Velocity Model Analysis Based on Integrated Well and Seismic Data of East Java Basin

Fathul Mubin\textsuperscript{1, a)}, Aviandy Widya\textsuperscript{1}, Budi Eka Nurcahya\textsuperscript{1}, Erma Nurul Mahmudah\textsuperscript{1}, IndroPurwaman\textsuperscript{2}, AryoRadityo\textsuperscript{2}, AgungShirly\textsuperscript{2}, CitraNurwani\textsuperscript{2}

\textsuperscript{1} Geophysics Department, Universitas Gadjah Mada, Yogyakarta, Indonesia
\textsuperscript{2} SKK Migas, Jakarta, Indonesia

\textit{a). mubinugm@gmail.com}

Abstract. Time to depth conversion is an important process of seismic interpretation to identify hydrocarbon prospectivity. Main objectives of this research are to minimize the risk of error in geometry and time to depth conversion. Since it’s using a large amount of data and had been doing in the large scale of research areas, this research can be classified as a regional scale research. The research was focused on three horizons time interpretation: Top Kujung I, Top Ngimbang and Basement which located in the offshore and onshore areas of east Java basin. These three horizons were selected because they were assumed to be equivalent to the rock formation, which is it has always been the main objective of oil and gas exploration in the East Java Basin. As additional value, there was no previous works on velocity modeling for regional scale using geological parameters in East Java basin. Lithology and interval thickness were identified as geological factors that effected the velocity distribution in East Java Basin. Therefore, a three layer geological model was generated, which was defined by the type of lithology; carbonate (layer 1: Top Kujung I), shale (layer 2: Top Ngimbang) and Basement. A statistical method using three horizons is able to predict the velocity distribution on sparse well data in a regional scale. The average velocity range for Top Kujung I is 400 m/s – 6000 m/s, Top Ngimbang is 500 m/s – 8200 m/s and Basement is 600 m/s – 8000 m/s. Some velocity anomalies found in Madura sub-basin area, caused by geological factor which identified as thick shale deposit and high density values on shale. Result of velocity and depth modeling analysis can be used to define the volume range deterministically and to make geological models to prospect generation in details by geological concept.

Keywords: Depth Conversion, Velocity Modeling, East Java

1. Introduction

1.1 Background

The world needs on oil and natural gas still on high demand, makes the exploitation and exploration really needed to cover the less back up in the future. As we know, the existence of hydrocarbons prospect on oil and natural gas cannot be easily found on the surface, so we need indirectly methods such as with geology and geophysical interpretation. The knowledge of subsurface regional geology and tomography technology insist that seismic method and logging are really absolutely needed to hydrocarbon...
prospectivity identification in an accurately and small risk on value in the next stages. Geophysical methods that play a role in the identification of hydrocarbon prospectivity is the seismic interpretation. One of the most important part on seismic interpretation is conversion from time domain to depth domain on the structure contour map. Lot of data and large research area delivered this research to regional scale research in East Java basin.

1.2. Challenges

There are many conversion study which are do in this East Java basin but none of them belongs to regional scale commonly limited by block. This study would be very supportive and helpful for the next studies on the regional scale to look at all the concepts of regional geology.

In simple interpolation method, velocity model would be depending on calibration wells/references. External Drift Kriging (Kriging with External Drift/KED) is a statistic method that used in this study to populating the well data as a calibration factor which is using contour map of time as a secondary parameter (Hengl et al., 2003). KED was considered as method on this regional scale study because it’s able to interpolate in a good way rather than others statistic methods. Geological analysis in order to velocity model analysis also required as a validation for statistic method. KED able to provide the image of velocity model which is fit with geological research area, this would be act as added value than other statistical methods.

Although many wells used in this study, limited checkshot data reminds as challenges to further evaluation. Checkshot number and distribution highly influenced the result of velocity model. In regional scale, if checkshot number is not well distributed, then horizons as second parameter data can be optimized with this geostatistical method (KED).

1.3. Objective

Regarding to the background and problems, there are some questions that will be answered through this study:

- Which geological factors affecting the anomalous velocity model in the study area?
- Are the use of data which is undistributed well or sparse in each block can be used to predict velocity models on regional scale optimally?
- Is the Kriging geostatistic with KED capable to generate velocity model and depth conversion which fit to the geological model?

