

Applied velocity versus offset (VVO) to validated & characterized fracturing zone in intra Baturaja Formation, South Sumatera Basin

Hilman Mardiyani, Saifatur Rusli

Samudra Energy, Cyber 2 Tower, 26th floor, Jakarta, 12950, Indonesia

E-mail: hilman.mardiyani@samudraenergy.com

Abstract. The velocity versus offset (VVO) as new geophysical method can be applied to detect some geological phenomenon, such as hydrocarbon trap, structural-fracture anomaly, facies changes, etc. The VVO method is data driven, based on the normal move out equation (NMO) and measuring the local event correlation between adjacent traces to get velocity gradient attributes which is derived from cross-plotting the velocity versus offset (VVO). This paper is describing applied VVO model that controlled by well data which indicated fracture from logs data, especially Resistivity Imager Logs or Formation Micro Imager (FMI). Images FMI logs data at Intra-Baturaja Carbonate Formation (BRF) in South Palembang Sub-basin (SPB), South Sumatera, shows vugs with fractures which orientation is roughly NNW-SSE. Meanwhile, the 2D NMO seismic gathers indicated those all as hockey stick at far offset. By applying VVO method, hockey stick can be identified and then used to validated, characterized and localized where the fracturing zone in intra-Baturaja Formation is. Laterally, VVO quantified as velocity gradient attribute which associated with geological model as the fracturing zone in study area. Characterization fracturing zone in Intra Baturaja Formation as geological lateral model by design is a challenging task for most exploration and production. In term of exploration where limited data is available, it can be used step ahead as carbonate fracture reservoir candidate in proven area and adjacent, especially in SPB South Sumatra.

1. Introduction

The South Sumatra Basin (SSB) Province consists of several structural sub-basins with Tertiary sedimentary section lying unconformably on the eroded and faulted topography of pre-Tertiary metamorphic and igneous rocks [1].

1.1. Regional Geology & Stratigraphy of South Sumatra Basin (SSB)

SSB is one of the most hydrocarbon prolific Tertiary back-arc basins today which located primarily onshore Sumatra, Indonesia. The province covers an area of approximately 117,000 km² consists of Tertiary half-graben basins infilled with carbonate and clastic sedimentary rocks. It was formed as a pull-apart basin related to NW-SE trending dextral strike-slip faulting.

SSB is divided into several sub-basins: Jambi, North Palembang, Central Palembang, South Palembang, and Bandar Jaya Basin [2] (figure 1). It experienced three tectonic deformation phases: Mesozoic compressional, Eocene-Oligocene extensional and Pliocene-Pleistocene compressional tectonics.



The general stratigraphy of SSB is one consisting of Pre-Tertiary and Tertiary Rocks. Basement Pre-Tertiary rocks consist of meta-sediment rocks, granitic and ultrabasic igneous rocks, volcanic rocks aged range from Permo-Carboniferous (248-354 Ma) to Mesozoic (Jurassic-Cretaceous, 170-110 Ma). Tertiary Rocks consist of Lemat Formation, Talang Akar Formation, Baturaja Formation, Telisa (Gumai) Formation, Air Benakat (Lower Palembang) Formation, Muara Enim (Middle Palembang) Formation, and Kasai (Upper Palembang) Formation (figure 2).

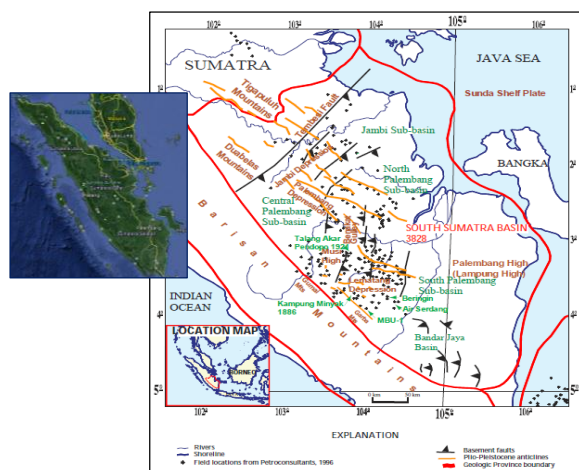


Figure 1. Research area: South Palembang Sub Basin, in proven area and adjacent South Sumatra Province [1].

