

Hydrocarbon Compound Microseepage and Vertical Migration, with Evidence from the GORE™ Survey for Exploration

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Abstract: Thermogenic hydrocarbon compounds leak in minute amounts from reservoir, through the overlying seal and to the surface, in a process known as microseepage. This movement is mostly vertical in direction, with hydrocarbons moving under buoyant forces. Reservoir hydrocarbons were initially sampled in studies of petroleum prospectivity in the late 1920's and early 1930's, in Europe and the United States. The most plausible mechanism for microseepage involves the upward movement of "microbubbles" of hydrocarbons, through networks of micro-fractures and along mineral grain boundaries. Alternatively, these compounds may escape the reservoir in continuous phase flow through the overlying seal. Significant lateral offset of migrating hydrocarbons has not been documented. Migration rates are estimated at approximately one meter per day. Microseepage signatures have been detected even through massive evaporitic sequences.

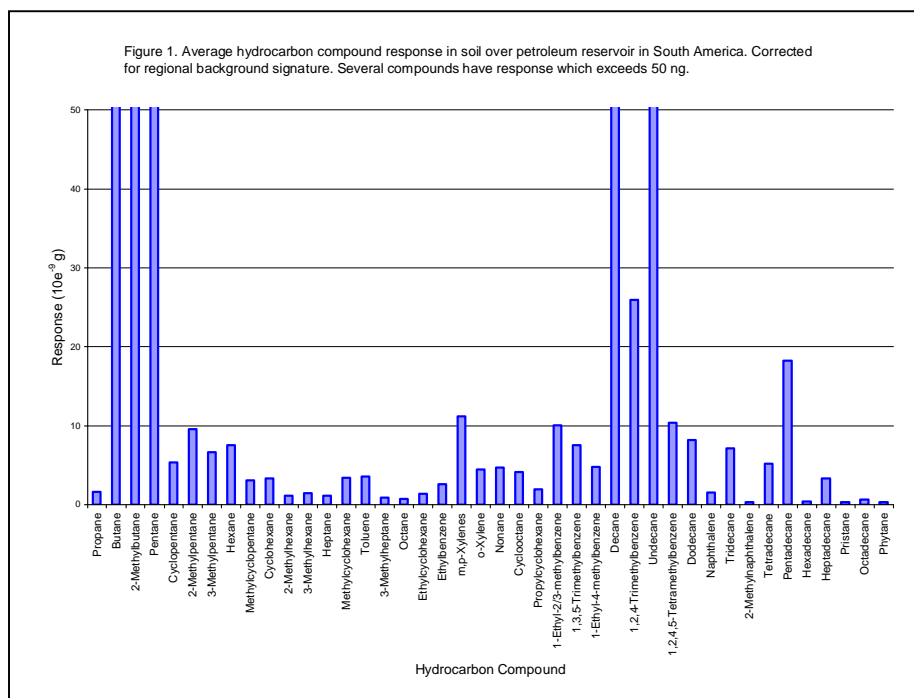
Thermal hydrocarbons are detectable in extremely low concentrations in the soil over subsurface petroleum reservoirs, as supported by extensive empirical evidence (Price, 1986; Klusman and Saeed, 1996). This form of leakage of hydrocarbons from reservoirs is known as "microseepage". Hydrocarbon compounds pervade the overlying seal and migrate vertically through the stratigraphic sequence to the surface under buoyant forces. The leakage is not massive, as with a breach of structural closure. This process is distinct from the movement of hydrocarbons along breaching faults or fracture swarms ("macroseepage"), with its consequent surface expression of an oil or gas seep.

The migration of hydrocarbon compounds is nearly vertical in direction, so that surface expressions of these compounds overlay the subsurface accumulations. In this manner, detection of thermal hydrocarbons provides a valuable exploration capability. The mechanism is also fairly rapid (geologic time scales are not necessary to invoke this process).

