Uranium and Helium in the Panhandle Gas Field Texas, and Adjacent Areas

By A. P. PIERCE, G. B. GOTT, *and* J. W. MYTTON

With contributions by HENRY FAUL, G. E. MANGER, A. B. TANNER, A. S. ROGERS, ROSEMARY STAATZ, *and* BETTY SKIPP

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 454-G

Prepared on behalf of the
U.S. Atomic Energy Commission

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1964

UNITED STATES DEPARTMENT OF THE INTERIOR
STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY
Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

Page
Abstract ---------- G1
Introduction ---------- 1
Acknowledgments ---------- 19
Geology of the western part of the Panhandle field ---------- 19
  Descriptive geology ---------- 22
    "Granite wash" ---------- 22
    "Moore County lime" ---------- 22
    "Brown dolomite" ---------- 22
    "Panhandle lime" ---------- 23
    "Red Cave" ---------- 24
  Structure ---------- 24
Uranium and other metals in the Panhandle field ---------- 24
  Uranium in the reservoir and cap rocks ---------- 24
Uranium and other metals in the Panhandle field—Con.
  Uranium and other metals in the crude oil ---------- G26
  Radium and uranium in the brine ---------- 28
  Uraniferous asphaltite ---------- 33
    Nomenclature ---------- 35
    Review of the literature ---------- 35
    Physical properties ---------- 38
    Composition and mineralogy ---------- 39
    Origin of the asphaltite ---------- 46
Radon in the natural gas ---------- 49
Helium in the natural gas ---------- 49
  Conclusions ---------- 55
Selected bibliography ---------- 55

ILLUSTRATIONS

[Plates are in pocket]

PLATE 1. Map of the western part of the Panhandle field, Texas, showing structure contours and radon and helium content in gas wells.
2. Isometric panel diagram showing geology of the reservoir rocks.
3. Correlation of gamma-ray logs with uraniferous asphaltite in some wells.

Page
FIGURE 1. Index map of the Panhandle area ---------- G2
2. Map showing major structural features ---------- 20
3. Generalized stratigraphic section of Upper Pennsylvanian and Lower Permian rocks ---------- 21
4. Sketch showing typical mineralogical relationships in porous "Brown dolomite" ---------- 23
5. Concentrations of metals in crude oil, asphaltite nodules, and connate brine ---------- 27
6. Radium, calcium sulfate, and salinity content compared to calcium to magnesium and chlorine to sulfate concentration ratios ---------- 29
7. Calcium, calcium sulfate, and salinity content compared to calcium to magnesium and chlorine to sulfate concentration ratios ---------- 32
8. Regional distribution of uraniferous asphaltite ---------- 34
9. Diagrammatic cross section from Moore County to Hockley County, Tex ---------- 36
10. *A*, Dense anhydritic oolitic dolomite containing disseminated nodules; *B*, Asphaltite nodules ---------- G38
11. Asphaltite in porous crystalline dolomite from a major gas-producing zone ---------- 39
12. Relation of anhydrite and nodular asphaltite to red organic material in oolitic dolomite ---------- 41
13. Polished sections of asphaltite nodules showing "nebular" dispersions of smaltite-chloanthite ---------- 44
14. Comparison of "capillary" structures in asphaltite nodules ---------- 45
15. Cataclastic pyrite crystals in an asphaltite nodule ---------- 45
16. Asphaltite associated with secondary anhydrite in dolomite ---------- 46
17. Asphaltite associated with secondary anhydrite ---------- 46
18. Asphaltite nodules surrounded by halos, in shale ---------- 47
19. Fossiliferous chert containing asphaltite nodules ---------- 48
20. Distribution of helium in the Panhandle field and adjacent areas ---------- 51
21. Graph showing ratio of helium to nitrogen in gas samples from the Panhandle, Cliffside, and Quinduno fields ---------- 52

TABLES

[Tables 5 and 6 are in pocket]

		Page
TABLE	1. Wells shown on plate 1, listed numerically	G3
	2. Wells shown on plate 1, listed alphabetically by company and name	14
	3. Uranium content of drill cuttings of reservoir rocks from some wells in the western part of the Panhandle field	25
	4. Radium content and radon-emanating power of core samples from two wells in the Panhandle field	25
	5. Spectrographic and chemical analyses of the ash of samples of crude oil from the Panhandle field.	
	6. Calculated concentration of metals in samples of crude oil from the Panhandle field.	
	7. Metal concentrations in thermodiffusion fractions of a sample of crude oil from well 731	28
	8. Radium content and chemical analyses of brine samples from some gas wells in the Panhandle and Hugoton fields, by A. S. Rogers	30
	9. Isotopic composition of radium in brine from two wells in the Panhandle field	33
	10. Size distribution of asphaltite nodules from the reservoir and cap rocks of the western part of the Panhandle field	38
	11. Fine-size distribution of asphaltite nodules from the reservoir and cap rocks of the western part of the Panhandle field	38
	12. Specific gravity and size of some asphaltite nodules from drill cuttings, western part of the Panhandle field	39
	13. Organic analyses of asphaltite nodules from the western part of the Panhandle field	40
	14. Spectrographic, radiometric, and X-ray crystallographic analyses of asphaltite nodules from the western part of the Panhandle field	42
	15. Estimated average concentration of metals in brine, crude oil, and asphaltite from the Panhandle field	47
	16. Comparison of ratios of percent metal in crude oil and asphaltite to percent metal in brine from the Panhandle field	47
	17. Composition of natural gas from the western part of the Panhandle field, the Cliffside field, and the Quinduno field	50

URANIUM AND HELIUM IN THE PANHANDLE GAS FIELD, TEXAS, AND ADJACENT AREAS

By A. P. PIERCE, G. B. GOTT, and J. W. MYTTON

ABSTRACT

The dominant structural feature of the Panhandle gas field of Texas is the Amarillo-Wichita uplift, a northwest-trending geanticline, extending over 200 miles from the Wichita Mountains of southern Oklahoma to the Dalhart basin northwest of Amarillo, Tex.

As a result of uplift that began during Late Mississippian or Early Pennsylvanian time the pre-Pennsylvanian rocks were eroded and the Precambrian basement complex of the Amarillo-Wichita area was exposed. By Early Permian time the Precambrian rocks were submerged and marine rocks were deposited over the uplift. Repeated crustal movement since that time has folded and faulted the rocks that overlie the uplift.

The rocks of the Panhandle field that have been studied as part of this investigation range from Upper Pennsylvanian to Lower Permian and include "arkose," shallow marine limestone and dolomite, and siltstone and shale interbedded with anhydrite.

The Panhandle gas field originally contained the largest commercial helium reserve in the United States. It also contains anomalous concentrations of radon. The reservoir rocks contain from 2 to 4 ppm (parts per million) of uranium. The uranium content of crude oil peripheral to the gas field ranges from less than 1 to 300 parts per billion. The uranium content of the brine is from less than 0.1 to about 10 ppb.

The highest concentration of uranium is in the cap rocks which have been estimated to contain between 10 and 20 ppm through a thickness of about 250 feet. The uranium in these rocks is concentrated in asphaltite which contains about 1 percent uranium. The asphaltite is a metalliferous organic mineraloid similar to thucholite, carburan, and huminite. It is brittle, highly lustrous, black, combustible at high temperatures, and almost insoluble in organic reagents. The principal organically combined elements in the asphaltite are carbon, hydrogen, and oxygen. The most abundant metallic elements are arsenic, uranium, nickel, cobalt, and iron.

X-ray analyses of asphaltite nodules show the presence of uraninite, chloanthite-smaltite, and pyrite. Although uraninite has been identified in some of the nodules, in others the uranium-bearing compound, which may be a metallo-organic complex, is not known.

The asphaltite occurs as botryoidal nodules and is nearly always associated with anhydrite and celestite that occur as cements in siltstone and as fillings in fractures and solution cavities in dolomite.

The asphaltite is probably a petroleum derivative; the uranium and other metals within it were derived from the rocks in which the asphaltite now occurs, and were concentrated in petroleum compounds. Subsequent radiation damage changed the physical and chemical characteristics of the original organic material.

The distribution of uraniferous asphaltite indicates that it is the source of the abnormally high radon concentration in the gases from a number of wells.

The highest concentrations of helium in the Panhandle field occur along the western boundary at points where faulting has brought the gas-reservoir rocks into contact with the uraniferous asphaltic rocks that normally overlie the gas reservoir. These rocks are unusually radioactive over a large area southwest of the field, and may have been the source of a significant part of the helium that has accumulated in the gas reservoir.

INTRODUCTION

The Texas Panhandle gas field covers about 5,000 square miles (fig. 1). Studies were made of drill samples, core samples, gas and brine from many parts of the Panhandle field and from adjoining areas. The most detailed investigation, however, was made in a 1,200-square-mile area at the western end of the Panhandle field that includes all of Moore County and parts of Hartley, Oldham, Hutchinson, Porter, and Carson Counties. The location and radon content of gas wells in this area are shown on plate 1. Index numbers, names, and ownership of the gas wells shown in figure 2 are listed in tables 1 and 2.

Investigations by the U.S. Bureau of Mines have shown that the western part of the Panhandle field contains one of the largest helium reserves in the United States. The discovery (by the late J. W. Hill, U.S. Geological Survey) of anomalous concentrations of radon-222, an intermediate product in the decay of uranium, in the gases suggested that a significant fraction of the helium might have been derived from uranium.

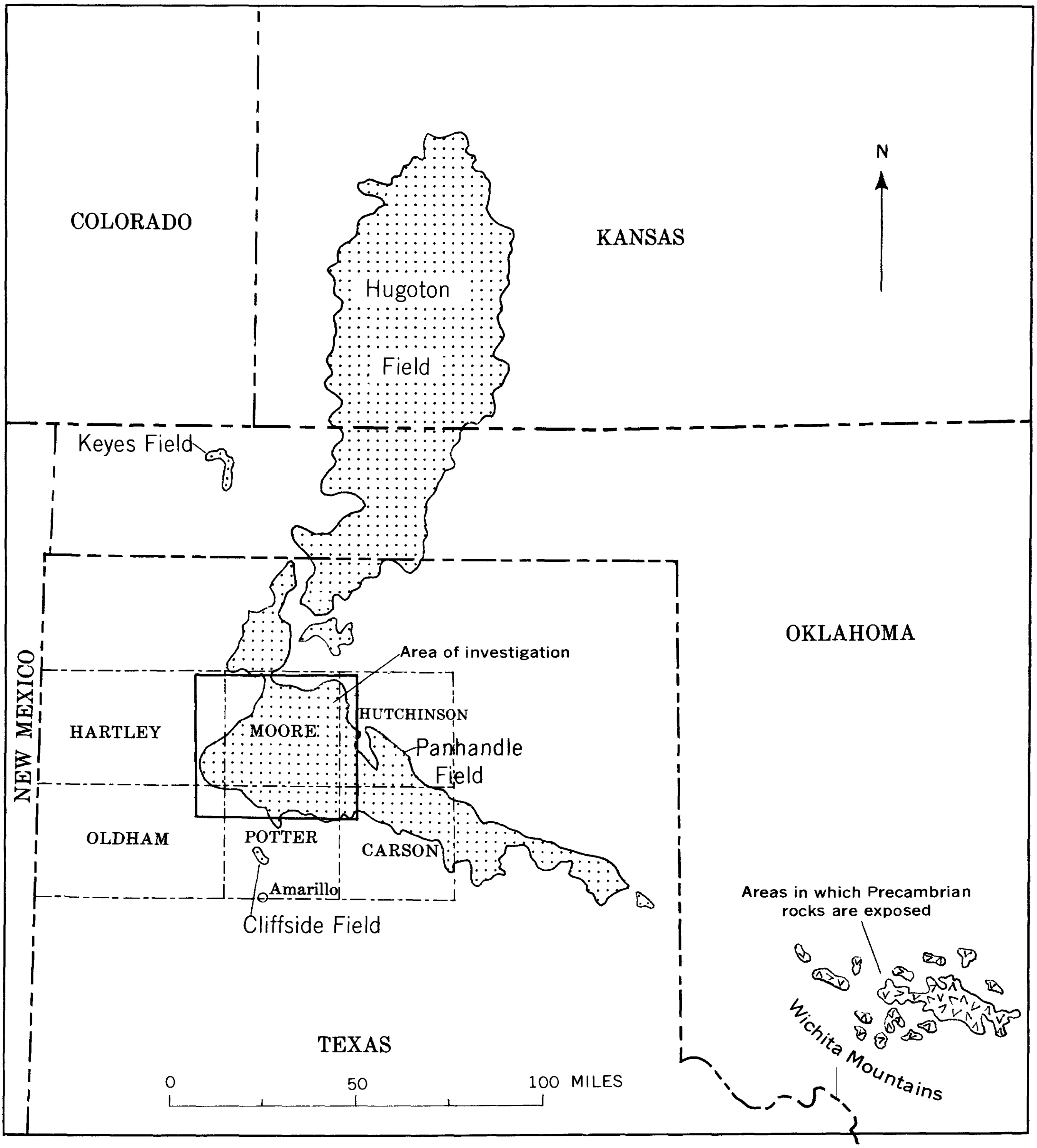


FIGURE 1.—Index map showing location of Panhandle field and adjacent areas.

TABLE 1.—*Wells shown on plate 1, listed numerically*

Abbreviation	*Company*
Cit. Serv.	Cities Service Oil Co.
C. I.	Colorado Interstate Gas Co.
Cont.	Continental Oil Co.
Gray Co. Prod.	Gray County Producing Co.
Kermac.	Kerr-McGee Oil Industries Inc.
Mag.	Magnolia Petroleum Co.
Nat. G.P.A.	Natural Gas Pipeline Co. of America (formerly Texoma Natural Gas Co.)
North. Nat.	Northern Natural Gas Co.
Pan. E.	Panhandle Eastern Pipe Line Co.
Pan. O.	Panhandle Oil Co.
Pan. Prod.	Panhandle Production Co.
Ph.	Phillips Petroleum Co.
R. R.	Red River Oil Co.
Sham.	Shamrock Oil & Gas Corp.
Sinc.	Sinclair Oil Corp.
T.I.P.L.	Texas Interstate Pipe Line Co.

[Asterisk (*) indicates well is not shown on map]

Map No.	*Company and name*
1	Ph. Jover 1
1a	Ph. Stocking 1
1b	Kermac. Zoeber 1
1c	Kermac. Schroeter 1
1d	Kermac. Elgin 1
1e	Kermac. Reeves 1
2	Ph. Beraw 1
3	Ph. Witherbee 1
3a	Ph. Zoeber 1
3b	Sinc. Phillips A–1
4	Sham. Read E–1
4a	Sham. Miller 1
5	Kermac. Creed 1
5a	Ph. Utey 1
5b	Huber Russell; Fuller 1
6	Ph. Cloby 1
7	Shell-Sinc. Flynn 1
8	Shell-Sinc. Russell 1
8a	Ph. Way 1
9	Mag. Miller 1
10	Sham. Robertson D–3
11	Shell-Sinc. Miller A–1
11a	Kermac. Humphries 1
12	Shell-Sinc. Kraker 1
13	Shell-Sinc. Longanbecker 1
13a	Ph. Butler 1
14	Ph. Mills 1
15	Shell-Sinc. Dash 1
16	Ph.-Kermac. Wells 1
17	Shell-Sinc. Miller 1
17a	Ph. Box 1
18	Ph. Pittman 1
19	Ph.-Kermac. McDowell C–1
19a	Ph.-Kermac. McDowell C–2
19b	Sinc. McDowell 1
19c	Ph. Estate 1
20	Sham. Robertson C–3
20a	Sham. Myers 1
20b	Ph. Laughter 1
20c	Sham. Perky 1
20d	Sham. Johnson C–1
20e	Sham. Atcheson 1
21	Sham. Robertson E–1
22	Sham. Robertson C–4
22a	Sham. Breesford 1
22b	Mag. Thompson 1
22c	Sham. Johnson B–1
22d	Sham. Anderson 1
23	Sham. Robertson C–2
23a	Sham. Robertson C–1
24	Sham. Jones 1
24a	Sham. Robertson D–2
25	Ph. Moore '66' 1
25a	Sham. Robertson B–4
26	Ph. Moore '66' 3
26a	Ph. Jones A–3
26b	Ph. Sunray A–2
27	Ph. Purdy 1
27a	Ph. Jones A–2
27b	Ph. Jones A–1
28	Mag. Britian 5
29	Mag. Britian 1
30	Mag. Britian 2
31	Ph. Donaldson 1
32	Ph. Glass 1
33	Shell-Sinc. Bartlett 1
34	Ph. Kelly 1
35	Ph. Wilson 2
36	Kermac. Flynn 1
37	Ph. McDowell 1
38	Ph. Ebling 12
38a	Ph. Ebling 1
38b	Sham. Stewart 10
39	Ph. Brumley 1
40	Sham. Brumley 3

TABLE 1.—*Wells shown on plate 1, listed numerically*—Continued

Map No.	*Company and name*
40a	Sham. Brumley A–1
40b	Shell-Sinc. Hill 1
40c	Sham. Tays 1
40d	Sham. Johnson 1
40e	Sham. Powell C–1
41	Sham. Brumley-Golf 1
41a	Sham. McKee C–1
41b	Sham. Brumley Ryan 1
41c	Shell-Sinc. Jones 1
41d	Sham. Jones A–1
42	Sham. Jones B–1
43	Sham. Jones C–1
43a	Ph. Albert 1
44	Kermac. Jones A–1
44a	Ph. Richard A–1
45	Sham. Sharkey 1
46	Cont. Brown 1
47	Mag. Britian 6
48	Mag. Britian 3
49	Mag. Britian 4
50	Ph.-Kermac. Donaldson 1
51	Shell-Sinc. Donaldson A–1
52	Kermac. Donaldson 1
52a	Cont. Wells 1
53	Ph. Guleke 1
54	Sham. McDowell 1
55	Shell Lucas 1
56	Ph. Lucas 4
56a	Sham. Logan "A"
56b	Sham. Logan 1
57	Ph. Lucas 1
58	Sham. Powell 1
58a	Sham. Burnett 1
58b	Sham. Burnett et al. 1
58c	Sham. Brumley 2
58d	Sham. Sunset Brumley 1
58f	Sham. Allen 1
58g	Sham. Powell-Magnolia 1
59	Sham. Rubert 1
60	Ph. Reeder 1
60a	Sham. Jones-Ryan 1
61	Ph. Reeder 2
61a	Ph. Jones 1
62	Cont. Jones B–1
63	Ph. Ozark 1
64	Kermac. McDowell 2
65	Cont. McDowell 1
66	Mag. Britian 8
67	Ph. Bush 1
68	Cont. Bush 1
69	Ph. Nunley 1
70	Shell-Sinc. Donelson B–1
70a	Shell-Sinc. Donelson C–1
71	Ph. Donelson 1
72	Kermac. A. Donaldson 1
73	Ph. Flynn 1
74	Shell-Sinc. Guleke 1
75	Ph. Powell 1
76	Rubin Carver 327
77	Rubin Barnhill 3
78	Rubin Barnhill 28
79	Nat. G.P.A. Texas C–1
80	Sham. Pritchard 1
81	Wittenburg 1
82	Huber B–4
83	Huber Henderson 1
84	Ph. Coffee 1
84a	Sham. Coffee A–1
84b	Sham. Hight 1
84c	Sham. Luckhard 1
84d	Ph. Faye 1
84e	Sham. Gearhart 1
85	Ph. Clark Gable 1
86	Kermac. Burnett 1
87	Ph. Texas 1
88	Ph. Sunray-Jones 1
89	Kermac. Avery 1
90	Ph. Hub 1
91	Shell-Sinc. McDowell B–1
92	Kermac. McDowell 1
93	(*)
94	Ph. Marguerite Ann 1
95	Sham. Wilson 1
96	Mag. Britain 7
97	Ph. Britain 1
98	Cont. Arnis 1
99	Ph. Reuter 1
100	Cont. Marsh 1
101	Kermac. Morton 3
102	Cont. Meier 1
103	Ph. Venable 1
104	Ph. Castleman B–1
105	(*)
106	Ph. Spur 1
107	Ph. Ada May 1
108	Wittenburg B–3
109	Huber 1
110	Huber 12
111	Huber 3
112	Sham. Dore 1
112a	Sham. Householder 1
112b	Sham. J. F. Ward 1
112c	Ph. Ward 1
112d	Ph. Kane 1
112e	Sham. McKeig 1
112f	Sham. Mercer 1
112g	Sham. McDade 2
113	Ph. Claudine 1
114	Ph. Clarence 1
114a	Ph. Marsh 1

TABLE 1.—*Wells shown on plate 1, listed numerically*—Continued

Map No.	*Company and name*
115	Cont. Burnett 1
116	Ph. Sturdy 1
117	Shell-Sinc. Jones 9–1
118	Kermac. Jones G–1–A
119	Cont. Jones A–1
120	Kermac. Jacobson 1
121	Ph. O. E. McDowell 1
122	Sham. Becker 1
123	Sham. Zwack 1
124	Sham. Olsson 1
125	Kermac. Wilson A–1
126	Mag. Nelson 1
127	Ph. Nelson 1
128	Shell-Sinc. Wilson 1
129	Kermac. Morton A–1
130	Kermac. Morton 4
131	Ph. Castleman A–1
132	Ph. Spurlock 1
133	Huber B–1
134	Cont. Spurlock 1
135	Cont. H. W. Carver 1
136	Cont. H. W. Carver 6
137	Sham. Schlee 1
137a	Ph. Melvin 1
137b	Nat. G. P. A. Dore 1–G
137c	Ph. Emily Nell 1
137d	Sham. McDade 1
137e	Sham. McDade 3
138	Kermac. Sullivan 1
139	Kermac. Strunk 1
139a	Nat. G. P. A. Pythian 1–P
140	Sham. Jones 1
141	Ph. Booker 1
142	Kermac. Jones M–1
143	Sham. Meinhardt 1
144	Sham. Cox 1
145	Kermac. Taylor A–1
146	Mag. Herndon 1
147	Ph. Winn 1
148	(*)
149	Shell-Sinc. Lindsey 1
150	Kermac. Wilbar 2
151	Shell-Sinc. Hohman 1
152	Shell-Sinc. Catlett 1
153	Ph. Ledlow 1
154	Ph. Kinney 1
155	(*)
156	(*)
157	Cont. W. A. Carver 1
158	Sham. Hatcher-Crosby 1
159	Ph. Vanta 1
159a	Ph. O'Hearn 1
159b	Ph. Ochsner 1
159c	Ph. Stigall 1
159d	Ph. Gearhart 1
159e	Sham. Frank Smith 1
159f	Sham. Bates 1
159g	Sham. Thaten 1
159h	Sham. Van Order 1
160	Kermac. Breyfogle 1
161	Sham. Geary 1
162	Sham. Fowlstone 1
163	Sham. Kelly 1
164	Sham. Coffee 1
165	Sham. Mary Smith 1
166	Kermac. Taylor C–1
167	Ph. Armi 1
167a	Kermac. Taylor A–2
168	Ph. Stanhope 1
169	Kermac. Wilbar 3
170	Shell-Sinc. Wilbar 1
171	Ph. Balfield 1
172	Huber Owens 1
173	Shell-Sinc. Munson 2
174	(*)
175	Ph. Knapp 1
175a	Ph. Shelton 1
175b	Ph. Dalla 1
175c	Sham. Dale Smith 1
175d	Sham. Young 1
175e	Adams Pool 1
175f	Adams Love 1
176	Nat. G.P.A. LaSalle 1
177	Nat. G.P.A. Schlee 1
178	Ph. Ethelyn 1
179	Nat. G.P.A. Troutnam 1–SP
180	Nat. G.P.A. Foster 1–S
181	Nat. G.P.A. Foster 2–FO
182	Ph. Hinkle 1
183	Ph. Kell 1
184	Ph. Lore 1
185	Nat. G.P.A. Taylor 1–P
186	Ph. Dardiff 1
187	Ph. Preston 1
187a	Ph. Fields 1
188	Cont. Armstrong 1
189	Kermac. Bridges 1
190	Cont. Shellberg 1
191	Ph. Twill 1
192	Pan. Prod. LaSater 1
193	Huber E. Herring 1
193a	Ph. Daisy 1
194	Ph. Ray 1
195	Nat. G.P.A. Williams 1–T
196	Ph. Stan 1
197	Ph. Rorax 1
198	Nat. G.P.A. Taylor 3–G
198a	Burrus 1
199	Nat. G.P.A. Taylor 1–G
200	Ph. Vent E–1

