It is Never too Late for Seismic, How Geophysics Contributed to Rejuvenating a Mature Field, Tunu Shallow Gas Development*

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Search and Discovery Article #20173 (2012)*
Posted September17, 2012

*Adapted from extended abstract prepared in conjunction with oral presentation at AAPG International Convention and Exhibition, Singapore, 16-19 September 2012, AAPG©2012

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Abstract

Tunu is a giant field delivering about 1,000 MMScfd gas and 18,000 bpd of condensate with about 80 wells drilled per year (more than 800 wells drilled) and almost 20 years of production from the Main Zone (2,500-4,500m TVDSS). Tunu Shallow Zone (TSZ) Upper Miocene to Pliocene unconsolidated formations (above 1,500 m TVDss) has always been considered as the main drilling hazard until they were recently identified as new production horizons.

The Shallow Zone consists of fluvio-deltaic parasequences vertically stacked according to a regressive-transgressive pattern. Two main reservoir types have been identified: point bars in fluvial channels and side bars in distributary channels.

Shallow gas reservoirs are scattered all over the field and present a limited extension. Then the use of seismic is essential to locate and evaluate them to enable the field development.

Gas reservoir detectability on seismic is due to a specific petro-elastic behavior in the TSZ. They behave as typical AVO Class III sands, corresponding to low impedance layers and a reflection coefficient increasing with angle. The main challenge on Tunu field is to discriminate them from the abundant coal layers.

Like gas sands, coal layers have low acoustic impedance that will appear as bright reflectors on seismic data. Nevertheless due to different Poisson's ratio values, with high angle of reflection (beyond 45°) gas sand becomes brighter whereas coal is dimming. It is now standard practice to combine very far angle and even seismic gather analysis to prove gas.

The interpretation of the amplitude anomaly will give access to its extension. The pay thickness is also derived from seismic data. Shallow gas reservoirs are below seismic resolution but the gross thickness of tuned layers is linked to the amplitude value. Well statistical

information is then used to derive a Net to Gross ratio, in order to correct for the presence of coal, and to derive the petrophysical and fluid parameters. Finally, wells are designed and followed-up directly on seismic.

In less than four years, shallow gas production has reached 180 MMScfd (20% of Tunu production), incrementing the potential of the field and enabling a major new development of over 80 wells. Based on this experience the reprocessing of vintage geophysical datasets and the acquisition of new seismic data on a very mature field should be systematically evaluated.

Introduction

Tunu is a giant field delivering about 1,000 MMScfd gas and 18,000 bpd of condensate with about 80 wells drilled per year (already more than 800 wells drilled) and almost 20 years of production from the Tunu Main Zone (TMZ between 2,500-4,500m TVDSS). Tunu Shallow Zone (TSZ) Upper Miocene to Pliocene unconsolidated formations (above 2500 m TVDss) have always been considered as the main gas operational risk while drilling. Many of these shallow gas reservoirs have recently been identified as new production horizons.

Today the shallow accumulations have been proved high productivity reservoirs with quite stable rates. Main reasons for that are the excellent rock and fluid properties found (dry gas), with porosities above 25% and permeabilities easily exceeding 1,000 mD (1 D) and a generally strong aquifer support.

Sand control is nevertheless mandatory due to the unconsolidated nature of the sediments. Gravel pack has been selected as the base case completion in order to enable the production of up to five zones. Individual or commingled production is therefore possible by operating downhole sleeves. Current productivities are of the order of 5 to 15 MMScfd, and can reach more than 20 MMscfd when several zones are commingled.

Stratigraphy

Tunu Shallow Zone stratigraphic framework is divided into six genetic units. Each unit consists of fluvio-deltaic parasequences vertically stacked according to a regressive-transgressive pattern. The lower part of a genetic unit is dominated by delta front deposits (shale prone and isolated mouth bars). The sand quantity as well as the coal content increases upwards in the section dominated by delta plain distributary channels. The most regressive part of the sequence often shows the presence of fluvial channels. The top of each genetic unit shows a rapid decrease of sand quantity to thick coals and marine shales (MFS). Two main reservoir types have been identified in TSZ: point bars in fluvial channels and side bars in distributary channels (Figure 1). The modern Mahakam Delta is a close analogue to what is observed in the Miocene/Pliocene deposits and its analysis is used to define guidelines to model reservoir sand body geometries for development proposals.

The distribution of coal layers is of great importance, as these layers will play an important role in reserves evaluation and well design. In the case of the Mahakam system, the dense equatorial vegetation is optimal for developing a coal-rich flood plain facies. Distributary channels are inside a coal-rich matrix, particularly in the upper delta plain, which is dominated by large trees. At the transition with the lower delta plain, the proportion of organic shale with palm leave debris should increase. Besides, the coal beds are thicker in the fluvial system as coals are formed in swamps and lakes.