Others have stated that only the light gaseous hydrocarbons (methane through pentane, or perhaps hexane), were involved in the microseepage and migration through the stratigraphic column (Saunders et al., 1999). GORE has collected significant empirical evidence to suggest that a broader range of organic compounds are involved in the microseepage signature, including hydrocarbons as heavy as phytane (2,6,10,14 – tetramethylhexadecane, a "C₂₀" compound). Figure 1 illustrates the difference in average surface geochemical signature between a petroleum production area and a non-productive, background area. This signature difference is characterized by positive enhancements of compounds in the light (C₂ – C₅), medium (C₆ – C₁₀), and heavy (C₁₁ – C₂₀) range of organic compounds.

The theory of hydrocarbon microseepage

Theoretical development of microseepage theory and vertical migration of petroleum has occurred over many decades. Davidson (1985) discusses the development of surface geochemical theory dating from the early 1900's. Klusman (1993), in the introduction to his text on surface geochemistry and petroleum exploration, recaps the discussion of empirical observation and theory. Gunter Laubmeyer is credited with the first substantial use of surface geochemical prospecting techniques in petroleum exploration, for work done in 1929. Laubmeyer's method focused on methane detection, which he found to be enriched in soil gases over productive areas as compared to background. This work was expanded upon by V. A. Sokolov, working in the Soviet Union in 1932. Sokolov confirmed Laubmeyer's conclusions for methane, and improved upon his sampling technique, to include heavier hydrocarbons. This enabled him to characterize the petroleum phase at depth as oil or gas (Sokolov, 1936).



This early work focused on light hydrocarbon (methane and ethane) detection in the soil, and seemed to indicate apical anomalies (hydrocarbon highs over reservoirs). These techniques were first applied in the United States by Ludwig Blau, then working with Humble Oil. In the early 1930's, Dr. Blau established in Houston the first geophysical research lab in the petroleum industry. He made early steps in the integration of seismic and surface geochemical data. (His strong advocacy of geochemical techniques over seismic acquisition led many to view geochemical methods suspiciously, a situation which persisted.) Subsequent work by Horvitz (1939) seemed to indicate "halo" anomalies, in contrast to earlier observation. The classic halo

anomaly is characterized by a hydrocarbon response low over the productive structure, surrounded by enhanced emanation rates in an annular shape around the reservoir.

Several mechanisms have been considered to explain microseepage from charged formations, with subsequent vertical migration through the stratigraphic column to the surface. Klusman and Saeed (1996) discuss three mechanisms commonly considered: diffusion, transport by water, and buoyancy of microbubbles. Diffusion requires time scales too great to establish surface anomalies from typical reservoir depths, and explain empirical observation of anomaly dissipation with production. Transport by ascending water masses would also require too much time to establish surface expressions, and would imply that lateral dispersion or translation of anomalies would occur, a condition that is not substantiated by empirical data. Hydrocarbon microbubble buoyancy theory seems to fit observational data, allowing for hydrocarbon expression over the reservoirs within a reasonable time frame. Reservoir hydrocarbons leak through the seal formation when fluid pressure overcomes the capillary pressure, allowing passage through pore spaces of the sealing formation. Alternatively, reservoir overpressure would create microfractures in the seal, allowing the escape of hydrocarbons in minute amounts. Hydrocarbon microbubbles move vertically along mineral grain boundaries and where present microfracture networks.

Brown (2000) accepts the buoyant mechanism but finds the capillary overpressure aspect of the microseepage problematic. Required pressures may be excessive and pore sizes may preclude larger hydrocarbon molecules from migrating. Brown advocates seepage of hydrocarbons from reservoirs through microfracture networks, in a continuous petroleum phase flow, requiring less energy to initiate. Migration of hydrocarbons in this fashion is also expected to be more rapid than for the microbubble buoyancy mechanism, providing a better fit with empirical observations of surface hydrocarbon anomalies. Such surface anomalies would be expected to align directly with fault / fracture projections by this theory. While more study is required, GORE experience does not indicate such direct fault/fracture zone alignment.

