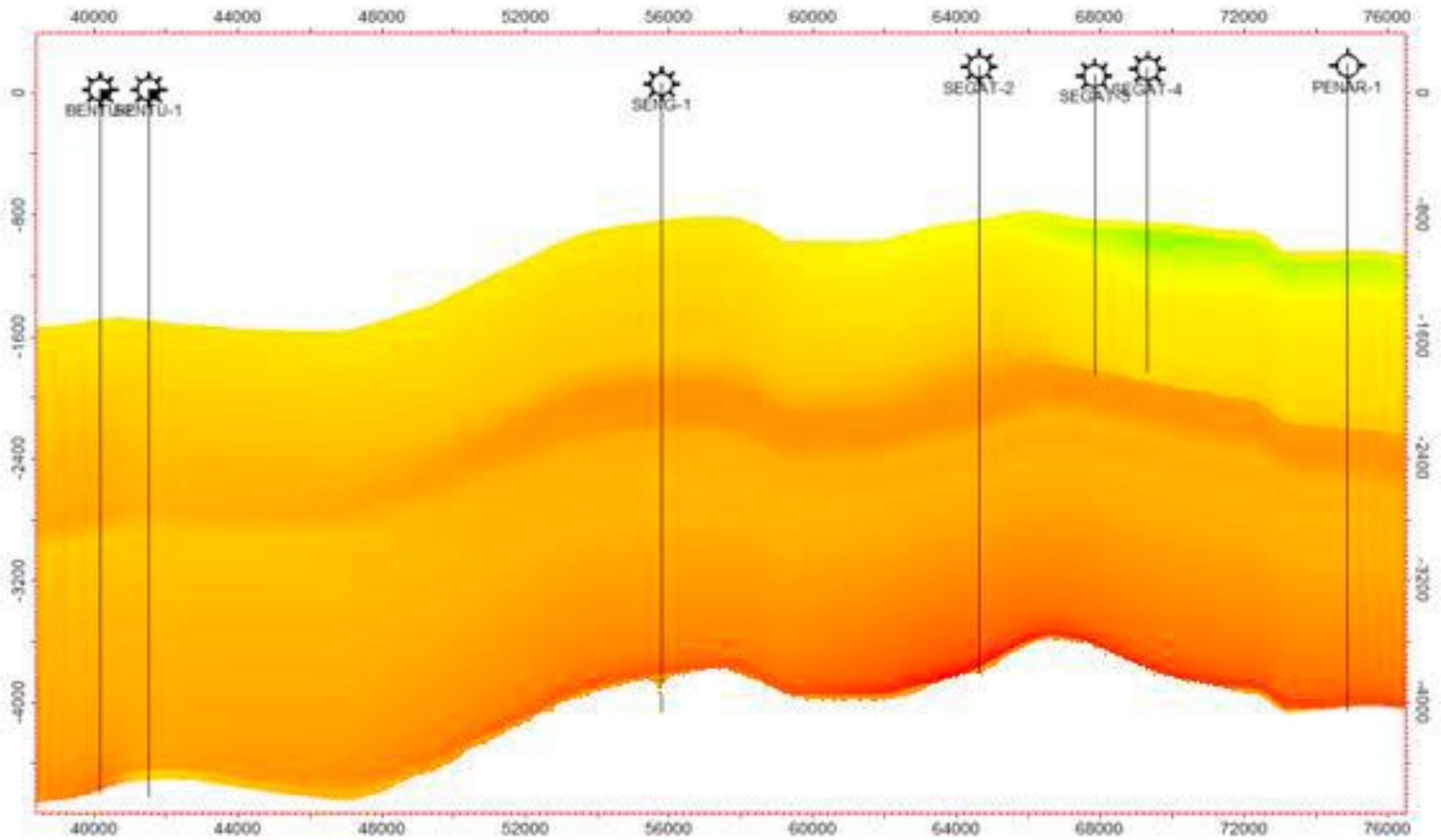


Figure 10b. Fracture gradient prediction cross-section.

