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Seismic Illumination Analysis in Poor Quality Data Using Focal Beam Method: Full 3D vs. Conventional 3D Acquisition Design

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Abstract: This research aims at improving our understanding on seismic data in shallow gas cloud region where subsurface image quality is generally poor. The distorted images underneath gas zones usually contain precious information of hydrocarbon accumulation. Previously, we analyze the different depths and shallow gas concentration by using focal beam method as both factors contribute to poor subsurface seismic image underneath the gas accumulation. Since those analyses used only full 3D survey design which unrealistic, the objective of this work is to compare full 3D illumination with industry standard 3D survey's illumination and analyze the suitability of both design in shallow gas cloud region. Standard 3D configuration contains single source line with four streamer lines on either side of source line. At the beginning, a velocity model was built with constant gas cloud velocity of 1400 m sec^{-1} to mimic the real field data. Then analyses on differences from both survey designs will be explained in term of resolution function and Amplitude Versus Ray Parameter (AVP) imprint for various frequency content, namely at 5 (low frequency), 30 (center frequency) and 45 Hz (high frequency). We will demonstrate that by using focal beam method for gas cloud image analysis, good images can be obtained irrespective of source–receiver configuration, particularly in high frequency content.

Key words: Seismic illumination, shallow gas cloud, acquisition design, focal beam

INTRODUCTION

In oil and gas exploration industry, having a highly illuminated seismic data is very important to image subsurface features, such as the rock layers and structures bound to it. Good illumination seismic data will improve the probability of determining correct location for hydrocarbons traps. For area where subsurface structure is generally flat with simple anticlines and fault system, the seismic data obtained is generally good. However, as search for more hydrocarbon reserve switch to seismically complex subsurface structure such as salt dome, carbonate and shallow gas cloud where the velocity variation is extremely high, the data quality after acquisition and imaging processes are very poor. This will lead to unclear and ambiguous interpretation of subsurface structure and subsequently wrong location of well placement.

In the shallow gas cloud area which is the focus of this research, low illumination seismic data is usually obtained u nderneath the gas accumulation, shown in Fig. 1, as result of severe wave propagation distortion from scattering and attenuation effects. Currently, major service provider in oil and gas industry like CGG and Schlumberger put more emphasis in developing advance imaging a lgorithm such as reverse time migration and Q-migration where these algorithms re-illuminate the dimmed part of seismic section. However, improving poor quality seismic data by using advance imaging algorithms usually need high performance computing power as well as plenty of disk storage for data processing.

Another solution to this low illumination issue is to re-acquisition gas cloud target area. Geoscientist also believes restoration of true earth cross section in seismic data can be achieved through innovative way of survey design, such as coil shooting technique and blended acquisition. This acquisition to imaging connection follow the seismic value chain where good acquisition configurations lead to high quality seismic image. However, designing the most economical survey configuration and evaluate its viability remains a lingering problem for many industry players. Since the process of imaging the subsurface data and use the outcome to design a new acquisition took plenty of time and data storage, a new method was introduce in focal beam technique (Van Veldhuizen, 2006). This method enables faster evaluations of an acquisition design while at the same time predict the illumination quality at target reflector.

Focal beam analysis concept is akin to downward continuation migration method. In order to produce the migrated image, the receiver profiles were propagated

