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Spatial and Temporal Variability of Hydrocarbon Seepage, Offshore Gulf of Mexico, Regional and Local Variations As Defined by Natural Seeps

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In 1967 the Gulf Oil Company initiated a program to develop technology for locating seeps in the marine environment. By 1974 a fairly sophisticated system had been developed and installed on Gulf's seismic vessel, the R/V Hollis Hedberg. This system, operated by Gulf from 1974 to 1983 was used to collect an extensive "sniffer" geochemical database in the Gulf of Mexico that contains over 191, 000 dissolved gas analyses. A detailed evaluation of this database made with respect to discoveries made after the geochemical data was recorded showed that the data was 88 % effective in finding new commercial production. This technology not only has the ability to predict whether a block has hydrocarbon potential, but also whether it is more likely to produce oil or gas, a very important economic factor in the evaluation of offshore blocks.

This marine "sniffer" database extends from Florida to the Mexican border, covering the entire Texas and Louisiana offshore shelf. Active seepage anomalies demonstrate the actual extent and variability of oil and gas seeps, defining both the spatial extent and vertical variability of hydrocarbon plumes as they raise from the seafloor sediments. Spatial and temporal changes are quite distinctive when comparing natural versus anthropogenic seeps, which are almost exclusively related to leaking well casing and/or pipelines. This marine database allows the full complexity of dissolved hydrocarbons associated with deep marine seepages from natural and anthropogenic sources to be illustrated by numerous examples that demonstrate the variability of dissolved hydrocarbon concentrations in seawater.

This hydrocarbon seepage database provides the most extensive and complete coverage of the entire Gulf of Mexico shelf that has ever been collected. Dissolved gas measurements have been made at the surface (hull inlet) and at two depths (mid-tow, 450 feet) and (deep-tow, 600 feet), allowing both vertical and temporal measurements on regional and localized grids that cover a vast expanse of the offshore Gulf of Mexico. Examples shown will demonstrate the spatial, vertical and temporal variability of natural and anthropogenic seepages.

We dedicate this paper to the memory of our friend and associate, J.C. Searcy, Jr. who passed away February 24, 2015. JC's guidance and inspiration were instrumental in the writing of this paper and will be sorely missed.

INTRODUCTION

In 1966, Dr. Hollis D. Hedberg, Vice-President of Gulf Oil Company initiated a long range research project to create an exploration vessel for collection of multi-source geophysical and geochemical data capable of evaluating the oil potential of all worldwide marine areas. This vessel, a 220 foot long converted fishing trawler christened as the R/V GULFREX set sail from West Palm Beach, Florida for South American waters in October 1967. This research vessel was the first fully-integrated multi-sensor marine geophysical gathering and processing vessel ever commissioned by a private company, including the distinction of being equipped with the first commercial satellite navigation. Measurement of underwater hydrocarbon seeps were incorporated from the start, and had advanced to a capability for sampling 100 foot below the surface using a towed pumping system by 1971. Over its seven year history the GULFREX led to the discovery of several successful wells, in addition to bringing numerous petroliferous basins to the attention of the host governments where the vessel conducted surveys. In addition to working for Gulf Oil, the GULFREX program aided Joint Oceanographic Institutions Deep Earth Sampling (JOIDES) in its deep sea drilling project, provided computer processing techniques to Lamont-Doherty Geological Observatory and advised the National Science Foundation on ways to improve the effectiveness of government oceanographic surveys.

Based on this success, Gulf commissioned a second entirely new research vessel, the R/V HEDBERG in May of 1974. This vessel designed from the keel up was the most modern marine geophysical research platform in the world and the only vessel equipped with a complete on-board seismic processing capability. This vessel, which could operate anywhere in the world on a 24 hours per day basis for 60 days without a port call traversed the world, in addition to all US offshore coastal areas. By 1974 Gulf's marine sniffer system was much more sophisticated and was capable of digitally recording seepage related hydrocarbons at three different depths (Jeffrey and Zarrella, 1970, Mousseau and Williams, 1979, Mousseau and Glezen, 1980, Mousseau, 1980, 1981a, 1981b, 1983, Williams, Mousseau, and Weismann, 1981). Each stream was analyzed for seven (7) hydrocarbon gases once every three (3) minutes with a sensitivity depending upon the hydrocarbon. For example, there are approximately 50 picoliters of propane at STP per liter of seawater. The towed pump/sensor systems (see Figure-1a) are connected by a fared umbilical to an onboard laboratory module. The hydrodynamic towfish shown in Figure-01a contains a submersible pump, conductivity, salinity, temperature, depth sensor (CSTD), and echo sounder transducer.

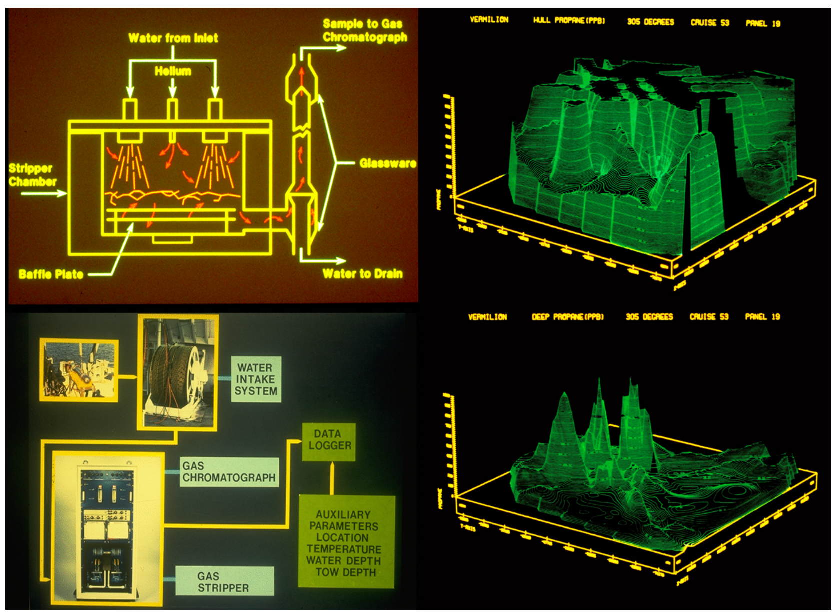

Figure-01 a) Partial Pressure Gas Stripper Chamber, b) Diagram of Dissolved Hydrocarbon System and c) Contour Maps of Propane: Contamination from Production Platform (top) and natural seeps (bottom).

Under normal operational conditions, the fish is maintained within the range of 4 to 8 meters above the seabed. The towfish is connected to the winch and handling gear by an umbilical. The umbilical consists of a central nylon hose surrounded by power and signal conductors encased in a polyurethane sheath with a woven stainless braid. Low-drag hydrodynamic farings insure the towfish follows close to the stern of the vessel and achieves the maximum depth for a minimum amount of deployed umbilical. Water is pumped through the umbilical to the laboratory module at approximately 6 to 9 liters per minute. The water sample is usually split into two independent streams to supply a dual gas extractor system. Duplication of the gas extractor system allows additional independent analytical equipment to be used. It also provides redundancy, when required due to failure, or for routine maintenance. As shown by Figure-1b, each gas extractor consists of a glass stripper chamber into which the seawater is sprayed through a fine jet nozzle. The water level in the stripper is maintained at a constant height by a pressure regulated flow control system.

In the Gulf Oil Corporation marine geochemical sniffer system, which is shown diagrammatically in Figure-1a, a helium carrier gas is equilibrated with a water phase in such a way as to allow the stripper to be operated under pressure, preventing any contamination from the onboard laboratory into the extracted gas stream. This dissolved gas analysis system has proven to be very reliable for conducting sniffer surveys because the stripper has no moving parts or pumps to fail. The dissolved gases from the stripper are then sent to a gas chromatograph by the helium stream. Analysis of these gases by Gulf included: methane, ethane, ethylene, propane, propylene, iso-butane, and normal butane. A computer system is used to continually monitor the conductivity, salinity and depth of the fish sensor signals, with navigation data in UTM coordinates acquired every three (3) minutes at the start of the GC analysis. The time lapse between collection of the water sample and the navigation time must be accounted for by the computer system. It is approximately three minutes using a 600 feet deep towfish.

The initial purpose for deploying the sampling inlets at different depths is to differentiate between surface contamination and natural microseeps. Although surface contamination can be a major interference to shallow sampling, as shown by contour maps in Figure-01c, surface contamination is not a factor in relating the seeps observed by the deep inlet to their seafloor location.

A typical display form for "sniffer" data when deployed in conjunction with seismic is illustrated in Figure-2, which shows methane and propane superimposed to scale on a seismic record from a deep tow inlet in profile form. The bright spot under this anomaly is likely a shallow drilling hazard. Note the bright spots marching down the SW dipping fault. Such records were produced at sea to aid the on-board explorationist in generating real time evaluations of hydrocarbon potential of structurally significant areas. The anomaly represented by Figure-2 is referred to as a "localized" anomaly because of the relatively short duration of the hydrocarbon signal and the magnitude of the hydrocarbon concentrations relative to regional background. Several "bright spots" may be seen on the seis-

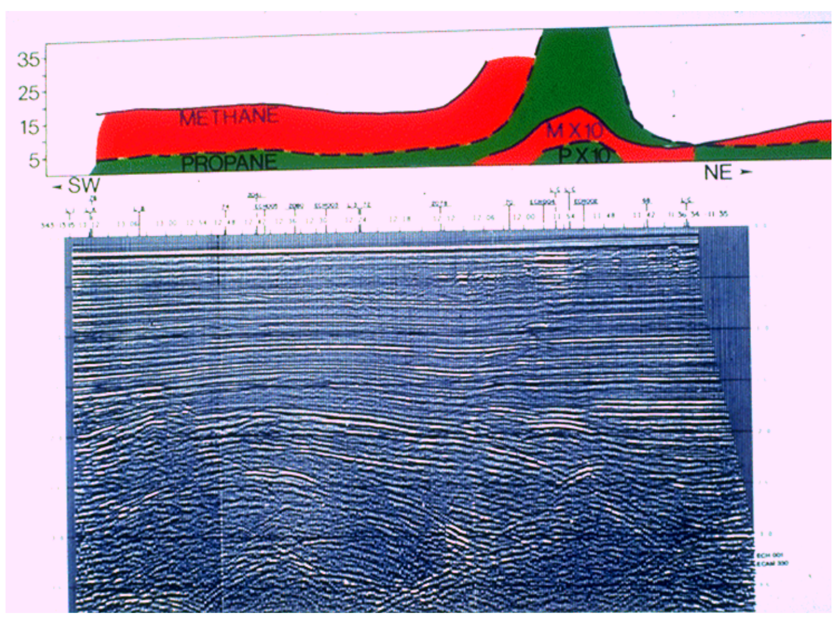

Figure-02 Marine Geochemical "sniffer" anomaly showing methane and propane concentrations measured over a Shallow Brightspot, Illustrating Association with deep seismic.

mic section at depth, as well as shallow gas-charged sands, presumably sourced by migration along the observed fault plane. Surface contamination can be a major interference to shallow sampling, but is not a factor in producing the seeps observed by the deep inlet. The objective was to generate deep localized anomalies that could be related directly to specific seismic features.

The offshore Texas and Louisiana Gulf Oil Gulf of Mexico sniffer data set consisting of over 190,000 gas measurements is shown in Figure-03. The data was given by Chevron to Texas University, who then gave it to Texas A&M University, then to HARC (Houston Area Research Council) and finally purchased from HARC by ETI in December 2000.

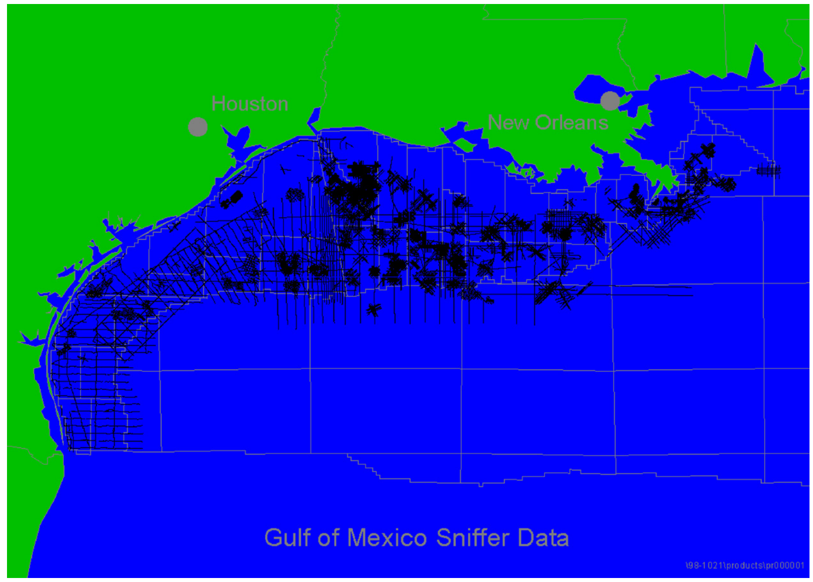

Figure-03 Gulf of Mexico "sniffer" Data Set showing 190,000 measurements collected along regional and gridded seismic lines from 1974-1983.

