UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Soil gas studies around hydrogen-rich natural gas wells in northern Kansas

by

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

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ABSTRACT

Soil gas measurements were conducted along east-west traverses in the vicinity of hydrogen-rich gas wells in northeastern Kansas. Hydrogen, helium, and other gas anomalies were found to correlate with known and suspected faults in the area of the Midcontinent Rift System and the Nemaha Arch. The gases may have originated at depth and migrated to the surface along faults and fractures. These soil gas studies did not indicate the areal extent of the hydrogen-rich gas.

INTRODUCTION

Two wells drilled for petroleum exploration in Morris and Geary Counties, Kansas, intercepted gas of unusual composition (Goebel and others, 1983). The gas encountered at a depth of 2,100 to 2,200 ft, consisted of about 50% hydrogen and 50% nitrogen with less than 1% light hydrocarbons (Goebel and others, 1984). The U.S. Geological Survey, in conjunction with the Kansas Geological Survey, conducted soil gas surveys in the vicinity of these wells and beyond to determine: (1) if the gases in the wells could be detected near the surface and (2) if these gas measurements could delineate the areal extent of the gas field.

Two separate surveys were conducted along two east-west traverses that extended about 40-60 mi east and west of the discovery wells. In the first survey, helium in soil gas was measured and in the second, hydrogen, nitrogen, and other gases were measured.

HELIUM GAS SURVEY

Two helium traverses were conducted in conjunction with other gas surveys in northern Kansas. The Hutchinson helium traverse is located on the Hutchinson 2° sheet and consists of 210 samples spaced approximately 1/2 mi apart (plate 1). The Manhattan traverse is located on the Manhattan and Hutchinson 2° sheets and consists of 149 samples at 1/2 mi spacing (plate 1). This latter traverse is the same as that used in the deep seismic reflection survey by COCORP (Consortium for Continental Reflection Profiling) (Serpa and others, 1984). Both of these surveys crossed over the Nemaha Ridge Fault zone and the Midcontinent Rift System, labeled MCRS on the maps (Anonymous, 1984). All helium analyses were obtained using the mobile helium analyzer developed at the U.S. Geological Survey (Friedman and Denton, 1976; Reimer, 1976; Reimer and Denton, 1978). The unit consists of a truck-mounted mass spectrometer which is self-contained and can operate either as a self-powered mobile lab or in a fixed location using 110-V conventional power. The unit features an inlet system modified to accept gas samples from hypodermic syringes. Soil gas samples are obtained by driving 0.75-meter hollow probes into the ground and attaching a septum holder to the top of the probe. Ten cc's are withdrawn from the probe and discarded then a ten (10) cc sample is withdrawn at each sample locality and analyzed for helium within 4-6 hours. All helium concentrations in this report are expressed as parts per billion (ppb) above or below the ambient air background of 5,240 ppb He established by Glueckaus (1946). Analytical precision is approximately ± 10 ppb He.

Sample numbers and helium concentrations are shown on (plate 1) and listed in tables 1 and 2. Stationary, permanent probes were established in areas central to each survey and soil gas was sampled at 2-3 hour intervals in order to detect significant changes in helium gas measurements induced by

Table 1. Sample site numbers, coordinates and concentration of helium in soil gas - Hutchinson traverse. Uncorr helium = raw data; corr helium = data corrected for diurnal variations.

SAMPLE ID	LONG	LAT	UNCORR HELIUM	CORR HELIUM
101	97.1139	38.9005	-9.	-2.
102	97.1034	38.9005	0.	9.
103	97.0940	38.9005	9.	21.
104	97.0835	38.9005	9.	22.
105	97.0739	38.9003	-9.	7.
106	97.0643	38.9003	-9.	9.
107	97.0556	38.9003	-36.	-17.
108	97.0462	38.9003	-32.	-62.
109	97.0378	38.9003	-127.	-106.
110	97.0289	38.9003	-45.	-23.
111	97.0188	38.9001	63.	67.
112	97.0097	38.9001	0.	25.
113	97.0010	38.9001	-32.	-54.
114	96.9910	38.8998	-72.	-43.
115	96.9817	38.8996	-27.	3.
116	96.9819	38.8926	-20.	-40.
119	96.9770	38.8353	0.	-7.
120	96.9735	38.8353	10.	8.
121	97.2312	38.9661	71.	92.
122	97.2312	38.9736	-10.	17.
123	97.2312	38.9804	10.	42.
124	96.6679	38.7984	-10.	-20.
125	96.6591	38.8113	312.	309.
126	96.6946	38.8123	-73.	-70.
128	96.6581	38.7977	-30.	2.
129	96.6487	38.7977	-40.	-6.
130	96.6393	38.7977	180.	215.
131	96.6309	38.7977	120.	164.
132	96.6219	38.7977	-20.	24.
133	96.6123	38.7977	0.	46.
135	96.3532	38.6670	37.	74.
136	96.3431	38.6670	87.	77.
137	96.3356	38.6670	0.	-7.
138	96.3264	38.6670	29.	25.
139	96.3159	38.6670	-29.	-29.
140	96.3063	38.6670	29.	34.
141	96.2979	38.6674	-19.	-13.
142	96.2878	38.6652	47.	68.
143	96.2805	38.6620	23.	47.
144	96.2688	38.6593	94.	121.
145	96.2608	38.6595	-70.	-39.
146	96.2604	38.6523	-47.	-11.
147	96.2508	38.6520	-70.	-31.
149	96.2333	38.6518	-23.	20.
201	96.7601	38.8120	30.	11.
202	96.7789	38.8195	40.	25.
205	97.4635	39.0889	-40.	-15.
206	97.4636	39.0839	0.	26.
207	97.4636	39.0803	-70.	-41.
208	97.4636	39.0740	0.	30.
209	97.4636	39.0659	-10.	20.
210	97.4636	39.0601	-60.	-29.
211	97.4519	39.0599	-10.	22.

