Macroseeps and Microseeps: A History of Unconventional Approach to Exploration Since the Start of the Petroleum Age*

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Abstract

Oil and gas macro-seeps were the initial exploration tool that started the Petroleum Age. Numerous oil macroseeps had been known to several cultures for centuries around the globe and early development targeted these locations aggressively. Fairly quickly almost all macroseeps in accessible areas were exploited causing new methodologies to be developed. In the 1920s, microseepage technologies began developing in various forms to be used in conjunction with other exploration tools such as surface mapping for subsurface structures. With the advent of seismic, microseep methodology took a backseat role. However, in the 1970s to 1990s there was resurgence in the technologies both on land and on sea. The success rate of microseepage methods during this time period increased due to highly sensitive, reliable and accurate laboratory equipment, better understanding of soil chemistry, more rigorous sampling methods and more robust analytical analysis utilizing computers. In the 1990s to present day the shift in the industry from conventional to unconventional reservoirs that covered large areas the use of microseep methods as an exploration tool diminished domestically US and Canada but internationally it is still used extensively in under developed or remote basins. These methods are a tool in a toolbox. This paper will present examples of successes, track records of some of the methods and discuss the place of these methods going forward in the industry.

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Abstract

Oil and gas macro-seeps were the initial exploration tool that started the Petroleum Age. Numerous oil macroseeps had been known to several cultures for centuries around the globe and early development targeted these locations aggressively. Fairly quickly almost all macroseeps in accessible areas were exploited causing new methodologies to be developed. In the 1920s microseepage technologies began developing in various forms to be used in conjunction with other exploration tools such as surface mapping for subsurface structures. With the advent of seismic, microseep methodology took a backseat role. However, in the 1970s to 1990s there was resurgence in the technologies both on land and on sea. The success rate of microseepage methods during this time period increased due to highly sensitive, reliable and accurate laboratory equipment, better understanding of soil chemistry, more rigorous sampling methods and more robust analytical analysis utilizing computers. In the 1990s to present day the shift in the industry from conventional to unconventional reservoirs that covered large areas the use of microseep methods as an exploration tool diminished domestically US and Canada but internationally it is still used extensively in under developed or remote basins. These methods are a tool in a tool box. This paper will present examples of successes, track records of some of the methods and discuss the place of these methods going forward in the industry.

Hydrocarbon Seepage

Macroseepage illustrate the presence of hydrocarbons in a basin.

Macroseepage
- large concentrations of migrated hydrocarbons;
- visible oi staining and odor;
- migrate laterally via porous, permeable breccia zones of faults, injectites or vents;
- can be detected visibly at the surface.

Microseepage
- chemically detectable at the surface;
- concentrations lower than macroseepage;
- no visible hydrocarbons or odor;
- migrate vertically via grain boundaries;
- diagenetically altering the rocks through which they pass.

- Onshore
  - Visible seeps
  - Mud volcanoes
- Offshore
  - Mud volcanoes
  - Visible seeps
  - Pockmarks
  - Gravity coring

Macroseeps

www.alamy.com - FM7CX8

Seeps

- The petroleum industry is first encountered In the archaeological record the petroleum industry is first found in Hit (Iraq) on the banks of the Euphrates river. The oil seep is known locally as The Fountains Of Pitch. Asphalt was quarried to be used as mortar between building stones as early as 4000 BC. It was also used as a waterproofing agent for baths, pottery and boats (Purdy, 1957).

- The Babylonians caulked their ships with asphalt.

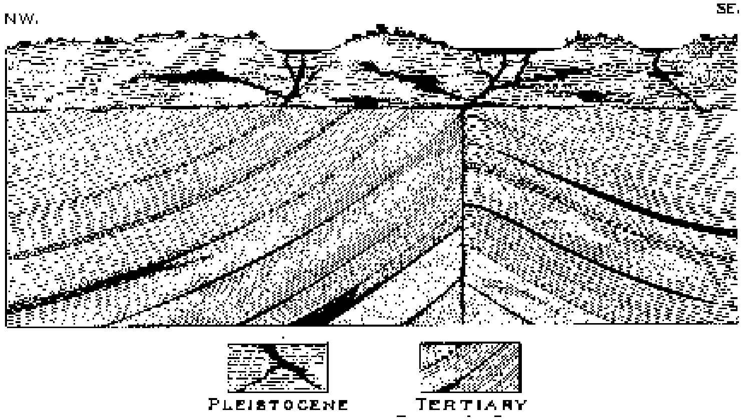
- In Mesopotamia around 4000 B.C., a tarry crude known as bitumen – was used to caulk ships, a setting for jewels and mosaics, and an adhesive to secure weapon handles.

- Egyptians used it for embalming, and the walls of Babylon and the famed pyramids were held together with it.

- Moses' basket and Noah's Ark being 'pitched' inside and out with it. Natural deposits of asphalt occur in pits or lakes as residue from crude petroleum that has seeped up through fissures in the earth.

- Bitumen was the Roman name for an asphalt used as a cement and mortar.

La Brea Tar Pits



This 1907 U.S. Geological Survey drawing shows how oil from underground rock layers migrates upward to fill the La Brea pits.

Seeps

Diatomite outcrop containing oil that seeps out in hot weather, near McKittrick, in Kern County California

- 347 AD In China oil wells drilled to 800 feet using bamboo poles.
- 900s Sumatrans and pre-Columbian Indians all believed that crude oil had medicinal benefits.
- 1264 Mining of seeps in medieval Persia witnessed by Marco Polo.
- 1300’s Oil gathered in Baku was already being exported to other countries of the Middle East.
- 1500s Oil mines in Poland for street lamps.
- 1539 First oil exported from Venezuela (in 1539) was intended as a gout treatment for the Holy Roman Emperor Charles.
- 1594 Oil wells dug by hand to 115 feet in Persia.
- 1597 Tribes living along the banks of the river Ukhta in the far northern Timan Pechora region gathered oil from the surface of the river and used it as a medicine and a lubricant.
- 1657 Jesuit missionaries noted that in the land of Cats heavy thick water that ignites and the savages cover themselves with it to anoint and grease their bodies.
- 1702, Tsar Peter the First ordered the setting up of Russia's first regular newspaper, Vedomosti. The paper's first issue carried a story about the discovery of oil on the surface of the river Sok in central Russia, while later issues carried similar stories about oil seeps elsewhere in Russia.
- 1735 Oil sands mined in Alsace France at the Pechelbronn Field.
- 1600’s to 1800s Indians and settlers noted seeps in Western Pennsylvanian and New York. The Seneca tribe traded oil and as the oil became known as “Seneca Oil” for $20 a quart.

