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COAL BED METHANE PROPERTIES MODELING USING IMPROVED SEISMIC RESOLUTION FOR ESTIMATING GAS RESERVES: A CASE STUDY OF EAST KALIMANTAN FIELD, INDONESIA

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ABSTRACT: Coal bed methane (CBM) potential resources are distributed in many areas of East Kalimantan and are estimated to total about 50 trillion cubic feet (TCF). To estimate more accurately the potential reserves of CBM, sub-surface modeling of CBM properties is required. The objective of this study is to estimate the gas methane reserves by using deterministic and probabilistic approaches, which are based on the identified coal seam distribution. This work is carried out by estimating the gas content parameters (moisture, ash, volatile matter, and fixed carbon), which are derived by empirical approximation from geological and geophysical information. The property modeling of CBM parameters is then distributed, based on the three-dimensional (3D) framework of the identified coal seam distribution. In the well log data, several coal seams can be recognized using the electric log characters, especially the gamma ray, resistivity, and density logs. Coal seams are indicated by a low-density value and high resistivity. In this field, coal seams can be identified at depths ranging from 400 to 1100 m. The gas-in-place (GIP) was estimated in reference to the identified coal seam along the 3D geometrical framework. The results show that based on the probabilistic approach, the GIP ranges between a minimum of 8.9 billion cubic feet (BCF) and a maximum of 493.7 BCF, with a mean of 47.7 BCF, while based on the deterministic approach the GIP is 107.7 BCF.

Keywords: CBM potential, deterministic approach, probabilistic approach.

1. INTRODUCTION

The abundance of massive coal deposits in Indonesia has become an exciting challenge in exploring and exploiting them for coal bed methane (CBM) development. The CBM potential resources in Indonesia are estimated at about 337 trillion cubic feet (TCF) spread out among 11 coal basins, that is, 120 TCF in South Sumatra, 50 TCF in Central Sumatra, 75 TCF in Barito, 50 TCF in Kutei, 10 TCF in Berau, and 20 TCF in Tarakan [1]. The Kutei basin is one of six large coal basins that have CBM potential resources distributed in many areas of East Kalimantan.

The exploration and exploitation of coal in Indonesia is mostly for mining purposes; therefore, investigations are focused on outcrop rock and open mining. Most of these surface coal layers are of Oligocene to Pliocene age, with the quality of coal ranking as sub-bituminous [2]. Therefore, the deeper coal layers at depths greater than 400 m will be very promising, since the coal rank and gas content are much higher. This means that knowledge of the gas content of the coal reservoir will be very important in CBM exploration [3].

Estimation of the CBM reserve in terms of gas-in-place (GIP) is very complex and requires the following information: a) the sweet spot area of coal seams, b) the thickness, c) the density, and d) the gas content of coal seams [4]. The total mass of coal can be directly calculated by considering the sweet spot area, the thickness, and the density of coal seams. The gas content is a crucial parameter that relies on direct measurement of the fresh coal. In contrast, direct measurement is not possible in new areas without direct coring. This gas content measurement must be corrected for the contents of moisture and ash. Moisture and ash absorb the gas content in CBM [5].

However, in the new frontier area, the availability of gas content data is very limited. In this paper, we performed modeling of CBM properties based on the limited data of GIP, which is constrained by the 3D geometrical framework from seismic data, in order to find more details of the CBM reserve.

2. IMPROVED SEISMIC RESOLUTION

Seismic resolution is the power of a seismic wave to separate two interfaces of a thin layer or distance of two interfaces, involving both temporal and lateral resolutions. These two resolutions are a function of the frequency content of a signal. In order to optimize the thin layer resolution, we require a broadband spectrum. In fact, the seismic data are band limited, so it is expected that the bandwidth of the seismic data will need to be expanded to obtain a detailed image of the geology [6], [7].

