Day: Friday 28 April **Session: 9**
Time: 11:50am

Low-cost Exploration in a Frontier Area: Breaking our Model with Data, Phu Khanh Basin, East Sea, Vietnam

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Problem

The Phu Khanh Basin of eastern Vietnam is one of the last remaining basins in South East Asia that is truly frontier. To date, no relevant wells have been drilled in the basin and only sparse 2D seismic and a few small 3D surveys offer any constraints on the interpretation of the potential hydrocarbon systems in this very large, offshore basin. Murphy Oil Vietnam and PVEP each operate two large licenses in the outboard portion of the basin (Blocks 144 and 145 and Blocks 148 and 149, respectively).

The total area of the four blocks exceeds 53,500 sq km (Fig. 1). Previous to this year, the data set for Blocks 144 and 145 was limited to only ~7,600 line kms of 2D broadband seismic that is widely spaced on a 4x8 km grid; 2D and 3D seismic surveys have been acquired in Blocks 148 and 149. However, no exploration well has been attempted in this area, hence the petroleum system is shrouded in uncertainties. Exploration strategy for the blocks was based entirely on using a stratigraphic model to fit the seismic interpretation into a known framework. Murphy technical teams debated which basin to use as a model for the unconstrained Phu Khanh Basin stratigraphic succession, as well as the various caveats for each analogue model. Eventually, the exploration team settled on the Nam Con Son (NCS) stratigraphy from the basin ~850km to the south and hence forward all interpretations and prospectivity were forced into this framework (Fig. 2). Subsequent seismic mapping defined a robust series of half-graben basins that have associated structural leads for future drilling candidates (Fig. 3). However, certain key questions could not be answered from the model-driven approach alone: most notably, nature of source rock facies, stratigraphic ages, and thermal maturity in these blocks and deep water area of the Phu Khanh Basin.

More data was needed to better constrain the petroleum system elements and reveal prospective areas. Murphy's upcoming work commitment in the contract is to acquire an efficiently-sized 3D seismic survey. The questions are: where to place this small 3D in the large contract area of Blocks 144 and 145, and which half-graben might have the best prospectivity?

Methodology

Several of the key unknowns in the hydrocarbon systems of the basin and specifically in Blocks 144 and 145 and 148 and 149 could not be mitigated by simply imposing a NCS stratigraphic model onto the 2D seismic interpretation. Therefore, Murphy Oil Vietnam and PVEP elected to acquire a low-cost, seabed mapping and coring program over the area before designing, locating,

and acquiring an expensive 3D data set in 144 and 145. Some further calibration was needed to appropriately risk and rank the prospective half-graben areas. In mid-year 2015, Murphy and PVEP acquired high-resolution multibeam bathymetry surveys including 17,000 sq km in Blocks 144 and 145 and 19,000 sq km in Blocks 148 and 149. The bathymetry, the subsurface seismic, and the backscatter attribute from the multibeam were used to select 145 seabed dropcore locations to acquire across all the blocks and across the different prospective half-grabens (Fig. 4).

In mid-2016, Murphy and PVEP conducted this coring survey. Three completely different datasets were collected for integration into the exploration potential of the area: A) Geochemistry piston cores for possible seep locations and locations to define background (Fig. 5), B) Heat flow probe locations to measure heat flow in near-seabed sediments (Fig. 6), C) Hard substrate cores designed to target sub-surface outcrops of relevant stratigraphy and retrieve hand-sample sized specimens for petrography and age dating (Fig. 7). Upon completion of operations, the majority of coring stations had acceptable recovery and all heat flow stations recorded excellent quality data. The entire coring acquisition was completed in less than 25 days with no safety or security incidents and under budget, for only a few million dollars.

Results

The data collected from the seabed coring campaign have proved to be enormously valuable for constraining the exploration team's interpretation of the area and its prospectivity. Some of the data have corroborated the previous interpretation. Conversely, some of the data have been surprisingly different than expected. However, most importantly, the low-cost data acquired will be paramount when designing a much more expensive 3D seismic survey, which is an imminent contractual commitment of Murphy Vietnam.

- *Geochemistry Results*: all samples were processed for geochemistry in the USA by both TDI Brooks and Biomarkers Technology Inc. Standard geochemistry consisted of total scanning fluorescence to high-grade the samples that needed advanced geochemistry and also to establish a baseline for background levels of hydrocarbons (Fig. 8). Most of the seeps based on the standard geochemical analysis have been considered as background noise, some have been elevated to a natural gas response, and a few to natural oil response. From these samples, some were chosen for carbon isotope analysis. The results showed that the methane encountered had a mixed origin, some from biogenic and some from thermogenic sources (Fig. 9). Biomarkers indicate that there may be two separate source rocks of different ages and that the source facies is mostly marine (Figure 10). Finally, Quantitative Diamondoid Analysis was performed on every sample above background levels, and these analyses further confirm the presence of thermogenic hydrocarbon seepage.
- *Heat Flow Results*: Seabed heat flow measurements from 25 locations across the area indicate higher heat flow values than observed in adjacent basins such as the NCS Basin in the south or Song Hong Basin to the north. These data are key to constraining the Murphy Vietnam basin models and source rock maturity interpretations (Fig.11).
- *Hard Substrate Results*: Not all stations were successful in retrieving useful pieces of sub-sea outcrop. However, 25 samples were sorted from the cores and selected for petrography and/or biostratigraphy (Fig. 12). The biostratigraphy of 13 key samples is groundbreaking in terms of understanding and calibrating Phu Khanh Basin stratigraphy (Fig. 13). The presence of rocks of specific ages could be determined either from the direct dating of outcrop samples, or from the presence of reworking within samples. Pliocene and Late Miocene stratigraphy was directly sampled and confirmed. A significant hiatus appears to be the location of the mid-Miocene unconformity (MMU) since no NN5, NN4, or NN3 nannofossil associations were recorded in any samples. The oldest strata sampled are either Early Miocene or Late Oligocene. However, there appears to be robust evidence for a

significant marine Oligocene and also marine Late/Middle Eocene section (from reworked assemblages). Figure 14 is a seismic correlation of the outcrop localities to the deeper graben areas.