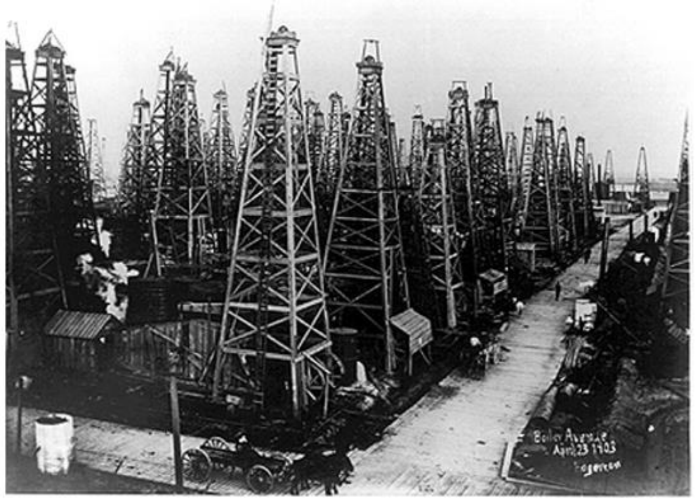
Seeps

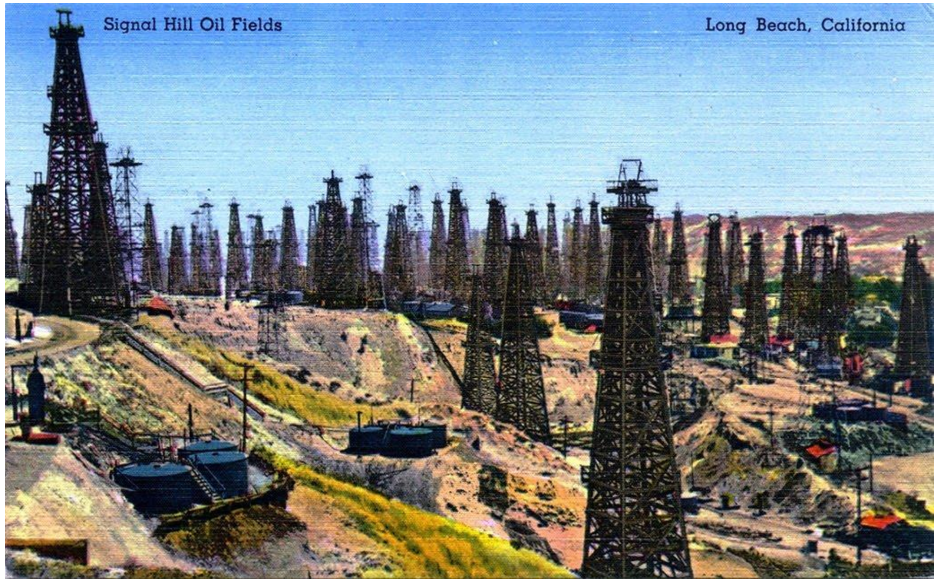
Natural asphalt with embedded wood, Pitch Lake, Trinidad and Tobago. Asphalt has been produced from Pitch Lake since 1851.

- 1802 A well drilled for brine in the Kanawha Valley of West Virginia produces oil instead.
- 1814 The Thorla-McKee well in Ohio produces oil as well as brine.
- 1821 The natural gas industry is born when William Hart dug a well to 43 feet into a gas shale and piped methane into the local inn, Fredonia, New York. Several more wells were drilled in the area.
- 1828 A brine well near Burkesville, Kentucky produced oil in large quantities as well.
- 1848 First modern oil well is drilled in Asia on the Aspheron Peninsula northeast of Baku by F.N. Semyenov – The Start of the Petroleum Age.
- 1849 Dr. Abraham Gesner (Canadian) distills kerosene from oil.
- 1850 Oil hand dug in Los Angeles, California to produce lamp oil by General Andreas Pico.
- 1854 First oil wells drilled in Bobrka, Poland.
- 1854 Gas well in Stockton, California drilled to light the Stockton, courthouse.
- 1857 Michael Detz invents the first kerosene lamp that forces whale oil lamps off the market.
- 1858 Canadians drill their first oil well in Ontario, Canada.
- 1859 Colonel Edwin Drake drills the first oil well in the US at Titusville, Pennsylvanian near a seep.

Seeps

- In the literature it is cited 80% of the major and minor oil fields have some sort of seep associated with them;
- Iran, Iraq, Algiers, Libya, Europe, North America, South America, Southeast Asia, China, India, etc. all have seeps that are associated in some cases with major fields;
- In the US seeps are associated with Spindletop, Signal Hill, Kern River, Lima-Indiana Trend, Florence Field, etc.
- Seeps were the main tool for several decades

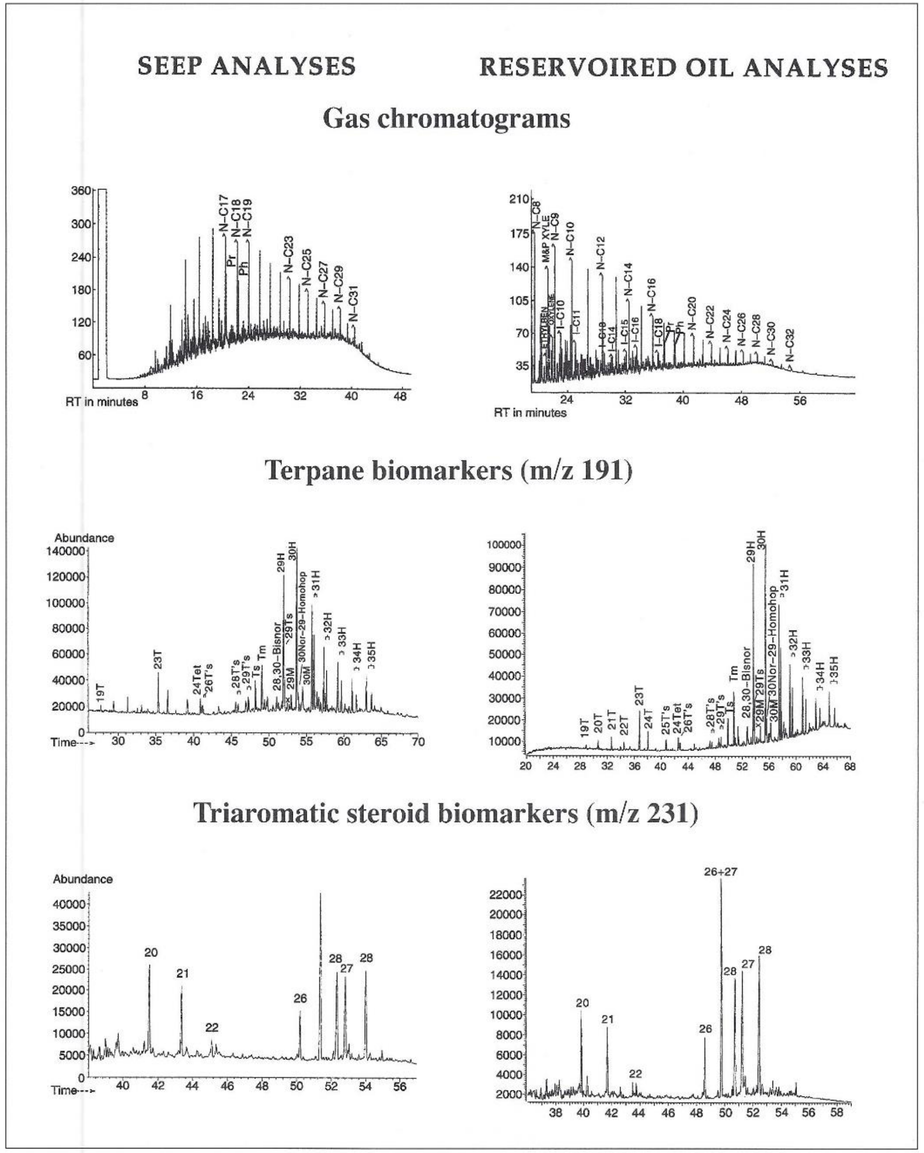




Edward L. Doheny,
California oil entrepreneur
in Mexico

Lazaro Cardenas del Rio, president of Mexico from 1934 to 1940. In 1938, Cárdenas ordered the expropriation of all oil companies in Mexico

Seeps



- The figure to the right is a comparison of oil profiles from reservoirs from being produced fields in Gulf of Mexico reservoirs to oil collected from deep cores in the same area.
- There is similarity in pattern but the core samples show degradation as would be expected.

