Recognition and Meaning of Hydrocarbon Seeps*

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Abstract

This year AAPG will publish a collection of new papers, techniques, and research regarding hydrocarbon seeps titled "Hydrocarbon Seepage: From Source to Surface," edited by Mike Abrams, Fred Aminzadeh, Tim Berge, David Connolly, and Geoff O'Brien. This collection deals with different aspects, observations, and implications of natural hydrocarbon manifestations colloquially known and referred to as "seeps." There is tremendous variation seen in seeps--their fluids, gases, setting, associations, and they are not very easy to characterize. Yet they are true oracles of nature and speak directly to the prospector. With the increased resolution power of many geophysical methods, we are seeing direct evidence of seeps on a wide variety of data, not just conventional seismic.

This new volume is designed and organized to help answer some key questions that workers may develop from working field data. It has 3 parts designed to answer common questions by workers including: 1) What do seeps look like in various perspectives, data types, and environments? 2) What kind of methodologies may be used to detect and measure seeps? 3) What does the seep tell me about the prospect or area hydrocarbon system and associated risks?

History

There is no vestige of mankind's initial use of hydrocarbons from seeps. Noah used pitch in constructing the Ark, the basket of baby Moses was lined with pitch to help keep it afloat. Pitch was being used for shipbuilding, in masonry, and in rope-making in pre-history. By the Bronze Age there are references to lighted gas seeps for religious purposes and use of petroleum in simple medicines and ointments and as a lubricant. In the 7th century, "Greek Fire" was made from oil collected from seeps in Mesopotamia.

Marco Polo on his trip in 1264 to the Persian city of Baku, now in Azerbaijan, remarked that he saw spectacular mud volcanoes, sourced by natural gas seeping through ponds, and a flaming hillside, the "Eternal Fires of the Apsheron Peninsula, a spit of land that juts eastward from onshore Azerbaijan into the Caspian Sea and where condensate and natural gas seeping through fractured shales has burned, and was worshiped for centuries (see Figure 1 in Aminzadeh, 2011). Interestingly, the area is known as an oil-producing area and does produce both free and associated gas, but the gas seepage is the most prominent phase in the surface seeps. Despite the growth of the drilling and production capabilities of the oil industry in the late 20th century, mankind's use of hydrocarbons has primarily been of hydrocarbons produced from seeps.

All early petroleum exploration efforts, the Chinese bamboo-cased wells ca. 800bc, Drake at Oil Springs, the trench wells in Baku ca. 1840, involved direct exploitation of seeps. The industry quickly moved to methods which could be used to detect oil and gas deposits indirectly, by inferring existence of their required parts (i.e., trap, seal, reservoir, source, etc.). Even by doing so, some of those data were over seeps as well.

It could be said that over 80% of all existing production has a seep association (Aminzadeh, 2011). Many large field such as Spindletop and East Texas fields were discovered by drilling on seeps. Drilling seeps continues to be an exploration strategy today and may help understand regional and individual pool-accumulation top seals and fault leakage (Langhi, et al., 2011).

Table 1 is a short list of well-known seeps and their locations. Seeps exhibit broad diversity yet tend to have some shared similarities that may be useful clues to their identification on diverse types of data. Seeps seem to share some obvious common elements, as follows:
1) They are distinctly mounded.
2) Hydrocarbons are visible.
3) Seepage is a complex mixture of oil, gas, mud, and water, although one phase component may be dominant.
4) They may be composed of several sites, and each site may have multiple vents.
5) Individual vents tend to be circular, may be fluid-filled.

In the upcoming volume, Hoveland (2011) clearly documents these and additional observations from marine submersible observations. Water is a common effluent of both oil and gas seeps.

There is a sampling bias--gas seeps are more obvious in marine conditions and oil seeps are more evident on land. Although most seeps are characterized either as an oil or gas seep, in fact most seeps emit a complex mixture of hydrocarbon gases, oils, water, and mud. Table 2 shows an analysis from the Romanian seeps including Buzau; some are dominantly methane, but others are dominated by nitrogen with a helium association and higher H^3/H^4 isotope ratio.

The methane seeps also contain some nitrogen, and CO_2, but lesser amounts. A common effluent of both oil and gas seeps is water. Although we tend to focus of the hydrocarbon contents of seeps, seep origins might begin with the generation of the water phase. There is a hypothesis that at least some if not all seeps begin as deep super-heated water plumes and might include mantle-derived elements (Hovland et al., 2005).

