Using Surface Hydrocarbon Mapping and Downhole Geochemical Logging to Derisk Field Development Efforts*

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Abstract

The 3 km by 6 km Pietu Siupariai field had until the end of 1999 produced a total of 0.2 MMBO from 3 wells. The Cambrian Daimena Formation reservoir was 70 meters thick in the field and had a porosity of 5% to 15% and a permeability 0.1 to 400 milliDarcy. The structure had a relief of only 30 meters above the 1,970 meter sub sea oil/water contact. Productivity of the old wells in the field varied considerably from no production in the G-14 well to 160 BOPD in the PS-1 well. The G-12 well tested 750 BOPD on a DST but was not completed due to mechanical problems.

Although the G-18 and G-7 wells both produced 120 BOPD, the latter well only penetrated the uppermost 15 meters of the reservoir.

The survey was performed with the objective to identify reservoir sweet spots within the closing contour. Towards that end 99 field modules were placed in a 250 meter by 500 meter grid within a 20 km^2 area over the field. The passive surface modules were exposed for 17 days. For calibration purposes 30 calibration or model modules were installed at a producing well, a dry well, and a well with shows.

Probability maps displaying similarity to the modeled geochemical fingerprints were statistically generated by correlating the field module fingerprints and the well model fingerprints. Since the survey microseepage mechanism was driven by a combination of reservoir pressure, porosity, and net pay thickness, the project results demonstrated a definite correlation between the geochemical probability maps and test/production data.

The data also showed that production varied considerably between wells within the closing contour, namely in the range from 0 to 160 BOPD in past wells, potentially indicating nonhomogeneous reservoir characteristics. Total production was approximately 403 BOPD.

After the geochemical survey three wells were drilled on positive geochemical anomalies. Production from these three wells totaled 6,130 BOPD resulting in a production increase of approximately 15 times. The survey demonstrated that it was possible to use surface geochemical hydrocarbon mapping to determine reservoir sweet spots and predict subsurface reservoir quality variations within a producing oil field.

References Cited

Haselton, T. and P. Willumsen, 2001, Reservoir sweet spots identified with surface geochemistry – an example from the Cambrian Pietu Siupariai oil field, Lithuania: 63rd EAGE Conference & Exhibition Case Study 5, E&P Case Studies. Web accessed November 26, 2013. http://www.earthdoc.org/publication/publicationdetails/?publication=4525

Potter II, R.W., P.A. Harrington, A.H. Sullivan, and J.H. Viellenave, 1996, Significance of geochemical anomalies in hydrocarbon exploration, *in* D. Schumacher and M.A. Abrams, eds., Hydrocarbon migration and its near-surface expression: AAPG Memoir 66, p. 431-439.

Using Surface Hydrocarbon Mapping & Downhole Geochemical Logging to Derisk Field Development Efforts

by Rick Schrynemeeckers

AAPG GTW - Revisiting Reservoir Quality Issues in Unconventional and Conventional Resources: Techniques, Technologies, and Case Studies

Applications for Field Development

Applications

- Reservoir extension
- Identify by-passed pay
- Identify compartment-talization due to faulting
- Monitor oil/water contact movement in EOR projects

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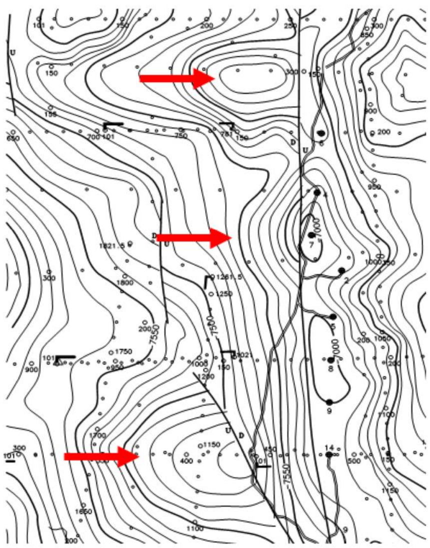
Survey Design

Where Do We Start



AGI delivers:

An image (map) of probable hydrocarbon charge based on direct measurement of C_2-C_{20} hydrocarbons directly emanating from the reservoir

Avoid dry wells and maximize ROI by choosing best lead to drill first.

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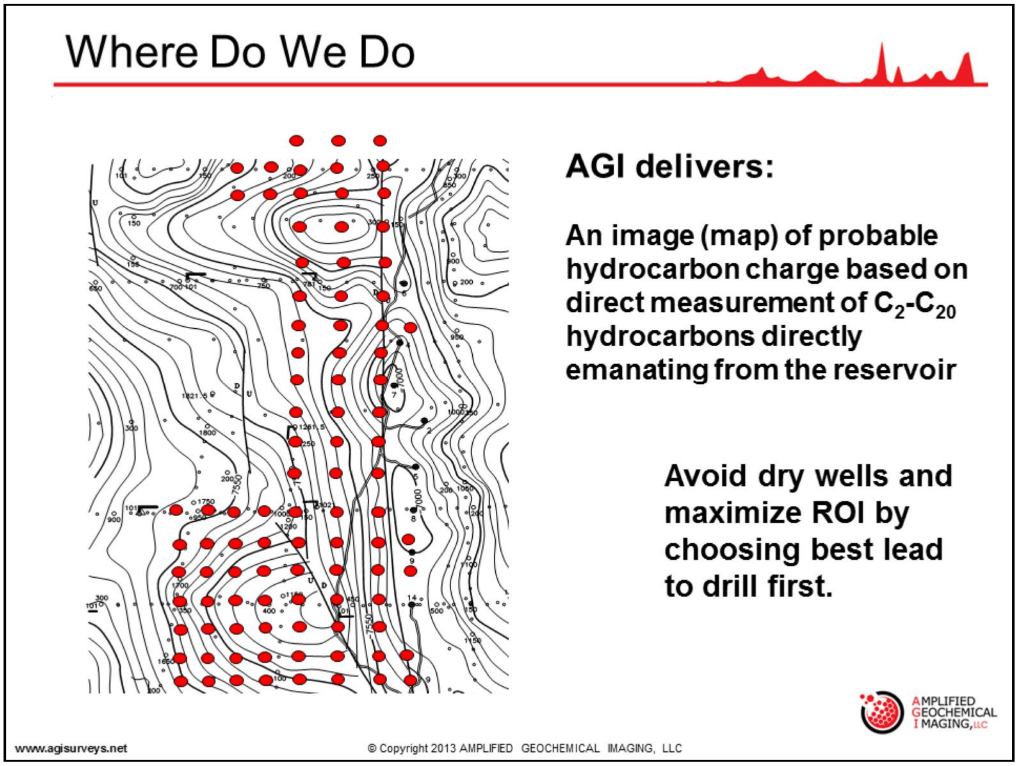
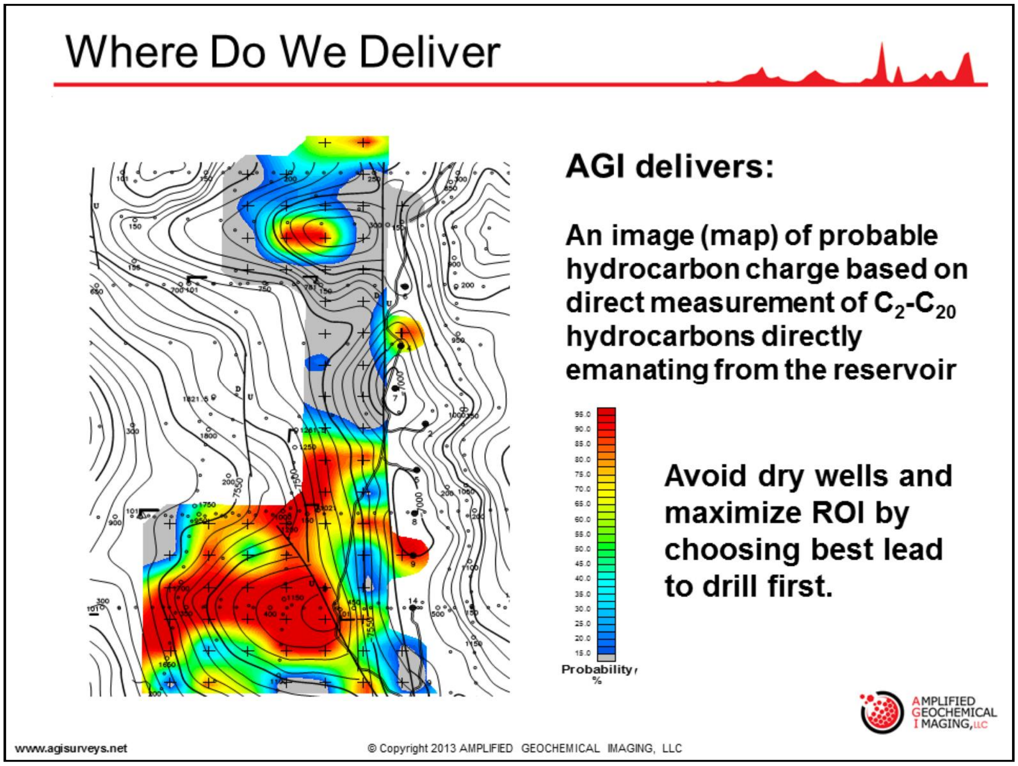
This is typically how we start a survey. We receive an electronic map from he client. In this case the client wanted to rank three prospects as indicated by the red arrows.