Microseeps

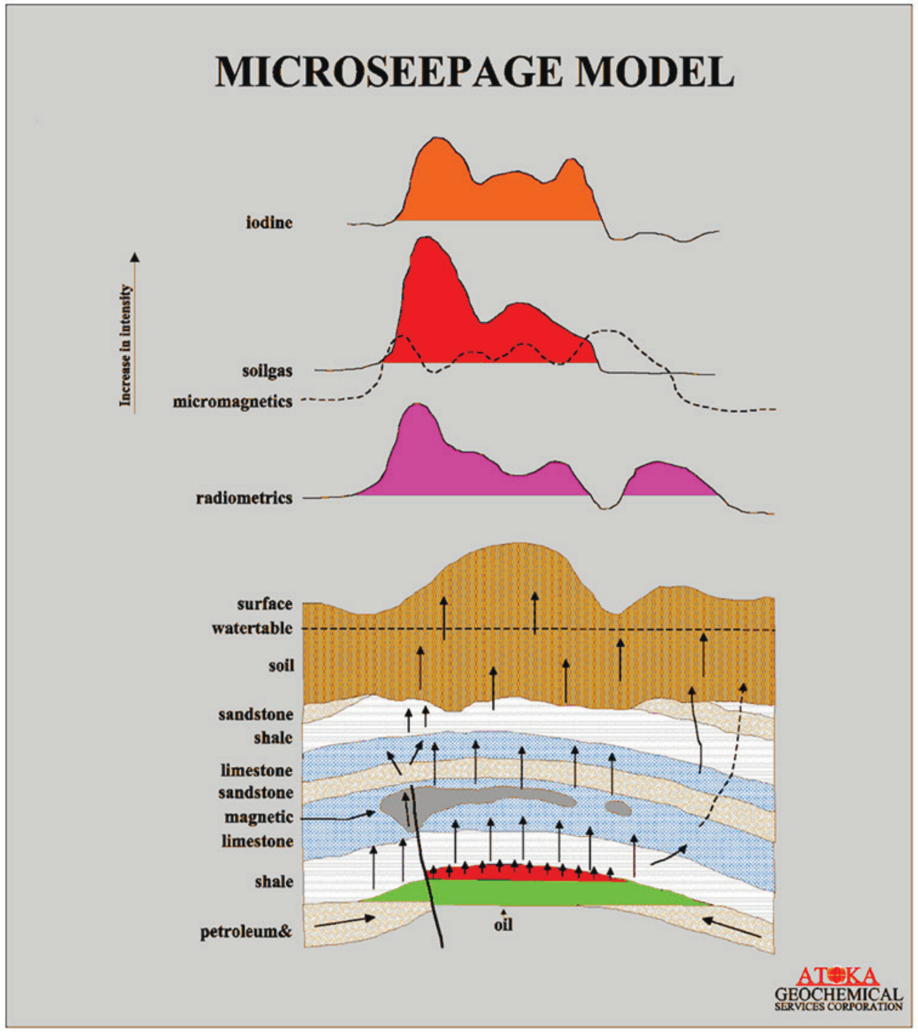
Generally Accepted Concept of the Trap

- The trapping of oil in a reservoir (poor or good) is the presence of a seal around the edges and over the top;
- The seal is usually perceived tp be an impermeable shale, carbonaceous mudstone, siltstone, salt, anhydrite, dense carbonate, etc.
- The seal is assumed to be ductile and prevents flow of hydrocarbons through it;
- Shale industry has proved there is minor fracturing, micro-pores, micro-unconformities, etc.

Microseeps

Surface geochemistry is based on the principal of hydrocarbons leaking to the surface through the process of vertical migration

Hydrocarbons in the soil cause a reducing environment that changes the chemistry. These changes can be detected and evaluated to define an area that may be a possible petroleum target.



The hydrocarbons can be detected or there by-products such as increases in iodine.

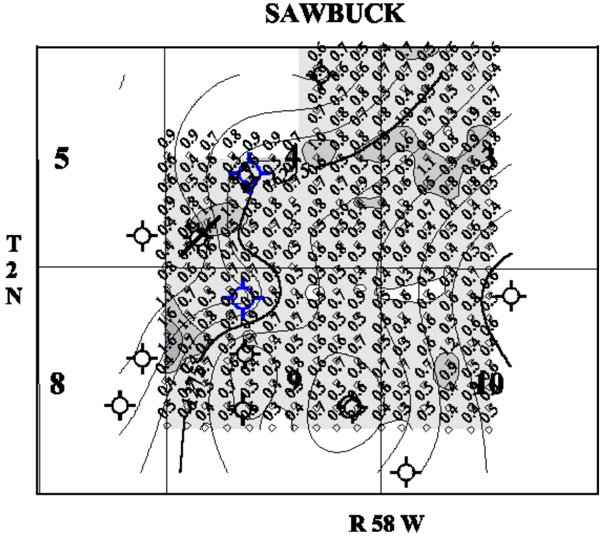
These hydrocarbons migrate to the soil from below.

The seal rock above a petroleum reservoir has minor fractures or disconformities that allow minor amounts of hydrocarbons to escape.

American Association of Petroleum Geologists 2017 Annual and Exhibition 100 Years Houston, Texas

Presenter's notes: Model of microseepage. Note the classic profiles over the target reservoir that is leaking hydrocarbons in the subsurface. What complicates this model in the real world is what are the migration pays. As we will demonstrate, is that the migration paths that are generally unknown above any reservoirs seem to be vertically migrating. The more complex the geology by faulting and wrenching can cause leakage in a larger area. However, the importance of iodine survey is that it can help determine whether a seismic or geologic target has potential hydrocarbons in it. If none is seen then it is over 95% chance it will result in a dry hole.

Results of microseepage at the surface



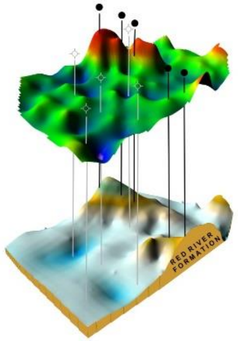
Predicted dry holes
Denver Basin

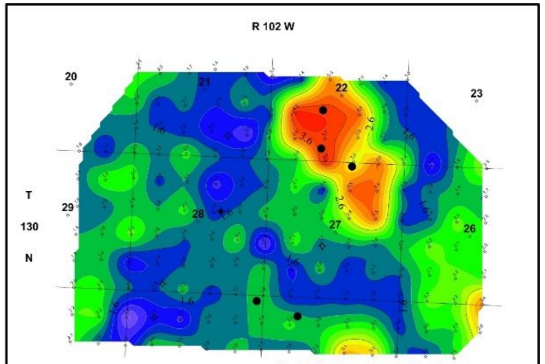
- Presence of C_2 and greater hydrocarbons in the soil horizons;
- Reducing environment;
- Increase in trace and major elements in and around the area of seepage;
- Increase in gamma content on the periphery of the seepage area;
- Increase in carbonate minerals;
- Increase in magnetic minerals;
- Significant changes in Eh and pH in and around the seepage area;
- Presence of petroleum eating bacteria;
- Plumes of seeping hydrocarbons in the air detectable by radar;
- Increase in halogens.