Gas Trapping Systems and Reservoirs

TSZ gas trapping system is a combination not only of stratigraphic but also structural and hydrodynamic features. TSZ gas accumulations are characterized by two domains: the west flank region is dominated by stratigraphic trapping in local structures (small changes of slope) with vertically stacked reservoirs and sharp lateral boundaries; the crest area shows more extended reservoirs with higher net pay principally controlled by the structure. Typical accumulations correspond to a 5 to 10 m gas column over an area of 0.1 to 0.6 km^2.

Tunu Shallow Gas in Place is difficult to estimate due to the small coverage of data available in the shallow section. Indeed, the existing wells dedicated to the deeper main zone have a limited spread under the development facilities and not all were logged in the shallow section, therefore the investigated area is limited compared to the Tunu field surface (Figure 2a).

As shallow gas reservoirs are more scattered and do not present a continuous distribution, given the limited size of individual accumulations, it is necessary to design wells that will go through several gas reservoirs (Figure 2b). An innovative method integrating geology, reservoir engineering and especially geophysics was therefore developed to evaluate the gas in place and design the best wells to produce it.

Seismic Integration

To support field development campaigns, two 3D seismic surveys were performed. A first 3D seismic survey was shot in 1995 at South-West Tunu (TUN-3D95), in the flank of TUNU, in order to help TMZ development. TMZ has been developed with a grid approach as seismic quality and petro-elastic properties of the TMZ reservoirs make difficult the use of seismic for reservoir characterization. Seismic data hence had only a minor impact on the development design and decisions. On the other hand, the first processing showed a potential to detect and characterize Shallow Gas reservoirs above 1,500 m TVDss. Therefore, a PSTM reprocessing was carried out in 2009 and 2011 in order to enhance the TSZ imaging and reservoir characterization in parallel to the maturation of the concept of TSZ development. It also led to the decision to acquire a second 3D survey in 2010 at the crest of the Tunu field (CT3D) which was specifically dedicated to the Shallow interval.

Shallow gas visibility on seismic is due to a specific petro-elastic behavior above 1,500 m TVDss. This low burial combined with the gas filling of sand reservoirs gives a relatively low bulk density and low wave propagation velocities. Gas reservoirs in Tunu are typical AVO Class III sands, which correspond to low impedance layers and a reflection coefficient to the background of Shale and water bearing sand increasing with angle (Figure 3a). The main challenge on Tunu field is to locate the gas reservoirs and discriminate them from the abundant coal layers and then assess their size in order to decide whether to drill them or not.

Both gas sands and coal appear as bright anomalies on the seismic data due to equivalent acoustic impedance properties. The two lithologies nevertheless behave differently in amplitude versus angle due to different Poisson's Ratio values. Tunu seismic data clearly shows that below a 45 degrees angle of reflection, coal and gas sand will be very difficult to discriminate. With a higher angle, on the other hand, gas sand remains bright and can even become brighter whereas coal amplitude strongly declines. It is now standard practice on Tunu to combine the analysis of Very Far angle (Figure 3c) and individual seismic gathers to prove gas presence (Figure 3b). In the case of limited offset or poor preservation of high angle during processing, discrimination has to rely only on geological information (geomorphology, stratigraphic position, etc). As development extends to areas where no well has ever been drilled, seismic information and the geological model will become the only available information.

Because gas sands can be proven from seismic data, the interpretation of the amplitude anomaly will give access to its extension. After having interpreted the horizon corresponding to the identified gas layer, the limits of the high amplitude will give the boundaries of the accumulations (Figure 4). Given the shape of the deposits it is known that part of the accumulation will fall below seismic detectability thickness and therefore not be seen. Geological models and analogues are used to assess the part of the reservoir that remains unseen. The uncertainty on surface definition is limited as the amplitude rises sharply from the background when reservoir is filled with gas.

Net Pay and Net-to-Gross from Seismic

The Net Pay itself can be derived from seismic data and then give access to the Net Rock Volume. Shallow gas accumulations seldom exceed 12 to 15 m hydrocarbon column (Figure 5d), which is below seismic resolution capacity. In this case, deriving the thickness from top and base anomaly picking is irrelevant. However, the thickness of tuned layers (most of the cases) can be directly linked to the amplitude value (Figure 5a). Frequency spectrum and amplitude are the two parameters needed to assess the thickness of a thin bed; both are accessible from seismic data. Multi-penetration of the same gas reservoir has proven the relation between amplitude and Net Pay (Figure 5b).