Conclusions

For a relatively low expenditure, Murphy Oil Vietnam and PVEP have dramatically advanced the understanding of the outboard Phu Khanh Basin and specifically the Block 144 and 145 and 148 and 149 area. Originally, tethered to the stratigraphic model imposed on the seismic from an analogue basin, now the interpretations and understandings of geologic risk are much more robust. A short list of advancements (below) conclude this paper.

- ✓ Evidence of confirmed thermogenic hydrocarbons
- ✓ BIndications of multiple source rocks, differing in age
- ✓ CSource facies appear to be marine with some terrestrial input
- ✓ Presence of a CO2 source that needs to be avoided
- ✓ Excellent calibration of the geothermal gradient for basin modeling
- ✓ Evidence of the MMU location in the section
- ✓ Age dating of basin-fill stratigraphy and depositional environments

Figures

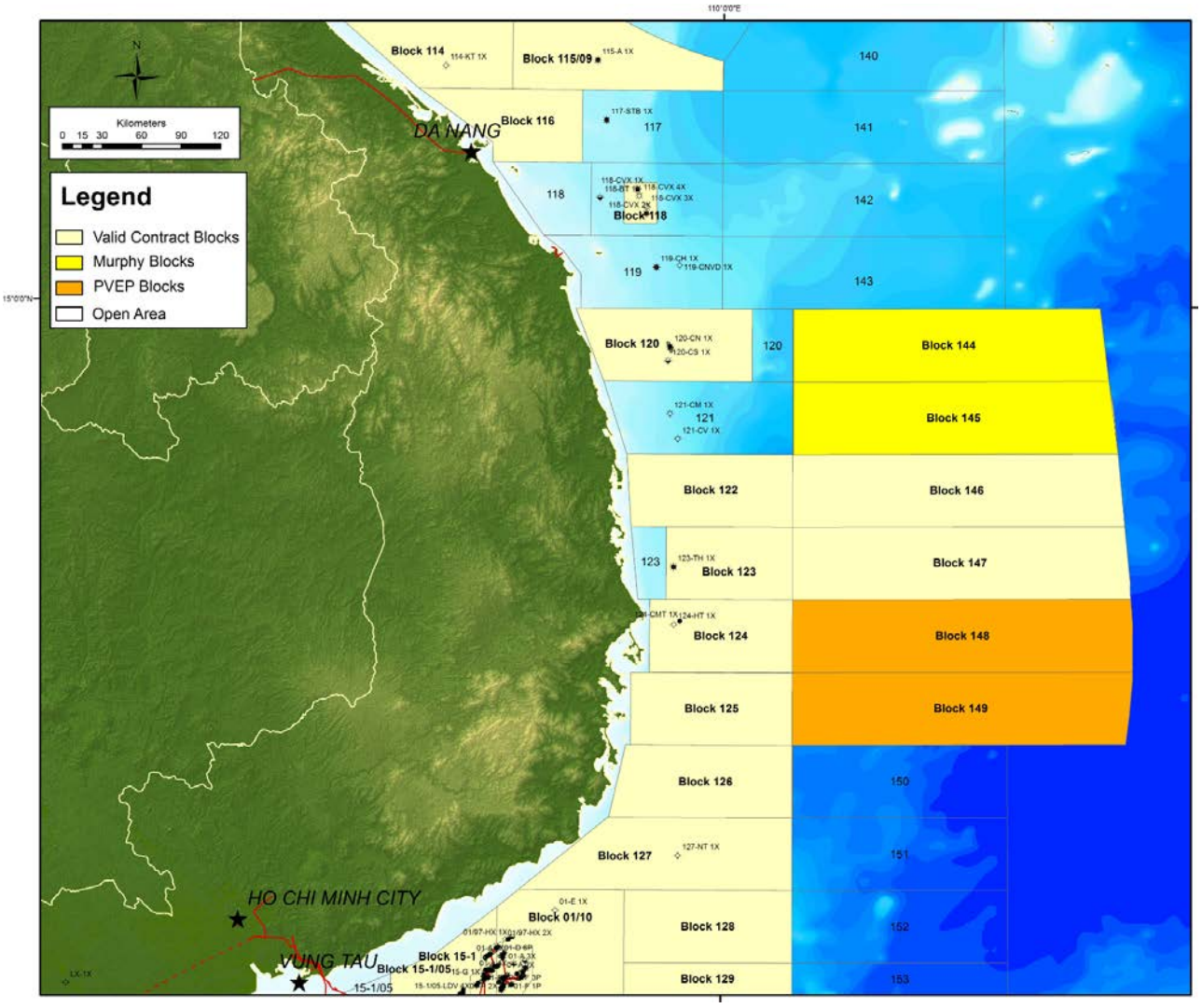

Figure 1: Blocks 144 & 145 and 148 & 149 in the outboard portion of the Phu Khanh Basin.