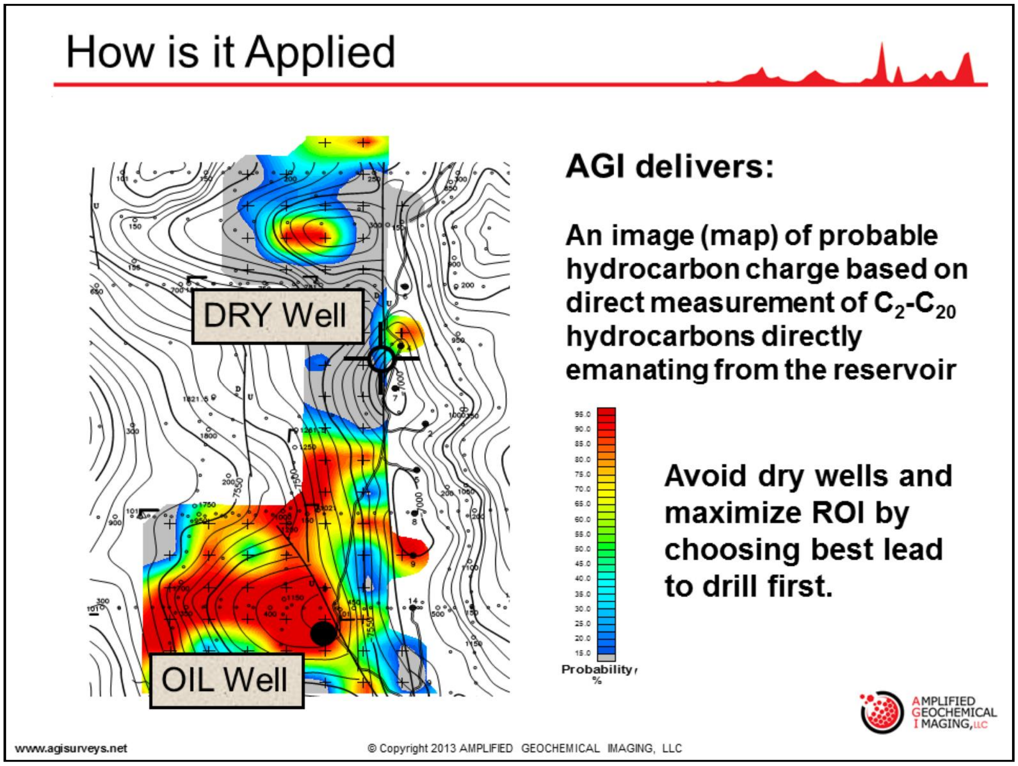


The red dots indicate the location of the survey modules. Spacing in a case like this is often about 500 meters and covers the area of interest.



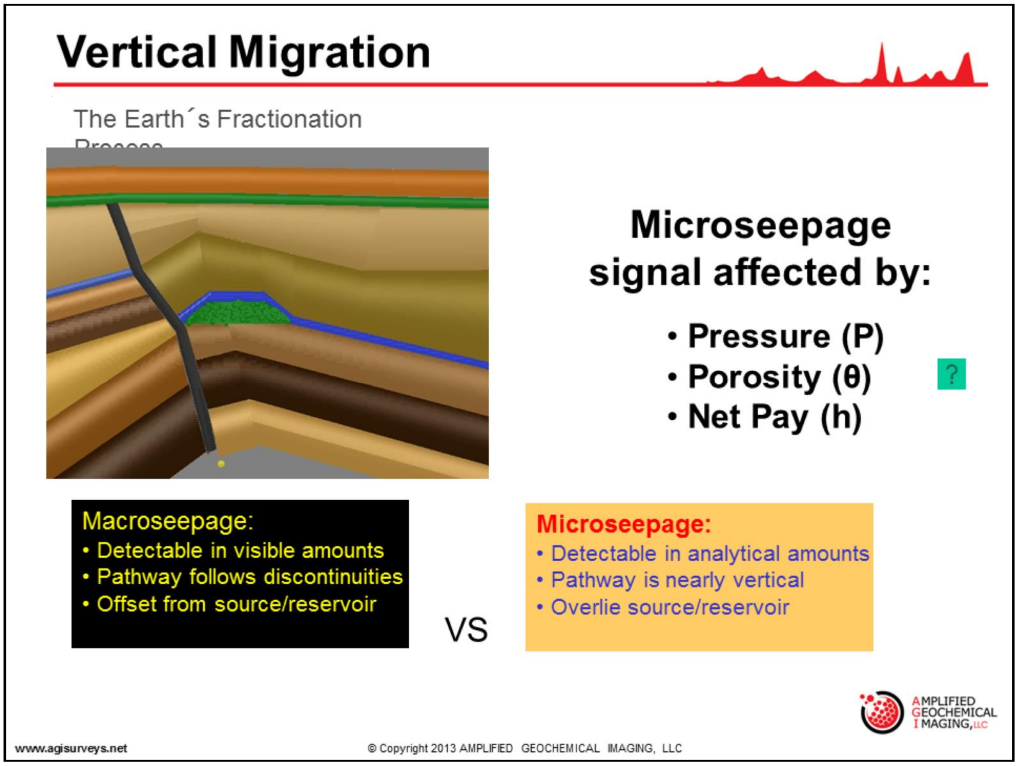
While traditional surface survey methodologies provide charts of the results, Gore surveys will provide data in a map view. Obviously, we provide all the data in an Excel spreadsheet so you can interrogate it and play with it as you see fit. But, for most geologists and explorationists a map view proves the easiest presentation form of the data.

Here the red area represents a high probability, 85% - 95% of finding oil that matches the calibration signature. As you can see on the legend to the right of the map, the probability decreases as the colors cool. S, the light blue indicates reduced probability of about 30% - 40%, while the gray area indicates less than a 15% chance of finding oil.



You can see here the client drilled two wells on the map we have shown. One well to the south in the “hot” zone was a positive producing well while the well drilled in the gray area was a dry hole as predicted.

The Science Behind the Technology

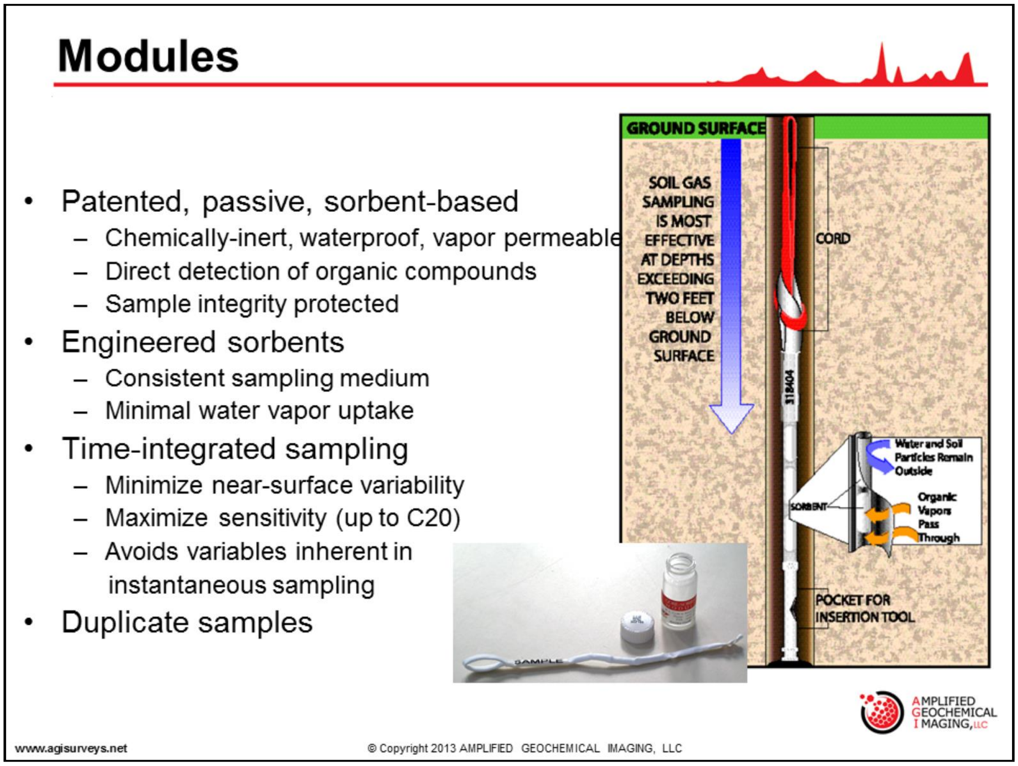


In this diagram the green section in the middle of the slide represents the reservoir and the horizontal blue line on top of it represents the seal. The thick gray vertical line next to the reservoir represents a fault.