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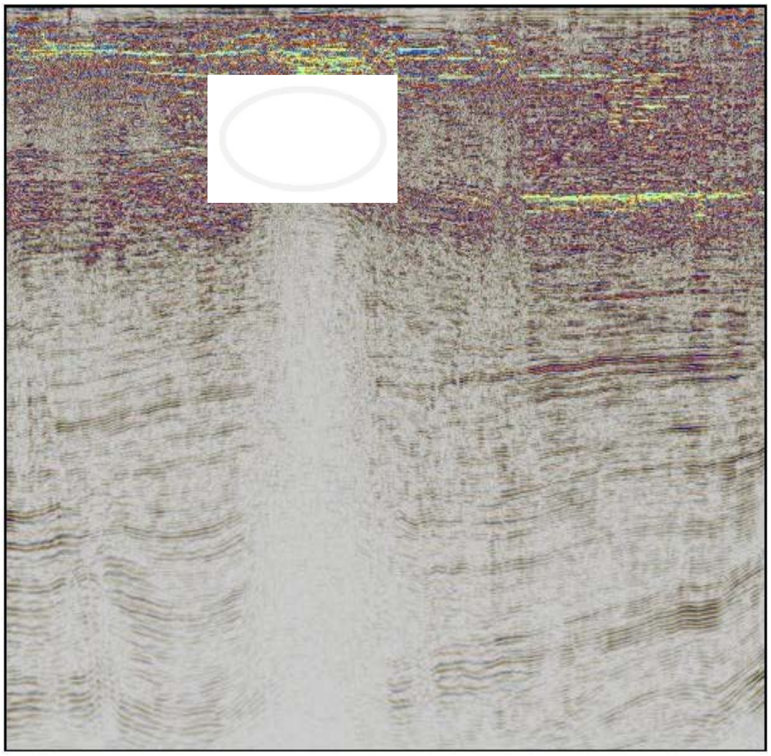

Fig. 1: Gas cloud affected field located in offshore Malaysia. Reflector underneath the gas cloud (circled) experience poor data quality

back to target reflector before being match to source profiles who were forward propagated. During the matching process, an imaging condition is applied by cross-correlated those two profiles and look for their similarity. Unlike other imaging procedure, focal beam able to produce a quantitative assessment of a potential reservoir field within the shortest time by provide illumination analysis in two different domains. Initially all result will be obtained in spatial domain where product of focal receiver beam and focal source beam will yield a focusing image of resolution function. If focal data were transformed into radon domain, an angle-dependent function called Amplitude Versus Ray-parameter (AVP) imprint will be used for illumination analysis. From these analyses, a suitable acquisition configuration for a particular survey area can be designed. Throughout this study, we will demonstrate the significant difference between using full 3D survey to conventional 3D survey.

METHODOLOGY

The origin of focal beam method comes from WRW wave propagation concept which was introduced by Berkhout (1980). The concept stated that total wave field signal can be represented by convolving all the responses: Starting from source, downward wave propagation, reflection coefficient and upward wave propagation before the signal detected at receiver. Focal beam is the expansion of this process, by introducing double focusing operator (Van Veldhuizen *et al*., 2008) which aims to remove all elements except reflector information. Based on this approach, several analysis were conducted to identify the illumination difference between target depth and discover the influence of gas accumulation concentration to the subsurface illumination (Abdul Latiff *et al*., 2013). In this study we expand the analysis by experimenting various seismic frequency contents and investigate the difference between full 3D acqusiition to conventional method. Slight modification was made to the same workflow that used during focal beam computation in previous study, as shown in Fig. 2.

At the beginning of study, a velo city model was built (Fig. 3) surrounded by an ellipsoid to represents the low velocity zone. The low velocity zone in model ex hibits similar characteristic as shallow gas accumulation and located between depth of 200-400 m, width of 200 m in both x and y direction, center at coordinate (1000, 1000, 3 00). The total dimensions for each model are

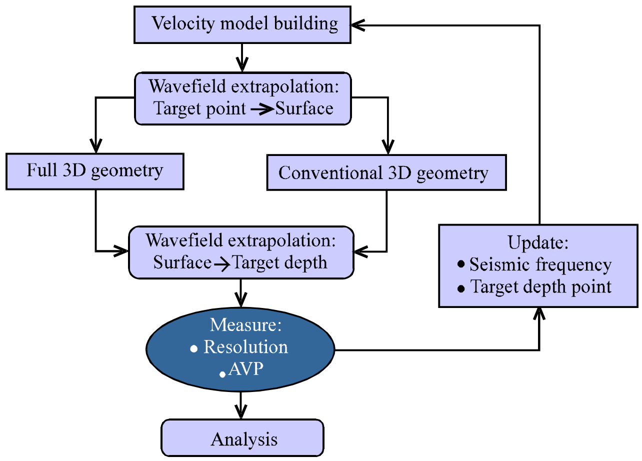

Fig. 2: Integrated workflow of acquisition design analysis by using focal beam method in gas cloud area

