Case Study: Reef or Volcano? - Offshore Lombok, Indonesia

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presented by Bain at SOVG, Caracas, 1991.

BP Exploration conducted a seismic program covering their Production Sharing Contract (PSC) area, offshore Lombok, Indonesia in 1991 which included some 20,000 km of seismic, gravity and magnetics data. Western Geophysical acquired the seismic data, and LCT acquired and processed the gravity and magnetics data. These data were then merged firstly with a number of industry data sets, secondly with the existing public domain gravity and magnetic data sets obtained from the U.S. National Geophysical Data Center (NGDC), and finally for the gravity, these results were merged together with satellite-derived gravity data. The satellite-derived data had been reprocessed from the original satellite tracks using seismic stacking algorithms, which were adapted by BP for this purpose (Lewis & Mitchell, 1991). The fully merged data set included approximately 122,000 line km of gravity and magnetics coverage.

The regional data sets proved to be highly valuable at the regional scale, providing a birds-eye view of the tectonic fabric of the area as well as an independent guide for linking up the numerous (and oftentimes nebulous) fault systems interpreted from the seismic data.

The portion of the work discussed herein involved a detailed analysis of the seismic, gravity and magnetics data over a subset of the total survey area, with the purpose being to delineate several seismic "bumps" and attempt to determine whether these were volcanic features, basement horsts, or reefal buildups, all of which are known to occur in other nearby areas. This multi-disciplinary modelling effort aided the farm-in of a 50% partner, and assisted the selection of drilling targets. One major benefit to the study discussed herein was that the modelling and interpretation of the seismic, gravity and magnetics were performed at the same time, and by a closely coordinated group effort. In this way, new ideas were driven by one geophysical method, quickly tested using the other methods and, accordingly, the ideas were either dismissed or strengthened in a truly real-time integrated exploration sense.

The carbonate fairway area of investigation was approximately 240 km west to east and 130 km south to north. Four analyses were undertaken simultaneously:

- Seismic mapping of the key horizons
- Construction of a depth to magnetic basement surface
- Lineament trend analysis using gravity and magnetics, including delineation of regional changes in basement composition
- A detailed analysis of the density and sonic logs for the entire study area and a susceptibility analysis from outcrops on surrounding islands and limited borehole information.

The next phase in the study involved detailed modelling over specific features of interest. The primary seismic problem was to determine whether specific seismic bumps were caused by: 1) thick carbonates, 2) buried volcanoes or basement highs, 3) thin carbonates seeded on top of buried volcanoes, or 4) non carbonate sequences. The seismic interpretation was straight-forward down to the top of the "reef." However, many differences of opinion were emerging for the interpretation of the section below the "reef" top, and many spirited discussions took place daily as the interpretation progressed. The variations in seismic interpretation ranged (for individual features) between a thin veneer of carbonates sitting on top of a basement high (on the order of 250 ms reefal buildup) to a reef with as much as 2500 ms of buildup.

Sensitivity models were constructed of the various lithological units comprised of recent sediments, deep water marine carbonates, platform carbonates, volcanics and basement types. The density and velocity study suggested that the gravity data would be useful for corroborating the seismic interpretation of the reef boundary, but indicated that there was insufficient detail regarding density to utilize the gravity data as a strong independent method for testing the various (deemed-to-be) equally-viable seismic interpretations. The sensitivity modelling indicated that the magnetics could provide an independent assessment of the shallowest possible level of volcanics, which could then be used to infer the maximum thickness of the "reef."

Two of the initial seismic interpretations for one of the seismic bumps are shown in Figs. 1a and 1b. Note that the variations in potential "reefal" thickness ranged from two separated buildups with 250 ms maximum isochron in Fig.1a to 2200 ms in 1b. The first task was to model the primary regional magnetic field components attributed to changes in basement composition and structure. The magnetic depth estimates were obtained using MAGPROBE™ (LCT), which allows the user to apply multiple depth estimation techniques in a real time session. The corroboration of depth estimates using differing algorithms allows a higher confidence factor to be assigned to a given depth estimate than if a depth is supported with only a single method. The magnetic depth and susceptibility estimates were found to be in very close overall agreement, with the primary magnetic basement surface at approximately 5,000 meters, with some suggestions of slightly shallower picks just under the "basement uplift". These depth estimates were, in general, somewhat deeper than the interpreted seismic basement, suggesting that acoustic basement is somewhat shallower than magnetic basement, which is a common occurrence.