Several techniques are applied to expand the bandwidth of the seismic signal, such as a deconvolution algorithm including spiking, which attempts to sharpen the wavelet, and spectral whitening to boost frequencies. However, these techniques tend to increase the noise level considerably more than the signal. New methods have been introduced to enhance the resolving power of seismic data that are comparable to geologic conditions, for example, high-frequency imaging [8]. Most of these methods have focused on extending the upper end of the spectrum, and in some situations, even extending the lower end is expected.

In this work, we improve the seismic resolution before we use it to guide the coal seam distribution. The improvement was performed using the Continuous Wavelet Transform (CWT) both to expand the signal frequencies and to extend the upper end of the spectrum.

In a general review of the CWT concept, CWT works on the basis of the wavelet function. The CWT is applied to produce a time-frequency domain, which is helpful in analyzing the characteristics of the signal in terms of spectra. The CWT is simply decomposing the seismic signal into its frequency components, which are scaled and translated into the form of a wavelet. The CWT is expressed by Eq. (1) [9]:

$$Fw(\sigma,\tau)=\left\langle f(t),\psi(t)\right\rangle=\int_{-\infty}^{\infty} f(t)\frac{1}{\sqrt{\sigma}}\psi(\frac{t-\tau}{\sigma})dt \qquad (1)$$

where σ is a scale parameter, τ is a translation parameter, and the ψ conjugate is a mother wavelet. The translation parameter considers the window location and the shifted window throughout the signal. This parameter is associated with time information in the transformation domain. The high scale has a general view and the low scale has a detailed view. The relation between the scale parameter and frequency is stated by Eq. (2):

$$Fa=\frac{FC}{\sigma\Delta} \qquad (2)$$

where *Fa* is a pseudo-frequency associated with scale (Hz), *Fc* is the center frequency in the wavelet (Hz), σ represents the scale, and Δ is the sampling time.

Figure 1 shows a comparison between a) the original seismic data and b) the improved seismic resolution, which resulted from the CWT of the Gaussian wavelet. The frequency content of the original seismic data is approximately 15–55 Hz, while the frequency content of the improved seismic data becomes approximately 15–110 Hz. In this broader spectrum (the high end of the spectrum), we can observe a much higher frequency in detail. The amplitude spectra of the original seismic data (a) and the improved seismic resolution (b) are presented in Fig. 2. One advantage of the improved seismic resolution is that we can clearly identify the coal seam distributions by means of 3D structural geometry.

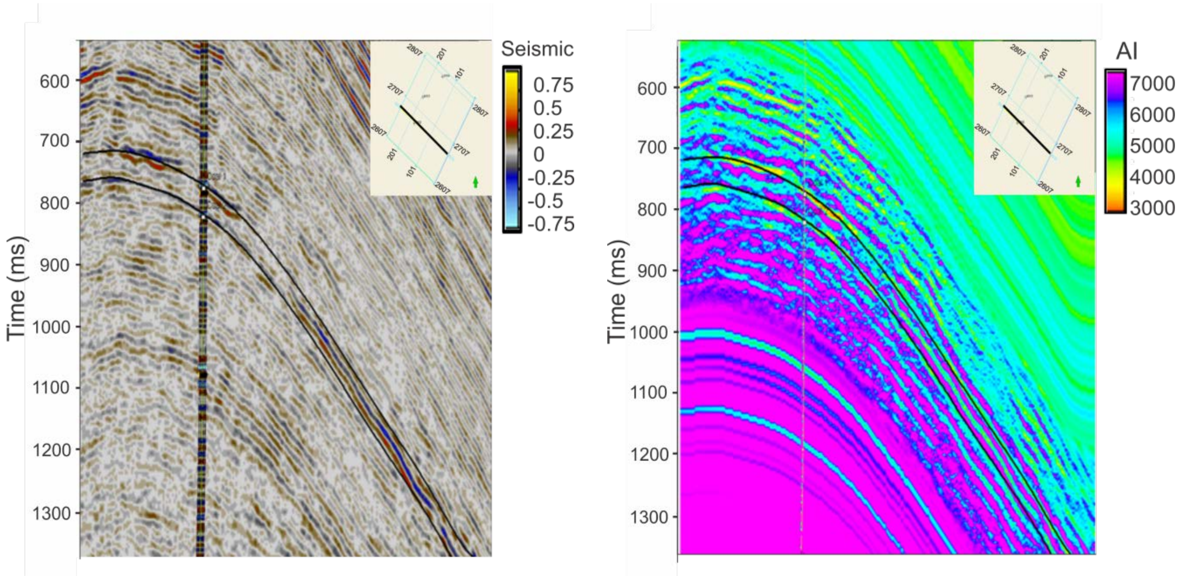
3. MODELING OF CBM PROPERTIES AND GAS RESERVE ESTIMATION