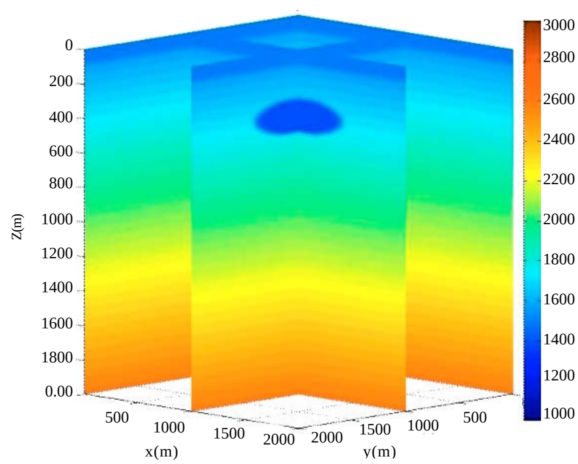

Fig. 3: Velocity model used throughout the study. The low velocity zone in the middle represents the shallow gas cloud area

approximately 2 km (x) by 2 km (y) by 2 km (z) with layer thickness of 15 m. The model's velocity start from water layer velocity of 1500 m sec^{-1} followed by horizontal layers stacked on top of each other with constant vertical velocity gradient of 0.56 m^2 sec^{-1}. Note that the velocity chosen in the gas area is approximately 1400 m sec^{-1} with maximum deviation for gas cloud velocity compare to constant gradient trend is 1.4%. The depth of target point was set constant at 2000 msec and lateral location of the target point is located underneath the gas cloud area, i.e. [1000, 1000] coordinate as indicate by black dot in Fig. 4.

Since gas accumulation also affected the frequency content of seismic wave propagation, we started the analysis by changing the frequency, from 5 Hz (low frequency), 30 Hz (centre frequency) to 45 Hz (high frequency). The significant of these analyses is to understand the real seismic data illuminations as they generally contains a broad range of frequency spectrum. Furthermore, the previous work by Abdul Latiff *et al*. (2013) was conducted on monochrome frequency values thus the results are not applicable to whole seismic data.

Due to importance of obtaining a quality acquisition data, desirable acquisition configurations should be designed as to bypass the high velocity variation zone and complex structure region such as salt dome and gas clouds. Therefore, we propose two different source-receiver configurations to understand the suitability of each of design in shallow gas cloud region. First, we will look into a full 3D survey which has the most wavefield coverage on the surface, by positioning the receivers and sources at minimal sampling interval. The distance between each receiver location is 10 m with both sources

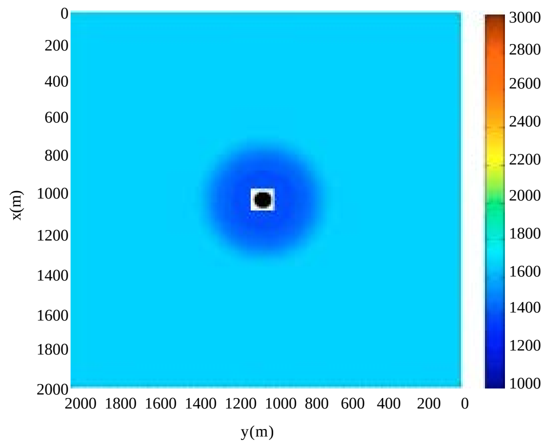

Fig. 4: Time slice of velocity model at 300 m depth. The black dot represents the lateral coordinate for target point