ALL THE SAME THINGS CAUSED BY MACROSEEPS

Early Years – Microseeps

1920s tp 1940s



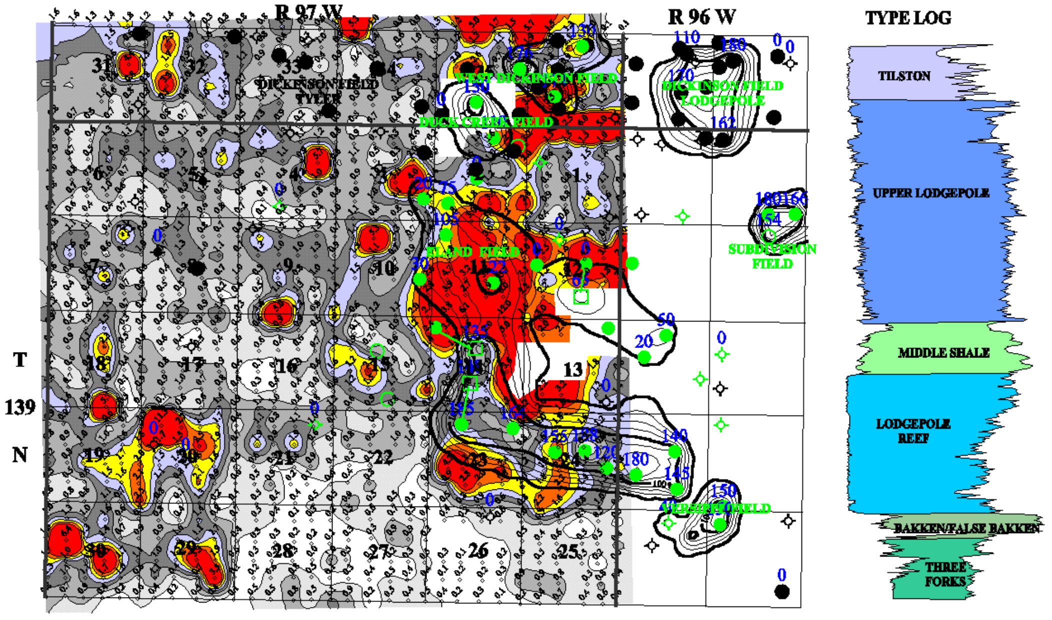


Cold Turkey Creek Field
Section 22, Township 130 North, Range 102 West
Bowman County, North Dakota
Red River Formation

- G. Laubmeyer of Germany in 1929 submitted patent to detect hydrocarbons;
- Soviets began conducting surveys in 1930 to 1932 began conducting soil gas surveys;
- 1930s and 1940s saw US companies use these methods with mixed results. Analysis was limited to methane and ethane due to the equipment of the day. Mobil Oil patents radar technology to map gas plumes;
- 1940s saw the Russians have notable success using these methods.

1950s and 1960s

- 1950s saw the resurgence of surface geochemistry as several successes were the result of the work by Crown Petroleum and Geochemical Surveys. Crown concluded that surface geochemistry was six times more effective than any other method used at the time. Phillips files a patent using bugs in soils to detect hydrocarbons;
- Horovitz Labs claimed 23 new fields out of 39 surveys done;
- Geochemical Surveys claimed that 38 new fields were discovered out of 160 surveys done;
- The methods used at this time in the use were radiometrics, delta C, microbial and soil gas;
- Major and foreign oil companies picked up the methods again. However, they had mixed results;
- At this time Horovitz work concluded that most of the anomalies that led to discoveries were not halo in nature.

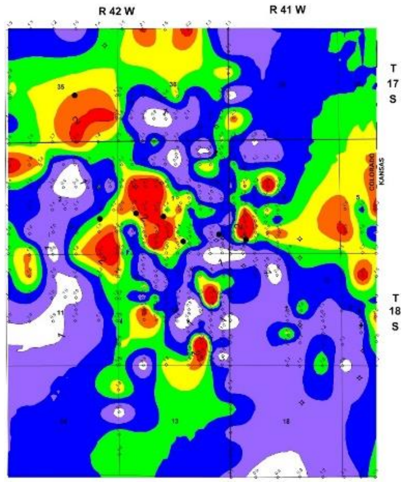


Eland Field, Stark County, North Dakota. Iodine data - Post Drilling. Dickinson Field was discovered several decades prior to the discovery of the Eland Field and produces from the Tyler Formation. No iodine anomalies would be expected over a depleted reservoir. Black lines are an isopach of the Lodgepole Mound based on documents submitted to the State of North Dakota. All wells in green are post survey and penetrate the the Lodgepole Formation.

Eland Field Post-Drilling Stark County,

North Dakota, Williston Basin

1970s and 1990s

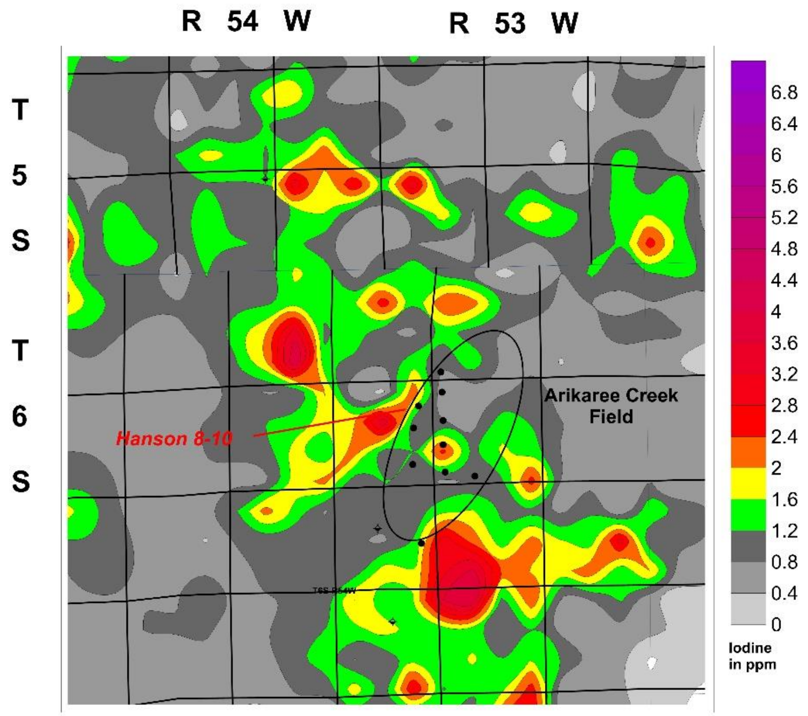


Jace Field
Kiowa Co., CO

- 1970s through the 1990s saw a surge in the use of surface geochemical methods especially after the crash in 1982 to 1986;
- The number of service companies exploded and new methods were introduced and developed;
- This new methods were iodine, helium, micromagnetics, trace and major elements and various soil methods;
- Numerous success were noted and the number of articles in various journal substantially increased;
- Laboratory technology also advance with the introduction of the mass spectrometer, XRD and XRF equipment. Also the portable nature of some of the laboratory equipment.