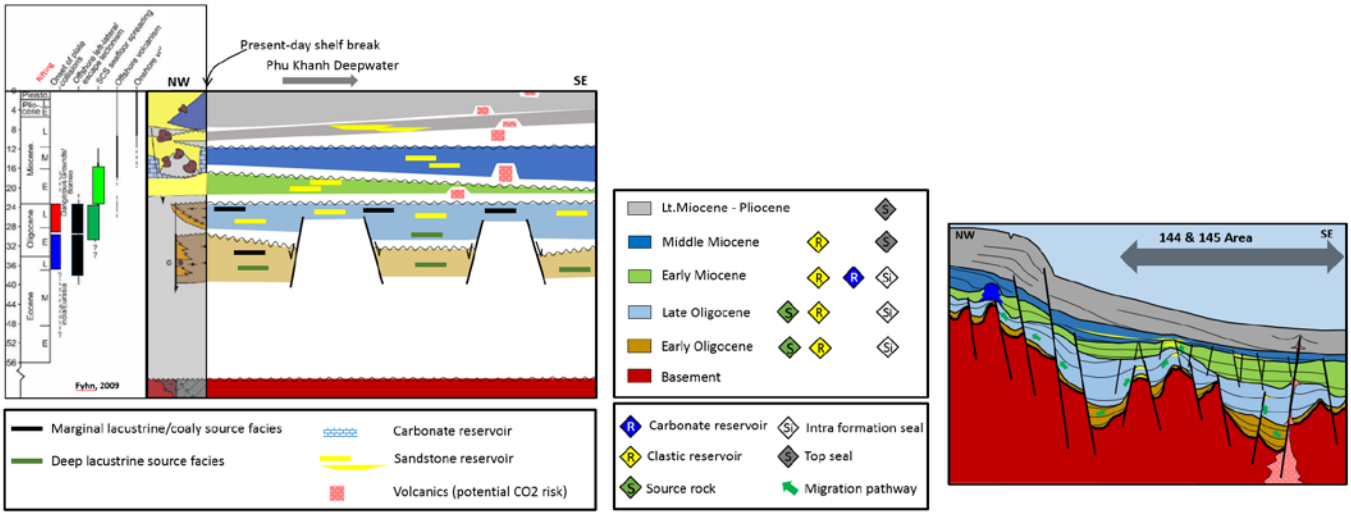

Figure 2: The stratigraphic framework from the Nam Con Son Basin in southern Vietnam was used as the analogue model for the interpretations of the seismic packages identified in the Phu Khanh Basin. This was necessary due to the total lack of any age constraints in the entire outboard portion of the basin.

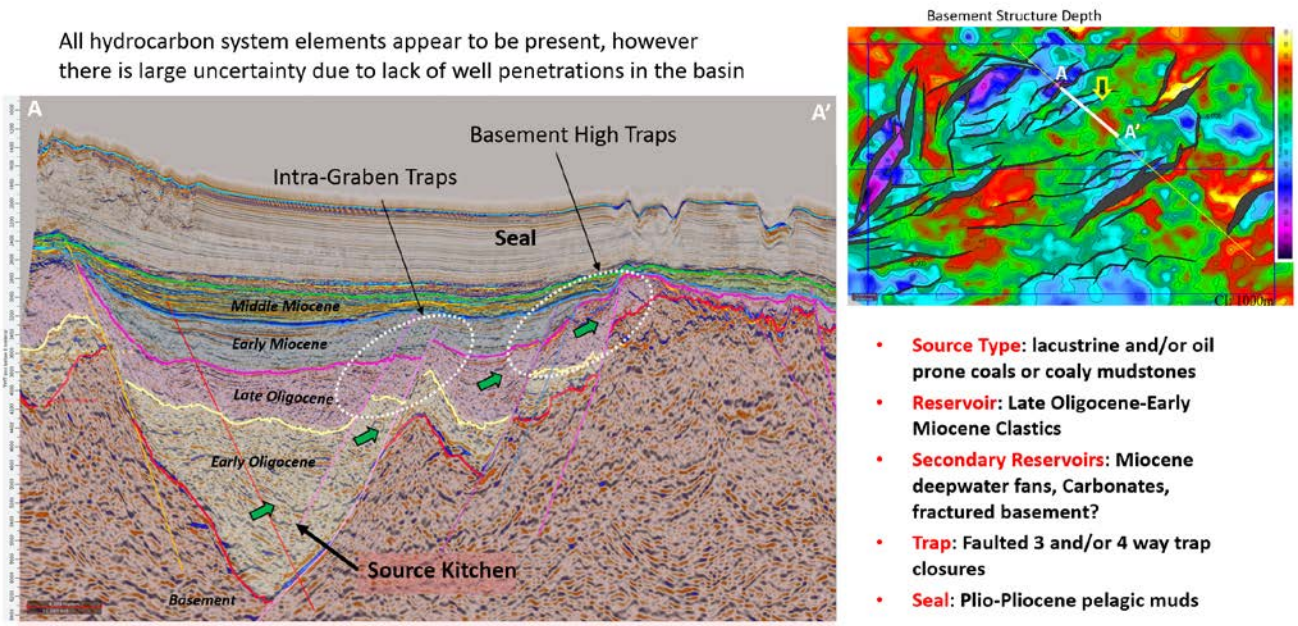

Figure 3: The evolution of a hydrocarbon system in the Phu Khanh Basin. This figure illustrates the state of knowledge from the technical team based only on the seismic mapping and the forced Nam Con Son Basin stratigraphic model before the seabed coring campaign.