Table 1. (continued)

SAMPLE ID	LONG	LAT	UNCORR HELIUM	CORR HELIUM
212	97.4456	39.0599	-10.	22.
213	97.4362	39.0599	-20.	13.
214	97.4252	39.0599	-20.	13.
215	97.4186	39.0599	180.	214.
216	97.4079	39.0599	-10.	25.
217	97.3990	39.0599	20.	56.
218	97.3898	39.0599	-50.	-14.
219	97.3898	39.0521	-10.	27.
220	97.3698	39.0453	-20.	18.
221	97.3802	39.0453	10.	49.
222	97.3712	39.0449	0.	40.
223	97.3618	39.0449	-30.	11.
224	97.3527	39.0451	-60.	-18.
225	97.3435	39.0451	-71.	-26.
226	97.3344	39.0453	-20.	24.
227	97.3346	39.0292	-10.	34.
228	97.3346	39.0292	-10.	35.
229	97.3346	39.0237	0.	48.
231	96.9449	38.8873	-31.	-54.
232	96.9545	38.8851	10.	-12.
233	96.9625	38.8851	0.	-21.
234	96.9360	38.8851	20.	1.
235	96.9275	38.8851	0.	-15.
236	96.9195	38.8780	42.	27.
237	96.9102	38.8835	115.	102.
238	96.8994	38.8849	0.	-12.
239	96.8877	38.8848	52.	42.
240	96.8797	38.8846	73.	65.
241	96.8712	38.8846	42.	35.
242	96.8618	38.8846	42.	36.
243	96.8527	38.8846	385.	380.
244	96.8527	38.8774	0.	-4.
245	96.8433	38.8844	31.	30.
246	96.8342	38.8844	31.	31.
247	96.8229	38.8844	417.	418.
248	96.8157	38.8844	292.	294.
249	96.8068	38.8772	-10.	3.
250	96.8068	38.8700	0.	14.
251	96.7922	38.8625	91.	110.
252	96.7836	38.8565	60.	80.
253	96.7789	38.8526	30.	51.
254	96.7789	38.8449	10.	32.
255	96.7789	38.8358	-10.	13.
256	96.7789	38.8277	-20.	4.
257	96.7789	38.8229	0.	26.
258	96.7789	38.8129	10.	37.
259	96.7732	38.8120	30.	58.
260	96.7639	38.8120	0.	30.
261	96.7554	38.8120	30.	61.
262	96.7460	38.8118	40.	72.
263	96.7340	38.8118	-60.	-27.
264	96.7242	38.8118	10.	44.
265	96.7143	38.8118	-30.	6.
266	96.5521	38.7975	20.	60.
267	96.5636	38.7975	10.	52.
268	96.5729	38.7975	30.	73.
269	96.5861	38.7975	0.	44.

Table 1. (continued)

SAMPLE ID	LONG	LAT	UNCORR HELIUM	CORR HELIUM
270	96.5940	38.7980	160.	205.
271	96.6029	38.7977	280.	327.
272	96.3623	38.6670	97.	82.
273	96.3707	38.6670	58.	44.
274	96.3300	38.6670	281.	268.
275	96.3900	38.6670	97.	86.
276	96.3990	38.6670	263.	253.
277	96.4093	38.6670	29.	20.
278	96.4189	38.6670	40.	40.
279	96.4264	38.6670	135.	128.
280	96.4367	38.6656	87.	82.
281	96.4456	38.6666	38.	34.
282	96.4547	38.6664	19.	17.
283	96.4636	38.6663	19.	17.
284	96.4641	38.6743	9.	10.
285	96.4639	38.6809	67.	69.
286	96.4732	38.6809	77.	81.
287	96.4810	38.6809	38.	44.
288	96.4903	38.6879	80.	101.
289	96.2218	38.6518	-46.	-20.
290	96.2057	38.6516	-57.	-30.
291	96.1975	38.6516	-127.	-99.
292	96.1881	38.6516	11.	41.
293	96.1861	38.6445	-46.	-15.
294	96.1679	38.6368	0.	31.
295	96.1782	38.6368	0.	32.
296	96.1686	38.6368	34.	65.
297	96.1689	38.6259	-57.	-22.
298	96.1684	38.6231	-69.	-33.
299	96.1581	38.6231	-60.	-43.
300	97.1198	38.9073	668.	650.
301	97.1205	38.9150	9.	-9.
302	97.1302	38.9175	39.	22.
303	97.1302	38.9249	0.	-14.
304	97.1302	38.9296	19.	6.
305	97.1302	38.9370	-10.	-22.
306	97.1302	38.9445	10.	0.
307	97.1302	38.9516	19.	10.
308	97.1302	38.9591	10.	2.
309	97.1391	38.9591	19.	12.
310	97.1480	38.9591	-10.	-15.
311	97.1576	38.9591	-10.	-14.
312	97.1672	38.9591	0.	-3.
313	97.1764	38.9591	0.	-2.
314	97.1857	38.9589	-29.	-30.
315	97.1954	38.9569	-20.	-19.
316	97.2045	38.9569	-20.	-18.
317	97.2139	38.9589	0.	3.
318	97.2230	38.9589	39.	43.
319	97.2326	38.9589	29.	34.
320	97.2599	38.9807	0.	-25.
321	97.2611	38.9877	20.	-3.
322	97.2683	38.9877	0.	-22.
323	97.2815	38.9877	41.	20.
324	97.2734	38.9956	10.	-9.
325	97.2782	39.0024	20.	3.