The presence of coal again complicates this ideal scenario. On Tunu field there is an 80% probability of a coal deposit existing within 10 m of the sand top. Given the seismic resolution achievable, it will interfere with the gas response. The seismic amplitude is then linked to a Gross Interval thickness rather than a direct Net Pay thickness. The configuration and succession of gas reservoir, shale and coal facies will have an impact on the seismic response. The same thickness of gas can lead to varying amplitude depending on the coal position deposited on top (Figure 6). To get access to the Net Pay, integration with geological data was needed, as the seismic data will not be sufficient to separate gas influence from coal. Statistics on coal and intra-shale thickness on top of sand deposits were derived from wells (Figure 7). This was used to derive a Net to Gross ratio. Finally, seismic will provide a Gross thickness that will be converted to Net Pay using statistical analysis from geological data.

Recovery Factor

The petrophysical and fluid parameters are derived statistically from the huge well database of porosity, saturation, etc. Then the final step to access reserves is to assess the recovery factor. Seismic interpretation showed that most of the targeted objects fit with fluvio-deltaic typical geometry. A phenomenological 3D dynamic model was used to evaluate recovery factors. The sensitivities to net pay, aquifer support (which is proven in 90% of our history cases) and reservoir body connectivity were assessed.

Finally, areas of interest are ranked according to shallow gas reserves evaluation. Wells are then designed directly on the seismic data. From an available surface location, the challenge is to navigate through up to five amplitude anomalies integrating the constraints from drilling and geosciences. To maximize the recovery, the best area is selected from the highest amplitude area on seismic amplitude maps. An In-House well design module, plugged directly into the geophysics interpretation workstation, enables the precise location of the target impact.

Conclusions

In less than four years, shallow gas production has reached 180 MMScfd (about 20% of Tunu production), incrementing the potential of the field and enabling a major new development of over 80 wells with new surface facilities extending Tunu production area. Based on this experience the reprocessing of vintage geophysical datasets and the acquiring of new seismic data on a very mature field should be systematically evaluated. New concepts and technology evolution in geosciences, drilling and production may unveil new potential. Tunu field is a perfect example of this strategy, which will soon be continued by acquiring a new seismic 3D survey in the northwestern area, more than 20 years after production started.