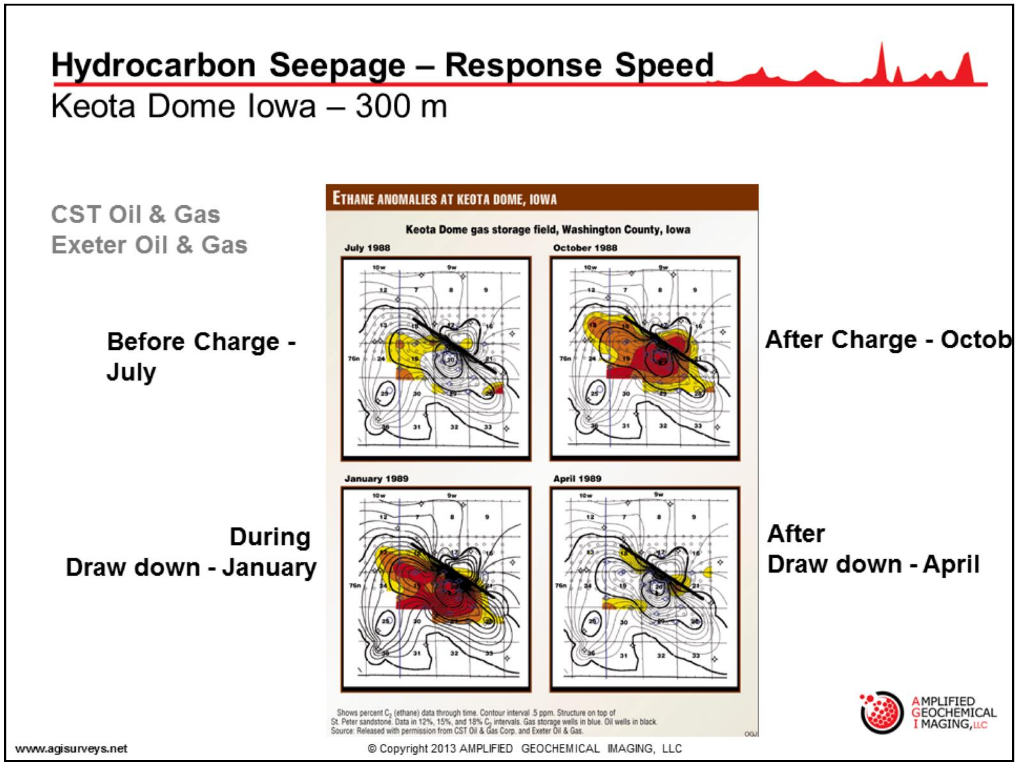
We are all familiar with macro seepage. Hydrocarbons from macroseepage travel along faults and find their way to the surface and can be visually seen. Their concentrations are at percent levels and they are normally visual. Additionally, their location at the surface is normally off-set from the source.

What most of us are less familiar with is microseepage. Microseepage occurs when hydrocarbon molecules in the reservoir go into the gas phase. These gas molecules are lifted-up by microbuoyancy from the pressure in the reservoir. These small gas molecules move upward, essentially vertically, along grain boundaries through the seal and through the lithology above the reservoir to the surface.

So, macroseepage occurs at percent levels and microseepage occurs at part per billion levels. Macroseepage travels along faults to get to the surface and microseepage moves upward due to microbuoyancy from reservoir pressure. The location of macroseepage hydrocarbons at the surface is off-set from the source while hydrocarbons from microseepage are essentially directly above the source.

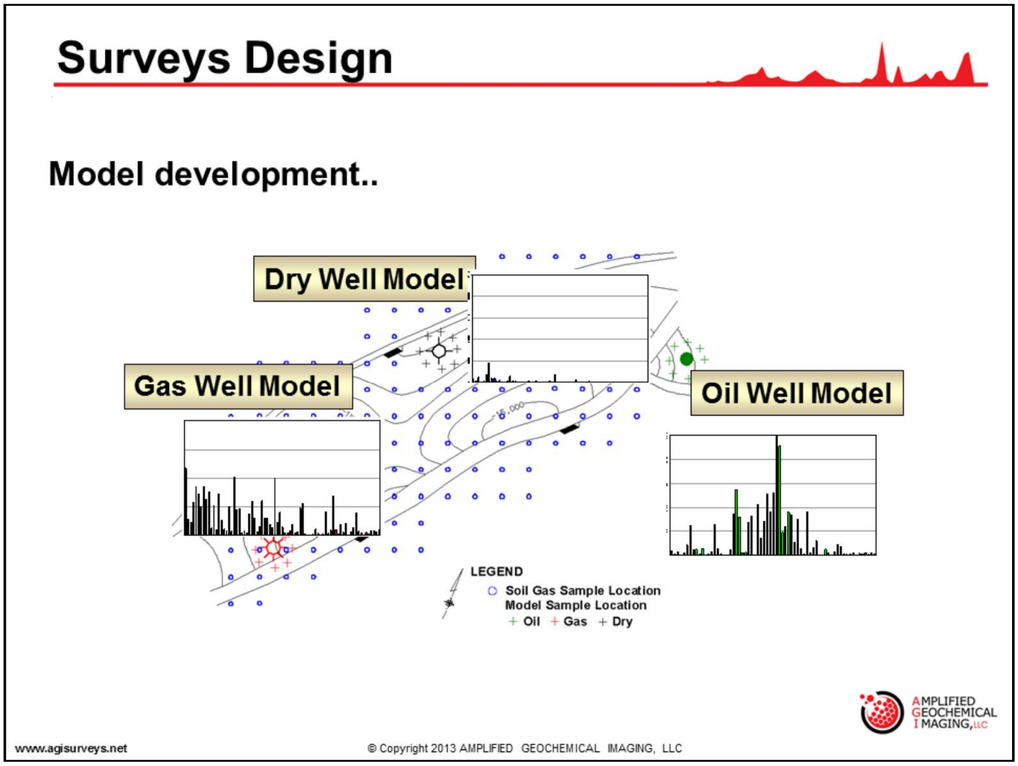


Amplified Geochemical ImagingSM Technology, was developed. This new technology uses passive adsorbent sampling. The passive sampler contains a specially engineered hydrophobic adsorbent encased in a layer of microporous expanded polytetrafluoroethylene (ePTFE). This module is placed in the ground about 1.5 – 2.0 ft down in a small hole and then covered. It remains in the ground for approximately 3 weeks. This 3 week period is important b/c it allows a sufficient volume of hydrocarbons to migrate to the surface and adsorb onto the module.

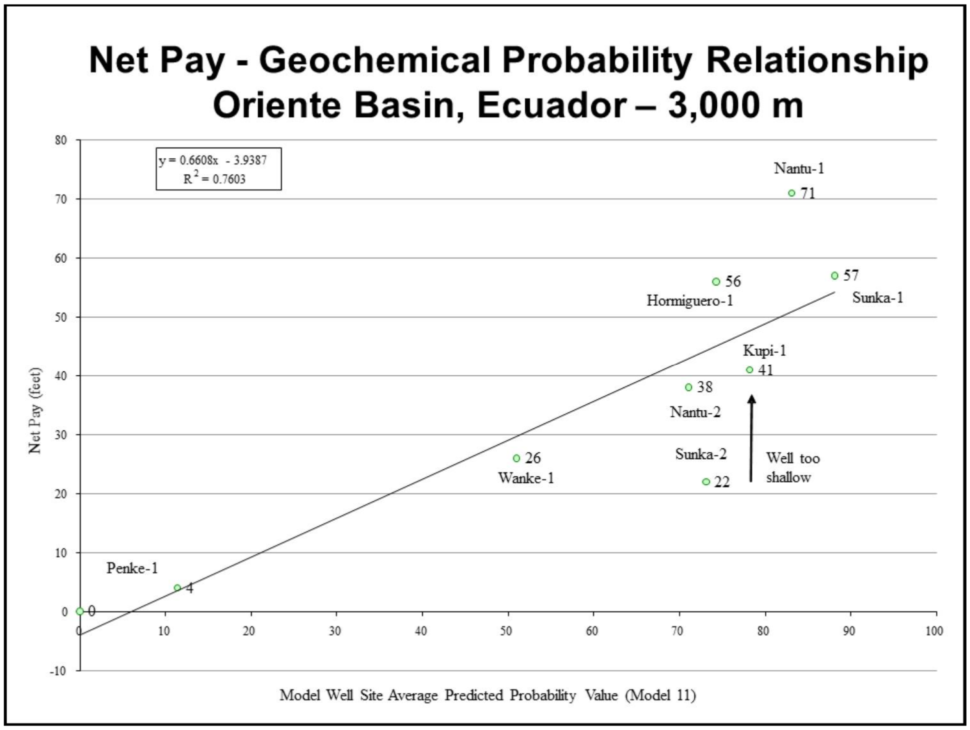


The Keota Natural Gas Storage Facility in Keota, Washington County, Iowa, stores gas in the St. Peter sandstone at approximately 1,000 ft defined as a northwest trending anticlinal structure. The dome or anticline produced minor amounts of oil in 1963 from the overlying Petaconica and McGregor carbonate formations before the reservoir was converted to gas storage. All three formations are Middle Ordovician in age. The gas is injected into the dome in summer through fall for winter withdrawal. The percentage of ethane at each sample location was measured on four occasions.