Table 1. (continued)

SAMPLE ID	LONG	LAT	UNCORR HELIUM	CORR HELIUM
326	97.2782	39.0094	0.	-16.
327	97.2793	39.0167	0.	-13.
328	97.2868	39.0167	-20.	-31.
329	97.2974	39.0165	-10.	-20.
330	97.3068	39.0163	-20.	-29.
331	97.3152	39.0163	-20.	-27.
332	97.3257	39.0162	20.	14.
333	97.3346	39.0162	-31.	-35.
334	97.4730	39.0960	-20.	-20.
335	97.4821	39.0962	-20.	-19.
336	97.4826	39.1033	0.	2.
337	97.4915	39.1033	-20.	-17.
338	97.5010	39.1054	20.	25.
339	97.5015	39.1112	-41.	-35.
340	97.5015	39.1176	31.	38.
341	97.5113	39.1176	174.	182.
342	96.5516	38.7905	68.	50.
343	96.5518	38.7330	113.	102.
344	96.5425	38.7530	29.	15.
345	96.5422	38.7751	29.	17.
346	96.5333	38.7680	0.	-9.
347	96.5190	38.7682	0.	-6.
348	96.5097	38.7684	255.	251.
349	96.5005	38.7685	23.	27.
350	96.5005	38.7610	59.	59.
351	96.5005	38.7537	19.	23.
353	96.4997	38.7320	0.	10.
354	96.4968	38.7249	-19.	-7.
355	96.4976	38.7144	441.	455.
356	96.4971	38.7012	-19.	-3.
357	97.5200	39.1176	20.	5.
358	97.5291	39.1176	20.	6.
359	97.5387	39.1176	10.	-3.
360	97.5479	39.1176	20.	5.
361	97.5577	39.1176	0.	-11.
362	97.5675	39.1176	82.	73.
363	97.5762	39.1176	30.	22.
364	97.5851	39.1176	-20.	-27.
365	97.5943	39.1176	10.	4.
366	97.6034	39.1176	-20.	-25.
367	97.6125	39.1175	10.	7.
368	97.6217	39.1176	82.	80.
500	96.1504	38.6231	-11.	26.
501	96.1323	38.6223	-69.	-30.

Table 2. Sample site numbers, coordinates and concentration of helium in soil gas - Manhattan travers.

ID	LAT	LONG	HELIUM
600	39.6393	96.6746	43
601	39.6393	96.5566	-64
602	39.6386	96.6571	301
603	39.6392	96.6464	-10
604	39.6392	96.6381	440
605	39.6386	96.6280	107
606	39.6393	96.6183	-21
607	39.6393	96.6006	-10
608	39.6393	96.5923	0
609	39.5676	96.0345	30
610	39.5662	96.0240	0
611	39.5662	96.0120	20
612	39.5662	96.0039	0
613	39.5662	95.9943	30
614	39.5662	95.9864	20
615	39.5662	95.9746	20
616	39.5662	95.9654	20
617	39.5662	95.9565	10
618	39.5662	95.9483	-10
619	39.5662	95.9391	21
620	39.5662	95.9313	-42
621	39.5662	95.9180	0
622	39.5662	95.9090	21
623	39.5662	95.8995	0
624	39.5662	95.8910	53
625	39.5722	96.4065	21
626	39.5662	96.3983	43
627	39.5662	96.3891	-32
628	39.5662	96.3775	43
629	39.5662	96.3681	-32
630	39.5662	96.3612	-32
631	39.5662	96.3494	-76
632	39.5662	96.3411	10
633	39.5662	96.3309	-31
634	39.5662	96.3247	-64
635	39.5662	96.3133	-73
636	39.5662	96.3051	-84
637	39.5662	96.2942	-42
638	39.5662	96.2840	-73
639	39.5662	96.2747	63
640	39.5662	96.2657	-52
641	39.5662	96.4042	-52
642	39.625	96.8735	10
643	39.625	96.8817	10
644	39.625	96.8917	54
645	39.625	96.9035	10
646	39.625	96.9106	-10
647	39.625	96.9194	0
648	39.625	96.9277	173
649	39.625	97.1438	-28
650	39.625	97.1630	225
651	39.625	97.1815	-9
652	39.625	97.2004	-18
653	39.625	97.2184	0

Table 2. (continued)

ID	LAT	LONG	HELIUM
654	39.625	97.2374	-9
700	39.6393	96.6829	0
701	39.6393	96.6940	10
702	39.6318	96.6940	0
703	39.625	96.6940	-20
704	39.625	96.7029	43
705	39.625	96.7130	-43
706	39.625	96.7216	-54
707	39.625	96.7315	-20
708	39.625	96.7400	-10
709	39.625	96.7492	-43
710	39.625	96.7620	-43
711	39.625	96.7684	-43
712	39.625	96.7781	-43
713	39.625	96.7859	-86
714	39.625	96.7973	-32
715	39.625	96.8081	10
717	39.625	96.8167	0
718	39.625	96.8245	-65
719	39.625	96.8340	20
720	39.625	96.8432	-20
721	39.625	96.8522	379
722	39.625	96.8624	173
723	39.5804	96.4090	96
724	39.5804	96.4156	-21
725	39.5804	96.4270	21
726	39.5804	96.4353	74
727	39.5804	96.4429	-32
728	39.5804	96.4623	-32
729	39.5880	96.4741	-21
730	39.5880	96.4947	0
731	39.5880	96.5093	21
732	39.5944	96.5195	96
733	39.6024	96.5286	42
734	39.5662	96.1212	-42
735	39.5662	96.1287	339
736	39.5662	96.1353	-73
737	39.5662	96.1457	10
738	39.5662	96.1550	-31
739	39.5662	96.1649	-52
740	39.5662	96.1756	-42
741	39.5662	96.1843	-52
742	39.5662	96.1948	-42
743	39.5662	96.2021	147
744	39.5662	96.2099	-31
745	39.5662	96.2213	-42
746	39.5662	96.2308	-52
747	39.5662	96.2398	-10
748	39.5662	96.2503	-10
749	39.5662	96.2575	-31
750	39.625	97.1155	0
751	39.625	97.1062	34
752	39.625	97.0778	0
753	39.625	97.0404	-45
754	39.625	97.0229	0
755	39.625	97.0039	-22
756	39.625	96.9848	0