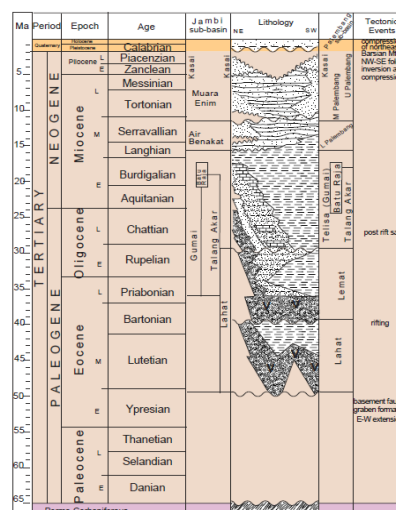


Figure 2. Generalized stratigraphic column for the SSB. ([3] and [4])

1.2. Fracture Identification: References Cited

Fractures are planar features with no apparent displacement in geological formation [5]. Fractures in limestone can be found in a wide range of scales from millimeters to tens of meter long. In general, four different types of fractures can be found: shear fractures, extensional fractures, stylolites and vuggy-a solution enlargement fractures [6]. Fracture-porosity is estimated from core laboratory tests or formation imaging using FMI or FMS methods, because there are no conventional well log tools that can directly determine fracture porosity [2]. Resistivity images respond to electrical contrast as fractures are generally resistive or conductive relative to the host rock. (Figure 3).

Some fractures study was conducted specially in Baturaja Formation SSB. showing fractures in BRF Fm. located on Southern part of SPB-SSB using FMI data proved as the main tools to help the next development well locations and reservoir zones. FMI images showing breakouts and drilling induced fractures in these Well which has NNW-SSE where localized vugular porosity as porous zones (cavities or vugs). On the other hands, Baturaja Formation (BRF)-SSB in thin sections is mouldic-micro vuggy with some fractures.

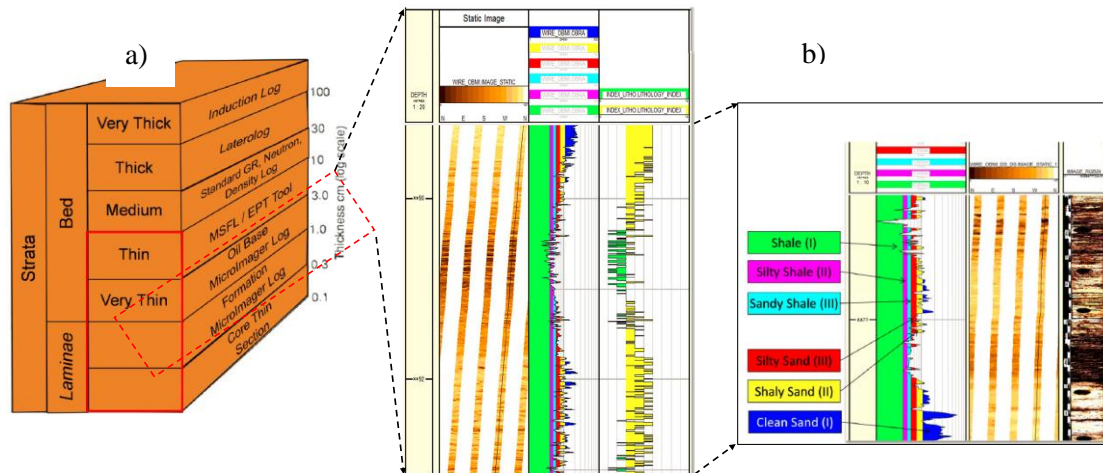


Figure 3. a) Bed classification and tools used for analysis, b) Lithological index log. The green color refers to the shale group and the yellow color refers to the sand and carbonate groups [7].

Much effort has focused on measuring amplitude variations with offset (AVO) for seismic reflections from a fractured reservoir [8, 9, and 10]. Amplitude variation with offset and azimuth (AVOA) has been widely used to identify the orientation of vertical fractures with variable levels of success [11, 9, 12, and 13]. In these applications, the fractures are assumed to be small relative to the wavelength of the seismic waves. This allows the fractured medium to be modeled using an equivalent anisotropic medium.