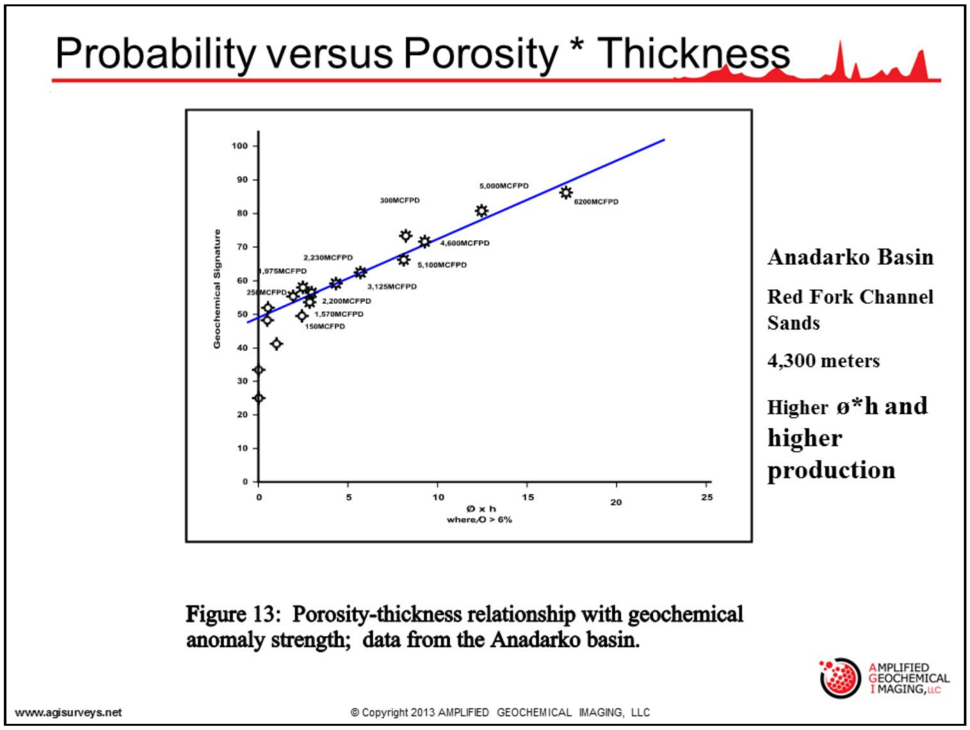
It can be seen the yellow indicates low ethane concentrations. The Orange indicates medium concentrations while the red indicates high level ethane concentrations. These maps demonstrate that the concentration changes can be detected and measured from quarter to quarter. This empirical data shows that microseepage rates occur at rates of meters per day through microbouyancy and that surface reading do not occur in geologic time, but essential current time.



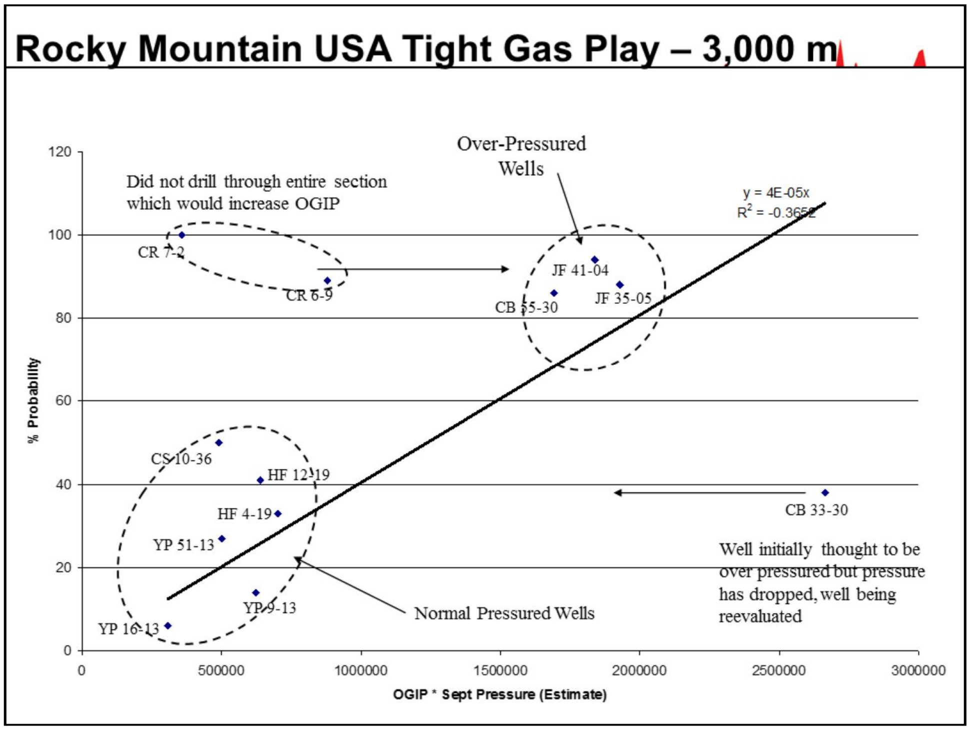
Deployment plans differ based on the project objective (i.e. frontier areas, prospect ranking, acreage relinquishment, field development, or phase identification for unconventional plays). The most common scenario is a grid pattern over the area of interest. The blue circles represent the location of each module. The spacing between the modules can range from 250 m to 2 km depending on the size of the field and the project objectives. Note the crosses around the dry well, gas well, and the oil well. Normally 15 modules are placed around such calibration wells. Calibration wells are used as hydrocarbon signal end-members for comparison during the evaluation and statistical analysis of the data. So, for example, if an oil signature is detected in the survey, that oil signature can be compared against the oil calibration signature. Also note, that there are distinct differences between the dry well, gas well, and oil well signatures. This ability is unique to Amplified Geochemical Imaging technology because this is the only surface geochemical technology that can measure the full range out to C20, thus providing a clear hydrocarbon signature – not just compound ratios.



Probability Value related to Net Pay: This is a sandstone formation at a depth of 3,000 meters in the Oriente Basin. Nine wells were modeled and the net pay is listed next to the point on the chart. This chart shows that the wells that have a higher net pay had a higher probability value. If you assume the porosity is about the same for each well, then this chart supports the next graph which is the porosity * thickness relationship.



Probability Value related to Porosity*Thickness (ø*h) of Reservoir: Daily production information for 17 wells are shown in the graph. The wells that had a higher probability value from our samplers at the surface have greater production and also a higher ø*h. In most cases a higher ø*h means increased well production and that is the case shown in the chart. So there appears to be a relationship between Reservoir Characteristics and our surface Probability value. This graph by Potter et al. was published in the AAPG Memoir 66. The wells were producing from the Red Fork channel sand at a depth of approximately 4,300 meters in the Anadarko Basin.



This is another independent example showing how Probability Value is related to Original Gas in Place (OGIP) times Reservoir Pressure (Estimated) :

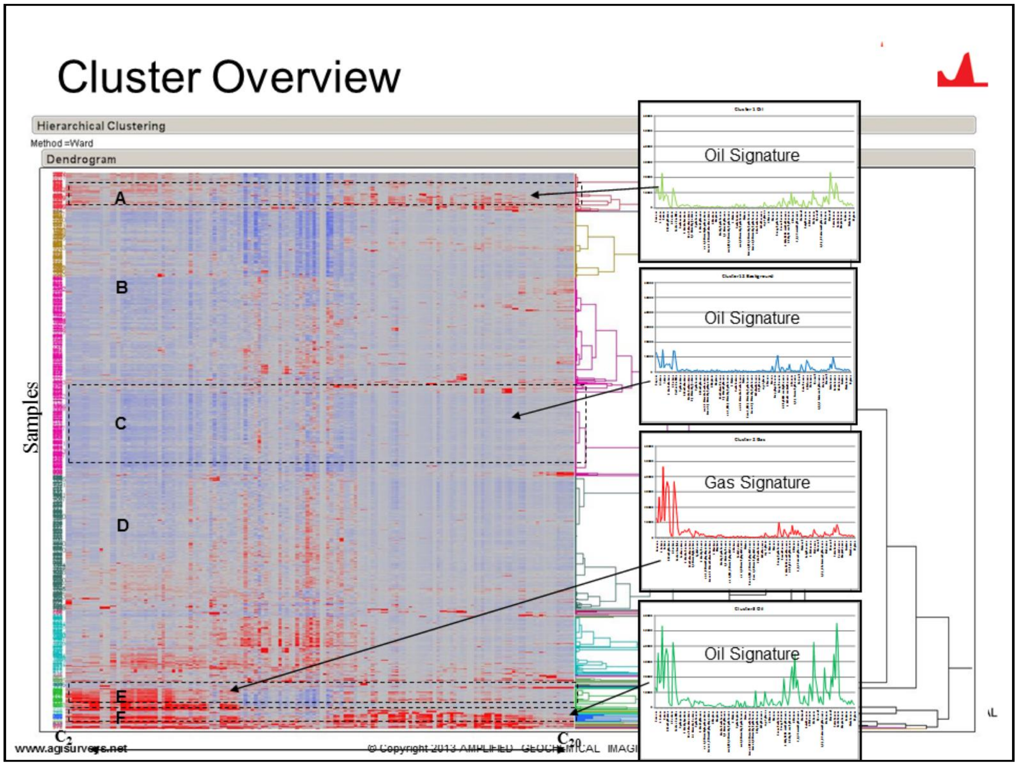
This was a tight sandstone play for gas in the western USA. Depth was around 3,000 meters. The sandstone thickness was around 400 meters. Twelve wells were sampled with 15 samples placed around each well.