Since hydrocarbons dissolved in the water column are derived from the underlying source rocks and reservoirs, it stands to reason the methane through butane ratios of the seeps should mimic their sources. All hydrocarbon reservoirs, even those which produce primarily liquids, contain low molecular weight hydrocarbon gases. The composition of these gases generally shifts toward higher molecular weight components (more propane and butane relative to methane) in oil reservoirs (Nikonov, 1971; Pixler, 1969; Bernard et al., 1976; Drozd et al., 1981; Jones and Drozd, 1983).

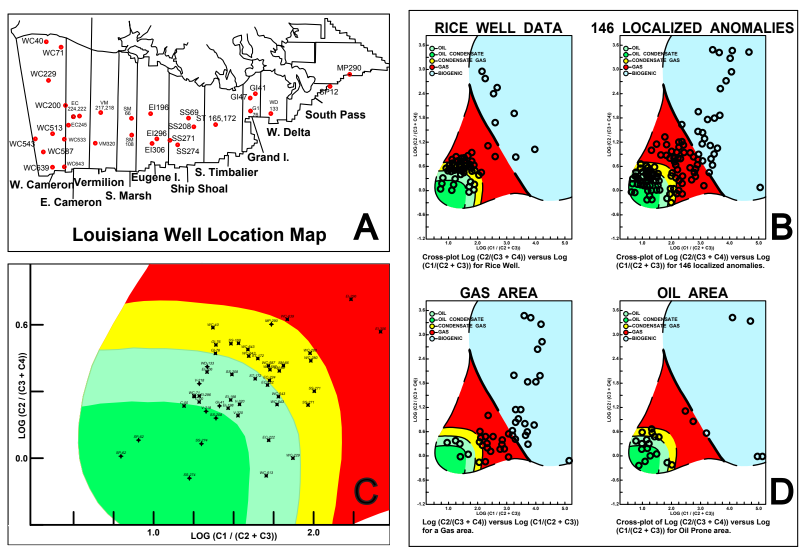

Figure-04 a) Location of Production Well Data Base Used to Calibrate Marine Compositional Cross Plots, Dudley Rice USGS open file report (1978) b) Cross Plot of Production Well Data showing Compositional Boundaries used to separate oil (green), oil-condensate (light green), gas-condensate (yellow), gas (red) subdivisions, Dudley Rice USGS open file report (1978) c) Cross Plot for 146 localized "sniffer" anomalies compared with Rice (1978) Production Wells d) Cross Plot for localized "sniffer" anomalies collected in an oil versus gas prone areas.

A data base of production well data is available from a USGS open file report published by Dudley Rice (Rice and Threlkeld, 1978). This report contains an analysis of the production gases for 70 producing wells collected from 32 fields, as shown by Figure-04a. Compositional cross plots generated from this well data base are shown in Figure-04b. For these plots the log of the ratio of ethane to propane plus butane is plotted against the log of the ratio of methane to ethane plus propane (Williams et al., 1981, Drozd et al., 1981). The color subdivisions shown were selected to show the range for oil (green), oil-condensate (*light green*), gas-condensate (yellow) and dry gas (red). These subdivisions were selected from a review of the wells GOR and carbon isotopes. A further division for biogenic gas, supported by the methane carbon isotopes, is shown in Figure-04c. For an initial test, one hundred and forty-six (146) localized Hedberg "sniffer" anomalies were plotted on the right hand side of Figure-04c for comparison with this Gulf of Mexico Rice well production data. As shown, these localized "sniffer" anomalies have a very similar distribution to the well production data, supporting this approach. Many additional comparisons were made, as shown by Figure-04d, where a survey in West Cameron over a gas-prone area was compared to a Vermilion oil-prone area.

Figure-05 shows a variety of seismic-geochemical examples from the Gulf of Mexico "sniffer" data base where methane, ethane and propane have been profiled on seismic lines. As shown, both gas, oil and condensate composition anomalies can occur on any line within any area due to the fact that both associated and independent gas and/or oil reservoirs can be formed within any area. However, the more regional, oil versus gas source trends are preserved (i.e. West Cameron versus Vermilion shown in Figure-04d). Such regional compositional changes can easily be observed given adequate sampling. Figure-06 shows a comparison of the gas versus oil reserves with the number of oil versus gas seepages for the selected Gulf of Mexico offshore blocks (Mousseau and Williams, 1979). Except for the Vermilion block, the seepage percentages match the known reserves very well. The obvious conclusion is more oil reserves can likely be found by directing future surveys towards areas containing the highest percentage of oil versus gas seeps (i.e., in this case the Vermilion area).

In 1979 Gulf Oil Company applied this approach for evaluating the offshore potential of all the offshore U.S. basins, as shown by Figure-07, where the mean methane is plotted against the mean propane for each area. A comparison of the

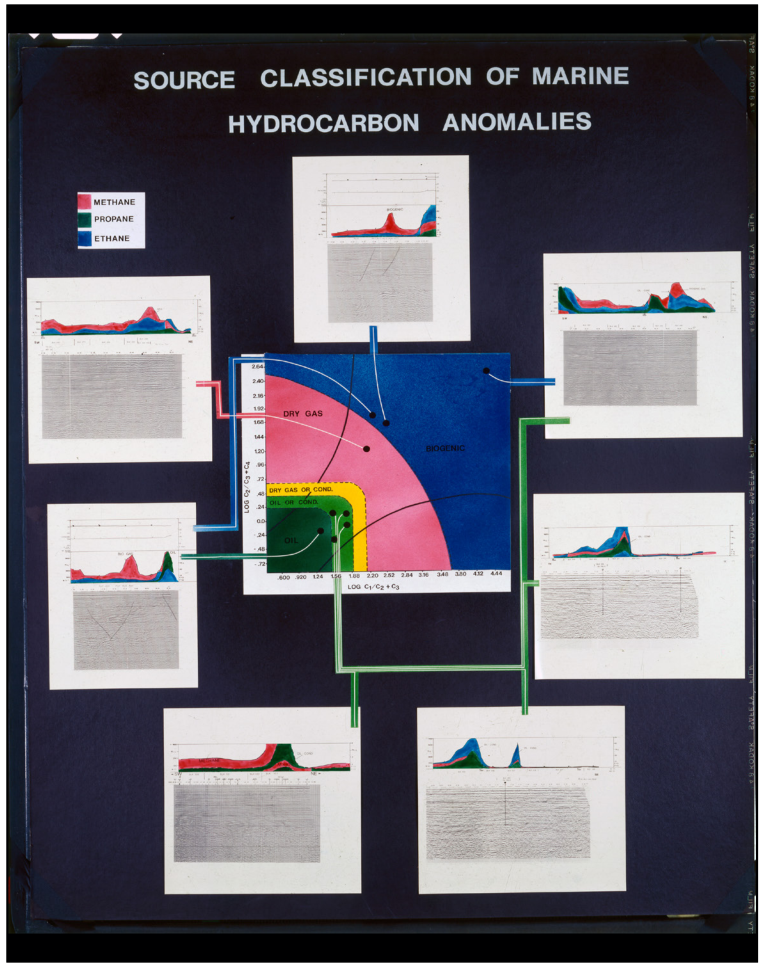

Figure-05 Variety of seismic-geochemical examples with methane, ethane and propane profiled above seismic lines from Gulf Oil Gulf of Mexico "sniffer" database.

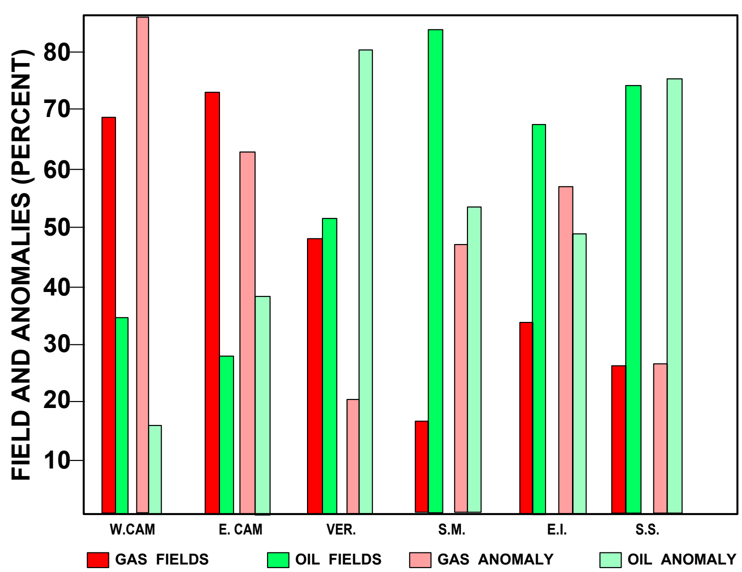

Figure-06 Comparison of known oil and gas reserves with the number of oil and gas seeps in selected offshore Gulf of Mexico blocks.

mean propane value posted on the U.S. offshore areas in Figure-08 appears to provide an excellent guide to the oil potential within each area. Clearly, the winner is the Louisiana offshore Gulf of Mexico with a mean propane of 2.7 nl/l, followed by the Oregon and California offshores, with means of 2.0 and 1.3 nl/l, respectively. This estimate made when the GOM data base contained only 66,000 measurements suggested that the offshore Texas and Florida areas were probably not as prospective as Louisiana. Evaluations of the Hedberg "sniffer" data played a significant role in Gulf's interest in the California offshore, which unfortunately, is no longer available for exploration.

The GOM "sniffer" data can be divided into regional and gridded data, as shown in Figure-09. The regional data collected from 1975 to 1983 contains approximately 470 lines covering 15,000 miles of data sampled on 0.25 mile spacing. The gridded data was mostly collected after 1980 in the Louisiana offshore for prospect development. A comparison of these two data sets shows that the offshore central Gulf has a lower density coverage as compared to offshore Texas, leaving the offshore Louisiana area under sampled. Trend surface methane, propane and ethylene contour maps generated from the regional data are shown in Figure-10. For these maps a moving average for the individual gas concentration was calculated using a 50,000 foot diameter circle by moving the circle 25,000 feet (50%) for each calculation. It is significant to note these contour maps fit the earlier mean values calculated back in 1979. Even more importantly, they are now confirmed by drilling, demonstrating that the oil potential of the Texas and Louisiana offshores are not equivalent.

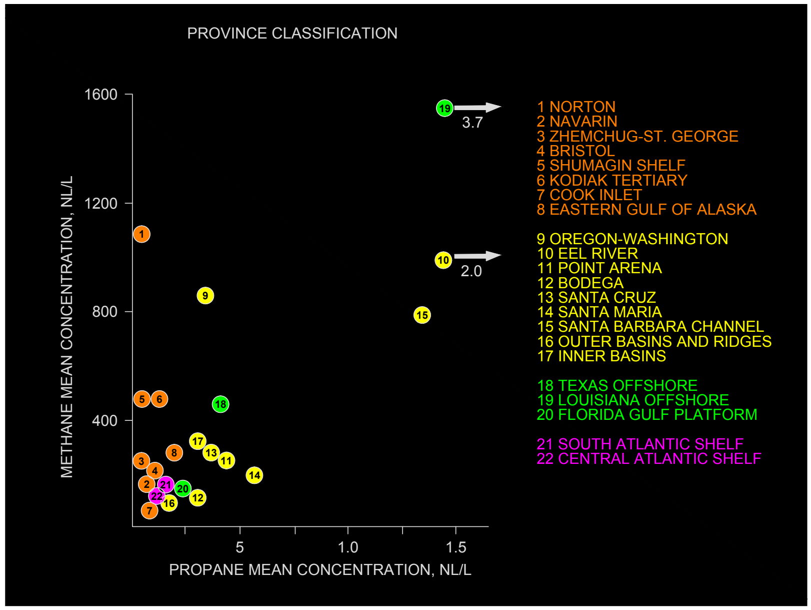

Figure-07 Ranking of U.S. offshore provinces based on the mean methane and propane concentrations derived from "sniffer" surveys conducted by 1979.

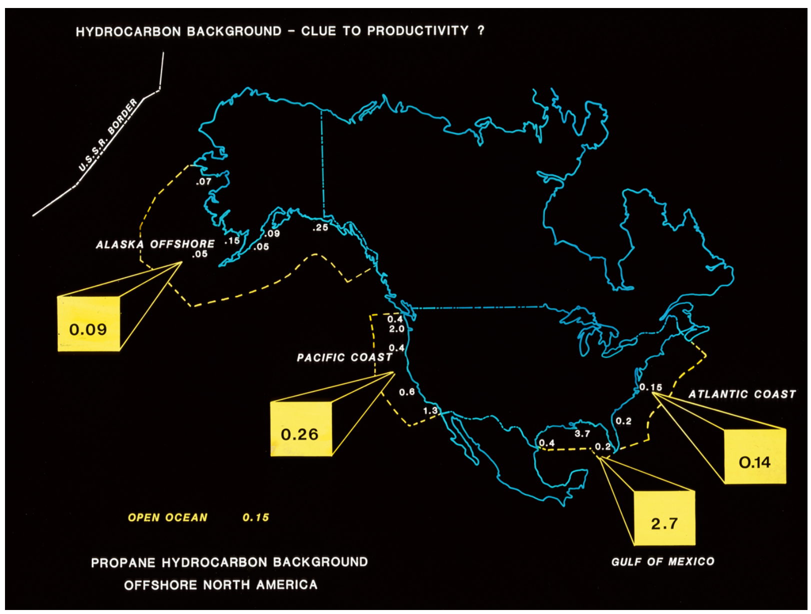

Figure-08 Posted mean propane concentrations measured by "sniffer" surveys conducted by 1979 over U.S. offshore provinces provides a measure for future oil potential.