TABLE 1.—*Wells shown on plate 1, listed numerically*—Continued

Map No.	*Company and name*
201	Sham. Zella 1
202	Ph. Stem 1
203	Ph. Longmack 1
204	Ph. Hagaman 1
205	Cont. Armstrong
206	Ph. Malcolm 1
207	Cont. Bricker 1
208	Ph. Bridges 1
209	Ph. Rubin 4
209a	Ph. Harrington 6
210	Ph. Lackey 1
211	Skelly M. B. Armstrong 1
212	Skelly Armstrong 1
213	Gray Co. Prod. Herring 4
214	Gray Co. Prod. Herring 16
215	Adams Nevenheim 1
215a	Sham. Huff C–1
215b	Sham. Huff 1
216	Kermac. Brady 1
217	Ph. Fullingim 1
217a	Adams Heck 1
218	Ph. Julius 1
218a	Mag. Hardwick 1
219	Ph. Kin 1
219a	Ph. Hardwick 1
219b	Sham. Simmons B–1
220	Sham. Yonque 1
220a	Sham. Schlee A–1
221	Ph. Stallwitz 1
221a	Sham. Fred Smith 1
222	Ph. McDade 1
222a	Kermac. Anderson 1
223	Sham. Fuqua 4
223a	Nat. G.P.A. Powell 1–G
224	Ph. Harrison 1
225	Nat. G.P.A. Coon 14–M
226	Nat. G.P.A. Coon 13–M
227	Nat. G.P.A. Coon 9–M
227a	Ph. Taylor 1
228	Ph. Vent D–1
229	Nat. G.P.A. Taylor 2
229a	Ph. Vent E–2
230	Nat. G.P.A. Gober 1–SP
231	Ph. Vent A–1
232	Ph. Vent A–2
233	Ph. Matler 1
234	Ph. Gob 1
235	Sham. Phillips A–1
236	Nat. G.P.A. Lucky Tiger A–1
237	Sham. Phillips 1
238	Sham. Underwood B–1
239	Ph. Rubin 2
240	(*)
241	Ph. Rubin 3
242	Barnsdall Harrington 4
243	Skelly M.B. Armstrong 12
244	Ph. Katherine 2
245	Huber E. Herring 12
246	Pan. Prod. Herring 3
247	Pan. Prod. Herring 5
248	Skelly E. Herring A18
249	Ph. Adams Sones 1
249a	Ph. Adams Appling 1
250	Ph. Adams Kilgore 1
250a	Ph. Rachel 1
251	Kermac. Arie 1
252	Kermac. Phillips 1
253	Ph. Drury 1
254	Ph. Ellie 1
255	Ph. Thaten 1
256	Ph. Love 1
257	Ph. Dollie 1
258	Ph. Farbert 1
259	Sham. Coffee E–1
260	Sham. Crump 1
261	Sham. Hastie 1
262	Ph. Augusta 1
263	Sham. Ansley 1
264	Ph. Alda 1
265	Sham. Fuqua 1
266	Sham. Fuqua 3
267	Sham. Fuqua 2
268	Ph. Coon 1
269	Nat. G.P.A. Coon 28–M
270	Nat. G.P.A. Coon 24–M
271	Nat. G.P.A. Coon 22–M
272	Nat. G.L.A. Coon 10–M
273	Nat. G.P.A. Coon 12–M
274	Nat. G.P.A. Coon 3–M
275	Nat. G.P.A. Coon 25–M
276	Nat. G.P.A. Coon 30–M
277	Nat. G.P.A. Coon 19–M
278	Nat. G.P.A. Coon-Sneed 12–M
279	Nat. G.P.A. Coon-Sneed 8–M
280	Nat. G.P.A. Taylor 1–H
281	Nat. G.P.A. Coon-Sneed 6–M
282	Nat. G.P.A. Coon-Sneed 4–M
283	Ph. Vent B–1
284	Nat. G.P.A. Gober 2–SP
285	Nat. G.P.A. Gober 3–SP
286	Nat. G.P.A. Sneed 12
287	Sham. Sneed 20
288	Ph. Vent A–4
289	Ph. Gober 1
289a	Ph. Priscilla 1
290	Sham. Sneed 21
291	Ph. Zella A–1
292	Nat. G.P.A. Haile 1–M
293	Ph. Zella A–3
293a	Ph. Sneed H–1

TABLE 1.—*Wells shown on plate 1, listed numerically*—Continued

Map No.	*Company and name*
294	Nat. G.P.A. Haile 2–M
295	Ph. Sneed B–8
296	Sham. Stewart 1
297	Ph. Gunter 1
298	Sham. Kempson 1
299	Ph. Need 1
300	Ph. Need 2
301	Rubin Beard 1
302	Rubin Beard A–1
302a	Kermac. Sneed C–1
303	Skelly M.B. Armstrong 2
304	Skelly M.B. Armstrong 14
305	Ph. Katherine 1
306	Huber-Texas W.E. Herring 2
307	Pan. Prod. Herring 7
308	Huber W.E. Herring 7
309	Huber Hobbs-Allen 1
310	Skelly–A8
311	Adams Disbrow 1
312	Ph. Adams-Ford 1
313	Bayou Herbert 1
314	Bayou Smith 1
315	Ph. Marni 1
316	Ph. Ola 1
317	Ph. Stockman 1
318	Ph. Clements A–1
319	Kermac. Drucilla 1
320	Sham. Brown A–1
321	Ph. Sallie 1
322	Ph. Jameson 1
323	Ph. Champ 1
324	Ph. Colwell B
325	Phl Colwell C
326	Nat. G.P.A. Coon 20–M
327	Nat. G. P.A. Coon 2–M
328	Nat. G. P.A. Coon 31–M
329	Nat. G.P.A. Coon 1–M
330	Nat. G.P.A. Coon 18–M
331	Nat. G.P.A. Coon-Sneed 9–M
332	Nat. G.P.A. Coon-Sneed 1–M
332a	Nat. G.P.A. Coon-Sneed 5–M
333	Nat. G.P.A. Sneed 20
334	Nat. G.P.A Sneed 16–SN
335	Nat. G.P.A. Sneed 1
336	Nat. G.P.A. Sneed 1–P
337	Ph. Zella A–2
338	Ph. Zella A–4
339	Shell Kelly 1
339a	Ph. Sneed G–1
340	Pan. Oil Sneed 1
340a	Ph. Need 3
341	Pan Oil Sneed A–4
342	Pan. Oil Sneed A–1
343	Ph. James 2
344	Ph. James 1
345	Ph. James 4
346	Ph. Byrd 2
347	Ph. Byrd 3
348	Huber W. E. Herring 10
349	Huber-Texas W. E. Herring 1
350	Huber W. E. Herring 5
351	Huber W. E. Herring 5
352	Huber W. E. Herring 12
353	Ph. Bay 1
354	Ph. Hollye 1
355	Ph. McLaughlin 1
356	Ph. Emmett 1
357	Ph. Joanna 1
358	Ph. Modine 1
359	Ph. Althouse 1
360	Ph. Collins 1
361	Ph. Inez 1
362	Ph. French 1
363	Ph. Colson 1
364	Ph. Elise 1
365	Ph. Daught 1
366	Ph. Carver 1
367	Ph. Stencil 1
368	Sham. Brown 3
369	Sham. Brown 2
370	Sham. Brown A–2
371	Sham. Brown 1
372	Ph. Ingrid 1
373	Ph. Hurwitz 1
374	Sham. Brown 4
375	Ph. Finch 1
376	Ph. Mass 1
377	Ph. Weidling 1
378	Ph. Colwell A
379	Ph. Chloe 1
380	Ph. Japhet 1
381	Ph. Biffle 1
382	Ph. Marvin 1
383	Nat. G.P.A. Beauchamp 1–P
384	Nat. G.P.A. Coon 15–M
385	Nat. G.P.A. Coon 27–M
386	Nat. G.P.A. Coon 5–M
387	Nat. G.P.A. Coon 29–M
388	Nat. G.P.A. Coon 26–M
389	Nat. G.P.A. Coon 17–M
390	Nat. G.P.A. Coon 32–M
391	Nat. G.P.A. Coon 21–M
392	Nat. G.P.A. Coon 6–M
393	Nat. G.P.A. Coon 23–M
394	Nat. G.P.A. Coon-Sneed 11–M
395	Nat. G.P.A. Coon-Sneed 13–M
396	Nat. G.P.A. Jester 1–T
397	Nat. G.P.A. Coon-Sneed 7–M
398	Ph. Vent C–1
399	Nat. G.P.A. Coon-Sneed 10–M

TABLE 1.—*Wells shown on plate 1, listed numerically*—Continued

Map No.	*Company and name*
400	Nat. G.P.A. Sneed18–P
401	Nat. G.P.A. Sneed 7–P
402	Nat. G.P.A. Sneed 9–SN
403	Pan. E. Sneed 1–9
404	Pan. E. Sneed 1–26
405	Nat. G.P.A. Brown 2–G
406	Pan. E. Sneed 1
407	Nat. G.P.A. Brown 3–G
408	Pan. E. Bennett 1–22
408a	Ph. Zella A–5
409	Pan. E. Sneed 1–3
410	Ph. Zella A–6
411	Ph. Sneed B–5
412	Ph. Sneed B–6
412a	Ph. Sneed E–1
413	Ph. Sneed B–4
414	Ph. Zell 2
415	Ph. Zell 1
416	Ph. Zell 3
416a	Ph. Zell 4
416b	Rowland Humphries 1
417	Skelly M. B. Armstrong 11
417a	Ph. Duboise 1
418	Pan. Oil Jameson-Dubois 1
419	Ph. Byrd 1
420	Huber Reed 2
421	Huber Reed 1
422	Ph. Burnett 1
423	Skelly W. E. Herring 2
424	Huber W. E. Herring 3
425	Huber W. E. Herring 8
426	Huber W. E. Herring 4
427	Skelly W. E. Herring 5
428	Skelly W. E. Herring 3
429	Skelly Yake C–1
430	Skelly W. E. Herring 1
431	Huber W. E. Herring 2
432	Huber Prewitt 2
433	Huber-Mag. Herring 1
434	Huber-Mag. Herring 4
435	Ph. Constant 1
436	Ph. Petty 1
437	Ph. Bradie 1
438	Ph. Temple 1
439	Ph. Rena 1
440	Ph. Leslie 1
441	Ph. Eve 1
442	Ph. Tooker 1
443	Ph. Bissell 1
444	Ph. Dona 1
445	Ph. Sunray-Feltz 1
446	Ph. Teddy 1
447	Ph. Josie 1
448	Ph. Dumas 1
449	Ph. Tanner 1
450	Ph. Tarris 1
451	Ph. Bri 1
452	Ph. Vinson 1
453	Kermac. Estate 1
454	Ph. Dale 1
455	Ph. Fuqua B–1
456	Ph. See 1
456a	Ph. Arris 1
457	Ph. Greiner 1
458	Ph. Hibbard 1
459	Ph. Drib 1
460	Ph. Harbert 1
461	Ph. Massey 1
462	Ph. Harb 1
463	Ph. Blanche 1
464	Ph. Jennie 1
465	C. I. Bivins A–68
465a	Kermac. Terry A–1
466	Ph. Jen 1
467	Pan. E. Henneman 1–100
468	Pan. E. Purvin 1–69
469	Nat. G.P.A. Coon 16–M
470	(*)
471	Nat. G.P.A. Coon 7–M
472	Nat. G.P.A. Thompson 9–TH
473	Ph. Brent 3
474	(*)
475	Nat. G.P.A. Thompson 6–TH
476	Nat. G.P.A. Coon 4–M
477	Pan. E. Brown 1–104
478	Nat. G.P.A. Thompson 8–TH
479	Nat. G.P.A. Coon 11–M
480	Pan. E. Brown 1–64
481	Pan. E. Jester 1–18
482	Nat. G.P.A. Sneed 2–P
483	Nat. G.P.A. Coon-Sneed 3–M
484	Pan. E. Sneed 1–20
485	Nat. G.P.A. Coon-Sneed 2–M
486	Nat. G.P.A. Sneed 14–SN
487	Nat. G.P.A. Sneed 8–SN
488	Ph. Sneed C–9
489	Ph. Sneed C–7
490	Pan. E. Sneed 1–24
491	Pan. E. Walker 1–6
492	Pan. E. Sneed 1–25
493	Nat. G.P.A. Sneed D–2–SP
494	Pan. E. Walker 1–S
495	Nat. G.P.A. Sneed 30–P
495a	Nat. G.P.A. Sneed 1–P
496	Nat. G.P.A. Sneed 29–P
497	Nat. G.P.A. Sneed 28–P
498	Nat. G.P.A. Sneed 27–P
499	Nat. G.P.A. Sneed 21–P
499a	Nat. G.P.A. Sneed 25–P
500	Nat. G.P.A. Sneed 22–P

TABLE 1.—*Wells shown on plate 1, listed numerically*—Continued

Map No.	*Company and name*
500a	Ph. Huckaby 1
501	Ph. Sneed B-7
502	Ph. Snow 4
503	Ph. Ingerton C-1
504	Ph. Cattle 1
505	Ph. Ingerton B-1
506	Ph. Ingerton A-2
507	Skelly Yake A-1
508	Skelly Yake D-1
509	Skelly Yake B-1
510	Ph. Queen 1
511	Ph. Ina 4
512	Ph. Ina 2
513	Ph. Terry 1
513a	C.I. Bivins A-76
514	Ph. Ina 3
515	Ph. Ina 1
516	Ph. Ploner 1
517	Ph. Bissell 2
518	Ph. Balfour 5
519	Ph. Balfour 6
520	Ph. Balfour 4
521	Ph. Ames 1
522	Ph. Dudley A-1
523	Ph. Viola 1
524	Ph. Messenger 1
525	Ph. Klatt 1
526	Ph. Arnella 1
527	Ph. Barre 1
528	Sham. Brian 1
529	Ph. McFarlin 1
530	Ph. Worsley 1
531	Ph. Lantz 1
531a	Sham. Finley 1
531b	Kermac. Bergeson 1
532	Sham. Davidson 1
533	Ph. Elbert 1
534	Nat. G.P.A. Moore 3-P
535	Nat. G.P.A. Moore 2-M
536	Pan. E. Kilgore 1-56
537	Sham. Kilgore 1-28
538	Pan. E. Kilgore 1-29
539	Pan. E. Kilgore 1-57
540	C.I. Thompson B-4
540a	Kermac. Terry B-1
541	Nat. G.P.A. Thompson 7-TH
542	C.I. Thompson B-5
543	Nat. G.P.A. Thompson 3-TH
544	Pan. E. Thompson 1-25
545	Nat. G.P.A. Thompson 1-P
546	Nat. G.P.A. Thompson 4
547	Nat. G.P.A. Thompson 2-TH
548	Ph. Brent 1
549	Pan. E. Thompson 1-63
550	Pan. E. Brown 1-22
551	Pan. E. Brown 1-34
552	Nat. G.P.A. Sneed E-1-P
553	Pan. E. Sneed 1-33
554	Pan. E. Brown 1-36
555	Ph. Sneed A-2
556	Ph. Sneed A-1
557	Pan. E. Sneed 1-37
558	Nat. G.P.A. Sneed 17-SN
559	Nat. G.P.A. Sneed 6-P
560	Pan. E. Sneed 1-23-6T
561	Nat. G.P.A. Sneed 23-P
562	Ph. Sneed C-4
563	Ph. Sneed C-11
564	Ph. Sneed C-5
565	Pan. E. Sneed 1-28
566	Ph. Sneed C-8
567	C.I. Sneed D-1
568	Pan. E. Sneed 1-27
568a	Kermac. Sneed B-2
569	Nat. G.P.A. Sneed 13-P
570	Nat. G.P.A. Sneed 5-P
571	Nat. G.P.A. Sneed 24-P
572	Nat. G.P.A. Sneed 19-SN
573	Nat. G.P.A. Sneed 10-P
574	Nat. G.P.A. Sneed 26-P
574a	Ph. Sneed F-1
575	Ph. Polly 1
575a	Ph. Latin 1
576	Ph. Snow 6
577	Ph. Record 1
577a	Ph. Snow 3
577b	Ph. Snow 5
577c	Ph. Snow 2
578	Ph. Wild Bill 1
579	Ph. Snow 1
580	Ph. Williams 1
581	Ph. Evelyn 1
582	Ph. Ingerton A-1
583	Ph. Jay 1
584	Skelly Merchant 1
585	Henderson Merchant 4
585a	Ph. Merchant 2
586	Henderson Merchant 1
587	Ph. Yake 2
588	C.I. Bivins A-72
588a	C.I. Bivins A-90
588b	Ph. Bivins 1-GG
588c	Kermac. Berneta 4
588d	Kermac. Berneta 1
588e	Kermac. Berneta 2
588f	Kermac. Berneta 3
588g	C.I. Bivins A-93
589	C.I. Bivins A-63
589a	C.I. Bivins A-71
589b	C.I. Bivins A-9

TABLE 1.—*Wells shown on plate 1, listed numerically*—Continued

Map No.	*Company and name*
590	C.I. Bivins A–64
591	C.I. Bivins A–56
592	Ph. Balfour 1–286–F
593	Ph. Gordon 1
594	Ph. Balfour 8
594a	Ph. Balfour 7
595	Ph. Balfour 1–294–F
595a	C.I. Bivins A–62
596	Ph. Balfour 3
597	Ph. Dudley B–1
598	Ph. Dudley C–1
599	C.I. Bivins A–61
600	Kermac. Helt 286–G
601	Ph. Dudley D–1
602	Ph. Pink St.
603	Ph. McFarlin 2
604	Rubin Brown 2
605	Ph. Ezelle 1
606	Fowlton-Coke 1
607	Ph. Victor 1
608	C. I. Kilgore A–10
609	Nat. G.P.A. Kilgore 5–P
610	Pan. E. Kilgore 1–10
610a	C.I. Kilgore A–13
611	C.I. Kilgore A–5
612	C.I. Kilgore A–6
613	C.I. Kilgore A–12
614	Nat. G.P.A. Kilgore 3–G
615	Nat. G.P.A. Moore 1–P
616	C.I. Kilgore A–2
617	Pan E. Massay 1–15
618	Nat. G.P.A. Walters 1–PAR
619	Nat. G.P.A. Kilgore 2–G
620	Pan. E. Kilgore 1–16
621	Nat. G.P.A. Kilgore 4–G
622	Nat. G.P.A. Haas 1
623	C.I. Thompson B–2
624	Nat. G.P.A. Thompson 11–TH
625	C.I. Thompson B–8
626	Pan. E. Nield 1–18
627	Ph. Nield D–1
628	C.I. Thompson B–6
629	C.I. Thompson A–2
630	Ph. Brent 2
631	C.I. Thompson A–1
632	Nat. G.P.A. Thompson 5
633	C.I. Thompson A–3
633a	Nat. C.P.A. Thompson 10
634	C.I. Thompson A–4
635	Pan. E. Sneed 1–50
636	Ph. Sneed G–2
637	C.I. Sneed A–1
637a	C.I. Sneed A–4
638	Ph. Sneed C–10
639	Ph. Sneed C–6
640	Pan. E. Sneed 1–48
641	C.I. Sneed A–3
642	Ph. Sneed C–3
643	C.I. Sneed A–2
644	C.I. Sneed C–1
645	Pan. E. Zoffness 1–55
646	Pan. E. Sneed 1–45
647	Pan. E. Sneed 1–44
648	C.I. Read A–3
649	Pan. E. Sneed 1–43
650	C.I. Read A–1
651	Ph. Sneed B–1
652	Nat. G.P.A. Sneed 11–SN
653	C.I. Masterson A–7
654	Nat. G.P.A. Sneed 15–SN
655	Nat. G.P.A. Sneed 3–P
656	Nat. G.P.A. Sneed 2–P
657	Nat. G.P.A. Sneed 4–P
657a	Ph. Sneed B–3
658	Ph. Sneed B–2
658a	Ph. Sneed J–1
659	C.I. Bivins A–65
659a	C.I. Bivins A–94
659b	C.I. Bivins A–11
660	Ph. Balfour 2
661	C.I. Bivins A–58
662	C.I. Bivins A–8
663	C.I. Bivins A–22
664	C.I. Bivins A–34
664a	C.I. Bivins A–59
665	(*)
666	C.I. Bivins A–60
667	Ph. Helton 1
668	Rubin Brown 3
669	Ph. Gasser 1
670	Rubin Brown 4
671	Rubin Brown 1
672	Rubin Brown 5
673	Rubin Brown 6–B
674	Sham. Rubin-Brown 5–B
675	Ph. India 1
676	Nat. G.P.A. Kilgore 6–P
677	Pan. E. Kilgore 1–8
678	C.I. Kilgore A–4
679	C.I. Kilgore A–1
680	C.I. Kilgore A–3
681	Nat. G.P.A. Johnson 1–P
682	C.I. Luberstadt A–1
682a	Nat. G.P.A. Haas 2
682b	C.I. Thompson B–10
683	C.I. Thompson B–1
684	C.I. Thompson A–5
685	C.I. Thompson A–6
686	C.I. Sneed A–7
688	C.I. Sneed A–8

TABLE 1.—*Wells shown on plate 1, listed numerically*—Continued

Map No.	*Company and name*
689	C.I. Sneed B–1
690	C.I. Sneed B–2
690a	C.I. Sneed B–4
691	Pan. E. Zoffness 2–55
692	Ph. Sneed C–1
693	C.I. Read A–2
694	C.I. Read A–5
695	C.I. Masterson A–10
696	C.I. Fee A–1
697	R.R. Shelton A–3
698	R.R. Shelton A–5
699	R.R. Shelton A–6
699a	Nat. G.P.A. Lea 1
700	R.R. Shelton A–7
701	T.I.P.L. Bivins 1–633
702	C.I. Bivins B–2
702a	C.I. Bivins B–5
703	C.I. Bivins A–10
703a	C.I. Bivins A–97
703b	C.I. Bivins A–111
703c	C.I. Bivins A–78
703d	C.I. Bivins A–77
703e	C.I. Bivins A–89
703f	C.I. Bivins A–83
704	C.I. Bivins A–7
705	C.I. Bivins A–66
706	Rubin Brown 7–B
707	C.I. Bivins A–17
707a	C.I. Bivins A–82
708	C.I Bivins A–67
709	C.I. Bivins A–6
710	C.I. Bivins A–55
711	C.I. Bivins A–15
712	C.I. Kilgore A–7
713	C.I. Kilgore A–8
714	C.I. Kilgore A–9
714a	Burnett & Smith Kane 1
715	C.I. Bivins A–54
716	C.I. Baker A–1
717	C.I. Bivins A–37
718	C.I. Cooper A–1
719	C.I. Kilgore A–11
720	C.I. Kilgore B–1
721	C.I. Bivins A–24
722	C.I. Seay A–1
723	C.I. Crawford C–1
724	C.I. Bivins A–52
725	C.I. Crawford A–1
726	C.I. Bivins A–21
727	C.I. Crawford A–2
728	C.I. Masterson A–5
729	C.I. Thompson B–3
730	C.I. Thompson B–9
731	C.I. Masterson J–1
732	C.I. Thompson B–7
732a	C.I. Thompson C–1
733	C.I. Masterson A–14
734	C.I. Masterson A–6
735	C.I. Masterson A–15
736	C.I. Masterson A–22
737	C.I. Masterson A–16
738	C.I. Sneed A–5
739	C.I. Masterson G–3
740	(*)
741	Pan. E. Sneed 1–6
741a	C.I. Masterson A–18
742	C.I. Sneed A–6
743	C.I. Sneed B–3
744	C.I. Masterson M–3
745	C.I. Masterson M–1
746	C.I. Masterson M–2
747	C.I. Read A–4
748	C.I. Masterson A–21
749	Pan. E. Masterson 1–38
749a	C.I. Masterson B–30
750	C.I. Masterson B–18
751	C.I. Masterson B–15
752	C.I. Read A–6
753	C.I. Masterson A–20
754	C.I. Masterson A–4
755	C.I. Masterson A–17
756	C.I. Masterson A–12
757	C.I. Masterson B–2
758	C.I. Masterson A–3
759	C.I. Masterson A–1
760	C.I. Masterson A–11
761	C.I. Masterson A–2
762	C.I. Masterson B–1
763	C.I. Bivins A–29
764	C.I. Bivins J–1
765	R.R. Shelton A–2
766	R.R. Shelton A–1
767	R.R. Shelton A–4
768	C.I. Warrick A–3
769	C.I. Bivins H–1
770	C.I. Bivins G–1
771	North Nat. Bivins 1
772	C.I. Bivins I–1
773	C.I. Warrick A–2
774	T.I.P.L. Bost 1
775	R.R. Bivins Est. 1
776	C.I. Bivins B–6
777	C.I. Bost A–1
777a	C.I. Dunnaway A–1
777b	C.I. Dunnaway A–2
778	C.I. Bivins F–1
779	C.I. Bivins B–4
780	C.I. Bivins B–1
781	C.I. Bost C–1
781a	(*)

TABLE 1.—*Wells shown in plate 1, listed numerically*—Continued

Map No.	*Company and name*
781b	C.I. Dunnaway B–1
781c	C.I. Bost B–1
782	C.I. Johnson A–1
782a	Nat. G.P.A. Johnson 1
783	C.I. Bivins A–36
783a	C.I. Bivins A–92
783b	C.I. Bivins A–91
783c	C.I. Bivins A–98
783d	C.I. Bivins A–109
783e	C.I. Bivins A–26
783f	C.I. Bivins A–106
783g	C.I. Bivins A–104
783h	C.I. Bivins A–103
783i	C.I. Bivins A–99
783j	C.I. Bivins A–100
784	C.I. Bivins A–35
785	C.I. Bivins A–33
785a	C.I. Bivins A–101
785b	C.I. Bivins A–102
785c	C.I. Bivins A–105
785d	C.I. Bivins A–95
786	C.I. Bivins A–5
787	C.I. Bivins A–14
788	C.I. Bivins E–1
789	C.I. Bivins A–48
790	C.I. Bivins A–4
791	C.I. Bivins A–32
792	C.I. Bivins A–31
793	C.I. Bivins A–2
793a	C.I. Bivins A–27
794	C.I. Bivins A–43
795	C.I. Bivins A–25
796	C.I. Coughlin A–1
797	C.I. Masterson A–13
798	C.I. Crawford B–1
799	C.I. Masterson B–17
799a	C.I. Masterson B–21
800	C.I. Masterson B–16
800a	C.I. Masterson B–22
800b	C.I. Masterson B–7
800c	C.I. Masterson B–45
800d	C.I. Masterson B–40
801	C.I. Masterson K–1
801a	C.I. Masterson G–5
802	C.I. Masterson B–8
803	C.I. Masterson B–10
804	C.I. Masterson B–9
804a	C.I. Masterson B–41
804b	T.I.P.L. Masterson 1–606
805	C.I. Masterson B–19
805a	C.I. Masterson A–9
806	T.I.P.L. Masterson 1–587
807	C.I. Masterson B–20
808	C.I. Masterson B–13
809	C.I. Masterson B–3
810	C.I. Masterson B–12
811	C.I. Masterson B–11
812	T.I.P.L. McBride 100
813	C.I. Bivins A–45
813a	(*)
814	C.I. Bivins A–42
815	C.I. Bivins A–44
816	C.I. Allison A–1
817	C.I. Warrick A–1
817a	C.I. Warrick A–4
818	C.I. Bivins A–39
819	R.R. Bivins A–1
819a	C.I. Bivins B–3
820	Navajo Poling 2
820a	Navajo Poling 1
821	C.I. Poling A–1
821a	C.I. Bost C–2
822	C.I. Bost D–1
823	(*)
824	(*)
825	C.I. Bivins A–50
825a	C.I. Bivins A–88
825*b*	C.I. Bivins A–107
825*c*	C.I. Bivins A–108
825d	C.I. Bivins A–129
826	C.I. Bivins A–38
827	C.I. Bivins A–70
827a	C.I. Bivins A–96
828	C.I. Masterson A–19
829	C.I. Crawford D–2
830	C.I. Crawford B–2
831	C.I.Masterson G–4
832	C.I. Masterson B–61
833	C.I. Masterson E–2
834	C.I. Masterson C–1
835	C.I. Masterson C–3
835a	C.I. Masterson B–4
836	C.I. Masterson J–2
837	C.I. Masterson B–5
837a	C.I. Masterson B–42
838	C.I. Masterson B–14
839	T.I.P.L. McBride 1
840	Pan. E. McBride 1
841	T.I.P.L. Rockwell 1
842	C.I. Bivins A–47
843	C.I. Bivins D–3
843a	C.I. Bivins A–46
844	C.I. Bivins A–40
845	(*)
846	C.I. Bivins A–16
847	R.R. Bivins B–1
848	R.R. Bivins A–7–728
849	R.R. Bivins A–2
850	R.R. Bivins A–3
851	R.R. Bivins A–4