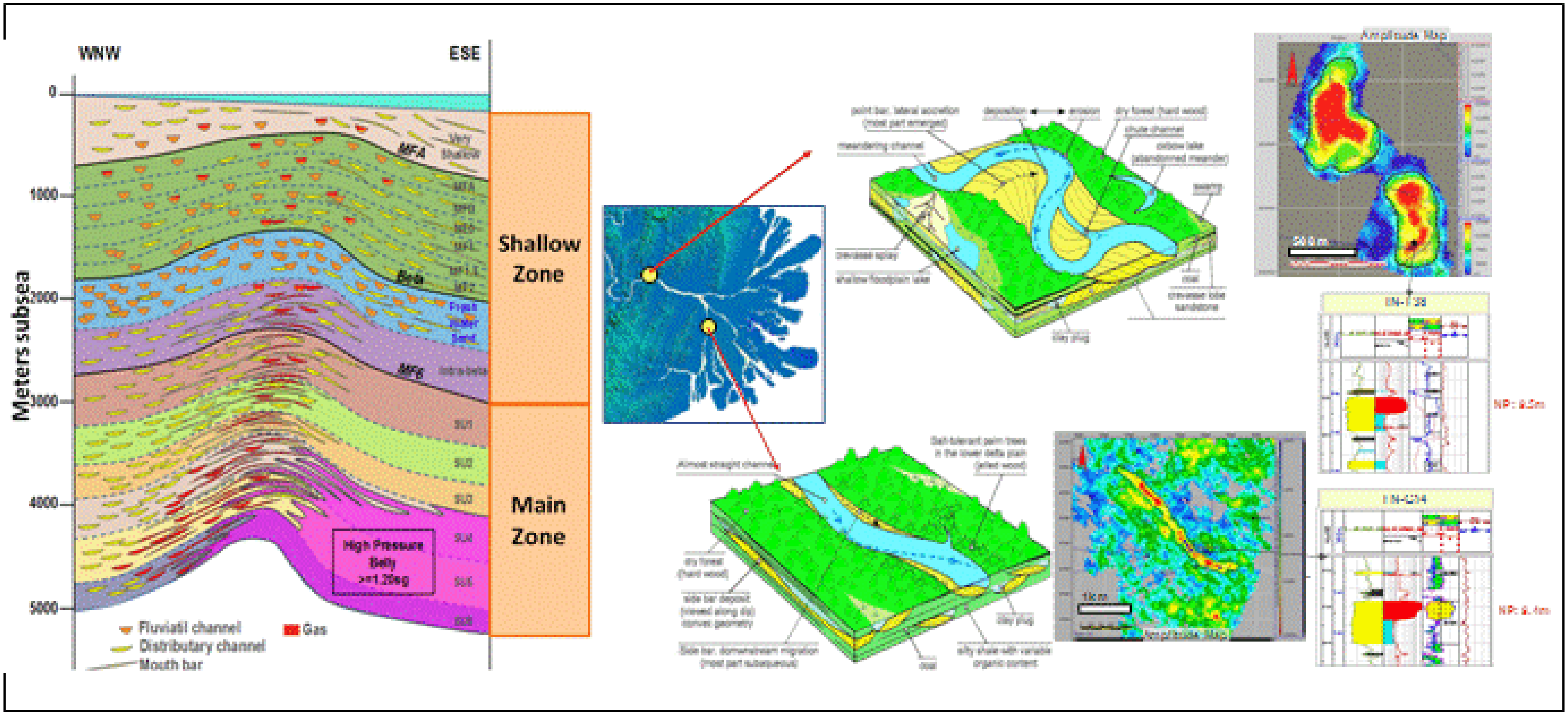

Figure 1. Tunu stratigraphic context and sedimentological settings.

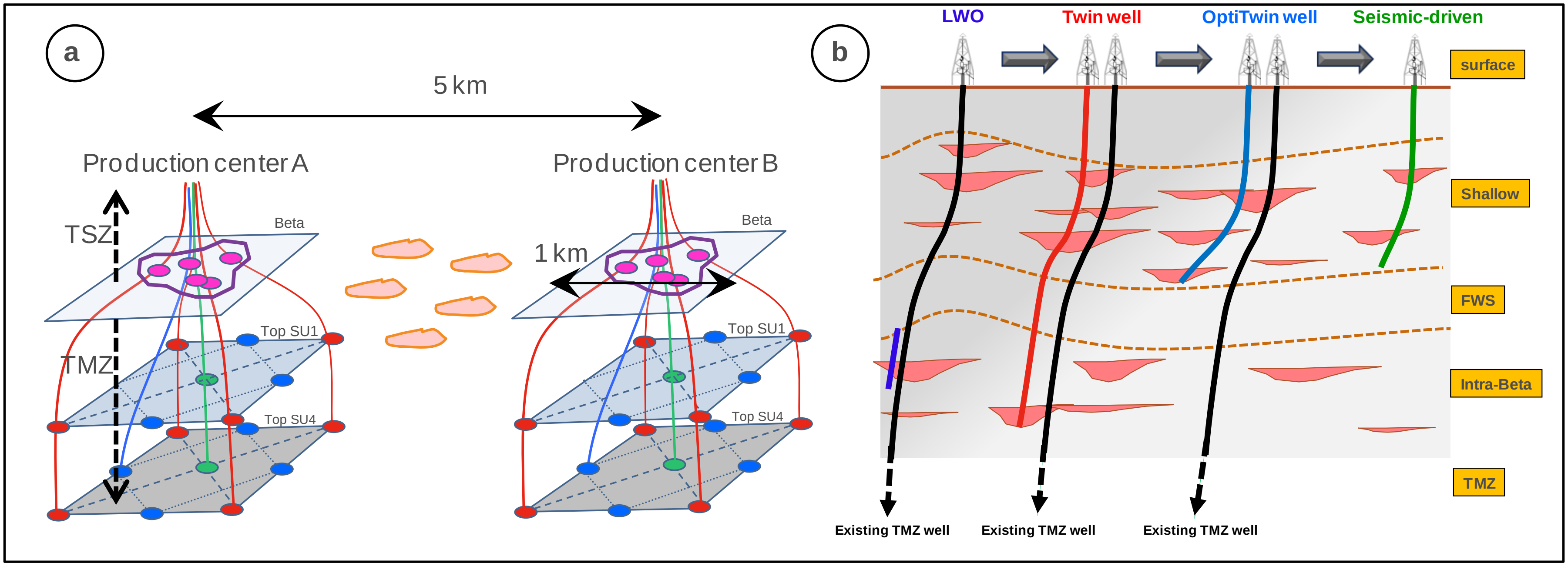

Figure 2. (a) Tunu development schematic for main zone and (b) shallow interval production strategy.