Vertical migration offset

In our experience, geochemical anomalies are expressed directly over petroleum reservoirs ("apical" anomalies). Significant lateral displacements of anomalies, with respect to the surface projection of the reservoir, are not noted. Other authors have postulated that such displacements might occur, particularly in sedimentary basins with robust hydrologic systems in place (Rostron and Toth, 1996). Potter et al. (1996) note only slight shift of apical geochemical features in the updip direction, with a maximum inferred offset of ~700 feet (214 m) from an oil reservoir (the reservoir happened to be at ~4,000 m depth). However, the authors noted that such shifts were more usually less than 500 feet (~150 m), or were simply not observed.

With average surface geochemical sampling intervals between 250 – 500 m, it would be difficult to show reliable and consistent lateral offset, if such offsets are limited in scale to something less than 1,000 m. However, typical geochemical sample densities are

able to preclude major offsets, on the order of several kilometers or more; in other words, basin-wide drift of hydrocarbon plumes by hydrologic movement is not substantiated by this technique.

Hydrocarbon microseepage rates

Numerous geochemical studies have determined the rate of vertical migration, based on some observed change in the surface biosphere or geochemical signature. Because “real-time” surface geochemical measurement is cost prohibitive, migration rate estimates are usually based upon changes measured between two surveys. Published migration rates are determined as the time between surveys, and probably overestimate actual rates. Arp (1992) presented a study of the Patrick Draw Field in Wyoming, which suggested a migration rate between ~75 – 300 m per year. Jones and Burtell (1996) studied a natural gas storage field, and inferred a rate of ~1,500 m per year. Horvitz (1969) compared geochemical studies of the Hastings Field in Texas, and inferred a rate of >100 m per year (his studies were separated by 22 years, so that migration rates are not well constrained). Araktingi et al. (1984) found rates of ~1,370 m per year in the Leroy gas storage field in Colorado.

The GORE experience involves two surveys conducted over an inclined channel sand with gas charge. After documenting changes in the surface geochemical anomaly related to depressuring of the gas reservoir, with consequent updip migration of the gas-water contact, an approximate vertical migration rate of 400 m per year was determined.

Overall, the vertical migration mechanism appears to function at a rate of approximately a meter per day.

Vertical migration and the stratigraphic column

Microseepage of hydrocarbons appears to be a robust phenomenon, able to occur regardless of the sort of stratigraphic column overlying the reservoir. Massive sequences of tight rock (with very low porosities and permeabilities), have not been shown to preclude measurable geochemical differences in the soils over petroleum production areas, as compared to background (uncharged) areas. El-Bishlawy et al. (2001) document a case in which surface geochemical signatures were able to delineate oil charge at depth through 8,000 feet (~2,400 m) of anhydrite. Many explorationists rate evaporate sequences as perhaps the best challenge to the microseepage mechanism, probably due to its rheological properties. The surface geochemical technique has had similar experience over massive shale and tight carbonate sequences as well. Thick volcanic sequences have also been encountered, and were not found to preclude thermal hydrocarbon signatures at the surface.

Conclusions

In conclusion, all reservoirs leak to a certain degree (on a microscopic scale), and there is no perfect seal in the geological system. Hydrocarbon compounds are under

substantial pressure to migrate vertically out of the reservoir and to the surface. All rock types are permeable to this migration, again on a microscopic level, with migration taking place either through microfractures (which all rock sequences have), or along mineral grain boundaries. Thermal hydrocarbons are detectable in the soil over petroleum reservoirs, using geochemical sampling techniques which are capable of extremely sensitive and precise measurement (detection of at least part per billion concentrations of hydrocarbons in air are required). The GORE™ Survey for Exploration is capable of detecting and distinguishing thermal hydrocarbons at the surface, and is suitable for use in petroleum exploration programs.

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