Geol. Soc Malaysia, Bulletin 25, December 1990; pp. 57 – 73

A discussion of "Sniffer" geochemical surveying offshore Malaysia

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Abstract: The following is a description of the SNIFFER geochemical technique and use of the technique off the West coast of Malaysia. SNIFFER analysis techniques, operational considerations and interpretive methods are discussed. Data from the SNIFFER are integrated with seismic, showing high correlation between interpreted structures and SNIFFER anomalies.

INTRODUCTION

In October 1988, InterOcean Systems conducted a proprietary geochemical SNIFFER survey in the Strait of Malacca off the West coast of Malaysia for Sun Malaysia Petroleum Company. SNIFFER coverage was outlined by Sun Malaysia, and a total of 1,009 line kilometers were surveyed. One of the goals of the program was to detect geochemical evidence of the presence of petroleum in the evaluation of petroleum potential in offshore Peninsular Malaysia (Figure1).

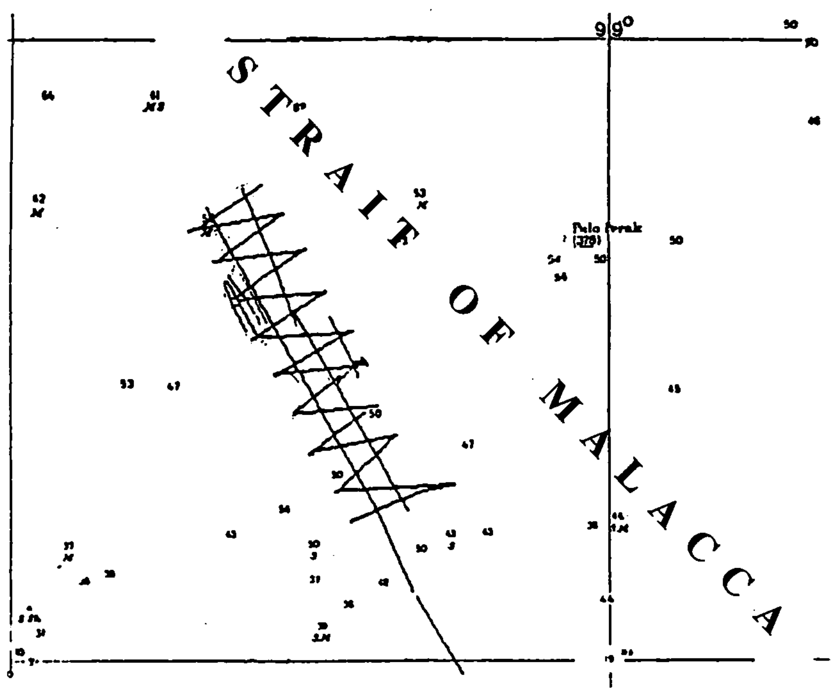

Figure 1: SNIFFER coverage Strait of Malacca.

Presented at GSM Petroleum Geology Seminar 1989

The SNIFFER method has met with the greatest degree of success in the evaluation of frontier areas where the presence of petroleum is uncertain and in high-grading portions of acreage within known petroliferous areas. SNIFFER methods can be used with a reasonable degree of confidence to evaluate individual prospects. This is especially true where the sub-surface geology is well known and the prospects of interest are reasonably separated.

GEOCHEMICAL EXPLORATION REVIEW

Pathways of Seepage

The success of surface geochemical exploration depends upon the occurrence of seepage. Petroleum seepage is known to occur in most petroliferous areas, although the magnitude of seepage can vary from one location to another. In some areas, petroleum seepage is so extensive that it is detectable without any special equipment. These are macroseeps and are found in petroliferous locations throughout the world. Microseeps are thought to occur in most, if not all, petroliferous areas. These are detected only by sensitive analytical instrumentation capable of measuring hydrocarbons at the part-per-billion (ppb) level. The gas chromatograph is the principal instrument used for this purpose.

The mechanisms and pathways by which petroleum seepage is believed to occur are:

1. Seepage at the petroleum-water contact in the reservoir.
2. Diffuse seepage through cap-rock and overlying reservoir.
3. Seepage at geologic "conduits" that breach the reservoir, such as faults.

Seepage along the oil-water contact is thought to produce a pattern of high hydrocarbons at the flanks of the reservoir with lower concentrations directly over the reservoir. From a map view, this pattern appears as a halo surrounding the reservoir. Diffuse seepage produces a broad anomaly directly over the leaking reservoir (assuming horizontal migration is small). Some geologists believe the halo pattern can also be attributed to diffuse seepage in which the sedimentary column directly over the reservoir has become impervious to seepage over time by secondary processes or biological effects. Seepage along conduits should produce the highest magnitude anomalies, but also should be limited spatially. Because few conduits are thought to have a perfectly vertical dip through the sedimentary column, the chance is increased that surface anomalies produced by this type of seepage will be displaced laterally from the sub-surface source.

Two surface geochemical methods are commonly employed to search for petroleum seepage:

1. Analysis of dissolved hydrocarbons in the water column near the sea-bottom (SNIFFER method).
2. Analysis of hydrocarbons in the near-surface sedimentary column (most commonly using sediment coring devices to collect the sediment).

SNIFFER TECHNIQUES AND OPERATIONS

A schematic of the SNIFFER method is shown in Figure 2. Seawater from near the bottom is continuously pumped to the ship by a submerged tow body containing a high capacity pump. The pump is generally towed about 10 meters above the sea floor. This altitude above the sea floor has been found to be optimum for intercepting seep plumes, while maintaining the required sensitivity for detection of the seep. Bottom water is pumped continuously as the ship moves. Ship speed varies between three to eight knots depending upon water depth, wave height, current speed, and desired coverage. A survey speed of six knots is normal for water depths less than 200 meters.

