NATURAL GAS MIGRATION PROBLEMS IN WESTERN PENNSYLVANIA

THE PITTSBURGH GEOLOGICAL SOCIETY

Civilization exists by geological consent, subject to change without notice.
Will Durant

What we normally think of as "natural gas" consists mainly of methane with smaller amounts of other compounds and elements. Methane is the simplest of a large family of carbon and hydrogen compounds, called **hydrocarbons**. Hydrocarbons also include, among other things, propane used in gas grills, butane used in disposable lighters, and crude oil. Methane is highly flammable. It is also odorless and tasteless. Some natural gases have strong odors - they smell like a refinery or rotten eggs because they contain more than just methane. The strong odor typically associated with the natural gas we use in our houses comes from a chemical **mercaptin** that the gas company adds before the gas is sent through pipelines.

NATURAL GAS FACTS

Oil and natural gas are natural products of degraded organic material. Most of the natural gas we deal with on a daily basis, called **thermogenic gas**, formed by a process of heating ancient organic matter over many millions of years under the intense heat and pressure deep within the subsurface of the earth. Ancient organisms living in the oceans settled to the sea floor after death where they were covered over by mud and buried. The thermogenic process converted the organic matter to droplets of oil and vapors of natural gas that moved into porous rocks such as sandstone and limestone.

A special type of natural gas is **microbial gas**, methane (mostly) produced through decay of organic matter by bacteria. Microbial methane commonly occurs in landfills and garbage dumps, but can also be found to a lesser extent in home compost piles, manure storage tanks on farms, and home septic tanks. Some large landfills produce enough methane to supply the energy needs of the landfill company, and still have enough left over to sell to the local gas company.

Another type of natural gas, called **coalbed methane**, is composed principally of methane and carbon dioxide occurring in most coal seams. Coal is composed of a wide variety of hydrocarbons and other compounds, and acts as both the source and reservoir for the gas. Natural gas in coal has long been treated as a safety hazard in mining and the mining companies generally vent the gas to the atmosphere to prevent explosions and suffocation. A few companies have begun selling the rights to the coalbed methane to oil and gas operators, or producing it themselves, but most still prefer to just vent it.

Methane of microbial and thermogenic origin occurs at shallow depths where it occurs dissolved in groundwater, or dispersed in rocks not commonly considered good reservoir rocks, such as shales.

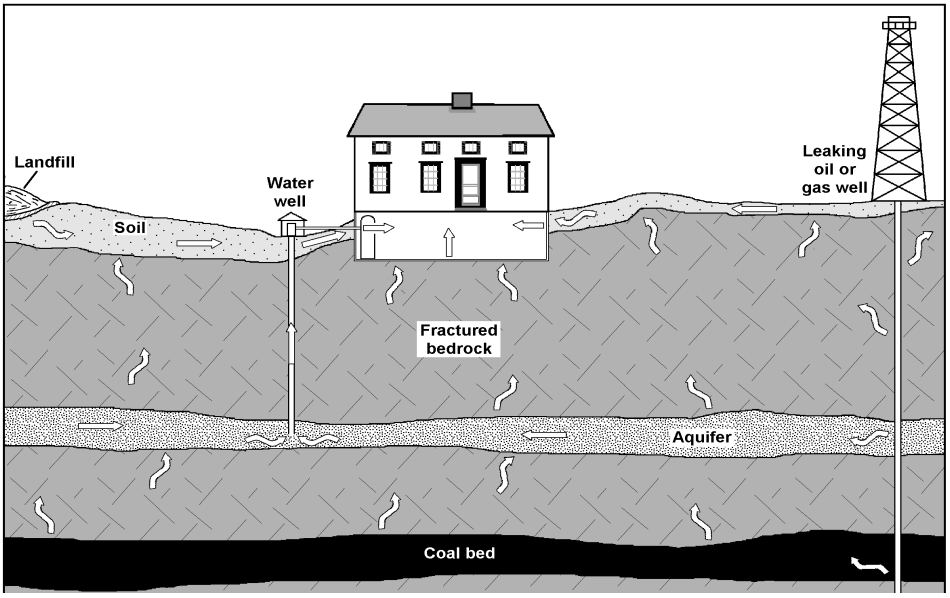

Figure 1. Some of the many sources and migration pathways that can be responsible for natural gas leaking into a building.

GAS MIGRATION PROBLEMS . . .