In order to make an assessment of the CBM potential of the coal-bearing strata, we have to pay careful attention to the gas content parameters, which measure the gas content directly. In this case, the availability of gas content information is very limited, coming from only one well of three available wells. The gas content information for the other two wells is then derived from the available data by using an empirical approximation.

In this paper, we performed 3D gas content modeling by integrating the geological and geophysical data of the East Kalimantan Field in terms of seismic interpretation and petrophysical log data. This 3D gas content modeling is an attempt to approximate the gas content condition with spatial arrays of discrete numerical properties including depth, area thickness, and orientation. This modeling is intended to accommodate the change of volumetric scenarios and the variability of lateral and vertical coal seam properties.

The first step in identifying coal seam distributions in terms of the seismic horizon is to define the coal seam characteristic, which is based on the sensitivity analysis of well log data. The sensitivity analysis was performed using a cross-plot between acoustic impedance and density. Figure 3 shows cross-plot and cross-section charts of the coal seam distribution, where the characteristic of coal seams is identified by their low density, low acoustic impedance, and high resistivity. The consistency of the coal seam characteristic is then correlated with the inter availability well, which consists of three wells. This well correlation is further used as a primary parameter of petrophysical (density, temperature, acoustic impedance, coal facies, volatile matter, and fixed carbon) and gas content (ash, moisture, and property). Figure 4 illustrates the inter-well correlation for coal seams at different depths, which indicates the coal seams and properties correlation.

The modeling of CBM properties for estimating the gas reserves is controlled based on the chosen horizon in the 3D geometrical framework, which is clearly indicated by the improved seismic resolution, as shown in Fig. 1. In this case, we identified the distributions of two coal seams, which were used as the basis for modeling the gas content properties from the data of three well logs.



a) b)

Fig. 1 Comparison between a) original seismic data and b) data with improved seismic resolution.

a)

b)