Seeps have not only a surface manifestation but also may be traced in the subsurface with seismic and geochemical chimneys. Processing has evolved to better visualize these on seismic (Connolly, Aminzadeh, et al., 2011). Surface sampling and geochemical techniques have also developed (Abrams, 2011; Ashby and Dimtser-Denk, 2011).

Seeps in fact are complex systems with surface expression, Chemotropic and micro-biotic associations, subsurface conduits, alteration zones, and they exhibit other complex reactions. Some of these are summarized in Figure 1. These systems may be observed on a wide variety of data inferred whole from their parts. Seep systems may be active, or manifestations of a fossil system.

Active oil seeps may leave a cohesive surface film or slick that may be visible by several photographic and IR and radar sources both airborne and satellite based (Figure 2). Satellites can be individually programmed at some cost. There may be several options.

Sea state may be a limiting factor in some areas. Knowledge about shipping lanes and practices, as well as local currents and tides, is essential to be able to eliminate commercial or man-made contamination from natural slicks. Finally, identified slicks can be field checked and sampled.

Seismic Indications of Seepage, Seismic Chimneys, and DHRC's

A typical seismic observation of a seep may be simply a vertical disruption in the continuity of the seismic reflection data due to a vertical migrating gas column. However, there are many other seismic artifacts that may have a similar appearance; so care should be taken and other forms of corroboration should be looked for.

Common elements of seep associations may include:
1) The chimney may form a connection between reservoir and the surface or other migration route element, such as a fault.
2) The chimney may have shallow recharge zones, and/or form shallow gas hydrates.
3) At the surface there may be a topographic anomaly, commonly a blow-out crater, chemotropic mound, or HRDZs, which are zones of high seismic velocity caused by enhanced carbonate cementation related to hydrocarbon seepage and oxidation.
4) They may be confirmed by seafloor sampling, water analysis, sonar, radar, laser flourosensor, geochemical sniffers in air or water, and other direct methods.
5) The reservoir charge route, from source rock to reservoir, is seldom seen. Seeps are usually due to remigration or trap leakage.

Seep chimneys may connect leaky reservoirs or source rocks to intermediate recharge zones and faults (Aminzadeh, 2011), then to craters, mounds, and shallow hydrate accumulations (Figures 3 and 4).

Confirmation of these linked elements helps confirm the seep interpretation. Elements of the seep system have been captured in many types of increasingly higher resolution data types. As examples Figure 5 shows an acoustic plume--active seep in multibeam sounder. Figure 6 shows subbottom sonar profiler data and an inset of depth finder of a sampled seep offshore Australia. Instead of dismissing these as artifacts they are actual seeps.

Meaning of Seepage; Evaluation of Petroleum Systems and Prospect and Play Risk

An active seep is a live indication of at least a partially functioning petroleum system. If a seep could be confirmed at or near a prospect, Source presence, maturity, and migration risks could all be reasonably assigned a zero risk, eliminating an entire risk category. There is little in the explorationist's toolkit that can achieve that level of risk reduction.

Nuances about trap integrity and regional and local seals may be derived from seep observations and their relationships to existing geologic structure, and several papers in section 1 of the new volume are examples of this. As another example, in the Coal Point area offshore California near Los Angeles, most of the seeps are located along the anticlines. These associations may be dynamic. Studies of the area around Platform Holly showed a 50 percent decrease in natural seepage over 22 years of commercial production (Hornafius et al., 1999; University of California, Santa Barbara, 1999). The researchers show that as the oil was pumped out the reservoir, pressure that drives the seepage dropped. "If the decrease in natural seepage found near Platform Holly is representative of the effect of oil production on seepage worldwide, then this has the potential to significantly alter global oil and gas seepage in the future."

Seeps and the Environment

Seeps have been polluting the environment for a long time. 'Unnatural' seeps--man-made uncontrolled spills ala Macondo, differ from their 'natural' counterparts by having better plumbing and that makes them very destructive. Howeve, many seeps around the globe have been prolific and more continuously active. Overall, natural seepage never stops.

Hydrocarbon seepage has profound local effects that may be widespread (Hovland, 2011), including vast blighted areas. The area around the Buzau mounds suffers repeated acidic mudflows, and these form large barren mounds. At many marine seeps the biota are different and are dominated by a changed biota that can tolerate and exploit the changed geochemistry (Figure 1). Some of these communities may be locally inhabited by very adept methanotrophs and paradoxically thrive, producing mounds similar to reefs. Fossil communities like the Burgess shale quarries, have been thought to be associated with seeps (Johnston et al., 2010).