The presence of hydrocarbons, especially gas in sand reservoirs, commonly creates the ‘hockey stick’ effect in the common midpoint (CMP) gathers when normal moveout (NMO) corrections have been applied, indicating that a faster NMO velocity is required to flatten the reflection events. Prior to scanning the amplitudes within CMP gathers, it is common practice to apply a time-offset mute to remove overcorrected traces, or to apply trim statics to force reflection events to be flat. A new method for calculating the correct V_{rms} automatically was developed without scanning the set of velocities, but by considering only the Local Even Correlation (LEC) of adjacent traces from the nearest to far end offset. The proposed method honors changes of velocity in each offset. Therefore, any anisotropic characters in the CMP gather will be measured automatically. This principle is simple, but requires high signal-to-noise-ratio data and good event continuity along the offsets within the CMP gather.

2. Velocity versus Offset

2.1. Offset-dependent velocity estimation

Velocity extraction from seismic data is formulated from the NMO equation. The CMP gather is first NMO-corrected using the initial stacking velocity, V_{stk} [14]. An offset-dependent moveout velocity, V_{hj} , is then calculated independently for each offset X_j by assuming moveout is hyperbolic:

$$\frac{1}{V_{hj}^2} = \frac{(\Delta t_j + T_j)^2 - T_0^2}{X_j^2} \quad (1) \quad \text{Where } T_j : T_j = \left(T_0^2 + \left[\frac{X_j}{V_{stk}} \right]^2 \right)^{1/2}$$

T_j is the traveltimes at offset X_j assuming hyperbolic moveout at the initial stacking velocity.

In Equation 1, Δt_j is the residual moveout at offset X_j , and is equal to the time shift measured using LEC method. The nearest-offset trace is used as the reference for measuring residual moveout on the other traces. V_h can be calculated for each individual offset across the CMP gather. Equation 1 thus acts as an operator to transform CMP data from amplitude gathers into velocity gathers. The VVO analysis is then carried out on the velocity gathers. The output V_h gather can be stacked or averaged to

produce a high resolution velocity field for NMO correction. Partial stacking can also be done to extract near- and far-offset velocity fields. The difference between far- and near-offset V_h values provides a quick scan of velocity gradient in the VVO method.

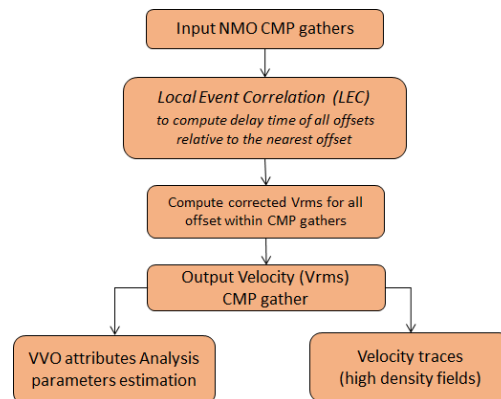


Figure 4. VVO attribute analysis workflow

The velocity analysis window was set to 40 ms and designed to follow the reflection curvature across offsets. The time step for calculating V_h is half of the analysis window, so the window steps downwards with 50% overlap over the record length. The complete workflow for VVO attribute analysis is shown in Figure 4 above.

3. Fracture Modelling

A great deal of research has focused on the applicability of finite difference (FD) methods to modeling seismic scattering phenomena. In particular, [15] test the performance of [16] equivalent medium anisotropic cell approach for FD modeling of discrete fractures. The FD method is advantageous when modeling the scattering effect of discrete fractures because of its stability over a wide range of material property contrasts and its ability to model all wave types with minimal numerical dispersion and anisotropy.

Our numerical experiments use a simple reservoir geometry consisting of three horizontal layers. The first and third layers bound the reservoir and are homogeneous and isotropic with the same material properties. The model uses a standard surface seismic reflection acquisition geometry, however, the source and receivers are embedded within the first layer to eliminate free surface effects. The receiver spacing is 20-m with the maximum source-receiver offset at 4000-m which corresponds to a maximum angle of incidence of 45° relative to the top of the reservoir (Figure 5).