2. Geology of Research Area

The East Java Basin bordered covers East Java, Madura Island, Java Sea to Kangean Island (BPMIGAS 2008). In geological structure, the research area divided into 8 (eight) main structures, There are: Bawean Arch, Muriah Trough, JS-1 Ridge, Tuban-camar Trough, Central Depression, North Madura Platform, RMKS zone dan Kendeng zone.

In the offshore, East Java basin subdivide as two zones of structure, central part and eastern part of Java Sea. The central part of Java Sea is dominated by structured which extend toward southeast-northwest (SE-NW) direction. Some varieties in morphology within this present Java Sea are Karimunjawa Arch, Bawean Arch, Meratus Arch, danPulau Laut Arch. Karimunjawa Arch are paleo high which have broad geometry and metasediment outcrop in Pra-Tersier age (Koesoemadinata and Pulunggono, 1975). Based on previous geophysics research, this paleo high had granite like in Bangka-Belitung Islands and granite-batholith as basement for this paleo high (Guntoro, 1996). Bawean Arch is composed by vulcanic Tertiary rock, while Meratus Arch and Pulau Laut Arch is developed by mélangé Cretaceous and appear in Meratus Mountain Range. Pulau Laut extend to the south until reach northern part of Java Island called JS-Ridge (north Tuban for exact location).
Despite the paleo high, some paleo low (trough) also found from west to east, Muria Trough, Tuban Trough, and Central Deep. Muria Trough is the half-graben structure developed in west Karimun Jawa Island which spread relative toward NE-SW direction till reach north Muria Mountain. Seismic section toward NW-SE along Karimun Jawa Arch showed a developed basin from normal fault NE-SW trending direction. Tuban Trough from tectonic point of view, is respectively a half-graben structure similar with Muria Trough. The southern part of Tuban Trough is bounded by fault system toward E-W direction and gradually vanishes toward northeast (NE) direction in the boundary of Bawean Arch and JS-1 Ridge. In the far east, Central Deep also developed half-graben structure type toward NE-SW direction. Central Deep is bounded by RMKS (Rembang-Madura-Kangean-Sakala) fault system toward E-W direction in southwest. Though, in the east, Central Deep is bounded by a paleo high called Northern Madura Platform.

Northern Madura Platform is broad carbonate sedimentation area during Miocene to Pliocene (Prasetyadi, 2007). In south is bounded by RMKS fault zone toward E-W direction and created morphology which has lower elevation than Madura Island due to compression along RMKS fault zone. In the eastern part of East Java basin is developed Sibaru Platform which is elongation from Pasternoster Platform in north. Sibaru Platform is a reefal platform which is bordered by reefal complex on the east and south of this area (Prasetyadi, 2007). The western and central part of Java Sea is commonly controlled by structure which elongate NE-SW, whereas in the eastern part of Java Sea developed structure toward W-E direction. It represent with the presence of Kangean and Lombok paleo high. Kangean paleo high is the most eastern part of RMKS fault zone which is plunging toward W-E, while Lombok paleo high located in southwest. Structure type in the eastern Java Sea is the extension of two major structures in present onshore East Java, Rembang and Kendeng zone, which elongate toward W-E direction.

3. Theoretical Framework

3.1. Velocity Models

There are many kinds of seismic wave of velocity, the different mathematic calculation in measuring seismic velocity also affect the definition of the velocity itself. These are some kinds of velocity:

3.1.1. Average Velocity ($V_{avg}$)

In horizontal layer formations, average velocity from n’s layer defined as:

$$V_a = \frac{1}{T_0} \sum_{k=1}^{n} V_k \cdot t_k$$

$V_k$ = velocity from k’s layer, $t_k$ = Two way time (TWT) from k’s layer and $T_0$ = Normal time (Two way normal incident) that can be formulated by:

$$T_0 = \sum_{k=1}^{n} t_k = 2 \sum_{k=1}^{n} \frac{h_k}{v_k}$$

$h_k$ = the thickness of k’s layer.

3.1.2. RMS Velocity (Root Mean Square)

RMS velocity is the total velocity from horizontal layers system in the form of average square roots. If considered $\Delta t_1$, $\Delta t_2$, $\Delta t_3$,..., $\Delta t_n$ and velocity in each layers $V_1$, $V_2$, $V_3$,..,$V_n$ then $V_{RMS}$ for the number of “n” can be formulated:

$$V_{RMS} = \sqrt{\frac{1}{n} \sum_{k=1}^{n} V_k^2}$$
The RMS velocity is not the result of velocity measuring, but the result from mathematic calculation process.