Table 2. (continued)

ID	LAT	LONG	HELIUM
757	39.625	96.9656	0
758	39.625	96.9467	11
760	39.625	97.1533	415
761	39.625	97.1718	-83
762	39.625	97.1900	-35
763	39.625	97.2090	-23
764	39.625	97.2284	0
765	39.625	97.2463	0
800	39.5662	96.0525	20
801	39.5662	96.0617	41
802	39.5662	96.0705	31
803	39.5662	96.0799	52
804	39.5662	96.0934	0
805	39.5662	96.0972	31
806	39.5662	96.1140	31
807	39.6390	96.5771	43
808	39.6322	96.5705	43
809	39.6269	96.5654	43
810	39.6202	96.5570	204
811	39.6132	96.5567	86
812	39.5804	96.4554	43
813	39.5880	96.4635	0
814	39.5880	96.4822	53
815	39.5880	96.5008	10
816	39.5830	96.5195	75
817	39.6022	96.5195	21
818	39.625	97.125	94
819	39.625	97.0970	42
820	39.625	97.0878	0
821	39.625	97.0591	-31
822	39.625	97.0695	-21
823	39.625	97.0503	42
824	39.625	97.0321	52
825	39.625	97.0127	0
826	39.625	96.9945	115
827	39.625	96.9748	-31
828	39.625	96.9559	73
829	39.625	96.9369	-21

either rainfall, extreme temperature changes, or other diurnal variations. A regression curve is prepared from the permanent probe helium measurements, and, by matching the time of any given sample to the time on the regression line, a correction can be calculated. If there is not a significant variation in the helium concentration from the permanent probes, no correction is made for the survey data. The helium data for the Hutchinson traverse required correction. Raw helium values are reported on the Hutchinson traverse (plate 1) immediately beneath the sample number and the corrected values beneath them. The Manhattan traverse did not require corrections.

MULTIPLE GAS SURVEY

Soil gases were sampled at 1/2-mi intervals along part of each of the two long traverses described above and along two shorter traverses (plate 2). A total of 190 soil gas samples were collected and analyzed over a 6-day period in July, 1984. Soil gas was sampled by driving a hollow steel probe into the ground to a depth of .75 m (Reimer and Bowles, 1979). Five cm^3 of soil gas were withdrawn from that depth with a hypodermic syringe and needle and immediately analyzed in a truck-mounted gas analyzer. The analyzer is a UTI model 100 c quadrupole mass spectrometer interfaced with a Tectronic model 31 programmable calculator.* This unit was used to analyze the multiple gases reported here but not the helium.

The gases are ionized in the mass spectrometer and the resulting positive ions are separated by a combined electrostatic and radio-frequency field imposed on four cylindrical rods. Each gas species has a unique mass-to-charge ratio that is detected in an electron multiplier. By varying the voltages on the rods at a constant rate, ions of different mass are sequentially scanned and the intensity of each mass/charge peak is measured. Standard gases are used to prepare calibration curves that relate peak intensity to concentration. The range of the analyzer is from 1 to 300 atomic mass units (AMU);** however, the range used in this study was for AMU's from 1-100 (this range is scanned in about 40 seconds). The peak height is digitized and printed on paper tape alongside the AMU and is also recorded on magnetic tape. Power to operate the analyzer is provided by a 160-amp alternator and a DC-to-AC converter. It takes about 10 minutes at each site to collect and analyze the soil gas sample. About 40-50 samples per day can be collected and analyzed.

Concentrations of gases are reported in percent for N_2 and CO_2 and as peak heights (relative concentration) for H_2 and C_3H_7.

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*The quadrupole mass spectrometer is manufactured by UTI Corp. of Sunnyvale, CA; a model c is interfaced with a Tectronic 31 calculator. The complete assembly was fabricated and installed in a field vehicle by Pernicka Corporation of Fort Collins, CO.

**AMU is the mass of atomic molecular species measured.

RESULTS

Helium Surveys

The concentration of helium in soil gas varied around the ambient 5,240 ppb in air, from -106 ppb to +650 ppb on the Hutchinson traverse and from -86 ppb to +440 ppb on the Manhattan traverse. Anomalous concentrations of He (>100 ppb) were found along the Hutchinson traverse at sites from west to east 341, 215, 300, 237, 243, 247-248, 251, 125, 130-131, 270-271, 343, 348, 355, 288, 279, 276, 274, and 144 (figs. 1A and 1B) Most of these anomalies occur where the traverse crosses rivers, creeks, or topographic lineaments. The highest He value (650 ppb) occurs at site 300 (fig. 1A) which coincides with the eastern contact of the rift-related rocks as mapped by Sims (1985). The next highest value (455 ppb) occurs at site 355 (fig. 1B) in the vicinity of the Nemaha Ridge Fault System (Sims, 1985). High values (up to 418 ppb) occur in the vicinity of Clarks Creek, Laird Creek, Munkers Creek, and Rock Creek. It appears that many of the He anomalies coincide with known or suspected faults which determined the location of creeks and which serve as conduits for the migration of gas to the surface.