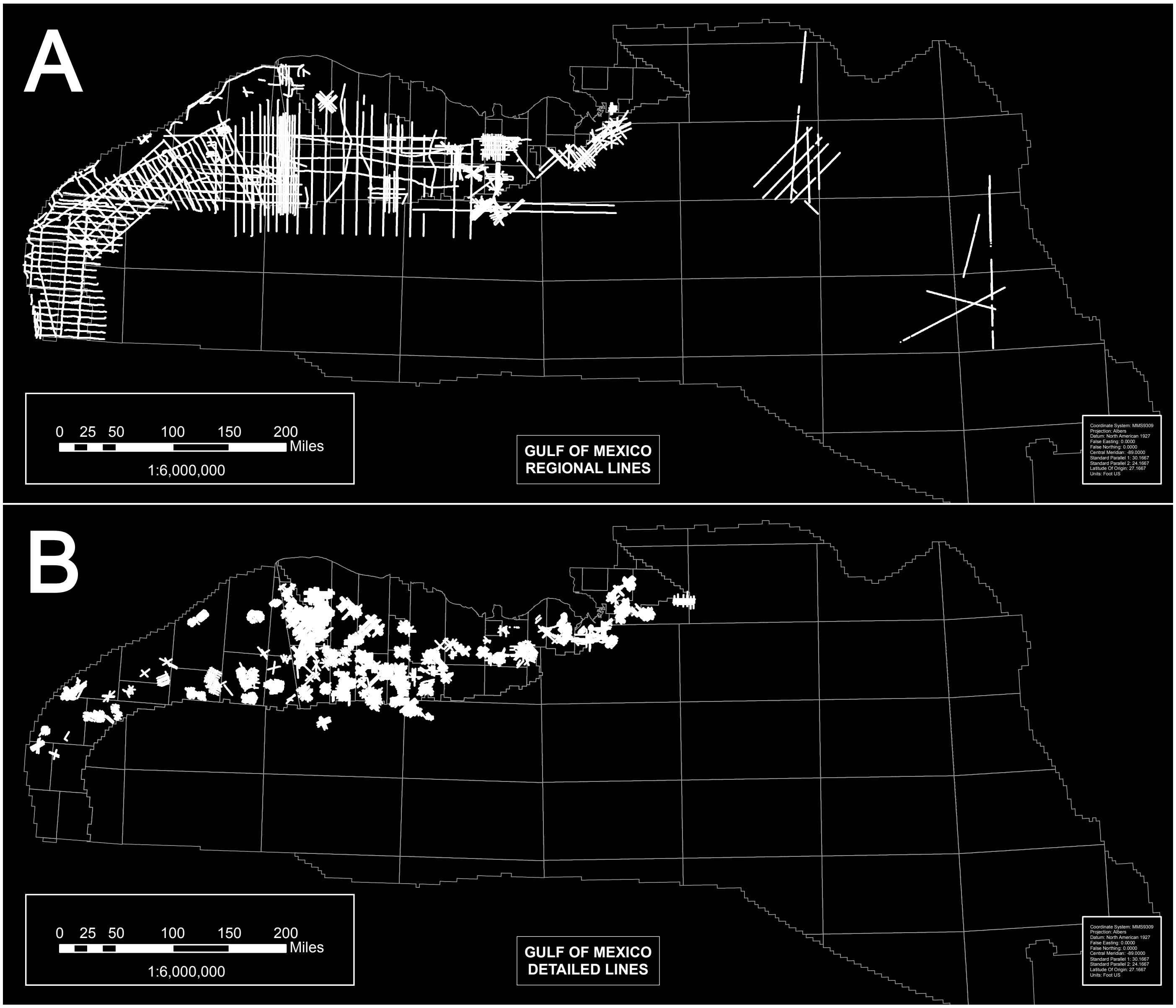

Figure-09 Gulf of Mexico a) regional and b) gridded sniffer surveys

Additional applications include pipeline leak detection and marine pollution monitoring (Aldridge and Jones, 1987). Two near-surface contamination examples have been included in Figure-11 and Figure-12. The first is a pipeline survey and the second is a leaky well casing in the Bonaparte Basin in Australia. This 82 km pipeline runs from a depth of 120 feet to the beach. Sniffer anomalies magnetically guided by an underwater ROV allowed the direct detection of vertically rising seeps, the largest seep had visual bubbles at the surface; lower magnitude seeps did not.

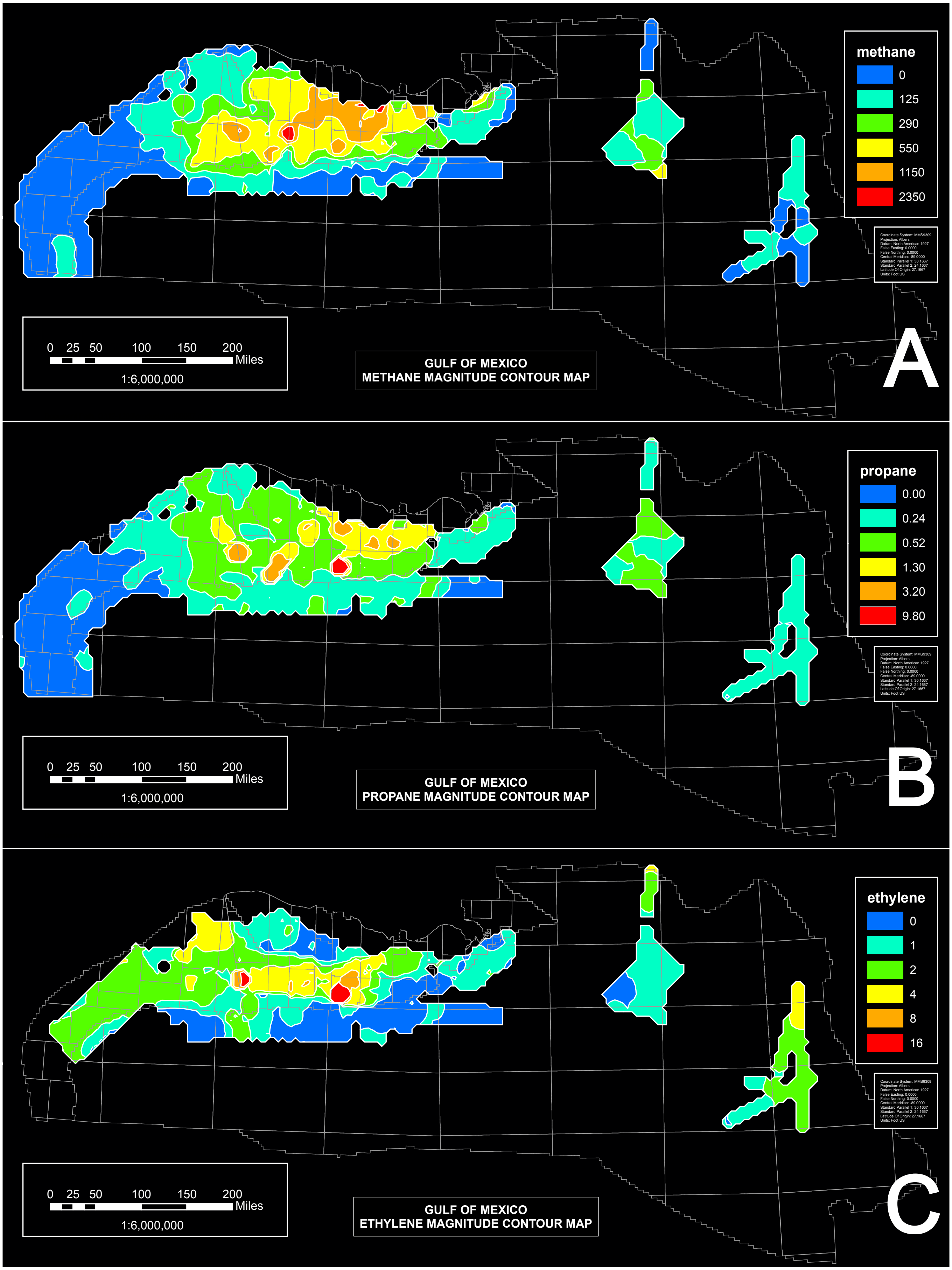

Figure-10 Trend surface contour maps for a) methane, b) propane and c) ethylene calculated from regional "sniffer" data. A 50,000 foot diameter circle was moved 25,000 feet (50%) for each grid point.

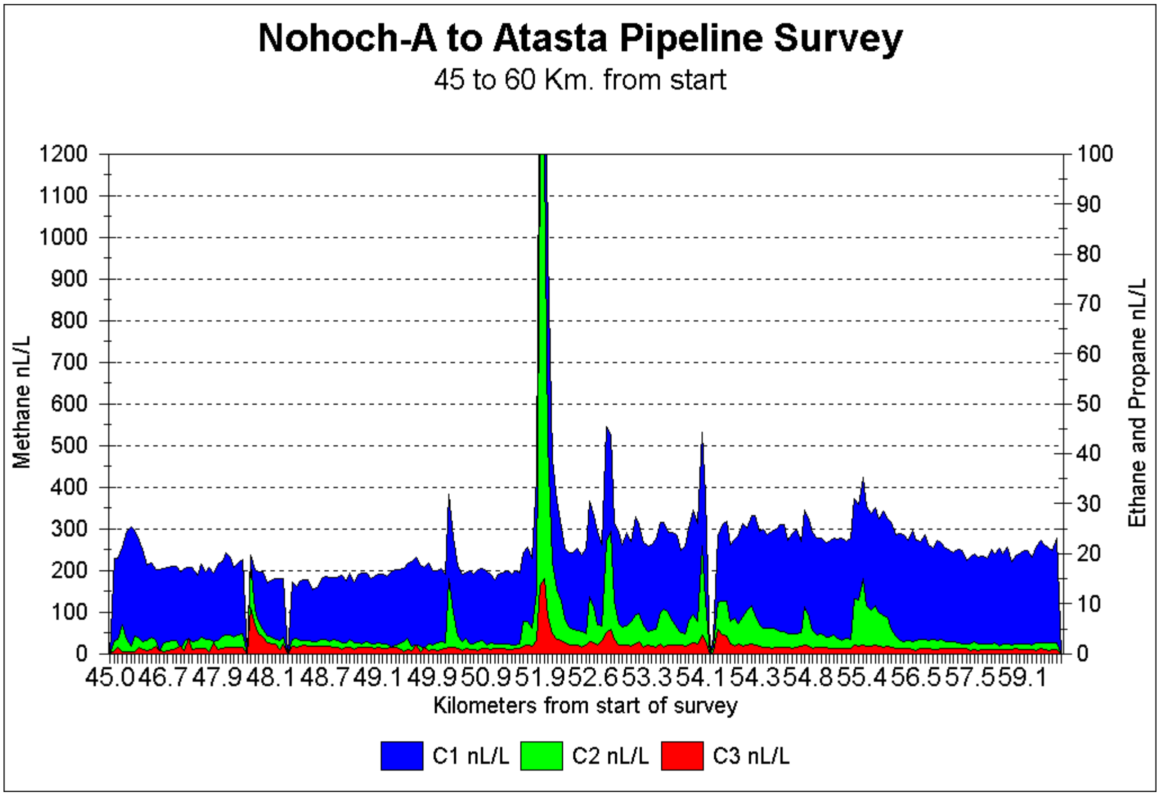

Figure-11 An 82 km offshore pipeline was surveys for leaking hydrocarbon gases using an underwater ROV magnetically tracking the pipeline.

Central Bonaparte Basin, Australia

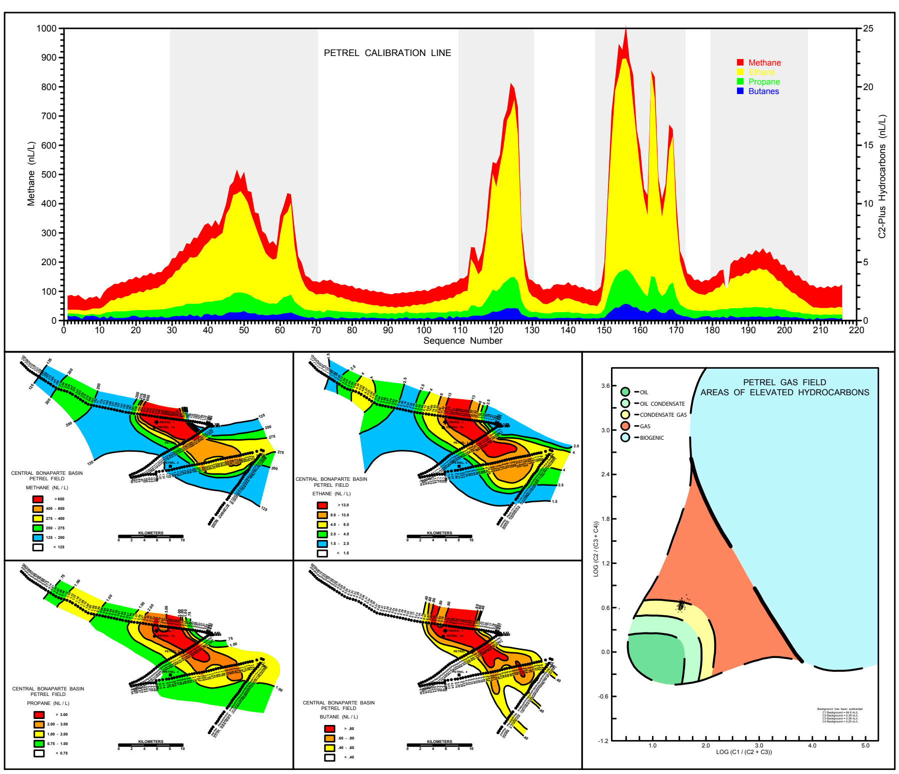

Figure-12 Hydrocarbon plumes from a leaking well casing conducted in the Central Bonaparte Basin, Australia.