2000s and beyond

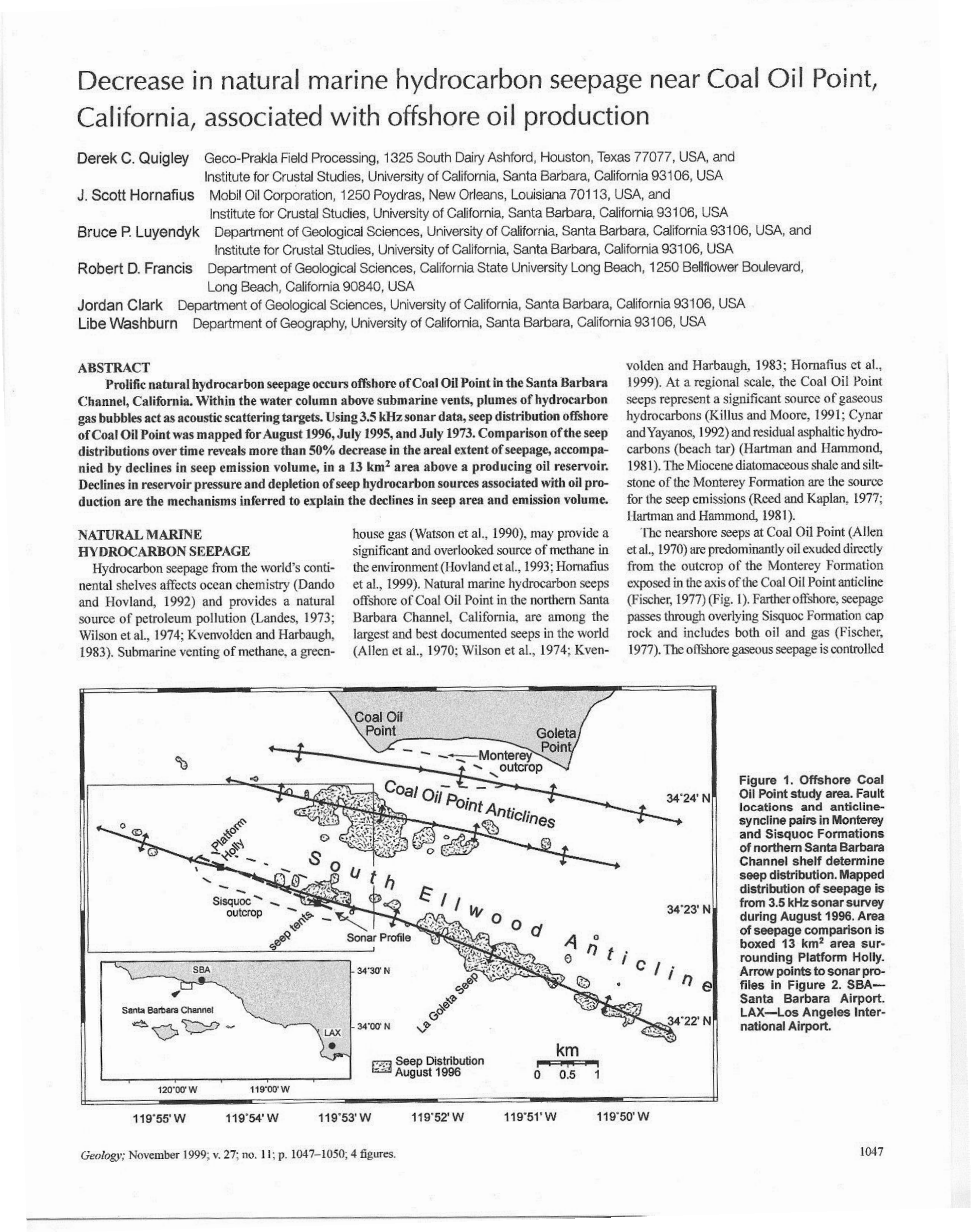
- The advent of first coalbed methane and tight gas sand plays diverted the industry away from conventional reservoirs;
- With the addition of shale gas plays on a basin wide scale followed by oil shale further diverted most US and Canadian Companies away from onshore conventional. The method reverted to being a small independents methodology;
- The advent of 3D seismic further caused the decline in the number of users of surface geochemistry;
- Where the methods did grow is in remote or poorly developed basins around the world;
- Even with the recent decline in industry drilling and many shale plays being uneconomic there has been to date no resurgence in these methods.



Iodine surface geochemical survey prior to discovery of Arikaree Creek Field, Lincoln County, Colorado

First two wells flow 400 BOPD each

Recent evidence of support for depletion of hydrocarbons over time - macroseeps



Decrease in natural marine hydrocarbon seepage near Coal Oil Point, California, associated with offshore oil production

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ABSTRACT

Prolific natural hydrocarbon seepage occurs offshore of Coal Oil Point in the Santa Barbara Channel, California. Within the water column above submarine vents, plumes of hydrocarbon gas bubbles act as acoustic scattering targets. Using 3.5 kHz sonar data, seep distribution offshore of Coal Oil Point was mapped for August 1996, July 1995, and July 1973. Comparison of the seep distributions over time reveals more than 50% decrease in the areal extent of seepage, accompanied by declines in seep emission volume, in a 13 km^2 area above a producing oil reservoir. Declines in reservoir pressure and depletion of seep hydrocarbon sources associated with oil production are the mechanisms inferred to explain the declines in seep area and emission volume.

NATURAL MARINE HYDROCARBON SEEPAGE

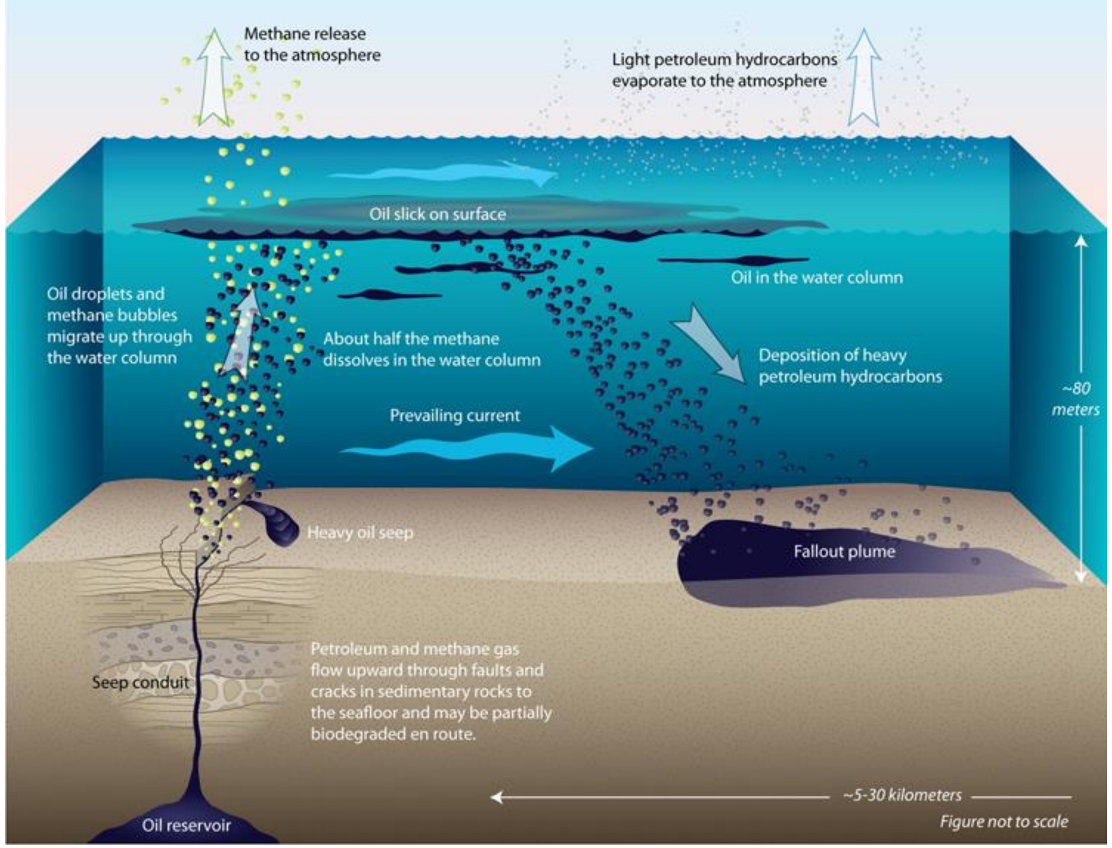
Hydrocarbon seepage from the world's continental shelves affects ocean chemistry (Dando and Hovland, 1992) and provides a natural source of petroleum pollution (Landes, 1973; Wilson et al., 1974; Kvenvolden and Harbaugh, 1983). Submarine venting of methane, a greenhouse gas (Watson et al., 1990), may provide a significant and overlooked source of methane in the environment (Hovland et al., 1993; Hornafius et al., 1999). Natural marine hydrocarbon seeps offshore of Coal Oil Point in the northern Santa Barbara Channel, California, are among the largest and best documented seeps in the world (Allen et al., 1970; Wilson et al., 1974; Kvenvolden and Harbaugh, 1983; Hornafius et al., 1999). At a regional scale, the Coal Oil Point seeps represent a significant source of gaseous hydrocarbons (Killus and Moore, 1991; Cynar and Yayanos, 1992) and residual asphaltic hydrocarbons (beach tar) (Hartman and Hammond, 1981). The Miocene diatomaceous shale and siltstone of the Monterey Formation are the source for the seep emissions (Reed and Kaplan, 1977; Hartman and Hammond, 1981).