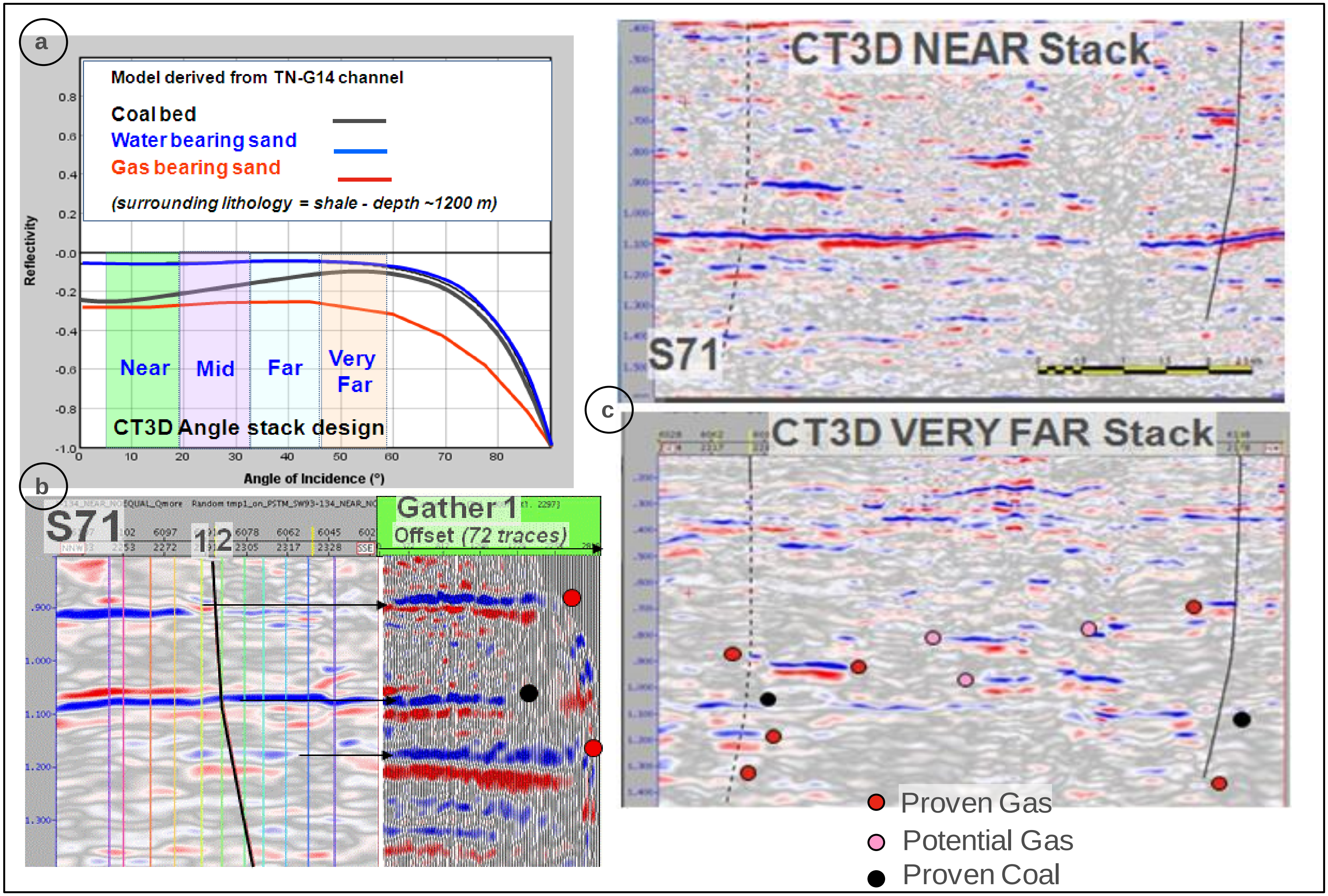

Figure 3. (a) Tunu shallow petro-elastic; (b) gas and coal response on seismic gathers, gas sand remain bright from near to very far offset; and (c) thick coal at 1,050 ms disappearing on very far stack.