All of the above examples included only the deep tow “sniffer” data using only localized anomalies like those shown by Figure-02 and Figure-05, with little to no regard for the hull data, which could possibly be compromised by contamination from production platforms. More recent evaluations of both the deep and hull inlet data has shown very little evidence of contamination. One reason is the ship with its trailing seismic array had to make wide berths around the platforms, and the second is the data was collected between 1974 and 1983, providing data long before many of the GOM offshore areas were developed. It is, quite instructive to make profiles of the deep and hull inlet data, which shows they are typically much better correlated than was originally expected. Each profile shows methane (red) at the top, followed by ethane (green), propane (green) and ethylene (green). Propylene is plotted in yellow, and water depth (green) is plotted on the bottom of each trace. The first three profiles show the typical, well-coordinated deep tow and hull inlet data.

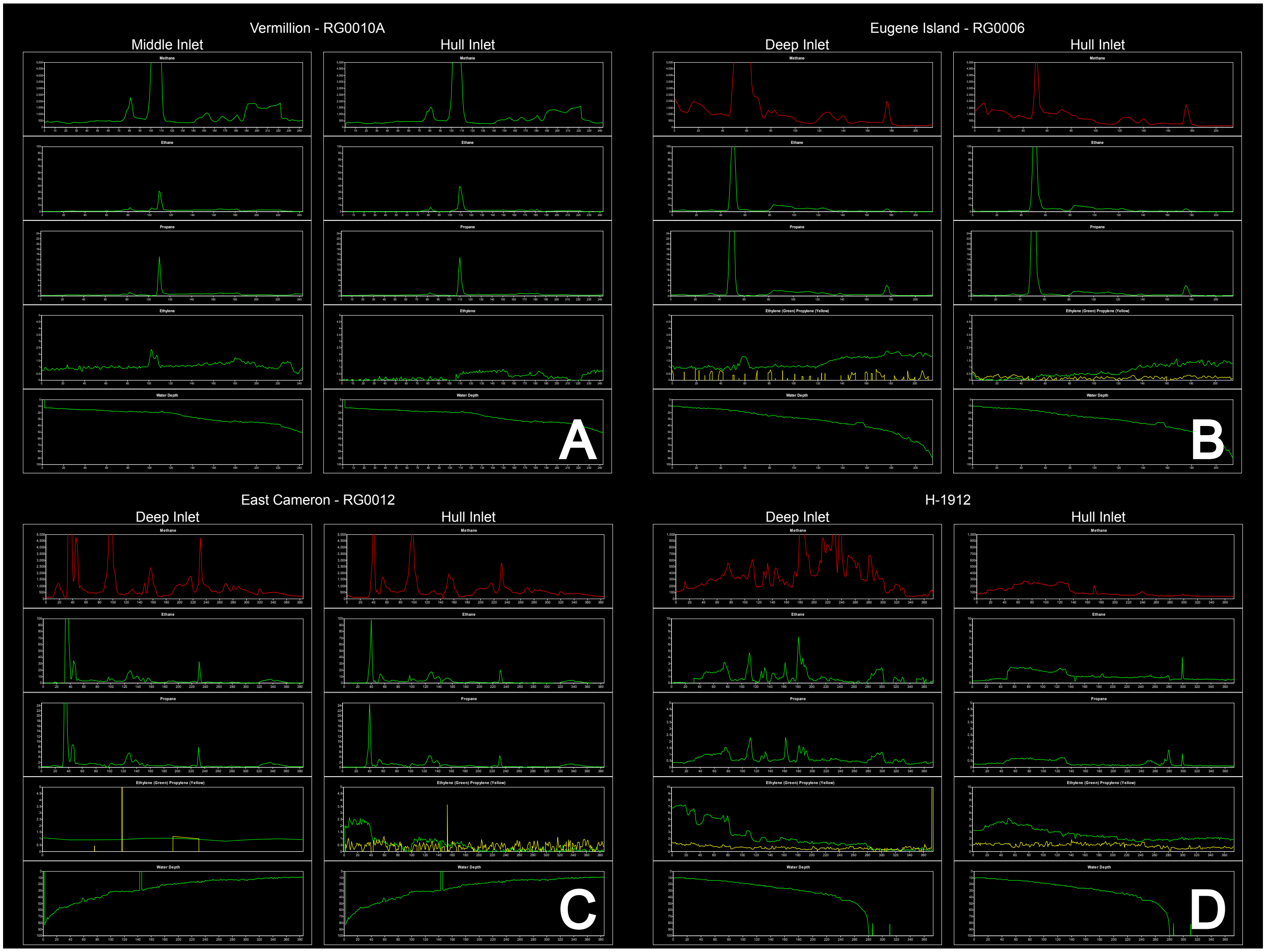

Figure-13 a) Deep and Hull inlet profiles on line RG0010A in Vermillion block showing identical peaks indicating vertical seepage. Note small ethylene in deep data, b) Deep and Hull inlet profiles on line RG0006 in Eugene Island block showing nearly identical peaks, with some independent methane, indicating vertical seepage, c) Deep and Hull inlet profiles on line RG0012 in East Cameron block showing nearly identical peaks indicating vertical seepage, d) Deep and Hull inlet profiles on line H-1912 shows an atypical line where the hull data does not match the deep inlet. Correlated peaks occur everywhere on the deep inlet except for sites from 220 to 280, where independent methane dominates.

Figure-13a is a north to south profile in Vermillion in approximately 20 fathoms of water. With the exception of a small ethylene peak in the deep data, the two profiles are remarkably similar. Again, nearly identical profiles are shown in Figure-13b, with the main difference being a wider methane peak in the deep data, suggesting some independent dry gas that dissolved before reaching the surface. There is also a small ethylene peak in the deep data that appears to correlate with the independent methane. Line RG0012 shown in Figure-13c exhibits several sharp, correlated anomalies on both the deep and hull inlets. Interestingly, this line has no ethylene peak.

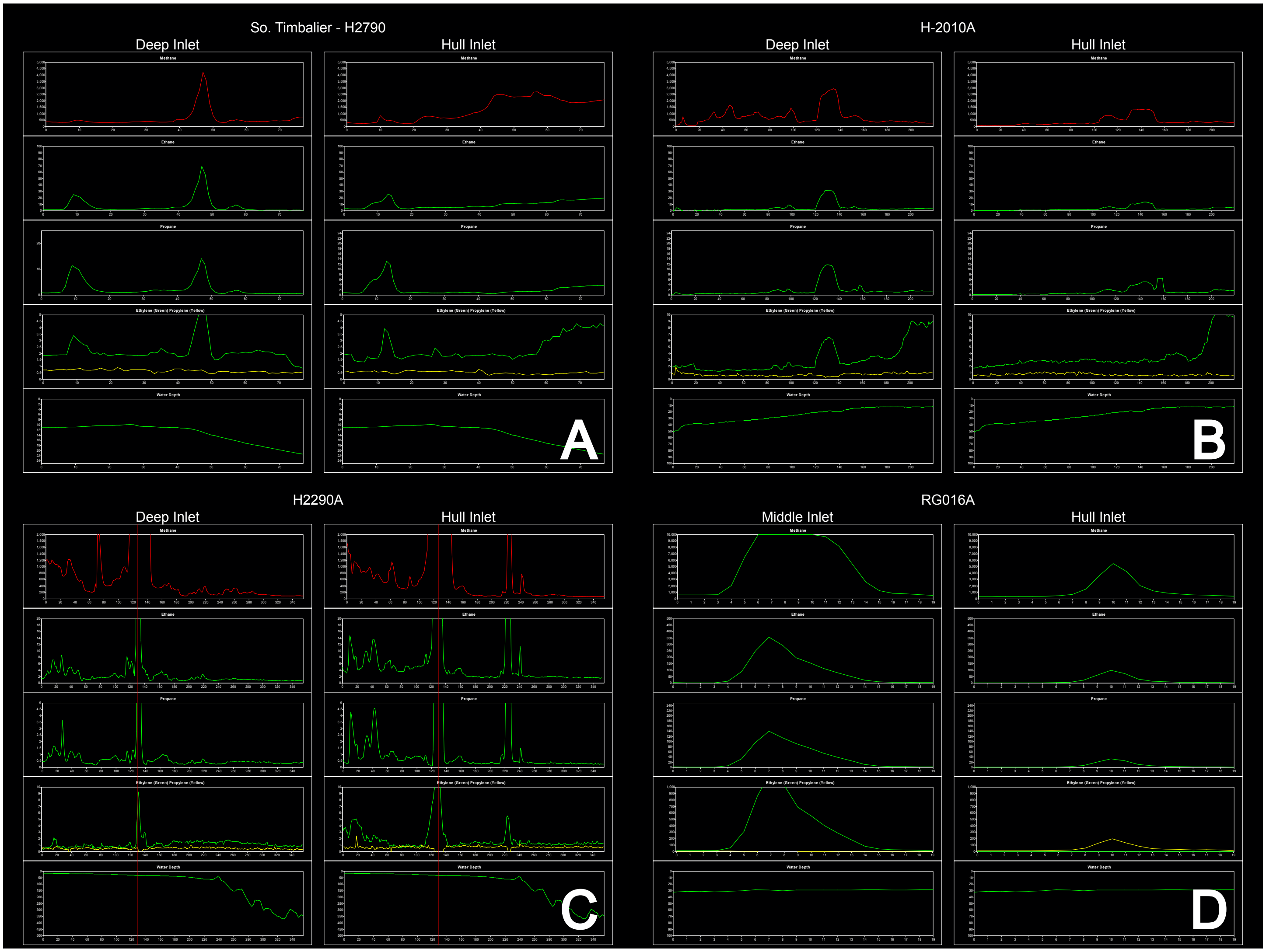

Figure-14 a) Deep and Hull inlet profiles on line H-2790 in South Timbalier shows another atypical line with one correlated peak at site 10 but no correlated peak at site 47 where the hull has only a broad anomaly, b) Deep and Hull inlet profiles on line H-2010A in South Timbalier shows another atypical line with on broad peak nearly 5 miles in width occurs at sites 120 to 140 in the deep inlet, c) Deep and Hull inlet profiles on line H-2290A shows an inverse relationship where the deep inlet has missed a fairly sharp set of peaks that occur from sites 220 to 240 in the hull data as the ship transitioned up onto the shelf. Good correlations are shown on the shelf, particularly at site 140. Ethylene is present in all seeps, including the hull data that was missed by the deep tow, d) Deep and Hull inlet profiles on line RG-016A shows a broad coordinated anomaly found in fairly shallow water where ethylene occurs in the deep and propylene in the hull inlets.

Figure-13d from High Island shows an atypical line where the hull data does not contain any of the anomalies present on the deep tow. Well correlated methane and ethane occur everywhere, except between sites 220 to 280, where dry gas dominates. Ethylene suggests a regional increase towards the shallower water, but no correlated peaks. Line H2790 located in South Timbalier in Figure-14a shows one correlated peak at site 10, but no correlated hull peak at site 47. Ethylene peaks occur at both deep inlets at sites 10 and 47, but only on the left seep at site10 in the hull inlet data. The hull inlet has only a broad anomaly that has dispersed near site 47. A broad full spectrum anomaly having a width of nearly 5 miles occurs in the deep data between sites 120 to 140, on line H-2010A in Figure-14b. This seepage may extend to the surface, but appear to have broadened and drifted to the right. Ethylene is present in the deep inlet.

Line H2290A in Figure-14c was selected to show a fairly sharp hull anomaly at sites 220 and 240 which was missed by the deep inlet. This suggests a sharp but intermittent seep that was missed by the deep tow. The big anomaly at site 140 is similar in all components in both inlets. This line, which moves from south to north from deep to shallower waters would have required fast action in adjusting the depth of the deep tow to avoid hitting the bottom, perhaps providing an explanation for the missed peaks in the deep inlet. This line is also unusual in having ethylene in both the deep and hull inlets.