Anomalous concentrations of He (>100 ppb) were found along the Manhattan traverse at sites (from west to east) 650 and 760, 828, 648, 722-721, 602, 604, 605, and 810 (all on fig. 2A), and 743 and 735 (fig. 2B). The highest He value (440 ppb) occurs at site 604 and coincides with a fault in the Rift Rocks mapped by Sims (1985). The next highest value (415 ppb) occurs at site 760 (fig. 2A) and coincides with the projection of a fault mapped by Sims (1985). The next highest value (399 ppb) occurs at site 735 (fig. 2B) and is in the vicinity of the Nemaha Ridge Fault System. Other high values occur at Carter Creek (site 826), Fancy Creek (site 648), Sulphur Creek (sites 721-722), and at the confluence of the Big Blue and Black Vermillion Rivers (site 810). The last site also coincides with the eastern contact of the Rift Rocks. As in the Hutchinson traverse, most Manhattan traverse He anomalies coincide with mapped or suspected faults.

Multiple Gas Surveys

Sample numbers, latitude and longitude of site locations, and the concentrations of selected gas species in the soil gas samples are given in tables 3 and 4. Absolute concentrations of N_2 and CO_2 are given in percent. Relative concentrations are given for H_2, C^+, and $C_3H_7^+$ and are all in the low parts per million range. The highest figures indicate the highest concentrations. These values are also plotted on maps (plate 2-4). The C^+ ion at AMU 12 is a fragment that results from ionization of methane and other hydrocarbons. The $C_3H_7^+$ ion is a fragment that results from ionization of propane and higher alkanes. The C^+ ion may indicate natural gas and the $C_3H_7^+$ ion may indicate wet gas or petroleum (Jones and Drozd, 1983). Surface measurement of volatile hydrocarbons is increasingly being used in exploration for oil and gas (Philp and Crisp, 1982; Jones and Drozd, 1983).

Anomalous sites or areas for each gas are briefly described below.

Table 3. Sample site numbers, coordinates and data for selected gases - Hutchinson traverse.

Sample	lat	long	H2+	C+	%N2++	C3H7+	%CO2
1	385732	971358	94	14	73.6	33	.053
2	385732	971324	89	16	79.5	32	.049
3	385732	971252	80	36	73.2	34	.15
4	385732	971216	78	37	79.3	33	.14
5	385732	971134	77	23	78.8	23	.11
6	385732	971108	71	27	78.9	25	.12
7	385732	971035	70	15	79.4	19	.06
8	385732	971002	72	9	78.6	13	.06
9	385732	970929	65	43	77.8	25	.17
10	385732	970855	63	25	76.7	16	.11
11	385732	970820	64	19	77.7	16	.075
12	385732	970748	60	21	77.1	14	.075
13	385705	970748	59	31	76.8	15	.13
14	385641	970748	59	27	77.2	15	.12
15	385613	970748	55	56	73.5	21	.23
16	385547	970748	58	29	75.1	19	.15
17	385521	970748	56	29	76.6	13	.14
18	385457	970748	53	16	75.0	10	.09
19	385453	970715	54	55	74.7	20	.22
20	385335	970642	55	33	76.2	11	.14
21	385308	970642	54	39	75.6	13	.18
22	385308	970608	52	13	75.0	5	.09
23	385308	970535	50	18	72.5	3	.11
24	385308	970502	50	10	74.2	ND	.08
25	385308	970430	50	21	75.0	5	.11
26	385308	970355	51	48	75.9	11	.20
27	385308	970322	49	14	75.6	1	.07
28	385308	970248	49	22	75.1	3	.12
29	385308	970215	47	8	75.5	ND	.075
30	385308	970143	49	29	77.1	5	.14
31	385308	970109	46	35	76.5	20	.32
32	385308	970036	47	39	76.7	8	.17
33	385308	970002	47	19	75.9	3	.11
34	385308	975930	52	11	77.0	ND	.08
35	385308	975855	46	1	77.6	ND	.04
36	385308	975822	105	ND	75.9	ND	.04
37	385308	975747	81	24	77.0	ND	.11
38	385308	975716	83	27	78.6	ND	.11
39	385308	975642	79	69	77.4	1	.22
40	385308	965603	77	41	73.6	ND	.15
41	385308	965535	74	40	77.9	ND	.16
42	385238	975535	72	109	75.8	2	.33
43	385241	965458	72	137	76.4	14	.52
44	385305	965432	70	119	75.9	2	.36
45	385305	965351	63	21	73.0	ND	.11
46	385305	965323	61	32	72.8	ND	.15
47	385305	965250	60	29	71.7	ND	.13
48	385305	965217	62	26	72.1	ND	.12
49	385305	965143	62	42	72.3	ND	.17
50	385305	965109	59	33	72.4	ND	.14
51	385305	965035	56	34	71.4	ND	.15

Table 3. (continued)