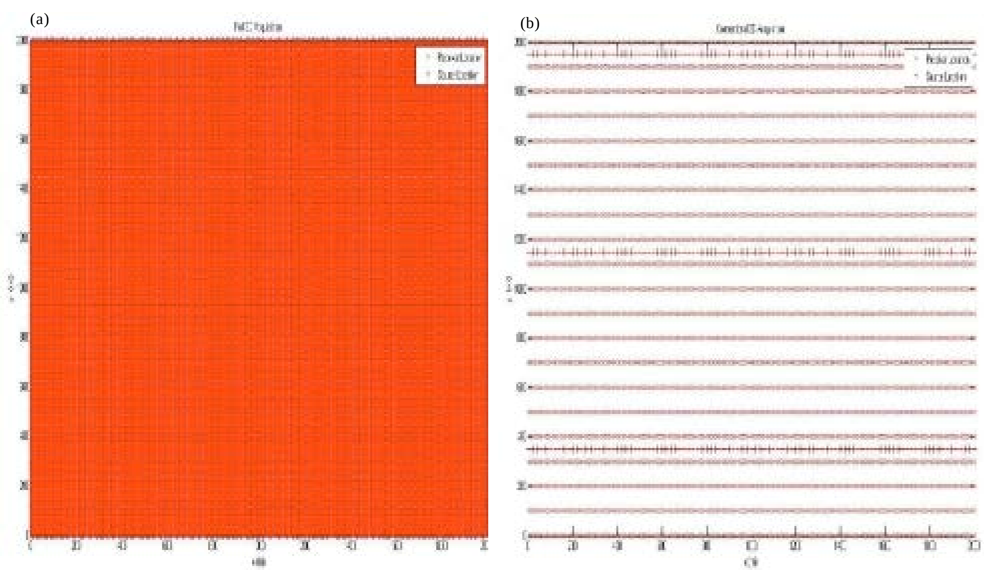

Fig. 5(a-b): Two different acquisition configuration used in the analysis, (a) Full 3D geometry and (b) Conventional 3D configuration

and receivers are at the same locations (Fig. 5a). It is not possible to create acquisition design with samplingparameter lower than 10 m due to limitation in computation.

Realistically, implementation of full 3D acquisition is not possible in real world due to dense sampling of sources and receivers lines. Furthermore, multiple source-receivers having the same location is impossible to be implemented on marine survey, due to extremely high cost. Thus an industry standard 3D survey design was initiated to compare with full 3D, for better understanding on illumination properties of the reservoir. The conventional acquisition geometry involves single source line and eight receiver lines arrange in a swath (Fig. 5b). This will continue until whole survey area is covered with acquisition geometry. Distance for each receiver location is 10 m in x-direction while 100 m in y-direction. On the other hand, source location was separated 10 m in x-direction and 800 m in y-direction.

ANALYTICAL RESULT

Spatial domain: Focal beam in spatial domain was obtained by convolving upward wave propagation with