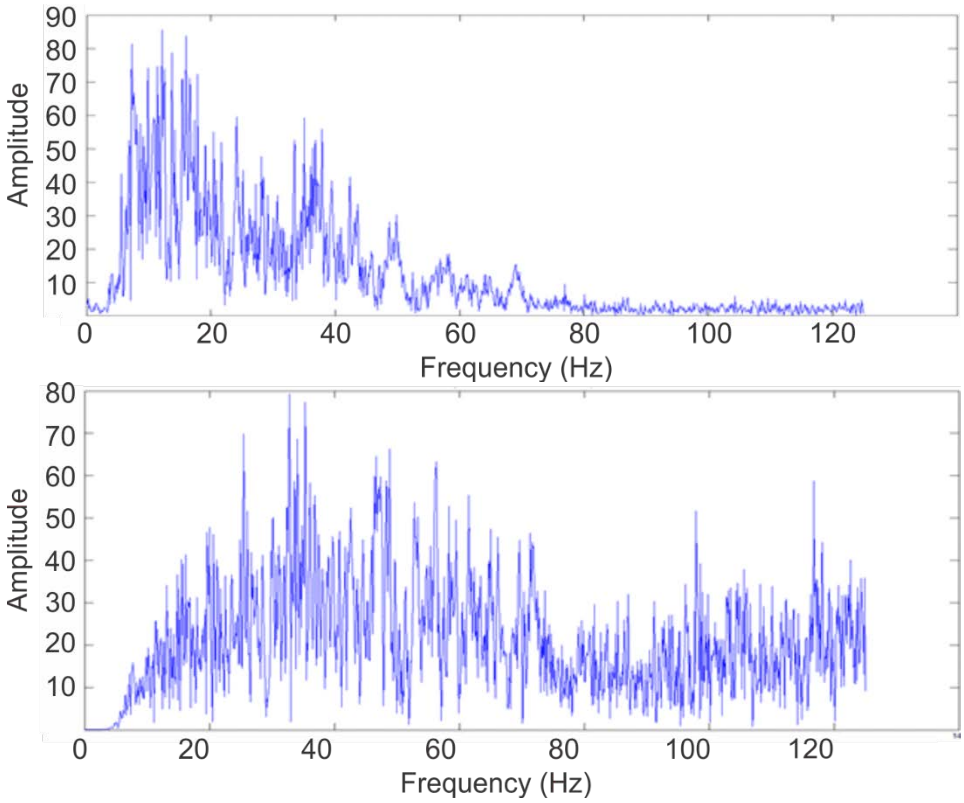


Fig. 2 Seismic signal frequency distribution of a) original seismic data and b) data with improved seismic resolution.

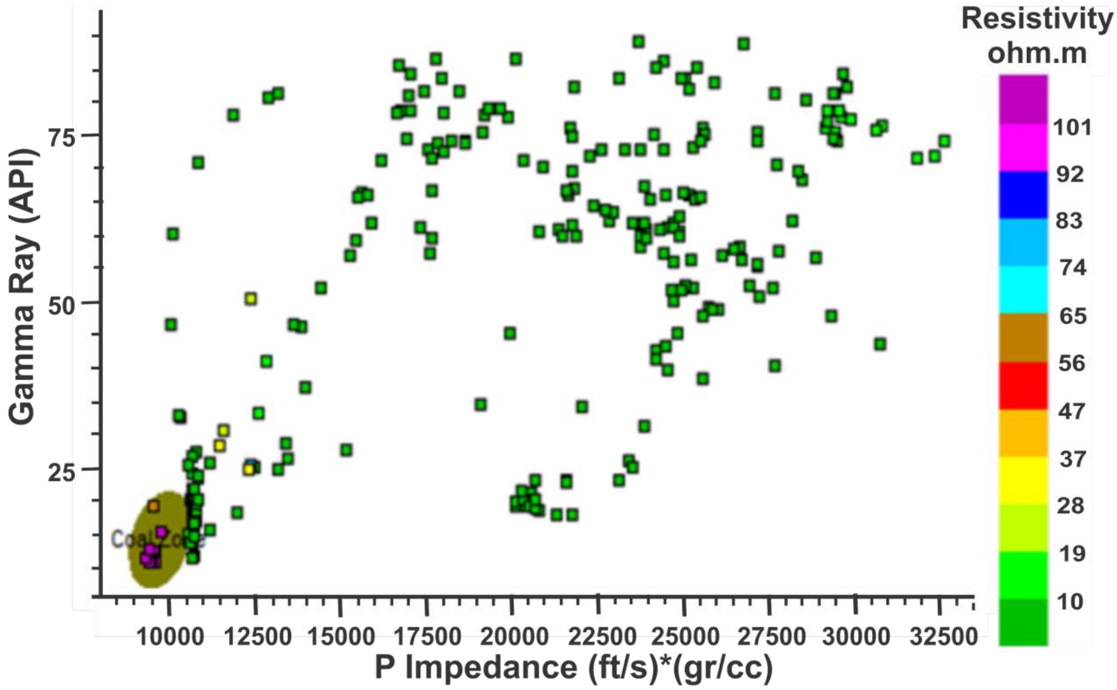


Fig. 3 Sensitivity analysis of coal seam properties, which are indicated by the ellipse zone.