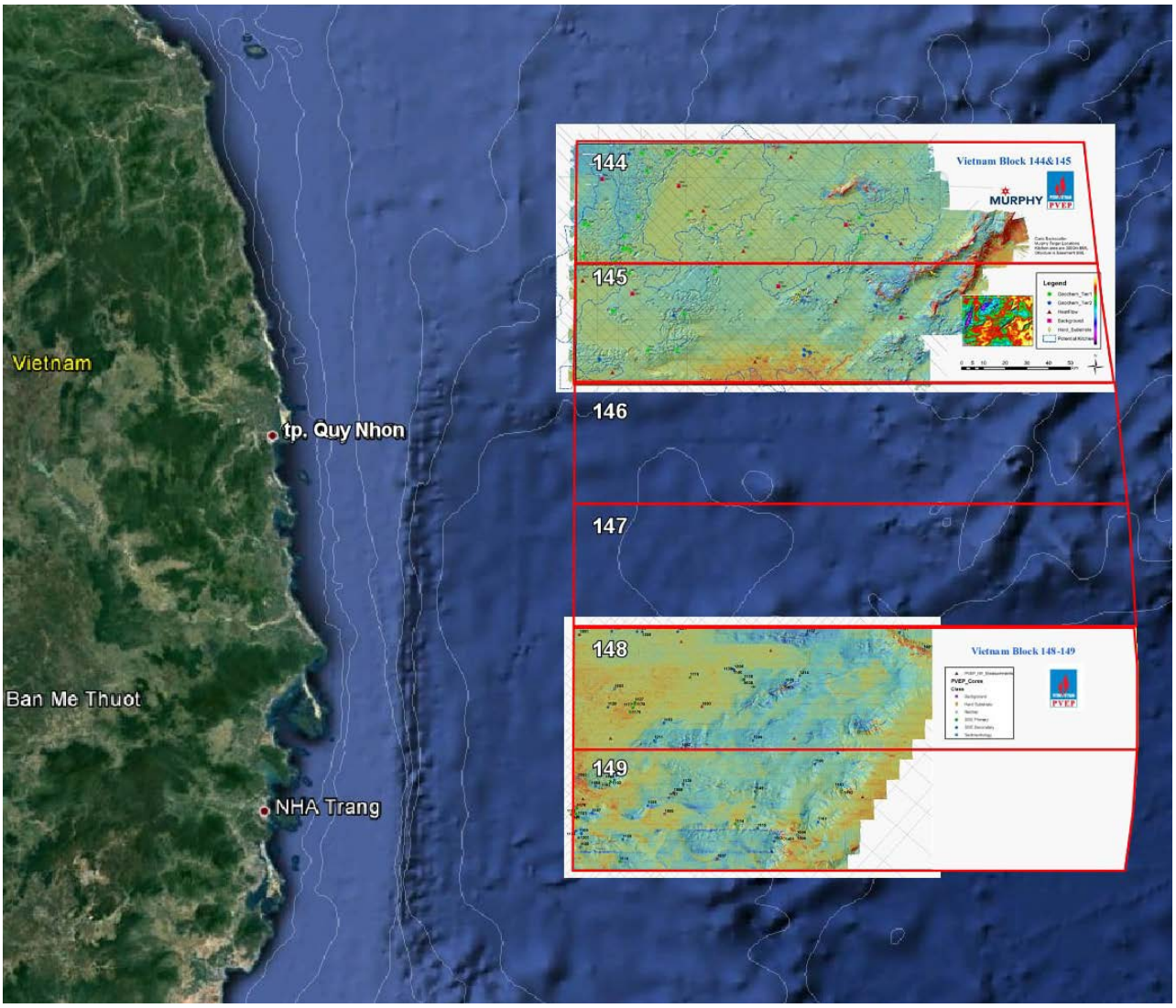

Figure 4: Backscatter from Multibeam and the 75 drop locations (144 & 145), 70 drop locations (148 & 149) that were chosen for A) possible hydrocarbon seep geochemistry (green circles and blue pentagons), B) background levels of geochemistry (magenta squares), C) heat flow probe measurements (red triangles), D) hard substrate cores on sub-sea outcrops (yellow diamonds). Six mapped half-grabens are outlined in blue-dash in 144 & 145.

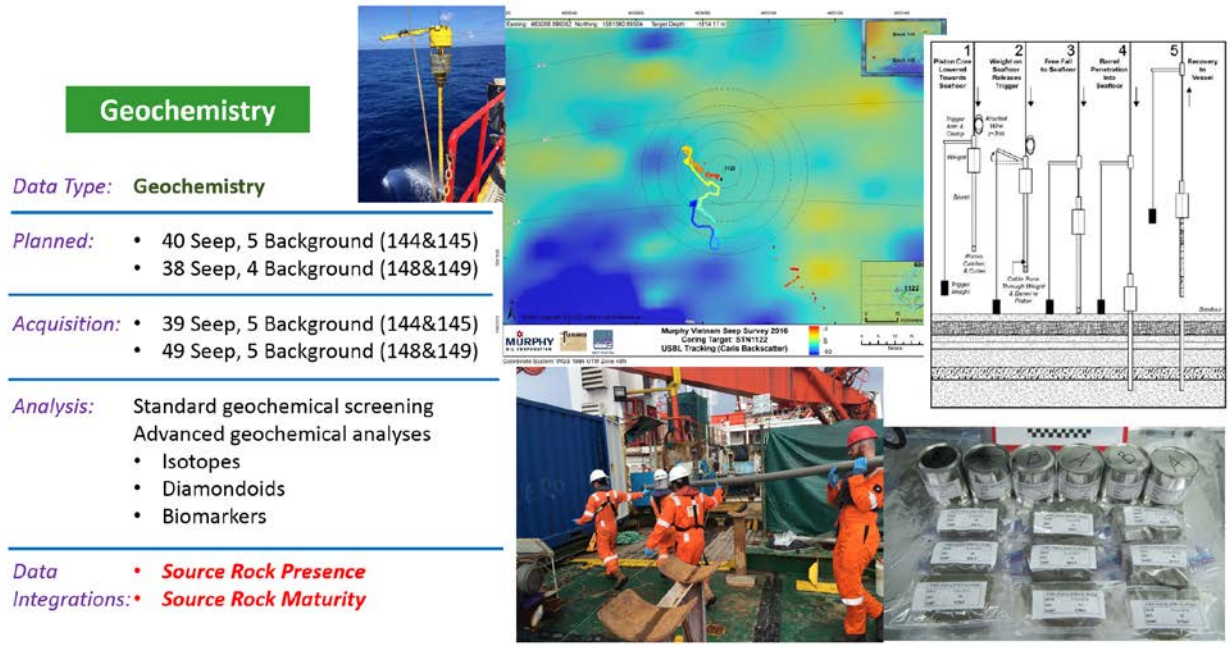

Figure 5: Seep hunting was carried out with a six meter piston core and using the Multibeam backscatter anomalies and knowledge of the subsurface from seismic to select sample localities. Water depths ranged from 700-2500 meters. All cores had successful recovery (one core out of 40 sampled a volcano).