The Original Gas in Place times the estimated September Pressure is on the x-axis. The survey was run in September which was important to estimate the pressure at the time of the survey. The average probability value for the 15 samples was taken as the probability value for each well. All 12 wells produce gas. The objective of this survey was to use Gore Amplified Geochemical Imaging Technology to differentiate normal pressured wells from those that were over pressured. The over pressured wells were the better producers. This chart clearly shows a difference in probability value between normal pressured wells and over-pressured wells. The 2 CR wells with high probability were not drilled through the entire gas section and therefore should have had a higher OGIP which would have moved them into the over-pressure zone on this graph. The CB 33-30 well had a significant pressure drop and was being reevaluated, so the estimated pressure was probably less than reported which would move this well in with the Normal pressured wells.

In summary, this slide is an example of how pressure plays a part in the microseepage signal we see at the surface. It emphasizes that a depleted well or field with low pressure is probably not going to give much of a hydrocarbon signature and should not be used as a strong producing model well.

Trinidad & Tobago Case Study

Depletion Affects



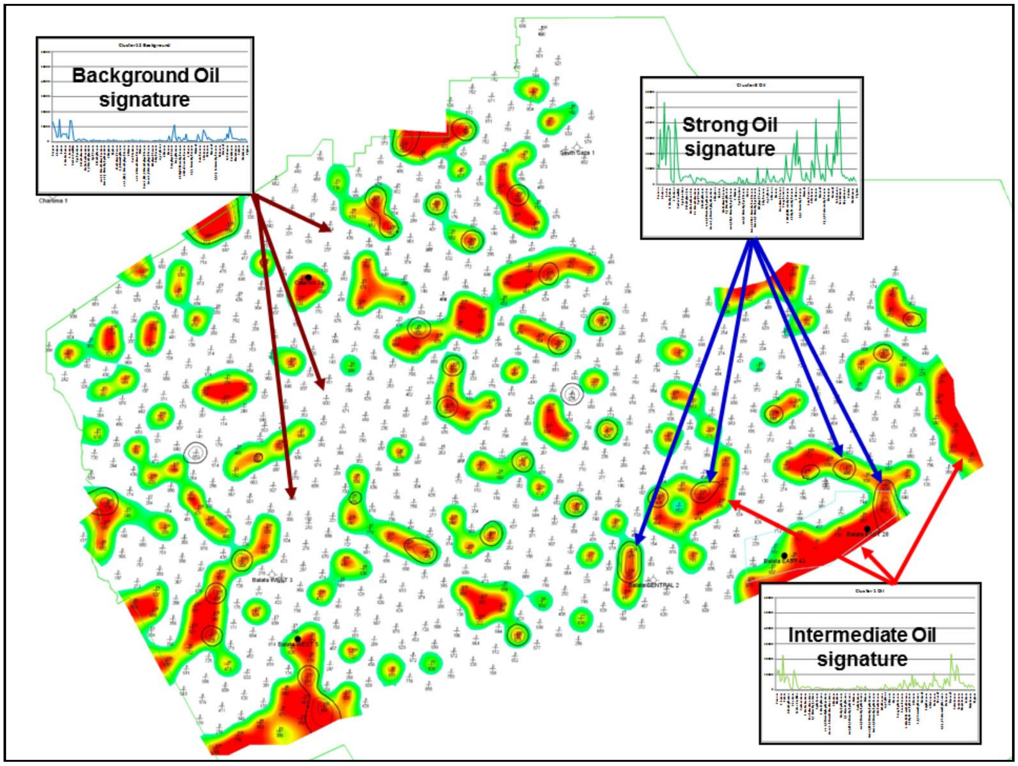
Trinidad is known for its oil seeps and its ubiquitous oil background signature that is everywhere in Trinidad. So, the question becomes, can this technology work in areas that are essentially highly contaminated with hydrocarbon background signatures that are everywhere and can you tell a reservoir hydrocarbon signal from a background hydrocarbon signal.

The cluster analysis of the data set shows the carbon range, C2 – C20, on the horizontal axis with the samples on the left grouped by similar chemistries. The data indicates several distinct hydrocarbon clusters. The blue areas indicate groups of samples that are not significantly different from background. The red shaded areas indicate hydrocarbon intensities at that carbon range above background levels.

Clusters B, C, & D essentially show background levels of oil signatures as seen in the blue oil fingerprint.

Cluster A shows an oil signature above background levels while Cluster F shows an oil cluster significantly above background levels.

Cluster F shows a gas finger print cluster.



In this final anomaly map the white area indicates the location of the background hydrocarbon signature.

The large red areas shows the areas where there is a 85%-95% probability of finding the mid-intensity oil signature.

Notice the circles on the red anomalies indicate areas of the high intensity hydrocarbon signature from the cluster analysis. So what does all this mean?

The black circles of high intensity hydrocarbons are field sweet spots with a higher combination of porosity, thickness, & pressure (i.e. higher hydrocarbon concentrations. The red areas around this circles are portions of the field that still are producing, but are showing signs of depletion.

In other words, the strong, medium, and background fingerprints are very similar. So, the signal intensity indicates the transition from highly productive (strong signal), to moderately productive (the medium intensity red area), to nonproductive (the low intensity white area).

Lithuania Case Study

Sweet Spots in Field Development Affects

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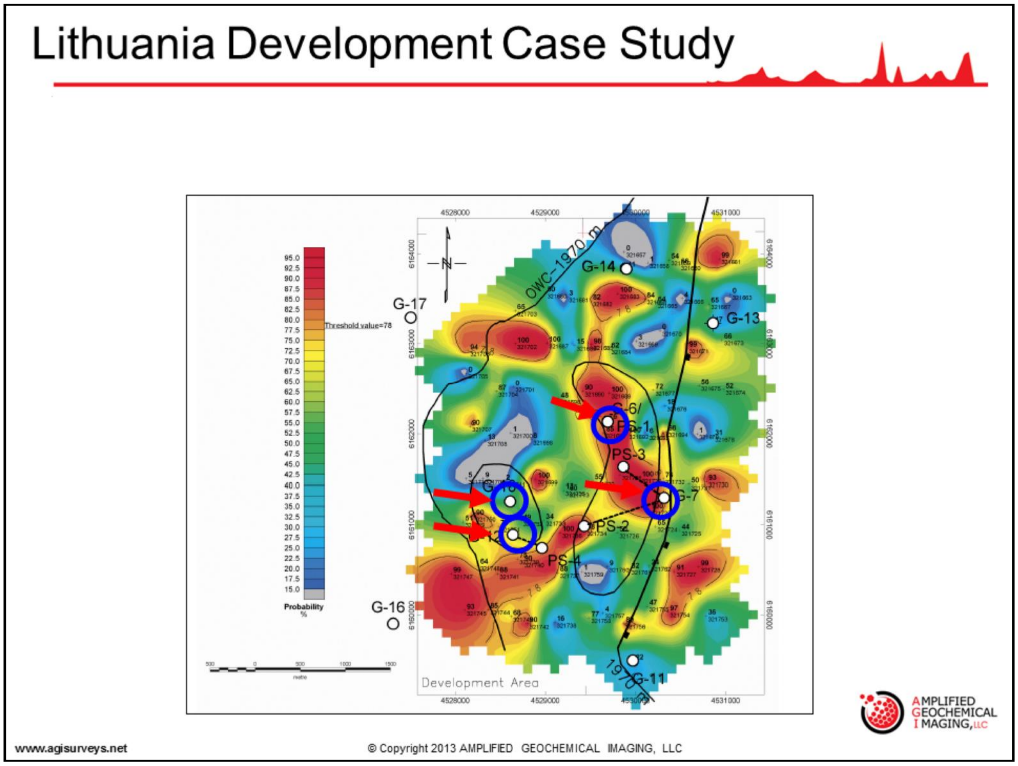
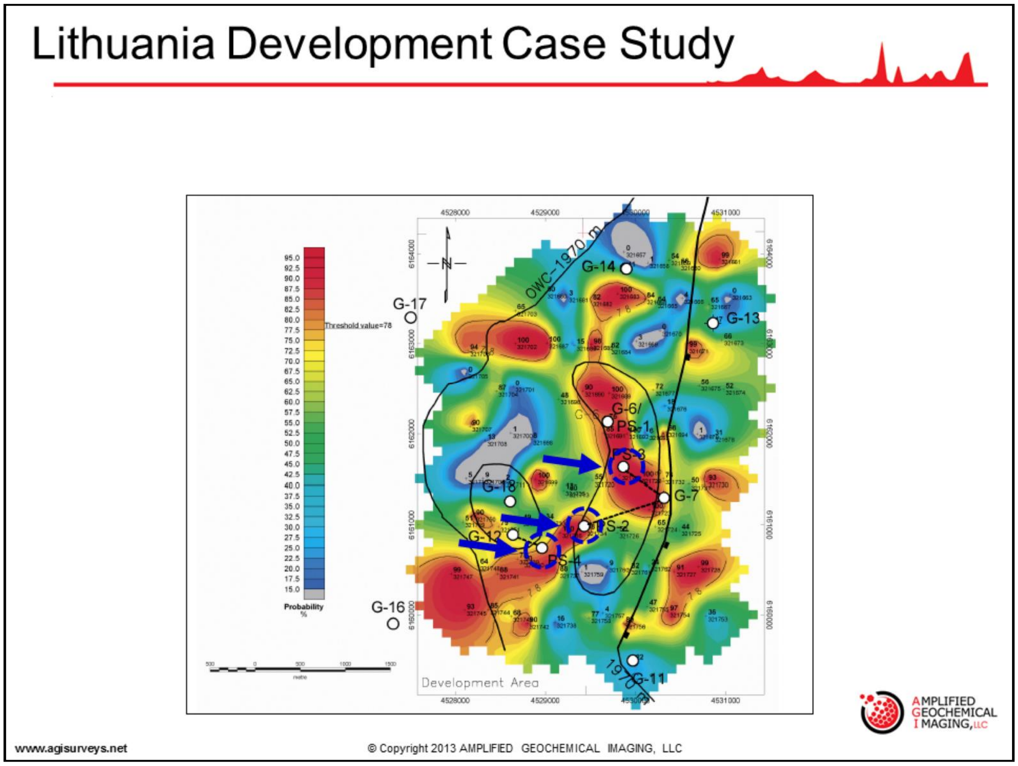
Lithuania Development Case Study