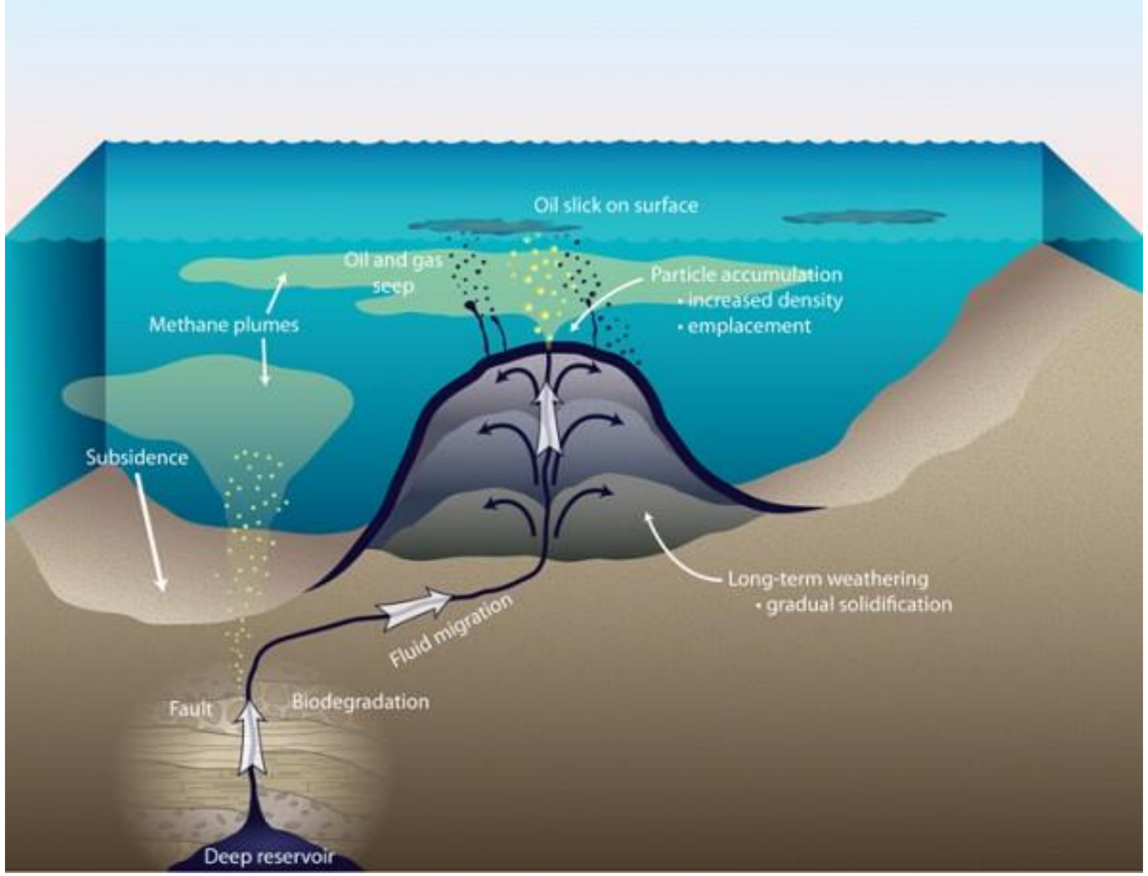
The nearshore seeps at Coal Oil Point (Allen et al., 1970) are predominantly oil exuded directly from the outcrop of the Monterey Formation exposed in the axis of the Coal Oil Point anticline (Fischer, 1977) (Fig. 1). Farther offshore, seepage passes through overlying Sisquoc Formation cap rock and includes both oil and gas (Fischer, 1977). The offshore gaseous seepage is controlled

Figure 1. Offshore Coal Oil Point study area. Fault locations and anticline-syncline pairs in Monterey and Sisquoc Formations of northern Santa Barbara Channel shelf determine seep distribution. Mapped distribution of seepage is from 3.5 kHz sonar survey during August 1996. Area of seepage comparison is boxed 13 km^2 area surrounding Platform Holly. Arrow points to sonar profiles in Figure 2. SBA—Santa Barbara Airport. LAX—Los Angeles International Airport.

Geology; November 1999; v. 27; no. 11; p. 1047–1050; 4 figures.

A 2009 study by the Woods Hole Oceanographic Institution and the University of California, Santa Barbara, was “the first to quantify the amount of oil residue in seafloor sediments that result from natural petroleum seeps off Santa Barbara, California.” This graphic depicts what happens to the oil from a natural seep.





“The area around Santa Barbara is very geologically active, because of the movement of the San Andreas and other faults. Extensive faulting or rupturing in the Earth allows oil and gas from subterranean reservoirs to seep up to the seafloor and ultimately into the ocean and to the atmosphere. But some oil solidifies to create asphalt volcanoes.” – Woods Hole Oceanographic Institution.

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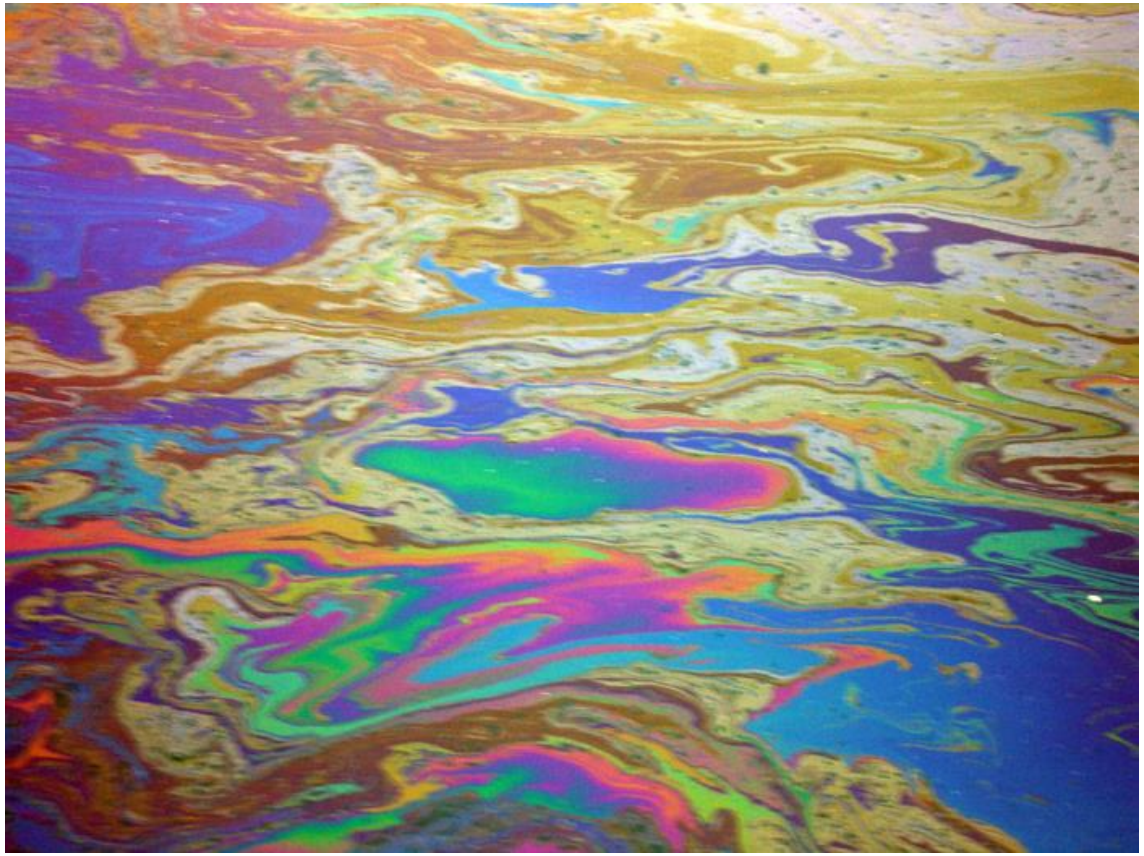