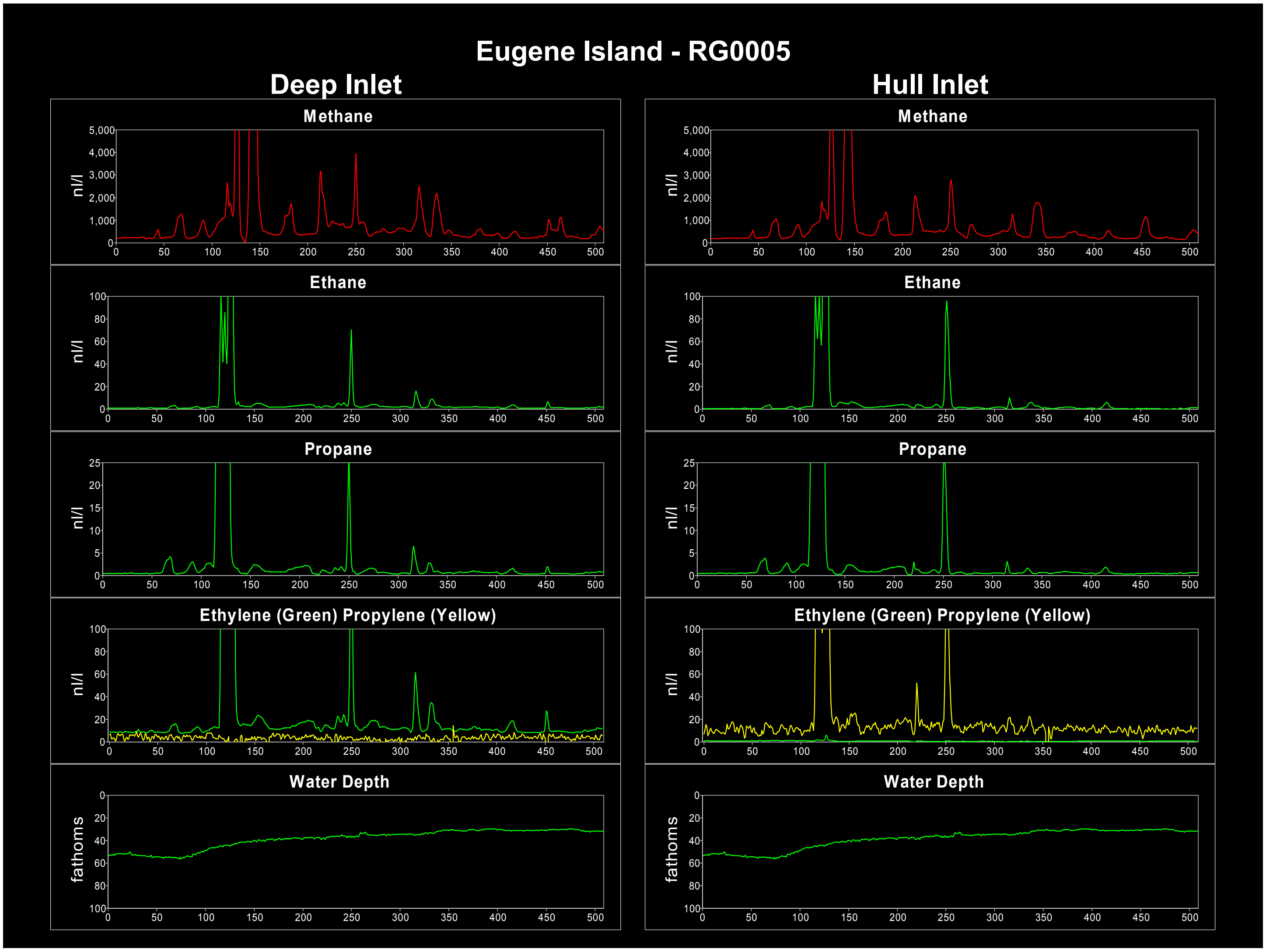

Figure-15 Deep and Hull inlet profiles on line RG-0005 in Eugene Island shows the typical coordinated response with both inlets showing several sharp peaks with varying compositions. This line was selected to show the very large olefins, ethylene in the deep inlet and propylene in the shallow inlet.

The last two examples were selected to show the presence of propylene in the hull inlet. Figure-14d shows the typical response when propylene is present, with ethylene found in the deep inlet and propylene, only in the shallow inlet. The second profile in Figure-15 was selected because it is the largest propylene concentration measured. This line RG0005 in Eugene Island exhibits a typical well-coordinated response, with both inlets showing several sharp and mixed composition anomalies. In general, ethylene is found mainly in the deep data and propylene in the shallower hull data whenever they occur in the data.

Ethylene and propylene are not present in the reservoirs at depth. They have normally been ignored, and have even been considered as negative rather than positive petroleum indicators (Harbert, et al., 2006). They are currently believed to be biological degradation products generated in the shallow vadose zone from their saturated counterpoints, ethane and propane under low oxygen conditions (Telegina, 1971). This extensive marine "sniffer" data set not only confirms their presence in large anomalous concentrations as dissolved gases in the deep water inlet, it also that ethylene usually correlates with ethane, not only in a profile by profile basis, but also in regional trend surface maps. Ethylene appears to associate with its ethane saturate counterpart. Propylene also occurs in the hydrocarbon seeps measured in the hull inlet, but only within full spectrum anomalies. Although their magnitudes are scattered by unknown biological factors, this data clearly shows that these two olefins occur only in areas where anomalous ethane and propane are present. They do not occur in anomalous concentrations within any background samples.

It is very important to note the hull and deep data sets are completely independent, they do not share water streams (depths), gas strippers, or gas chromatographs. They are also out of time phase due to the lag imposed by their collection from different depths. In most cases they correlate very well with one another in location, suggesting that most of these seeps travel vertically to the surface with little deflection from their source. This near universal agreement between the hull and deep tow data provides the ultimate in duplicate sampling. Unlike sediment related seepage, the free and/or dissolved gases in the seawater are driven by pressure, making "sniffer" anomalies class-A macroseeps. In early discussions during planning and development of the Gulf Oil sniffer systems arguments were made that deposition rates in the GOM were too large to allow seeps to reach the surface via diffusion. This is probably true, further confirming that seepages in the water migrate by pressure-driven effusion, and not by diffusion.

The volume and number of seeps were a surprise to most explorationists, but cannot be denied given the data collected. It is fitting, and very interesting to note Larry Cathles from Cornell University, after studying the seepage in only a 9,600 square mile area in the Eugene Island area of the GOM made a 2003 presentation at an ACS Meeting in New Orleans where he suggested that 70% of the generated hydrocarbons were vented, with 10% in reservoirs and 20% remaining in the source rocks. Cathles said "We're dealing with this giant flow-through system where the hydrocarbons are generating now, moving through the overlying strata now, building the reservoirs now and spilling out into the ocean now". A follow-up note was published in the Geotimes Magazine entitled "Raining Hydrocarbon in the Gulf" (Pinsker, 2003). Cathles did not have access to this sniffer data set, which also confirms his conclusions of extensive and active seepage.

CASE STUDIES

West Cameron Block 615 Area

Geochemical “sniffer” data was first collected in the West Cameron Block 615 area in 1976, followed by a second survey in 1978. Localized deep tow “sniffer” anomalies are marked by red and gray dots. Gray dots represent methane anomalies having inadequate butanes for the cross-plot classification scheme described in Figure-4. Production wells and dry holes are marked as white (Before) and yellow (after) the collection of the sniffer data.

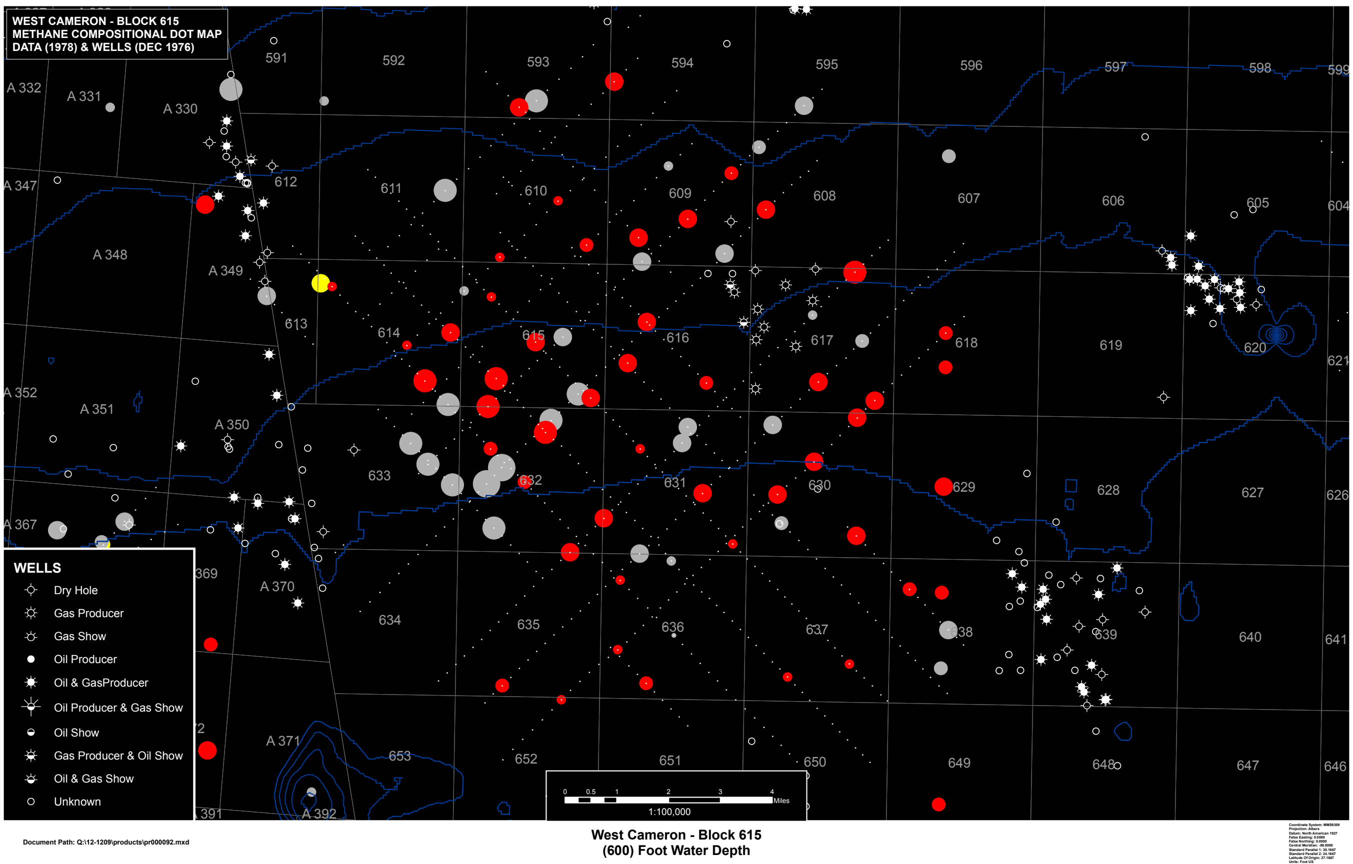

Figure-16 West Cameron block 615 area – data and wells through 1976.

As shown in Figure-16 a number of large methane magnitude anomalies, indicative of gas potential were found when production included only 9 gas wells in blocks WC616 and WC617. Since the seismic track lines go around the existing wells there are no anomalies over the field. Geochemical anomalies do surround the existing production. Anomalies, located to the south (WC631 and WC630) and southwest (WC614, WC615, WC616, WC632 and WC633) suggest that potential likely extends to those blocks. During the interim as Gulf was adding some new lines (see Figure-17) production had expanded in blocks WC616 and WC617 and two new gas wells, had been found in block WC630, where anomalies had been previously noted. Currently, production in block WC630 area has developed considerably and, as shown on Figure-18, has spilled over into blocks WC616, WC615, WC631 to the west and WC637 to the south.