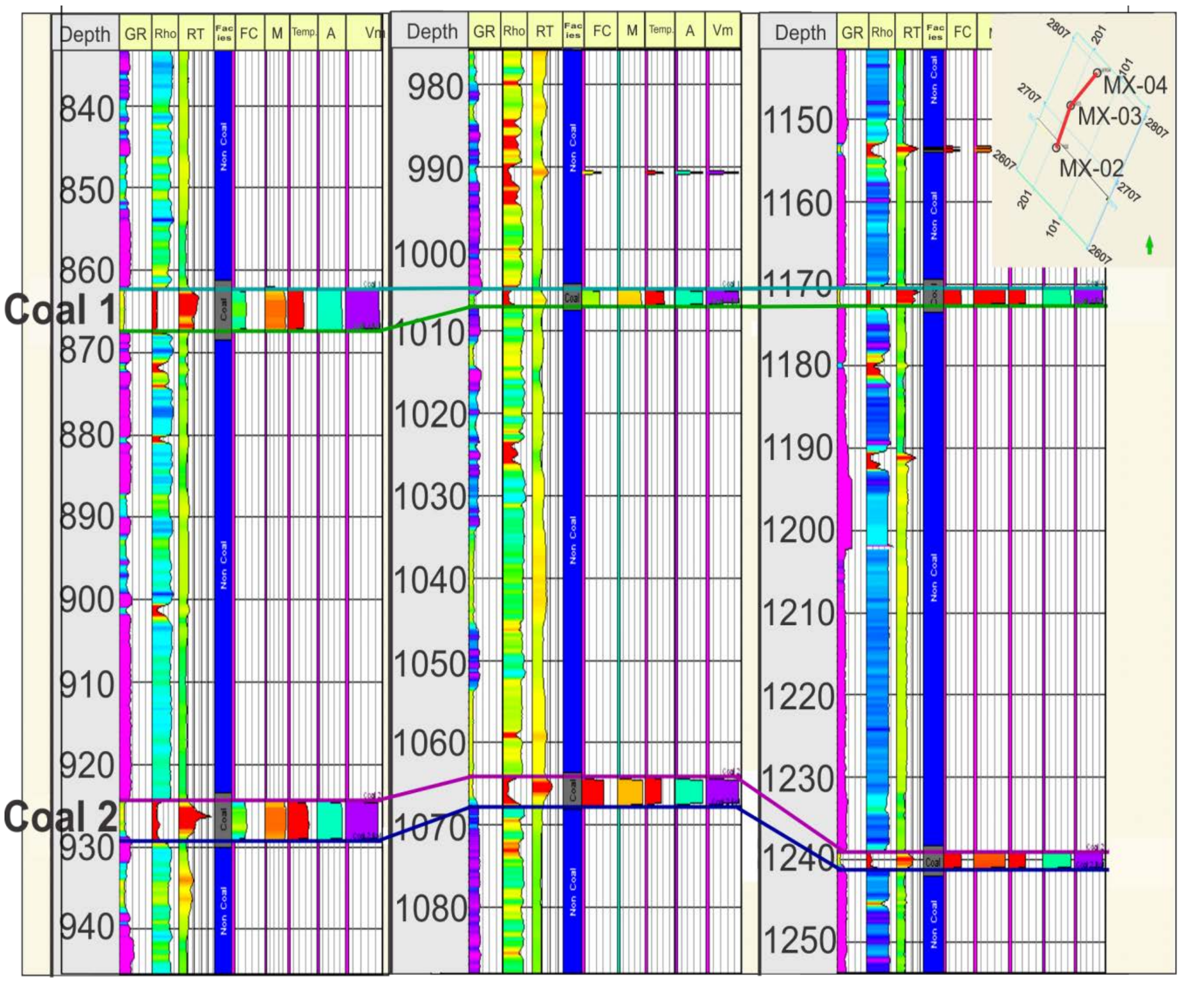


Fig. 4 Well correlation of the corresponding wells that show coal distribution.