Fig.2 illustrates the basement model using the depth and susceptibility estimates discussed above. The primary magnetic field range and character across this line is due to intrabasement susceptibility changes. Three primary basement compartments are evident, with the central core being "acidic", that is low susceptibility (assigned here as 1200 µ CGS) relative to the surrounding basement rocks, which appear to be more "basaltic" in character, with average susceptibilities in the range of 3500 to 4000 µ CGS. The regional magnetic field, containing most of the magnetic field relief, was easily matched with no structural edits.

Note that the calculated and observed fields match well over much of the model, but a localized anomaly is clearly evident in the central portion of the profile, coincident with the reef (or volcano?). This initial portion of the regional modelling was performed using a 2D assumption (infinite extent along the strike, which is perpendicular to the plane of the cross section). The subsequent modelling of the localized feature was performed firstly in a 2.5D mode and, after all seismic units were mapped both above and surrounding the individual features, 3D modelling was performed over certain of the "reefs" to fully fold in all available geometrical information.

With a reasonable model (i.e., cross corroborated with all available control) of the regional basement in place, and the imposition of seismic constraints for the top of the reef and surrounding sedimentary sequences, the number of possible interpretations was decreased from a non-unique solution (with an infinite number of possible solutions) to a small set of feasible solutions. The next phase involved the selection of plausible lithological scenarios for the "reefal" section between top of magnetic basement and the top of the "reef". The scenarios deemed feasible (based on knowledge of similar features in surrounding areas) included: 1) acidic volcanics filling all volume up to top of "reef", 2) basaltic volcanics filling all volume up to top of "reef," 3) reefal buildup seeded on a basaltic basement horst block, or 4) reefal buildup seeded on acidic basement horst block.

Modelling of the reef as acidic volcanics indicated a rapid departure in the anomaly gradient and amplitude between the calculated and observed fields. While one should recognize the amplitude could be suspect owing to lack of susceptibility control, the departure in gradients is quite diagnostic. This model was deemed implausible. Similarly, modelling of the "reef" as being basaltic volcanics was a further exaggeration of the acidic volcanics in both amplitude and, particularly, gradients. This model was also deemed implausible.

The next alternative examined the "reef" modeled as a reefal buildup seeded on a basaltic basement horst block. In this model the central basement compartment was replaced with "basaltic" susceptibilities, including the uplifted section. The response and dramatic departure from the observed further supports this central basement block being "acidic". Thus, the basalt-cored, reefal buildup model was also deemed implausible.

Fig. 3 illustrates the preferred interpretation, wherein the reef was seeded on an acidic basement horst block. With the assigned constraints in place including the seismic control (with corroboration from gravity modelling results), the magnetic source depth estimates, and a limitation on the possible scenarios based on similar features in the region and rock properties from borehole and outcrop samples, this interpretation is deemed the most reliable model which adheres to the data. This adherence was both local, as well as regional, i.e., no "local" changes for the sake of a nice "curve" match were made. These results were used, in part, to high-grade this feature's prospectivity, and it was selected as a drilling target. Subsequent drilling results proved that the structure was, indeed, a reef, with thickness very close to that of the integrated model.