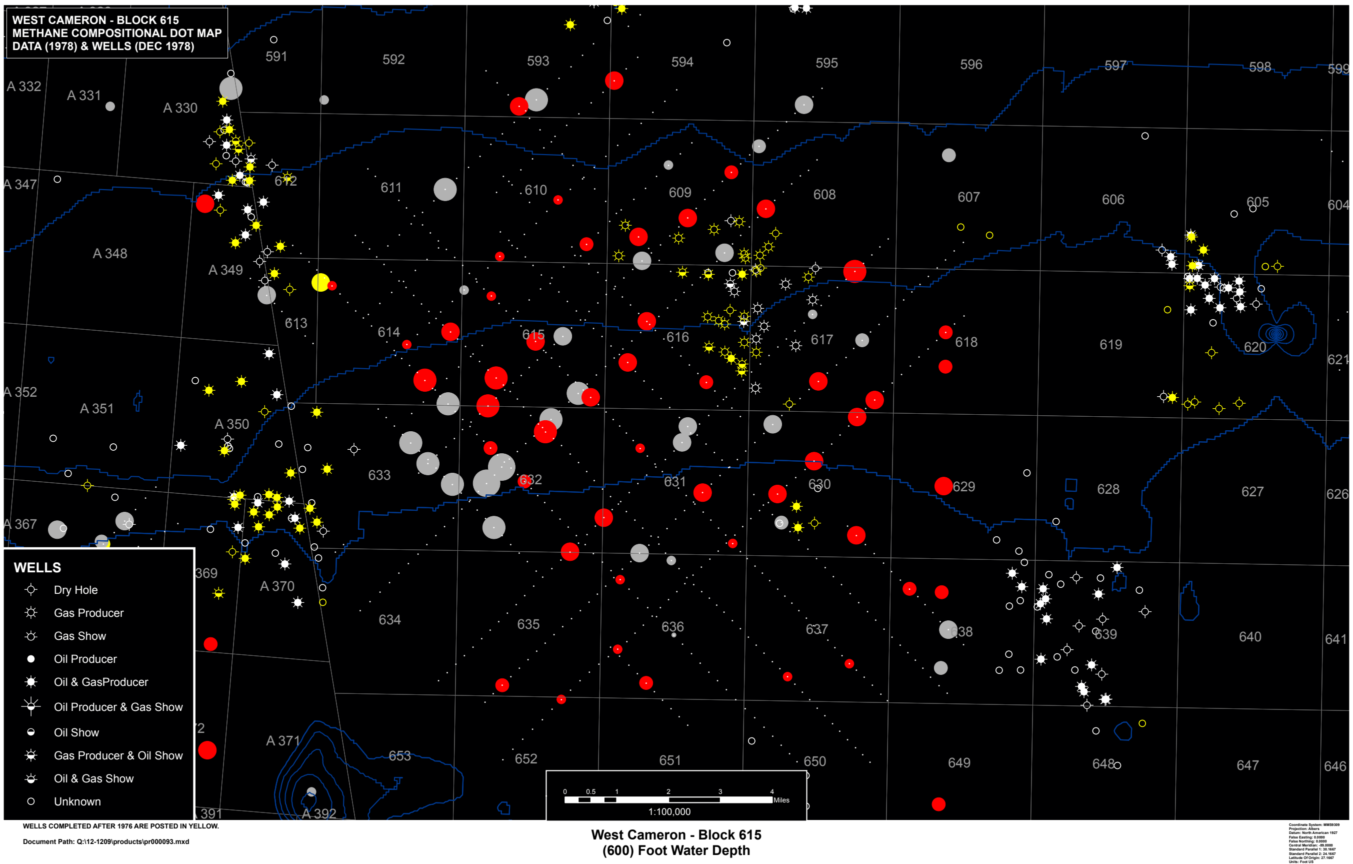

Figure-17 West Cameron block 615 area – data and wells through 1978.

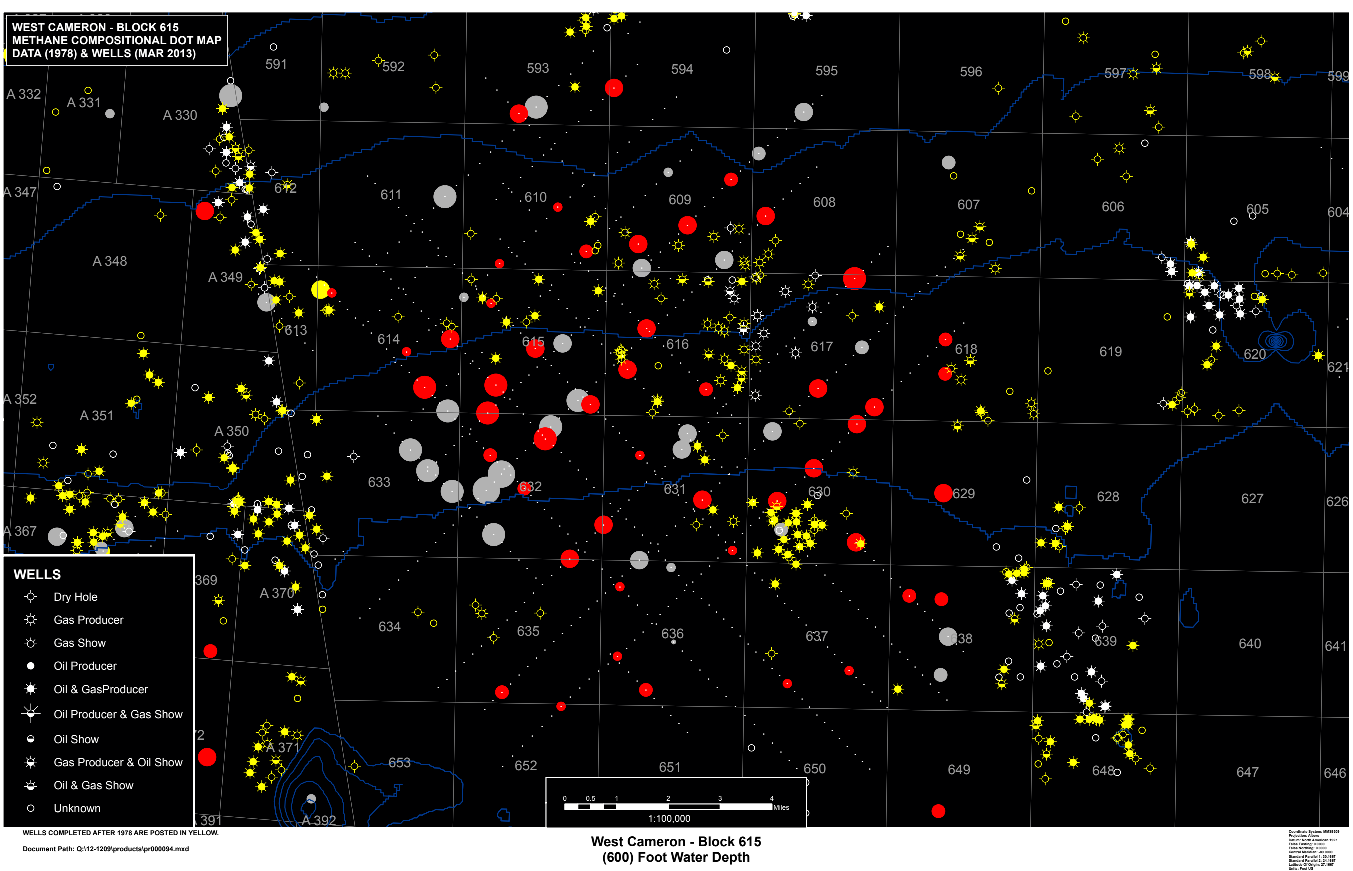

Figure-18 West Cameron block 615 area – all data and wells.

Anomalies in blocks WC632, WC633 and the southeast corner of WC614 are similar in composition and even larger in magnitude than the seeps found near the existing production, but remain unleased and have never been tested. Only WC610 is under active lease.

Eugene Island Block 252 Area

Sniffer data was collected in Eugene Island bock EI252 in 1976 and in 1978 as shown in Figure-19. Sniffer anomalies are again represented as red and gray dots as before, but in this case also include some yellow and green dots, representing oilier compositions. Pre-survey wells are white and post survey in yellow. In 1976, production was located only in blocks EI238 and EI252, plus the two gas wells in block EI261. The "sniffer" anomalies suggest additional gas potential is likely to extend to the western edge of blocks EI252 and EI251. During this two year interval between surveys gas and condensate production had been discovered in the SW corner of block EI252 and the NW corner of block EI261 in proximity to the geochemical anomalies (see Figure-20). The 1978 sniffer data added more anomalies which indicated gas with oil/condensate liquid potential. As shown today in Figure-21, the field in block EI238, which consisted of only 7 wells in 1978, was substantially expanded in proximity to these geochemical anomalies. In addition note the numerous blocks were production has expanded near these geochemical anomalies, such as EI 229, EI230, EI237, EI240, EI251, EI252, EI253, EI261 and EI262.

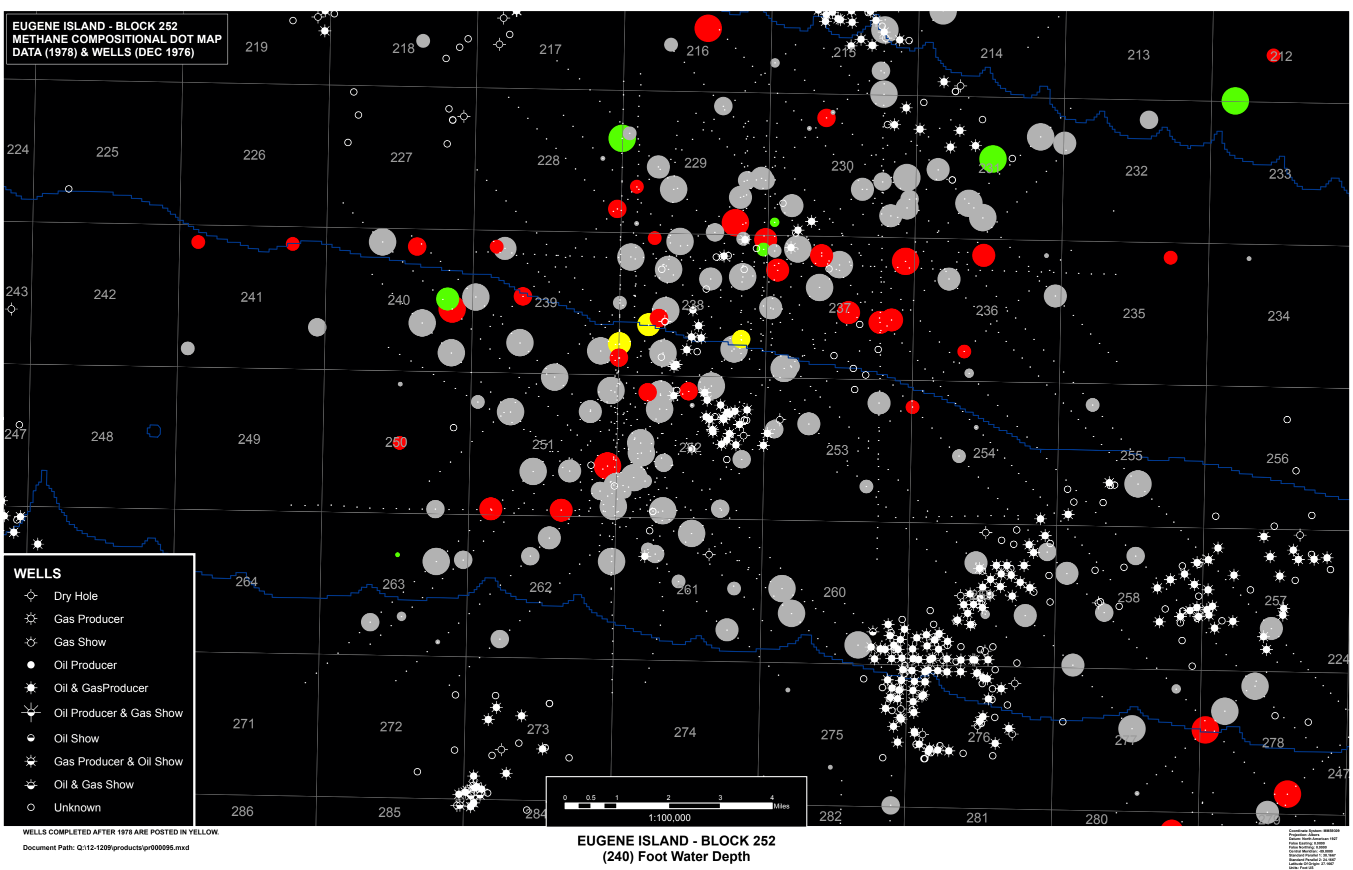

Figure-19 Eugene Island block 252 area – data and wells through 1976.