It is extremely difficult to estimate seep rates. Coal Oil Point seeps leak an estimated 150 to 200 BO/d (Environmental Science and Technology, 2009) and 5 MMcfg/d gas (Hornafius et al., 1999); estimates were made using sonar, flux buoys, and direct capture, and seepage there has been the subject of ongoing studies by UCSB for several decades. The most recent Coal Point area estimates are 4 times these estimates, and they suggest that global emissions of methane from natural seepage have been underestimated.

What is the volume of seepage worldwide? It is estimated that the Coal Point seeps are a large source of air pollution in Santa Barbara County. The Coal Oil Point seeps are similar in many ways to many of the seeps discussed in this volume, multiplied by any reasonable assumption of seep numbers worldwide, and it is easy to imagine that seepage of oil in the range of thousands of barrels per day and gas leakage of 100's of millions of cubic feet per day is not unreasonable. These are not sporadic events either, but leakage of hydrocarbons that occurs every day.

With all these changes in detail of observation, including new technology for seep sampling, detection, source correlation, seismic attributes, and a developing catalog of examples and detailed field-study examples, it is a good time to note the organization of this new volume: 3 parts--1) *Descriptions and Observations of Seeps*, 2) *Science of Seepage, Methodology* and 3) *Implications of Seeps*--consisting of individually authored papers. This is expected to be a standing key reference and resource for someone who has questions about artifacts or seep observations in their data and would like some comparisons and ideas about what to do. We wish to further understanding and recognition of seep connections both to resources and to our environment.

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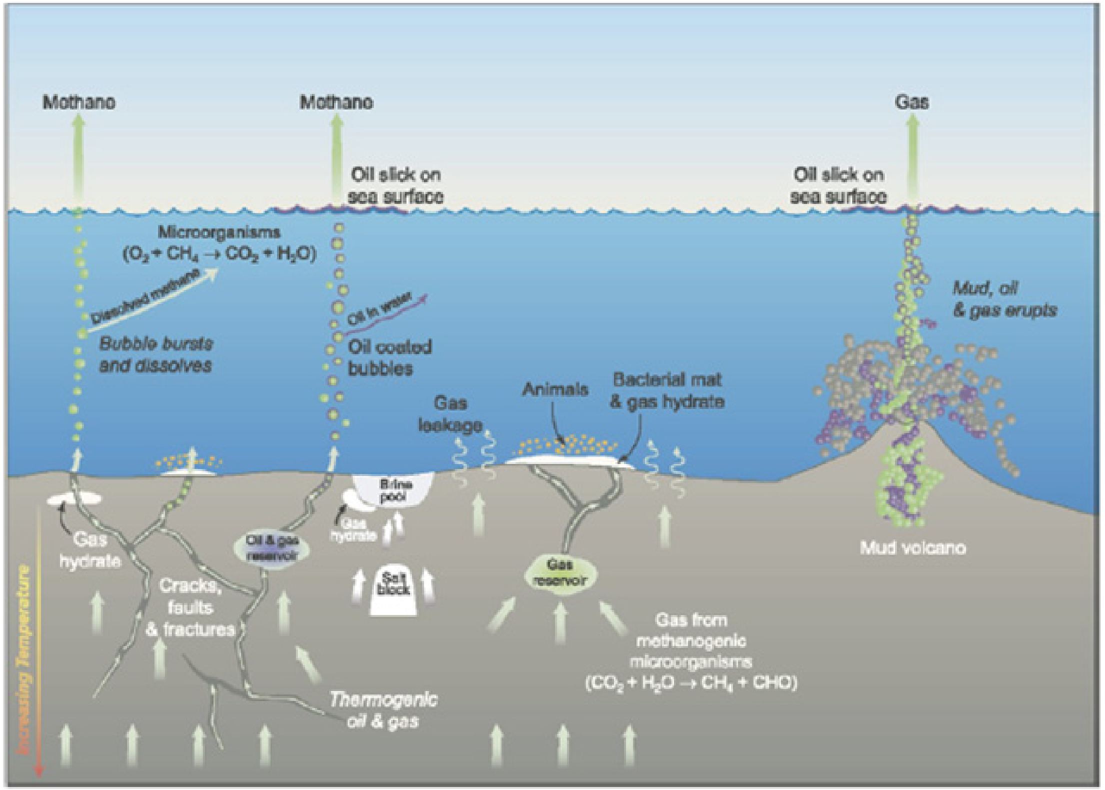
Brief Catalog of Examples

