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Enhancing Low-Frequency Model for Post-Stack Inversion using Geostatistics: A Case Study in Imaging Carbonate Structure

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Abstract: Post-stack model-based seismic impedance inversion can be a fast and efficient first step in deriving reservoir properties based on seismic data. It can further be used as an input for quantitative interpretation, however, behind that seemingly oversimplified process, we should not forget the nature of bandlimited seismic data and how we should carefully extract and model the low-frequency component. In the worst case, the low-frequency or background impedance model (LFM) might not even be possibly estimated correctly due to the limited logging data interval. In this paper, we will demonstrate how to create an absolute impedance volume to delineate porous reefal carbonate reservoir that has low acoustic impedance by carefully interpolating available well logs data and incorporating knowledge of local spatial continuity with cokriging. The result is an LFM that can accommodate all available well data but still honor local geological structures and continuities
Keywords: Carbonate, cokriging, low-frequency model

Abstrak: Inversi post stack data seismik berdasarkan teknik pembuatan model awal (*model-based*) adalah salahsatu cara yang cepat dan efisien untuk menurunkan properti reservoir. Hasilnya dapat digunakan kemudian dalam alurkerja interpretasi kuantitatif, walaupun demikian dalam prosesnya tidak terlepas dari limitasi keterbatasan rentang frekuensi data seismik dan proses ekstraksi komponen frekuensi rendah. Bahkan dalam kondisi terburuk karena keterbatasan data sumur, pembuatan model awal (LFM) tidak dimungkinkan untuk dapat dilakukan secara akurat.Dalam paper ini akan ditunjukkan alurkerja untuk mendapatkan impedansi absolut pada reservoir karbonat dengan teknik pemodelan model awal melalui *cokriging* dan pengetahuan geologi lokal. Sehingga hasil LFM tetap menggunakan data sumur tetapi juga konsisten dengan kerangka struktur dan fitur geologi yang ada.
Kata kunci: Karbonat, cokriging, low-frequency model

1 INTRODUCTION

Absolute impedance value is critical information for quantitative interpretation purposes, yet it is missing in our bandlimited seismic data. To extract absolute impedance value from seismic inversion, we have to have a reliable and geologically plausible low-frequency model (LFM). This LFM is commonly built from interpolating well data and using interpreted horizons as constraints for interpolation. The problem is we do not know for sure how it varies laterally, and simple interpolation may introduce undesirable bull's eye features that might not be geologically meaningful. Several authors have developed methods to build a reliable LFM, such as using first-pass inversion to construct a new updated LFM for second pass inversion (Jarvis, 2006; Sams & Carter, 2017), Pendrel* (2015) uses the first-pass inversion cube to create preliminary facies mapping, and construct a low-frequency model for each mapped facies, Ray and Chopra (2016) proposed a method using a neural network to build an updated low-frequency model using LFM that is populated only using only one well and carefully choosing other seismic attributes to minimize the spurious relationship between input and predicted dataset (Kalkomey, 1997) such as relative impedance cube and resulting in an LFM that is more geologically-consistent compared to an LFM that is constructed from simple interpolation of well data. In this study, we will demonstrate how to build an absolute impedance cube by carefully reconstructing a low-frequency model that can accommodate all available datasets while still honoring local spatial continuity and geology using the geostatistical method. This low-frequency model is obtained by using the first pass model-based impedance inversion as a secondary attribute in cokriging interpolation. One of the benefits of using first-pass inversion is that we can get more insight into spatial continuity from highly dense sampled seismic data to interpolate between wells and construct a more reasonable variogram.