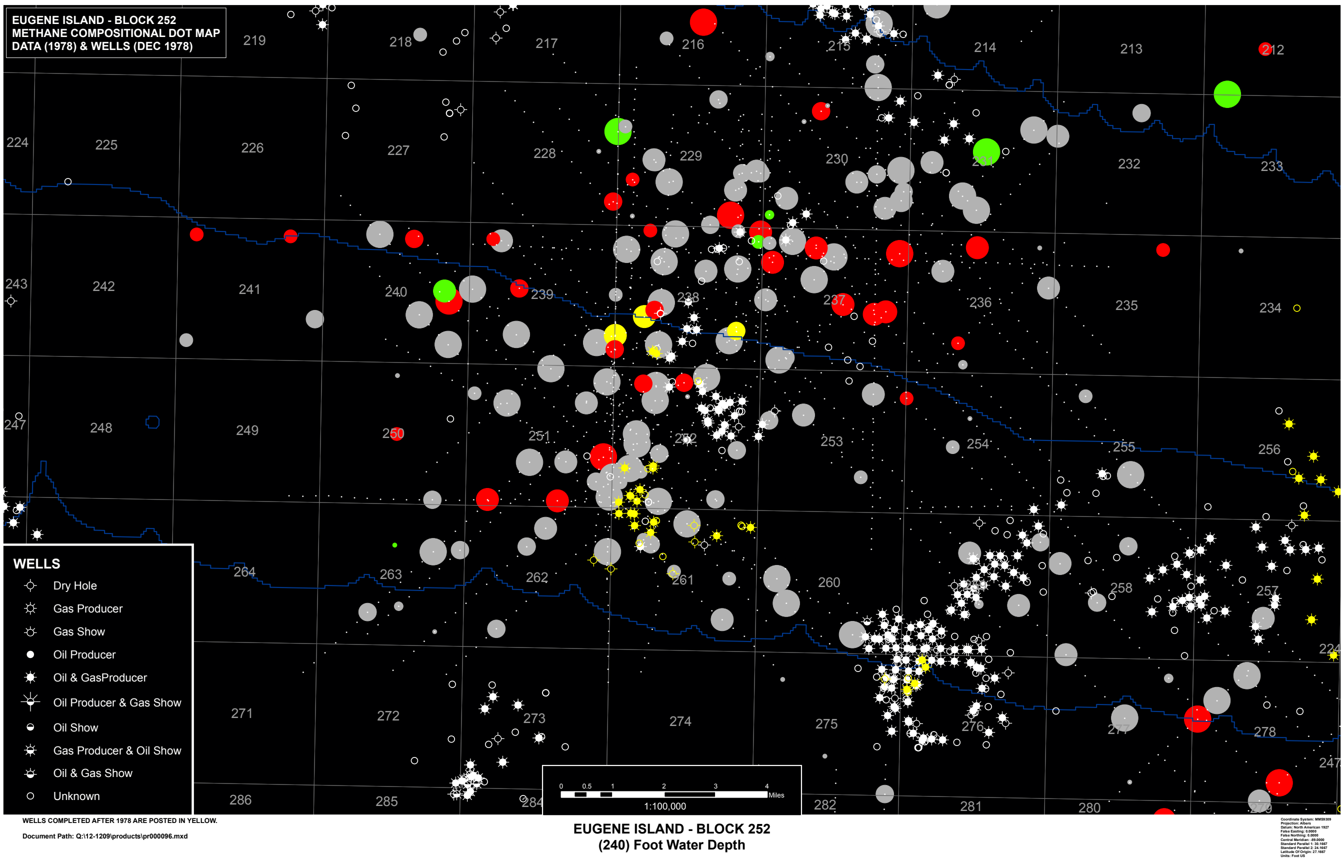

Figure-20 Eugene Island block 252 area – data and wells through 1978.

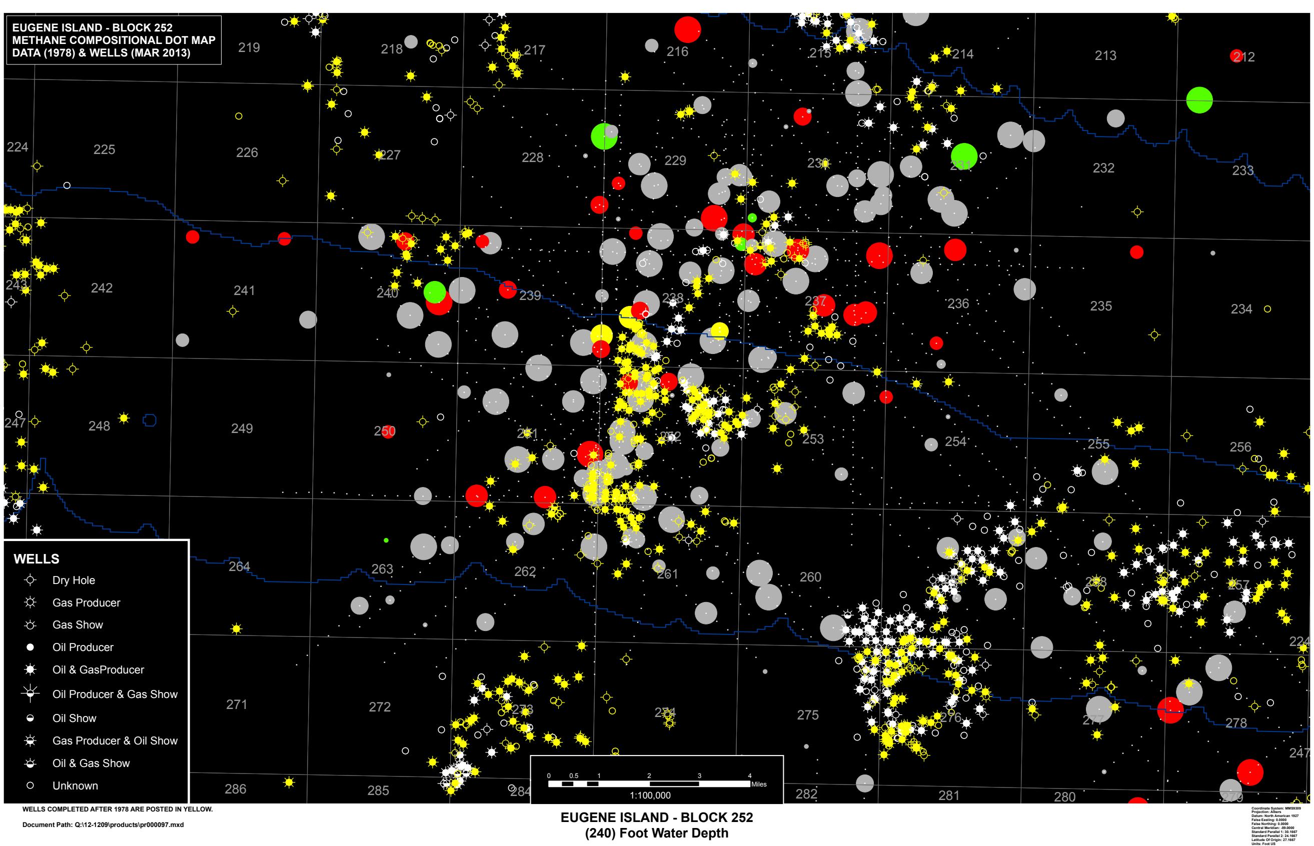

Figure-21 Eugene Island block 252 area – all data and wells.

East Cameron Block 248 Area

East Cameron Block 248 Area contains several examples where geochemical anomalies preceded the discovery of production, in additional to numerous anomalies indicative of future potential. Although gas production had been found in EC231 in 1978, there was no production in block EC240 when these methane anomalies were posted in Figure-22. These anomalies suggest that the field in EC231 likely extends to the south into EC240. Today, as shown in Figure-23, production has been extended to the south into blocks EC239 and EC240. This production includes both gas and oil, as suggested by the compositional data.

Just to the south, note that blocks EC258, EC259, EC266 and EC267 also contained methane “sniffer” anomalies in 1978, but no production. There were three dry holes in the NE corner of block EC266. As shown in Figure-23, gas was subsequently discovered in blocks EC266 and EC267.

In 1978, a small gas field existed in block EC245 which had been discovered in 1972. Methane magnitude anomalies are shown in blocks EC246 and EC247 to the east, and several methane anomalies are noted in blocks EC243 and EC244 to the north. Most of these anomalies suggest gas. However, several anomalies in block EC246 to the east, suggest a potential for oil or condensate liquids, a potential not yet realized in this area in 1978. One well (A001) drilled in 1990 did discover oil and gas production. There have been a few scattered wells drilled in EC245 and EC246, but none in EC244 and only one in EC243 since this geochemical data was collected in these blocks in 1978. Structural considerations made by Pirkle and Williams from the 1988 Transco map suggests that the gas field in block EC245 is south of a NW/SE trending fault system, so anomalies in blocks EC243 and EC244 to the north, and several anomalies in the eastern part of block EC246 appear to be separated from the block EC245 accumulation. These are excellent leads.

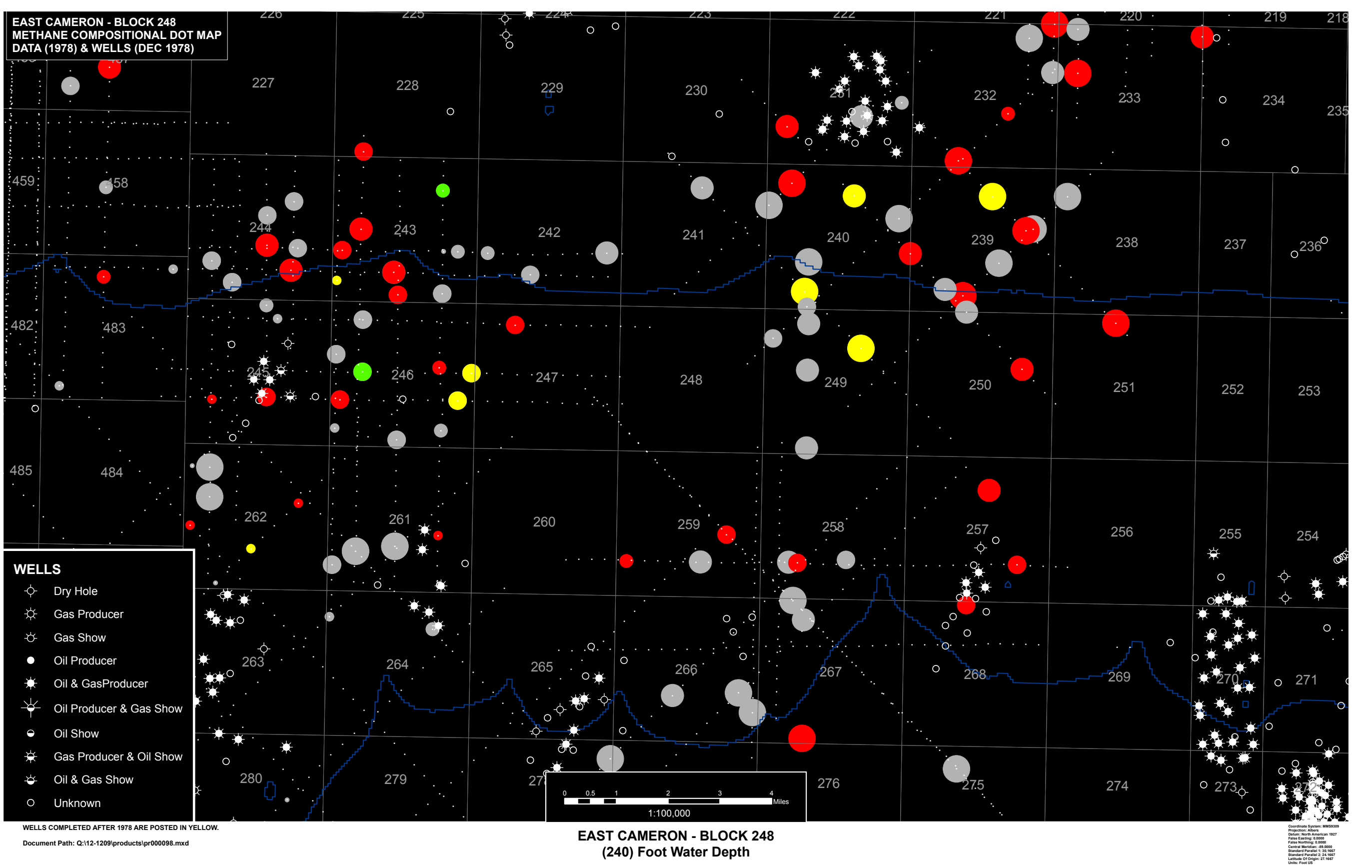

Figure-22 East Cameron block 248 area - data and wells through 1978.

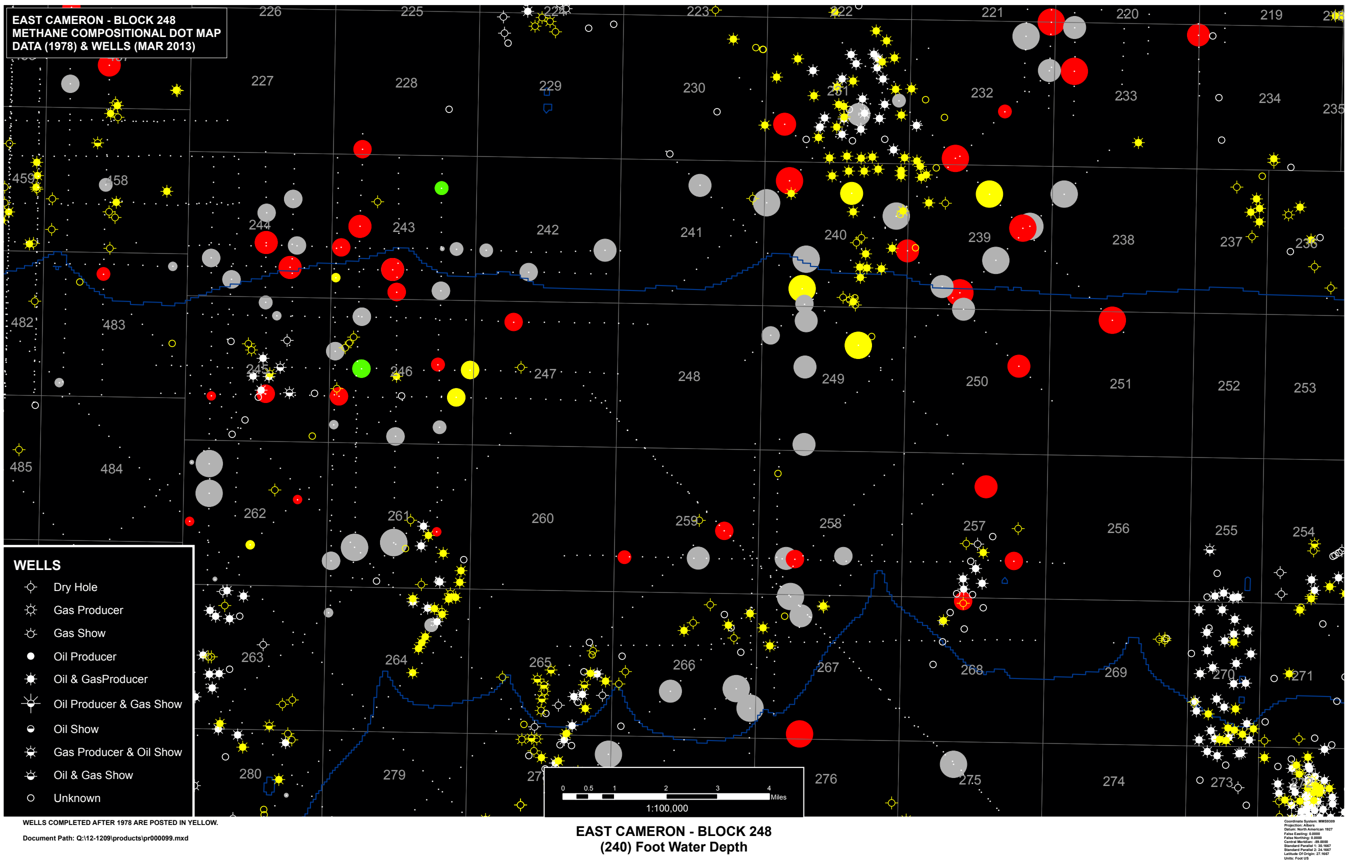

Figure-23 East Cameron block 248 area – all data and wells.