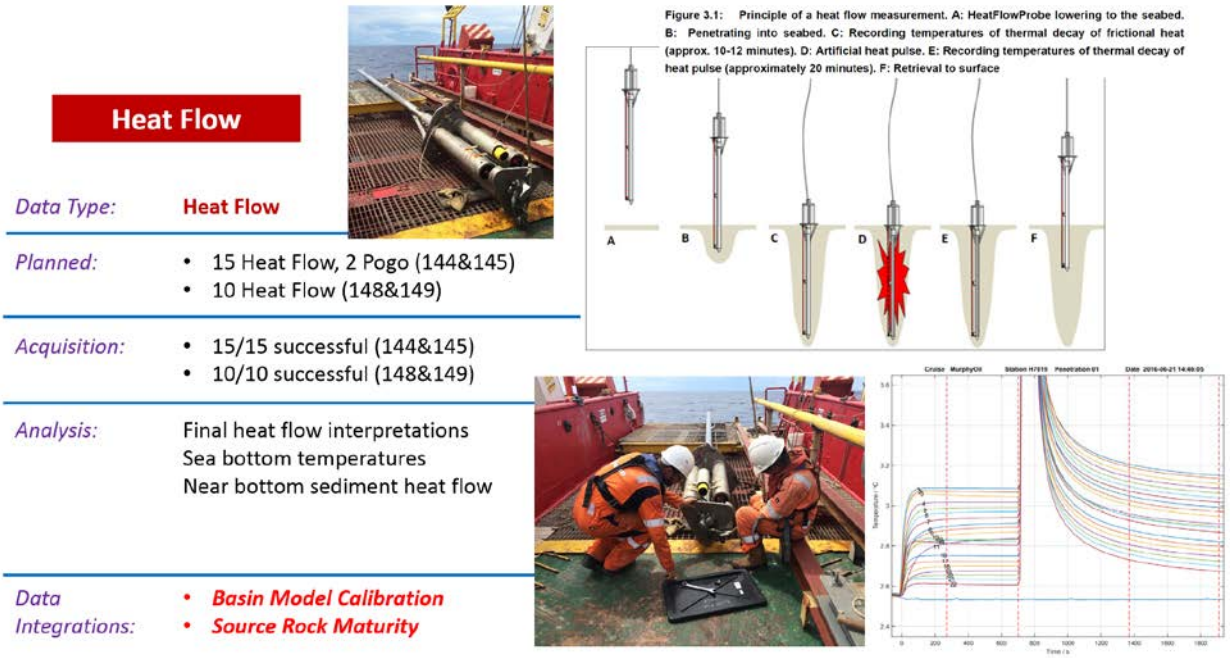

Figure 6: Surficial heat flow and seabed temperatures were recorded in 25 stations with excellent quality data and good repeatability using a Fielax heat flow probe

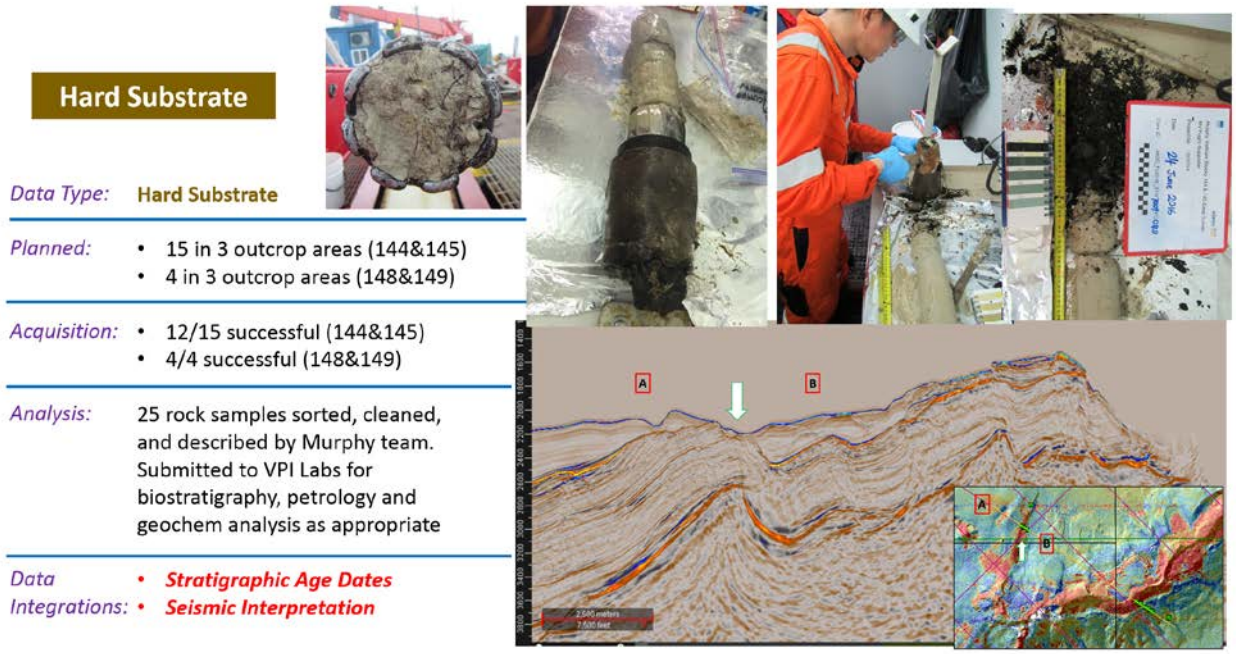

Figure 7: Using a special reinforced core barrel and different designed core catcher, 15 locations in block 144 & 145 and 4 locations in block 148 & 149 were sampled for hard substrate (a.k.a. real rocks). The block areas are fortuitous to have some recent faulting that has exposed the older syn-rift stratigraphy at the surface of the sea bottom.