Figure 5 shows the property modeling of identified coal 1, which consists of a) the depth map of coal seams, b) density, c) coal facies, d) fixed carbon, e) moisture, f) acoustic impedance, g) temperature, h) ash, and i) volatile matter. This property modeling provides a more realistic approach of quantity laterally and vertically in estimating the gas content rather than a constant value. The same illustration for identified coal seams 2 is shown in Fig. 6. The resulting property modeling of the gas content parameter is then used to estimate the gas content of CBM potential by using Kim's equation (3), which is written as [10]:

$$V = \frac{(100 - M - A)}{100}\left[\frac{V_w}{V_d}\right]\left[K(P)^N - (bT)\right] \quad (3)$$

where V represents the reverse density of the adsorbed gas content (cc/g), M is the fractional moisture (%), A is the fractional ash (%), N is the composition of coal (for most bituminous coals) described as 0.39–0.013 × K, and b is the adsorption coefficient related to a change of temperature (cc/g/◦C) [11]. Moreover, K is defined by Eq. (4) as follows:

$$K = 0.8(FC/VM) + 5.6 \quad (4)$$

where FC describes the content of fixed carbon (%) and VM represents the content of volatile matter (%), while

$$\frac{V_w}{V_d} = 1/(0.25M + 1) \quad (5)$$

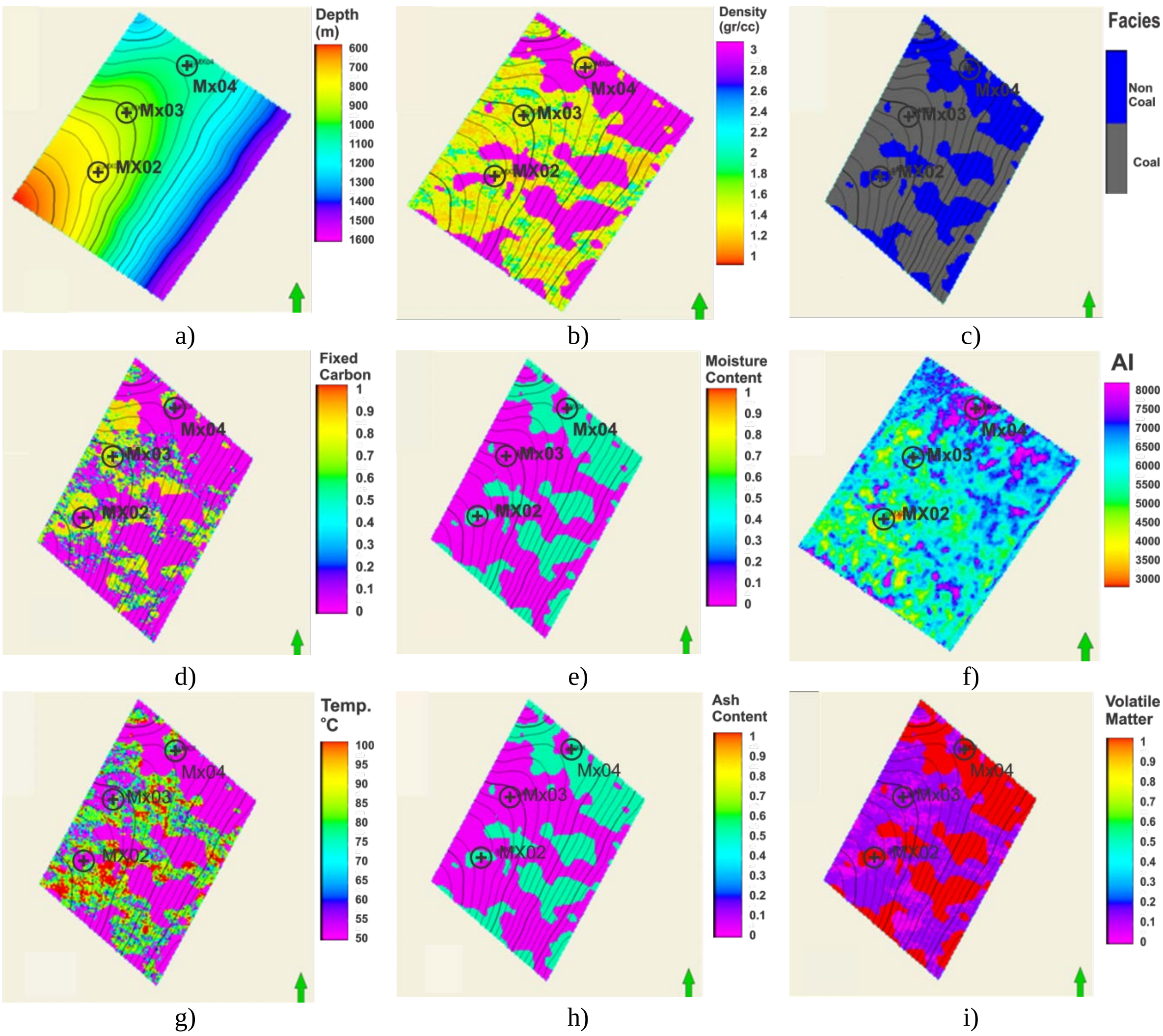


Fig. 5 Property model of identified coal 1: a) depth structure map, b) density map, c) coal facies map, d) fixed carbon content map, e) moisture content map, f) AI extraction from inversion map, g) temperature map, h) ash content map, and i) volatile matter content.

where V_w describes the adsorbed gas volume in fresh coal (cc/g) and V_d represents the adsorbed in dried coal (cc/g). T is described as follows:

$$T = ThermalGradientx(\frac{h}{100}) + T_o \tag{6}$$

where T is the temperature at the measured depth, T_o is the surface temperature, and h is the depth (m).

To estimate the gas reserves, we use two approaches: deterministic and probabilistic. The deterministic approach is based on the gas content model and 3D geometrical framework, while the probabilistic approach is based on Monte Carlo simulation.