2 GEOLOGICAL BACKGROUND

Sonya field is located in Musi Platform, South Sumatra Basin which is bounded by Benakat Gulley depression and Lematang Trough to the east, and Bukit Barisan volcanic arc to the west. Musi Platform was a paleohigh basement since Tertiary and remained high until the Middle Miocene when carbonate reefs of the Baturaja formation started to develop (Patra, Noeradi, & Subroto, 2011). Massive thrust fault that occurred earlier on the Plio-Pleistocene caused this carbonate reef structure to be tilted. This carbonate reef thickness varies within 90 to 120 meters and is the main

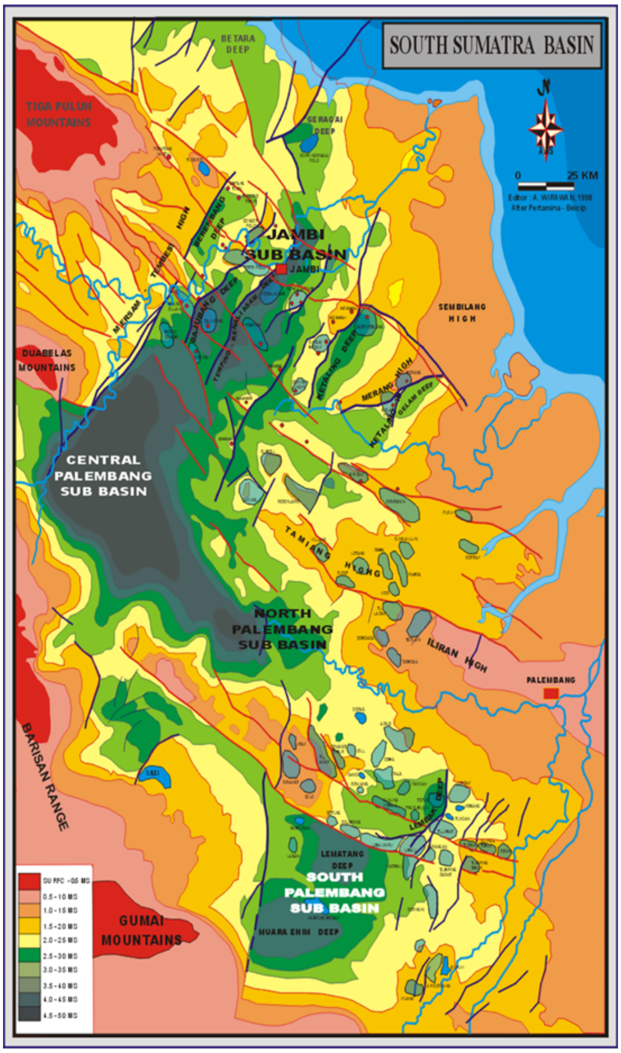

Figure 1. Geological Setting of South Sumatra Basin (Artono & Tamtomo, 2000)

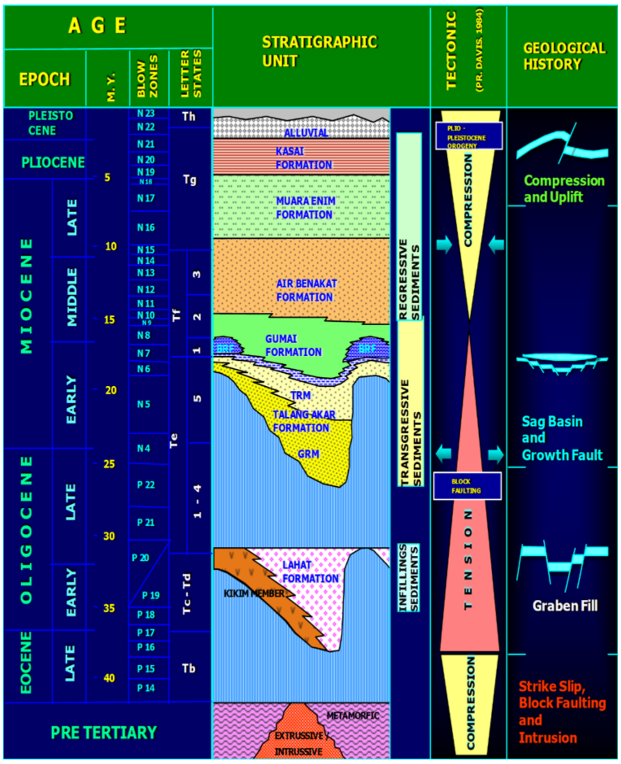

Figure 2. Geological Stratigraphy of South Sumatra Basin (Ryacudu, 2008) modified by Irman Firman, Pertamina)

producer formation in the Sonya field with an initial production rate of 1350 BOPD. Exploration and production activity mainly focused on the porous main reef facies in their early stage, but as time went on, the production rate started to decline. Thus, the need to explore new potential zones arises (Figure 1 and 2).