Survey information

- Located in the Baltic Syneclise petroleum province
- Target was an onshore marine Cambrian sandstone
- Producing horizon 2,000 meters deep
- 150 samples were located in a grid over 20 km^2



The “G” wells were in-place prior to the survey and several of them were used as calibration models. Based on that known calibrated oil signature this probability model map was generated. Once again, remember the red is good and the blue and gray is bad. Well based on the survey results you can begin to see why this was not a highly productive field. First of all notice all of the G-wells that are in light blue areas which are areas if low probability. And of the 4 producing well, G6, G7, G12, & G18, two of the four are in moderate probability area.



Based on the survey results 3 new wells were drilled: P2, P3, & P4. Notice their locations……..very high probability areas.

Lithuania Development Case Study

Production Test Data (BOPD)			
Wells drilled before the AGI survey		Wells drilled after the AGI survey	
G6/PS1	160		
G7	120		
G11	Dry		
G12	------		
G13	Dry		
G14	3		
G18	120		
	403		

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Based on the GORE survey data and the subsequent wells drilled on that data production increased 14-fold. And that is with just 3 additional wells. Obviously production could be increased further as new wells are drilled. 6,130 BOPD – 403 BOPD/ 403 BOPD = 14.2 fold increase in production

Lithuania Development Case Study

Production increased 14-fold

Production Test Data (BOPD)				
Wells drilled before the AGI survey			Wells drilled after the AGI survey	
G6/PS1	160		PS-2	3,350
G7	120		PS-3	2,020
G11	Dry		PS-4	760
G12	------			
G13	Dry			
G14	3			
G18	120			
	403			6,130

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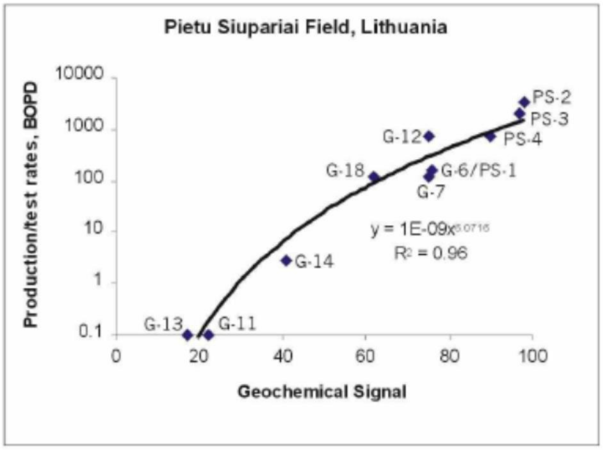
Probability versus Production Rate



Production Test Data (BOPD)				
Pre-survey			Post-survey	
G6/PS1	160		PS-2	3,350
G7	120		PS-3	2,020
G11	Dry		PS-4	760
G12	------			
G13	Dry			
G14	3			
G18	120			

"Reservoir sweet spots identified with surface geochemistry – an example from the Cambrian Pietu Siupariai oil field, Lithuania."

Authors: T. Haselton and P. Willumsen

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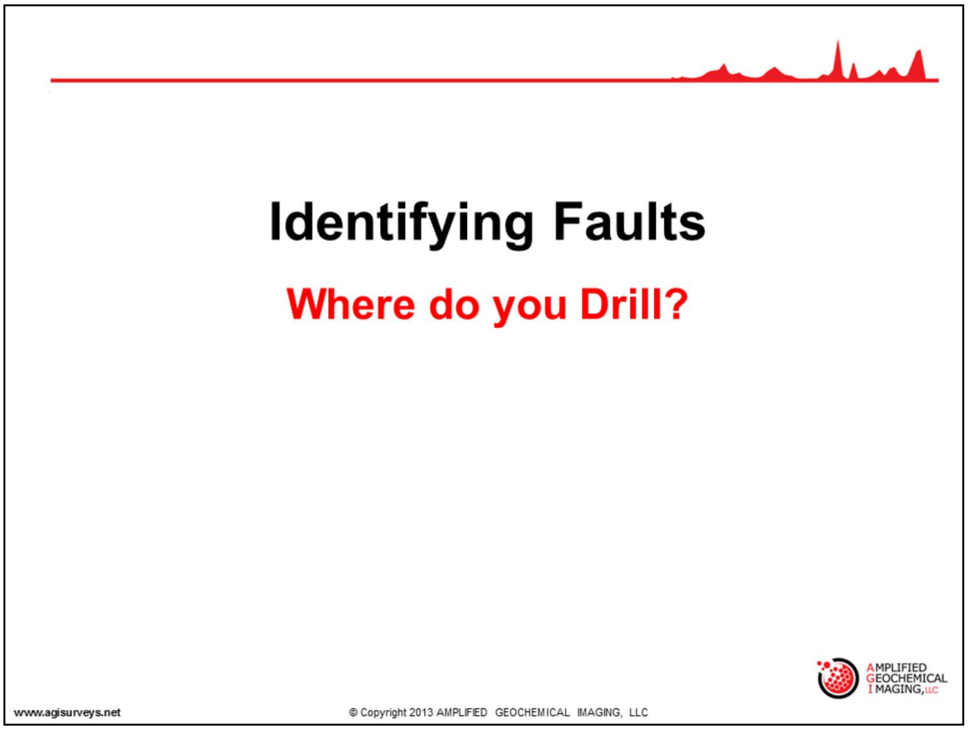
Probability Value related to Production: Production rates for 11 wells are graphed. The wells with a higher production in barrels of oil per day (BOPD) have the higher probability values associated with them at the surface. Onshore marine Cambrian sandstone, depth 2000 meters, reservoir traps are a result of Caledonian tectonism.



