



Rock Physics and Seismic Modelling of Andaman's First Biogenic Gas Discovery

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Summary

The first biogenic gas discovery of Andaman-Nicobar Basin is an offshore well located in the Diligent strait, near the Andaman and Nicobar Islands. The carbonate reservoir of the well has been evaluated through seismic wedge modelling, which is a technique used to analyze the geological structures of any region by examining the reflection and refraction of seismic waves. The study aims to understand the reservoir properties and seismic response of the gas-bearing limestone formation for effective exploration and development of the hydrocarbon resources in the Andaman-Nicobar Basin. The analysis involves integrating well log data and seismic data to characterize the rock properties and model the seismic response. Rock physics helps in understanding the relationship between petrophysical properties and elastic properties of the rocks and is therefore essential to validate the inferences made from seismic amplitude measurements. Rock physics analysis helped to establish relationships between the reservoir properties, such as porosity and the observed seismic attributes. Well log data, including gamma ray, resistivity, density, and sonic logs, are also used to estimate the rock properties. Well log data cross-plot analysis helps predict the nature of lithology and possible fluid content in the formation. The seismic wedge model of the discovery provides insights into the geological features of the region, such as the distribution of rock layers. These valuable insights have significantly contributed to our understanding of the potential reasons for the limited presence of hydrocarbons in five other wells drilled near the discovery. Moreover, they have greatly improved our comprehension of the diverse characteristics and distribution of the reservoir rocks. Overall, seismic wedge modelling and integration of rock physics has enhanced insight and new

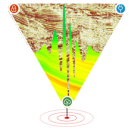
dimension of understanding in Andaman-Nicobar basin.

Introduction

The Andaman first biogenic gas discovery (FBD) in an offshore well is located within Shaheed Deep, Swaraj Deep and South Andaman within 20 k.m. areal distance from Port Blair, capital of the Andaman and Nicobar Islands. The reservoir of the well is primarily composed of carbonate rocks, which are notoriously difficult to accurately evaluate using traditional seismic analysis techniques. Seismic wedge modelling is a technique that has been used to analyze the geological structures of the discovery carbonate reservoir, by examining the reflection and refraction of seismic waves. The resulting model provides detailed information on the internal structure and geometry of the carbonate reservoir, including the symptomatic distribution of porosity, permeability, and fluid content. This information is essential for the extrapolation of successful exploration of the discovery, as it can help in identifying future optimal drilling locations, optimizing well locations, and estimating the reserves and potential yield of the field. The seismic wedge modelling approach is considered proven to be an invaluable tool for evaluating carbonate reservoirs, particularly those in challenging offshore environments, and is likely to be an essential technique for future oil and gas exploration and development activities in the region like this.

Study Area

The Andaman-Nicobar Basin is a prominent geological and marine study area situated in the vicinity of the Andaman Sea, flanking the eastern and western sides of the Andaman Islands. This



basin is in the eastern part of the Bay of Bengal, encompassing a vast region of approximately 210,000 square kilometers. The study area in the Andaman-Nicobar Basin offers a unique blend of diverse geological formations with possibilities of natural resources. It is characterized by a complex interplay of tectonic activities, volcanic processes, and sedimentary deposits, making it an ideal location for hydrocarbon deposit investigations. Geologically, the Andaman-Nicobar Basin is an active site where the Eurasian Plate and the Indo-Australian Plate converge. This convergent boundary gives rise to seismic activity, including occasional earthquakes and tsunamis. The basin also exhibits volcanic features, with dormant volcanic islands dotting the landscape.