Natural gas, which occurs in significant quantities in the subsurface rocks in western Pennsylvania, is a useful commodity. However, it can also be a major geologic hazard in some circumstances. Under certain conditions it can escape from the reservoir rock, coal seam, pipeline, gas well, or landfill. If the gas **migrates** through the bedrock and soil, it can result in an explosion capable of damaging property and causing loss of life. Changes in barometric pressure or temperature contrasts can cause diffuse gas molecules to migrate from high concentration areas, like a leaking gas well, to areas of low concentration, like a basement. Gas migration typically occurs along fractures in bedrock and through permeable soils and groundwater aquifers. The gas can then enter a building through cracks in foundations and basement walls, along pipes, through water wells, or other openings (Figure 1). If the air circulation in the building is poor, the gas can build up to dangerous levels. Then, a spark from a furnace or a faulty wire, a cigarette, or a lit match might cause the gas to explode with devastating results (Figure 2).

Although it rarely makes headlines, damage or threats caused by gas migration is a common problem in western Pennsylvania. The culprit might be an old oil or gas well that hasn't been properly maintained or plugged, an active or abandoned coal mine, a nearby landfill, or some other problem. Because of the large number of possible methane sources, it is necessary to determine the origin of the problem before a solution can be finalized. Pointing fingers without investigating the actual cause is unproductive and may result in legal issues.

. . . AND SOLUTIONS

Geologists have begun to resolve some of these problems by analyzing the chemistry of natural gas samples collected at the problem site and from suspected culprits. Although the chemical signatures of natural gases have been known for years, they have only recently been recognized as a potential tool for "fingerprinting" natural gases and tracing those gases back to their sources.

Gases created by different processes have different chemical or molecular compositions and stable isotope signatures. Composition

Figure 2. Photograph of a house in western Pennsylvania that exploded and burned as a result of natural gas leaking into the basement from a nearby gas well. The gas built up in the cellar and ignited when the furnace fired up. Photo courtesy of Fred Baldassare

studies typically look at ratios of various hydrocarbon compounds -the ratio of methane to ethane-plus-propane, for example. Studies of carbon and hydrogen isotopes examine the differences between the isotope values of the sample being analyzed and those of an established standard. These ratios are then plotted on graphs, like the one shown in Figure 3. Experiments have shown that different kinds of natural gases segregate into different areas of these graphs.

gas sample (16 on Figure 3) was collected from a natural gas leak in a yard in Indiana County, Pennsylvania, an area that has been heavily impacted by both well drilling and coal mining. The source of the gas is unknown. Was it leaking from a nearby gas well? From a nearby coal mine? The ratio of methane to ethane-plus-propane (not shown) seemed to indicate a microbial origin for the gas, but the $\delta^{13}C$ and δD values of the gas place this sample within the thermogenic source area in Figure 3. But there