The seawater is degassed in a vacuum chamber, or stripper (refer to the top-half of figure 2)

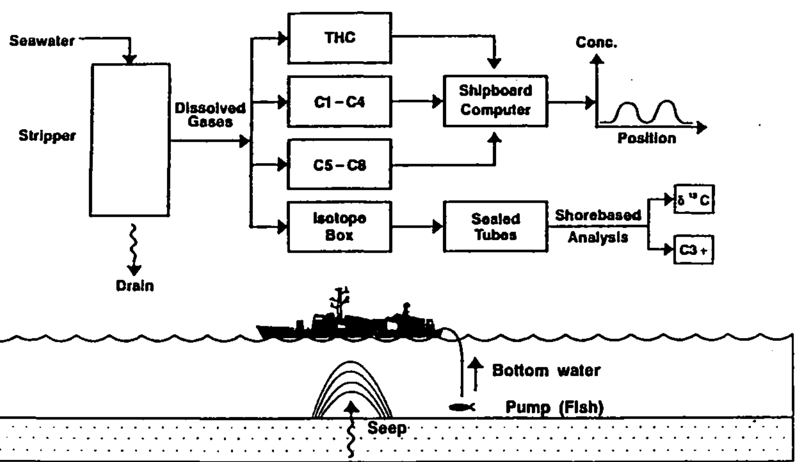

Figure 2: SNIFFER geochemical exploration method.

Approximately seven liters of seawater are degassed each minute, yielding approximately 120 milliliter (ml) of dissolved gas per minute. The stripped gases are passed through a series of analytical instruments for measurement of hydrocarbons and other compounds of interest. An aliquot of the gas is injected into a gas chromatograph for analysis of total hydrocarbons (THC) every 30 seconds. Every 90 seconds, another aliquot of gas is injected into a gas chromatograph which measures the individual gaseous light hydrocarbons, methane, ethane, ethylene, propane, propylene, iso-butane, and normal-butane. Every 15 minutes, a pre-concentrated sample of the dissolved gases is back-flushed into a gas chromatograph for measurement of the individual gasoline-range hydrocarbons (pentane through octane).

Additional automated measurements performed by the system include: salinity, temperature, water depth and tow body altitude above bottom. Additional instruments may be added for measurement of other inorganic gases such as carbon dioxide, oxygen, and helium.

Concurrently with automated measurements, a portion of the dissolved gases are passed through a purification and combustion system (isotope box) for collection of samples for analysis of the carbon isotope ratio of methane and, if desired, samples of the hydrocarbons heavier than ethane (C3+). A computer coordinates all the instrument, collects and displays all the data within six minutes from the sample location. This enables operators and scientists to recognize hydrocarbon anomalies immediately. They can then modify the survey track to confirm results and to pinpoint the spatial extent and location of the anomaly.

The extreme sensitivity of the hydrocarbon analytical system permits detection of minor additions of hydrocarbons to seawater. Instrument sensitivity ranges from five to ten ppb in the stripped gas phase. One part-per-million (ppm) in the gas phase equals 20 nanoliters of hydrocarbon per liter (nl/l of seawater. Open ocean seawater has methane concentrations ranging from 2,000 to 10,000 ppb, ethane and propane concentrations ranging from 10 to 50 ppb, and butanes below 10 ppb (0.2 nl/l) thus, the instrument sensitivity is suitable for detection of microseepage.

A measurement of the total hydrocarbons is made approximately every 100 meters at six knots. At this speed a measurement of the light hydrocarbons is made every 250 meters, and a measurement of the gasoline-range hydrocarbons every 2.5 kilometers. This excellent coverage maximizes the chance of detecting bottom hydrocarbon seepage.

High-resolution/shallow geophysical profiling is often performed simultaneously or in conjunction with the SNIFFER to locate sub-surface features associated with petroleum seepage (faults, gas-charged sediments, shallow structures, gas in the water column, etc.) This information helps to confirm that observed anomalies are due to bottom seepage, to determine the bottom source of the seepage, and to correlate the geochemical data with subsurface geology.

INTERPRETATIVE METHODOLOGIES

Primary sources of hydrocarbon seepage

Figure 3 illustrates the three primary sources of hydrocarbon seepage in the marine environment:

1. Biological activity in the shallow sediments and water column.
2. Reservoired petroleum (oil and gas).
3. Deep sediments with hydrocarbons produced by the thermal degradation of organic matter (source rocks).

Determination of the source of detected anomalies is based upon difference in the hydrocarbon signature. Some of the primary differences in the light hydrocarbon signatures are summarized in Figure 3 and are discussed below.

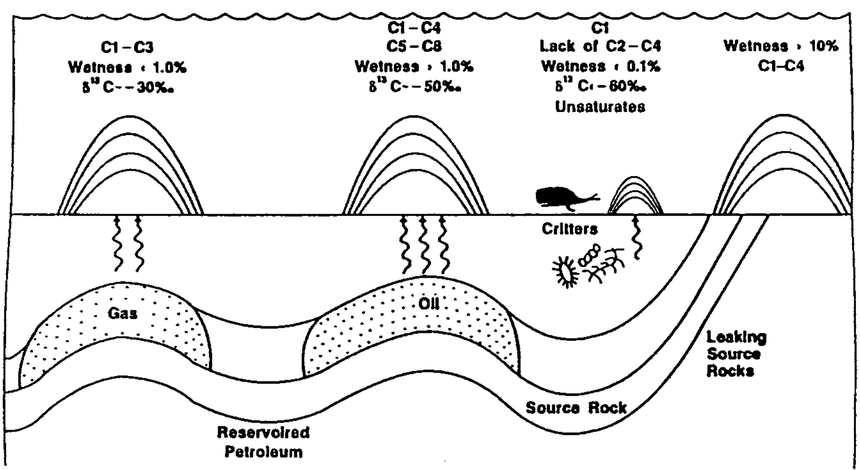

Figure 3: Primary sources of hydrocarbon seeps.

Biologically derived hydrocarbons are predominantly composed of methane. Some quantities of the higher carbon compounds (C2+) are produced but the unsaturated hydrocarbon compounds (ethylene and propylene) are thought to be produced in greater quantities than the saturated compounds (ethane and propane. The ratio of the C2+ compounds to methane, termed the hydrocarbon wetness, generally is less than 0.1%. The carbon isotopic signature of the methane is extremely depleted in carbon-13 relative to carbon-12, having values less than -60 per milliliter.