3 DATA AND METHODOLOGY

In this study, we use a 3D seismic cube, two interpreted horizons, and 12 wells that have gone through the well logs and seismic tie QC processes as an input for deriving acoustic impedance volume through iterative model-based inversion. Our proposed workflow is summarized in figure 11.

3.1 Spatial Interpolation Methods

The interpolation method that is commonly used to populate stratigraphic framework in building a low-frequency model for seismic inversion is inverse distance weighting (IDW), in which unknown points are estimated to have a value from a linear combination of known values weighted by their inverse distance to the unknown points. This practically means further points will have a smaller contribution in estimating unknown points than the one close to the estimation location. The concept of IDW makes perfect sense for spatial data, but the downside of IDW is that we cannot incorporate our knowledge of spatial continuity or structures within our data, such as depositional direction or reefal geometry in carbonate. Hence, care must be taken in this method such that, when possible, one should suppress the presence of bull's eye features that are not geologically plausible. Kriging and the family of kriging methods may arguably be the most well-known spatial interpolation technique because of its simplicity, and it is resulting in Best Linear Unbiased Estimation (BLUE). In a way, kriging is similar to IDW where it tries to estimate the unknown sample points based on a linear combination of known sample points, but instead of using inverse-distance as the weight of the known sample points, it uses variogram as a measure of spatial continuity. Most of the time, in subsurface modeling workflow, we have two kinds of data set, the first one being sparsely sampled with the high vertical resolution (well data) and the other being densely sampled in space but has a poor vertical resolution (seismic), we always want to try to combine both to create a reasonable subsurface property map or volume that honors both data. Cokriging, which is a variation of the kriging method not only can accommodate such workflow but can also help us in estimating a more reasonable variogram when paired with the Markov-Bayes assumption where a linear relationship is assumed between the primary and secondary dataset. Naturally, we are required to estimate well-to-well, well-to-seismic, and seismic-to-seismic

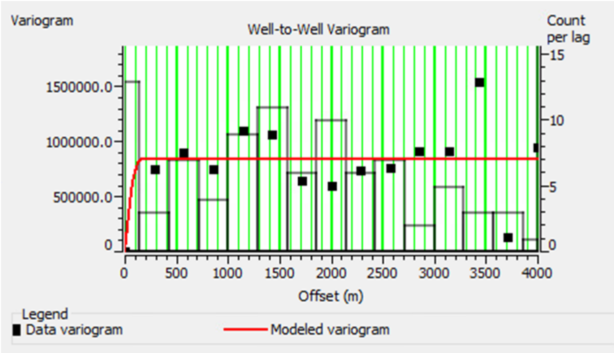

Figure 3. Experimental variogram (black dots) and variogram model (red line) derived from well data

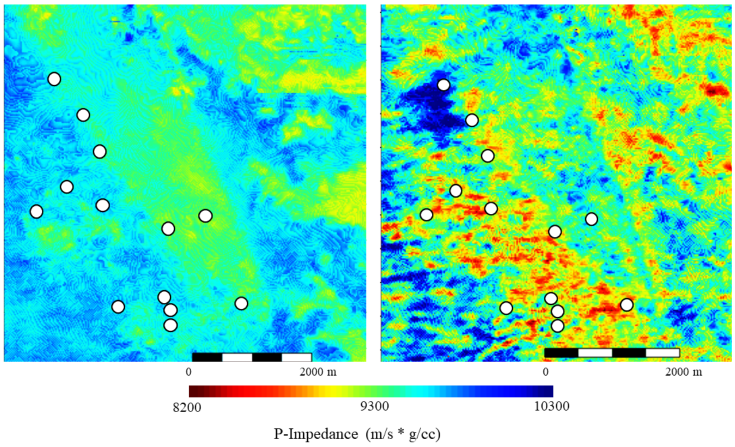

Figure 4. Low-frequency model built only using one well (left), and the result of first-pass inversion (right)