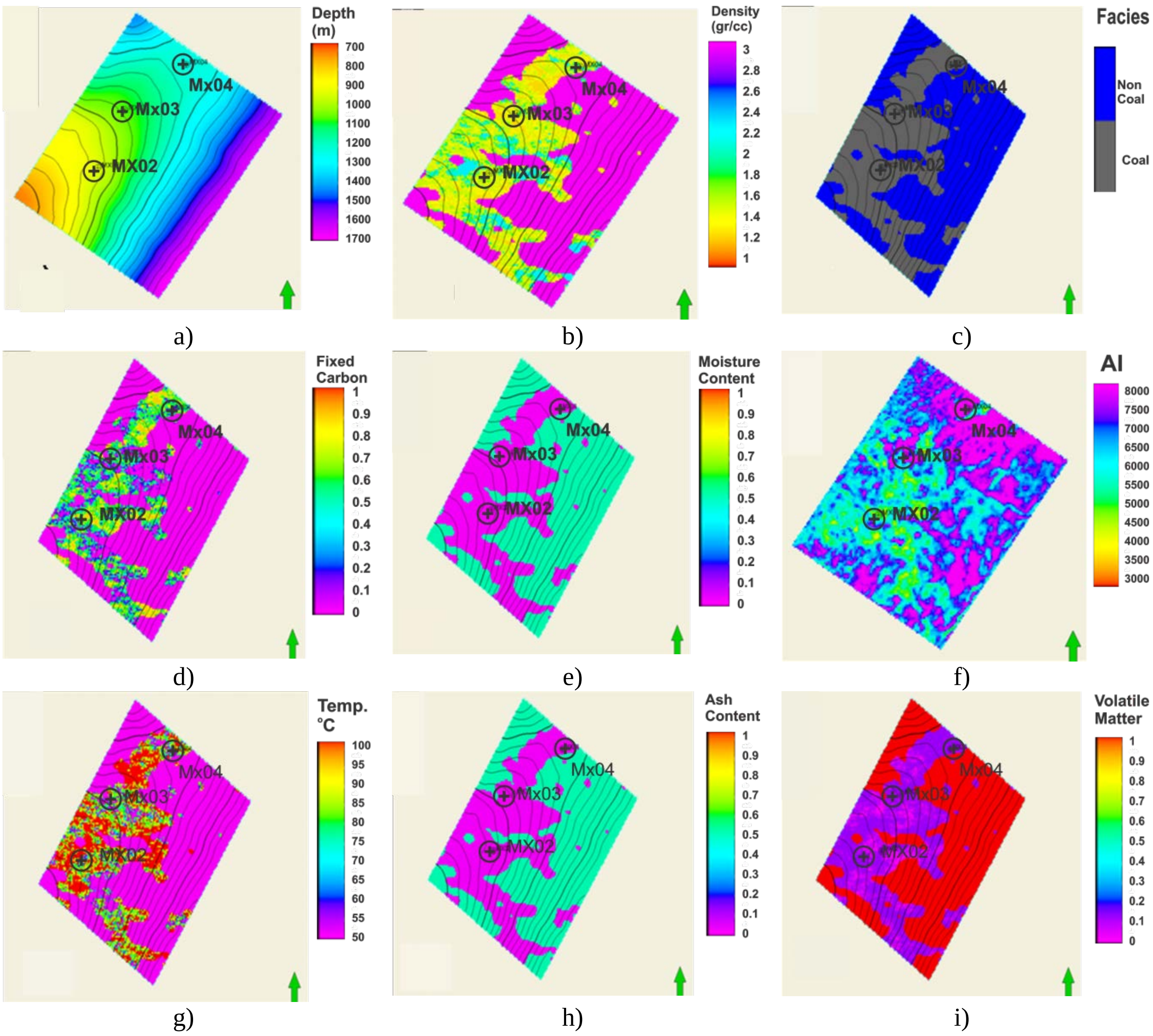


Fig.6 CBM properties model of coal seams 2: a) depth structure map, b) density map, c) coal facies map, d) fixed carbon content map, e) moisture content map, f) AI extraction from inversion map, g) temperature map, h) ash content map, and i) volatile matter content.

In the deterministic approach, we take into account the property model value of every cell in the model according to Kim's formula, which is presented in Figs. 5 and 6. In contrast, the probabilistic approach is carried out by taking the minimum and maximum values of each gas content parameter log and then distributing into a typical distribution for each parameter. The typical distributions of density, ash content, moisture fixed carbon, and volatile matter are normal, while the temperature follows an exponential distribution. The probabilistic approach is carried out by an iterative process, where more iteration will come with a narrow bandwidth of data. The calculated GIP, which is based on the probabilistic approach, ranges between a minimum of 8.9 BCF and a maximum of 493.7 BCF, with a mean of 47.7 BCF. Figure 7 shows the GIP calculated by using