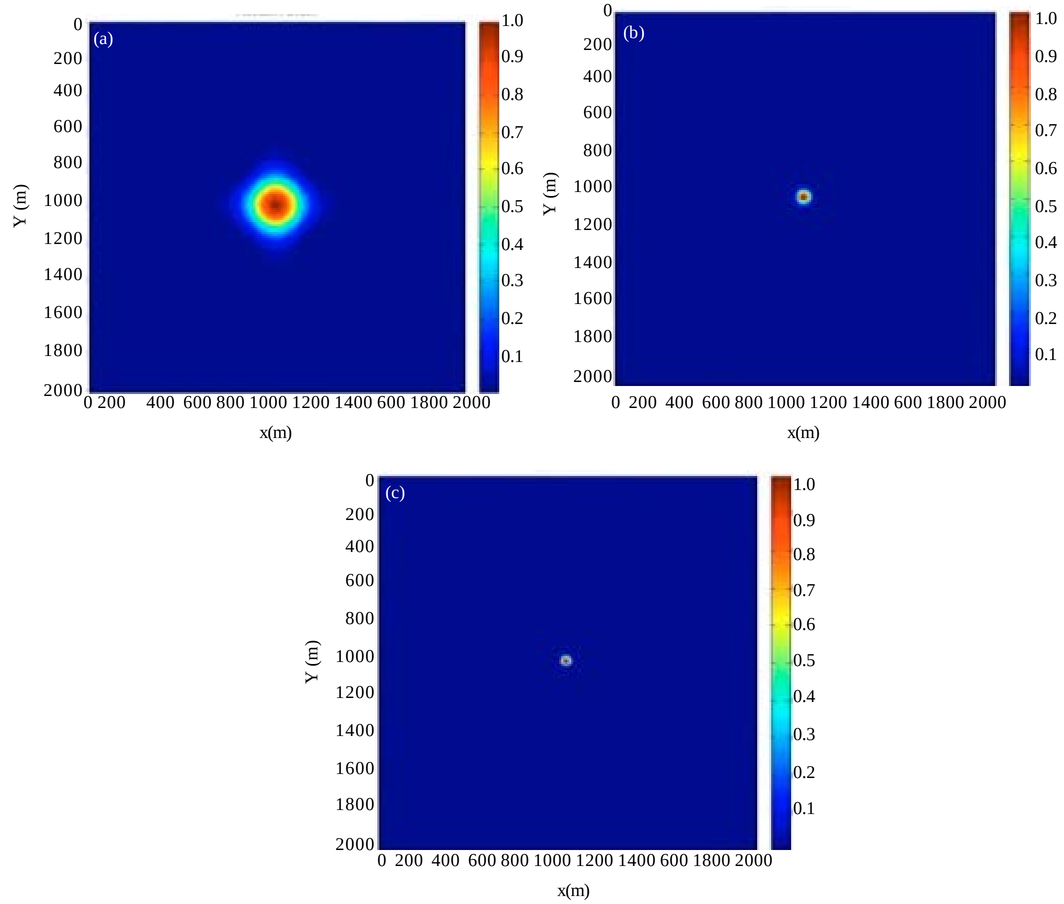

Fig. 6(a-c): Resolution function in spatial domain analysis by using full 3D acquisition design, (a) 5, (b) 30 and (c) 45 Hz

acquisition geometry configuration and downward wave in depth domain, creating a beam look alike in the process. As full 3D acquisition setup contain identical source and receiver geometry, focal source beam and focal receiver beam producer similar focal response. By multiplying both focal functions, we obtained a focusing image as in Fig. 6 and 7 which indicate good illumination coverage.

The result shown in Fig. 6 are obtained after applying full 3D geometry with monochrome frequency of 5, 30 and 45 Hz. Initial assessment of 5 Hz image is unfocused compare to 30 and 45 Hz frequencies which have sharper images. In addition all three image quality is considerably good with their round shape results which means that the spatial sampling in x and y directions are adequate.

Meanwhile, Fig. 7 shows the focal beam result with conventional 3D survey design for all three frequency components. In term of focusing, both 30 and 45 Hz data still having the focused image due to higher frequency nature, with 5 Hz image remains unfocused. A distinctive trait from full 3D images can be seen in 5 Hz data where the image appears a little smear in y direction. Similarly in 30 and 45 Hz, the side lobes emerge in vertical direction indicate the aliasing effect in spatial domain.

Radon domain: Analysis in radon domain begins with transforming spatial domain data components into their respective lines and angle information. Then, each of data components: Upward wave propagation, acquisition geometry and downward wave propagation were multiplied in radon domain to yield Amplitude Versus Ray-parameter (AVP) imprint as an illumination indicator of subsurface. As a rule of thumb, a good quality seismic data will produce high illumination image in focal beam technique that cover the whole survey area.

From the result of full 3D survey shown in Fig. 8, lowest seismic frequency of 5 Hz in both type of acquisition will exhibit smaller amplitude coverage compare to higher frequencies. Towards higher frequencies of 30 and 45 Hz of full 3D survey, the