TABLE 1.—*Wells shown on plate 1, listed numerically*—Continued

Map No.	*Company and name*
852	R.R. Poling 3
853	R.R. Poling 4
853a	R.R. Deahl A–1
853b	R.R. Bennett A–1
854	(*)
855	(*)
856	(*)
857	(*)
858	C.I. Sanford A–3
858a	C.I. Sanford A–4
858b	C.I. Sanford A–5
859	C.I. Sanford A–1
860	C.I.Bivins A–69
860a	C.I. Bivins A–13
860b	C.I. Bivins A–110
860c	C.I. Masterson A–23
860d	C.I. Masterson J–4
860e	C.I. Bivins A–128
860f	C.I. Masterson A–25
861	C.I. Bradley A–1
861a	C.I. Masterson J–3
862	C.I. Crawford D–1
862a	C.I. Masterson B–44
862b	C.I. Masterson J–5
862c	C.I. Masterson A–24
862d	White and Parks
863	C.I. Masterson D–4
863a	C.I. Masterson B–38
864	C.I. Masterson B–24
865	C.I. Masterson B–23
866	C.I. Masterson B–25
867	T.I.P.L. Bivins 1-540
868	C.I. Bivins A–49
869	C.I. Bivins C–4
870	C.I. Bivins A–51
871	C.I. Bivins A–18
872	C.I. Bivins A–41
873	C.I. Bivins A–3
874	C.I. Bivins A–19
875	C.I. Bivins A–20
875a	R.R. Bivins A–7
876	R.R. Bivins A–6
877	R.R. Bivins A–5
878	Cit. Serv. Poling 1
879	R.R. Deahl B–1
880	R.R. Deahl B–2
881	(*)
882	(*)
883	(*)
884	(*)
885	(*)
886	C.I. Masterson G–2
886a	C.I. Masterson B–39
887	C.I. Masterson H–1
887a	C.I. Masterson B–36
888	C.I. Masterson I–1
888a	C.I. Masterson B–35
889	(*)
890	C.I. Masterson B–6
890a	C.I. Masterson B–33
891	C.I. Masterson F–1
891a	C.I. Masterson B–34
892	C.I. Masterson L–1
893	C.I. Masterson N–1
893a	C.I. Masterson B–31
893b	C.I. Masterson B–32
893c	C.I. Masterson B–37
894	C.I. Masterson B–28
895	C.I. Masterson B–29
895a	C.I. Masterson B–55
896	C.I. Masterson B–27
897	C.I. Masterson B–26
898	C.I. Bivins C–1
899	C.I. Bivins A–53
900	C.I. Bivins A–74
901	C.I. Bivins A–79
902	C.I. Bivins A–80
902a	C.I. Bivins A–84
902b	C.I. Bivins A–85
902c	C.I. Bivins A–87
903	C.I. Bivins A–81
903a	C.I. Bivins A–86
904	C.I. Bivins A–23
905	C.I. Bivins A–57
905a	C.I. Bivins A–73
905b	C.I. Bivins A–75

TABLE 2.—*Wells shown on plate 1, listed alphabetically by company and name*

Company and well	*Number (pl. 1)*
Adams, K. S., Jr., Co.:	
Disbrow 1	311
Heck 1	217a
Love 1	175f
Nevenheim 1	215
Pool 1	175e
Barnsdall Oil Co.:	
Harrington 4	242
Bayou Gas Co.:	
Herbert 1	313
Smith 1	314
Burnett & Smith Co.:	
Kane 1	714a
Cities Service Co.:	
Poling 1	878
Colorado Interstate Gas Co.:	
Allison A–1	816
Baker A–1	716
Bivins A–2	793
A–3	873
A–4	790
A–5	786
A–6	709
A–7	704
A–8	662
A–9	589b
A–10	703
A–11	659a
A–13	860a
A–14	787
A–15	711
A–16	846
A–17	707
A–18	871
A–19	874
A–20	875
A–21	726
A–22	663
A–23	904
A–24	721
A–25	795
A–26	783e
A–27	793a
A–29	763
A–31	792
A–32	791
A–33	785
A–34	664
A–35	784
A–36	783
A–37	717
A–38	826
A–39	818
A–40	844
A–41	872
A–42	814
A–43	794
A–44	815
A–45	813
Colorado Interstate Gas Co.—Continued	
Bivins—Continued	
A–46	843a
A–47	842
A–48	789
A–49	868
A–50	825
A–51	870
A–52	724
A–53	899
A–54	715
A–55	710
A–56	591
A–57	905
A–58	661
A–59	664a
A–60	666
A–61	599
A–62	595a
A–63	589
A–64	590
A–65	659
A–66	705
A–67	708
A–68	465
A–69	860
A–70	827
A–71	589a
A–72	588
A–73	905a
A–74	900
A–75	905b
A–76	513a
A–77	703d
A–78	703c
A–79	901
A–80	902
A–81	903
A–82	707a
A–83	703f
A–84	902a
A–85	902b
A–86	903a
A–87	902c
A–88	825a
A–89	703e
A–90	588a
A–91	783b
A–92	783a
A–93	588g
A–94	659a
A–95	785d
A–96	827a
A–97	703a
A–98	783c
A–99	783i
A–100	783j
A–101	785a
A–102	785b

TABLE 2.—*Wells shown on plate 1, listed alphabetically by company and name*—Continued

Company and well	*Number (pl. 1)*
Colorado Interstate Gas Co.—Continued	
Bivins—Continued	
A–103	783h
A–104	783g
A–105	785c
A–106	783f
A–107	825b
A–108	825c
A–109	783d
A–110	860b
A–111	703b
A–128	860e
A–129	825d
B–1	780
B–2	702
B–3	819a
B–4	779
B–5	702a
B–6	776
C–1	898
C–4	869
D–3	843
E–1	788
F–1	778
G–1	770
H–1	769
I–1	772
J–1	764
Bost A–1	777
B–1	781c
C–1	781
C–2	821a
D–1	822
Bradley A–1	861
Cooper A–1	718
Coughlin A–1	796
Crawford A–1	725
A–2	727
B–1	798
B–2	830
C–1	723
D–1	862
D–2	829
Dunnaway A–1	777a
A–2	777b
B–1	781b
Fee A–1	696
Johnson A–1	782
Kilgore A–1	679
A–2	616
A–3	680
A–4	678
A–5	611
A–6	612
A–7	712
A–8	713
A–9	714
A–10	608
A–11	719
Colorado Interstate Gas Co.—Continued	
Kilgore—Continued	
A–12	613
A–13	610a
B–1	720
Luberstadt A–1	682
Masterson A–1	759
A–2	761
A–3	758
A–4	754
A–5	728
A–6	734
A–7	653
A–9	805a
A–10	695
A–11	760
A–12	756
A–13	797
A–14	733
A–15	735
A–16	737
A–17	755
A–18	741a
A–19	828
A–20	753
A–21	748
A–22	736
A–23	860c
A–24	862c
A–25	860f
B–1	762
B–2	757
B–3	809
B–4	835a
B–5	837
B–6	890
B–7	800b
B–8	802
B–9	804
B–10	803
B–11	811
B–12	810
B–13	808
B–14	838
B–15	751
B–16	800
B–17	799
B–18	750
B–19	805
B–20	807
B–21	799a
B–22	800a
B–23	865
B–24	864
B–25	866
B–26	897
B–27	896
B–28	894
B–29	895

TABLE 2.—*Wells shown on plate 1, listed alphabetically by company and name*—Continued

Company and well	*Number (pl. 1)*
Colorado Interstate Gas Co.—Continued	
Masterson—Con.	
B-30	749a
B-31	893a
B-32	893b
B-33	890a
B-34	891a
B-35	888a
B-36	887a
B-37	893c
B-38	863a
B-39	886a
B-40	800d
B-41	804a
B-42	837a
B-44	862a
B-45	800c
B-55	895a
B-61	832
C-1	834
C-3	835
D-4	863
E-2	833
F-1	891
G-2	886
G-3	739
G-4	831
G-5	801a
H-1	887
I-1	888
J-1	731
J-2	836
J-3	861a
J-4	860d
J-5	862b
K-1	801
L-1	892
M-1	745
M-2	746
M-3	744
N-1	893
Poling A-1	821
Read A-1	650
A-2	693
A-3	648
A-4	747
A-5	694
A-6	752
Sanford A-1	859
A-3	858
A-4	858a
A-5	858b
Seay A-1	722
Sneed A-1	637
A-2	643
A-3	641
A-4	637a
A-5	738
Colorado Interstate Gas Co.—Continued	
Sneed—Continued	
A-6	742
A-7	686
A-8	688
B-1	689
B-2	690
B-3	743
B-4	690a
C-1	644
C-3	642
D-1	567
Thompson A-1	631
A-2	629
A-3	633
A-4	634
A-5	684
A-6	685
B-1	683
B-2	623
B-3	729
B-4	540
B-5	542
B-6	628
B-7	732
B-8	625
B-9	730
B-10	682b
C-1	732a
Warrick A-1	817
A-2	773
A-3	768
A-4	817a
Continental Oil Co.:	
Armstrong	205
Armstrong 1	188
Arnis 1	98
Bricker 1	207
Brown 1	46
Burnett 1	115
Bush 1	68
Carver, H. W., 1	135
6	136
Carver, W. A., 1	157
Jones A-1	119
B-1	62
McDowell 1	65
Marsh 1	100
Meier 1	102
Shellberg 1	190
Spurlock 1	134
Wells 1	52a
Fowlton Co.:	
Coke 1	606
Gray County Producing Co.:	
Herring 4	213
16	214

TABLE 2.—*Wells shown on plate 1, listed alphabetically by company and name*—Continued

Company and well	*Number (pl. 1)*
Henderson, E. C., Co.:	
Merchant 1	586
4	585
Huber Corp.:	
1	109
3	111
12	110
B-1	133
B-4	82
Henderson 1	83
Herring, E., 1	193
12	245
Herring, W. E., 2	431
3	424
4	426
5	350
5	351
7	308
8	425
10	348
12	352
Hobbs-Allen 1	309
Huber-Mag.	
Herring 1	433
4	434
Huber Russell	
Fuller 1	5b
Huber-Texas W. E.:	
Herring 1	349
2	306
Owens 1	172
Prewitt 2	432
Reed 1	421
2	420
Kerr-McGee Oil Industries, Inc.:	
Anderson 1	222a
Arie 1	251
Avery 1	89
Bergeson 1	531b
Brady 1	216
Berneta 1	588d
2	588e
3	588f
4	588c
Breyfogle 1	160
Bridges 1	189
Burnett 1	86
Creed 1	5
Donaldson, A., 1	72
Donaldson 1	52
Drucilla 1	319
Elgin 1	1d
Estate 1	453
Flynn 1	36
Helt 286-G	600
Humphries 1	11a
Jacobson 1	120
Jones A-1	44
M-1	142
Kerr-McGee Oil Industries, Inc.—Con.	
Jones—Continued	
G-1-A	118
McDowell 1	92
2	64
Morton 2	129
3	101
4	130
Phillips 1	252
Reeves 1	1e
Schroeter 1	1c
Sneed B-2	568a
C-1	302a
Strunk 1	139
Sullivan 1	138
Taylor A-1	145
A-2	167a
C-1	166
Terry A-1	465a
B-1	540a
Wilbar 2	150
3	169
Wilson A-1	125
Zoeber 1	1b
Magnolia Petroleum Co.:	
Britian 1	29
2	30
3	48
4	49
5	28
6	47
7	96
8	66
Hardwich 1	218a
Herndon 1	146
Miller 1	9
Nelson 1	126
Thompson 1	22b
Natural Gas Pipeline Co. of America:	
Beauchamp 1-P	383
Brown 2-G	405
3-G	407
Coon 1-M	329
2-M	327
3-M	274
4-M	476
5-M	386
6-M	392
7-M	471
9-M	227
10-M	272
11-M	479
12-M	273
13-M	226
14-M	225
15-M	384
16-M	469
17-M	389

TABLE 2.—*Wells shown on plate 1, listed alphabetically by company and name*—Continued

Company and well	*Number (pl. 1)*
Natural Gas Pipeline Co. of America—Con.	
Coon—Continued	
18–M	330
19–M	277
20–M	326
21–M	391
22–M	271
23–M	393
24–M	270
25–M	275
26–M	388
27–M	385
28–M	269
29–M	387
30–M	276
31–M	328
32–M	390
Coon-Sneed 1–M	332
2–M	485
3–M	483
4–M	282
5–M	332a
6–M	281
7–M	397
8–M	279
9–M	331
10–M	399
11–M	394
12–M	278
13–M	395
Dore 1–G	137b
Foster 1–S	180
2–FO	181
Gober 1–SP	230
2–SP	284
3–SP	285
Haas 1	622
2	682a
Haile 1–M	292
2–M	294
Jester 1–T	396
Johnson 1–P	681
1	782a
Kilgore 2–G	619
3–G	614
4–G	621
5–P	609
6–P	676
LaSalle 1	176
Lea 1	699a
Lucky Tiger A–1	236
Moore 1–P	615
2–M	535
3–P	534
Powell 1–G	223a
Pythian 1–P	139a
Schlee 1	177
Sneed 1 Poitevent Survey	335
Natural Gas Pipeline Co. of America—Con.	
Sneed 1–P T&NO Survey	336
1–P Jones Survey	495a
2–P D&P Survey	656
2–P G&M Survey	482
3–P	655
4–P	657
5–P	570
6–P	559
7–P	401
8–SN	487
9–SN	402
10–P	573
11–SN	652
12	286
13–P	569
14–SN	486
15–SN	654
16–SN	334
17–SN	558
18–P	400
19–SN	572
20	333
21–P	499
22–P	500
23–P	561
24–P	571
25–P	499a
26–P	574
27–P	498
28–P	497
29–P	496
30–P	495
E–1–P	552
D–2–SP	493
Taylor 1–G	199
1–H	280
1–P	185
2	229
3–G	198
Texas C–1	79
Thompson 1–P	545
2–TH	547
3–TH	543
4	546
5	632
6–TH	475
7–TH	541
8–TH	478
9–TH	472
10	633a
11–TH	624
Troutman 1–SP	179
Walters 1–PAR	618
Williams 1–T	195

TABLE 2.—*Wells shown on plate 1, listed alphabetically by company and name*—Continued

Company and well	*Number (pl. 1)*
Navajo Co.:	
Poling 1	820a
2	820
Northern Natural Gas Co.:	
Bivins 1	771
Panhandle Eastern Pipe Line Co.:	
Bennett 1–22	408
Brown 1–22	550
1–34	551
1–36	554
1–64	480
1–104	477
Hanneman 1–100	467
Jester 1–18	481
Kilgore 1–8	677
1–10	610
1–16	620
1–29	538
1–56	536
1–57	539
McBride 1	840
Massay 1–15	617
Masterson 1–38	749
Nield 1–18	626
Purvin 1–69	468
Sneed 1–3	409
1–6	741
1–9	403
1–20	484
1–23JP	406
1–23–6T	560
1–24	490
1–25	492
1–26	404
1–27	568
1–28	565
1–43	649
1–44	647
1–45	646
1–48	640
1–50	635
Sneed, A. R., 1–33	553
1–37	557
Thompson 1–25	544
1–63	549
Walker 1–6	491
1–S	494
Zoffness 1–55	645
2–55	691
Panhandle Oil Co.:	
Jameson-DuBois 1	418
Sneed 1	340
A–1	342
A–4	341
Panhandle Production Co.:	
Herring 3	246
5	247
Panhandle Production Co.—Continued	
Herring—Continued	
7	307
LaSater 1	192
Phillips-Kerr-McGee Co.:	
Donaldson 1	50
McDowell C–1	19
C–2	19a
Wells 1	16
Phillips Petroleum Co.:	
Ada May 1	107
Adams, K. S., Jr.:	
Appling 1	249a
Ford 1	312
Kilgore 1	250
Sones 1	249
Albert 1	43a
Alda 1	264
Althouse 1	359
Ames 1	521
Armi 1	167
Arnella 1	526
Arris 1	456a
Augusta 1	262
Balfield 1	171
Balfour 1–286–F	592
1–294–F	595
2	660
3	596
4	520
5	518
6	519
7	594a
8	594
Barre 1	527
Bay 1	353
Beraw 1	2
Biffe 1	381
Bissell 1	443
2	517
Bivins 1–GG	588b
Blanche 1	463
Booker 1	141
Box 1	17a
Bradie 1	437
Brent 1	548
2	630
3	473
Bri 1	451
Bridges 1	208
Britain 1	97
Brumley 1	39
Burnett 1	422
Burrus 1	198a
Bush 1	67
Butler 1	13a
Byrd 1	419
2	346

TABLE 2.—*Wells shown on plate 1, listed alphabetically by company and name*—Continued

Company and well	*Number (pl. 1)*
Phillips Petroleum Co.—Continued	
Byrd—Continued	
3	347
Cardiff 1	186
Carver 1	366
Castleman A-1	131
B-1	104
Cattle 1	504
Champ 1	323
Chloe 1	379
Clarence 1	114
Clark Gable 1	85
Claudine 1	113
Clements A-1	318
Cloby 1	6
Coffee 1	84
Collins 1	360
Colson 1	363
Colwell A	378
B	324
C	325
Constant 1	435
Coon 1	268
Daisy 1	193a
Dale 1	454
Daught 1	365
Della 1	175b
Dollie 1	257
Dona 1	444
Donaldson 1	31
Donelson 1	71
Drib 1	459
Drury 1	253
Duboise 1	417a
Dudley A-1	522
B-1	597
C-1	598
D-1	601
Dumas 1	448
Ebling 1	38a
12	38
Elbert 1	533
Elise 1	364
Ellie 1	254
Emily Nell 1	137c
Emmett 1	356
Estate 1	19c
Ethelyn 1	178
Eve 1	441
Evelyn 1	581
Ezelle 1	605
Farbert 1	258
Faye 1	84d
Fields 1	187a
Finch 1	375
Flynn 1	73
French 1	362
Fuller 1	5b
Fullingim 1	217
Phillips Petroleum Co.—Continued	
Fuqua B-1	455
Gasser 1	669
Gearhart 1	159d
Glass 1	32
Gob 1	234
Gober 1	289
Gordon 1	593
Greiner 1	457
Guleke 1	53
Gunter 1	297
Hagaman 1	204
Harb 1	462
Harbert 1	460
Hardwick 1	219a
Harrington 6	209a
Harrison 1	224
Helton 1	667
Hibbard 1	458
Hinkle 1	182
Hollye 1	354
Hub 1	90
Huckaby 1	500a
Hurwitz 1	373
Ingerton C-1	503
Ina 1	515
2	512
3	514
4	511
India 1	675
Inez 1	361
Ingerton A-1	582
A-2	506
B-1	505
C-1	503
Ingrid 1	372
James 1	344
2	343
4	345
Jameson 1	322
Japhet 1	380
Jay 1	583
Jen 1	466
Jennie 1	464
Joanna 1	357
Jones 1	61a
A-1	27b
A-2	27a
A-3	26a
Josie 1	447
Jover 1	1
Julius 1	218
Kane 1	112d
Katherine 1	305
2	244
Kell 1	183
Kelly 1	34
Kin 1	219
Kinney 1	154
Phillips Petroleum Co.—Continued	
Klatt 1	525
Knapp 1	175
Lackey 1	210
Lantz 1	531
Latin 1	575a
Laughter 1	20b
Ledlow 1	153
Leslie 1	440
Longmack 1	203
Lore 1	184
Love 1	256
Lucas 1	57
4	56
McDade 1	222
McDowell 1	37
McDowell, O. E., 1	121
McFarlin 1	529
2	529
McLaughlin 1	355
Malcolm 1	206
Marguerite Ann 1	94
Marni 1	315
Marsh 1	114a
Marvin 1	382
Mass 1	376
Massey 1	461
Matler 1	233
Melvin 1	137a
Merchant 2	585a
Messenger 1	524
Mills 1	14
Modine 1	358
Moore '66' 1	25
3	26
Need 1	299
2	300
3	340a
Nelson 1	127
Nield D-1	627
Nunley 1	69
Ochsner 1	159b
O'Hearn 1	159a
Ola 1	316
Ozark 1	63
Petty 1	436
Pink St. 1	602
Pittman 1	18
Ploner 1	516
Polly 1	575
Powell 1	75
Preston 1	187
Priscilla 1	289a
Purdy 1	27
Queen 1	510
Rachel 1	250a
Ray 1	194
Record 1	577
Reeder 1	60
Phillips Petroleum Co.—Continued	
Reeder—Continued	
2	61
Rena 1	439
Reuter 1	99
Richard A-1	44a
Rorex 1	197
Rubin 2	239
3	241
4	209
Sallie 1	321
See 1	456
Shelton 1	175a
Sneed A-1	556
A-2	555
B-1	651
B-2	658
B-3	657a
B-4	413
B-5	411
B-6	412
B-7	501
B-8	295
C-1	692
C-3	642
C-4	562
C-5	564
C-6	639
C-7	489
C-8	566
C-9	488
C-10	638
C-11	563
E-1	412a
F-1	574a
G-1	339a
G-2	636
H-1	293a
J-1	658a
Snow 1	579
2	577c
3	577a
4	502
5	577b
6	576
Spur 1	106
Spurlock 1	132
Stallwitz 1	221
Stan 1	196
Stanhope 1	168
Stem 1	202
Stencil 1	367
Stigall	159c
Stocking 1	1a
Stockman 1	317
Sturdy 1	116
Sunray A-2	26b
Sunray-Feltz 1	445
Sunray-Jones 1	88

TABLE 2.—*Wells shown on plate 1, listed alphabetically by company and name*—Continued

Company and well	*Number (pl. 1)*
Phillips Petroleum Co.—Continued	
Tanner 1	449
Tarris 1	450
Taylor 1	227a
Teddy 1	446
Temple 1	438
Terry 1	513
Texas 1	87
Thaten 1	255
Tooker 1	442
Twill 1	191
Utey 1	5a
Vanta 1	159
Venable 1	103
Vent A-1	231
A-2	232
A-4	288
B-1	283
C-1	398
D-1	228
E-1	200
E-2	229a
Victor 1	607
Vinson 1	452
Viola 1	523
Ward 1	112c
Way 1	8a
Weidling 1	377
Wild Bill 1	578
Williams 1	580
Wilson 2	35
Winn 1	147
Witherbee 1	3
Worsley 1	530
Yake 2	587
Zell 1	415
2	414
3	416
4	416a
Zella A-1	291
A-2	337
A-3	293
A-4	338
A-5	408a
A-6	410
Zoeber 1	3a
Bennett A-1	853b
Bivins A-1	819
A-2	849
A-3	850
A-4	851
A-5	877
A-6	876
A-7	875a
A-7-728	848
B-1	847
Est. 1	775
Deahl A-1	853a
B-1	879
Phillips Petroleum Co.—Continued	
Deahl—Continued	
B-2	880
Poling 3	852
4	853
Shelton A-1	766
A-2	765
A-3	697
A-4	767
A-5	698
A-6	699
A-7	700
Rowland, A. H., Co.:	
Humphries 1	416b
Rubin, Dave, Oil Properties:	
Barnhill 3	77
28	78
Beard 1	301
A-1	302
Brown 1	671
2	604
3	668
4	670
5	672
6-B	673
7-B	706
Carver 1	76
Shamrock Oil and Gas Co.:	
Allen 1	58f
Anderson 1	22d
Ansley 1	263
Atcheson 1	20e
Bates 1	159f
Becker 1	122
Breesford 1	22a
Brian 1	528
Brown 1	371
2	369
3	368
4	374
A-1	320
A-2	370
Brumley 2	58c
3	40
A-1	40a
Brumley-Golf 1	41
Brumley Ryan 1	41b
Brumley Sunset 1	58d
Burnett 1	58a
et al 1	58b
Coffee 1	164
A-1	84a
E-1	259
Cox 1	144
Crump 1	260
Davidson 1	532
Dore 1	112
Finley 1	531a

TABLE 2.—*Wells shown on plate 1, listed alphabetically by company and name*—Continued

Company and well	*Number (pl. 1)*
Shamrock Oil and Gas Co.—Continued	
Fowlston 1	162
Fuqua 1	265
2	267
3	266
4	223
Gearhart 1	84e
Geary 1	161
Hastie 1	261
Hatcher-Crosby 1	158
Hight 1	84b
Householder 1	112a
Huff 1	215b
C-1	215a
Johnson 1	40d
B-1	22c
C-1	20d
Jones	140
1	24
A-1	41d
B-1	42
C-1	43
Jones-Ryan 1	60a
Kelly 1	163
Kempson 1	298
Kilgore 1-28	537
Logan 1	56b
"A"	56a
Luckhard 1	84c
McDade 1	137d
2	112g
3	137e
McDowell 1	54
McKee C-1	41a
McKeig 1	112e
Meinhardt 1	143
Mercer 1	112f
Miller 1	4a
Myers 1	20a
Olsson, M., 1	124
Perky 1	20c
Phillips 1	237
A-1	235
Powell 1	58
C-1	40e
Powell-Magnolia 1	58g
Pritchard 1	80
Read E-1	4
Robertson B-4	25a
C-1	23a
C-2	23
C-3	20
C-4	22
D-2	24a
D-3	10
E-1	21
Rubert 1	59
Rubin-Brown 5-B	674
Schlee 1	137
Shamrock Oil and Gas Co.—Continued	
Schlee—Continued	
A-1	220a
Sharkey 1	45
Simmons B-1	219b
Smith, Dale, 1	175c
Smith, Frank, 1	159e
Smith, Fred, 1	221a
Smith, Mary, 1	165
Sneed 20	287
21	290
Stewart 1	296
10	38b
Tays 1	40c
Thaten 1	159g
Underwood B-1	238
Van Order 1	159h
Ward, J. F., 1	112b
Wilson	95
Yonque 1	220
Young 1	175d
Zella 1	201
Zwack 1	123
Shell Oil, Inc.:	
Kelly 1	339
Lucas 1	55
Shell-Sinclair Co.:	
Bartlett 1	33
Catlett 1	152
Dash 1	15
Donaldson A-1	51
Donelson 1	70a
B-1	70
Flynn 1	7
Guleke 1	74
Hill 1	40b
Hohman 1	151
Jones 1	41c
9-1	117
Kraker 1	12
Lindsey 1	149
Longanbecker 1	13
McDowell B-1	91
Miller 1	17
Miller A-1	11
Munson 2	173
Russell 1	8
Wilbar 1	170
Wilson 1	128
Sinclair Oil Corp.:	
McDowell 1	19b
Phillips A-1	3b
Skelly Oil Co.:	
Armstrong 1	212
Armstrong, M. B., 1	211
2	303
11	417
12	243
14	304

TABLE 2.—*Wells shown on plate 1, listed alphabetically by company and name*—Continued

Company and well	*Number (pl. 1)*
Skelly Oil Co.—Con.	
Herring A-8	310
A-18	248
Herring, W. E., 1	430
2	423
3	428
5	427
Merchant 1	584
Yake A-1	507
B-1	509
C-1	429
D-1	508
Texas Interstate Pipeline Co.:	
Bivins 1-540	867
1-633	701
Bost 1	774
McBride 1	839
100	812
Masterson 1-587	806
1-606	804b
Rockwell 1	841
White and Parks Co.	862d
Whittenburg Co.:	
1	81
B-3	108

Uraniferous asphaltite is sparsely disseminated throughout the cap rocks and, in places, occurs within the reservoir rocks of the field. Analyses of this material show that it contains from about 0.2 to 5 percent uranium. The discovery of the uraniferous asphaltite presented the problems of evaluating the processes that resulted in its formation and of determining the source of the uranium and other metals that have been concentrated in the asphaltite. The concentration and distribution of uranium and other metals, therefore, were investigated in the reservoir rocks, asphaltite, residual petroleum, crude oils, and brines.

