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OCCURRENCE AND ORIGIN OF NATURAL GAS IN GROUND WATER, SOUTHERN WELD COUNTY, COLORADO

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ILLUSTRATIONS

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INTRODUCTION

This report deals with the occurrence and origin of methane-rich gas in ground water in the southern part of Weld County, north-central Colorado. The gas generally occurs in solution in the ground water of the aquifer. However, exsolution resulting from reduction of hydrostatic pressure during water production may create free gas which can accumulate in wells and buildings and pose an explosion and fire hazard. On the basis of evidence discussed below, we conclude that the gas originates within the aquifer from the microbiological degradation of organic matter.

The ground water is produced from siltstones and sandstones which make up the Upper Cretaceous Laramie-Fox Hills aquifer (Robson and others, 1981). The aquifer is present at depths of about 150 m or less in the study area. The Laramie-Fox Hills aquifer is an important source of water for residents and ranches in the greater Denver area.

The gas-bearing aquifer of the Laramie-Fox Hills is underlain by the Wattenberg field which contains major reserves of natural gas at depths ranging from 2,300 to 2,600 m. Reservoirs are low-permeability sandstones of Early Cretaceous age that require massive hydraulic stimulation to provide economic flow rates. Reserves in the field are estimated to be 1.5 trillion cubic feet (Matuszczak, 1973).

Natural gas is formed by two distinct processes. At shallow depths of burial and low temperatures, methane-rich gas is generated during decomposition of organic matter by microorganisms. This gas is formed in environments free of dissolved oxygen and sulfate and is referred to as biogenic gas.

Natural gas can also be generated by thermal degradation and cracking of kerogen and other nonhydrocarbon precursors with increasing temperature and advancing geologic time. This type of gas is referred to as thermogenic and probably is the origin of most gas produced from commercial oil and gas fields.

Natural gases can generally be distinguished by their chemical compositions and carbon isotope ratios. Biogenic gas is predominantly methane that is isotopically light ($\delta^{13}C$ values lighter than -55 ppt) because of biological ^{12}C-enrichment (Rice and Claypool, 1981). During early and intermediate stages of thermal history, methane generation is accompanied by heavier hydrocarbons including oil and is isotopically heavier than biogenic gas ($\delta^{13}C_1$ values are generally heavier than -50 ppt) because of smaller kinetic isotope effects associated with thermal cracking. During late stages of burial history at very high temperatures, natural gas becomes devoid of all heavier hydrocarbons and the isotopic composition of methane approaches that of the original organic matter ($\delta^{13}C$ values are generally heavier than -35 ppt).

In order to determine the source of the gas in the ground water in southern Weld County, natural gas was sampled and analyzed from three private water wells and three gas wells from the Wattenberg gas field. All of the wells are located within a small area (secs. 12, 13, and 24, T. 3 N., R. 65 W.). Samples were analyzed by the methods described by Claypool and others (1980).

RESULTS AND DISCUSSION

The analyses for the water and gas wells are summarized in Tables 1 and 2, respectively. The volume percentage of selected components is reported together with the proportion of methane in the hydrocarbon fraction and the carbon isotope ratio of the methane.

The gases from the water wells occur at depths of less than 125 m, and are uniformly dry ($C_1/C_{1-5} > 0.99$) and enriched in the light isotope ^{12}C ($\delta\,^{13}C_1$ values are about -73 ppt) (Table 1). The relatively high percentage of N_2 (nitrogen) and (or) air probably represents air contamination resulting from sampling procedures. These gases are interpreted to be of biogenic origin and are being (were) generated in an anoxic, sulfate-free environment within the aquifer system. The probable source of carbon is the organic matter originally deposited with the Upper Cretaceous sediments. These biogenic gases are similar in composition to those from ground water reported by Coleman and others (1977) and Barker and Fritz (1981).