variograms as input for cokriging, but the main problem is that the well data usually have poor spatial sampling and we cannot create a reliable variogram out of it. The problem of a sparse well can be tackled if we use the Markov-Bayes assumption where we assume a linear relationship between primary and secondary variables. By knowing that linear relationship, we can use seismic to seismic variogram and create the other two variograms using the linear regression coefficients.

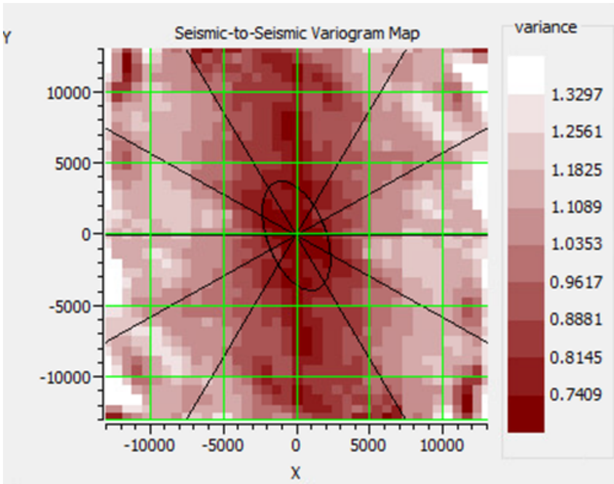

Figure 5. 2D directional variance map

4 RESULTS AND DISCUSSIONS

4.1 First-pass Inversion

When constructing LFM for first-pass inversion, we found that a model that is built only using one well with IDW shows a reasonably good result. The benefit of only using one well to build an LFM is that it minimizes the chance to have bull's eye artifacts, but choosing which well works best in building the LFM and gives the best result for the first pass inversion may take time. In this study, we used a trial-and-error scenario in which we made one LFM for each well and tried which one can give the best inversion result from looking at their impedance prediction and synthetic errors. One might be tempted to incorporate all well data and use an experimental variogram derived from samples that are in the well position and use ordinary or simple kriging to build the initial model. But as shown in Figure 3, this variogram most of the time will be noisy and may not give a representative view of our local spatial continuity because of the sparse sampling of well data in space.

4.2 Building LFM with cokriging

After getting our first-pass inversion result which is shown in Figure 4, we then created a new LFM using all available wells, but instead of using IDW, we use cokriging with the first-pass inversion result as the secondary attribute and create a variogram model based on experimental variogram derived from the same first-pass inversion cube. A linear relationship between first-pass inversion and well log data is shown in fig 10. In this case, because we use the same physical property between primary attribute and secondary attribute, the Markov-Bayes assumption is automatically fulfilled, thus eliminating the need for a well-to-seismic variogram. In the case of using another secondary attribute that may not have a clear physical meaning to the primary attribute, e.g. amplitude envelope as a secondary attribute to interpolate acoustic impedance from well, one has to check for a linear relationship between those two to fulfill Markov-Bayes assumption.

From our interval of interest, we expect an anisotropic variogram with a major direction at around N150E-N170E that corresponds to the orientation of the local reefal structure. This spatial continuity is confirmed from the 2D directional variance map which is shown in Figure 5. In this study, we used a variogram that is derived from the first-pass inversion cube to interpolate well data to build a new updated LFM for the second-pass inversion. The result is shown in Figure 6, and compared to a well-to-well variogram, it gives a clearer variogram structure.