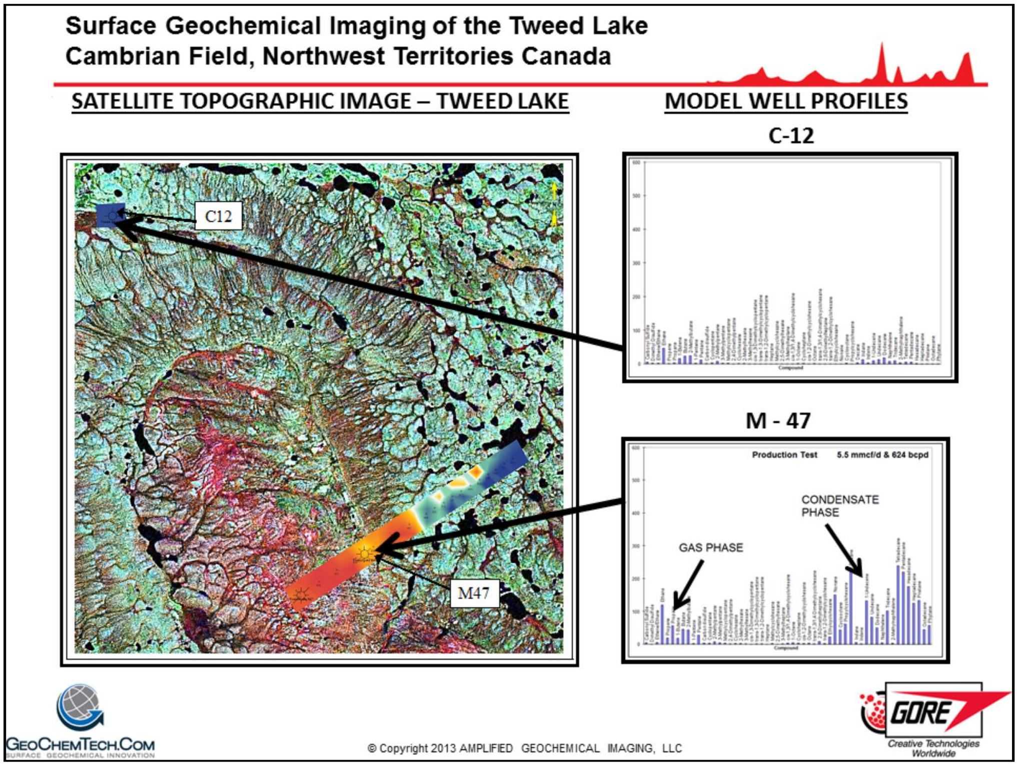
Compartmentalization can be an important issue in development programs for several reason.

1.) you may have areas of by-passed pays.

2.) seismic data may be old and not clearly differentiate faults.

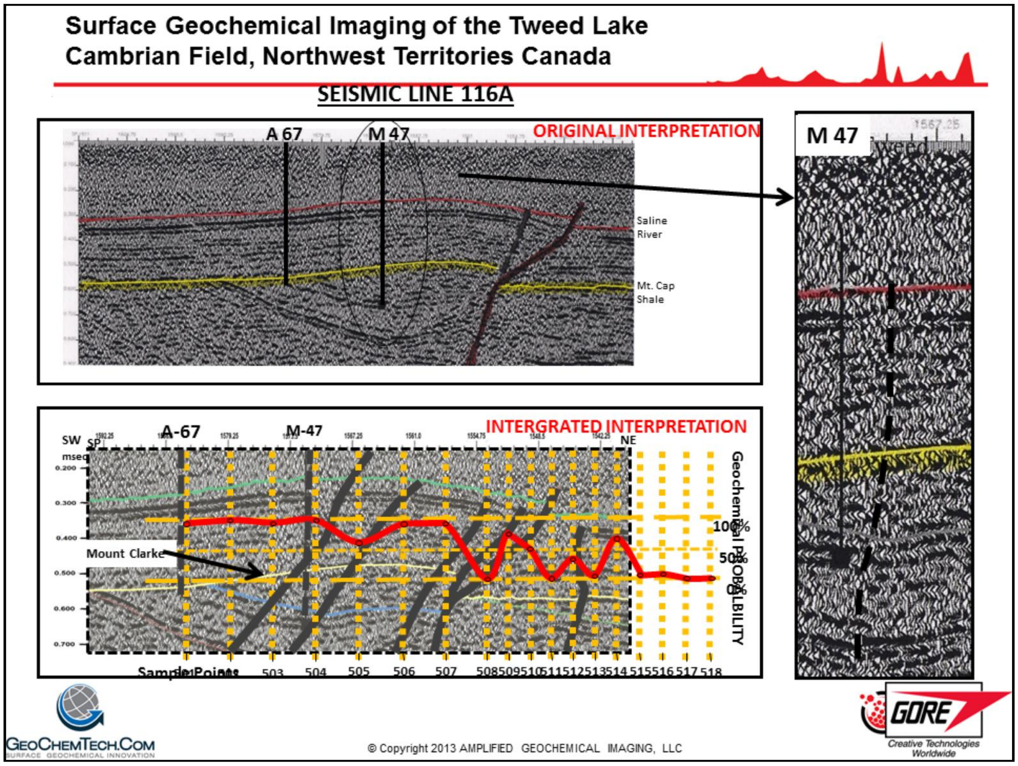
3.) compartments can seriously affect water floods and CO_2 floods

4.) obviously compartmentalization can affect the design and location of injection wells and production wells



This slide shows the design of the model survey on a satellite Image showing the surface expression of the anticline and the geochemical profiles of the two model wells. The survey consisted of placing 15 modules around the M-47 discovery well and 13 modules around the C-12 abandon well. A 3.5 km transect consisted of 18 modules at a spacing of 250 and 500 meters. The model well profiles consist of hydrocarbon compounds C_2 to C_{20} along the horizontal axis and mass on a scale of 0 to 600 Ng on the vertical axis.

The C-12 model well profile indicates very low levels of hydrocarbon compounds while the M-47 discovery well profile indicates levels of about 100 ng in the gas phase and about 250 ng in the liquid phase. The weak gas signal strength may be caused by the low BTU gas in the Mount Clarke reservoir. It should be noted that the M-47 well tested 5.5 mmcf/d of gas and 624 bcpd. The orange/red portion of the transect indicates the gas -condensate signal as defined by M 47 while the blue portion indicates no hydrocarbon signal as define by C 12. These signals are interpreted to be the result of microseepage from the trapped hydrocarbons.



This slide correlates the interpretation of Line 116A and the profile of the chemical probabilities along the transect. The discoveries wells are indicated on both the seismic and geochemical probability section. Line 116A images the anticline structure that forms the Tweed Lake trap and interpreted flower structure . The seismic line does not image the flower structure in detail.

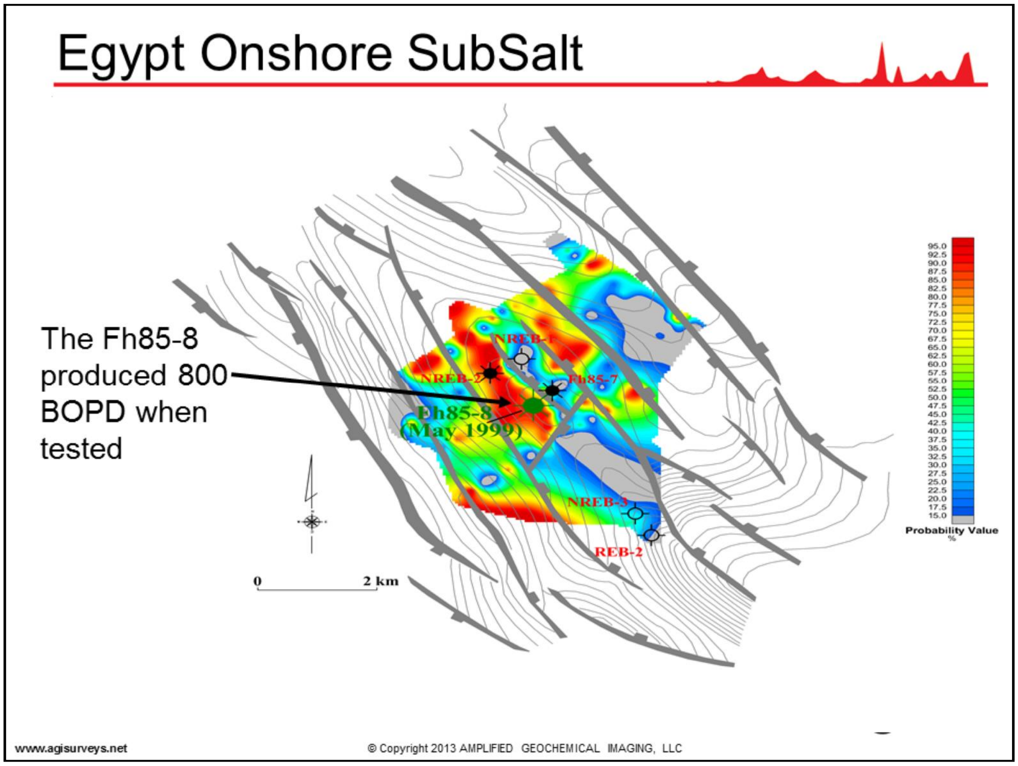
- •Line 116A images the anticline structure that forms the Tweed Lake trap.
- •Shows fault offsetting M-47 interpreted to compartmentalize the Tweed Lake pool.
- •Trapping structure complex appears to consist of four normal faults forming tilted fault blocks that contain hydrocarbons.