East Cameron Block 215 Area

Figure-24 shows a large cluster of large magnitude methane anomalies which cover blocks EC214, EC215, EC216, the northeast part of EC220, and the northwest part of EC219. The higher density of coverage suggests the grid was driven by positive geophysical/geochemical results. Structural data does not indicate the presence of a dome, but several fault systems at depth, which appear to intersect in block EC215 (Pirkle and Williams, Transco map, November 1988). Only a few dry holes had been drilled in this area by 1978 when the “sniffer” data was collected. According to Pirkle and Williams, the data can be divided into at least two sets, based on the 1988 Transco structural map. The first set is south and west of a large fault which cuts across block EC215. These anomalies suggest gas potential. As shown by Figure-25, gas production was subsequently discovered in blocks EC214, EC215, EC219, EC220 and EC221. A small gas field was also discovered by Gulf in the southern portion of block EC215. Attention should and may have been directed to this area by the size and number of the sniffer anomalies, particularly in relation to the subsurface structure.

Blocks EC197, EC198, EC201 and EC202 also contain numerous methane anomalies that were first observed in 1978. The composition class of the western most set of these anomalies suggests gas, whereas anomalies in the eastern portion of blocks EC198 and EC201 suggest some liquid potential. No production existed in any of these four blocks in 1978. One dry hole was drilled in EC202 in 1988 and one oil and gas producer was drilled in VR201 in 1990, and all are unleased. Structural consideration by Pirkle and Williams suggest the observed seepage may be related to faults trending E-W across the southern portion of blocks EC197 and EC198, that turn SW across block EC202. Mapped structures related to these faults in all four blocks should be further evaluated.

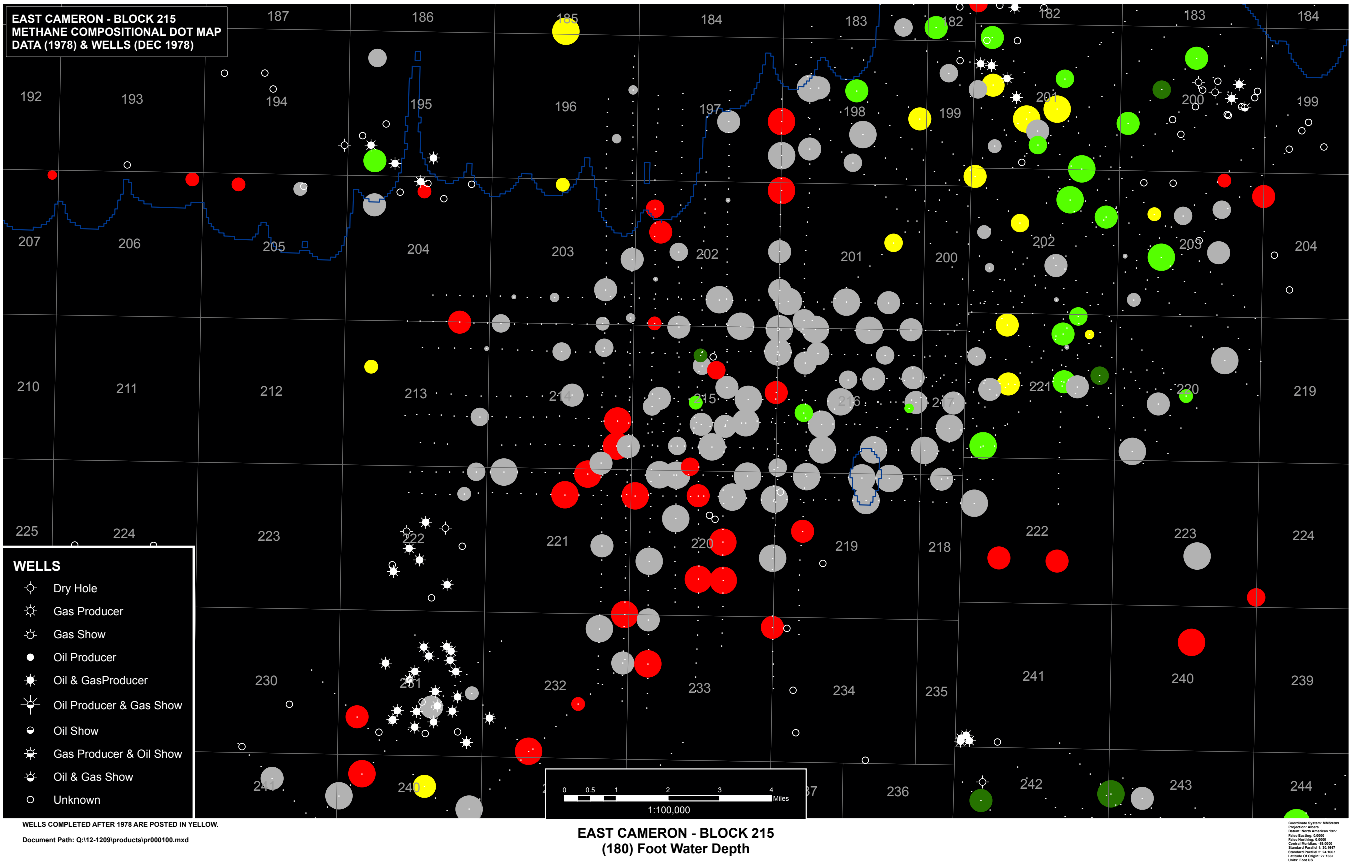

Figure-24 East Cameron block 215 area - data and wells through 1978.

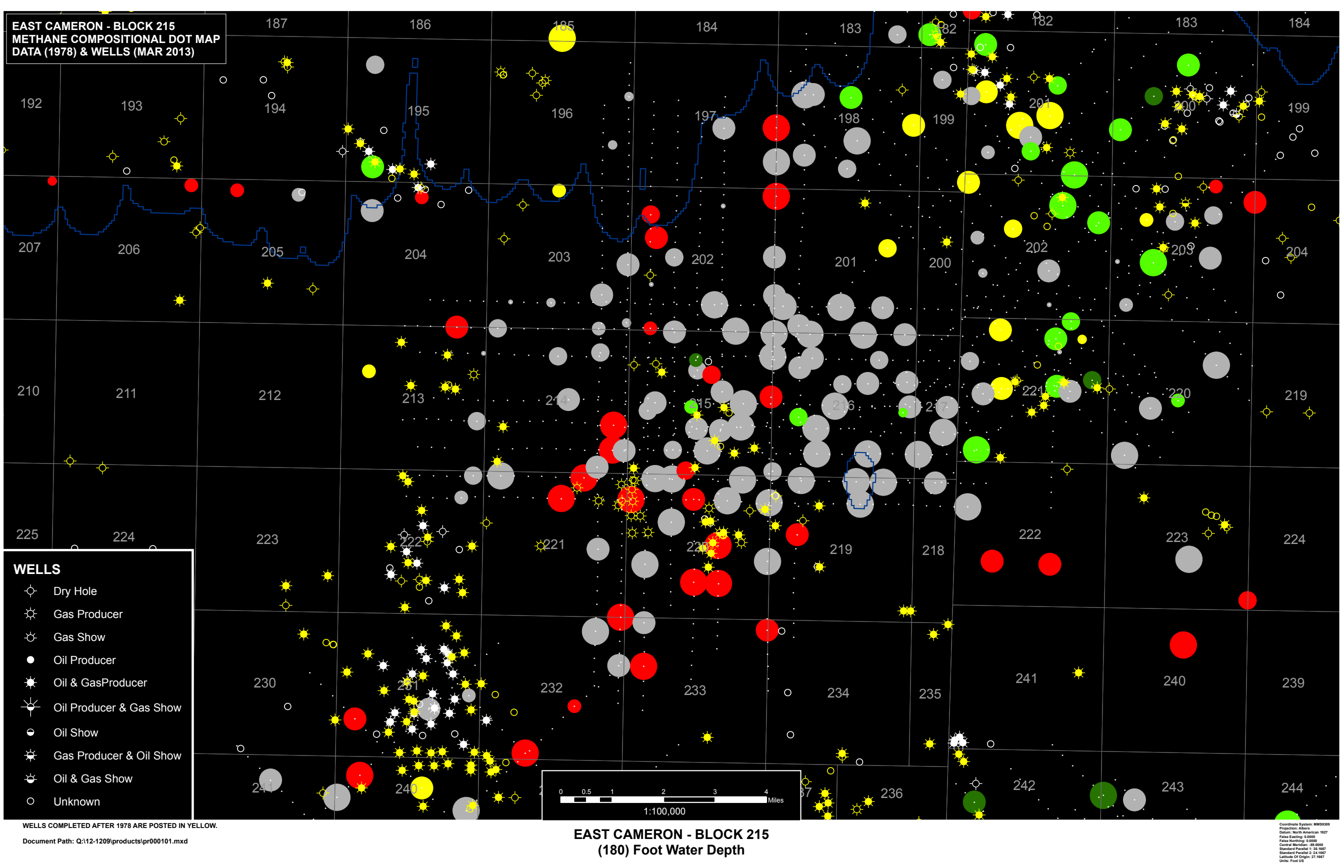

Figure-25 East Cameron block 215 area – all data and wells.

SUMMARY AND CONCLUSIONS

Offshore seep detection allows areas of the continental shelf to be surveyed for seeping hydrocarbons as part of an integrated exploration program. It is important to note that the "sniffer" anomalies are detecting natural macroseeps that prove the existence of active, mature petroleum sources at depth. Seepage data can be interpreted to differentiate areas with a mature source rock from those without, and to provide evidence for differentiating between mature gas and oil prone source rocks. Integrated with seismic/structural data, survey results can be used to identify or confirm likely migration routes, (e.g. gas chimneys), and in areas of sea floor pock marks, differentiate a biogenic from a thermogenic source for the gas. In exceptionally simple geological cases, such surveys have been used to identify hydrocarbon-filled structures at depth, although in most regions the relationship between surface anomalies and deep structure is complex, requiring an integrated interpretation of all available geological and geophysical data.

The advantages of ship towed seawater monitoring are it is relatively inexpensive when conducted with seismic and provides large numbers of statistically significant analyses on a precisely located grid. This Gulf Oil "sniffer" database is particularly valuable because much of this extensive seepage was collected in 1974 to 1983, long before many of the producing fields were discovered. The more detailed grids, gathered mainly between 1980 to 1983 exhibits a much higher density of macroseeps than the regional grids, providing a more accurate picture of the vast quantity of seepage that is naturally occurring. Four-D seismic and heat-flow studies conducted by Cathles (1983) in the Eugene Island area provide supporting documentation of this seepage. Evaluation of both the deep tow and shallow hull inlet data shows that they typically track one another, providing the ultimate in duplicate sampling. These independent data streams not only validate one another, but add a complete additional set of data for interpretation and confirmation of the results, much of which has never been evaluated. The data also provides a baseline, establishing natural hydrocarbon concentrations across the Gulf prior to 1983.

Gulf Oil's "sniffer" data has been used to rank and evaluate the oil and gas potential on all of the U.S offshore provinces, from Alaska to the Atlantic coast. Data collected prior to 1979 indicated that the offshore Louisiana contained vastly more oil and gas potential than either the Texas or Florida coasts. Final evaluation of the entire data set with three times as much data has not changed these initial predictions, which have been massively confirmed by drilling. It is likely that the predictions on the other provinces are equally valid, indicating that the west coast, California and Oregon remain the best offshore exploration areas that remain undeveloped.

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