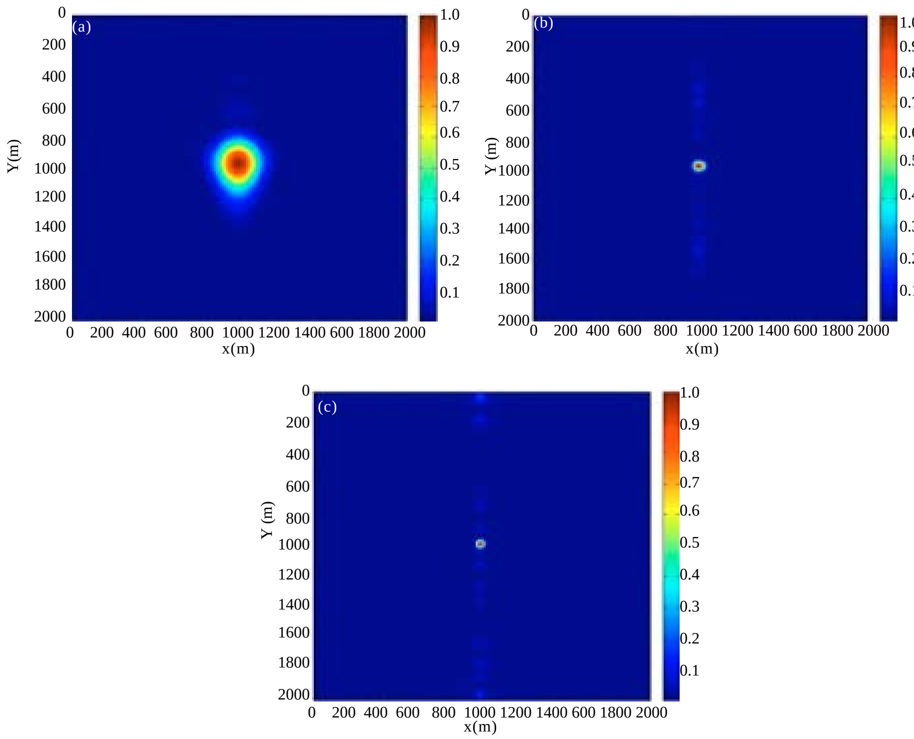

Fig. 7(a-c): Resolution function in spatial domain analysis by using conventional 3D acquisition design. (a) 5 Hz, (b) 30 Hz and (c) 45 Hz

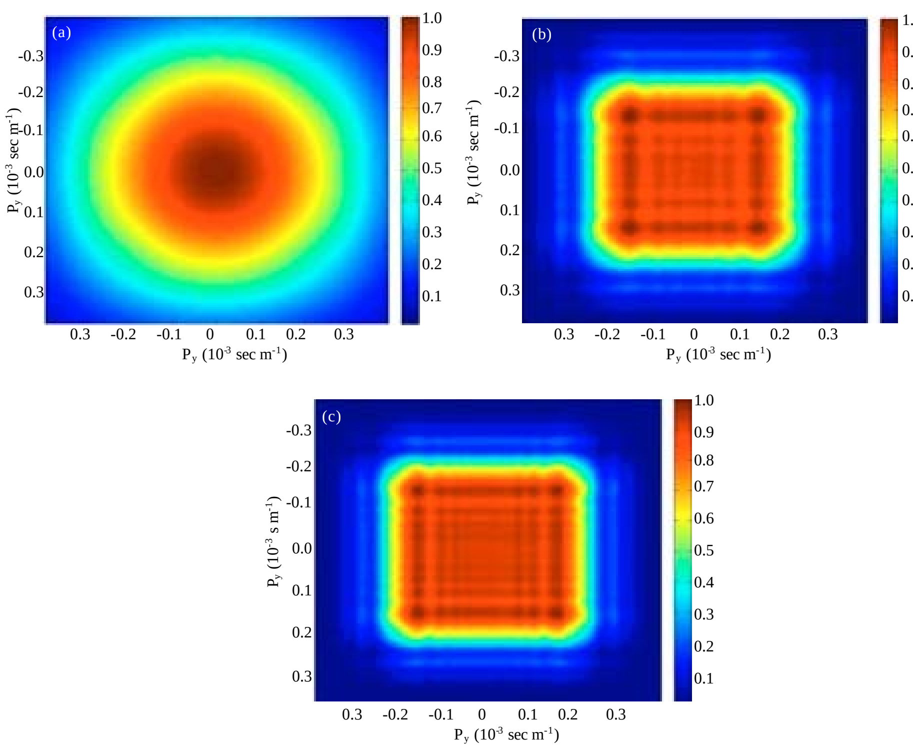

Fig. 8(a-c): AVP imprint in radon domain analysis by using full 3D acquisition design. (a) 5 Hz, (b) 30 Hz and (c) 45 Hz