the probabilistic approach. On the other hand, the deterministic approach provides a more optimistic calculated value of around 107.7 BCF compared to the probabilistic approach.

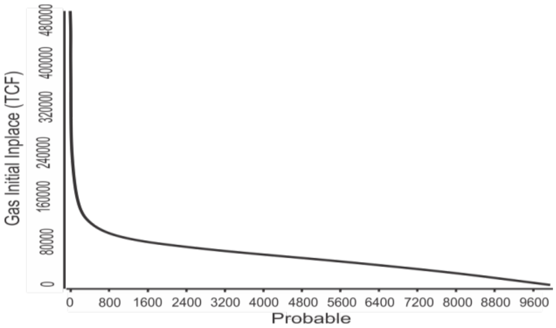


Fig. 7 The GIP calculated by the probabilistic approach.

4. CONCLUSIONS

The improved seismic resolution, which was obtained using a CWT algorithm, in combination with the acoustic impedance of inverted seismic, is able to help us identify coal seam distributions clearly. The CBM property modeling of gas content provides a more realistic approach for estimating the CBM potential in terms of methane gas content laterally and vertically rather than a constant value. This modeling is able to accommodate the change of volumetric scenarios and the variability of the lateral and vertical contents of the coal seam properties. The estimated gas content determined by the probabilistic approach provides a more realistic estimation, which is represented by min = 8.9 BCF, mean = 47.7 BCF, and max = 493.7 BCF, compared to the deterministic approach, which estimates a single value of 107.7 BCF.

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