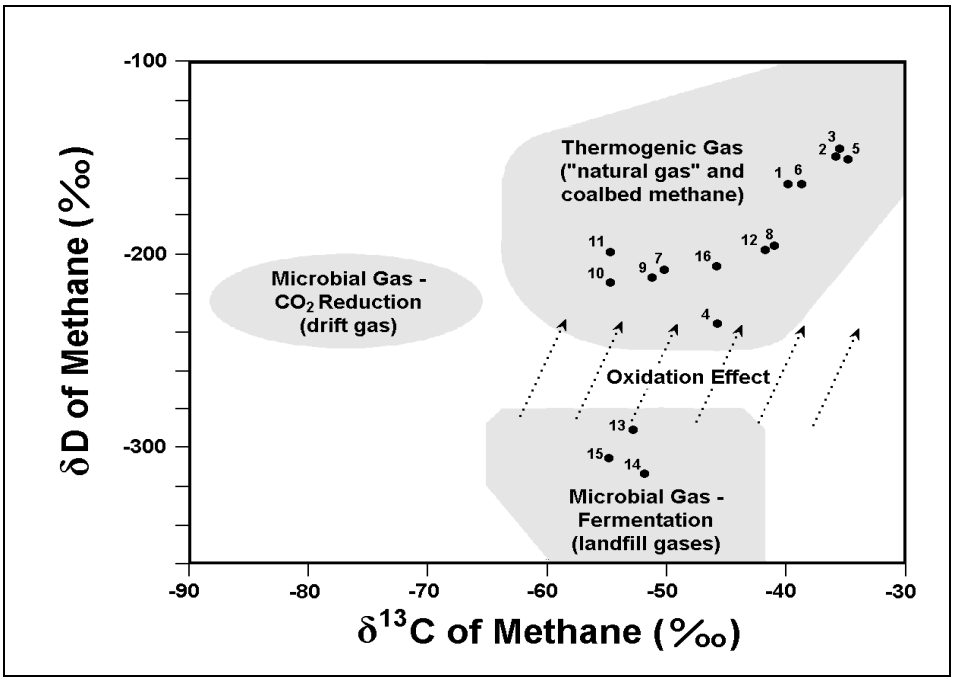

Figure 3. Cross plot graph used to help determine the origins of natural gas samples. Shown is a random sample of gases collected in western Pennsylvania (courtesy of Fred Baldassare and Christopher Laughrey). Samples from natural gas wells (samples 1-9) plot within the thermogenic source area, whereas gases generated in landfills by bacterial action (samples 13-15) plot within the microbial source area. Some landfill gases plot within the thermogenic area or between the two areas because of oxidation of the methane, as shown by the dashed arrows. Notice that coalbed methane (samples 10-12) also plots within the thermogenic source area. δD is the value for deuterium, an isotope of hydrogen. $\delta^{13}C$ is the value for the ratio of carbon 13 to carbon 12.

In Figure 3, the thermogenic gas samples (1 to 9) and microbial gas samples (13 to 15) fall right where they should based on their ratio values. Even the coalbed methane samples (10-12) indicate that they are thermogenic in origin. Some gases, however, fall between or outside the areas designated. Such gases might be mixtures of thermogenic and microbial gas - for example, coalbed methane commonly includes both gas generated in the coal (thermogenic) and gas generated by bacteria in stagnant groundwater in the adjacent rocks (microbial). Microbial gas that has been oxidized by bacteria will fall between the two areas or even within the thermogenic area (shown by the dotted arrows in Figure 3). In western Pennsylvania, methane oxidation is very common in landfill gases because of the abundance of oxidizing bacteria.

Here is an example of how gas analyses can be used to identify the source of a problem: A

are no nearby landfills, so based on the isotope evidence, the most likely explanation is that this gas came from a nearby coal seam. In fact, the sample was taken from an area where room-and-pillar coal mining has been extensive, and it is probable that the gas migrated to the surface through fractures in the bedrock following localized mine subsidence.

Where the standard analyses are ambiguous, other tests should be done. Landfill gases commonly contain high ratios of carbon dioxide. Landfill gases that appear to be thermogenic because of methane oxidation might be distinguished by analysis of the stable carbon isotopes in carbon dioxide produced with the methane. Another solution is to test for the carbon 14 isotope. Carbon 14 is radioactive, so it is always in a state of decay to nitrogen. It has a very short half life, and is completely stabilized to nitrogen within 70,000 years. If carbon 14 shows up in analysis, the gas must have been generated within the last 70,000 years - it has to be of recent origin because thermogenic gases were generated millions of years ago. They will contain no carbon 14.

WHAT CAN YOU DO?

Once the source of the gas has been determined, a solution to the problem can be developed. Leaking pipelines can be fixed, leaking gas wells can be fixed or properly plugged, and coal mines, landfills, and water wells can be vented or reengineered to produce the gas.

In Pennsylvania, any oil and gas well that has been abandoned by its owner must be plugged or the owner is liable for fines and legal action by the state. In cases where the owner is not known, the well becomes an “orphan” of the state and the Pennsylvania Department of Environmental Protection (DEP) assumes the responsibility of plugging it. Unfortunately, there are many thousands of orphan wells in Pennsylvania and DEP has only a small pool of money for the plugging operations. Therefore, the wells that are most troublesome (i.e. posing a serious health and safety hazard) are targeted for immediate plugging, and the rest remain on the list until funds become available.

Avoiding natural gas leaks is difficult because there are no set rules for where gas will or will not migrate to the surface. Methane untreated with mercaptans has no color or odor, so it is essentially undetectable except by a combustible gas indicator (commonly called a “gas sniffer”), a tool used by gas utilities to find pipeline leaks. Western Pennsylvania is riddled with unplugged oil and gas wells (possibly several hundred thousand); natural gas pipelines crisscross the area in profusion; and almost all of southwestern Pennsylvania is underlain by shallow, often gassy, coal seams. Active landfills are easily identifiable and avoidable when looking to purchase land, but reclaimed landfills can look as innocent as a rural pasture.

Natural gas leaks generally are covered by insurance if they cause loss of property or life. If a neighboring well leaks noxious fumes that migrate into your house and contaminate the fabrics in your rugs and furniture, you probably are not covered. However, severe damages caused by natural gas migrating into your house probably are covered as long as your insurance policy covers losses due to fires and explosions. Contact your insurance agent for more details.

Western Pennsylvania residents wishing to determine if their property lies in an area underlain by coal and/or natural gas reservoirs are encouraged to call the Pittsburgh office of the Pennsylvania Geological Survey at (412) 442-4235 and request assistance.

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