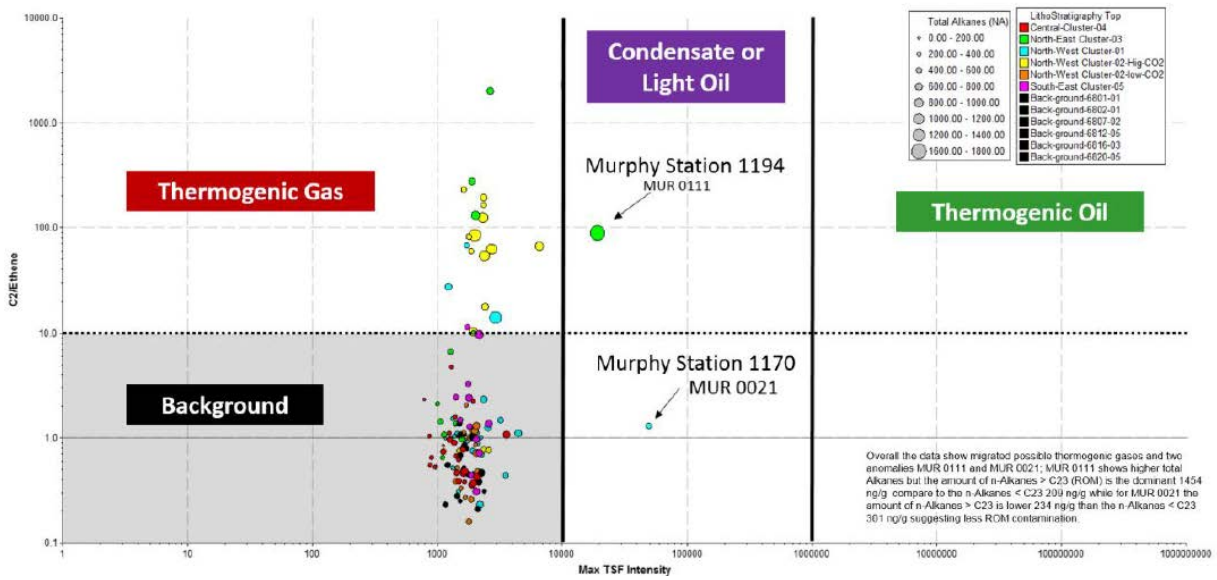

Figure 8: Standard geochemistry results (Total Scanning Florescence) identified several samples for further analysis.

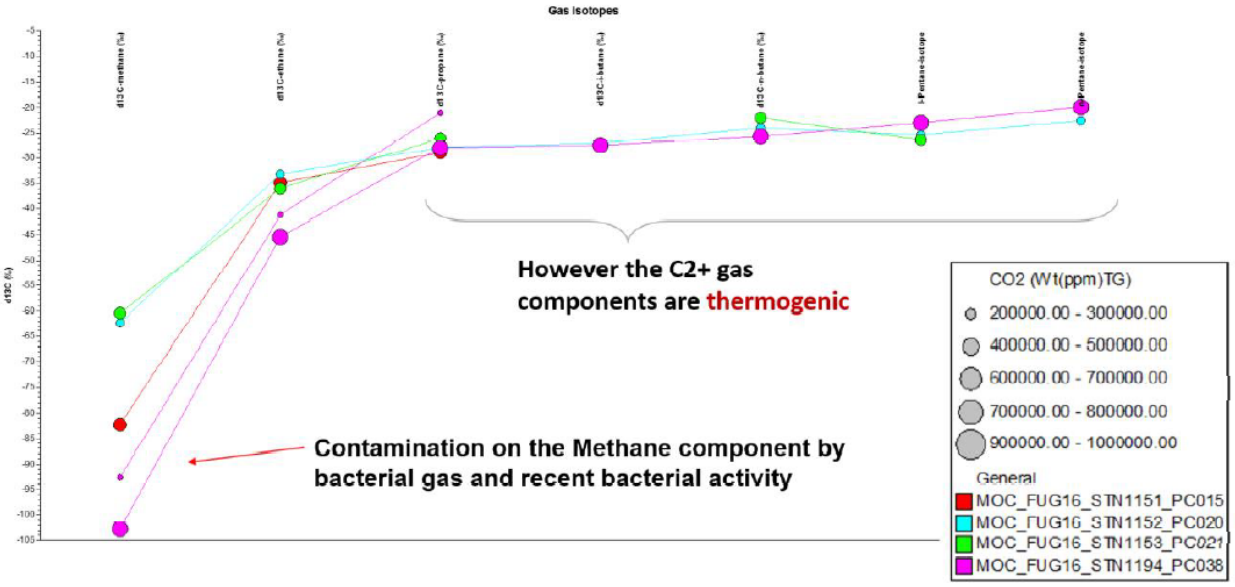

Figure 9: Methane in some samples appears to be contaminated from biogenic sources, however a thermogenic source is demonstrated as well.