Area	Seep Type	Location	latitude	longitude
La Brea Tar Pits	Oil	Los Angeles, California	34 03 46.39N	118 21 21.70W
Ateshkah	Gas and Oil	Baku, Azerbaijan	40 25 00.73N	50 00 29.04E
Tarbaj	Oil	Kenya	2 10 00.85N	40 15 14.88E
Buzau	Gas	Romania	45 20 19.88N	26 42 26.79E
Baba Gurgur	Gas	Kirkuk, Iraq	35 31 41.78N	44 20 56.48E
Anderscu de Jos	Gas	Romania	45 45 03.33N	26 49 58.60E
Grieve seep	Oil	Wind River Basin, Wyoming		

Table 1. Examples of Hydrocarbon seeps.

Sample	He (ppmv)	N_2 (% v)	CH_4 (% v)	CO_2 (% v)	$^3He/^4He$
Transylvanian Depression					
Homorod (pool)	14856.8	91.5	0.3	6.7	
Homorod (well)	14405.5	92.6	0.4	5.6	5.9×10^{-7}
Bazna	16.5	1.0	97.9	1.2	2.8×10^{-8}
Sarmasel	27.0	0.6	98.7	0.7	2.9×10^{-8}
Carpathian Foredeep					
Andreiasu	10.3	2.2	95.8	2.0	4.3×10^{-8}
Paclele Mari	25.1	15.3	82.7	2.0	6.1×10^{-8}
Paclele Mici	24.0	2.8	94.9	2.3	6.1×10^{-8}
Fierbatori	14.3	6.2	91.3	2.5	2.1×10^{-8}

Table 2. Gas composition variation of Romanian land gas seeps (from Baciu et al., 2007).



(European Commission, 2007: Sketch of gas seep related processes. The processes shown include thermogenic oil and deeper gas generation (to the left) and biogenic methane generation (to the right). Gas from either source can migrate upwards, either rapidly through faults and fractures or more slowly by diffusion through sediments into overlying oil and gas reservoirs. If methane concentrations reach saturation in the seafloor, methane hydrate deposits form within the hydrate stability zone. When gas migrates further up to the sediment-water interface it is consumed by anaerobic methanotrophs (bottom right), or by aerobic methanotrophs at the seafloor or in the water column. If gas bubbles escape the seafloor and survive to within 100m of the surface of the ocean, they can emit methane into the atmosphere. After *Whelan et al, 2005, Mar. Pet. Geol. 22, 479-497*).

Figure 1. Marine seeps (after Whelan et al., 2005).