ACKNOWLEDGMENTS

The investigation was made by the U.S. Geological Survey on behalf of the U.S. Atomic Energy Commission.

The writers wish to acknowledge the cooperation of the following companies: Colorado Interstate Gas Co., Phillips Petroleum Co., Kerr-McGee Oil Industries, Inc., Natural Gas Pipeline Co. of America, Shamrock Oil and Gas Corp., Panhandle Eastern Pipe Line Co., Continental Oil Co., Shell Oil Co., Standard Oil and Gas Co., Skelly Oil Co., Texas Co., Red River Oil Co., Dave Rubin Oil Properties, Nabob Production Co., Cities Service Oil Co., Gray County Producing Co., Magnolia Petroleum Co., Northern Natural Gas Co., Panhandle Oil Co., and the Sinclair Oil Corp.

The writers are particularly indebted to B. B. Morgan, G. H. Tomlinson, H. S. Carver, and R. Rogers of the Colorado Interstate Gas Co.; R. K. Lanyon and H. B. Bishop of the Phillips Petroleum Co.; O. C. Barton of Kerr-McGee Oil Industries, Inc.; and G. Galloup of Natural Gas Pipeline Co. of America, whose time and assistance are greatly appreciated. They also wish to express their gratitude to H. Neal Dunning, E. M. Frost, G. B. Shelton, C. W. Seibel, C. C. Anderson, W. M. Deaton, and other members of the U.S. Bureau of Mines for their interest and invaluable help.

Special recognition is due the following members of the U.S. Geological Survey for their contributions to this investigation: C. Albert Horr, for the chemical analyses; A. Tennyson Myers and Pauline J. Dunton, for the spectrographic analyses; John N. Rosholt, Jr., and Sylvia Furman, for the radiometric determinations; A. J. Gude 3d and William F. Outerbridge, for the X-ray crystallographic determinations; and to A. Y. Sakakura, for discussions of the source of radon in the natural gas.

GEOLOGY OF THE WESTERN PART OF THE PANHANDLE FIELD

The dominant structural feature of the Panhandle field is the Amarillo-Wichita uplift, a northwest-trending geanticline between the Anadarko and Palo Duro basins, which extends over 200 miles from the Wichita Mountains of southwestern Oklahoma to the Dalhart basin (fig. 2).

The basement complex of the western part of the Panhandle field is composed of granite, porphyritic rhyolite, and diabase. Of these rocks types, rhyolite is most commonly penetrated by drill holes in the basement rocks (pl. 2). Flawn (1954) assigned all the igneous rocks to the late Precambrian. According to Flawn, the granite is part of the "Wichita igneous province" that constitutes the core of the Amarillo-Wichita uplift, and the rhyolite represents flows of late Precambrian age which made up the "Panhandle volcanic terrane." Diabase dikes and sills penetrate the porphyritic rhyolite and are considered to be the youngest rock type of the Precambrian complex.

The porphyritic rhyolite is a dull-red welded tuff composed of sodic plagioclase phenocrysts and some high-temperature quartz phenocrysts, in a microcrystalline groundmass showing flow structure. The diabase which has intruded the rhyolite is composed of labradorite, augite, ilmenite-magnetite, chlorite, and serpentine relics after olivine. The granite is a coarse-grained pink variety composed of perthitic orthoclase, quartz, green hornblende, brown biotite, zircon, and apatite (petrographic description by Charles Milton, U.S. Geological Survey, Washington, D.C.).

The sedimentary rocks of the western part of the Panhandle field range from Virgil (Cisco Group) to early Leonard (Clear Fork Group) age, as shown in figure 3. The sequence is made up of "granite wash," arkose, arkosic limestone; white crystalline fossiliferous limestone locally known as the "Moore County lime"; light brownish-gray fine- to medium-crystalline dolomite known as the "Brown dolomite"; light yel-

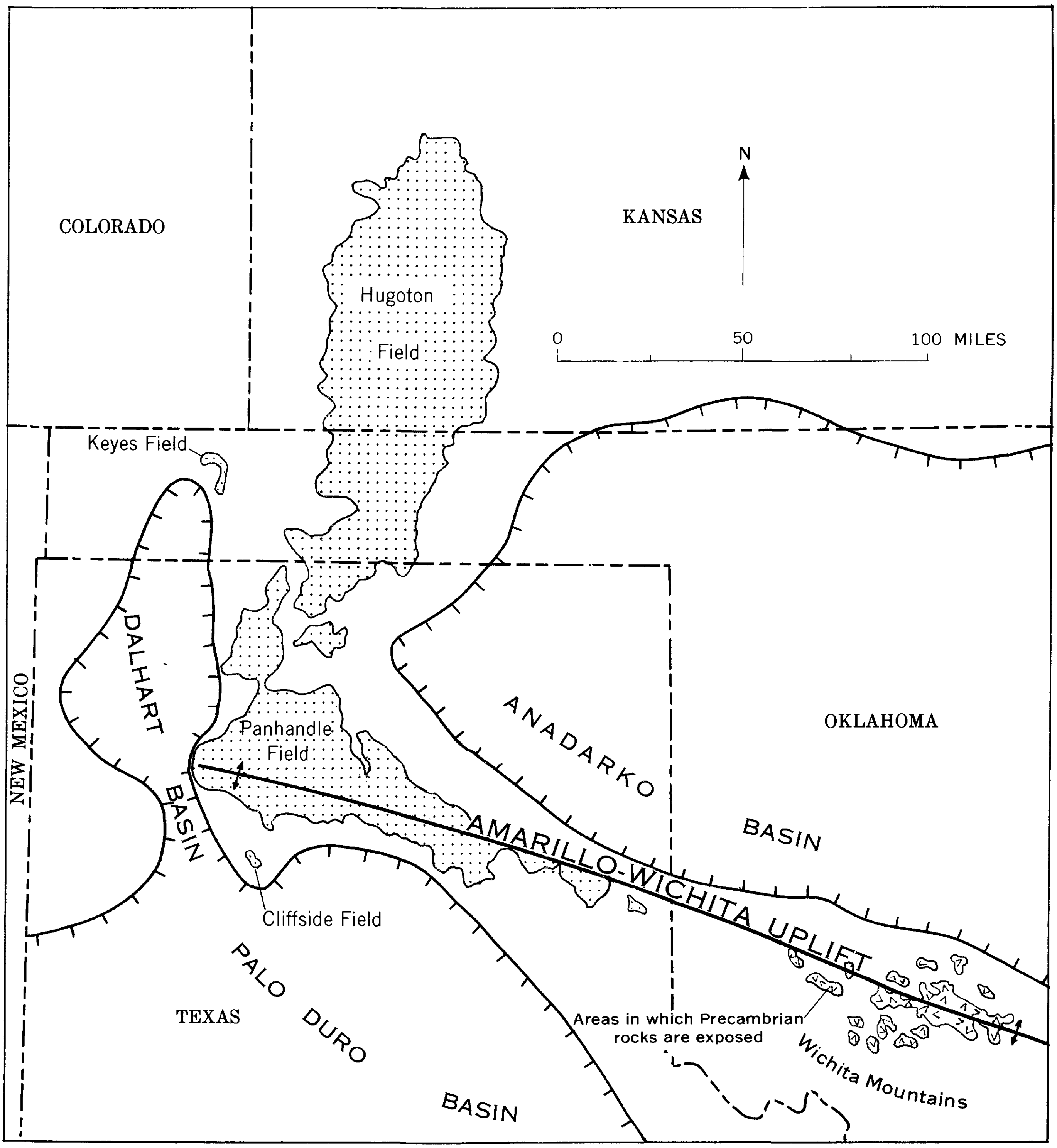
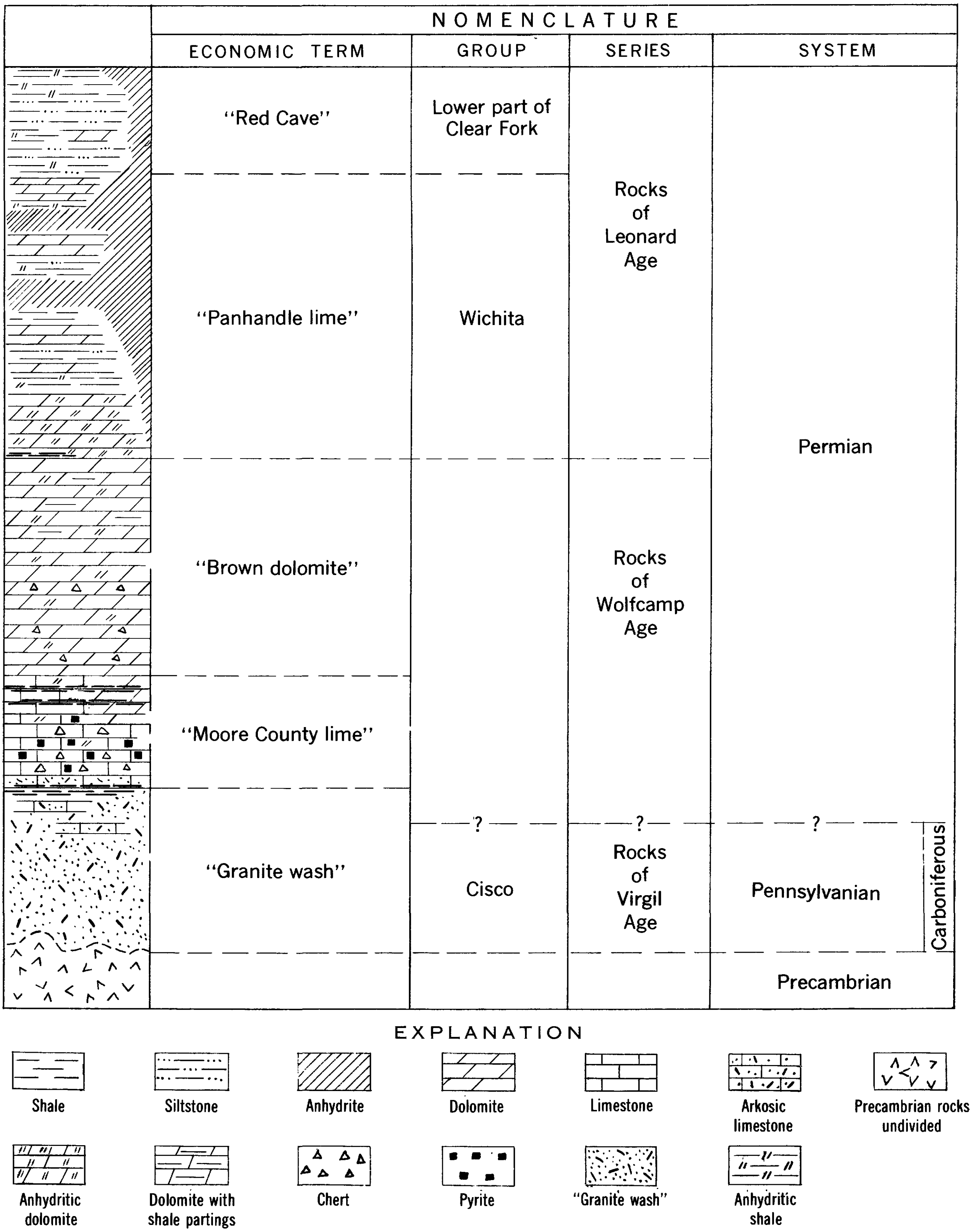


FIGURE 2.—Map showing major structural features of the Panhandle field and adjacent areas.

lowish-brown to light olive-gray dense dolomite known as the "Panhandle lime"; and red siltstone and shale interbedded with white, gray, and brown anhydrite known as the "Red Cave."

This stratigraphic sequence resembles the basin-margin class of evaporites of Sloss (1953) and represents a shifting depositional environment that ranges from normal marine to penesaline, modified by the influx of coarse to fine clastics. The white crystalline limestone is typical of a normal marine environment in that it is light in color, ranges from fine to coarse crystalline in texture, and contains abundant fossils and fossil frag-



NOMENCLATURE			
ECONOMIC TERM	GROUP	SERIES	SYSTEM
"Red Cave"	Lower part of Clear Fork	Rocks of Leonard Age	Permian
"Panhandle lime"	Wichita		
"Brown dolomite"		Rocks of Wolfcamp Age	
"Moore County lime"			
"Granite wash"	? Cisco	? Rocks of Virgil Age	? Pennsylvanian (Carboniferous)
			Precambrian

FIGURE 3.—Generalized stratigraphic section of Upper Pennsylvanian and Lower Permian rocks of the western part of the Panhandle field, Texas.

ments. The anhydrite-dolomite rocks of Wolfcamp to early Leonard age are typical of a penesaline environment (Lang, 1937); they represent a transition from an environment with abundant marine life to one in which nearly all life was absent, from a predominantly organic one to one represented mainly by chemical precipitates.

DESCRIPTIVE GEOLOGY

"GRANITE WASH"

The term "granite wash" is used locally for all fragmental rocks derived from the Precambrian complex. In the western part of the Panhandle field the "granite wash" consists chiefly of fragmental rhyolite, quartz, pink feldspar, biotite, ilmenite, and magnetite derived from basement rocks. In many drill samples, it is unweathered and difficult to distinguish from the parent rock.

The "granite wash" ranges in age from Pennsylvanian to Early Permian as is shown by its interfingering with limestones and dolomites of Virgil to early Wolfcamp age on the crest of the uplift and with limestones of Des Moines age along the margins of the uplift. Basinward, the "granite wash" attains a thickness of several hundred feet, but on the crest of the uplift it is generally thin, and in places it is absent. It is commonly interbedded with lenses of hematitic shale. On the crest of the uplift, there is important gas production from the "granite wash" and from fractures in the Precambrian rocks (pl. 2). Impregnations, fracture-fillings, and nodules of uranium-bearing asphaltite have been found in the "granite wash" and in the underlying Precambrian rocks.

"MOORE COUNTY LIME"

The rock unit that overlies the "granite wash" locally is called the "Moore County lime" or "White lime" and is considered by petroleum geologists working in the area to be of early Wolfcamp age. It is composed chiefly of light pinkish-gray to white fine- to coarse-crystalline, very fossiliferous limestone. In places along the flanks of the uplift the lower part of the limestone is a mixture of reworked arkose and recrystallized lime pellets forming a gradational contact with the "granite wash" below. Numerous beds of dominantly greenish gray to dark-gray shale occur in the upper part, and beds of red shale occur in the lower arkosic facies. Chert, which occurs in the "Moore County lime," is white, gray, brown, or red, and is smooth, mottled, or spicular in appearance. Pyrite, usually in the form of minute cubes, and small amounts of marcasite are disseminated in the limestone.

Fusulinids, brachiopods, and crinoid segments are common. The fusulinids which have been identified are Late Pennsylvanian to Early Permian in age and include *Schwagerina emaciata* which occurs in formations of Late Pennsylvanian and early Wolfcamp age in west Texas, *Triticites ventricosus* and *Triticites uddeni*, which occur in the lower beds of the Wolfcamp Formation of West Texas, and *Triticites subventricosus*, which is common in the Uddenites zone of the Wolfcamp Formation (King, 1937). The Uddenites zone is believed to be of Late Pennsylvania age, however similar forms of *T. subventricosus* continue into rocks of Permian age (identification by Raymond C. Douglass, U.S. Geological Survey). Identifiable brachiopods have not been recovered in the drill cuttings.

Thin sections show that much of the limestone is composed of interlocking calcite crystals with disseminated oolites, fusulinids and, in some samples, detrital quartz and microcline. Many of the oolites have been nearly obliterated by crystallization. The limestone was most likely deposited as a foraminiferal lime-pellet mud mixed with some quartz and feldspar. Where the "Moore County lime" grades into the "granite wash" on the flanks of the uplift, the rock is fine- to medium-grained arkosic or feldspathic limestone consisting of numerous angular fragments of microcline-orthoclase and some plagioclase in a fine-grained matrix of lime pellets and fossil debris cemented with calcite. The feldspar is predominantly kaolinized and the crystals are embayed by calcite.

The "Moore County lime" is approximately 200 feet thick on the north flank of the uplift and thins and disappears southward toward the crest. It thickens to several hundred feet in the Dalhart and Anadarko basins and overlies thick limestone units of Virgil and Missouri ages. Along the flanks of the uplift, several gas-producing zones occur in the "Moore County lime," especially at its gradational contact with the "granite wash," and some uranium-bearing asphaltite has been observed in sample cuttings of the "Moore County lime" in these areas.

"BROWN DOLOMITE"

The dolomite that overlies the "Moore County lime" is of Wolfcamp age and is locally referred to as the "Brown dolomite." The color is caused, at least in part, by oil stains associated with the secondary porosity. Extraction of the oil from several core samples of "Brown dolomite" showed that the pores contain about 5 percent oil by volume. The dolomite is light olive gray or brownish gray to very light gray, and contains fine- to medium-grained crystals. Shale partings, irregularly shaped inclusions and stringers of white crystalline anhydrite, and occasional chert zones and gray shale lenses also occur in the "Brown dolomite."

Nearly all thin sections of the dolomite show patches and veinlets of secondary anhydrite and celestite that sometimes contain uraniferous asphaltite nodules. Analyses of core samples from well 316 showed from 5 to 25 percent strontium. The strontium and calcium sulfates in the rock and part of the magnesium in the dolomite were probably derived from marine bitterns enriched in sulfates. The paragenetic sequence in the thin sections studied is dolomite-celestite (with asphaltite) and anhydrite (with asphaltite). Typical mineralogical relationships in porous asphaltite-bearing "Brown dolomite" are illustrated on figure 4.

The "Brown dolomite" is probably the most homogeneous and, therefore, the most easily recognized unit in the sequence. It varies in thickness from about 50 to 300 feet. Its thickness has been controlled by lateral changes in lithology and limited deposition on the structural highs. Vertically, the "Brown dolomite" grades into a dense anhydritic dolomite which is usually assigned to the basal part of the "Panhandle lime" by geologists working in this area. It thickens basinward and also thickens and thins on the crest of the uplift (pl. 2).

The "Brown dolomite" is an important reservoir rock. Its porosity is due largely to a fine network of intracrystalline cavities that give the rock its "pinpoint" pore texture. The permeability is significantly increased by fracturing. Both open fractures and older, partially cemented fractures are observed in samples of this rock.

"PANHANDLE LIME"

The upper part of the sequence is of early Leonard age and is known locally as the "Panhandle lime." It is made up of light yellowish-brown to light olive-gray aphanitic dolomite, light-tan to reddish siltstone, maroon and green shale, and anhydrite. Polyhalite and some gypsum occur with the anhydrite. The anhydrite and dolomite contain numerous uraniferous asphalt nodules. Much of the maroon shale contains green mottled patches and minute uraniferous asphaltite nodules surrounded by green halos.

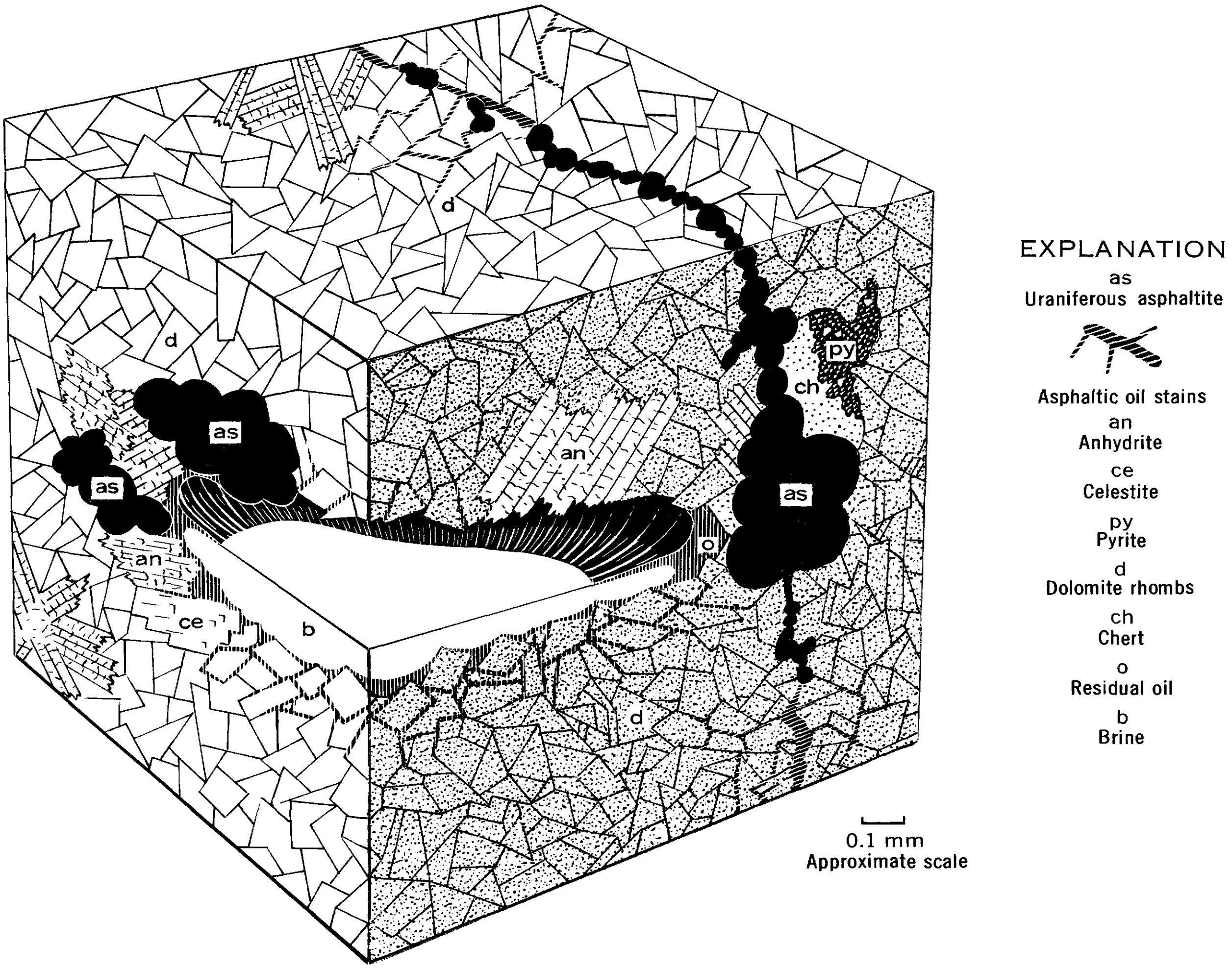


FIGURE 4.—Sketch showing typical mineralogical relationships in porous "Brown dolomite."

The lower part of the "Panhandle lime" has a mottled appearance caused by anhydrite disseminated throughout the dolomite. Large aggregates of anhydrite commonly occur in the aphanitic dolomite; the aggregates consist of anhydrite crystals arranged in radial manner, surrounding unoriented prismatic crystals. These aggregates are similar to those described by Adams (1932) as replacing the dolomitic phase of the limestones of Permian age of West Texas. Similar replacement of dolomite by anhydrite in an evaporite sequence in Yorkshire, England, has been described by Stewart (1951).

The "Panhandle lime" and the "Red Cave" (described below) contain the cap rocks for the western part of the Panhandle gas field. The upper part of the "Panhandle lime" and the lower part of the "Red Cave" contain massive beds of anhydrite and shale that are relatively incompetent and subject to plastic flowage as shown by distorted layering in core samples of the rocks. Comparison of sample logs of different wells indicates that some of the massive anhydrite strata are 10 to 30 feet thick and probably extend over hundreds of square miles. The effective porosity and permeability of such beds is probably very low. These beds and interbedded red shales form a barrier to the escape of gases from the underlying rocks.