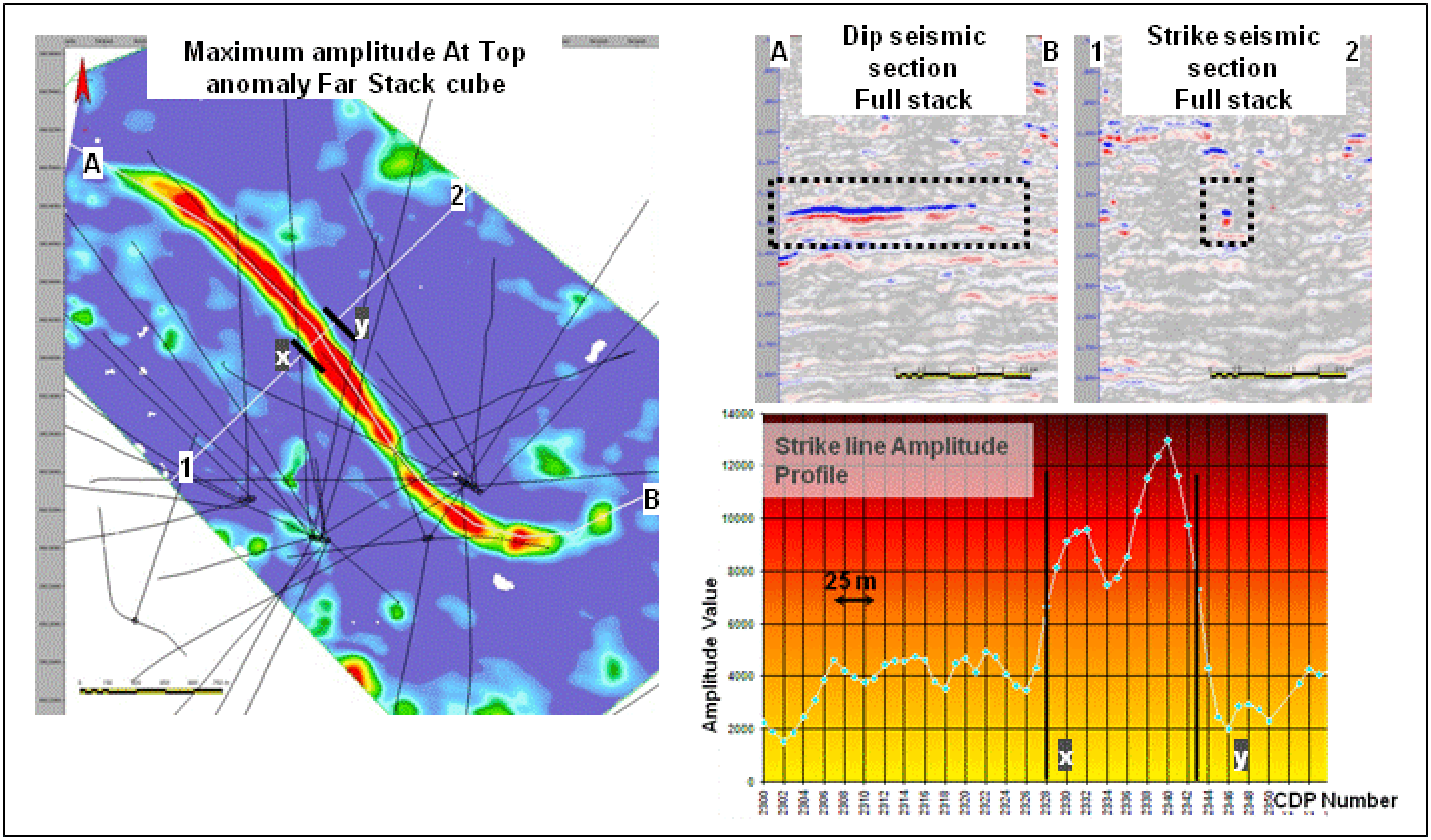

Figure 4. Gas reservoir surface definition from amplitude anomaly extension.