Thermal processes produce larger quantities of the C2+ hydrocarbons (higher hydrocarbon wetnesses) and little of the unsaturated compounds. The relative amount of the C2+ compounds, branched to straight chain compounds, and carbon-13 to carbon-12 of hydrocarbons produced by thermal mechanisms very depending upon the type of organic matter and thermal maturity as shown in Figure 4.

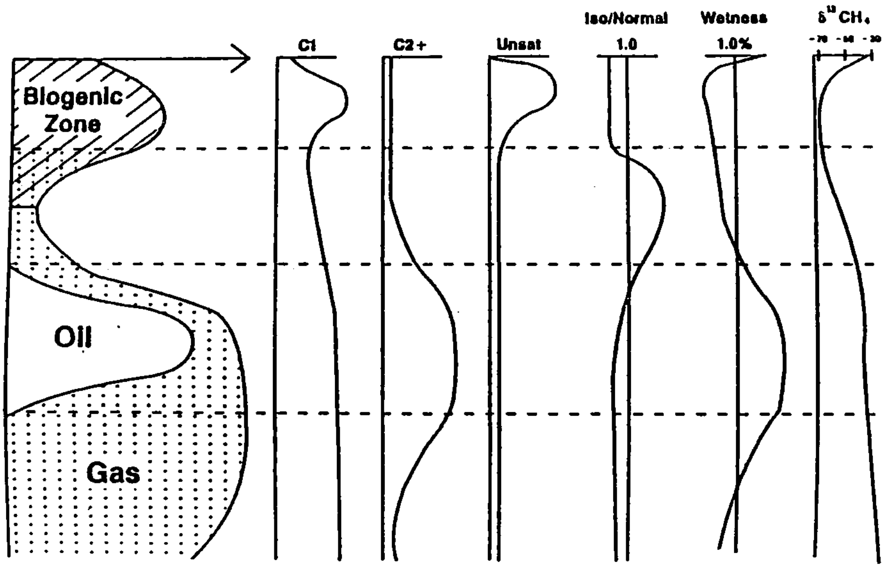

Figure 4: Hydrocarbon generation

Oil-associated hydrocarbon seepage tends to have the entire suite of the light hydrocarbons (C1 thru C4). Depending on the seepage rate, they can contain significant quantities of the gasoline range (C5 thru C8), longer straight-chained hydrocarbons (C15+ alkanes), and two- and three-ring aromatic hydrocarbon. Hydrocarbon wetness tends to be greater than 1% and the carbon isotopic signature of the methane is in the neighborhood of -50 per milliliter. Hydrocarbon seepage from thermally produced gas lacks significant quantities of compounds greater than propane (C3) and tends to have hydrocarbon wetness less than 1.0%.

The signature of hydrocarbons leaking from near-surface or outcropping source rock may differ from the typical thermogenic signatures described previously because of the differing mobility of the hydrocarbon compounds. Although the entire suite of light hydrocarbons may be present, wetness may be extremely high due to the preferential loss of methane.

A summary of the light hydrocarbon signature for the different sources is given in Table 1. Natural variations exist in light hydrocarbons derived from the different sources and secondary processes (oxidation, differential migration, etc.) may alter hydrocarbon compositions.

It is important to realize that the criteria summarized in Table 1 are not rigid and, at best, can only be used as guidelines in the classification of hydrocarbon seeps. Nevertheless, they allow geochemical interpretation which can be refined by integration with the sub-surface geology and local oceanography.

Table 1. Primary geochemical criteria used to characterize the source of hydrocarbon seeps.

Hydrocarbon Source	wetness (%)	C2:/C2	ibut/nbut	13C(‰)	(C5+)	CORRELATIONS ClvsC2	ClvsC3	ClvsC4	C2vsC3	C2vsC4
Thermogenic Oil-Associated	<1.0	<1	<1	–40 to –50	possible	good	good	good	good	good
Thermogenic Wet gas to condense	>0.1	<1	<1	–30 to –50	none	good	good	poor to none	good	good
Thermogenic Dry Gas	<0.5	<1	>1	–25 to –40	none	good	possible	none	possible	none
Biogenic Gas	<0.1	>1	>1	<–55	none	possible	none	none	none	none

Determination of seepage characteristics

The criteria defined in Table 1 are applicable to pure and unaltered hydrocarbon seepage. However, seawater and marine sediments both contain low quantities of hydrocarbons which are unrelated to deep seepage, and thus detected hydrocarbon anomalies represent a mixture of the pure seepage with this hydrocarbon "background" population. The processes creating and controlling the hydrocarbon background population are not well defined, but include biological production and fractionation, photosynthetic production and destruction reactions, and oceanographic transport. The background population has extremely variable characteristic from one location to another, but is always characterized by low quantities. For example, background concentrations of methane in the bottom water of the outer Bering Sea Basins off Alaska ranged between three and 10 ppm but the background hydrocarbon wetness ranged from 0.2% (similar to a dry gas signature) to 5% (similar to an oil signature). Thus, it is imperative that the background hydrocarbon population be considered before attempting to characterize hydrocarbon seepage.

Because the background population varies throughout the oceans, subtraction of a defined background level from the measured data can lead to erroneous conclusions. The SNIFFER approach uses cross-plots of key hydrocarbon parameters and searches for mixing trends between the back-ground population and hydrocarbon seeps. This interpretation method assumes that the hydrocarbon background population, for a given area, is defined by the majority of data at the lowest hydrocarbon value. When hydrocarbons are added to the background pool (as from seepage) a mixture of the two sources results. As the ratio of seepage to background hydrocarbons increases (higher hydrocarbon values) the various characteristics of the mixture such as C13, wetness, etc., approach the values of the pure seep hydrocarbons. Thus, when plotting a property (eg. 13C or wetness) versus hydrocarbon concentration, the background pool lies on the portion of the plot corresponding to the lowest hydrocarbon values and the purest seepage hydrocarbons lie on the portion of the plot corresponding to the highest hydrocarbon values. The characteristics of the hydrocarbon seepage deducted from these plots are then compared to the criteria in Table 1.