"RED CAVE"

Buff to red siltstone composed of subangular to subrounded quartz grains and chlorite and brick-red shale interlaminated with anhydrite and dolomite overlies the "Panhandle lime." These rocks are of early Clear Fork (early Leonard) age and because of their incompetence in boreholes are locally referred to as the "Red Cave." The siltstone, especially that associated with anhydrite, contains appreciable quantities of uraniferous asphaltite in the form of botryoidal nodules.

STRUCTURE

The Panhandle field is at the western end of an uplift that extends from southwestern Oklahoma nearly across the Texas Panhandle to New Mexico (fig. 2). This feature is known as the Amarillo-Wichita uplift, but because the structural relief between it and the Anadarko basin to the north approaches the unusual magnitude of 28,000 feet, it is frequently referred to as the "buried Amarillo-Wichita Mountains."

Uplifting began during Late Mississippian or Early Pennsylvanian time. After the region was uplifted, the basement complex was exposed by erosion of the pre-Pennsylvanian rocks. By Early Permian time, the truncated Precambrian rocks were submerged and marine rocks were deposited over the uplift. Repeated crustal movement since that time has folded and faulted the rocks that overlie the uplift.

A zone of en echelon faults bound the south side of the uplift in the western end of the Panhandle field. The faults that are shown on plate 1 are inferred principally from information that has been derived from drill holes spaced about 1 mile apart. This spacing is not close enough to permit the interpretation of the structural complexities that may exist in the subsurface rocks. The lineation, configuration, and gradients of the helium contours indicate other possible faults that act as permeability barriers prohibiting free migration of the helium into the crest of the anticlines. The structural sinks near Bivins, and fractured and broken rock encountered during drilling, also suggest that the subsurface structure in this area is probably more complex than is indicated by plate 1.

URANIUM AND OTHER METALS IN THE PANHANDLE FIELD

URANIUM IN THE RESERVOIR AND CAP ROCKS

The western part of the Panhandle field, one of the largest helium reserves in the United States, contains high concentrations of radon (Rn^{222}). Inasmuch as both helium and radon are decay products in the uranium series a study of the distribution and concentration of uranium in the reservoir and cap rocks is necessary to understand the origin of these gases.

Thorium, from which helium may also be derived, has not been investigated because of the lack of suitable analytical techniques. The radon isotope of the thorium series, however, is not present in detectable amounts in the gases, and only normal amounts of the radium isotopes of the thorium series are present in the oilfield brines. Mineralogic and spectrographic studies of the rocks also indicate that no abnormal amounts of thorium are present.

Uranium-bearing asphaltite is consistently present in the cap rocks and is locally present in the reservoir rocks in the Panhandle field (see pl. 2), but determining the quantitative distribution of this material is handicapped by the lack of representative samples. Although several hundred wells on approximately 1-mile centers have been drilled into the gas reservoir, drill cuttings, largely from percussion drilling, are virtually the only samples that are available. Much of the uranium in the drill cuttings occurs in brittle asphaltite nodules that are readily shattered and lost during drilling; analyses of such samples may not show the true uranium content of the rocks from which the samples were derived. Accordingly, several types of data have been used to estimate the average uranium content of the rocks: radiometric and chemical analyses of drill cuttings, radium analyses of core samples, and estimates of the amount of uranium that would be required to support the radon in the gases. An estimate of the mean uranium content of the asphaltite-bearing cap rocks has been made from chemical and radiometric analyses of drill cuttings, gamma-ray logs of drill holes, spectrochemical analyses of the asphaltite, and visual estimates of the abundance of asphaltite in drill cuttings.

Chemical analyses of 81 samples of asphaltite-free drill cuttings from various parts of the Panhandle field indicate that the uranium content of the reservoir rocks (the “Brown dolomite,” “Moore, County lime,” and parts of the “granite wash”) ranges from 1 to 5 ppm (parts per million) (table 3). The average radium content of two sets of core samples of “Brown dolomite” from two wells (table 4) is 1.44×10^{-12} g per g and 0.40×10^{-12} g per g which is equivalent, respectively, to 4.0 and 1.1 ppm uranium in equilibrium with radium. Calibrated gamma-ray logs by Schlumberger Well Surveying Corp. show radioactivity equivalent to 2 to 3 ppm uranium in the gas-producing “Brown dolomite.” Radiometric analyses of several hundred samples have shown that the equivalent uranium content of the reservoir rocks is less than the measurable lower limit of 10 ppm, by the beta-gamma counting technique that was used. Sakakura and others (1959) concluded that radon concentrations of 23 to 522 micromicrocuries per

TABLE 3.—*Uranium contents of drill cuttings of reservoir rocks from some wells in the western part of the Panhandle field*

[Samples contributed by Colorado Interstate Gas Co., Amarillo, Tex.; collected by G. E. Manger. Chemical uranium analyses by I. Barlow and M. Delevaux]

Well (fig. 2)	Depth of sampling (feet)	Stratigraphic unit	Lithologic description	Percent chemical uranium
723	2512–2516	“Brown dolomite”	Dolomite	0.0001
	2635–2650	“Granite wash”	Arkose	.0003
	2667–2681	do	do	.0002
	2735–2750	do	do	.0002
	2785–2802	do	do	.0003
	2870–2885	Precambrian	Rhyolite(?)	.0002
727	2595–2690	“Brown dolomite”	Dolomite, mottled with anhydrite.	.0004
	2885–2987	“Granite wash”	Arkose with pink feldspar.	.0002
	2987–3028	do	do	.0003
	3100–3155	Precambrian	Rhyolite(?)	.0005
830	2294–2347	“Brown dolomite”	Dolomite	.0002
	2504–2542	“Moore County lime”	Fossiliferous limestone.	.0002
	2588–2633	“Granite wash”	Arkose	.0002
	2640–2714	do	do	.0001
	2828–2874	do	do	.0002
	2984–3024	do	do	.0001
	3024–3071	do	do	.0002
	3202–3280	Precambrian	Rhyolite(?)	.0002
862	2716–2725	Precambrian	Diabase	.0001
	2740–2760	do	do	.0001
	2819–2825	do	do	.0001
	2881–2885	do	Diabase and rhyolite	.0001
	2913–2915	do	do	.0002
862	2338–2328	“Brown dolomite”	Dolomite	.0001
	2438–2442	“Granite wash”	Arkose	.0001
	2478–2481	Precambrian	Rhyolite(?)	.0002
	2548–2555	do	Diabase	.0001
	2608–2611	do	do	.0002
680	2855–2865	“Brown dolomite”	Dolomite	.0001
	3095–3106	do	do	.0001
	3182–3144	“Granite wash”	Arkose	.0001
	3223–3234	do	do	.0001
	3288–3305	do	do	.0002
611	3202–3209	“Brown dolomite”	Dolomite	.0001
	3317–3322	do	do	.0001
	3509–3512	“Moore County(?) lime”	Limestone	.0001
	3514	do	do	.0001
	3516	“Granite wash”	Arkosic limestone	.0001
	3523	do	do	.0001
612	2800–2850	Panhandle lime”	Dolomite and anhydrite.	.0001
	2950–3000	do	do	.0001
	3090–3139	“Brown dolomite”	Dolomite	.0004
	3227–3260	do	do	.0003
	3321–3357	do	do	.0001
	3424–3440	“Granite wash”	Arkosic limestone	.0001
	3470–3481	do	do	.0001
693	2258–2272	“Brown dolomite”	Dolomite	.0003
	2465–2487	“Granite wash”	Arkose	.0001
	2700–2721	do	do	.0001
	2834–2846	do	do	.0001
	3071–3090	do	do	.0001
	3255–3265	do	do	.0001
	3406–3428	do	do	.0001
	3482–3500	do	do	.0001
747	2135–2145	“Granite wash”	do	.0003
	2165–2175	do	do	.0002
	2185–2195	do	do	.0003
694	2575–2604	“Granite wash”	do	0.0002
	2614–2655	Precambrian	Rhyolite(?)	.0003
	2823–2846	do	do	.0002
	2885–2915	do	do	.0002
	2956–3015	do	do	.0002
	3015–3060	do	do	.0001
	3150–3180	do	do	.0001
724	2659–2670	“Granite wash”	Arkose	.0002
	2670–2681	do	do	.0002
	2673–2703	Precambrian	Rhyolite(?)	.0002
666	3125–3210	“Brown dolomite”	Dolomite	.0001
	3450–3490	do	do	.0001
764	2880–2890	“Granite wash”	Arkose	.0005
	3287–3295	do	do	.0004
	3435–3445	do	do	.0003
804	2339–2355	“Granite wash”	Arkose	.0002
	2658–2682	Precambrian	Rhyolite(?)	.0001
	2821–2837	do	do	.0001
	3089–3102	do	do	.0001
801	2440–2450	“Granite wash”	Arkose	.0002
	2468–2470	Precambrian	Rhyolite(?)	.0002
141	3470	“Brown dolomite”	Dolomite	.0001
891	2040	Precambrian	Coarse red quartzite	.0002
	2040	do	Porphyritic rhyolite	.0002

TABLE 4.—*Radium content and radon-emanating power of core samples from two wells in the Panhandle field*

[Samples collected by Phillips Petroleum Co. for G. E. Manger. Analyses for porosity and permeability by U.S. Bur. Mines, Franklin, Pa.; radium and radon analyses by F. J. Davis and A. F. Gabrysh, Oak Ridge National Laboratory]

Depth of core (feet)	Core recovered (feet)	Part of core analyzed	Ra content (10^{-12}g Ra per g)	Porosity (percent)	Permeability (10^{-3} darcies)	Radon emanating power (percent)
Phillips Petroleum Co. Ola well 1, Moore County Tex. (No. 312 on fig. 2)						
3530–3540	8	2d ft	2.97	7.69	0.1	5.98
		5th ft	1.86	8.62	.1	5.45
		6th ft	1.33	2.72	.33	5.38
		7th ft	.79	2.77	.1	1.23
3574–3580	4		1.58	6.53	.1	12.39
3573–3577	1.5		1.36	12.07	61.23	4.74
3577–3590	5.6		1.10	3.19	.1	4.44
3597–3607	5		.92	22.22	66.4	4.57
3611–3613	1		1.05	7.27	.1	5.91
Phillips Petroleum Co. Louise well 1, Sherman County, Tex.						
2771–2773		Top ½ ft	0.64	16.49	7.11	8.10
		Bottom 1 ft	.77	7.83	.1	7.75
2773–2774		Middle 1 ft	.70	8.95	21.39	5.65
		Bottom 1 ft	.45	8.99	.1	6.60
2777–2781		Top 1 ft	.64	8.17	.52	6.25
		Bottom 1 ft	.20	14.63	34.12	15.08
2781–2784		Bottom ½ ft	.17	25.47	1858.0	14.62
2785–2788		Top 1 ft	.23	10.19	8.25	12.16
2788–2792		Top 1 ft	.14	12.85	21.04	7.79
		Bottom 1 ft	.10	9.86	3.09	6.88

liter (STP, standard temperature and pressure) in gases from the field correspond to reservoir rocks containing from about 0.4 to 9 ppm uranium, respectively. The average radon content of gases in the Panhandle field is about 100 micromicrocuries per liter (STP) (pl. 1) which would correspond to about 2 ppm in the reservoir rock. In summary these data indicate that the mean uranium content of the reservoir rocks is from 2 to 4 ppm.

The uranium content of the cap rocks (the upper part of the "Panhandle lime" and lower part of the Clear Fork Group) apparently is several times higher than the uranium content of the reservoir rocks. Radiometric analyses of 335 percussion-drill samples of the upper part of the "Panhandle lime" and lower part of the Clear Fork Group in 13 wells distributed over the Panhandle field, show an average equivalent uranium content of 20 ppm. The rocks represented by these samples have an average thickness of 260 feet. Gamma-ray logs calibrated by Schlumberger Well Surveying Corp. show an average radioactivity through the same rocks equivalent to 18 ppm uranium.

Seventy-five uncalibrated gamma-ray logs, examples of which are given in plate 3, show that the radioactivity of the asphaltite-bearing interval, after allowance is made for absorption by the casing, is about 5 times greater than the radioactivity of the underlying "Brown dolomite." The "Brown dolomite" has been estimated to contain from 1 to 4 ppm uranium (table 3); the uranium content of the upper part of the "Panhandle lime" and basal part of the Clear Fork Group is, therefore, indicated to be in the range of 5 to 20 ppm if the radioactivity is due entirely to the presence of uranium and its decay products.

The asphaltite is estimated, on the basis of the examination of 500 mineralized drill samples, to compose on the average about 0.5 percent by weight of the samples. The average uranium content of the asphaltite is about 1 percent as indicated by spectrochemical analyses. The mean uranium content of the mineralized drill samples is calculated at about 50 ppm.

The distribution of mineralized drill samples is shown on plate 2. Each asphaltite nodule symbol represents a 10-foot thickness of asphaltite-bearing rock. It is estimated that from one-third to one-half of the samples from the "Panhandle lime" and lower part of the Clear Fork Group contain asphaltite. These results indicate that, if no asphaltite has been lost during drilling, the average uranium content of the mineralized rocks is from about 15 to 25 ppm. Although this estimate has only semiquantitative significance, when considered with the radiometric analyses discussed above, it suggests that the mean uranium content of a 200- to 300-foot-thick interval in the upper part of the "Panhandle lime" and lower part of the Clear Fork Group is at least 10 ppm and perhaps is as much as 20 ppm.

URANIUM AND OTHER METALS IN THE CRUDE OIL

Semiquantitative spectrographic, radiometric, and chemical analyses of the ash of 26 crude oil samples from wells peripheral to the western part of the Panhandle gas field (table 5) show that the metal content of the crude oil is low (table 6). Their uranium content ranges from less than 1 to about 300 ppb. Many of the predominating elements, particularly sodium, potassium, calcium, magnesium, and strontium, are those elements that are normally most concentrated in the brine, and the presence of these elements in the oil may have resulted, therefore, from incomplete desalting of the samples. Uranium, nickel, vanadium, molybdenum, cobalt, and arsenic, however, are concentrated in the crude oil to a greater degree than can be explained by contamination of the oil sample by brine. This fact is illustrated in figure 5 by the comparison of the concentrations of trace metals in the oil, brine, and asphaltite. The data for the oil are from tables 5 and 6. The data for asphaltite nodules and brine are presented in a following part of this report (tables 8 and 14). Semiquantitative spectrographic analyses of the salts of these brines used in preparing figure 5 are not presented elsewhere in this report.

The possibility of the occurrence of discrete minerals in the crude oil was investigated by filtering the materials in suspension from several samples and studying them under high magnification. Some of the suspended materials were concentrated by passing the crude oil through a bacteriological filter. Other smaller particles were obtained by diluting the filtered oil with benzene and passing it through a column of powdered aluminum chloride (Sanders, 1928). The column of aluminum chloride was dissolved in water to form a saturated solution from which the extremely fine particles that had been adsorbed from the oil were collected. The materials separated by these means were examined under 1500 × magnification in diffuse reflected light. They consisted of abundant tiny fragments of carbonized organic material, some micron-sized globules of brassy minerals, and particles of a black pitchy material. All these materials were mounted on glass slides, coated with liquid nuclear emulsion, and exposed for 2 months, but they showed no significant alpha activity. The low alpha activity suggests that the relatively high uranium contents of the ashes of these crude oil samples (table 5) do not originate from suspended materials. The tiny brassy globules from less than a micron to as much as tens of microns in diameter are probably made

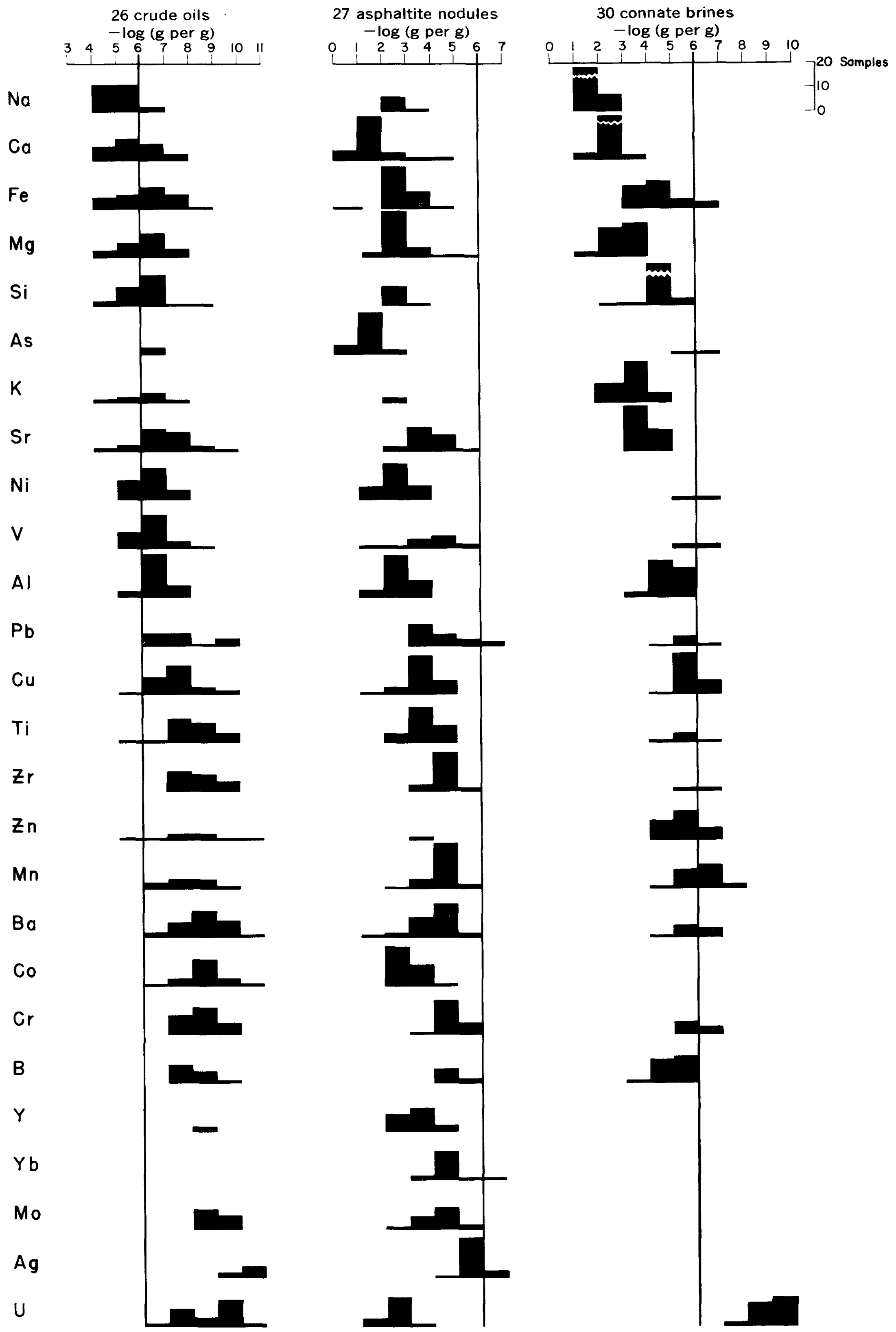


FIGURE 5.—Concentrations of metals in crude oil, asphaltite nodules, and connate brine.

up of pyrite and chalcopyrite, and may contribute significantly to the iron, copper, and sulfur contents of the oil ash. Inasmuch as the crude oil samples prior to analysis were filtered through frits of about 50 microns pore diameter, the metallic particles must have been present in the ashes of the samples that were analyzed.

An analysis of the material removed by filtering a Panhandle crude-oil sample (table 5, sample 25) shows that iron and copper are the most abundant heavy metals removed followed by chromium, manganese, nickel, tin, lead, vanadium, and a trace of silver. A sodium fluoride flux test for uranium was negative. All these metals are also present in the filtered oil (table 5, sample 24). In relation to the major constituents such as silicon and sodium, the filter held back more than half of the iron, potassium, magnesium, aluminum, tin, barium, boron, titanium, lead, chromium, strontium, and manganese, about one-tenth of the copper, calcium, and possibly silver, and only about one-hundredth of the vanadium and nickel. Cobalt and molybdenum were detected in the oil but not in the residues from filtration. It seems probable from these results that of all the metals present, vanadium and nickel and possibly cobalt and molybdenum occur chiefly as compounds soluble in the oil.

Vanadium, iron, and nickel are the three major metals occurring in the ash of the Panhandle crude oil. Both vanadium and nickel have been shown to occur as porphyrin complexes soluble in petroleum (Dunning, Moore, and Myers, 1954). A sample of crude oil from the Panhandle field has been analyzed for its porphyrin content by H. N. Dunning and J. W. Moore of the U.S. Bureau of Mines. They found 8 ppm of "free" or nonpolar porphyrins (Dunning, written communication, 1953). Quantitative spectrographic analyses of this oil showed that it has a nickel content of 1.2 ppm and a vanadium content of 1.0 ppm. The amount of porphyrin present in the oil is sufficient to complex about one-half of the total vanadium and nickel present.

A sample of oil from well 731 was passed through a large adsorbent candle filter of about 5 microns pore size and then diffused for 48 hours in a thermal diffusion column. The resulting fractions were analyzed for their metal contents. The data, listed in descending order in the diffusion column (table 7), show that during diffusion the metals concentrated towards the bottom of the column with the heavy asphaltic molecules of the crude oil. The extent to which the various metals concentrated is also shown in table 7. Vanadium, which probably occurs in the oil as a soluble porphyrin complex, is concentrated to a much greater degree than are the other metals.

Small amounts of lead are present in the crude oil of the Panhandle field and a large proportion of this metal may be of radiogenic origin. The radon concentrations in the gases of the West Panhandle field are as much as 10^4 micromicrocuries per liter of pore space at reservoir temperature and pressure. Radon is highly soluble in oil, and calculation shows that petroleum saturating these rocks could have accumulated as much as 10^{-6} g Pb/206 per g oil since Permian time (250 million years) from decay of radon dissolved in it. Inasmuch as the actual lead content of the crude oil (table 6) ranges from only 10^{-10} to 10^{-6} g Pb per g oil, a major part of the lead could have been derived from decay of radon.

RADIUM AND URANIUM IN THE BRINE

The radium and uranium contents and the chemical compositions of brine samples collected from the Panhandle field are presented by Rogers (table 8). The radium content of 75 brine samples ranges from 3 to 1560×10^{-12} g Ra^{226} per liter, and the uranium content of 29 of these samples ranges from less than 0.1 to 13×10^{-6} g U per liter.

Calculation shows that the amount of uranium in the 29 samples analyzed is sufficient to support from less than 0.01 to 24 percent of the radium (Ra^{226}) present in individual samples. The major part of the uranium from which the radium was derived must, therefore, be in the reservoir rocks.

The chemical compositions of the Panhandle brines are portrayed graphically in figures 6 and 7, which

TABLE 7.—*Metal concentrations, in parts per million, in thermodiffusion fractions of a sample of crude oil from well 731*

[Spectrochemical analyses by A. T. Myers. Thermodiffusion separation, chemical uranium analyses, and ash determinations by C. A. Horr. Fractions are listed in order of appearance in thermodiffusion column]

Fraction	Description	V	Ni	Na	Mg	Ba	Pb	U	Ag	Cu	Ca	Mo	Co	Al	Ti	Cr	Mn	Fe	Ash (percent)
1	Light paraffinic oil	0.09	0.9	4	2	0.09	0.2	0.006	0.3	2	20	0.03	0.03	8	0.9	0.9	0.9	20	0.011
2	Intermediate paraffinic oil	.7	3	6	3	.14	.3	.036	1.4	3	30	.14	.07	12	.1	1.4	.7	30	.035
3	Intermediate asphaltic oil	8	20	40	20	.8	.8	.054	2	20	200	.2	.4	80	8	4	2	80	.105
4	Viscous asphaltic oil	40	80	170	80	4	8	.210	8	40	500	.8	.8	170	17	17	17	170	.092
	Ratio of fraction 4 to fraction 1	450	90	40	40	40	40	35	25	20	30	30	30	20	20	20	20	10	8.4

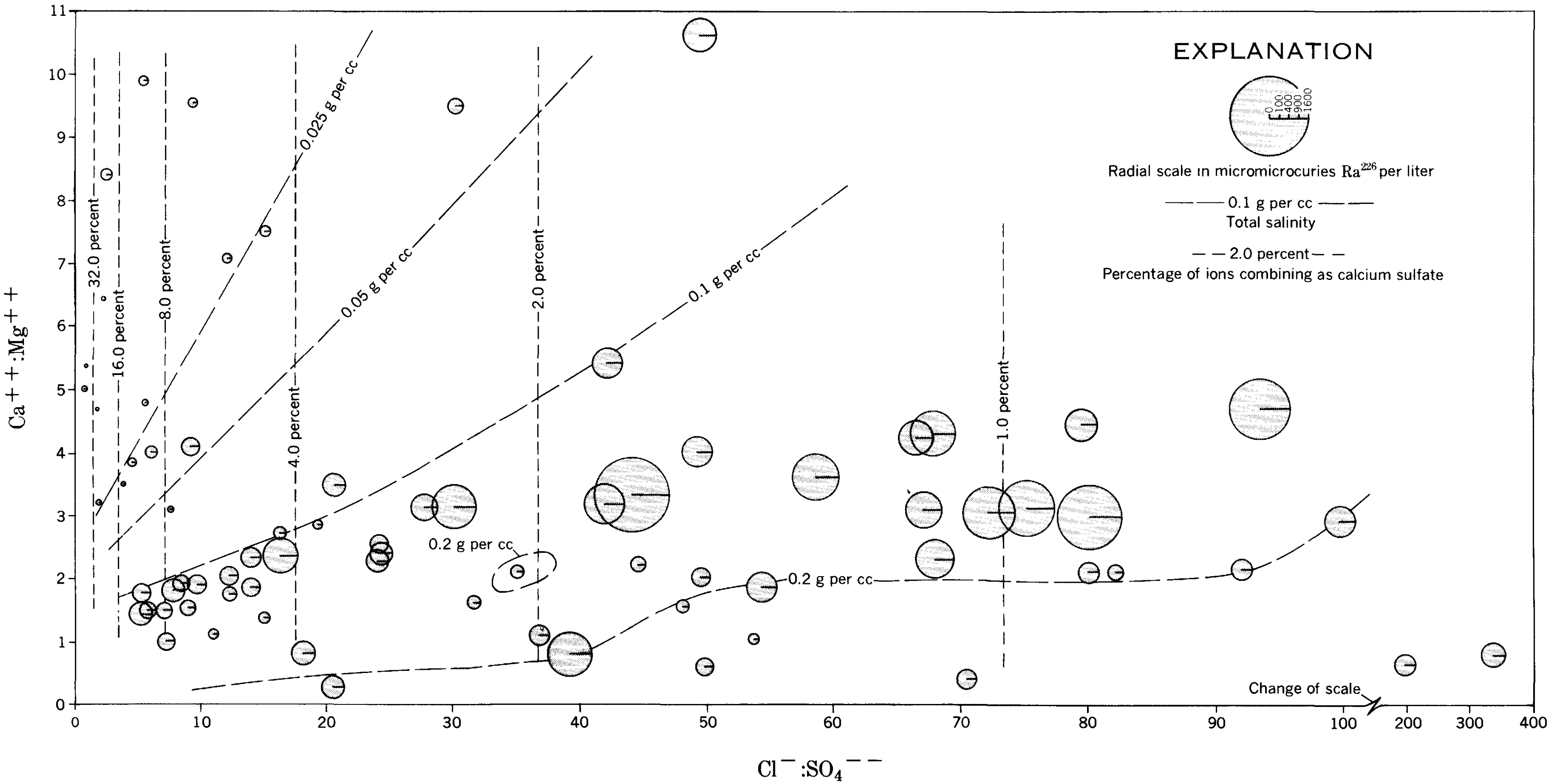


FIGURE 6.—Radium, calcium sulfate, and salinity contents compared to calcium to magnesium and chlorine to sulfate concentration ratios in Panhandle field brines.