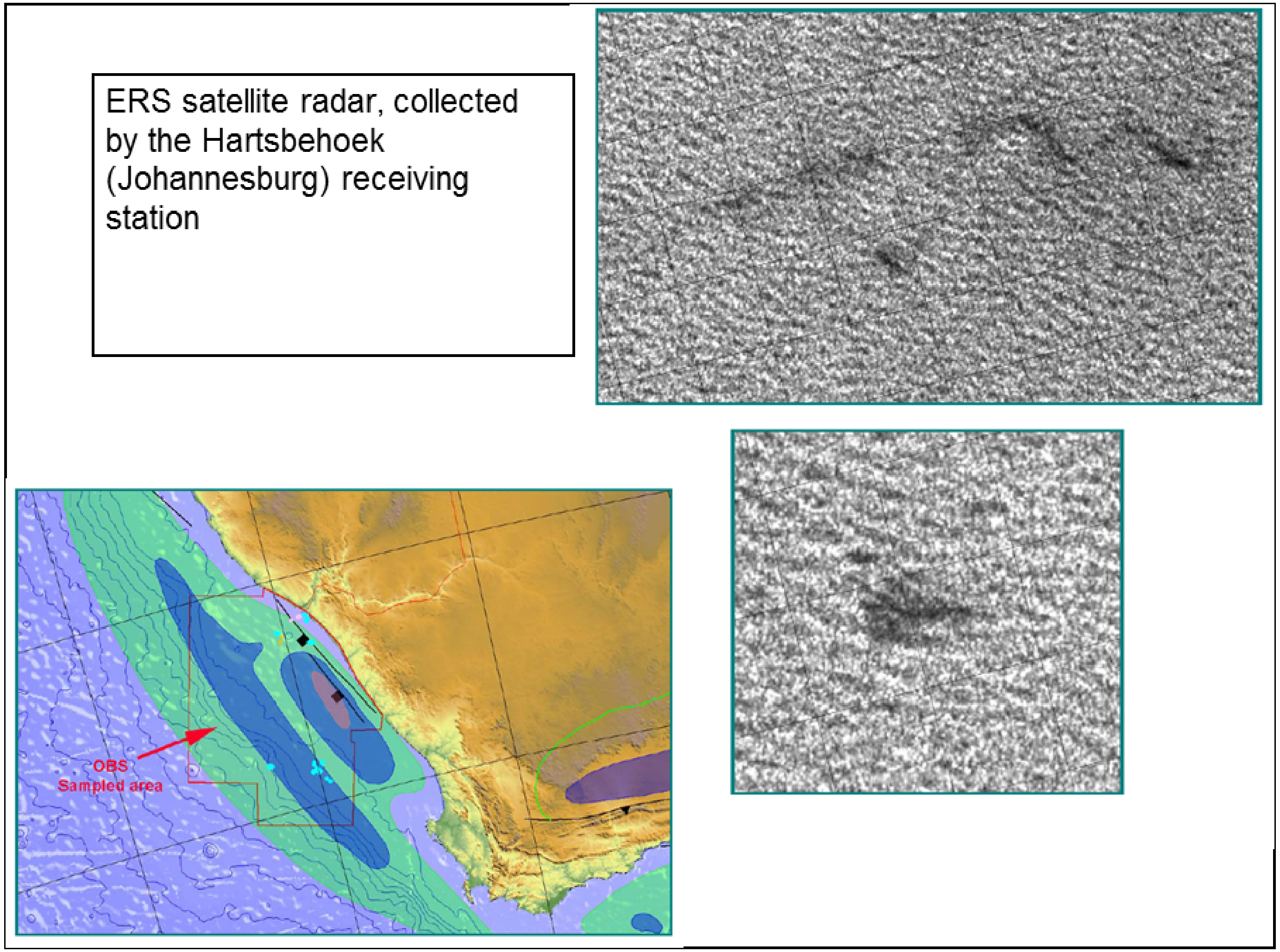


Figure 2. Radarsat image of a surface slick interpreted to be