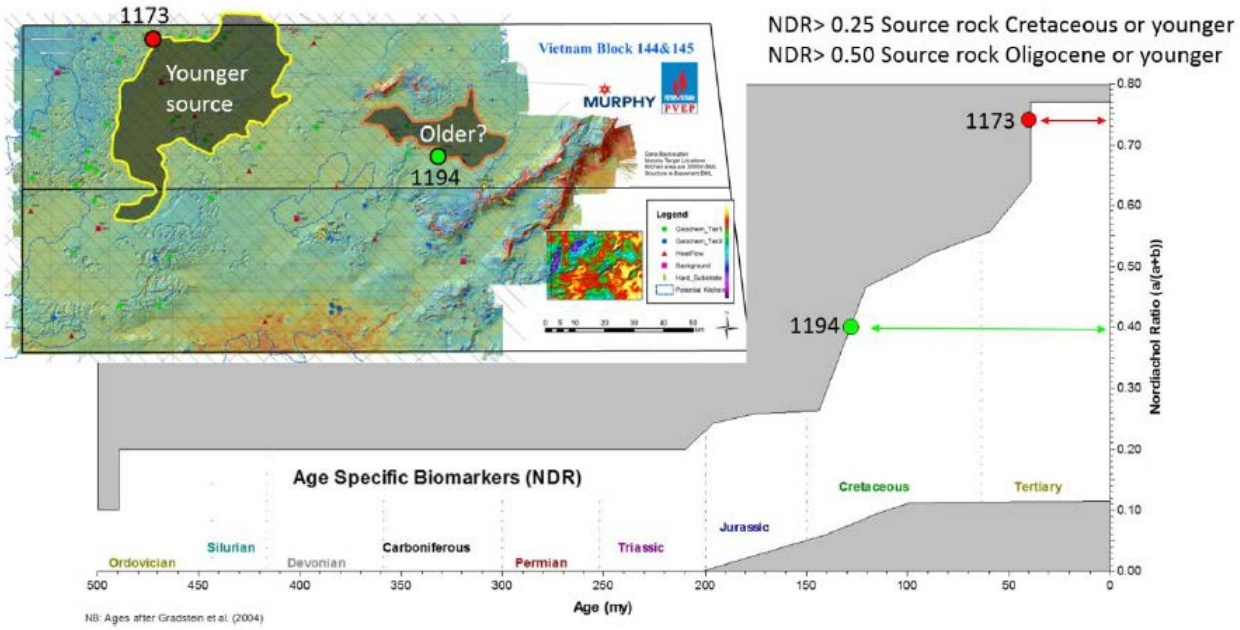

Figure 10: Biomarkers analyses indicate that there could be different aged source rock in the different grabens. Also, the source facies from the biomarkers indicates mostly a marine algal organic matter with only minor input from terrestrial higher plants.

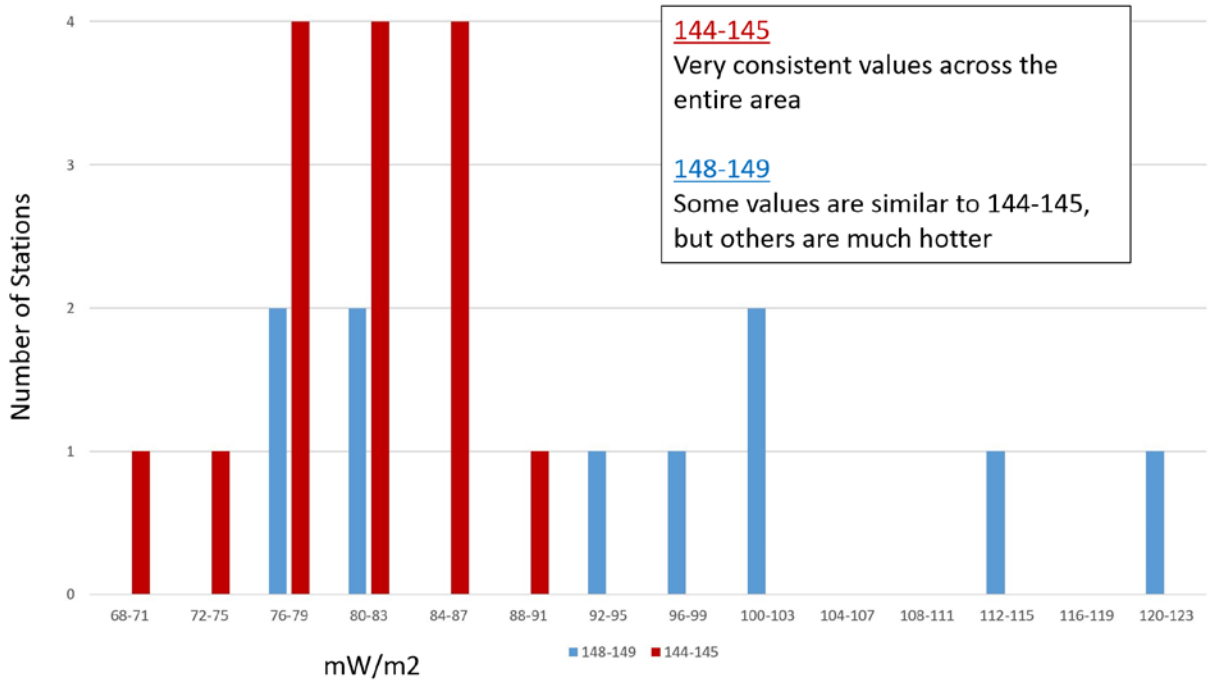

Figure 11: Heat flow values are higher than the adjacent Vietnam basins to the north (Song Hong) and to the south (NCS). With these data, Murphy has been able to carefully calibrate basin models for each half-graben in the area and better predict source rock maturity and timing.

Figure 12: Hard substrate core locations were successful in retrieving outcrop rock samples from 12 different locations, and several cores contained multiple rock types. Overall, 25 separate samples were analyzed for biostratigraphy and/or petrography. Above are just a few examples. Clockwise from upper left, A) Murphy team sorting samples in the office, B) small Miocene coral head, C) sandstone sample, D) volcanic tuff material, E) shale with nodules, F) carbonate breccia with a large benthic foraminifera.