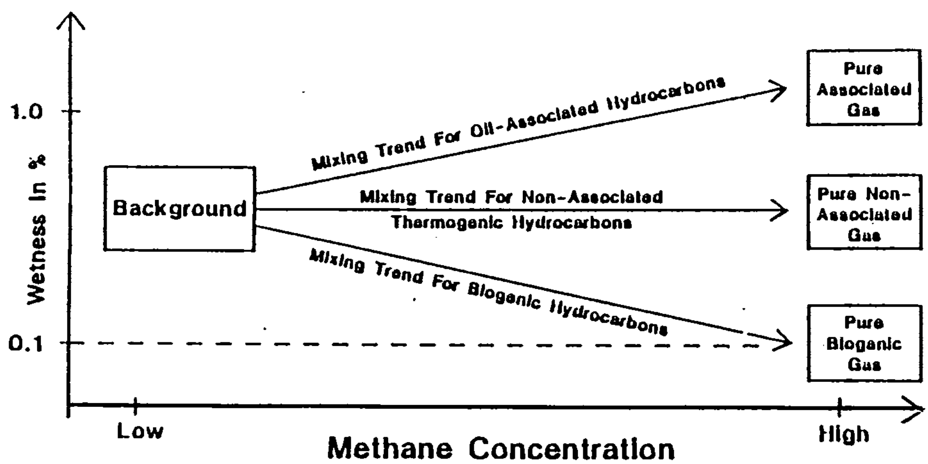

Figure 5: Seep characterization based upon mixing model.

This approach is illustrated in Figure 5, which shows the wetness ratio [(C2 +/ C1+) × 100] plotted against methane. The background hydrocarbon pool lies to the left-hand side of the plot, and the pure hydrocarbon source lie to the right side of the plot. Based on the criteria defined in Table 1, hydrocarbons from biogenetic and oil-associated sources would follow mixing lines characteristic of adding hydrocarbons with wetness of <0.1% and > 1.0%, respectively to the background. Presumably, wet-gases would lie between these two trends. The exact direction and slope of the mixing lines vary depending upon the characteristics of the background hydrocarbons and the hydrocarbon source.

Figure 6 shows a wetness versus methane plot for actual SNIFFER data.

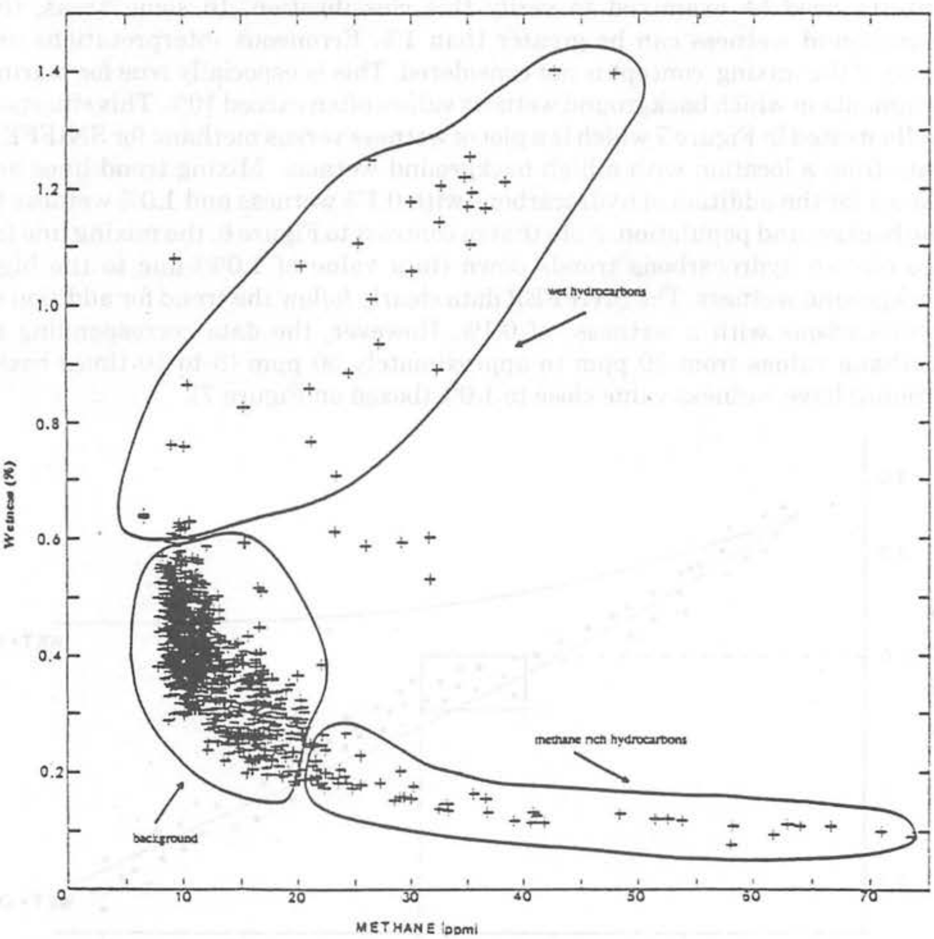

Figure 6: Wetness versus methane plot for actual SNIFFER data.

Three distinct hydrocarbon populations are apparent. The background group constitutes the majority of the data points and have methane values less than 20 ppm. The wetness of the background varies in this area from 0.2% to 0.6%. Two distinct mixing trends are clearly defined. One trend exhibits a decreasing wetness with increasing methane which is caused by the addition of hydrocarbons with a wetness of 0.1% or less. This source is clearly a dry gas, although a biogenetic versus thermogenic source cannot be deducted from this plot alone. The second trend exhibits an increase in the wetness with increasing methane which is reflecting the addition of hydrocarbons to the background with a wetness of at least 1.4%.

This wetness is characteristic of oil-associated hydrocarbons, although other criteria need be examined to verify this classification. In some areas, the background wetness can be greater than 1%. Erroneous interpretations are likely if the mixing concept is not considered. This is especially true for marine sediments in which background wetness values often exceed 10%. This situation is illustrated in Figure 7 which is a plot of wetness versus methane for SNIFFER data from a location with a high background wetness. Mixing trend lines are shown for the addition of hydrocarbons with 0.1% wetness and 1.0% wetness to the background population. Note that in contrast to Figure 6, the mixing line for the oil-like hydrocarbons trends down (to a value of 1.0%) due to the high background wetness. The SNIFFER data clearly follow the trend for addition of hydrocarbons with a wetness of 0.1%. However, the data corresponding to methane values from 30 ppm to approximately 50 ppm (8 to 10 times background) have wetness value close to 1.0% (boxed on Figure 7).