natural seepage (PetroSA).

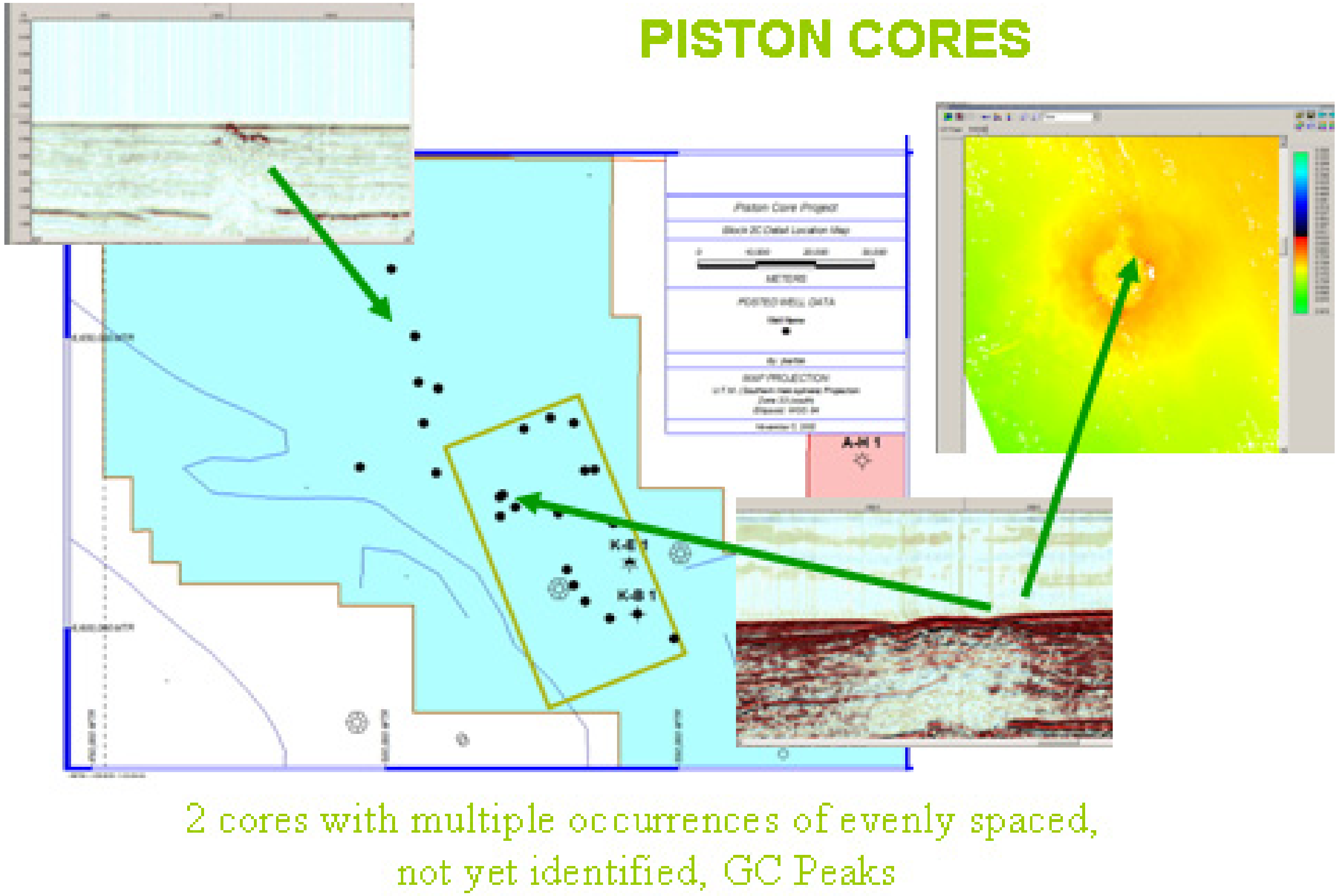
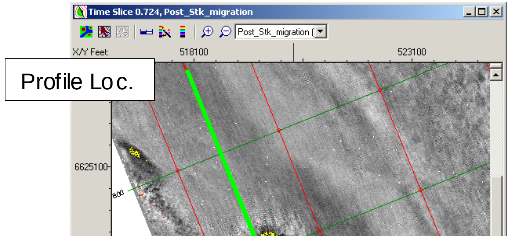