TABLE 8.—*Radium content and chemical analyses of brine samples from*

Samples 1–30, 36–49, and 72–74 were collected and analyzed for their major con
J. N. Rosholt, Jr., James McGurk, Jesse Meadows, W. J. Mountjoy, J. E. Wilson,
and 75 were analyzed by Water Resources Laboratory, U.S. Geological Survey,
tion of samples 31, 51–59, and 63, which were analyzed for radium content by J. N.
Lake City, Utah. Analyses for arsenic, J. T. Slayback and R. R. Beins, U.S. Geo
Total solids include some constituents that are not reported.

Sample	Well			Location					Depth (feet)	Density (g per cc)
	No. (pl. 1)	Name	Company	Land description		Survey	County	State		
				Sec.						
1		Jones F–1	Phillips	15	T. 2 N., R. 17 E.		Texas	Okla.	2,570	1.1746
2		Atkins B–1	do.	32	T. 1 N., R. 17 E.		do.	do.	2,854	1.1315
3		Hitch R–1	do.	35	T. 1 N., R. 16 E.		do.	do.	2,864	1.0514
4		Karel 1	do.	8	T. 1 N., R. 15 E.		do.	do.	2,858	1.1280
5		Deakin 1	do.	7	T. 1 N., R. 15 E.		do.	do.	2,814	1.1323
6		Armour 1	do.	2	T. 1 N., R. 14 E.		do.	do.	2,775	1.1299
7		Mundy 1	do.	13	T. 1 N., R. 13 E.		do.	do.	2,816	1.1012
8		Borah 1	do.	15	T. 1 N., R. 13 E.		do.	do.	2,871	1.0996
9		Nichols A–1	do.	11	T. 1 N., R. 12 E.		do.	do.	2,900	1.0984
10		Wacker 1	do.	26	T. 1 N., R. 13 E.		do.	do.	2,951	1.0965
11		Waugh 1	do.	31	T. 1 N., R. 13 E.		do.	do.	2,939	1.0186
12		Atkins C–1	do.	26	Blk. 1	IWC	Hansford	Tex.	2,896	1.1346
13		Math 1	do.	70	Blk. 2	GH and H	do.	do.	3,189	1.0816
14		Dix 1	do.	4	Blk. 3	GH and H	do.	do.	3,182	1.0856
15		Cator 1	do.	33	Blk. 3	GH and H	do.	do.	5,315	1.1372
16		Ander 1	do.	236	Blk. 2	GH and H	do.	do.	2,930	1.1128
17		Renner 1	do.	1	Blk. 1–C	GH and H	Sherman	do.	2,968	1.1006
18		Property 1	do.	45	Blk. 1–C	GN and H	do.	do.	2,959	1.1025
19		Witter A–1	do.	19	Blk. 1–C	GH and H	do.	do.	2,885	1.0293
20		O'Brien 1	do.	171	Blk. 1–T	T and NO	do.	do.	2,890	1.1282
21		Bivins F–1	do.	57	Blk. 3–B	GH and H	do.	do.	3,300	1.1073
22		Ivens T–1	do.	34	Blk. 3–B	GH and H	do.	do.	3,161	1.1022
23		Tina 1	do.	17	Blk. 2	T and NO	do.	do.	3,456	1.0556
24		Merkle 1	do.	267	Blk. 1–T	T and NO	do.	do.	3,339	1.0171
25		Trumbell 1	do.	246	Blk. 1–T	T and NO	do.	do.	3,378	1.0046
26		Jeff 1	do.	268	Blk. 1–T	T and NO	do.	do.	3,347	1.0158
27		Louise 1	do.	280	Blk. 1–T	T and NO	do.	do.	3,069	1.0153
28		Cindy 1	do.	51	Blk. 1–C	GH and H	do.	do.	2,929	1.0016
29		Berry C–1	do.	2	Blk. 1–T	T and NO	do.	do.	2,703	1.0991
30		Berry D–1	do.	12	Blk. 2	PSL	do.	do.	2,701	1.1014
31		Lee 10	Kerr-McGee	72	Blk. 3–B	GH and H	do.	do.	------	------
32		Lee 11	do.	69	Blk. 3–B	GH and H	do.	do.	3,205	1.107
33		Lee 1	do.	68	Blk. 3–B	GH and H	do.	do.	3,220	1.124
34		Flyr 1	do.	66	Blk. 3–B	GH and H	do.	do.	3,250	1.124
35		Jessie 1	do.	8	Blk. 3–T	T and NO	do.	do.	3,300	1.113
36	19c	Estate 1	Phillips	13	Blk. M–16	AB and M	Hutchinson	do.	3,173	1.0047
37	578	Wild Bill 1	do.	53		R. Sikes	do.	do.	2,564	1.0322
38		Johnson EE 1	do.	3	Blk. 1	B and B	do.	do.	2,937	1.0984
39		Eddie 1	do.			B and B	do.	do.	2,550	1.0056
40	244	Katherine 2	do.	3	Blk. 1	Wm. Cole	do.	do.	3,148	1.1840
41	8a	Way 1	do.	17	Blk. M–16	AB and M	do.	do.	3,190	1.0071
42		Arlene 1	do.	126	Blk. 3–T	T and NO	Moore	do.	3,279	1.1145
43		Vilas 1	do.	394	Blk. 44	H and TC	do.	do.	3,428	1.0088
44		Idell 1	do.	349	Blk. 44	H and TC	do.	do.	3,527	1.0779
45	253	Drury 1	do.	117	Blk. 44	H and TC	do.	do.	3,600	1.0765
46	316	Ola 1	do.	162	Blk. 44	H and TC	do.	do.	3,788	1.1057
47	452	Vinson 1	do.	92	Blk. 44	H and TC	do.	do.	3,603	1.0637
48	527	Barre 1	do.	35	Blk. 44	H and TC	do.	do.	3,491	1.1791
49	455	Fuqua B–1	do.	76	Blk. 44	H and TC	do.	do.	3,624	1.0932
50		Robertson B–3	Shamrock	165	Blk. 3–T	T and NO	do.	do.	3,300	1.097
51		Robertson B–3	do.	165	Blk. 3–T	T and NO	do.	do.	3,300	------
52	24a	Robertson D–2	do.	232	Blk. 3–T	T and NO	do.	do.	------	------
53		High 4	do.	354	Blk. 44	H and TC	do.	do.	------	------
54	222a	Anderson 1	Kerr-McGee	238	Blk. 44	H and TC	do.	do.	------	------
55	319	Drucilla 1	do.	159	Blk. 44	H and TC	do.	do.	------	------
56	453	Estate 1	do.	77	Blk. 44	H and TC	do.	do.	------	------
57	138	Sullivan 1	do.	314	Blk. 44	H and TC	do.	do.	------	------
58		Wells 1–B	do.	153	Blk. 3	T and NO	do.	do.	------	------
59		McDowell C–2	do.	15	Blk. M–16	AB and M	do.	do.	------	------
60	570	Sneed 5–P	Nat. G.P.A.	7	Blk. B–12	D and P	do.	do.	3,065	1.123
61		Taylor 1–G	Phillips	21	Blk. M–1	D and P	do.	do.	3,399	1.085
62		Bivins G–G	Kerr-McGee	29	Blk. 21	Capitol Lands	Hartley	do.	5,834	1.130
63	588d	Berneta 1	do.	29	Blk. 21	Capitol Lands	do.	do.	------	------
64		Burnett Est. 1–G	Nat. G.P.A.	91	Blk. 5	I and GN	Carson	do.	3,502	1.169
65		Jordan et al 1–T	do.	83	Blk. 4	I and GN	do.	do.	2,435	1.003
66		Schafer 9–S	do.	86	Blk. 4	I and GN	do.	do.	2,920	1.079
67		Urbanzyk 1–T	do.	25	Blk. 4	I and GN	do.	do.	2,702	1.178
68		McConnell B–1–T	do.	185	Blk. 3	I and GN	do.	do.	2,670	1.188
69		Cobb 1–G	do.	202	Blk. 3	I and GN	do.	do.	2,651	1.194
70		McEwen 1	do.	204	Blk. 3	I and GN	do.	do.	2,630	1.195
71		Ledrick 1–S	do.	239	Blk. B–2	I and GN	do.	do.	2,750	1.206
72		Gill-Morrow 1	Phillips	123	Blk. 7	I and GN	do.	do.	2,927	1.1130
73		Britton A–1	do.	254	Blk. B–2	H and GN	do.	do.	2,930	1.1025
74		McKnight 1	do.	178	Blk. B–2	H and GN	Gray	do.	2,772	1.1953
75		Hexter 3–E	Nat. G.P.A.	215	Blk. B–2	H and GN	do.	do.	2,885	1.069

some gas wells in the Panhandle and Hugoton fields, by A. S. Rogers

stituents by Phillips Petroleum Co.; samples 31, 50–59, and 63, were analyzed by
and C. A. Horr, U.S. Geological Survey, Denver, Colo.; samples 32–35, 60–62, 64–71,
Washington, D.C. All radium analyses were made by A. S. Rogers, with the excep-
Rosholt, Jr. Analyses for fluorine and boron, Chemistry Dept., Utah Univ., Salt
logical Survey, Denver, Colo.

Milligrams per liter of brine														10^{-12} g per l Ra^{-26}	Remarks; other analyses
Total solids	Ca	Mg	Na and(or) K		Br	I	Cl	SO_4	HCO_3	Cu	Fe	Mn	U		
231,034	49,913	1,452	83,122		--------	--------	140,064	1,412	71	--------	--------	--------	--------	193	11 ppm F; 6.8 ppm B.
176,357	2,194	689	65,516		--------	--------	104,150	3,768	40	--------	--------	--------	--------	179	
171,108	1,338	431	25,692		--------	--------	39,138	5,083	26	--------	--------	--------	--------	9	
175,084	1,183	584	65,890		--------	--------	99,350	10,092	21	--------	--------	--------	--------	92	7 ppm F; 3.7 ppm B.
178,286	937	500	67,257		--------	--------	99,240	10,277	75	--------	--------	--------	--------	119	
171,019	844	475	64,381		--------	--------	93,442	11,800	77	--------	--------	--------	--------	100	
134,011	898	494	48,314		--------	--------	70,892	13,253	155	--------	--------	--------	--------	183	
134,018	907	628	49,390		--------	--------	69,978	12,948	167	--------	--------	--------	--------	112	
132,798	1,065	1,075	48,371		--------	--------	72,276	9,839	172	--------	--------	--------	--------	150	
130,334	948	544	48,155		--------	--------	68,757	11,853	77	--------	--------	--------	--------	89	
25,361	1,628	342	7,423		--------	--------	13,540	2,407	21	--------	--------	--------	--------	12	
183,099	1,926	798	68,218		--------	--------	107,655	4,449	53	--------	--------	--------	--------	163	
111,583	1,970	1,121	39,472		--------	--------	63,780	5,168	59	--------	--------	--------	--------	85	
116,397	1,897	1,657	40,523		--------	--------	66,172	5,987	136	--------	--------	--------	--------	27	
181,904	9,490	2,032	58,109		--------	--------	112,084	120	69	--------	--------	--------	--------	1,060	
153,678	1,296	699	57,280		--------	--------	87,907	6,436	60	--------	--------	--------	--------	100	
135,868	1,055	705	50,110		--------	--------	73,478	10,403	117	--------	--------	--------	--------	83	
138,342	937	612	51,572		--------	--------	76,784	8,358	79	--------	--------	--------	--------	90	
39,195	1,730	428	12,480		--------	--------	20,974	3,433	150	--------	--------	--------	--------	34	
173,797	4,406	2,189	59,952		--------	--------	105,038	2,128	84	--------	--------	--------	--------	121	3 ppm F; 3.3 ppm B.
145,033	5,176	956	49,719		--------	--------	87,140	1,996	46	--------	--------	--------	--------	206	
127,404	18,358	8,502	16,886		--------	--------	82,502	895	261	--------	--------	--------	--------	123	9 ppm F; 4.4 ppm B.
71,911	3,290	1,121	11,763		--------	--------	44,585	915	103	--------	--------	--------	--------	171	7 ppm B; 7.0 ppm B.
24,536	1,538	205	7,547		--------	--------	14,213	954	79	--------	--------	--------	--------	34	
5,883	364	51	1,798		--------	--------	3,320	276	74	--------	--------	--------	--------	17	
23,445	706	74	8,520		--------	--------	12,478	1,339	328	--------	--------	--------	--------	13	
69,902	1,911	671	24,118		--------	--------	40,826	2,130	46	--------	--------	--------	--------	21	
1,169	49	14	345		--------	--------	475	119	167	--------	--------	--------	--------	4	
134,545	4,046	3,632	42,683		--------	--------	81,918	2,244	22	--------	--------	--------	--------	127	
138,398	2,045	2,595	47,742		--------	--------	81,568	4,403	45	--------	--------	--------	--------	170	
228,607	4,900	1,600	71,000	1,140	--------	--------	138,000	1,920	47	--------	--------	--------	0.01	720	
154,111	4,640	1,470	51,400	442	59	4	93,500	2,240	--------	1.4	64	0.76	0.0008	435	1.2 ppm Al; 4.0 ppm Zn.
161,178	3,440	4,220	53,100	507	72	22	96,900	2,490	--------	.0	1.4	.21	.0022	565	4.2 ppm Al; .0 ppm Zn.
205,190	5,860	1,370	55,100	578	85	2.8	140,000	2,080	--------	--------	--------	.2	.0023	575	
154,189	5,110	1,270	54,600	471	82	2.9	90,700	1,850	--------	.0	18	.97	.0065	218	200 ppm Al; 10 ppm Zn.
5,880	658	104	1,292		--------	--------	2,478	1,087	--------	--------	--------	--------	--------	6	
45,047	1,230	320	15,345		--------	--------	23,041	4,924	--------	--------	--------	--------	--------	15	7 ppm F; 7.0 ppm B.
128,201	12,232	5,776	28,104		--------	--------	81,018	1,008	63	--------	--------	--------	--------	120	7 ppm F; 7.0 ppm B.
6,277	771	143	1,123		--------	--------	1,769	1,966	505	--------	--------	--------	--------	4	
246,963	1,175	566	94,556		--------	--------	146,436	4,206	26	--------	--------	--------	--------	44	1 ppm F 1.8 ppm B.
7,623	11,236	356	894		--------	--------	3,200	1,774	163	--------	--------	--------	--------	6	
151,202	8,647	3,798	44,035		--------	--------	93,200	1,369	153	--------	--------	--------	--------	318	6.0 ppm F; 14 ppm B.
8,247	1,045	222	1,533		--------	--------	3,354	1,866	--------	--------	--------	--------	--------	3	
106,533	2,621	1,116	36,898		--------	--------	61,867	3,827	204	--------	--------	--------	--------	289	
103,773	5,262	1,788	32,090		--------	--------	62,395	2,096	142	--------	--------	--------	--------	483	0.2 ppm As.
140,965	6,703	2,263	44,503		--------	--------	86,084	1,290	122	--------	--------	--------	--------	350	
86,110	3,792	1,084	27,787		--------	--------	50,816	2,475	156	--------	--------	--------	--------	140	
238,347	1,989	1,248	69,336		--------	--------	142,722	2,991	61	--------	--------	--------	--------	39	3.0 ppm As.
125,973	6,205	1,863	39,703		--------	--------	76,247	1,731	224	--------	--------	--------	.002	1,560	
121,303	1,110	684	44,700		--------	--------	64,700	6,220	--------	.43	.38	--------	<.0001	98	1.5 ppm Al; 0.08 ppm Zn.
148,228	2,397	1,230	53,800		--------	--------	80,900	9,484	342	--------	--------	--------	.003	126	
182,233	4,696	2,047	63,800		--------	--------	107,000	4,485	205	--------	--------	--------	.004	140	
55,778	1,565	613	20,500		--------	--------	33,900	1,408	735	--------	--------	--------	.004	120	
32,168	5,500	580	5,750	94	--------	--------	19,500	654	90	--------	--------	--------	.01	22	8.0 g per l sludge; 0.5 ppm U in sludge.
22,311	3,700	900	3,250	95	--------	--------	12,900	1,370	86	--------	--------	--------	<.01	29	1.0 g per l sludge.
44,865	3,800	1,300	12,250	225	--------	--------	25,300	1,850	140	--------	--------	--------	<.01	22	2.7 g per l sludge; 0.5 ppm U in sludge.
14,202	1,600	240	3,350	224	--------	--------	8,100	617	71	--------	--------	--------	<.01	10	52. g per l sludge; 0.2 ppm U in sludge.
28,468	1,400	270	9,350	138	--------	--------	15,600	1,600	110	--------	--------	--------	<.01	16	1.1 ppm U in heavy oil emulsion.
169,182	3,400	2,100	55,000	264	--------	--------	105,000	3,350	68	--------	--------	--------	<.01	14	
165,411	1,690	771	61,600	245	30	3.2	97,900	2,700	--------	8.8	161	.4	.0022	58	6.5 ppm Zn.
113,585	5,160	2,470	34,800	240	351	12	69,300	845	--------	2.1	124	.5	.0004	224	1.6 ppm Al; 4.9 ppm Zn.
171,156	4,810	1,600	58,300	600	--------	--------	104,000	1,300	--------	1.2	29	.2	<.0001	1,170	Oil well producing from "granite wash"; 16.0 ppm Al; 3.8 ppm Zn.
195,151	8,704	2,634	65,000		--------		117,000	1,743	--------	--------		--------	.005	724	Do.
261,984	14,500	18,800	57,700	1,640	833	42	167,000	493	--------	6.8	510	21	.010	147	33 ppm Al; 17 ppm Zn.
4,246	813	162	419	19	4	.57	1,130	1,630	--------	1.0	31	.32	.0005	7	29 ppm Al; 2.9 ppm Zm.
105,550	2,560	1,870	32,800	1,060	365	6.0	62,300	4,140	--------	2.5	96	.60	<.0001	33	2.5 ppm Al; 4.7 ppm Zn.
241,706	3,220	5,400	88,100	2,330	692	9.8	139,000	2,800	--------	4.5	53	1.4	.0008	97	16 ppm Zn.
235,044	2,360	8,400	69,500	2,210	853	20	144,000	7,100	--------	1.2	41	.2	.0008	62	24 ppm Al; 5.0 ppm Zn.
247,708	1,670	863	88,000	2,310	146	17	151,000	2,800	--------	1.5	47	.4	.0006	227	11 ppm Al; 5.0 ppm Zn.
238,749	8,280	13,100	62,500	1,490	782	52	151,000	754	--------	2.2	275	8.8	.0025	150	22 ppm Al; 7.5 ppm Zn.
271,330	2,870	7,010	92,200	3,650	1,050	20	162,000	2,310	--------	5.4	27	.06	.0042	141	14 ppm Al; 17 ppm Zn.
152,114	7,823	1,844	48,314		--------	--------	92,658	1,396	52	--------	--------	--------	--------	288	
135,355	7,963	2,227	41,391		--------	--------	82,270	1,421	83	--------	--------	--------	--------	550	4.0 ppm F; 12 ppm B.
258,706	1,650	1,589	97,200		--------	--------	155,314	2,927	26	--------	--------	--------	--------	27	
10,373	1,550	184	2,280	77	--------	--------	4,350	1,760	--------	.62	132	3.7	.0011	48	1 ppm Zn.

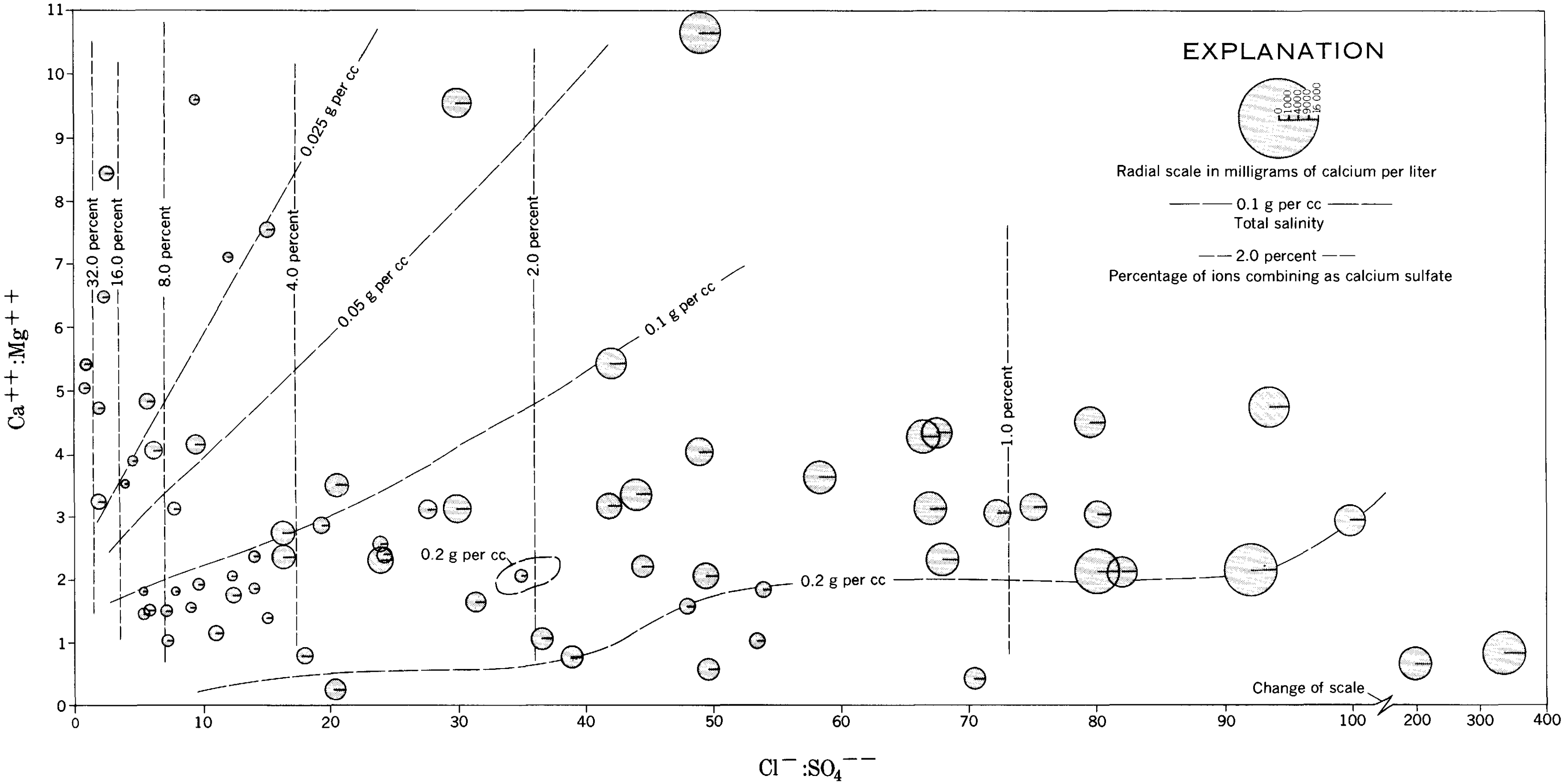


FIGURE 7.—Calcium, calcium sulfate, and salinity content compared to calcium to magnesium and chlorine to sulfate concentration ratios in Panhandle field brines.

show the radium, calcium, total salinity, and calcium sulphate contents of the individual brine samples as a function of their calcium to magnesium and chlorine to sulfate concentration (weight) ratios. The diagrams show that both radium and calcium are enriched in brine samples having high chlorine to sulfate ratios and high salinities. The parallel enrichment of radium and calcium in these waters probably can be attributed to the fact that both elements, as members of the alkaline-earth family, have similar chemical properties, are more soluble as the chloride than as the sulfate, and may tend to form similar complex ions. Ion exchange reactions with interstitial clay, organic substances, and other materials in the rocks may also have an important influence on the radium and calcium concentrations in the waters. Inasmuch as calcium is a major constituent of the reservoir rock, the calcium content of a brine is probably determined by the relative concentrations of other ions in solution. In particular, the sulfate ion concentration seems to be important, and contouring of the analytical data suggests that the brines are saturated with calcium sulfate (fig. 7). This saturation would be expected because anhydrite is an abundant reservoir mineral that is probably always present in excess of the amount that could dissolve in the brine.

The distribution of the radium in the brines (fig. 6) does not suggest the presence of reservoir rocks that are very highly enriched in uranium. Brines having approximately the same chemical compositions also have radium concentrations that are to within one order of magnitude of one another, despite the fact the brine samples were taken from different wells. The sample with the highest radium concentration (1560×10^{-12} curies per liter) comes from a well where the reservoir rocks contain uraniferous asphaltite; however, the radium content of this sample is only about five times that of brines of similar composition.

