Pore pressure prediction using probabilistic neural network: case study of South Sumatra Basin

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Abstract. Pore pressure prediction in the planning of the drilling well commonly carried out using seismic stacking velocity and Normal Compaction Trend (NCT) analysis with Eaton’s equation. There are other parameters that correlate to pore pressure, i.e. density, P-impedance, S-impedance, and Vp/Vs ratio. The aims of this study are to predict pore pressure distribution from 2D pre and post-stack seismic data of South Sumatera field by applying the Probabilistic Neural Network (PNN). The pre-stack seismic inversion, which resulted in the elastic parameters such as Density ($\rho$), Vp/Vs ratio, P-impedance (Zp), S-impedance (Zs), is used as input for PNN training. In another hand, the post-stack seismic data, which resulted in the following parameters such as the average frequency, absolute integrated amplitude, apparent polarity, and dominant frequency, is also used to predict the lateral distribution of pore pressure. Our data training using PNN with pre-stack seismic data provided the best correlation up to 98% compared with the post-stack seismic data. Our prediction, in general, provides the pore pressure model and in detail provides over-pressure. The advantage of PNN shows vertical resolution as good as seismic resolution and provides more helpful information for a further drilling operation.

1. Introduction

An understanding of pore pressure distribution and its mechanisms are important in the planning of drilling, both in term of security aspect and cost. The pore pressure knowledge can also be a consideration in the exploration strategy, as an example of consideration for drilling on the flank rather than on the peak of the structure. The use of velocity to pore pressure transformation by utilizing conventional stacking velocity has been commonly used to pore pressure prediction in the planning of drilling [1]. There are problems in pore pressure prediction using stacking velocity. First, conventional seismic stacking velocities are commonly not appropriate for pore pressure prediction since stacking velocity is not the real wave velocity in rocks [2]. Second, stacking velocity has a lower resolution in the depth that cannot detect changes in the pressure in short intervals.

There are other parameters that are affected by the overpressure zone. The less granules contacts in overpressure zone, which is low effective stress area, gives more influence on the Vs rather than Vp [3]. They expressed that Vp/Vs ratio is a suitable parameter for pore pressure prediction. The elastic parameter such as S-impedance, P-impedance, and density has a strong correlation to the pore pressure. These parameters are used to identify the possible presence of overpressure. In this paper, we predict the pore pressure by applying the PNN from 2D different seismic data, i.e., pre and post-stack seismic data.
The area of study is located in the western part of South Sumatra Basin as shown in Figure 1, which is indicated by yellow shadow. Geologically, the South Sumatra Basin is a basin formed by the interaction of Asian plate with Indo-Australian plate in the Middle Mesozoic. Extension phase during the Palaeocene to Early Miocene formed half graben filled by clastic sediments and carbonate where old tertiary and precipitated were not aligned above the basement (igneous, metamorphic, volcanic and limestone) which was formed pre-Eocene. South Sumatera Basin was separated by Central Sumatera Basin with Tigapuluh mountains, separated by Sunda Basin with Palembang/Lampung high and in the western part of Barisan mountains. This basin was divided into five sub-basins: Jambi Sub-basin, North Palembang Sub-basin, Central-Palembang Sub-basin, South-Palembang Sub-basin and Bandar Jaya Sub-basin [4]. The study area is located in South-Palembang Sub-basin that has the potential for over-pressure.

Figure 1. Map of South Sumatera Basin, where the yellow shadow is study area [4]

Our observation to the study area, which is based on the existing well data, shown overpressure zone particularly in Air Benakat and Gumai formation. The identified overpressure is indicated on the pore pressure changes with exceeding the value of the normal pressure. Therefore, further study is needed to map the distribution of pore pressure and delineate the over-pressure in the study area.

2. PNN pore pressure prediction

Neural networks have been widely used for several years in geophysical studies [5]. One of neural network algorithms is a probabilistic neural network (PNN). PNN is an interpolation scheme in mathematics that uses neural network implementation. By implementing PNN, the approach of pressure log can be estimated with multi attributes as training inputs without having to build models of Normal Compaction Trend (NCT) in advance. PNN is more superior to the Multilayer Feedforward Neural Network (MLFN), where the mathematical formulas of PNN are more understandable than MLFN [6].

In this work, PNN is applied to two different types of 2D seismic data, i.e., pre-stack and post-stack seismic data from South Sumatera field. Both processes including training and validation are carried out in predicting pore pressure distribution. The availability of data in the present study consists of 2
wells data and 14 line of land 2D seismic data, where two seismic line (JR-01 and JR-02) are pre-stack seismic data. Two pre-stack seismic line (Figure 2) crossing to the wells, in which seismic line of JR-01 passes through XX-1 wells and seismic line of JR-02 passes through ZZ-1 wells.

![Image](https://example.com/image.png)

**Figure 2.** Seismic section of JR-01 and JR-02, which is passing through 2 wells (XX-1 and ZZ-1)

Before further use of seismic data, a pre-conditioning of seismic data is performed in advances such as the amplitude balancing and time shifting. The XX-1 well contains density, Vs, Vp, pore pressure and fracture gradient, while the ZZ-1 well contains only density, pore pressure, and fracture gradient. The same treatment to seismic data, we applied the pre-conditioning to the well data including the environmental correction to caliper log. Figure 3 shows the well log data of XX-1 and ZZ-1 well. These two well data show over-pressure condition with a mechanism of disequilibrium compaction.