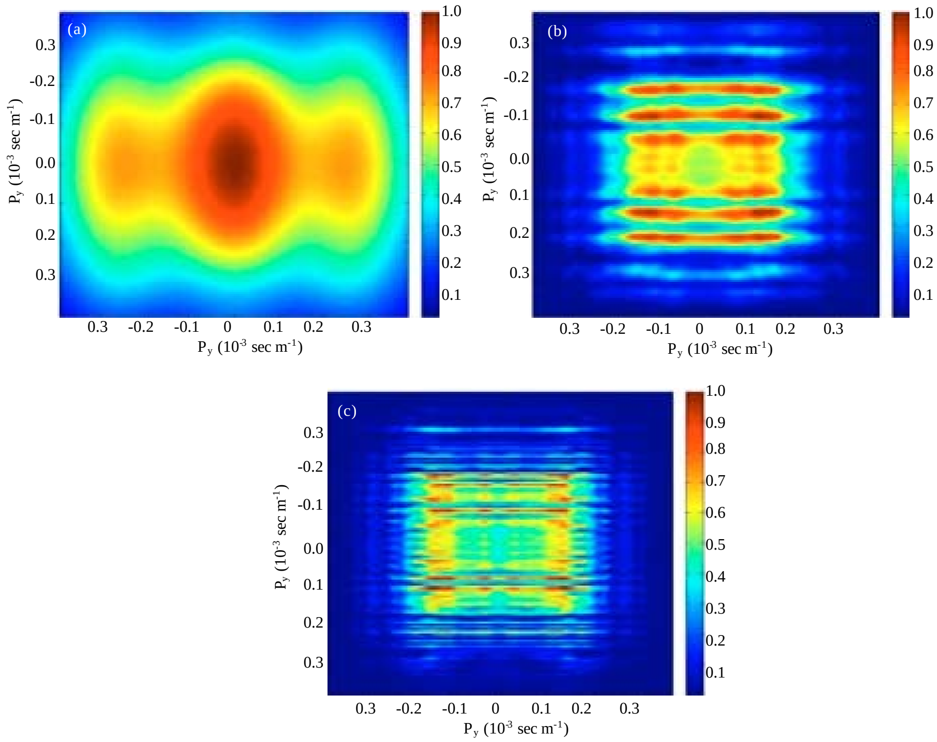

Fig. 9(a-c): AVP imprint in radon domain analysis by using conventional 3D acquisition design. (a) 5, (b) 30 and (c) 45 Hz

images also become sharper with better illumination, indicates the subsurface image is in good quality.

Similar to spatial domain, result obtained for conventional acquisition in radon domain suffered from spatial aliasing, as seen in Fig. 9 where images exhibits sides lobes mirroring the centre image. Nonetheless, wave propagation in this velocity model still able to produce good illumination coverage, due to low amplitude attenuation and scattering.

DISCUSSION

Full 3D vs. conventional 3D acquisition design: Due to simple structure of velocity model used throughout the analysis (flat layers underneath the gas clouds), full 3D acquisition rightfully produce the best resolution as well as high illumination coverage. On the other hand, single source with eight streamers configuration technique also produce reasonably good amplitude coverage and focusing image albeit suffered from aliasing phenomenon. This can be explained in spatial domain results (b and c picture of Fig. 7) where emphasize was given to obtain a focus image, sparse sampling between consecutive sources line prove crucial in obtaining quality data in three dimensions. Note that throughout the analysis, attenuation factor and scattering effect has not been incorporated in the computation; hence the amplitude strength for a deeper position is almost similar to shallower position.

Effect of frequency: From the result of the analysis, frequency content in focal beam analysis has little effect on choosing the acquisition design as irrespective of the design, as all 5, 30 and 45 Hz frequency exhibits almost similar traits in both designs. However, as the frequency increase, the amplitude coverage increases while signal become more focus and increase in resolution.

CONCLUSION

In summary, focal beam analysis in gas cloud model shows good imaging can be achieve for both full 3D and conventional 3D design particularly for target reflector at 2000 m depth. However the good illumination result obtained using perfect acquisition geometry setup is not realistic given the constraint of time and resources of real worlds. Therefore our suggestion to replace full 3D design with single source-eight streamers configuration has proven will produce acceptable data quality. The reduction in sources and receivers location during an acquisition is important for cost optimization process. In addition, the existence of various frequency contents did not affect illumination coverage but will degrade the image resolution, particularly in lower frequency.

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