Sample	lat	long	H2+	C+	%N2++	C3H7+	%CO2
52	385305	965002	57	30	71.4	ND	.14
53	385305	964930	59	51	71.0	ND	.19
54	385305	964856	57	60	70.5	ND	.27
55	385305	964824	53	36	71.5	ND	.15
56	385237	964624	59	36	76.3	ND	.15
57	385212	964824	55	36	70.4	ND	.16
58	385205	964751	56	90	71.3	ND	.30
62	385158	964732	81	38	77.2	30	.09
63	385146	964732	75	71	77.6	39	.13
64	385136	964721	66	49	80.4	38	.10
65	385128	964658	78	53	85.6	37	.085
66	385122	964644	58	46	78.8	22	.095
67	385053	964644	55	49	77.6	21	.10
68	384935	964644	50	18	75.9	11	.05
69	384843	964644	50	43	75.3	16	.095
70	384843	964610	50	27	75.9	12	.065
71	384843	964537	50	14	75.2	9	.045
72	384843	964503	48	41	75.1	16	.095
73	384843	964431	52	52	73.2	17	.11
74	384843	964357	47	52	73.6	17	.12
75	384843	964323	44	15	75.8	7	.06
76	384843	964249	46	1	72.5	ND	.03
77	384843	964217	45	3	74.3	ND	.035
78	384843	964142	43	24	73.9	7	.075
79	384843	964112	44	19	74.6	1	.06
80	384843	964037	44	8	74.4	ND	.04
81	384843	964003	44	25	75.4	3	.07
82	384843	963932	44	16	75.0	ND	.055
83	384843	963844	42	10	74.5	ND	.05
84	384843	963823	45	63	74.7	12	.14
85	384843	963752	46	103	75.2	21	.21
86	384843	963720	42	50	74.3	7	.12
87	384843	963647	43	23	75.8	ND	.07
88	384843	963612	41	36	75.7	1	.095
89	384843	963538	41	25	74.9	ND	.075
90	384843	963505	39	31	73.7	12	.18
91	384843	963434	38	32	74.9	4	.085
92	384843	963400	41	72	70.4	16	.17
93	384843	963327	42	55	76.9	9	.12
94	384843	963253	41	83	75.9	13	.17
95	384843	963218	44	46	77.9	4	.11
96	384843	963145	43	32	77.2	ND	.09
97	384843	963111	41	34	76.9	ND	.095
98	384843	963037	41	20	77.4	ND	.07
99	384843	963003	41	11	77.2	ND	.06
100	384843	962931	39	ND	77.3	ND	.03
101	384843	962857	43	ND	76.5	ND	.025
102	384843	962824	23	ND	76.7	ND	.03
103	384843	962749	43	54	76.4	ND	.13
104	384843	962714	43	77	76.3	3	.17
105	384843	962643	39	39	75.5	ND	.11
106	384843	962608	41	54	75.5	ND	.13

Table 3. (continued)

Sample	lat	long	H2+	C+	%N2++	C3H7+	%CO2
107	384843	962535	42	123	77.1	13	.25
108	384843	962500	43	64	76.6	ND	.15
109	384843	962428	72	7	67.8	ND	.06
110	384843	962355	43	34	77.2	ND	.10
111	384843	962322	42	35	77.5	ND	.10
112	384843	962249	40	40	77.5	ND	.11
113	384843	962217	43	32	77.7	ND	.10
114	385634	965219	134	33	75.7	50	.06
115	385657	965213	118	50	78.5	47	.09
116	385712	965157	111	101	77.2	52	.15
117	385727	965123	104	183	78.2	65	.26
118	385738	965052	90	115	74.3	47	.18
119	385740	965013	96	92	80.2	36	.14
120	385818	965003	74	60	69.3	29	.13
121	385851	965000	62	56	77.0	26	.11
122	385912	964935	83	80	73.9	25	.14
123	385917	964850	76	49	79.2	23	.095
124	385928	964810	78	42	79.4	23	.085
125	385910	964752	76	43	78.3	16	.09
126	385843	964752	74	55	77.5	16	.10
127	385831	964720	71	107	76.5	22	.18
128	385801	964720	70	99	76.2	22	.18
129	385752	964646	70	98	76.2	19	.18
130	385745	964612	ND	ND	ND	12	.15
131	385726	964538	68	40	76.3	6	.10
132	385758	964535	67	34	75.1	9	.09
133	385818	964504	61	37	73.9	3	.09
134	385723	964444	63	16	74.1	ND	.065
135	385732	964430	64	24	73.9	ND	.08
136	385712	964415	61	64	72.4	3	.14
137	385658	964340	64	126	73.4	9	.23
138	385608	964302	60	124	72.5	6	.24
139	385522	964223	60	100	72.4	3	.21
140	385416	964212	59	47	70.8	ND	.12
141	385028	963900	52	34	70.6	ND	.11
142	385003	963900	54	36	70.5	ND	.11
143	384938	963900	58	36	72.3	ND	.11
144	384910	963900	49	13	61.9	ND	.085
145	384843	963900	61	58	69.7	ND	.14
146	384818	963900	54	60	68.8	ND	.15
147	384752	963900	53	31	67.5	ND	.10
148	384726	963900	52	37	74.2	ND	.11
149	384658	963900	43	14	69.2	ND	.075
150	384633	963915	45	5	63.6	ND	.065
151	384607	963915	46	13	65.5	ND	.08

Table 4. Sample site numbers, coordinates and data for selected gases - Manhattan traverse.