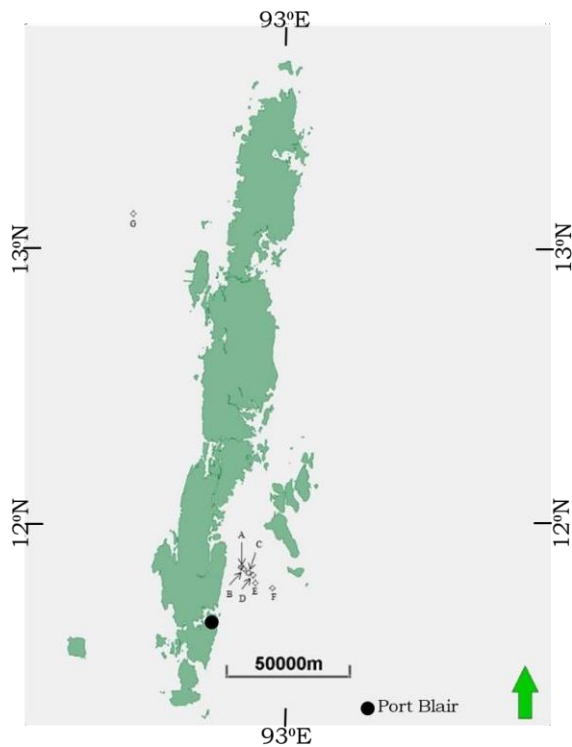


Figure 1: Study area with well locations

There are 22 wells that have been drilled so far in this under-explored basin for oil and gas exploration purposes. The discovery of the first biogenic gas in the Middle Miocene limestone in well C (Figure 1) is a significant milestone. Additionally, minor gas indications have been observed from the Cretaceous sandstone of the same well C. This FBD well was drilled in the first quarter of 1980 up to a depth of 3734 m. Additional 5 numbers of wells were drilled in the vicinity of the first well within 2 to 12 k.m. radius. The nearby wells were drilled to chase the same or similar reservoir, but the results turn out to be discouraging. The most favorable source rock in the basin is the Baratang Formation, which is of Late Cretaceous-Late Eocene age. This formation consists of shale, silt,

sand, carbonaceous shale, limestone, and minor anhydrite and gypsum. It was deposited in a range of environments, from bathyal to shallow marine, with some areas experiencing restrictive euxinic conditions. Well C has indicated the presence of rich organic matter in the Pre-Neogene section. The Baratang Formation, currently in the early phase of maturation, lies within the principal phase of oil generation at depths up to ~5 k.m. While the Neogene sequence is not yet mature for significant thermogenic hydrocarbon generation, it holds interest for biogenic gas potential, as observed in the limestone of well C. Several studies suggest that the discovered gas is generated by biological processes rather than from deep thermal sources. However, the possibility of thermal origin gas can't be ruled out in the deeper area. Further exploration and evaluation of the Neogene sequence may shed light on its biogenic gas potential. Presently Indian oil and gas NOCs are exploring in the several corners of the basin.

Methodology

To comprehend lateral variability in the seismic amplitude response as a combined function of formation thickness and source wavelet, wedge models are developed (Widess, 1973; Cooper, 2007). To model a seismic wedge, the elastic wave equation can also be solved numerically using finite-difference or finite-element methods as described by Youzwishen and Margrave (1999). In this study, quality control of velocity data was carried out to ensure the representativeness of geological formations of interest. The depth intervals of well logs were then carefully aligned using depth matching, assuring interoperability between wells used in the modelling. Then, using the mathematical equation 1, the average acoustic velocity for each depth interval is carefully calculated, taking into account the individual velocity readings inside the interval.

$$V_{avg} = 1/n \sum_{i=1}^n V_i \dots \text{(Equation 1)}$$

where V_{avg} is the average velocity for the depth interval, V_i represents the individual acoustic velocity values within the depth interval and n is the number of velocity measurements within the depth interval.

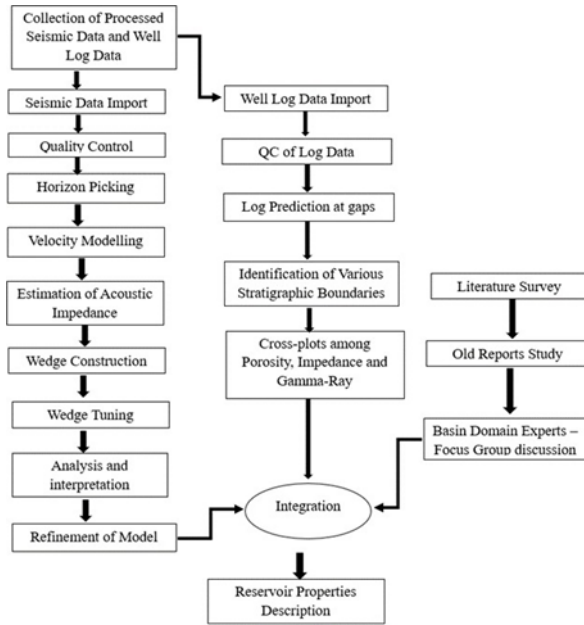


Figure 2: Workflow of the study

To simplify the modelling process and provide a reliable representation of subsurface features for each interval under investigation, these averaged velocities are assigned as constant values inside their respective depth intervals. The geometry of the wedge is carefully specified, including crucial elements like the wedge angle, thickness, and lateral extension. Typically, seismic data and geological interpretations are used to extract this important information, which serves as the model's conceptual underpinning. The wedge is then split into separate layers, with each layer having a constant average velocity that was determined during the initial velocity averaging process. The subsurface structure can be represented more precisely thanks to these layers. The propagation of acoustic waves through the wedge construction is then simulated using numerical modelling techniques like ray tracing with the constant average velocities built into the modelling programme.

This thorough method guaranteed the development of a precise and perceptive wedge model for geological and geophysical study. For Rock Physics calibration, elastic parameters (e.g., density) are assigned to each layer and available petrophysical parameters incorporated. Sensitivity analyses was done by varying the input parameters (e.g., wedge angle, layer thickness, elastic properties) to assess their impact on the modelled results before comparing the modelled results with observed seismic or well data to assess the accuracy of the wedge model and the chosen methodology.