Figures 6 and 7 show that the salinity of the brines decreases with an increasing calcium to magnesium ratio and decreasing chlorine to sulfate ratio. The decrease in salinity probably is a result of dilution of highly saline connate brines either by encroaching ground water having low salinity, by condensation of water vapor in boreholes of the gas wells, or by leakage of artesian water from above the casing points of the wells.

The highly saline brines of the Panhandle field are most likely derived from the evaporites of Leonard age, which overlie the oil and gas reservoir rocks. They may represent bitterns which were incorporated during deposition of the rocks and were released through subsequent compaction of the thick shales that are interbedded with the evaporites. Or they may represent meteoric water which has percolated downward through the evaporite sequence prior to accumulation of the gases in the reservoir rocks.

The radium data discussed above are analyses of Ra^{226}, a decay product in the uranium series that has a half life of 1620 years. There are three other naturally occurring radium isotopes in the Panhandle field brines: Ra^{223}, Ra^{224}, and Ra^{228}. Ra^{223} has a half life of 11.7 days and is a decay product in the actinium series. Ra^{224} and Ra^{228} have half lives of 3.64 days and 6.7 years, respectively, and are decay products in the thorium series.

Analyses of these short-lived radium isotopes in brine samples from two wells (table 9) show that significant amounts of the radium isotopes are present in the waters. The uranium contents of these brines are insufficient to support the radium. The relative concentrations of the radium isotopes consequently provide a basis for estimating the time that they have been in solution. At radioactive equilibrium Ra^{226} equals Ra^{223}, and Ra^{228} equals Ra^{224} when expressed in "equivalent" units. (See headnote, table 9, for definition of equivalent units.) Calculation shows that for the brine from well 455 the disequilibrium age (the time since the isotopes were in equilibrium) of the Ra^{226} and Ra^{223} is about 5 days, and the age of the Ra^{228} and Ra^{224} is about 4 days. Similarly the data for the brine from well 316 show a disequilibrium age of about 15 days for the Ra^{226} and Ra^{223} and 2 days for the Ra^{228} and Ra^{224}. The samples were 1 day old when they were analyzed. Allowing for this time interval and the time required for the brines to flow from the reservoir rock into the boreholes (about 4 days), the results indicate that the radium isotopes were derived from parent radioelements existing in the rock pores in the immediate vicinity of the wells.

TABLE 9.—*Isotopic composition of radium in brines from two wells in the Pandandle field*

[Analyses by J. N. Rosholt, Jr. The data are expressed in terms of the equivalent amounts of uranium and thorium that would be in equilibrium with the observed concentrations of their respective radium daughter products (Rosholt, 1954)].

	Milligram equivalents per liter[1]	
Isotope	*Well 455*	*Well 316*
Ra^{226}	4. 23	0. 096
Ra^{223}	3. 1	. 04
Ra^{228}	1. 7	. 037
Ra^{224}	. 73	. 026

The ratio of Ra^{228} and Ra^{226} is 0.40 for well 455 and 0.39 for well 316. These values should approximate the ratio of thorium to uranium at the source of the radium.

URANIFEROUS ASPHALTITE

The search for the parent radioelements of the radon and helium in the Panhandle field resulted in the discovery of a uranium-bearing carbonaceous material,

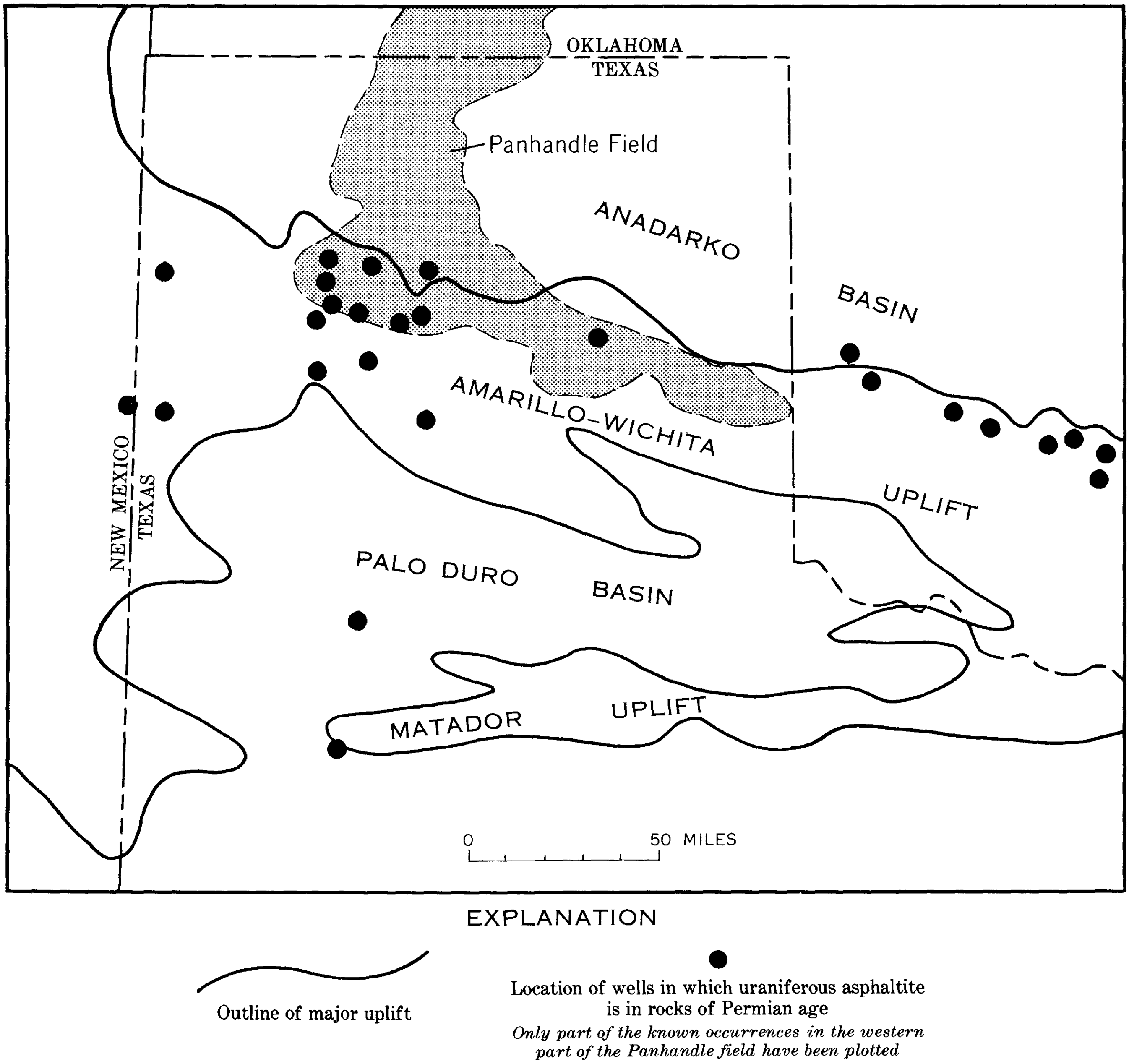


FIGURE 8.—Regional distribution of uraniferous asphaltite in the Texas Panhandle and adjacent areas.

termed “asphaltite,” in drill cuttings of the reservoir and cap rocks of the gas field.

The asphaltite is a metalliferous carbonaceous mineraloid that occurs as botryoidal nodules and impregnations filling secondary pore spaces and fractures. It is a black solid brittle, highly lustrous substance, combustible at high temperatures and insoluble in organic reagents. The hardness ranges from 4 to 5, the average specific gravity is 1.3, and the index of refraction is about 1.7.

The asphaltite is enriched with arsenic, uranium, cobalt, and nickel. Autoradiographs indicate that the uranium is rather evenly distributed throughout the asphaltite, whereas studies of polished surfaces indicate that the arsenic, cobalt, and nickel are present in mineral inclusions finely disseminated within the asphaltite.

X-ray analyses of the asphaltite have shown the presence of uraninite, chloanthite-smaltite, xenotime, anhydrite, pyrite, dolomite, celestite, quartz, and graphitic carbon. Erythrite, the hydrous cobalt arsenate “bloom,” has been observed on one sample but it had evidently formed after the sample had been obtained from the well.

Uranium-bearing asphaltite is present throughout the stratigraphic sequence studied as part of this investigation. It is sparsely disseminated throughout the lower part of the "Brown dolomite," "Moore County lime," "granite wash," and fractured parts of the Precambrian complex. It is most abundant in drill cuttings from the "Red Cave" and the upper part of the "Panhandle lime." Plate 2 illustrates the distribution of asphaltite in the western part of the Panhandle field.

Uraniferous asphaltite has also been observed in these rocks where they are exposed along the north flank of the Wichita Mountains (fig. 8), in drill samples from numerous wells along the north side of the uplift, and from wells in the Palo Duro basin.

Of possible genetic significance is weakly uraniferous organic material in oil-producing dolomites and shales of the upper part of the "Panhandle lime" in the Anton oil field in the Palo Duro basin (well 7, fig. 9). The dolomites and black shales contain graptolites and other fossil marine-plant remains throughout a thickness of 400 feet. Some samples of the plant remains contain as much as 30 ppm uranium. These organic materials have been deposited in the same carbonate-evaporite sequence in which the Panhandle asphaltite occurs and may represent the type of materials from which the asphaltite was derived.

NOMENCLATURE

A variety of names have been introduced into the literature dealing with the solid forms of carbonaceous substances, especially substances enriched in heavy metals. Terms that have been used to describe carbonaceous materials enriched in uranium are: "huminite," "thucholite," "carburan," "anthraxolite," "carbon," "hydrocarbon," "bitumen," "pyrobitumen," and "asphaltite." Serious objections can be raised to the use of any of these terms. Use of the words "carbon" and "hydrocarbon" conflicts with their definitions in chemical terminology. The words "thucholite" and "carburan" indicate a more specific association of elements than is present in many localities. The generic terms "huminite," "anthraxolite," "bitumen," and "asphaltite" imply that the substances were derived from definite source materials, which has in no case been demonstrated. In addition to these terms, geographic and personal names have been applied to these types of substances, such as: "albertite," "grahamite," "elaterite," and "gilsonite."

No single convenient name embracing all these materials has been widely accepted. The confusion of nomenclature results from the fact that little is known about the origin of these substances and the nature of the chemical compounds which compose them. Systems of classification based upon their physiochemical properties and ultimate chemical compositions such as Abraham's (1945, p. 56–59) have, thus far, proved to be inadequate. In a mineralogical sense, the substances can be grouped together as carbonaceous or organic "mineraloids." This term, revived by Levorsen (1954), was originally introduced by Rogers (1937, p. ix) who defined it as follows: "Naturally occurring amorphous substances with chemical compositions and physical properties less definite than those of crystalline minerals are considered as mineraloids."

It is informative when describing these types of materials to modify the description with some petrologic term describing their shape or their relation to the host rock. Most solid carbonaceous mineraloids occur either as nodules, as vein or fracture fillings, as impregnations, or rarely as lenses, layers, or pseudomorphs. The nodular variety is the most characteristic form of occurrence of the uranium-bearing carbonaceous mineraloids. The nodules frequently possess a botryoidal or warty surface, and in the writers' experience no nodules of this kind have proved to be nonuraniferous.

In the absence of detailed knowledge regarding the chemistry of these substances, some term of common usage is desirable. In this report, the word "asphaltite" is used as a general term embracing all solid amorphous dark, apparently homogeneous carbonaceous mineraloids that are physically distinct from surrounding materials. It is in this sense that "asphaltite" has been used as a mineralogic field term in a large volume of literature, and its continued use would appear to be justified. Although the word suggests an asphaltic or petroliferous source material, such a source is not inconsistent with the observations and conclusions concerning the materials described in this report.

REVIEW OF THE LITERATURE

Many occurrences of carbonaceous nodules that are enriched in different metals have been reported in the literature. The most unusual of these occurrences is, perhaps, the nodular thucholite found in pegmatites of Precambrian age of the Parry Sound area, Ontario, Canada. Ellsworth (1928a) was the first to make a detailed study of these nodules. Analyses showed them to be enriched in thorium, uranium, vanadium, and rare earths; the chief organic constituents were carbon, oxygen, and hydrogen. On the basis of its chemical composition, Ellsworth termed the substance composing the nodules "thucholite." Repeated analyses showed that the chemical composition was variable and that the material was not a single mineral but apparently a mixture of compounds. Because of the nature of its physical occurrence, Ellsworth believed the thucholite to be a primary mineraloid formed through reaction of uranium and thorium with carbonaceous gases escaping from a granite magma. However, a subsequent examination of

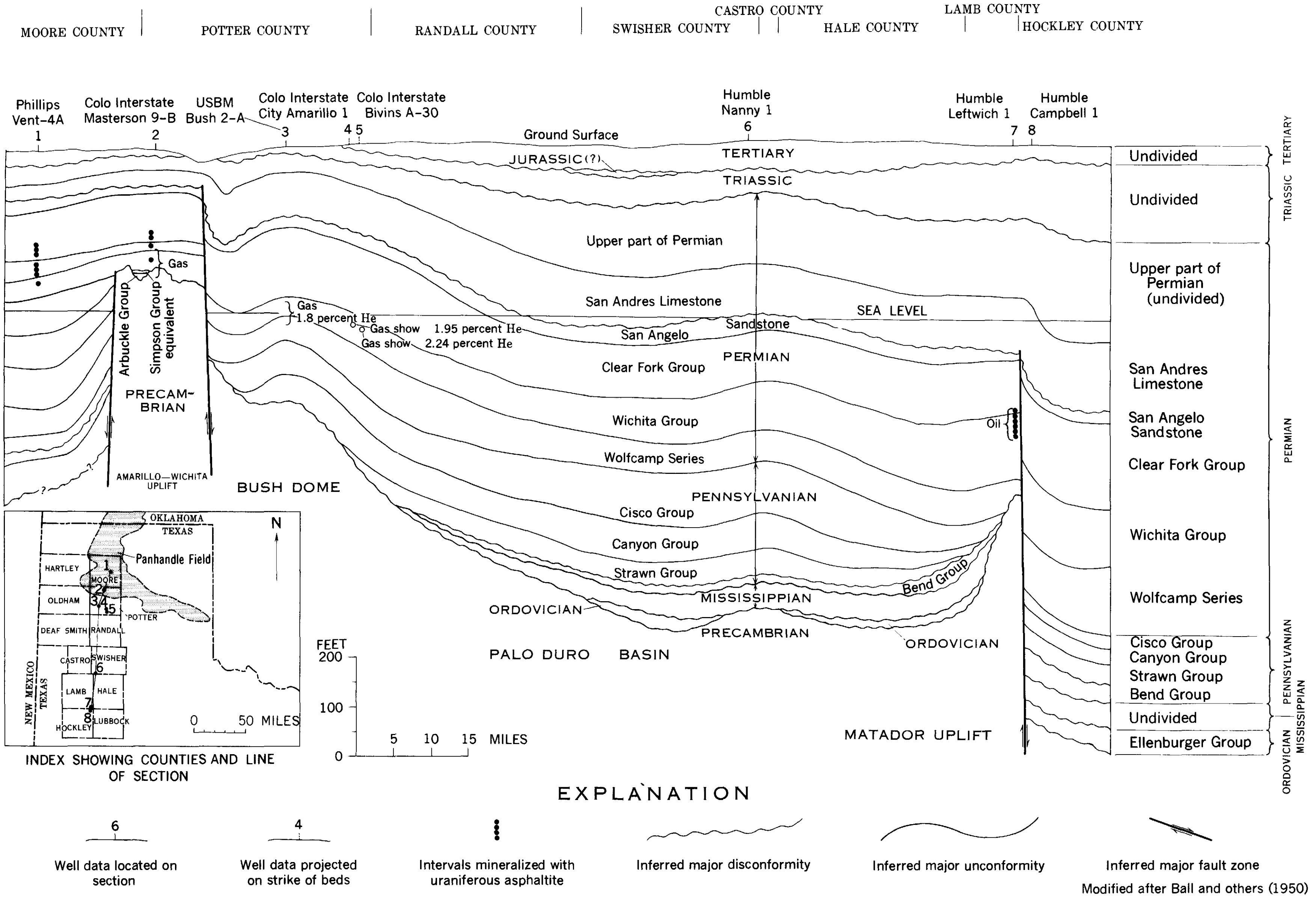


FIGURE 9.—Diagrammatic cross section from Moore County, Tex., to Hockley County, Tex. (modified after Ball and others, 1950).

one of the pegmatites of the Parry Sound area by Spence (1930) revealed the presence of petroleum and asphalt seeps within the dike. Spence noted that the thucholite in the dike was most abundant in proximity to cross-fractures containing the oil and asphalt seeps. The thucholite nodules were in many places associated with pockets of minerals containing uraninite and also occurred as pseudomorphs in which thucholite appeared to have replaced uraninite. Other relationships included veinlets of thucholite cutting fractured minerals. Spence suggested that the thucholite had been formed from petroleum which had seeped into the dike and had been polymerized by the effects of radiation from uranium and thorium minerals to form the nodules.

Thucholite, apparently similar to that described by Ellsworth and Spence, has since been reported from a large number of localities on the Canadian shield. Ellsworth (1928a, b) originally reported thucholite from four widely separated localities in eastern Canada. A tabulation by Lang (1952) mentions the presence of thucholite in a number of uranium districts on the Canadian shield of Saskatchewan and the Northwest Territories, Canada. The thucholite is reported to occur in quartz veins, frequently with pyrite and pitchblende; however, no detailed studies have been made of it in these areas.

Uranium-bearing carbonaceous nodules similar to thucholite have also been reported in pegmatites of Karelia, Russia, where the material has been termed "carburan" (Labuntsov, 1939; Grigoriev, 1935). A "carbonaceous uraninite" from a granite pegmatite in Fukuoka prefecture, Japan, has also been described (Kimura and Iimuri, 1937).

Uranium-bearing carbonaceous substances have been known for nearly a century in Sweden where they have been described by a number of investigators. A review of the data of this early literature is given by Davidson and Bowie (1951).

Grip and Odman (1944) have described thucholite nodules in quartz lenses and veins in Precambrian andalusite rocks at Boliden, Sweden. Drill holes in the vicinity of the thucholite nodules discharge unusual amounts of helium-rich hydrocarbon gases. Analyses of the gases from a number of drill holes showed they contained from 2.3 to 5.4 percent helium, 22.9 to 36.6 percent nitrogen, 59.6 to 68.8 percent methane, and small amounts of carbon monoxide, carbon dioxide, hydrogen, and hydrogen sulfide. Grip and Odman proposed that the thucholite nodules had resulted from polymerization of the hydrocarbon gases by radiations from uranium minerals.

The thucholite or uranium-bearing carbonaceous material in the Witwatersrand reefs of South Africa is economically the most important deposit of this type known. A study of this material as well as of similar materials from several occurrences in Australia, England, and Canada was made by Davidson and Bowie (1951), who concluded that the "hydrocarbon-uraninite complexes" had been formed as the result of polymerization of hydrocarbon gases by radiation from previously deposited uranium. Analysis of a gas from faults in underground workings in the Witwatersrand reefs showed 8.3 percent helium, 13.9 percent nitrogen, 76.6 percent methane, 0.5 percent argon, 0.2 percent oxygen, 0.4 percent carbon dioxide and 0.1 percent hydrogen (Bowie, 1958).

Hess (1922) reported uranium-bearing nodules in sandstones of the San Rafael Swell, Utah, and regarded them as being of detrital origin. Later Gott and Erickson (1952) suggested that the uranium and other metals present in these nodules had been introduced by petroleum.

From a reconnaissance study of uranium and trace metals in crude oil, asphalt, and petroliferous rocks, Erickson and others (1954) showed that uranium and a characteristic suite of other trace metals, notably nickel, vanadium, cobalt, copper, zinc, and lead, were consistently associated in the ashes of crude oil, asphalt, and asphaltite from many different localities. The greatest enrichment of these metals in the petroleum was found to be in the heavy surface-active fraction which adheres to the surface of the rock. The results suggested that petroleum might be an important agent in the formation of some types of uranium deposits, but the authors pointed out that further research on the nature of metallic compounds soluble in petroleum was required to evaluate the significance of petroleum as a possible transporting agent of these metals.

Uraniferous, but noncarbonaceous, nodules that are similar in several respects to those occurring in red beds of the Texas Panhandle field have been found in red beds of Permian age of Great Britain, and have been studied by a number of investigators (Carter, 1931; Perutz, 1939; and Ponsford, 1954, 1955). As originally described by Carter (1931), these nodules occur in red marlstones, and consist of a hard, black nucleus surrounded by a bleached greenish-white halo. Concentric black bands are often present in the bleached area, and a photograph by Ponsford (1954) shows the presence of well-developed liesegang rings surrounding the nucleus of a nodule from a core sample. Analyses of these nodules (Carter, 1931) show that the black nucleus consists of a silty matrix that is enriched in vanadium, uranium, cobalt, and nickel. Niccolite (NiAs) was identified in the nucleus, and analyses of the red and white parts of the rock by Perutz (1939) indicated that ferric iron had been removed from the bleached halos and redeposited at their external boundaries.

Uraniferous nodules that are similar to those described above also have been reported in red mudstones of the Sibley Series of Precambrian age in Canada (Tanton, 1948). Still another occurrence may be present in the red beds of Permian age of Saxony, Germany (Schreiter, 1925), although the presence of uranium was not investigated. These occurrences are of interest with respect to the uraniferous nodules described in this report in that they suggest that uranium, vanadium, nickel, cobalt, and arsenic may be deposited in red beds of lithology similar to those described here without the aid of an organic medium.

PHYSICAL PROPERTIES

The uraniferous asphaltite in the Panhandle field occurs in intergranular secondary pore spaces and fractures. Morphologically, two varieties of asphaltite are present: relatively large nodules as much as 1 inch in diameter characterized by irregular and botryoidal shapes, and small nodules that are characterized by high sphericity and are generally less than 0.1 mm in diameter. Nodules 1 to 3 mm in diameter constitute most (by volume) of the asphaltite seen in the drill cuttings (table 10). The most numerous nodules, however, are less than 0.1 mm in diameter (table 11).

TABLE 10.—*Size distribution of asphaltite nodules from the reservoir and cap rocks of the western part of the Panhandle field*

Lithology	Nodules					
		Diameter (millimeters)				
	Total	<1	1-2	2-3	3-4	4-5
		Distribution (percent of total)				
Limestone, anhydrite, dolomite	324	93	3	3	1	0
Sandstone, siltstone	279	94	4	2	0	1
Arkose	107	93	6	1	0	0
Total or average	710	94	4	2	1	1
Asphaltite ——volume percent	--------	6	26	59	4	5

TABLE 11.—*Fine-size distribution of asphaltite nodules from the reservoir and cap rocks of the western part of the Panhandle field*

Lithology	Nodules						
		Diameter (millimeters)					
	Total	<0.1	0.1–0.2	0.2–0.3	0.3–0.4	0.4–0.5	>0.5
		Distribution (percent of total)					
Limestone, anhydrite, dolomite	302	43	19	12	6	6	14
Sandstone, siltstone	264	48	19	12	5	3	13
Arkose	101	41	17	15	12	6	9
Total	667	45	19	12	7	5	12

The large nodules are formed through intergrowth of many small ones as is shown by figures 10 and 11. The numerous small nodules are of approximately the same dimension as the pores of the rocks in which they occur. This similarity indicates that the asphaltite originated as dispersed globules or films of an organic fluid which had permeated these rocks. The veinlet type of asphaltite likewise consists of a series of small and closely packed nodules along the length of the veinlet (fig. 11).

The specific gravity of the nodules ranges from 1.26 to 1.53 and averages about 1.3 (table 12). The range in specific gravity is due to variations in metal content. When the weight that can be attributed to the average metal content of the nodules is subtracted from their average specific gravity, a residual specific gravity of about 1.1 is obtained which probably represents the density of the organic phase.

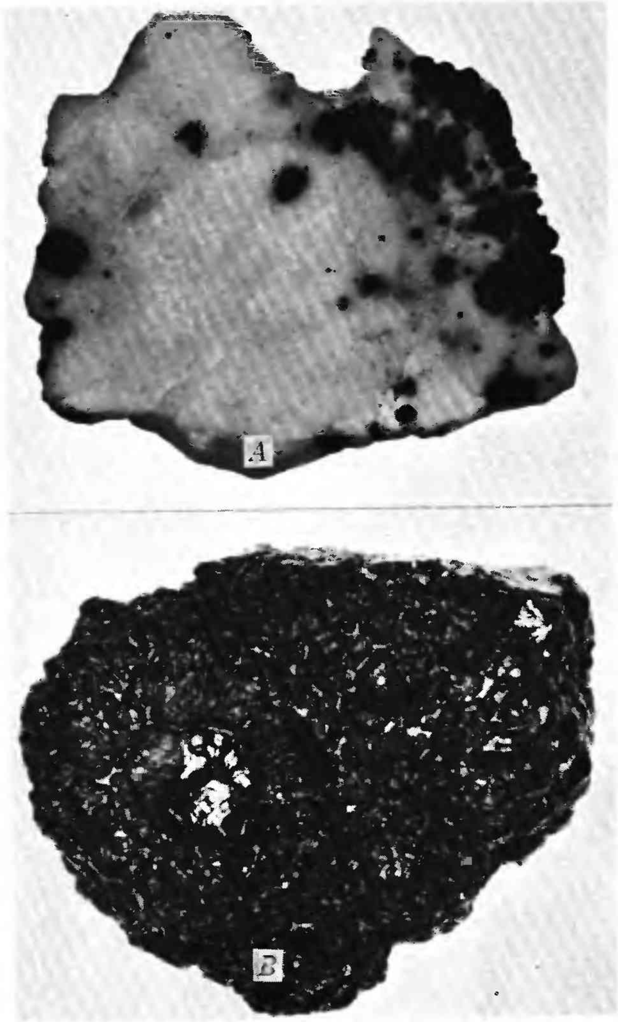


FIGURE 10.—*A*, Dense anhydritic oolitic dolomite from the "Red Cave" containing disseminated nodules of asphaltite, well 825a. × 9.8. *B*, Asphaltite nodule from the "Red Cave" showing botryoidal structure, well 832. × 5.