\[
V_{RMS} = \sqrt{\frac{\sum_{k=1}^{n} V_k^2 \Delta t_k}{\sum_{k} \Delta t_k}}
\]

3.1.3. Interval Velocity
Interval Velocity \( V_{\text{int}} \) (Interval \( V_{\text{int}} \)) is the average speed between 2 points measured perpendicular toward velocity layers that considered equals, Interval velocity considered as the velocity in each layers that can be formulated by:

\[
V_{\text{int},j} = \frac{\Delta z_j}{\Delta t_j}
\]

The velocity definition can be understood easily by:

\[\text{Figure 1. RMS velocity in each layers}\]

\[\text{Figure 2. The velocity definition on time-depth domain (Marsden, course handout)}\]
3.2. Geostatistical Methods
Geostatistical methods has been used in many geophysical exploration field, thus it can integrate various type of data for modeling. The Geological model usually based on log data that really depend on the number and distribution of wells. Seismic provide spatial geometry information, but has certain of limitations such as resolutions and noises. Those limitations can be minimalized with integrating between 2 types of those data to produce a good model with the existing geological concepts.

3.3. Kriging with External Drift (KED) Methods
KED method in estimating a new prediction of point value, with equation:

\[
\hat{z}(s_0) = \sum_{i=1}^{n} w_i^{KED}(s_0) \cdot z(s_i)
\]

for

\[
\sum_{i=1}^{n} w_i^{KED}(s_0) \cdot q_k(s_i) = q_k(s_0)
\]

With \( k = 1, \ldots, p \) or at matrix notation:

\[
\hat{z}^{KED}(s_0) = \delta_0^T \cdot z
\]

With \( z \) : variable target, \( q_k \) : prediction variable (prediction value), \( (s_0), \delta_0 \) : vector from KED \( W_i^{KED} \), \( p \) : amount that predicted and \( z \) : vector of \( n \) value. KED uses extended matrix, equation:

\[
\lambda_0^{KED} = \begin{bmatrix} w_1^{KED}(s_0), \ldots, w_n^{KED}(s_0), \varphi_0(s_0), \ldots, \varphi_p(s_0) \end{bmatrix}^T = C^{KED-1} \cdot c_0^{KED}
\]

Matrix system of KED are (Webster and Oliver, 2007):

\[
C^{KED} = \begin{bmatrix} C(s_1, s_1) & \cdots & C(s_1, s_n) & 1 & q_1(s_1) & \cdots & q_p(s_1) \\
\vdots & \cdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
C(s_n, s_1) & \cdots & C(s_n, s_n) & 1 & q_1(s_n) & \cdots & q_p(s_n) \\
1 & \cdots & 1 & 0 & 0 & \cdots & 0 \\
q_1(s_1) & \cdots & q_1(s_n) & 0 & 0 & \cdots & 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
q_p(s_1) & \cdots & q_p(s_n) & 0 & 0 & \cdots & 0 \\
\end{bmatrix}
\]

So \( c_0^{KED} \):

\[
c_0^{KED} = \{ C(s_0, s_1), \ldots, C(s_0, s_n), q_0(s_0), q_1(s_0), \ldots, q_p(s_0) \}^T; q_0(s_0) = 1
\]
Drift (geo-regression) is the result of the KED operation, which is a function of the variogram that predicts average regression against linear regression functions. This regression has proportional value from the impact on the entire data.

4. Methodology
In this study, the types of data that used by the researcher are 2D seismic data (802 tracks), 3D seismic (8 fields), wells logging data (106 wells), Checkshot (25 wells).

![Diagram](image-url)

**Figure 3.** Time domain to Depth domain conversion plot.

The first step to do time-depth conversion is tie the wireline log data from well and seismic data in the exact marker for each horizons/formations, then used a line from 2D seismic survey as reference to standardize the reflector in each line both 2D and 3D seismic data. However, before converting to depth domain, we used well-seismic tie from previous process to pick the correct reflector for each formations and resulting seismic interpretation in time domain. Availability of 2D and 3D seismic data also well data for this research are shown in Figure 4.

At this moment, all resulted horizons from seismic interpretation remain in time domain and should be converted to depth domain. To acknowledge that situation, velocity map for each horizon has created. The velocity maps made from interval velocity which is generated from checkshot data in all wells. Missing checkshot data can be utilized by taking checkshot from the closest well. After created interval velocity in
each well using checkshot data, a grid was generated from each point to build velocity interval maps for every horizons.