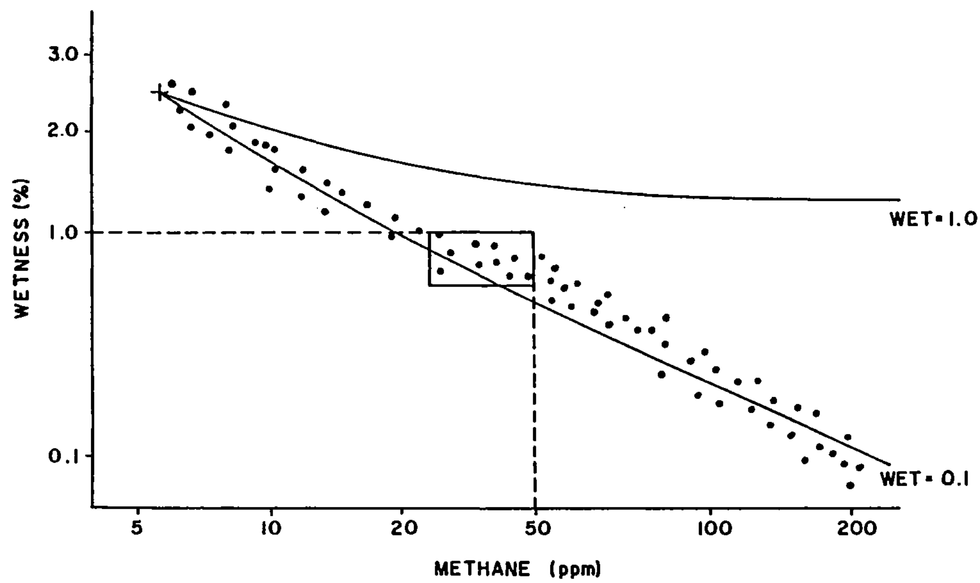

Figure 7: Plot of SNIFFER data from a location with high background wetness.

If the mixing concept was not considered, these data would be interpreted as representing oil-associated hydrocarbons. Identification and characterization of trends require a significant variation in the hydrocarbon concentrations (generally > 5 times background). The chance of observing variations of this magnitude is increased by collecting a large quantity of data. Cross-plots for the other criteria listed in Table 1 (iso-butane/normal-butane, ethylene/ethane, 13C) and any additional parameters of interest are also constructed and interpreted using the same approach. Discernible patterns versus the other hydrocarbons besides methane are often useful in characterization.

DATA INTEGRATION

Before any confidence can be placed in any data integration technique, case histories have to be developed to prove the worthiness of such integration. There have been several documented case histories which have been developed showing the use of SNIFFER data in locating and classifying productive basins and identifying structures within a basin.

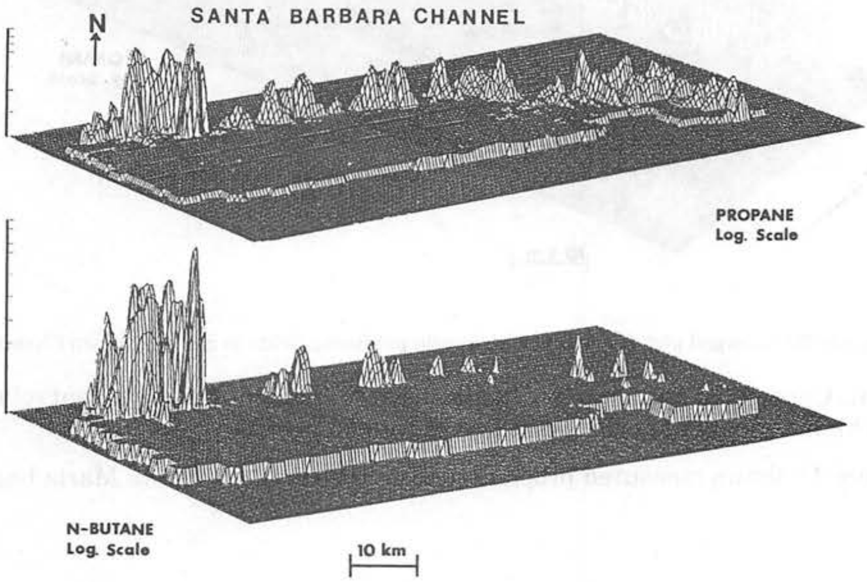

Figure 8: Measured propane and butane concentrations in Southern California and Santa Barbara Channel.

Southern California contains an abundance of onshore and offshore petroleum seepage. Macroseepage is apparent in some areas as visible slicks on the sea surface. SNIFFER surveys have been conducted along the entire offshore borderland from San Diego to Santa Maria. As expected in this region of known seepage, microseepage of hydrocarbons were numerous throughout many areas, three of which will be reviewed. Measured propane and butane concentrations in the Santa Barbara channel (extending from Oxnard to Santa Barbara) are shown in Figure 8 (propane = top figure and n-Butane = bottom Figure).

Discrete anomalies are present, superimposed on a regional elevated background population, Figure 9 shows an enlarged plot of propane annotated with the known producing fields.

The excellent correlation between individual anomalies and production is encouraging considering the high background and relatively rapid currents in this area. Notice the Santa Rosa location which was drilled, and reported barren as the absense of a SNIFFER anomaly indicated.