![Image](https://example.com/image.png)

**Figure 3.** From left to right: a) density, S-wave, P-wave and pressure log of XX-1 well. (b) Density and pressure log of the ZZ-1 well. The pressure log consists of hydrostatic pressure (green), pore pressure (blue) and fractures pressure (red).

In the first step, PNN pore pressure prediction is applied to the pre-stack seismic data, where pre-stack seismic inversion is performed to extract elastic parameter such as Density ($\rho$), $V_p / V_s$, P-wave impedance ($Z_p$), S-wave impedance ($Z_s$). The extracted elastic impedance is then used as input of PNN for data training. In the second step, PNN pore pressure prediction is applied to the post-stack seismic data, where seismic attributes such as average frequency, dominant frequency, absolute
integrated amplitude, and apparent polarity. In this study, the training process is done by using XX-1 well and validation by using ZZ-1 well.

3. Result and Discussion
PNN pore pressure prediction by using the extracted elastic parameter resulted in different sensitivity to the predicted pore pressure. Our analysis to the predicted pore pressure from the elastic parameter is shown in Table 1. The input of density produces more accurate pore pressure prediction compared to the other elastic parameters, which is indicated by the highest correlation.

| No | Target | Elastic Parameter | Correlation |
|----|--------|-------------------|-------------|
| 1  | Pressure | Density           | 0.94        |
| 2  | Pressure | P-impedance       | 0.89        |
| 3  | Pressure | S-impedance       | 0.88        |
| 4  | Pressure | Vp/Vs ratio       | 0.75        |

The important step in this work is validation, which is performed by using one of the existing wells (XX-1 well). The validation aims to see the level of confidence of PNN predicted pore pressure. Figure 4 shows PNN predicted pore pressure and its validation. PNN predicted pore pressure is indicated by the red line and the pore pressure log of XX-1 well is indicated by the black line. Our observation concludes that PNN predicted pore pressure shows good agreement with the pore pressure log, which is indicated by 98% correlation coefficient. In term of vertical resolution, it can be seen that the predicted pore pressure shows similar resolution by mean that we can observe the sudden change pore pressure distribution.

![Figure 4](image.png)

**Figure 4.** PNN predicted pore pressure section from pre-stack seismic data, which is overlaid with (a) ZZ-1 well for data training and (b) XX-1 well for validation.

After having the validated prediction, the PNN pore pressure is then applied to all seismic section. PNN predicted pore pressure by using the extracted seismic attribute (average frequency, dominant frequency, integrated absolute amplitude, and apparent polarity) is shown in Figure 5. This work is carried out to have a dense distribution of predicted pore pressure since the availability of post-stack
seismic data is denser compared to the pre-stack seismic data that is only represented by two seismic line. It can be seen that PNN predicted pore pressure generated by post-stack data have a strong lateral variation than PNN predicted pore pressure generated by using pre-stack data. This result can be understood since the PNN predicted pore pressure produced by using pre-stack data is strongly controlled by the well, which is guided by the horizon during the inversion process. Although there are no controls on the horizon during the PNN pore pressure prediction by using post-stack data, we can observe that PNN predicted pore pressure shows a trend to follow the pattern of the structure. This means that predicted lateral pore pressure distribution is also controlled by the pattern of structure.

![Figure 5](image)

**Figure 5.** PNN predicted pore pressure section from post-stack seismic data from the different 2D seismic line, which is indicated in index map.

Roughly speaking to the mechanisms of over-pressure, it can be understood that overpressure can be caused by loading (associated with sediment loading) and unloading mechanisms that influences decreasing the effective stress. Our analysis to over-pressure potential in this study area can be caused by disequilibrium compaction occurs in the thick shale formation, which is Gumai formation. This formation was deposited during the Lower to Middle Miocene, which was composed of fine clastic sediments in the form of shale, marl, and calcareous claystone. This formation represented a phase of maximum transgression in South Sumatra Basin and deposited in deep-sea environments. The over-pressure mechanism in this study area can be understood by the relationship between density and sonic log from XX-1 well, where the shale compaction in the smectite zone strongly control to the over-pressure. So that it can be summarized that over-pressure in the study area occurs as burial process, which occurs so fast and pores fluid did not drain out from the formation.

Figure 6 shows section and map of overpressure, where green is the zone with normal pore pressure. The zone which has a deviation of less than 1500psi is marked in yellow and areas with greater than 1500psi deviation is shown in purple. Top of overpressure zone is commonly located in the upper Gumai formation, but there are anomalies that occur in Air Benakat formation, as in Figure 6 marked with an ellipse with the red dotted line.
4. Conclusions
PNN Pore pressure prediction has been successfully applied to two different 2D seismic data i.e., pre-stack and post-stack seismic data. PNN predicted pore pressure generated by post-stack data have a strong lateral variation than PNN predicted pore pressure generated by using pre-stack data. This result can be understood since the PNN predicted pore pressure produced by using pre-stack data is strongly controlled by the well, which is guided by the horizon, during the inversion process. The predicted pore pressure produces the same vertical resolution as seismic resolution, which is very important to evaluate the pore pressure change at intervals of 100 ft.

The over-pressure potential in this study area is identified at the upper Gumai formation, but there are small anomalies that occur in Air Benakat formation. The over-pressure at the upper Gumai formation can be caused by disequilibrium compaction occurs in the thick shale formation. This formation was deposited during the Lower to Middle Miocene, which was composed of fine clastic sediments in the form of shale, marl, and calcareous claystone. This formation represented a phase of maximum transgression in South Sumatra Basin and deposited in deep-sea environments.

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