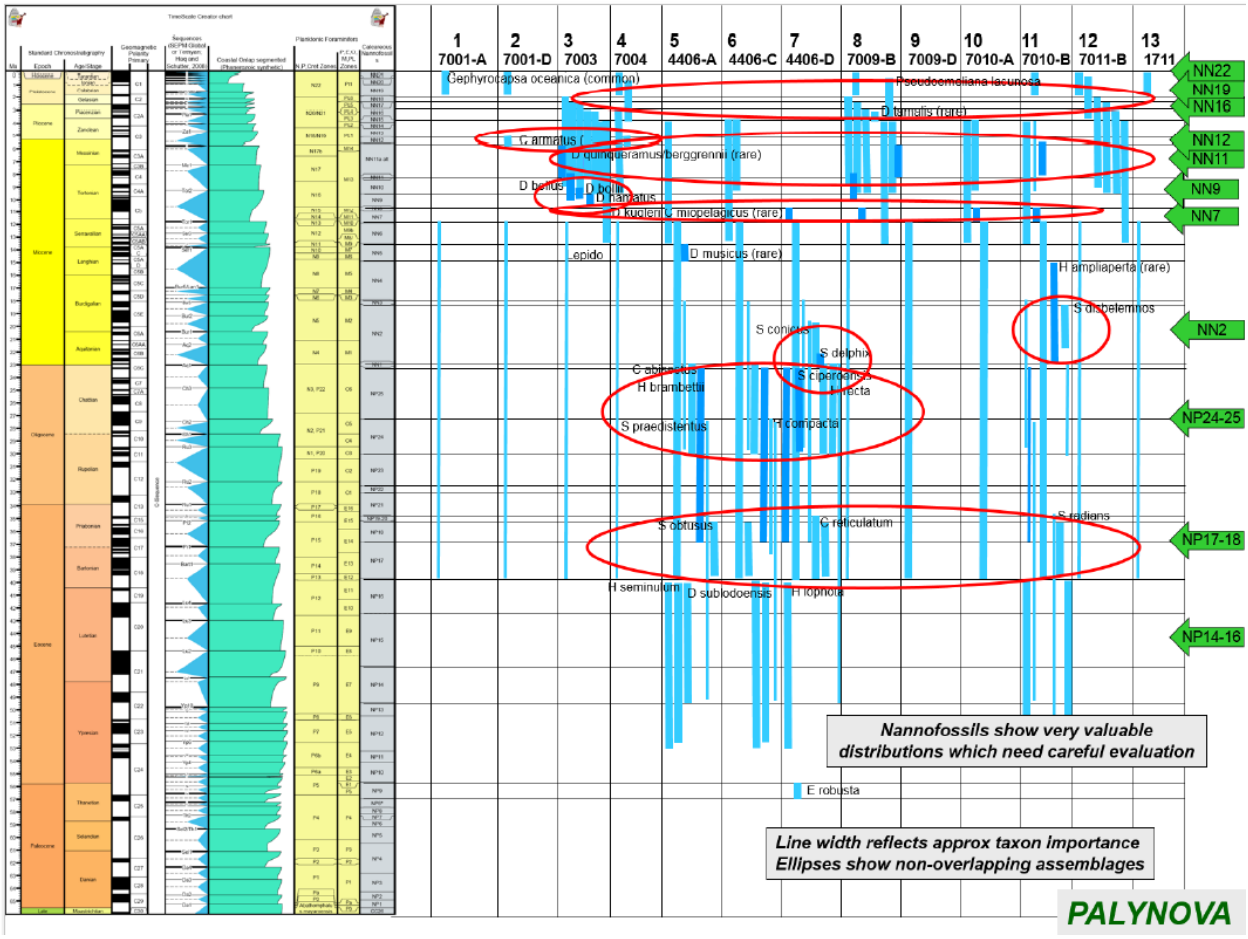

Figure 13. Palynova summary of the palynology analyses from 13 key hard substrate samples. Red circles indicate biozones of higher confidence and probable stratigraphic ages of the basin fill. Note a hiatus around the MMU time. Also note that there is significant evidence for an Eocene age section. Some of the earliest assemblages are interpreted to be reworked (older ages incorporated into younger strata via erosion and transport). Upper Oligocene NP24-25 is likely the oldest strata sampled.

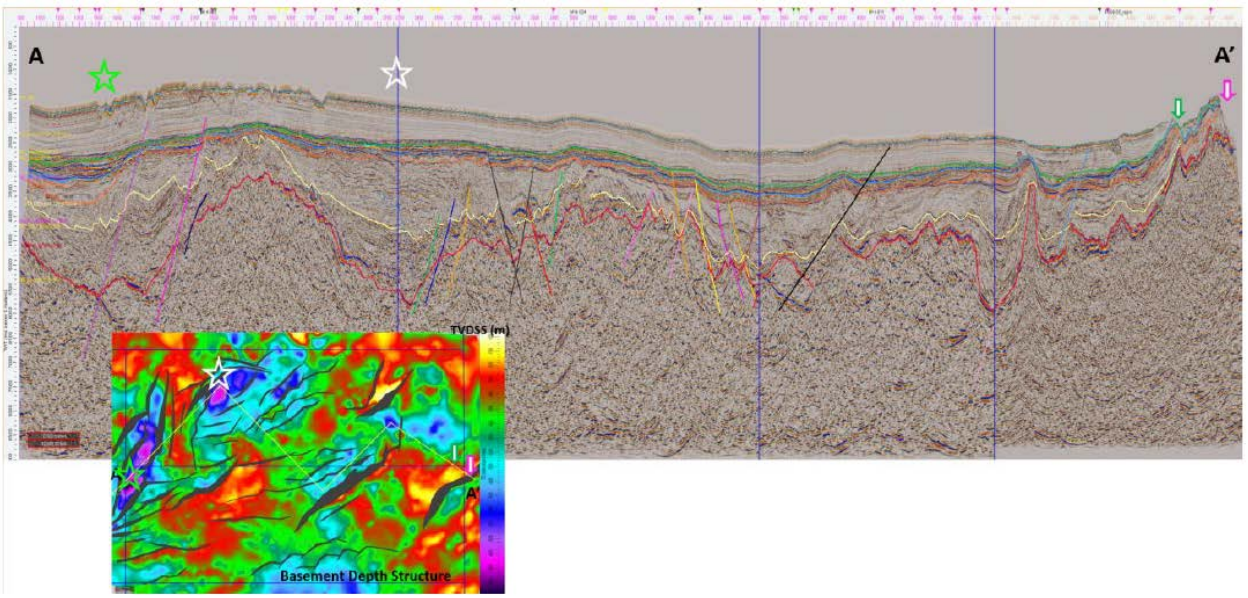

Figure 14: Hard Substrate sample locations in relation to the major half grabens. The green and magenta arrows on the extreme eastern portion (A' side) of the seismic line are the sub-sea outcrops. The green and white stars are the locations of the best developed half-graben sedimentary section