Figure 10 shows the measured propane and butane concentrations offshore

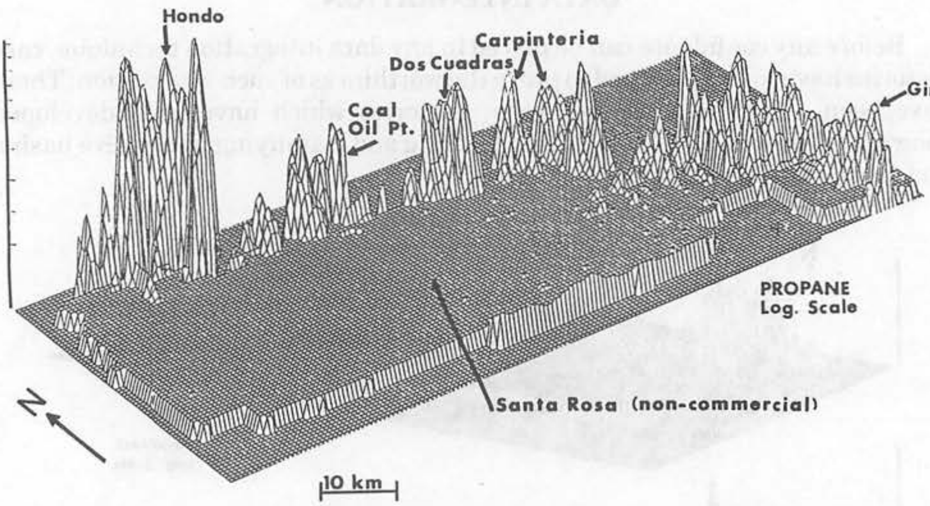

Figure 9: Enlarged plot of propane with known producing fields in Santa Barbara Channel.

Points Conception and Arguello. Again, discrete anomalies are apparent relative to a high regional background in this proven oil province.

Figure 11 shows measured propane concentrations in the Santa Maria basin

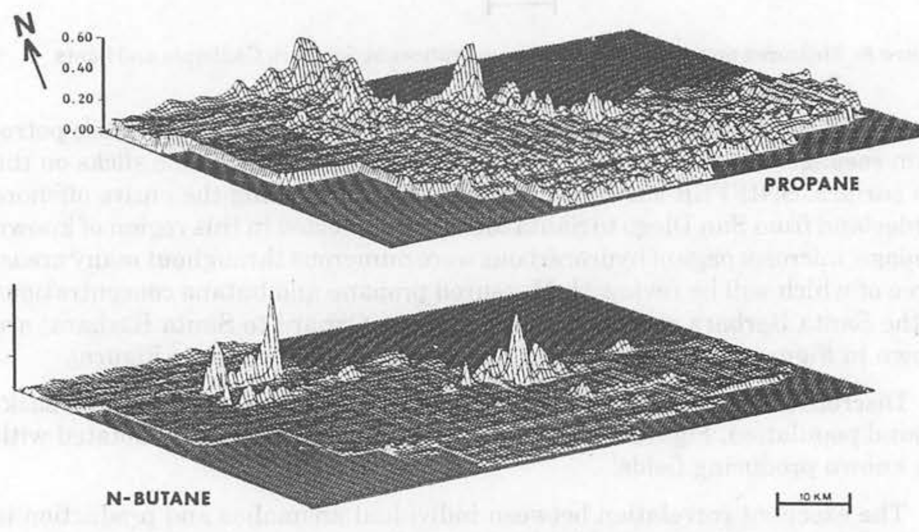

Figure 10: Measured propane and butane concentrations offshore California and Arguello.

The maximum propane values follow a linear north-south trend, coincident

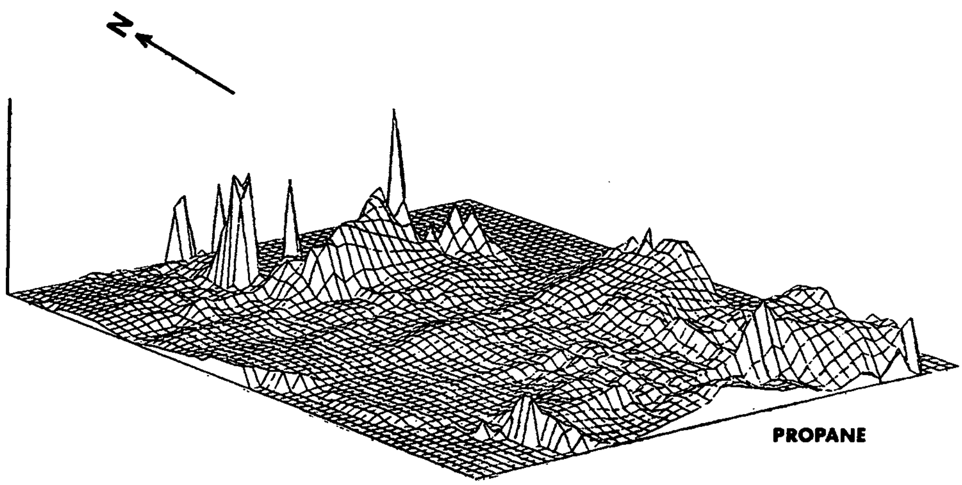

Figure 11: Measured propane concentrations in the Santa Maria basin.

with the "Hosgrie" fault. The other light hydrocarbons follow a similar pattern in this area and are characteristic of oil-associated seepage. Elevated hydrocarbon concentrations characteristic of an oil associated source were also observed near the major point Arguello field discovery. However, the concentration levels were not as large as observed along the fault zone. This observation is important because it illustrates that the magnitude of seepage is not related to the size of the underlying petroleum accumulation, but rather is dependent upon the conduit through the sedimentary section.

Gulf of California

Methane and propane concentrations from the northern Gulf of California are shown in Figure 12.

High ethane concentrations were also observed in this area. Two discoveries were announced by Pemex after this survey. The "Extremenio 1" gas-condensate field corresponded well with a methane through propane anomaly, a signature thought to represent thermally produced wet-gas. The "Carbon" dry-gas discovery had an associated methane and ethane anomaly but no ethylene or propane; a signature consistent with a dry thermal gas source.

Gulf of Mexico-Offshore Texas

A discrete geochemical anomaly was found associated with a structural feature. The high methane to propane ratio and lack of a significant increase in the butane concentrations indicated than reserves at depth were likely to be gas

(Figure 13)

Approximately 1 1/2 years after the lease sale, several wells encountered commercial quantities of gas in the structure.