The difference between an LFM that is constructed using all wells but only using IDW and the one that uses cokriging can be quite dramatic as shown in Figure 7. Though the result still shows bull's eye features, we can observe that it is more geologically plausible than the model derived using IDW. In this case, we are only interested in one specific interval, but we must be cautious if we want to create an

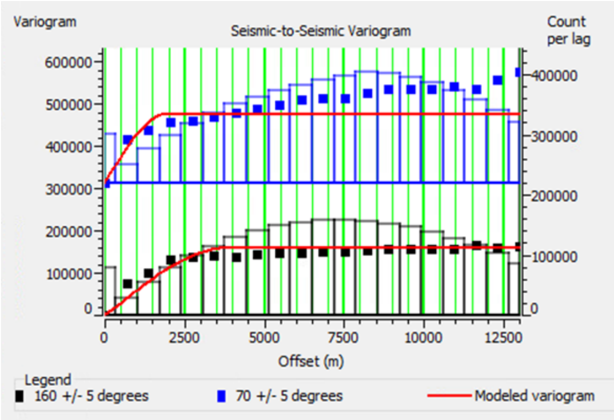

Figure 6. Experimental variogram (black dots) and variogram model (red line) derived from seismic data

LFM that spans several geological intervals that might not have similar spatial continuity. In the case of multiple geological intervals that might not have the same spatial continuity pattern, it is advised to interpolate the impedance data from the well for each layer and use a different variogram for each layer.

4.3 Second-pass Inversion

The updated LFM is used to proceed to the second-pass inversion, we also show how the inversion result would look like if we were to use a model that is constructed using all well data but interpolated using IDW in Figure 8. The second-pass inversion result derived from cokriging LFM shows a more representative image of the subsurface that incorporates all available data while still honoring local spatial continuity, contrary to the inversion result derived from IDW low-frequency model. Unlike first pass inversion result where low impedance amplitudes that represent reef build-up are localized, second pass inversion shows better images where it is easier to interpret the main reef, which is known to have massive bodies and patch reefs that are formed in a localized manner behind the main reef as interpreted in Figure 9. While inverted IDW model yields a great correlation between inverted and data in well location compared to second-pass inversion as shown in Figure 10, the bull's eye artifacts from simple IDW interpolation still exist in the inverted result, this again show that model-based inversion depends on the initial model / low-frequency model being used, thus, in the case of bandlimited seismic data, we have to use all of our knowledge to create a more geologically plausible model while still incorporating all available datasets. Because there is no special metric that can compare the goodness of fit between inverted impedance cube derived from simple IDW model and cokriging model, it is advised to look at other data such as production data or conceptual geological model or even outcrop to choose which impedance model is more favorable.

This iterative workflow can be extended if we have a newly acquired dataset. The recommended iterative workflow in case we have new data is that new well data should be used as a blind inversion test, and from that result, we may judge whether we should update our initial model and run a new model-based inversion based on a model derived from previous iterations.

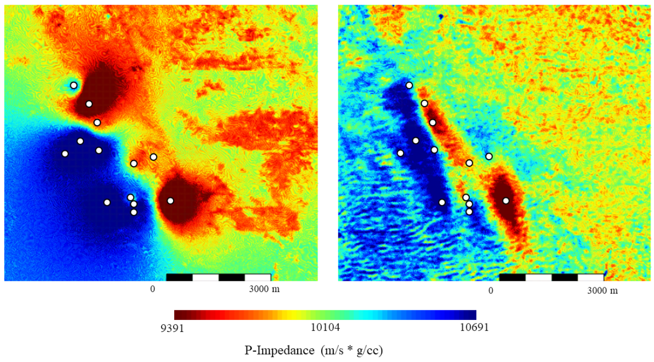

Figure 7. Low-frequency model built using all wells and interpolated using IDW (left) and using cokriging with first-pass inversion cube as secondary attribute (right)

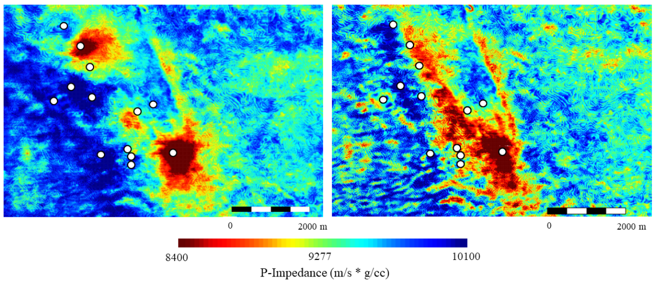

Figure 8. Comparison of inverted impedance using IDW low-frequency model (left) and cokriging low-frequency model (right)