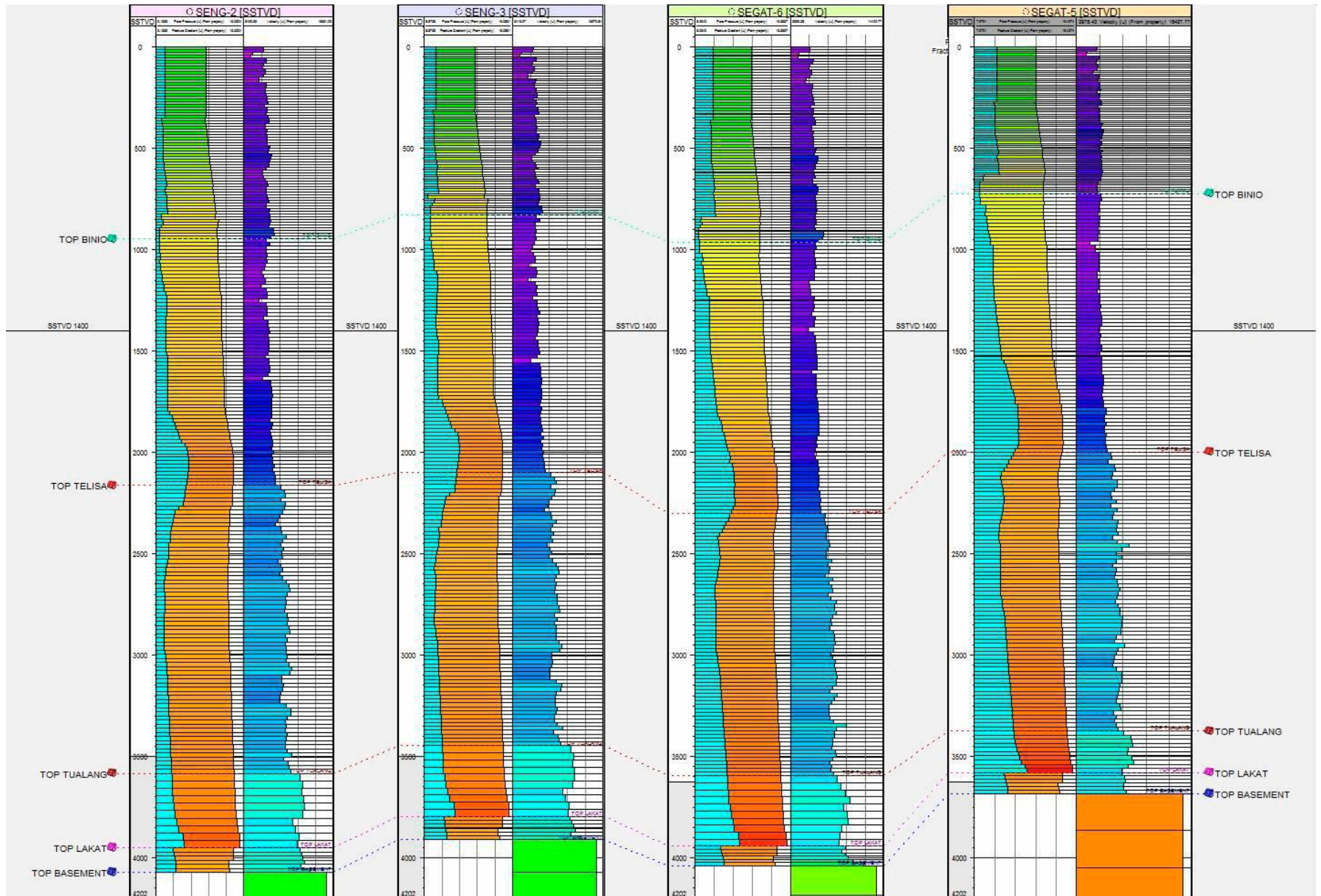


Figure 11. Four delineation proposed wells with interval velocity and pore pressure property from the model.

Blow Out Case in Bentu-Korinci Block

No	Well	Spud date	TD (ft)	Blow Out Depth (ft)	Formation	mw (ppg)	Note
1	Baru-1	17-Oct-51	1680.00	780	Binio	9.7 – 10.3 ppg at 497 ft 10.8 ppg at 621 ft 10.8 ppg at 675 ft	Blew out in depth 780 ft while running 25 joints of 9 5/8 " casing
2	Baru-2	25-Jun-67		710	Binio	12.5 ppg to 1075 ft. Below 1100 ft used 11 ppg	
3	Korinci-1	9-Nov-83		1199	Binio	9.6 ppg at 113' 9.3-9.5 ppg at 303' (Gas = 5-13 units) 9.4 ppg at 410' (Gas = 270 units) 9.7 ppg at 620' (Gas = 210 units) 9.9-10.7 ppg at 694' (Well kick) 10.4 ppg at 980' (Gas = 238 units) 10.5 ppg at 1070' (Gas = 162 units) 10.5 ppg at 1100' (Gas = 300 units) 10.7 ppg at 1170' (Gas = 50 units) 10.7 ppg at 1199' (Gas > 1000 units) ☐ Blew out	
4	Segat-1	18-Jul-65		1035	Binio	10.2 lb/gal	

Table 1. Blow Out Case in Bentu-Korinci Block.