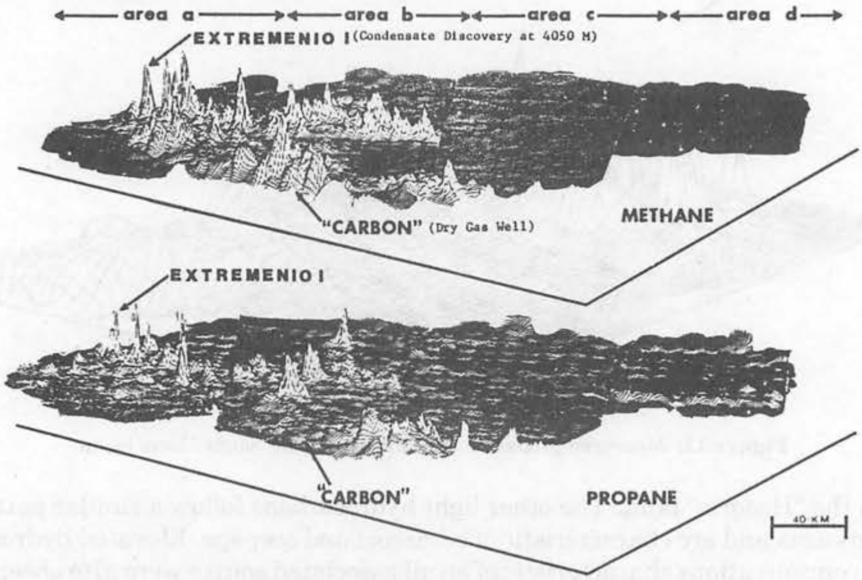

Figure 12: Methane and propane concentrations, northern Gulf of California.

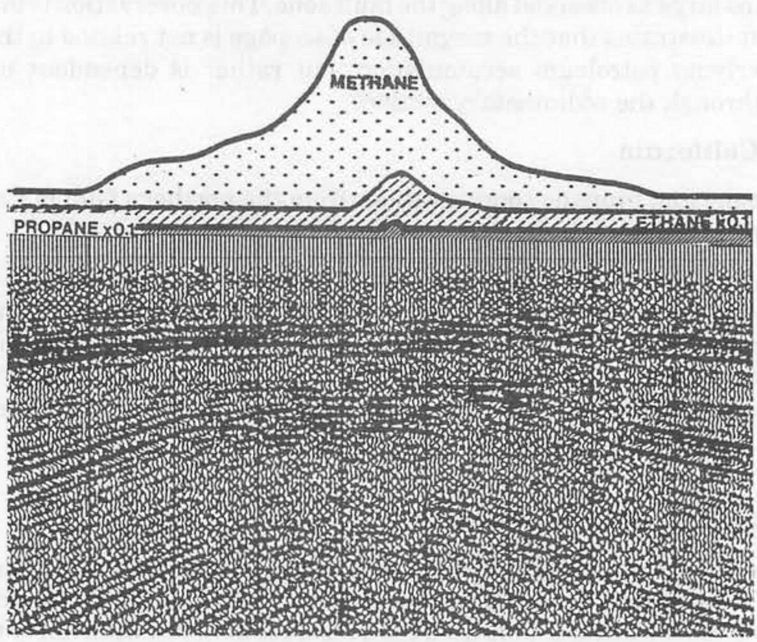

Figure 13: Discrete geochemical anomaly associated with structural feature.

Australia

Initial evaluation of this project focussed on the problem of selecting prospects from among a very large number of potential traps apparent in earlier seismic work (Figure 14). This led to consideration of a marine hydrocarbon SNIFFER detection survey as a possible method of detecting submarine oil seeps and thereby localizing the most interesting prospects.

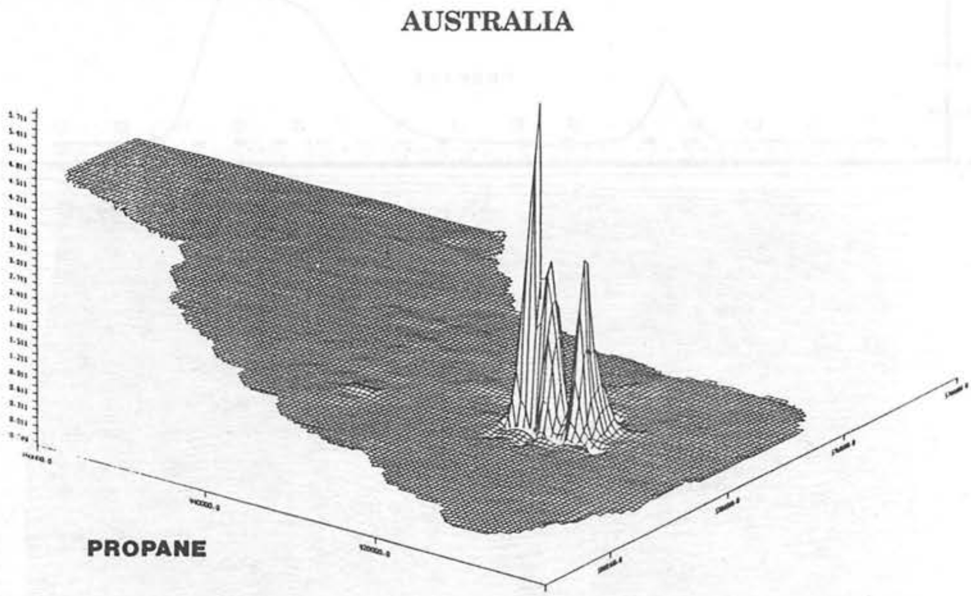

Figure 14: Submarine hydrocarbon detection SNIFFER survey, Australia.

Accordingly, a 1600/km submarine hydrocarbon detection SNIFFER survey was conducted and found a very large anomaly (figure 14) and numerous small anomalies throughout the southern half of the prospect. The ratios of the hydrocarbons detected are indicative of mature, natural crude oil seeps on he ocean floor. The large anomaly coincides with clouds of gas bubbles observed in sonar records, and occurs directly over a Late Tertiary river channel which breached the underlying Gambier Limestone. Additional seismic was conducted in the area of the seepage and revealed the existence of as many as a dozen deep Cretaceous folds which were not readily apparent in the earlier seismic work (Figure 15).