The geochemical profile section indicates a number of interest details:

- •Strong correlation between the gas wells and the 100% probabilities.
- •Numerous gas-bearing fault slices are interpreted from the geochemical transect northeast of the M 47 model well. The updip fault complex that forms the trap is interpreted to consist of at least 4 separate faults.
- • A low probability of 66% at sample point 505 has been correlated to a disturbance in the seismic section that could be a fault within the pool. This fault is supported by a surface lineament on the satellite image.

Because the fault could act as a barrier within the pool, it might impact production.

28



This map shows the modeled results as provided to the client. The thick gray lines indicate the fault lines that the client added to the map. The red shading indicates an 85% - 95% probability that there is oil in this area that matches the oil from the producing wells. What is interesting is that the red anomaly is bounded by the fault lines. We were not aware of these structural faults when we generated the findings. The light blue, or cooler colors, indicate areas of much lower probability – in the range of 25% - 40%. Notice all the dry wells are located in areas of light blue or dark blue which, according to the survey data, indicating a high probability of dry holes. You will notice one producing well in the blue area, but while the well platform was located in a blue area the well was actually drilled on a slant and penetrated the fault.

The client later drilled a well on the red positive anomaly and obtained a well that produced 800 BOPD.

Compartmentalization can be an important issue in development programs for several reason.

1.) you may have areas of by-passed pays.

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3.) compartments can seriously affect water floods and CO2 floods

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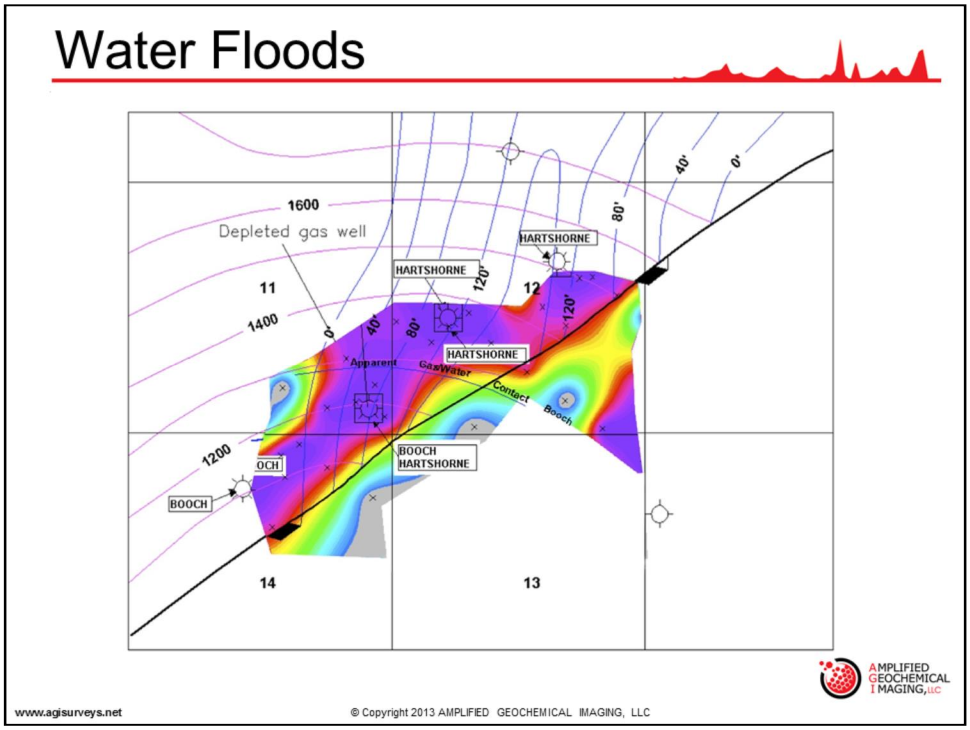
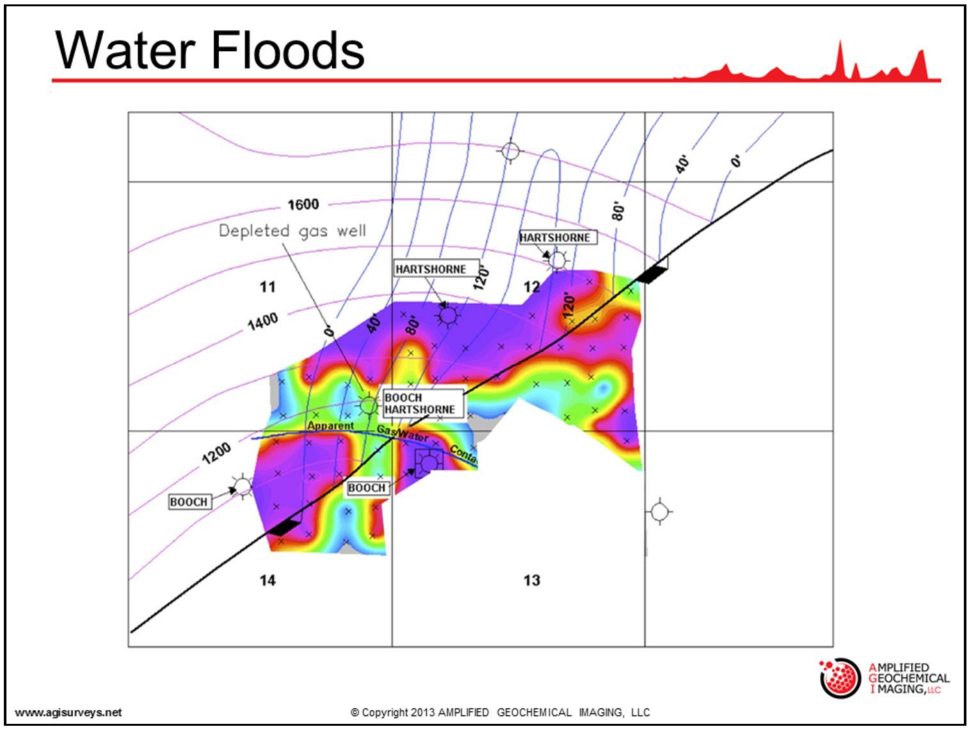
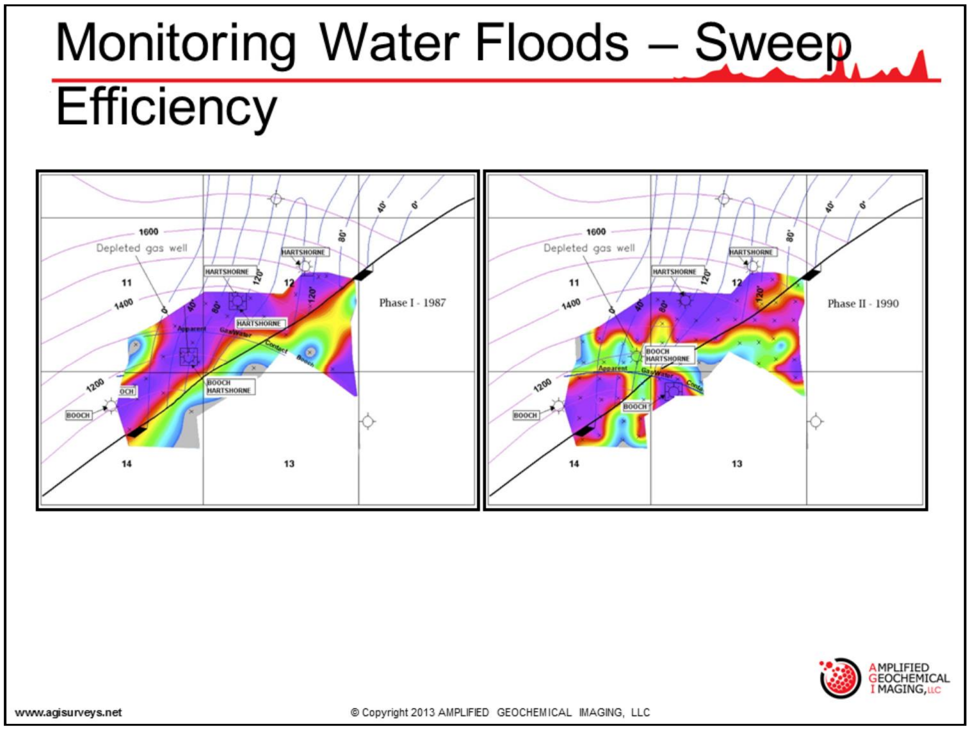


Use the survey to generate a hydrocarbon map to illuminate the field prospectivity and non-prospectivity.

If existing wells are in place then this field survey can be used to calculate the placement of new economic step-out wells.



In this slide after a water flood you can see the movement of the gas/water contact and the movement of the hydrocarbons.



Some shale plays may have sweet areas where in addition to gas they find liquids. We can help companies to find those areas using AGI. Just an example of how we can use cluster to identify gas, wet gas/condensate, or oil.

Conclusion

AGI Surveys allow you to:

- Map petroleum hydrocarbon accumulations
- Identify hydrocarbon phase
- Identify reservoir Sweet Spots (i.e. economic drilling prospects)
- Identify geohazards
- Identify by-passed pays
- Monitor the movement of oil-water or gas-water contacts

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Thank You!

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