Gamma Ray (GR) logs measure the natural radioactivity emitted by rocks and sediments. The GR readings are typically used as a proxy for lithology and can help identify different rock types and their properties. On the other hand, acoustic impedance is a measure of the resistance of a material to the propagation of sound waves, as mentioned earlier. Cross plots among NPHI (Neutron Porosity),

Acoustic Impedance (AI), and GR are important in petrophysical analysis and reservoir characterization. These cross plots provide valuable insights into the lithology, porosity, and fluid content within a formation. By incorporating additional data, such as permeability, lithofacies, or rock mechanical properties, along with NPHI, Acoustic Impedance, and GR, more comprehensive reservoir descriptions can be obtained to aids in reservoir modelling, reservoir performance prediction, and decision- making for future exploration strategies. The workflow adopted for this study has been provided in Figure 2.

Results and Discussion

Seismic modelling for seismic response helps in understanding the nature of reflections from reservoir top/base and enables us to map out such features in detail. 1D seismic modelling with a Ricker 15Hz wavelet was carried out to understand the seismic amplitude response of the limestone reservoir in FBD well (Figure 3). The numerical values on the wedge model indicate the acoustic impedance of the layers A to E. In general limestone top (B) shows a peak because of increase in impedance from the overlying shale (A). However, heterogeneity within the limestone and the step wise increase in AI makes the response more complicated as a strong trough can be seen between layer B and C. Tuning wedge model shows this can be attributed to the interference of the side lobes of the two consecutive peaks. At the bottom of the limestone (C, D and E), similar but the opposite effect can be seen due to step wise drop in acoustic impedance profile.

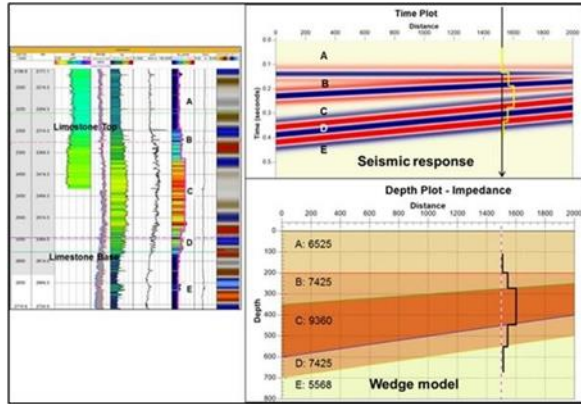


Figure 3: Seismic modelling for well C limestone response of Middle Miocene age. The numerical values indicate acoustic impedance of the layers A to E

part). AI increases with clay content.

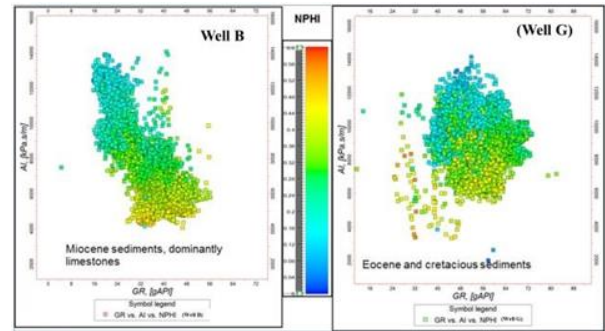


Figure 6: Miocene limestones of well B (fore-arc) show a linear decrease in AI with increase in GR. However, in the well G (accretionary prism), no clear trend can be established.

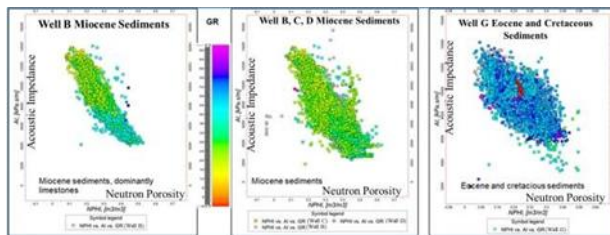


Figure 4: Acoustic Impedance (AI) versus porosity (NPHI) trends of Well B Miocene Sediments, Well B, C, D Miocene Sediments and Well G Eocene and Cretaceous Sediments (coloured by GR)

Acoustic Impedance shows complex multitrends with GR in the discovery area which is a part of fore-arc sub-basin geotectonic element. AI decreases with GR in general for Miocene limestones but increases with GR for Miocene claystones (Figure 5). For the western part, there is hardly any correlation of AI and GR in the western block as observed from well G with dominant data from Cretaceous and Eocene sediments (Figure 6). It may be noted that well G is located on the accretionary prism where thickness of formations is different in comparison to the fore-arc sub-basin discovery area. Thus, seismic amplitude with better S/N might show variations with clay content, especially for Miocene sediments in the study area. Although, seismic data of accretionary prism area are challenged due to highly faulted zone with deformed sediments with antiformal stacking and piggy-back structures.