Case Analysis

We have permission from Sun Malaysia to disclose the methane values in this region. This information alone will not allow for the classification of the seep (gas or oil), but it will demonstrate the anomalous activity occurring.

A number of structures were identified from seismic data in offshore Malaysia. These structures occur at depths no greater than 4,000 feet and are believed to be capable of reservoiring hydrocarbons. The SNIFFER survey was conducted over an area containing some of the mapped structures and the results plotted over the structure map.

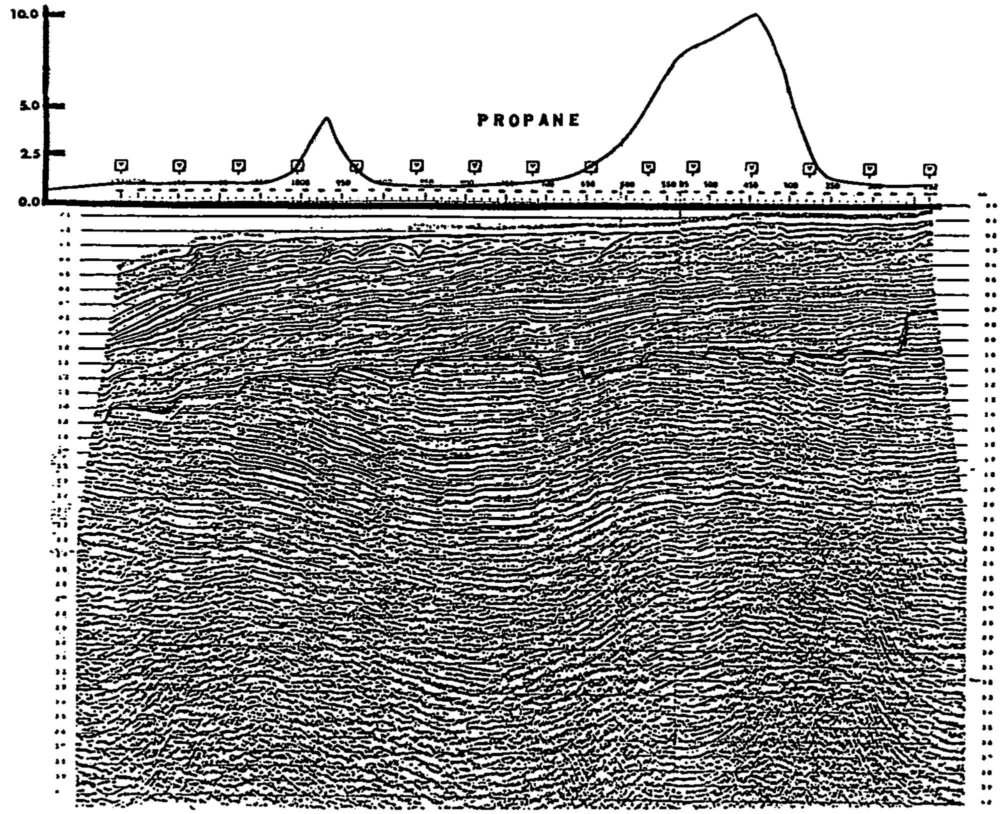

Figure 15: Additional seismic conducted in area of seepage.

A SNIFFER anomaly was detected, which directly overlays a seismically defined structure. Figure 16 shows the outline of the SNIFFER anomaly.

The SNIFFER anomaly clearly depicts seepage from the structure. The anomaly you are looking at shows the methane component which has gone from a background of 15 ppm to a high greater than 30 ppm, more than double the back-ground in the region. The information, along with the seismic, can help exploration geologists improve the odds of finding reservoired hydrocarbons. Several other anomalies were noted throughout the survey and correlation was made with other structures.

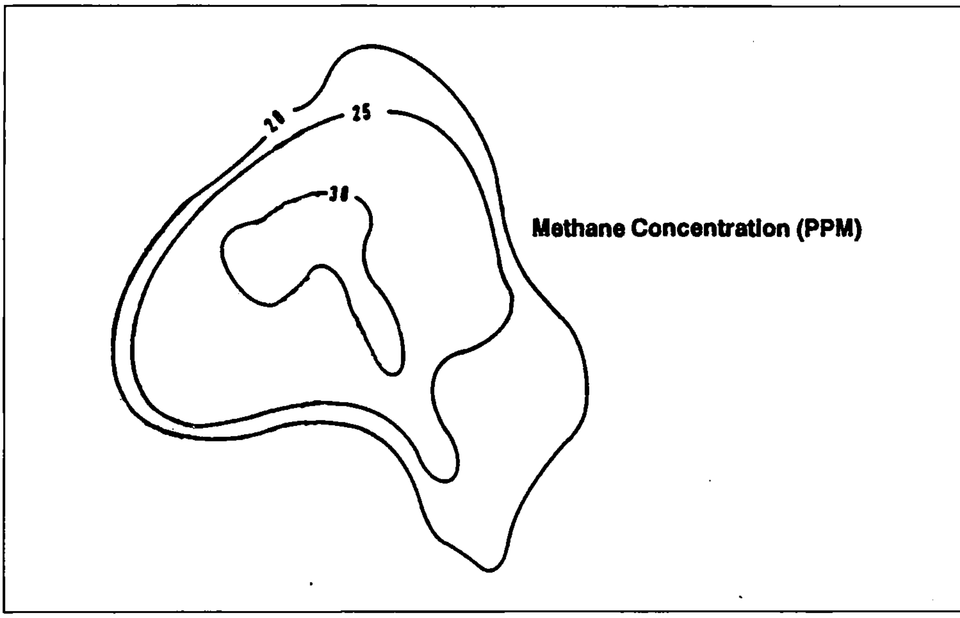

Figure 16: Outline of SNIFFER anomaly.

CONCLUSION

The integration of geochemical SNIFFER data with seismic and geological data has proven a valuable tool in its use throughout the world. Recent use in the waters off Malaysia is providing explorationists with additional information, aiding in the evaluation of the region along with individual prospects.

We want to thank Sun Malaysia for permission to disclose these partial results on their working prospects.

Manuscript received 18th January 1990.