Snapshots of the wavefield in the presence of discrete fracture zones highlight the different scattering events and their interactions. Figure 6 shows the vertical component of velocity after 0.6-second. We see that the P-wave reflection from the top of the reservoir remains relatively coherent, while the P-wave reflection from the base of the reservoir is much more effected by the presence of the discrete fractures. This figure also illustrates the difference in coherence of the scattered wavefield normal and parallel to the fractures. Normal to the fractures, interference of scattered waves from the fractures results in a complex wavefield (Figure 6a). Fractures act as secondary sources with observable forward and backscattering as well as multiple scattering events. Parallel to the fractures the wavefield is much more coherent and the fractures appear to act as waveguides (Figure 6b).

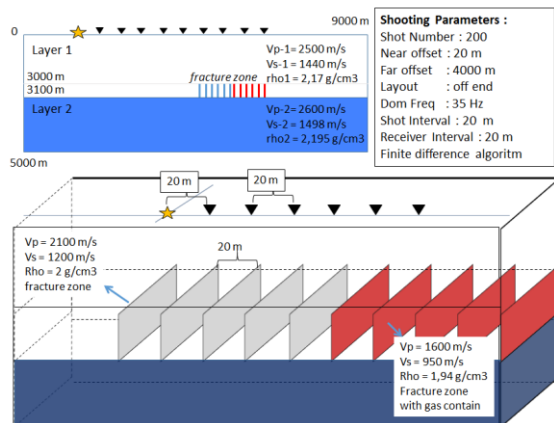


Figure 5. The model geometry for fracture zone showing source and receiver locations, fracture locations, and density parameters

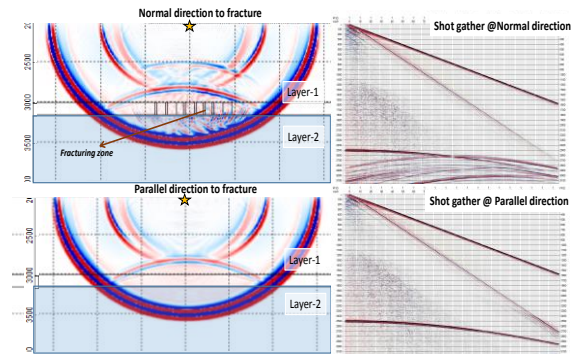


Figure 6. Snapshot of the vertical component of wave propagation in the normal (a) and parallel directions (b).

4. Result & Discussion

A CMP gather was generated using the elastic wave equation. The gather was NMO corrected using the initial stacking velocities estimated from the (vertical) interval velocities in the input model. The reflection event from the top of the fracture zone is flat and strong across all offsets. However, the reflection from the base of the fracture gas zone is only relatively flat up to mid-offsets. At the far offsets, the reflection event curves upwards indicating anisotropy in the fracture gas reservoir. VVO analysis was done on this simple CMP model over the fracture gas reservoir, as seen on Figure 7. Analysis of the hyperbolic moveout velocity was carried out on the base reservoir event using the LEC method and Equation 1. Computed offset-dependent RMS velocity increases with offset (Figure 7c).

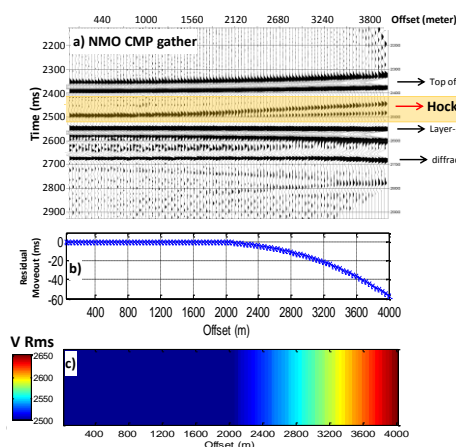


Figure 7. VVO attribute analysis at zone of interest.