Sample	lat	long	H2+	C+	%N2++	C3H7+	%CO2
152	393502	963002	146	25	85.2	12	.065
153	393502	963037	130	24	85.1	8	.07
154	393502	963110	120	35	83.0	3	.09
155	393606	963117	103	11	79.3	ND	.065
156	393608	963144	101	109	77.5	7	.21
157	393623	963218	94	37	73.6	ND	.20
158	393713	963327	95	68	72.9	ND	.16
159	393742	963403	92	53	77.5	ND	.13
160	393819	963428	86	99	71.1	ND	.22
161	393819	963710	76	16	70.3	ND	.075
162	393818	963743	76	28	73.2	ND	.10
163	393819	963817	80	57	71.6	ND	.14
164	393819	963851	80	43	71.5	ND	.12
165	393818	963924	86	39	71.3	ND	.11
166	393819	963958	82	42	71.4	ND	.12
167	393819	964032	74	26	70.9	ND	.09
168	393819	964104	72	3	70.9	ND	.055
169	393819	964138	72	3	74.7	ND	.07
170	393728	964138	71	10	71.0	ND	.065
171	393728	964212	71	77	69.3	ND	.18
172	393728	964245	71	65	69.9	ND	.16
173	393728	964319	68	39	70.5	ND	.12
174	393728	964353	71	6	70.2	ND	.06
175	393728	964426	74	32	69.8	ND	.10
176	393728	964500	74	19	70.1	ND	.085
177	393728	964534	70	70	69.9	ND	.13
178	393728	964608	64	22	69.8	ND	.095
179	393728	964642	70	22	69.5	ND	.095
180	393728	964716	69	79	68.4	ND	.20
181	393728	964749	67	96	70.1	ND	.22
182	393728	964823	65	63	69.6	ND	.17
183	393728	964856	69	147	71.1	ND	.31
184	393728	964930	67	118	70.1	ND	.25
185	393728	965004	71	36	71.6	ND	.13
186	393728	965038	66	31	68.7	ND	.11
187	393728	965112	71	16	70.0	ND	.085
188	393728	965147	70	9	69.5	ND	.07
189	393730	965220	76	53	72.5	ND	.16
190	393728	965254	76	20	72.3	ND	.10

Hutchinson traverse

H_2 (plate 2)

Several sites are considered to be anomalous based on increases in the trend of the analyses rather than on the absolute values because the absolute values changed from day to day. Each day there was a downward trend of hydrogen values and only at sites where the trend is interrupted are the values considered anomalous. Sites considered anomalous are (from west to east) 20, 21, 34, 58, 65, 73, 76, 84, 85, 93, 95, 96, 101, and 109. The anomalies at sites 95 and 96 are on the projection of the Nemaha fault. The anomalies at sites 20 and 21 coincide with the eastern contact of the Rift Rocks while those at sites 93, 95, and 96 coincide with the Nemaha Ridge Fault Zone (Sims, 1985).

N_2 (plate 2)

Most values for N_2 are below the atmospheric abundance of N_2 (78.1% v/v). The lowest values are found in the vicinity of Lairds Creek; high values (as high as 85.6% N_2 v/v) occur near the Clarks Creek drainage on a line between the Heins and Scott 1 boreholes.

CO_2 (plate 3)

Values >0.1% are considered anomalous. The highest anomalies (>0.3%) occur at sites 31, 42, 43, 44, and 58 and samples on either side are commonly >0.1%. All samples from west of Lyon Creek to Clarks Creek are >0.1%, a distance of about 10 mi. Anomalous samples on the short traverse to the north coincide with a projection of the Lyons Creek drainage anomaly. Other anomalies occur along the traverses and frequently coincide with drainages.

C^+ (plate 3)

The highest values for C^+ occur at sites (from west to east) 42, 43, 44, 107, 116, 117, 118, 137, 138, and 139. Lower but still anomalous values occur on either side of the above sites and at other localities. These anomalies commonly coincide with stream drainages, Lyons Creek and to the northeast, Davis Creek, Clarks Creek, Lairds Creek, and Munkers Creek, and may reflect areas of methane leakage.

$C_3H_7^+$ (plate 3)

The highest values for $C_3H_7^+$ occur at sites 1-6, 114-119, 63, and 65. Again, the highest values coincide with drainages and may reflect leakage of petroleum-related gas.

Manhattan traverse (plate 4)

H_2 (plate 4)

Several sample sites are considered to be anomalous based on slight increases in the trend of analyses, rather than on absolute values. Sites considered anomalous are 158, 163-166, 175, 176, 189, and 190. Anomalous H_2 at site 158 coincides with the eastern contact of the Rift Rocks as mapped by Sims (1985). The H_2 anomalies at sites 163-166 coincide with a basement fault (Sims, 1985).

N_2 (plate 4)

Most values for N_2 in the soil gas are below atmospheric abundance, however, several values are considerably higher (sites 152-154).

CO_2 (plate 4)

Values >0.1% are considered to be anomalous. The highest values are near the Sulphur Creek drainage at sites 183 and 184. Other anomalous sites are (from east to west) 156-160, 162-166, 171-173, 175, 177, and 180-186. Anomalies at sites 155-157 coincide with the eastern contact of the Rift Rocks and the anomalies at sites 162-166 are over a basement fault.

C^+ (plate 4)

Anomalous values (>50) occur in the area at the confluence of the Blue and Black Vermillion Rivers and at sites (from east to west) 163, 171, 172, 177, 180-182, and 189. Most of these anomalies coincide with drainages. The anomalies at the confluence of the Blue and Black Vermillion Rivers coincide with the eastern contact of the Rift Rocks and that at site 163 with a basement fault.

$C_3H_7^+$ (plate 4)

This gas species was found at only four sites, 152-154 and 156. These sites are east of those that are anomalous in C^+ and may indicate petroleum-related leakage.

GASES FROM BOREHOLES

Gas from two wells in the vicinity of Skiddy, Kansas, was sampled and analyzed in the field. The Scott 1 well is located in Morris County (20-14s-6e) and the Heins well is in Geary County (27-13s-6e). The analyses of gas from these wells is given in table 5.

Increase of approximately two times AMU 17 (OH^+) and 18 (H_2O^+) in Heins gas indicates an increase in water vapor. The ion fragment of AMU 17 (HO^+) is about 20% that of AMU 18 (H_2O^+) in the usual mass spectrogram for water (Heller and Milne, 1978). However, in the Heins well gas samples the AMU 17 fragment is nearly 50% of the AMU 18 ion, suggesting the presence of ammonia (NH_3) at AMU 17.