Figure 3. Seep examples from offshore West Africa sampled and verified by piston cores. Example A (upper left) shows a distinct vertical chimney that terminates in a marked HDRZ. Note that the seafloor reflection onlaps the HDRZ, indicating the seep is older. The data are 2D. The seep in example B (lower right, 3D data) has a vertical seismic anomaly but shows additional signs of current seep activity including a blow-out crater.

- Seep originates at mapped prospect level.
- Shows shallow re-charging at 2 levels.
- Wide blow-out crater, creates erosional surface.



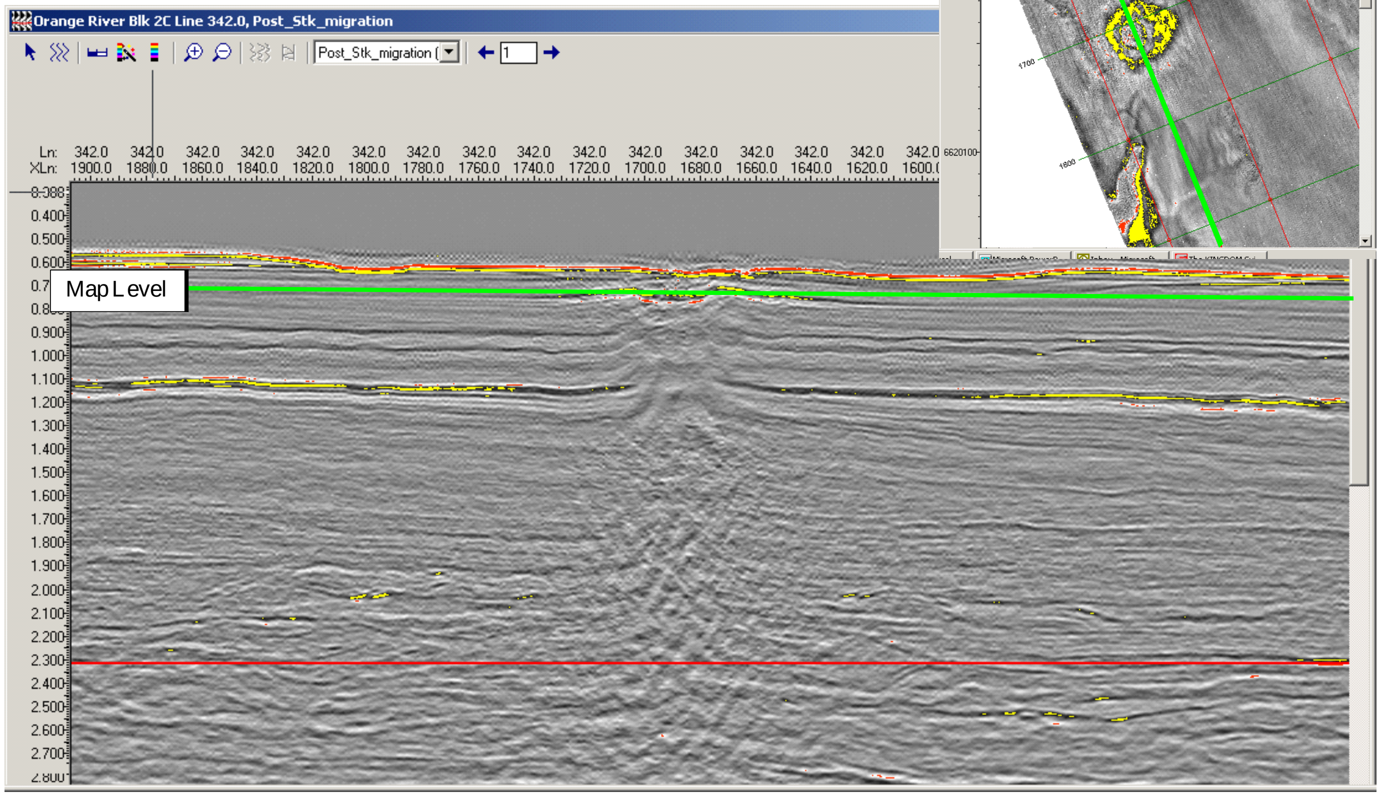
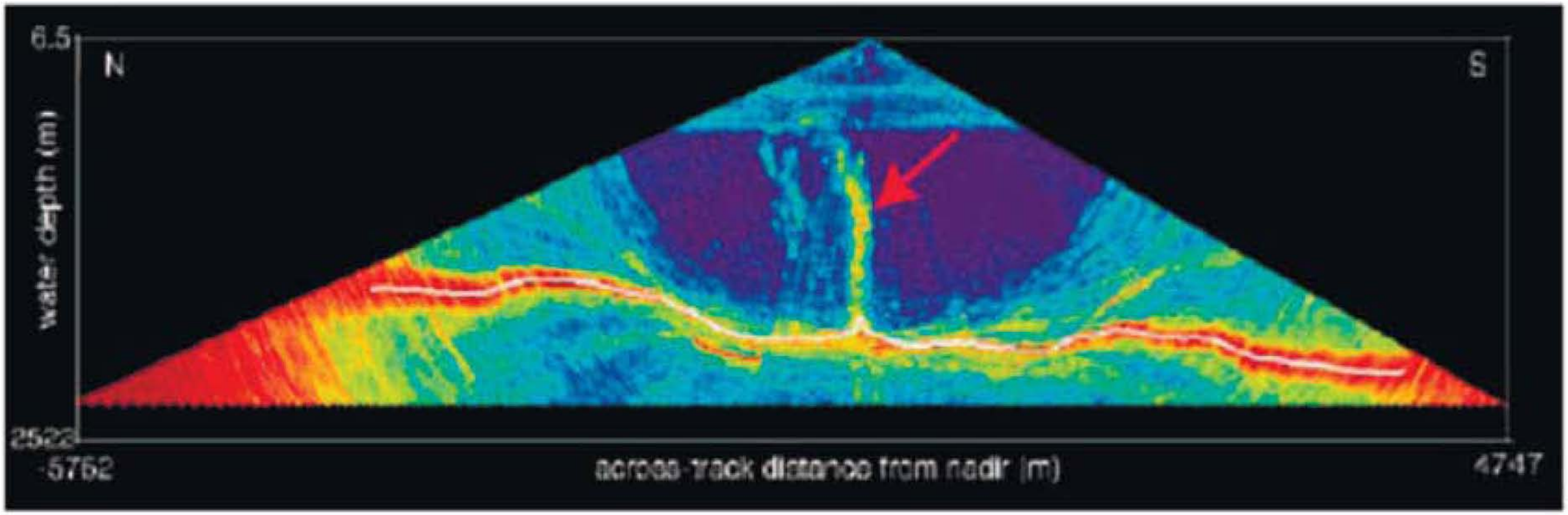


Figure 4. Additional details of seep B, offshore West Africa, showing broad blow-out crater and two recharge zones indicated by anomalously high seismic reflection amplitudes (yellow response). Small map is a timeslice at .7 sec TWT.