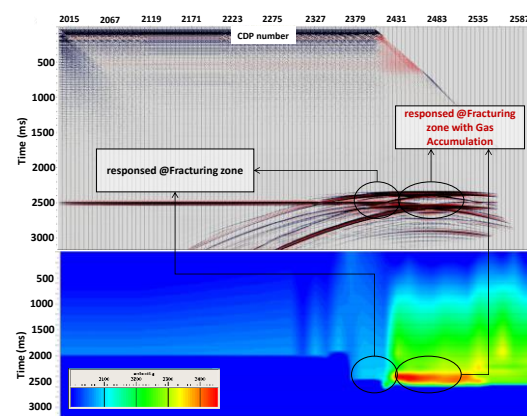


Figure 8. Stack section using Vrms derived from LEC and Vint gradient in colour

At location where the amplitude is bright, the V_h gradient is also positive (bright) as indicated by red to yellow colours. The V_h gradient is one product from direct velocity scanning of RMS velocity gathers. Before deriving the gathers for interval velocity V_{int} , the V_h gathers have to be converted to V_{int} gathers using a smoothing gradient equation. Linear regression is done on the V_{int} gathers to derive interval velocity gradient. Figure 8 shows the V_{int} gradient attribute across the seismic line. The V_{int} gradient also exhibits high positive anomalies localized at location of fracture reservoir zone (Higher interval velocity gradient).

5. Conclusion

The Vrms field produced by the LEC method is a high-resolution velocity field. This high-resolution velocity field is very useful, for instance for developing a velocity model for depth conversion and for pore pressure prediction. The VVO method is not affected by processing algorithms and parameterization, unlike the AVO method. Observations from VVO attributes of hyperbolic moveout velocity gradient and interval velocity gradient that fracture reservoir zone with gas accumulations is more easier to identified. Meanwhile, the existence and orientation fractured zone are recognized in FMI logs of study wells due to the overall good quality of electrical images which can be used as reservoir characterization and fracture determination as good as the results of prospect development.

References

- [1] Bishop M G 2001 South Sumatra Basin Province, Indonesia: The Lahat/Talang Akar-Cenozoic Total Petroleum System
- [2] De Coster G L 1974 The geology of the Central and South Sumatra Basins *Proceedings Indonesian Petroleum Association 3rd Annual Convention* p. 77-110
- [3] Gray D, Roberts G, and Head K 2002 Recent advances in determination of fracture strike and crack density from P-wave seismic data *The Leading Edge* v. **22** p. 280-285
- [4] Gudmundsson Agust 2011 *Rock Fractures in Geological Processes* Cambridge University Press, Cambridge, England, ISBN 978-0-521-86392-6
- [5] Hutchison C S 1996 *South-East Asian Oil, Gas, Coal and Mineral Deposits*: Clarendon Press Oxford
- [6] Minsley B J, Burns D R, and Willis M E 2003 *Fractured reservoir characterization using azimuthal AVO* ERL Industrial Consortium Annual Report MIT
- [7] Nihei K T et al 2002 Finite difference modeling of seismic wave interactions with discrete, finite length fractures 72nd Ann. Int. Mtg. *Soc. Expl. Geophys* Expanded Abstracts
- [8] Perez M A, Grechka V, and Michelena J 1999 Fracture detection in a carbonate reservoir using a variety of seismic methods *Geophysics* v. **64** p. 1266-1276
- [9] Ruger A 1998 Variation of P-wave reflectivity with offset and azimuth in anisotropic media *Geophysics* **54** 680-688
- [10] Sapiie et al 2011 Carbonate Fractured Reservoir Characterization Using Analogue Outcrop Study Of The Rajamandala Carbonate Complex, West Java *Proceedings Indonesian Petroleum Association*
- [11] Schoenberg M and Sayers C M 1995 Seismic anisotropy of fractured rock *Geophysics* v. **60** p. 204-211
- [12] Shen F et al 2002 Case History: Azimuthal offset dependent attributes applied to fracture detection in a carbonate reservoir *Geophysics* v. **67** p.355-364
- [13] Shen F and Toksöz M N 2000 Scattering characteristics in heterogeneously fractured reservoirs from waveform estimation *Geophys. J. Int.* v. **140** p. 251-266
- [14] Supriyono 2011 *Velocity Variation with Angle or Offset (VVO) A New Tool for Direct Hydrocarbon Indicator: Case Studies in Low and High Impedance Clastic Reservoirs* PhD dissertation Department of Geophysical Engineering Bandung Institute of Technology Bandung
- [15] Suseno P H, Zakaria, Mujahindin, Nizar, and Subroto E A 1992 Contribution of Lahat Formation as hydrocarbon source rock in South Palembang area, South Sumatera, Indonesia *Proceedings Indonesian Petroleum Association Twenty First Annual Convention* p.325-337
- [16] Wijaya O 2015 *Prediction of Fracture Porosity from Well Log Data by Artificial Neural Network, Case Study: Carbonate Reservoir, "Depok" Field*