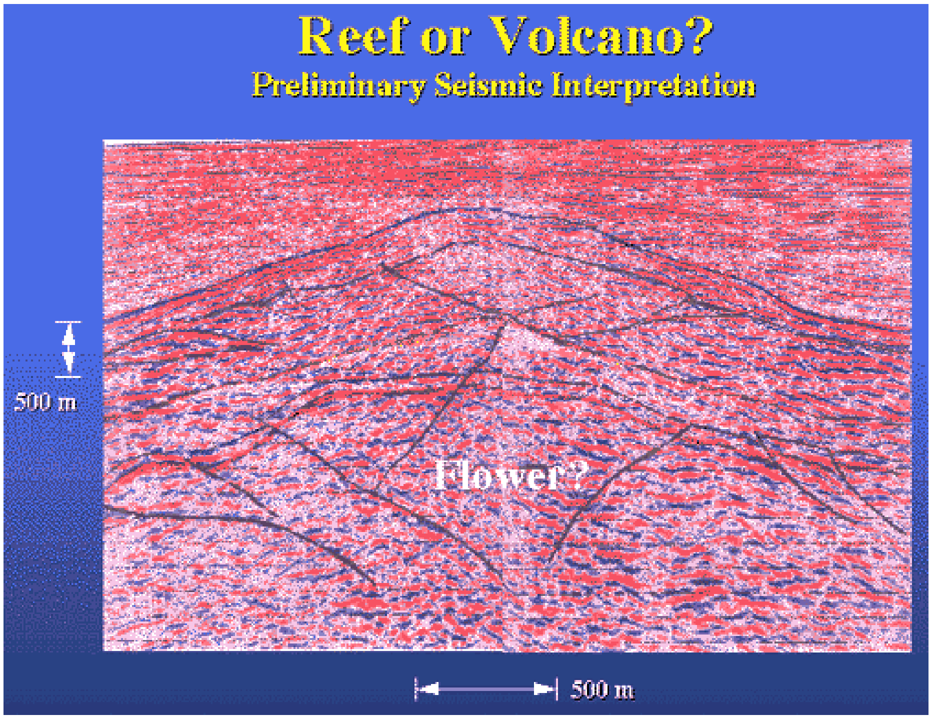

Figure 1a - Preliminary Seismic Interpretation – Thin Reef

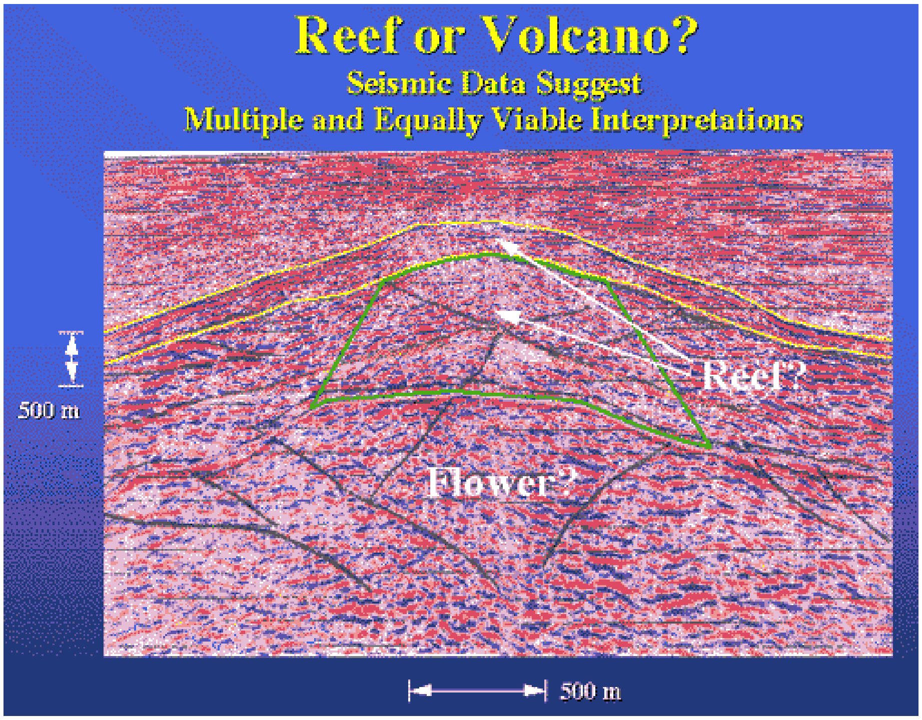

Figure 1b - Preliminary Seismic Interpretation – Thick Reef

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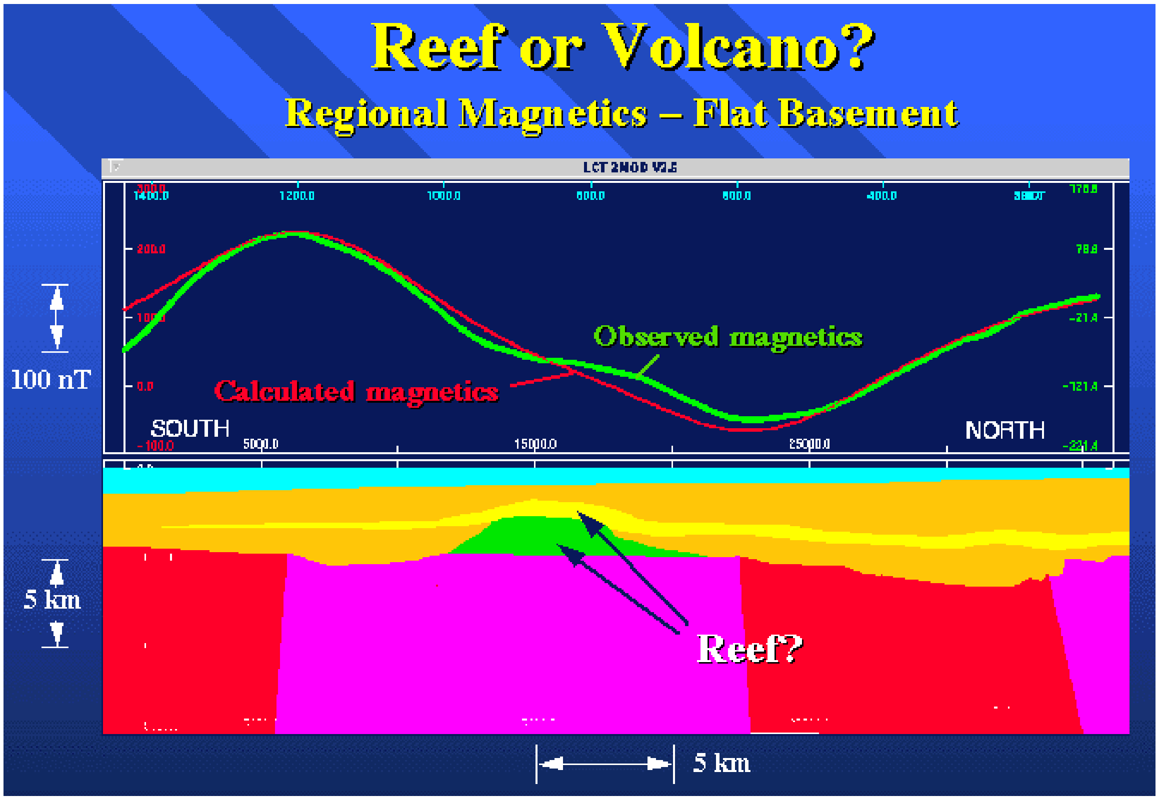