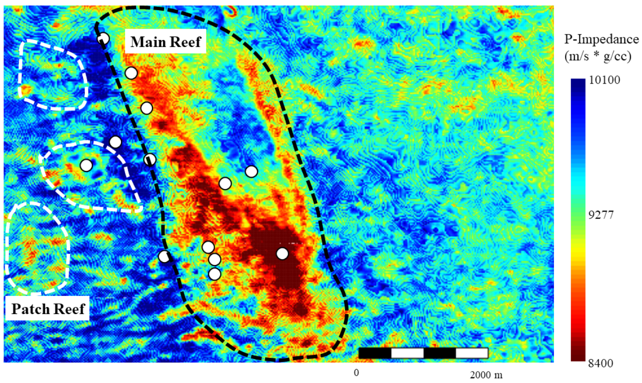

Figure 9. Second-pass inversion result and interpretation of carbonate facies

5 CONCLUSIONS

In this study, we once more showed that LFM is a very important input in model-based inversion and must be inspected thoroughly before advancing to the inversion process itself to suppress interpolation artifacts in the inversion result. We demonstrate that, when possible, we should always incorporate our knowledge of spatial continuity in building an LFM. The Spatial continuity model can be derived by inspecting experimental variogram from well data as an in-

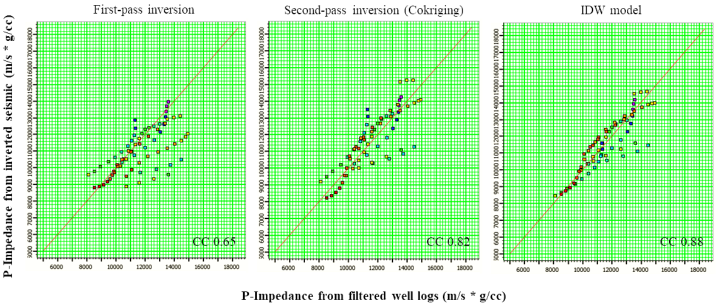

Figure 10. Correlation between filtered impedance logs extracted in our zone of interest and inverted impedance from seismic

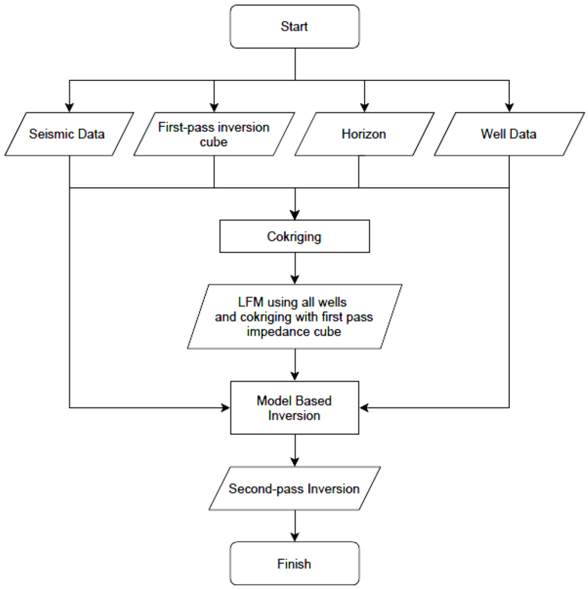

Figure 11. Proposed iterative model-based inversion workflow using first-pass inversion cube and cokriging.

put for the kriging process. But most of the time, wells are sparsely sampled around our survey area, thus we may not get a reliable estimate of spatial continuity in our area. It is advised to use another attribute that has a good correlation to the primary attribute and use that to derive a spatial continuity model and secondary attribute in the cokriging process. Using this proposed workflow, we managed to create an acoustic impedance model that honors all of the available data and geological knowledge that can be used to guide further exploration.

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