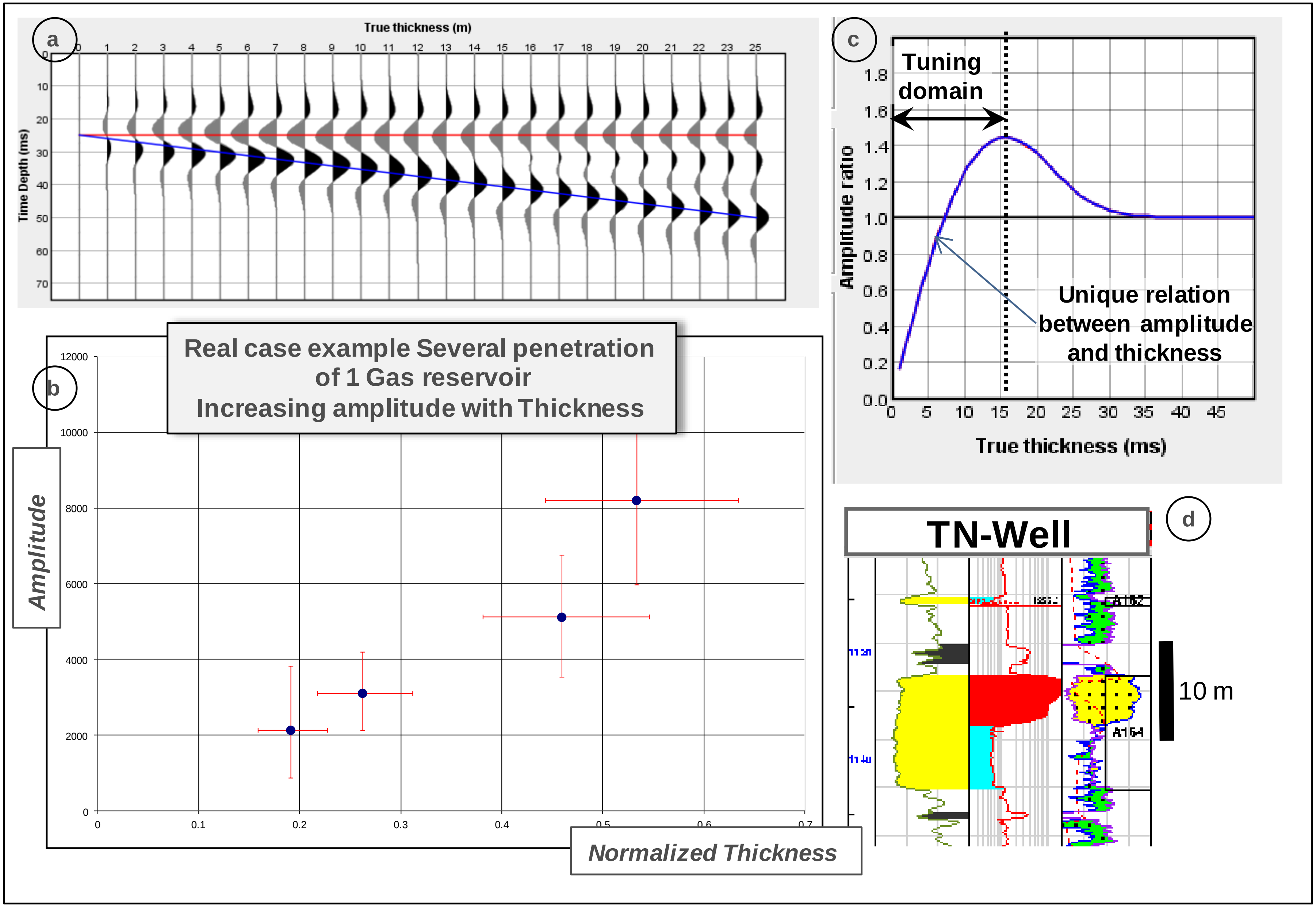

Figure 5. Use of tuning phenomenon (a) and (c) to predict reservoir thickness; (b) amplitude increases with net pay in proven gas reservoir (b); typical column rarely above 15 m (d).