Figure 2 - Model Test – Thick Reef on Flat Acidic Basement Block

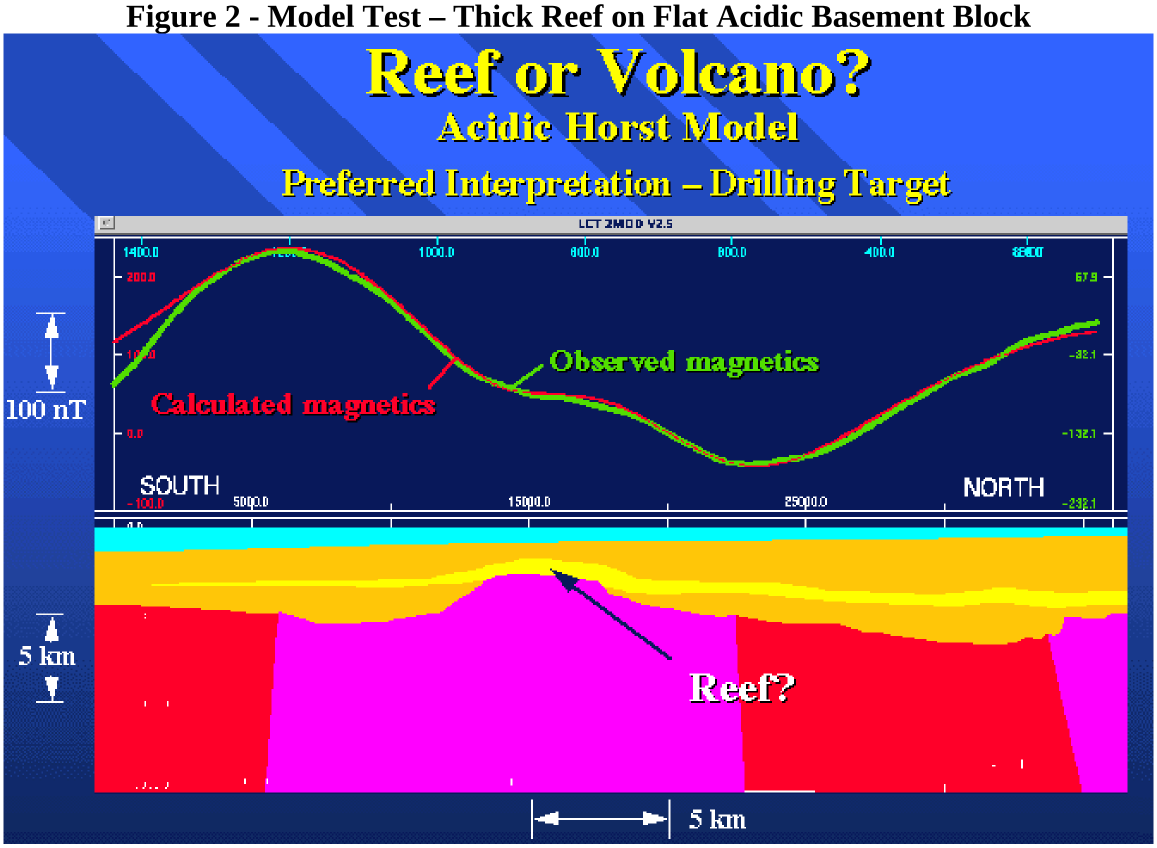

Figure 3 - Preferred Integrated Interpretation
Thin Reef Seeded on Top of an Acidic Basement Uplift

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