There’s an oil spill every day off the coast of Santa Barbara, Calif., where oil is seeping naturally from cracks in the seafloor into the ocean. Lighter than seawater, the oil floats to the surface. Some 20 to 25 tons of oil are emitted each day. (Photo by Dave Valentine, University of California, Santa Barbara)

Oil and methane bubble to the ocean's surface from natural seeps off Coal Oil Point, near Santa Barbara, California. (Photo courtesy of Dave Valentine, UCSB) tion pathways due to viscous tar sealing (Vernon and Slater, 1963) or seismic activity (Fischer, 1977). Although these effects may account for second-order variations (illustrated in Fig. 4), the dominant trend is most likely attributable to the effect of oil production on the reservoir pressure that drives seepage. The disappearance of seepage around Platform Holly and decline in emission volumes collected at the adjacent seep tents indicate a long-term decline in seepage. The similarity in seep distribution near Platform Holly in the July 1995 and August 1996 data suggests that changes in seep distribution are negligible on a time scale of 1 yr. That the observed reductions in seepage are spatially associated with oil production from Platform Holly suggests that decline in seepage between 1973 and 1995 is associated with effects of oil production.

Oil production affects seepage as reservoirs of hydrocarbons are drawn down by producing wells (Landes, 1973; Wilson et al., 1974; Kvenvolden and Harbaugh, 1983), leading to reduction in reservoir pressure. The seepage rate is proportional to the pressure gradient based on Darcy's law (Craft and Hawkins, 1959). Since production from Platform Holly began in 1967, more than 50 million barrels of oil, an equal volume of water, and more than 30 billion cubic feet of natural gas have been produced by wells drilled from the platform. This withdrawal of subsurface fluids is reflected in a recorded decrease in subsurface pressure (Fig. 4). Prior to 1977, gas was reinjected, which may have increased formation pressures and could have increased seepage rates (Kvenvolden and Harbaugh, 1983). Pressure in the Monterey Formation reservoir beneath Platform Holly began to drop below hydrostatic levels in 1983 (Fig. 4; Mobil Oil Corporation data supplied in 1997). By 1994, the total pressure drop was about 35%. There is a lag of several years between the pressure drop under Holly and the drop in collection rates at the seep tents beginning in 1989. This can be explained as due to the low permeability of the Monterey Formation migration pathways (Isaacs and Peterson, 1987). The reduction in reservoir pressure is inversely correlated with distance to Platform Holly (Quigley, 1997). Near the platform, subsurface pressure was approximately hydrostatic at 11.9 MPa in 1972, about the time of the earlier 3.5 kHz sonar survey. By 1994, the pressure had decreased to 7.54 MPa. At 1.5 km east of the platform under the seep tents, the pressure was 9.65 MPa in 1994, suggesting that pressure decrease was greater near Platform Holly.

Although mechanisms other than pressure, such as gravity flow of meteoric recharge waters or buoyancy of gaseous hydrocarbons (Hunt, 1979), can potentially drive seepage, the seepage at Coal Oil Point is most likely pressure driven (Quigley, 1997). If the fracture pathways, which serve as seepage conduits, are gas charged, then the pressure gradient between the reservoir source and the sea-floor vents would be equivalent to the hydrostatic pressure, providing a considerable driving force. However, if the fracture pathways are liquid filled, then the pressure gradient would need to be above hydrostatic to drive seepage. This characteristic would pertain only to the early production history of the reservoir, which could explain the decrease of some seepage. In addition, if fracture pathways are liquid filled and the fracture apertures are too small (submillimeter), capillary pressure would oppose hydrocarbon expulsion (Hunt, 1979; England and Fleet, 1991). Thus, water intrusion into the fracture network could augment the effect of declining reservoir pressure and contribute to the disappearance of seepage.

Time variation in seepage would affect estimates of methane leakage from continental margins (Hovland et al., 1993; Hornafius et al., 1999). This has important repercussions, because methane is a greenhouse gas (Watson et al., 1990). A larger global estimate for natural seepage rates would help to explain the unknown source of isotopically heavy methane in the global methane budget (Crutzen, 1991; Lacroix, 1993).

CONCLUSIONS

The distribution of seepage observed in maps of 3.5 kHz sonar data reveals a significant reduction in the area of seepage within 13 km^2 of Platform Holly between 1973 and 1995. The seepage area has decreased by more than 50% over a 22 yr time period, and declines in volume emissions of gas collected at the seep tents declined by more than 50% from 1989 to 1994. Lacking sonar surveys between 1973 and 1995, we cannot say whether sea-floor discharge decreased at the same time as tent collection volumes.

The spatial coincidence between offshore oil production at Platform Holly and the observed decrease in seepage around Holly are probably related and attributable to the impact of oil production on reservoir pressure. Oil production from the Monterey Formation oil and gas reservoirs caused subsequent declines in reservoir pressure, thus removing the primary driving mechanism of the seepage. This finding implies that worldwide oil production may lead to declines in natural emissions of hydrocarbons on a global scale.

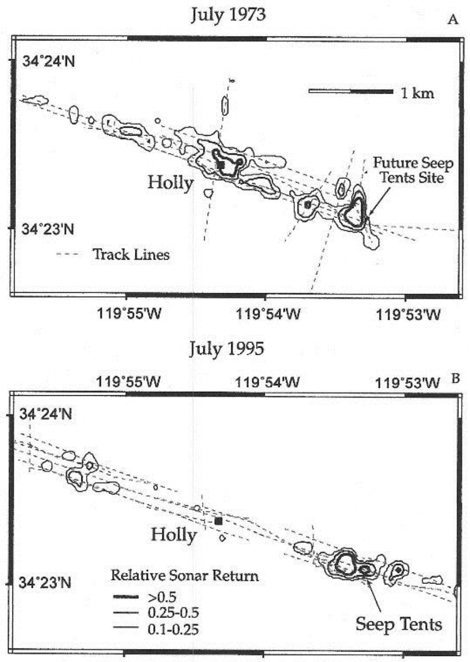

Figure 3. Comparison of distribution of gaseous hydrocarbon seepage in vicinity of Platform Holly in (A) 1973 and (B) 1995. Note nearly complete disappearance of seepage immediately adjacent to Holly in 1995. Map location is box in Figure 1.