In an area immediately north of the study area, methane generally is not detected or reported from ground water (J. C. Romero, oral commun., 1982). This area coincides with a region of higher amounts of dissolved sulfate (greater than 250 milligrams per liter) in the ground water (Robson and others, 1981). The water from the wells in this region has a putrid odor and probably contains hydrogen sulfide (H_2S) resulting from microbial sulfate reduction. Methanogenesis generally is not concurrent with the process of sulfate reduction and usually begins after dissolved sulfate is removed from ground water (Claypool and Kaplan, 1974). Therefore, the absence of methane and the apparent presence of H_2S in the area to the north of the study area is probably explained by the occurrence of sulfate.

Gases sampled from the Wattenberg field occur at considerably greater depths (about 2,300 m) and are distinctly different from gas from water wells in both chemical and isotopic composition (Table 2). They contain significant amounts of heavier hydrocarbons (C_1/C_{1-5} values are about 0.87) and are isotopically heavier ($\delta\,^{13}C_1$ values are about -43 ppt). The chemical and isotopic composition of the gases indicate that they are thermogenic in origin and were generated by thermal cracking processes during intermediate stages of thermal maturity in the deeper part of the Denver Basin. This interpretation is consistent with the level of maturation determined by Clayton and Swetland (1980) in their study of petroleum generation in the Denver Basin.

The possibility that thermogenic gas from deeper reservoirs in the Wattenberg field may have leaked into shallow ground water of Laramie-Fox Hills aquifer has been discounted. Several field studies have shown that although chemical fractionation of gas by migration is possible, with nearly complete removal of heavier hydrocarbons, there is no significant effect on the isotopic composition of the methane (Bernard and others, 1977; Coleman and others, 1977; Rice, 1980). Therefore, we conclude that in this case the isotopic analysis is the most reliable evidence to establish the source of the natural gas.

In conclusion, selected gases from ground water and from deeper gas reservoirs in southern Weld County, Colorado are: (1) separated vertically by 2,000 m of rock, (2) have distinct chemical and isotopic compositions, and (3) were formed by two separate processes. The isotopically light, methane-rich gas in the ground water is of biogenic origin and was or is being generated in the anoxic, sulfate-free aquifer by decomposition of organic matter deposited with the sedimentary rocks that constitute the aquifer. In contrast, isotopically heavy, chemically wet gas of the Wattenberg field is clearly of thermogenic origin resulting from sedimentary organic matter that was subjected to increased temperatures and depths of burial. The possibility of leakage of thermogenic gas into the shallow ground water system is discounted because of the distinct and characteristic isotopic compositions of the two types of gases and because subsurface migration is incapable of producing the required change in isotopic composition.

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Table 1.--Chemical and isotopic composition of gas from private water wells.

Location	Total depth (m)	C_1	C_2	CO_2	N_2-air	C_1/C_{1-5}	$\delta^{13}C_1$ (ppt)
1. SW 1/4 SW 1/4 sec. 12, T. 3 N., R. 65 W.	122	28.18	.04	.03	71.75	.9989	-73.5
2. SE 1/4 NE 1/4 sec. 13, T. 3 N., R. 65 W.	95	51.19	.06	.33	48.42	.9988	-73.3
3. SE 1/4 SE 1/4 sec. 13, T. 3 N., R. 65 W.	94	56.00	.07	.18	43.75	.9988	-72.8

Table 2.--Chemical and isotopic composition of gas from wells in Wattenberg gas field.

Well Name	Location	Pay zone (m)	C_1	C_2	C_3	${}_iC_4$	${}_nC_4$	${}_iC_5$	${}_nC_5$	CO_2	N_2-air	C_1/C_{1-5}	$\delta^{13}C_1$ (ppt)
1. Amoco UPRR 39 B No. 1	SW 1/4 sec. 13, T. 3 N., R. 65 W.	2314- 2322	82.66	7.81	2.39	.73	.73	.33	.25	4.72	.38	.8711	-43.1
2. Amoco Weld Co. Lumber No. 1	SW 1/4 NE 1/4 sec. 24, T. 3 N., R. 65 W.	2305- 2318	82.75	7.94	2.6	.5	.57	.37	.24	4.63	.4	.8714	-43.4
3. Amoco Gurtler No. 1	SW 1/4 SW 1/4 sec. 24, T. 3 N., R. 65 W.	2310- 2331	82.72	8.19	2.18	.53	.53	.55	.33	4.54	.43	.8704	-43.5