In the discovery well C, Acoustic Impedance (AI) shows a good negative correlation with Neutron Porosity (NPHI) i.e., AI decreases with porosity for Miocene sediments (Figure 4). The low Gamma ray (GR) values indicate cleaner limestones which have relatively higher impedance values. The trend is similar for other wells in the area with dominant data from Cretaceous and Eocene sediments of Well G, which is in the accretionary prism. Thus, seismic amplitude with better Signal-to-Noise ratio is therefore expected to show variations with porosity of the sediments in the study area.

Conclusions

In seismic imaging, side lobes refer to unwanted energy that can interfere with the primary signal, causing distortion and reducing the quality of the image. Side lobes can be especially problematic in seismic imaging of wedge-shaped geological structures, such as seismic wedges. To model the observed side lobes in seismic wedge imaging, a variety of techniques can be used. One common approach is to use finite-difference or finite-element methods to simulate the propagation of seismic waves through the wedge. This can help identify the sources of unwanted energy and determine how it can be mitigated. Another approach is to use advanced processing algorithms to filter out the side lobe energy from the seismic data. For example, dip-steering filters can be used to remove the side lobe

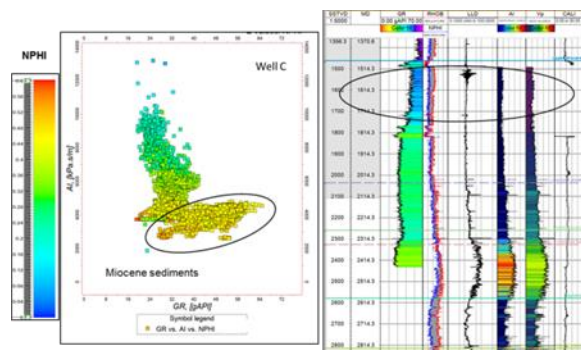
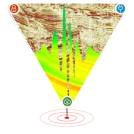


Figure 5: AI and GR variation in well C (eastern



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energy that is not aligned with the dip angle of the seismic wedge.

The presence of clay particles in rock has significantly increased its density in Well C. Since, clay is a fine-grained soil composed of tiny particles, and its density is generally higher than that of other soil types like sand or gravel. As a result, when clay content increases in a material, its overall density increases. Since acoustic impedance is directly proportional to density, an increase in clay content leads to an increase in the acoustic impedance of the material. Whereas the decrease in acoustic impedance along with increasing GR values suggests a transition from low-density formations (e.g., shales, clays) to higher-density formations (e.g., sandstones, carbonates). Other reasons may be indication of an increase in porosity and fluid changes.

The limestone reservoir in well C is highly argillaceous and detrital in nature and considered as a "porosity-pod". Argillaceous limestone typically has lower porosity compared to non-clay-rich limestone. The presence of clay minerals can reduce the overall pore space and restrict fluid flow. However, there can be variations depending on the degree of clay content and compaction in the basin area. Argillaceous limestone generally has lower permeability due to the presence of clay minerals, which can act as barriers to fluid flow. The clay content in this kind of argillaceous limestone plays a crucial role in determining reservoir quality. Although the presence of clay minerals can sometimes limit porosity and permeability, it's important to note that certain clay minerals, such as smectite or illite, exhibit a higher cation exchange capacity. This positive attribute can effectively boost hydrocarbon retention and play a crucial role in sealing potential migration pathways. Argillaceous limestone may contain varying amounts of organic matter, which can significantly affect its reservoir quality. Probably, this has led to spurious distribution of organic matter as reported and experienced by earlier operators in already drilled wells within the basin. Compaction can reduce porosity and permeability, particularly in the presence of clay minerals. Diagenesis processes, such as cementation and mineral growth, can further impact the rock's ability to store and transmit hydrocarbons.

Argillaceous limestone reservoirs of well C exhibit heterogeneity in terms of clay distribution, porosity, and permeability. Variations in clay content, organic matter content, and diagenetic processes can lead to significant spatial variability in reservoir quality. Detailed reservoir characterization and modelling are crucial for understanding and optimizing production from these heterogeneous reservoirs. Additionally, modelling, and mitigating side lobes in seismic wedge imaging is an important area of research that can improve the accuracy and resolution of seismic data in FBD well area and can enhance our understanding of Andaman subduction zone geology. The detrital nature of limestone observed in the well can form in various depositional settings, such as beach environments, nearshore areas, tidal flats, or even in fluvial systems. The specific characteristics of detrital limestone can vary depending on the source rocks, transport mechanisms, and environmental conditions during deposition.

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