An increase in both AMU 15 and AMU 29 indicates a slight enrichment in hydrocarbons in the Heins well gas. The principal ion fragment in the mass spectrogram for propane occurs at AMU 29 (fig. 1), and C_4-C_6 alkanes also have mass fragments at AMU 29. Thus, a small component of wet gas or petroleum is indicated. Interestingly, however, the AMU 15 fragment is increased more than twice that of the AMU 29 fragment suggesting enrichment in ^{15}N. No increase is found at AMU 13, a fragment typical of the ionization of methane which would be expected if the AMU 15 enrichment resulted from an increase in methane.

DISCUSSION

It does not appear that the soil gas studies reported here successfully delineated a hydrogen-rich gas field. Slightly anomalous concentrations of hydrogen were measured but it is not possible to say whether these anomalies originated at depth. Many of the gas anomalies occur at the same sites or in the same areas and frequently coincide with rivers and creeks, suggesting that their migration to the surface may be fault controlled. A good correlation is noted between gas anomalies and known and suspected faults (F. W. Wilson, written commun., 1984).

The hydrogen enrichment reported in the Scott 1 well, and especially in the Heins well, has been confirmed by our field analyses. Various hypotheses have been proposed for the origin of the hydrogen (Goebel and others, 1984). Hydrogen gas is extremely mobile and very difficult to contain, thus, the great enrichment found in the Heins well suggests that it is continually produced or outgassed from depth. Production of hydrogen by serpentinization has been proposed but the lack of known ultramafic rocks in the area argues against this (Paul Sims, pers. commun., 1986).

The light deuterium values found in hydrogen gas from the Heins and Scott No. 1 wells are compatible with hydrogen that is in equilibrium with water at 200-300°C (Irving Friedman, pers. commun., 1986). Assuming an average geothermal gradient of 30°C/km in the vicinity of the gas wells, the temperatures indicated would be found at a depth of 7-10 km.

As mentioned above, nitrogen from the Heins well is enriched in ^{15}N (by an estimated 20-30°/₀₀). Batard et al. (1982) found ^{15}N enrichments of +22 and +26°/₀₀ in thermal spring gases in France and concluded that the nitrogen was probably of deep-seated origin. Becker and Clayton (1977) found ^{15}N enrichment in mantle-derived basalts from Hawaii.

Stahl (1977) measured the change in the C and N isotope composition of natural gases from fields in the Wustrow area of northwestern Germany and found that the N-isotope fractionation systematically increases with increasing migration distances in favor of the heavier ^{15}N isotope. Thus, the apparent enrichment of the ^{15}N isotope in the gas of the Heins well is compatible with migration over a considerable distance (depth?).

Maksimov et al. (1976) investigated high nitrogen gas pools in northern Europe and the USSR and concluded that the N_2 originated during metamorphism, tectonic and magmatic activity, radioactivity, and constant release of "deep-seated nitrogen" from the crust or mantle. They also found that ^{15}N was enriched in some pools by as much as 15°/₀₀ and noted that high nitrogen gases are restricted to "tectonic zones or to ancient lineaments" and postulated a deep-seated source.

Although not conclusive, the H and N isotopic composition of the gases suggests a deep source. This latter hypothesis will be tested by analysis of ^{3}He in the gases.

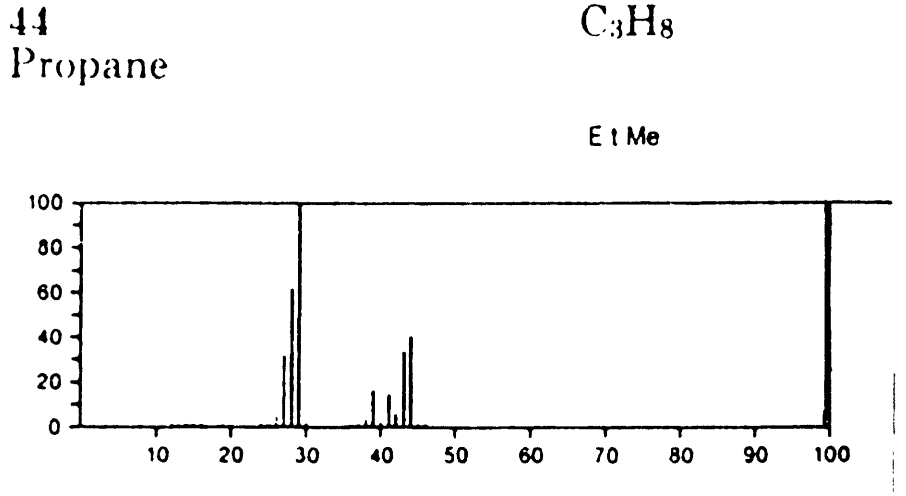

Figure 1. Mass spectrum for propane (molecular weight 44). Mass units shown on horizontal axis, relative intensities of peaks on vertical axis (from Heller and Milne, 1978).

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Table 5.--Concentration of gases in samples from wellhead of Heins and Scott 1 boreholes

	AMU	Heins well	Scott well
H_2	2	54.8%	4%
N_2	14	37%*	92%
O_2	32	4.9%	0.8%
H_2O	18	2.2%	2.0%
Ar	40	.85%	1.2%
CO_2	44	90 ppm	100 ppm
D**		-520°/∘∘	-670°/∘∘

*N_2 content of Heins well obtained by difference.
**Deuterium analysis by Irving Friedman.