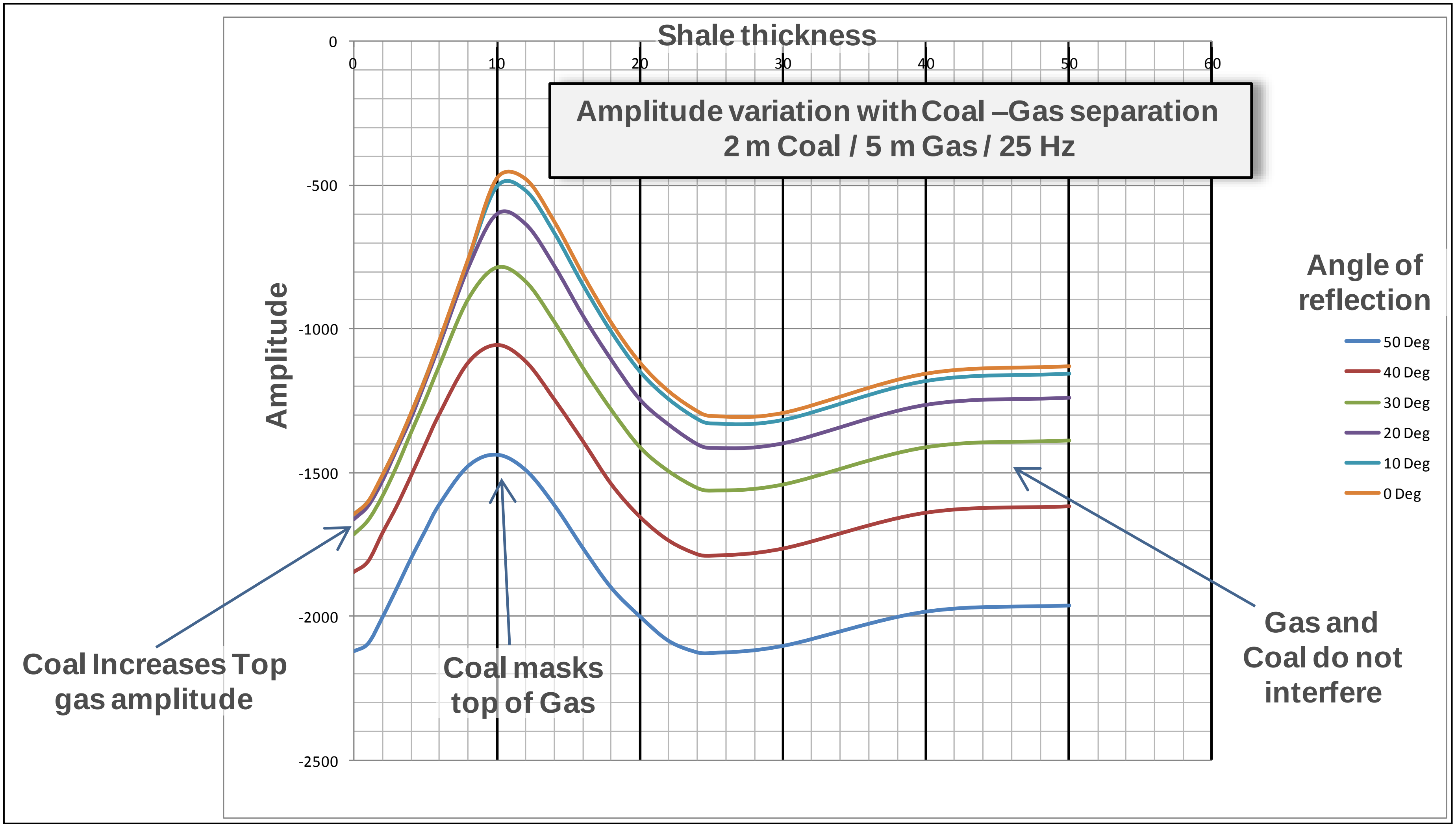

Figure 6. Effect of coal on amplitude response of gas reservoir function of Shale separation between coal and gas.

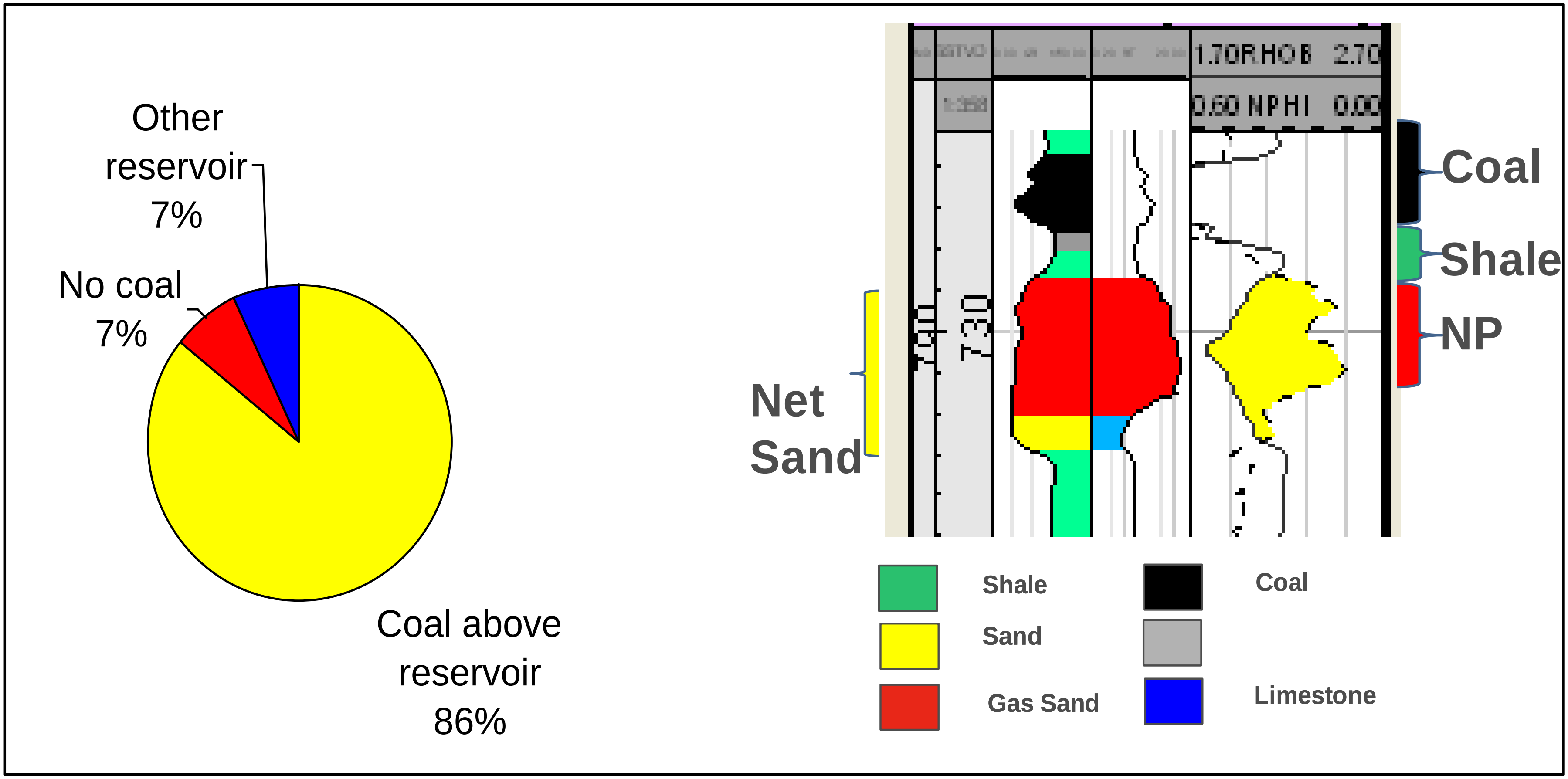

Figure 7. Coal distribution statistics. The 800 wells drilled on Tunu enable a fair knowledge of coal vs. reservoir distribution.