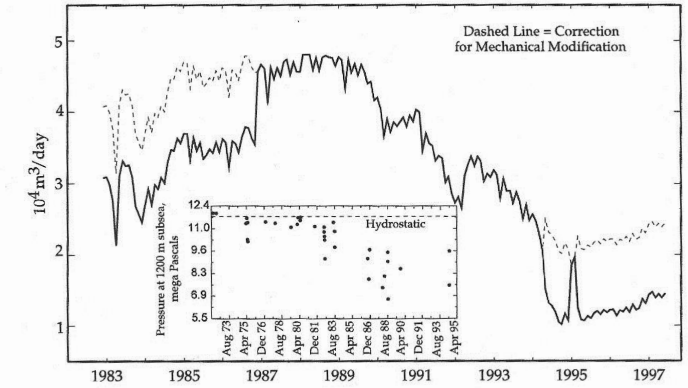

Figure 4. Time series of seep-gas volumes collected at seep tents. Dashed line provides estimated correction due to changes in seep tent areas (see text). Dominant trend is long-term decline in gas collection beginning in 1989. Inset shows reservoir pressure in Holly wells since 1973.

ACKNOWLEDGMENTS

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Microseeps

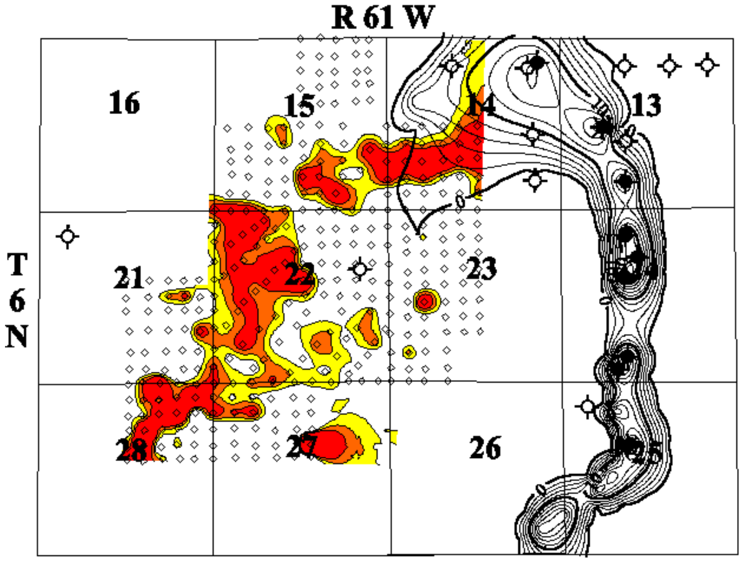
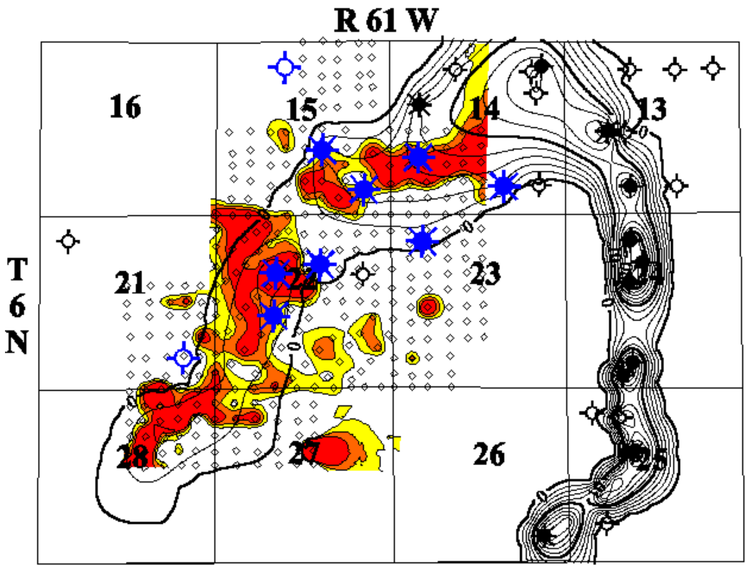


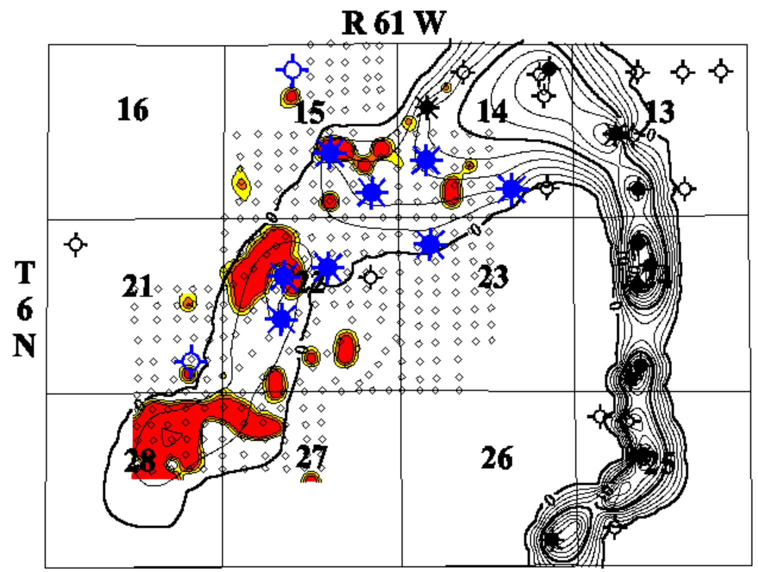
Figure 1 - Dolley Field, Weld County, Colorado. Iodine Survey (1991), pre-drilling, contour interval is .2 ppm. Isopach of the D sand channel (pre-drilling), ci: 2 feet

Pre-Discovery

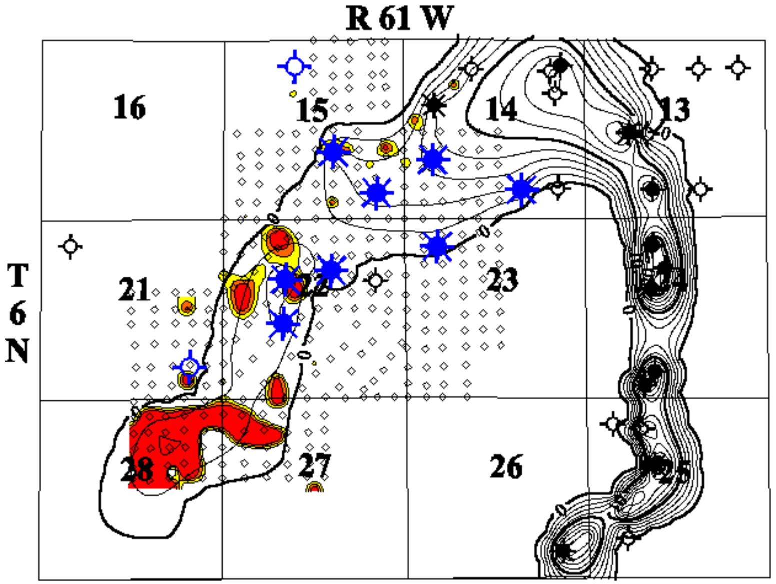
Post Discovery



Three Years After Discovery



Four Years After Discovery



American Association of Petroleum Geologists 2017 Annual and Exhibition 100 Years Houston, Texas

The Petroleum to Digital Age

1911

Summary

- Macroseeps were the initial exploration tool in the petroleum business;
- Microseeps are the micro version of macroseeps. While controversial there is significant evidence all reservoirs leak;
- Presence of seepage while not always be indicative of a commercial accumulation but it makes the explorationist feel a whole lot better;
  - **MACRO AND MICROSEEPS ARE THE ONLY DIRECT EXPLORATION TOOL FOR HYDROCARBONS.**

Exploration – leaping into the unknown for fun and profit based on limited understanding of the subsurface

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