Screen grab of the multibeam echo sounder water column display showing the plume (red arrow). The horizontal axis is across-track distance, and the vertical axis is water depth. The somewhat horizontal white line embedded in the red band is the seafloor acoustic return. The plume disappears from the water column at roughly 400 meter water depth.

Figure 5. Multibeam echo sounder water column display (screen “grab”) (text figure from Gardiner et al., 2009).

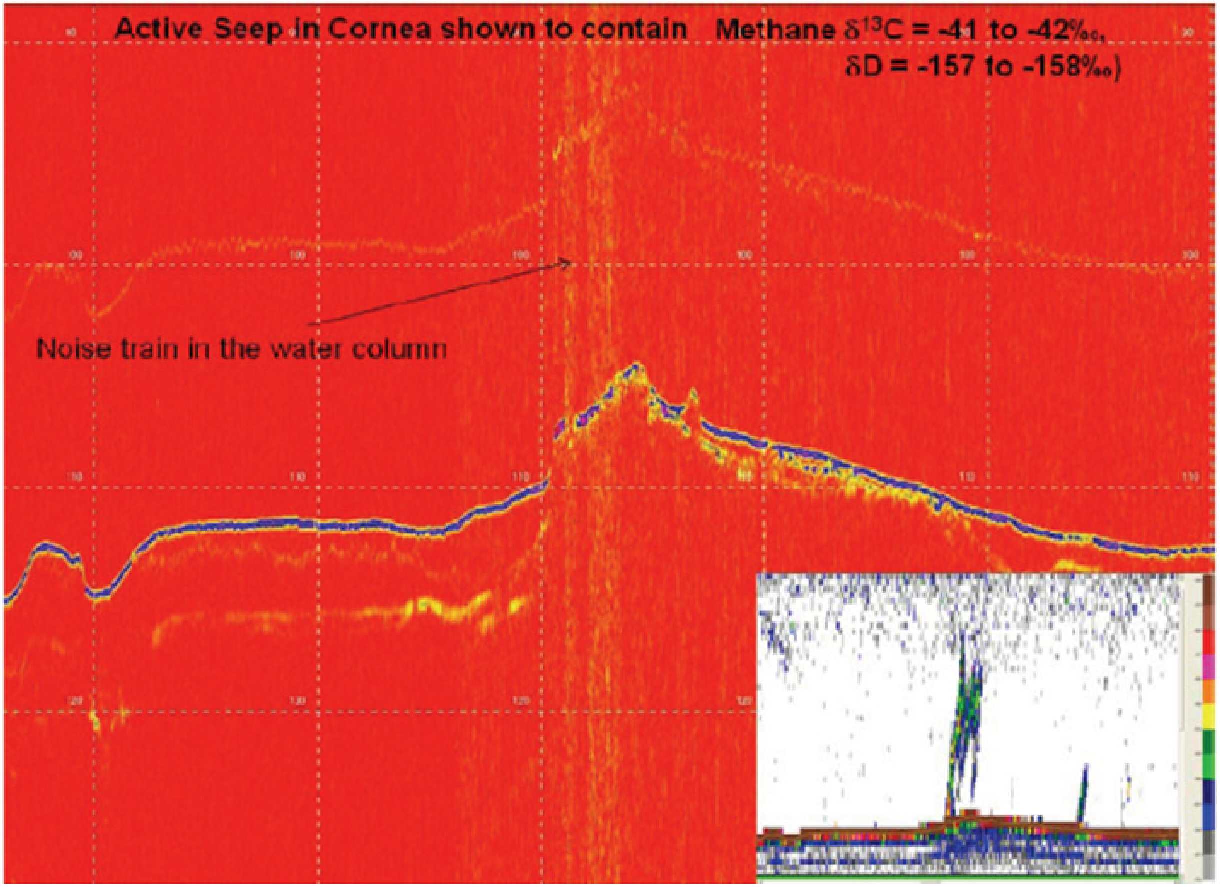


Figure 6. Subbottom sonar profiler record over a sampled seep, offshore New South Wales, Australia. Note phase change of bottom reflection and noise caused by bubbles in the water. Observations indicative of gas include multi beam echo sounder profiles, TOPAS sub-bottom profiles (red display), side-scan sonar (inset), and visual observations of sea surface bubbles which were sampled. From Kron et al., 2006.