![Figure 4. 2D and 3D Seismic data distribution and wells data on the research area.](image)

5. Result and Discussion

5.1. Time Surface Map
Figure 5. Time Surface map on the horizon a) Top Kujung 1, (b) Top Ngimbang Klastik, (c) Basement.

From the time maps result in those horizons (Figure 5), the study area relatively have value 500 – 5000 ms with the deepest part represent as dark color (purple-dark blue) is located in the south of Madura island (Madura subbasin) reach almost 3500 ms till 5000 ms due to depression phase which differ from other place in this basin, while the shallowest part denote as bright color (light blue-red) is located in the North
East Java sea extent from 100 ms till 3500 ms. In fact, morphological of every maps is quite similar due to basement involved in each sedimentology process for younger formations.

5.2. Velocity Model
Figure 6. Interval Velocity model ($V_{int}$) on horizon (a) Top Kujung 1, (b) Top Ngimbang Klastik, (c) Top Basement.

Figure 6. shows interval velocity model in every single horizon based on checkshot data. Some difficulties come from the complexity in structural variation within study area and lack of checkshot data. Lack of checkshot was corrected by using the nearest well which has checkshot. Some pseudo wells were created not only to solve the gap between one to another well but also to accommodate some areas with complex structure, for example in the southern of Madura Island. The pseudo well is developed by using checkshot from nearby well then calculating interval velocity in particular area. Other parameter is secondary parameter from interpreted horizon to calculate interval velocity model for every horizon. Based on lithology and formation thickness, interval velocity will calculate high value when its lithology has high density and thick.

Top Ngimbang Clastic Map (figure 6.b.) in Madura subbasin have high velocity value (more than 3000 m/s) than its surrounding area due to low area and thick sediment deposit about 14000 ft thick filled with mostly shale in lithology. However, this thick sediment accumulation interpreted as source for hydrocarbon source for this area. Thick shale in this area also is the main factor for increase interval velocity.
5.3. **Depth Surface Map of Conversion Results**

(a)

(b)
Figure 7. Depth surface map of conversion results on horizon (a) Top Kujung 1, (b) Top Ngimbang Klastik, (c) Basement.

Depth contour map in Figure 7 relatively has the same structure pattern with time contour map. It became the early control to measure whether the process of making velocity model is correct or not.

6. Conclusion
Lithology and thickness of each formation are the main geological factor controlling the velocity model in East Java Basin. Depression area known as Madura Sub Basin dominated by thicker clay compare to surrounding area and indicating velocity anomalies. Kriging with External Drift (KED) method in geostatistical is able to make a depth conversion in regional scale pretty well. The main obstacle that needs to be completed for the further research is the availability and distribution of seismic and checkshot for cover regional area.

Acknowledgements
This study initiated by SKK Migas cooperated with UPN Veteran Yogyakarta, Universitas Gadjah Mada and several PSC (production sharing contract) companies that developing East Java Basins. This study became motivation and example for geoscientists and practitioners of oil and gas industry to keep spirit doing research and exploration in the effort of national oil and gas resources and production enhancement.

Thanks to Deputy for Planning Management Chief and Exploration Division Chief of SKK Migas for the support, also all of the PSC helping the realization of this study. Data and result have a permission from SKK Migas and PSC to be published. Also we thank to UPP university partnership program Chevron-UGM for supporting hardware and software facility.
References

[1]. Chambers, R. L., Yarus, J. M, Hird, K.B, 2000, Petroleum geostatistics for non-geostatisticians, The Leading Edge, May 2000 (Part 1), June 2000 (Part 2).

[2]. Hengl, T., Heuvelink, G.B.M., and Stein, Alfred, 2003, Comparison of Kriging with External Drift and Regression-Kriging. Technical note, DepartmentofEarthSystemsAnalysis,InternationalInstituteforGeo-informationScienceandEarthObservation(ITC), Netherlands.

[3]. Kaufman, H., 1953, Velocity functions in seismic prospecting, Geophysics, 18, 289-297.

[4]. Prasetyadi, C., Paleogene Tectonic Evolution of Eastern Part of Java (Dissertation ITB, Bandung, 2007).

[5]. Reilly, M., 1993, Integration of well and seismic data for 3D velocity model building, First Break, 11, no. 6, 247-260.

[6]. Satyana, A. H., New Consideration on the Cretaceous Subduction Zone of Ciletuh – LukUlo – Bayat – Meratus: Implications for Southeast Sundaland Petroleum Geology (Proceeding of IPA Convention and Exhibition, 2004).

[7]. Schlumberger, 2010