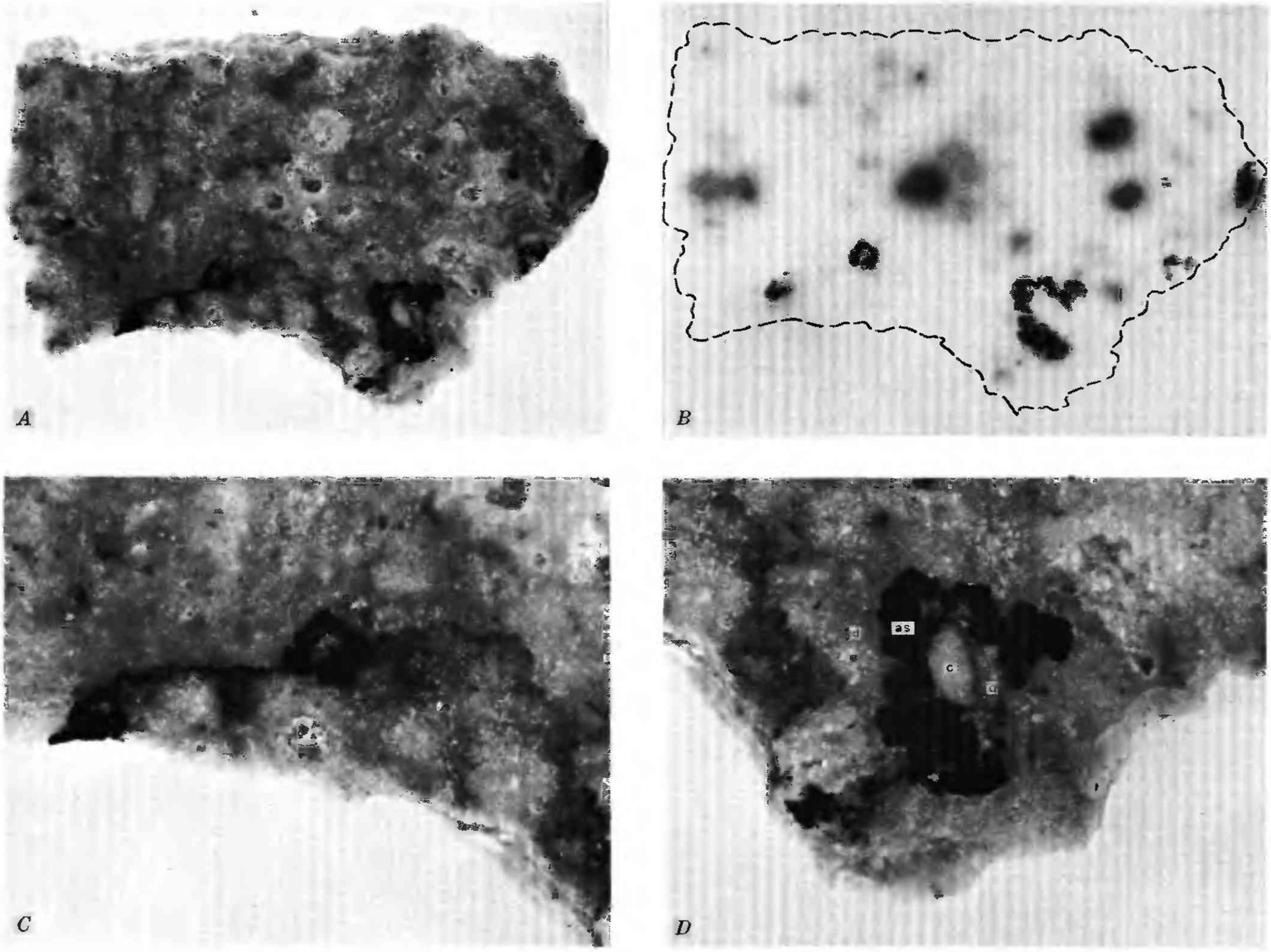


FIGURE 11.—Asphaltite in porous crystalline dolomite from a major gas-producing zone in the "Brown dolomite," well 623. *A*, Veinlets filled with closely packed asphaltite nodules. × 4.9. *B*, Autoradiograph of *A* on alpha-sensitive film. Sharply bounded black areas are due to uraniferous asphaltite, and diffuse areas are due to radon emanated from the pores. (Exposure time 8 weeks.) *C*, An enlarged part of *A* showing relation of asphaltite (as) to residual oil. × 12.6. *D*, An enlarged part of *A* showing apparent replacement of chert (c) and dolomite (d) by asphaltite (as). × 12.6.

Polished-section studies indicate that the asphaltite has a variable hardness ranging from 4 to 5 on Mohs scale. Most of the nodules break with a conchoidal or platy fracture, but some fracture along radial or concentric lines. The carbonaceous matrix of the nodules is neutral gray in reflected light, slightly pleochroic in reflected polarized light, and moderately anisotropic. Amber-colored internal reflections originating from metallic minerals buried just below the plane of the polished surface are common within the carbonaceous matrix. When finely powdered, the material transmits amber light at thicknesses of less than 2 microns, and the index of refraction averages about 1.7.

COMPOSITION AND MINERALOGY

Approximately 90 percent of the uraniferous asphaltite is composed of carbon, hydrogen, and oxygen; the remainder consists chiefly of metals, notably arsenic, uranium, nickel, cobalt, and iron.

TABLE 12.—*Specific gravity and size of some asphaltite nodules from drill cuttings, western part of the Panhandle field*

Well (pl. 1)	Nodules		
	Weight (mg)	Specific gravity in toluene at 30° C	Mean diameter (mm)
542	0.279	1.33±0.02	0.67
623	.389	1.33±0.02	.74
583	.812	1.53±0.02	1.09
887a	1.231	1.30±0.02	1.37
887a	1.815	1.26±0.02	1.68
887a	.634	1.34±0.02	----------
401	.198	1.32±0.02	----------

Organic analyses show the asphaltite to be made up of 78 to 80 percent carbon, 3 to 6 percent hydrogen, more than 3 percent oxygen, and as much as 0.43 percent nitrogen (table 13). The presence of oxygen and nitrogen suggests that the organic source material of the asphaltite consisted in part of complex organic compounds as well as hydrocarbons. The most prob-

TABLE 13.—*Organic analyses, in percent, of asphaltite nodules from the western part of the Panhandle field*

[Analyses by Clark Microanalytical Laboratory, Urbana, Ill.]

Well (pl. 1)	Sample (table 14)	Elevation of sample interval above sea level (feet)	Stratigraphic unit	Lithology of host rock	Ash	Carbon	Hydrogen	Oxygen	Sulfur	Nitrogen
825a	3	1492–1462	"Red Cave"	Siltstone cemented with secondary anhydrite.	5.39	77.63	3.59	3.41	0.00	Tr.
	18	1292–1262	"Panhandle lime"	Medium-grained oolitic dolomite cemented with secondary anhydrite.	10.93	79.86	5.91			
832			"Red Cave"	Shale	10.97	79.88	5.61			.43

able source of oxygen- and nitrogen-bearing compounds are asphaltenes, resins, and organic acids found in petroleum and associated brine.

Petrographic and X-ray studies suggest that the uraniferous asphaltite has formed from a nonuraniferous red organic material with which it sometimes occurs. The spatial relation of these two materials is shown on figure 12*A* where a veinlet of the red organic material, which is highly fluorescent, grades into uraniferous asphaltite. Secondary anhydrite occurs interstitially with uraniferous asphaltite but not with the red organic material. The paragenetic sequence suggests that the asphaltite has formed from the red organic material and implies that the uranium was introduced by the aqueous solutions from which the anhydrite was deposited.

The manner in which the red organic material occurs suggests that it was adsorbed from oil or precipitated from brine that permeated the rock. A study of its chemical properties by X-ray diffraction and infrared spectroscopy indicates that it is related to the uraniferous asphaltite.

X-ray studies of both the red organic material and the uraniferous asphaltite show the diffuse halo patterns characteristic of armorphous carbonaceous substances. Two sets of diffraction halos are present in X-ray powder patterns of both materials. One set of halos has "d" spacings of 3.4 and 2.0 angstroms and is attributed to graphitic carbon (for example, see Clark, 1955). The other set of halos have "d" spacings of about 4.8 and 2.2 angstroms that correspond to the expected spacings for halos produced by aliphatic C–C bonds with lengths of 1.54 angstroms (for example, see Simard and Warren, 1936). This set of halos is more intense in the red organic material than in the uraniferous asphaltite; the relation suggests that these structures have been partially destroyed by radiation damage during conversion to asphaltite.

Infrared analyses of the uraniferous asphaltite and the red organic material also indicate the presence of aliphatic structures (Pierce, Mytton, and Barnett, 1958). Both materials contain infrared absorption bands that are due to aliphatic carbon-hydrogen groups. A possibly significant feature of the infrared patterns is the presence in both materials of weak carbonyl absorption bands which suggests that the materials may have been derived in part from organic acids or esters occurring in the petroleum and petroleum brine. These types of compounds often possess strong polarities and are attracted to oil-water and oil-mineral interfaces (for example, see Bartell and Niederhauser, 1946).

Significant concentrations of arsenic, uranium, cobalt, nickel, and iron occur in the asphaltite (table 14). Copper, silver, lead, vanadium, bismuth, molybdenum, and rare earths are enriched to a lesser degree.

X-ray crystallographic identifications show that the asphaltite contains anhydrite, dolomite, celestite, quartz, uraninite, chloanthite-smaltite, xenotime, pyrite, and graphitic carbon. (See table 14.) The identifications conform well with the spectrographic data inasmuch as the most frequently occurring metals in the asphaltite constitute the minerals identified. Other metallic minerals that have been observed in intimate association with, but not as inclusions in, the asphaltite, are galena, sphalerite, chalcopyrite, and native copper. A few nodules from the "Red Cave" are composed largely of smaltite-chloanthite with minor amounts of asphaltite. Tiny isolated cubes of skutterudite ($(\mathrm{Co,Ni})\mathrm{As}_3$) were found in one core sample of hematitic shale from the "Red Cave."

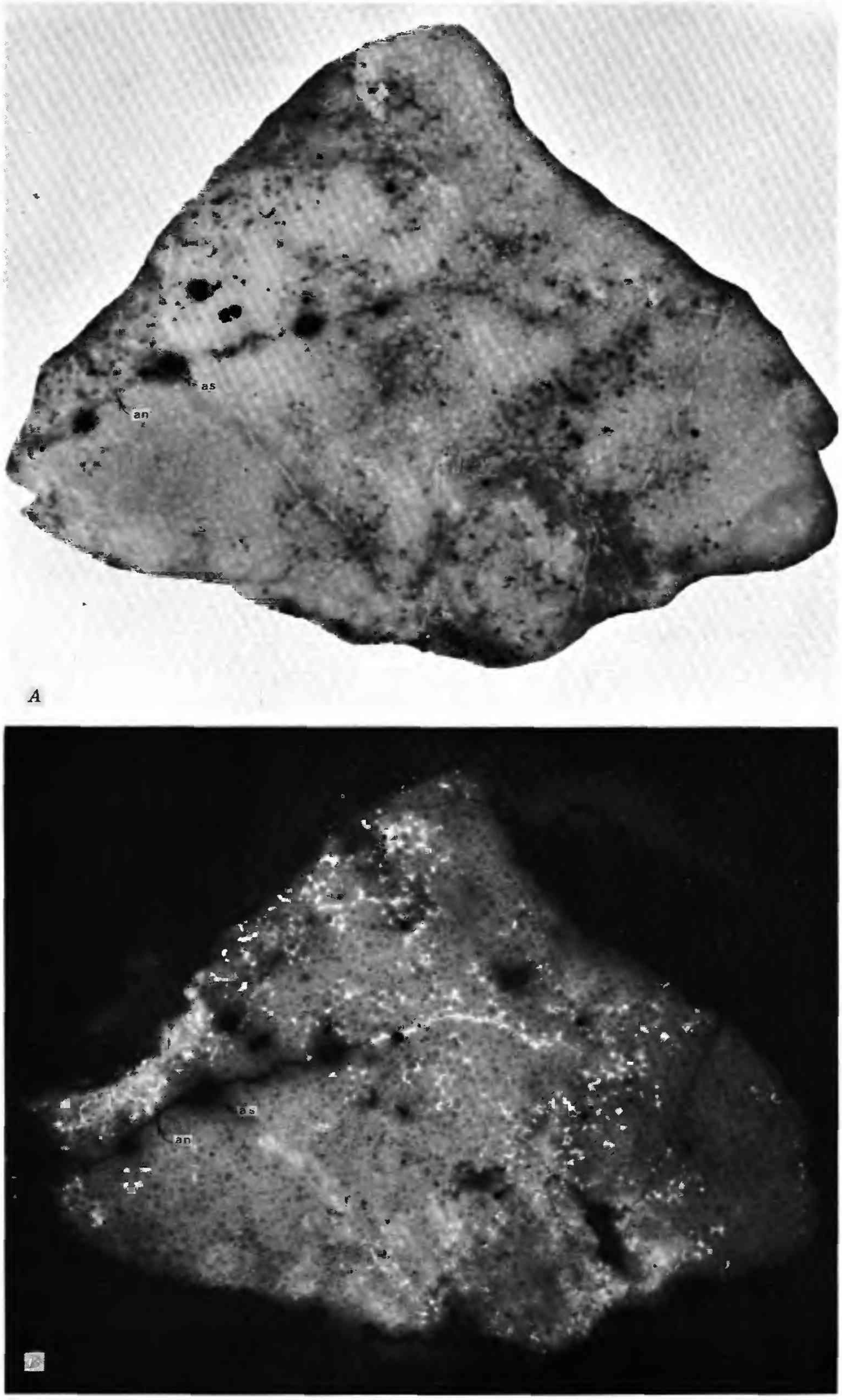


FIGURE 12.—Relation of anhydrite and nodular asphaltite to red organic material in oolitic dolomite from the "Panhandle lime," well 825a. *A*, White-light photograph of anhydrite (An) and nodular asphaltite (As) in oolitic dolomite. × 11.7. *B*, Ultraviolet light photograph of specimen *A* showing asphaltite (As), anhydrite (An), and fluorescent red organic material (white). × 10.7.

TABLE 14.—*Spectrographic, radiometric, and X-ray crystallographic*

[Spectrographic analyses by A. T. Myers and P. J. Dunton, radiometric analyses by J. N. Rosholt, Jr.; X-ray crystallographic analyses by W. F. Outerbridge and Evelyn Cisney, all with the U.S. Geological Survey. The elements are arranged according to their periodic chemical families (Moellar, 1952). Elements which were detected, but not listed in the table are: 0.0x− Gd and 0.000x− Be in sample 4; trace of Nb in sample 11; 0.0x Ge in sample 26; 0.0x Zn, 0.00x Sn, and 0.000x Ga in sample 27; and 0.000x+ Ga in sample 28. The analyses were made with substandard amounts of sample. eU, equivalent uranium, is defined as "the ratio of the net counting rate of

Sample	Well (pl. 1)	Sample interval (elevation above sea level, in feet)	Stratigraphic unit	Na	K	Cu	Ag	Ca	Mg	Sr	Ba	Sc	Al	B	Ti
1	231	1338–1328	"Red Cave"	0	0	0.0x+	0.000x−	x.+	0.x	0.00x	0.x−	0	x.	0	0.0x−
2	751	[1] 1629–1609	do	0	0	.0x	.000x−	x.	.x+	0	.00x	0	.x	0	.00x+
3	825a	1492–1462	do	.x−	0	.00x+	.000x−	.x	.x−	.000x	.00x+	.000x+	.x−	0	.x−
4	887a	1408–1398	do	.x	.x+	.0x	.0000x+	.x−	.x+	.00x−	.0x	.00x	x.−	.00x+	.x+
5	487	[1] 1499–1169	"Red Cave," "Panhandle lime."	.x−	0	.0x	Tr.	x.−	.x	.0x−	.0x+	.00x−	.x+	Tr.	.0x
6	699a	[1] 1445–1275	do	0	0	.0x	Tr.	x.	.x	.00x	.00x	0	.0x	0	.0x
7	739	[1] 1565–1385	do	0	0	.0x+	.000x+	x.	.x+	.00x	.00x	0	.x	0	.0x−
8	815	[1] 1441–1081	do	0	0	.0x	.000x+	x.	.x−	0	.0x−	0	.x	0	.0x
9	871	[1] 1412–1142	do	.0x+	0	.x	.00x	xx.	.x−	.0x−	.00x+	0	.x	.00x	.0x+
10	890a	1535–1345	do	0	0	.x−	0	x.−	.x	0	.00x	0	.x	0	.0x−
11	20b	677–667	"Panhandle lime"	0	0	.0x−	.000x−	.00x	.000x	0	.00x	.00x	.0x−	.00x−	.x−
12	736	987–977	do	--------	0	.00x	.000x	.0x	.00x	0	.000x	0	.0x	0	.000x
13	736	[1] 1097–907	do	.x	0	.00x	.000x	x.	.x	.0x	.0x	0	.x	.00x	.00x
14	748	1542–1532	do	--------	0	.00x	0	.x	.0x	.00x	.00x	0	.0x	0	.00x
15	814	1199–1189	do	--------	0	.00x	.000x	x.	.0x	.0x	.00x	0	.0x	0	.00x
16	814	[1] 1489–1389	do	0	0	.0x	0	x.+	.x	0	.00x−	0	.x	0	.0x+
17	818	[1] 1477–1367	do	0	0	.0x	.000x−	xx.	.x	.0x	.0x+	0	.x	0	.0x−
18	825a	1292–1262	do	.x−	0	.0x	.000x+	x.−	.x	.00x+	.00x+	Tr.	.x−	0	.0x
19	843a	[1] 1446–1206	do	0	0	.0x+	.000x−	xx.	.x−	.00x	.00x	0	.x	0	.0x
20	874	[1] 1269–1229	do	0	0	.x+	.000x+	x.	.x+	0	.00x−	0	.x	0	.0x
21	894	[1] 1461–1361	do	0	0	x.−	.000x+	xx.	x.	.0x+	.0x−	0	.x	.00x	.0x
22	896	1268–1258	do	--------	0	.0x	.000x	x.	.x	.0x	.00x	0	.x	Tr.	.0x
23	897	1408–1398	do	0	0	.0x+	.000x−	x.	.x	.0x+	.0x+	0	.x	0	.0x
24	897	1388–1378	do	0	0	.00x	0	x.	.0x	.x	.x	0	.0x	0	.00x
25	748	[1] 1542–1052	"Panhandle lime," "Brown dolomite."	0	0	.0x	0	x.−	.x+	.0x+	.0x	0	.x−	0	.00x+
26	487	899–889	"Brown dolomite"	0	0	0	0	x.	.0x−	.0x−	.000x	0	.0x−	.00x+	.00x
27	896	1128–1115	do	.x	.x	.0x	Tr.	x.	x.	.x	x.	.00x	x.	0	.x
28[2]	231	[1] 628–378	"Brown dolomite," "Moore County lime."	.x+	x.−	.00x+	.000x−	xx.	xx.	.0x−	.0x−	.000x+	x.+	.0x−	.x+

[1] Composite sample.
[2] Consists of heavy asphaltic coatings.

The X-ray diffraction films of 17 asphaltite samples and the trace metal content of the samples indicate that chloanthite-smaltite and possibly uraninite are consistently present as mineral inclusions, but in variable crystal sizes and amounts. Both the crystal sizes and the concentration of the crystals limit the intensity of the diffraction pattern recorded. Mineralographic studies indicate that the crystals range gradationally from approximately 2 microns to a dimension below the resolving power of the microscope.

Measurements of the uraninite lattice constants in several X-ray diffraction patterns of the asphaltites all gave cell edges of 5.46 angstroms; this measurement corresponds to uraninite composed of pure uranium oxide (UO_2) (Katz and Rabinovitch, 1951).

Three varieties of dispersed metallic mineral inclusions are seen in polished surfaces of the asphaltite nodules. The most abundant of these mineral dispersions generally form "nebular" patterns concentric to the center of the asphaltite nodule as is shown in figure 13. The individual crystals, probably chloanthite-smaltite, have a brassy luster and range in diameter from 1 to 2 microns to a dimension below the resolving power of the microscope. Exposure of the polished surfaces of the nodules to nuclear emulsions shows that the areas of these dispersions are less radioactive than the rest of the nodule. Figure 13*A* shows a sample containing a high concentration of the mineral inclusions. When this sample was coated with nuclear emulsion, almost no alpha tracks were recorded above the central metallic *analyses of asphaltite nodules from the western part of the Panhandle field*

a sample to the counting rate per percent of a uranium standard in equilibrium with all of its disintegration products, both measured under similar geometry" (Rosholt, 1954). Mineral identification was based upon X-ray diffraction patterns obtained from sample splits. x$^+$., x., and x.$^-$ means 4.64 to 10, 2.15 to 4.64, and 1.0 to 2.15 percent respectively; 0.x$^+$, 0.x, and 0.x$^-$ means 0.464 to 1.0, 0.215 to 0.464, and 0.10 to 0.215 percent respectively, and so forth. p, present as indicated by uranium flux test, but in amounts too small to be detected spectrographically.

Zr	Si	Pb	V	AS	Bi	Cr	Mo	Mn	Fe	Ni	Co	Y	Yb	U	eU	Minerals identified
0.0x	--------	0	x.	x.	0.0x$^-$	0.00x$^-$	0.0x$^-$	0.00x	0.x	0.x	0.x$^+$	0.x	----------	p	0.15	Quartz.
.00x$^-$	--------	.0x	0	x.$^-$	.00x$^+$	.00x$^-$	0	.00x$^+$	.0x	.x	.x$^-$	0	0	p	.34	Submicrocrystalline carbon, quartz.
.0x$^-$	x.0	.03	.00x	x.$^-$	.00x	.000x$^+$	0	.00x$^+$	.0x	.0x$^+$	.0x$^-$	.0x	.00x	.6	----------	Uraninite, quartz.
.0x	x.$^+$	.0x$^+$	.0x	xx.	.0x$^+$	.00x	.00x$^+$	.00x$^+$	.x$^+$	.x$^+$	.x	.x	.0x$^-$	.x$^+$	----------	Chloanthite-smaltite, quartz, pyrite.
.000x$^+$	x.	.0x$^-$	.x$^-$	xx.	0	0	.00x$^+$	.0x$^-$	.x$^-$	x.$^-$	.x$^+$	.0x$^+$	.00x	1.0	----------	Sample was not analyzed.
.00x	x.	0	0	x.	0	0	.x$^-$	.00x$^-$	.0x$^+$	x.	.x$^-$	.0x$^+$	.00x	.5	----------	Do.
.00x$^-$	--------	.0x	0	x.$^-$	.0x$^-$	.00x$^-$	0	.00x$^+$	.x$^-$	.x	.x$^-$	.0x$^-$	.00x$^-$	p	.11	Celestite, quartz.
.00x$^-$	--------	0	0	x.$^-$	.00x$^+$	.00x$^-$	.00x$^+$	.00x	.0x$^+$	.x	.x$^-$	0	0	p	.18	Quartz.
.00x	--------	.0x$^-$	.00x$^-$	x.$^+$	.0x	.000x	.00x	.00x	.x	x.$^-$	.x	.0x$^+$	.00x	.x	.21	Quartz, anhydrite.
.00x	--------	.0x$^+$	0	x.	.0x	.00x$^-$	0	.00x	.0x$^+$	.x$^+$	.x$^-$	.x$^-$	.00x	Tr.	.04	Quartz.
.00x	x.	.00x	.00x	xx.	0	.000x	.0x	.0x$^-$	.x$^-$	.x	.x	.0x	.00x$^-$	5-10	----------	Sample was not analyzed.
0	--------	Tr.	0	0	Tr.	0	0	.00x	.0x	.0x	.00x	0	0	.2	.2±	Do.
0	--------	.000x	0	.x	.00x	.000x	Tr.	.00x	.x	.0x	.0x	0	Tr.	p	.01–0.1	Do.
0	--------	Tr.	0	0	.00x	0	0	.00x	.0x	.0x	.0x	0	0	p	.1±.1	Do.
0	--------	.00x	Tr.	.x	.00x	0	.00x	.00x	.x	.x	.0x	.00x	0	.7	.77	Do.
.00x$^+$	--------	0	0	x.$^-$	.0x$^-$	.00x$^-$	0	.00x	.x$^-$	.x$^+$	.0x$^+$	0	0	.0x	.45	Quartz, anhydrite.
.00x$^-$	--------	0	0	x.$^+$	.0x$^-$	.00x$^-$	.0x$^-$	.00x$^+$	.x	.x$^+$	.x$^+$	.x$^-$	.00x	.x	.13	Submicrocrystalline carbon, quartz.
.00x$^+$	x.$^-$	.04	.0x$^-$	x.	.00x$^+$	.00x$^-$	.00x	.0x$^-$	.x$^-$	.0x$^+$	.0x$^+$	.x$^-$	.0x$^-$	.9	----------	Uraninite, quartz, chloanthite-smaltite.
.00x$^-$	--------	0	0	x.	.x$^-$	.00x$^-$	Tr.	.00x$^-$	.x$^-$	.x$^+$	.x$^+$	.0x	.00x$^-$	Tr.	.26	Uraninite, dolomite, quartz.
.00x$^+$	--------	0	.00x$^+$	x.$^+$	.0x$^+$	.00x$^-$	.00x$^+$	.00x$^+$	.x$^-$	x.$^-$	.x$^+$	.0x$^-$	.00x$^-$	.x$^+$	.33	Chloanthite-smaltite, dolomite.
.00x	--------	.0x$^-$	.00x	x.	.0x$^-$	.000x$^+$	.00x	.0x$^-$	.x$^-$	.x	.x	.0x	.00x$^-$	.x	.35	Dolomite.
0	--------	.00x	Tr.	x.	.0x	0	.0x	.00x	.x	.x	.x	.x	0	1.6	1.5	Sample was not analyzed.
.00x	--------	0	0	xx.	.0x$^+$	.00x$^-$	.0x$^-$	.000x$^+$	.x$^-$	x.$^-$	.x$^+$	.x$^-$	.00x$^+$	.x$^+$	.45	Xenotime.
0	x.	.00x	0	x.	.0x	0	.00x	.000x	.0x	.x	.0x	.0x	0	.2	.2	Sample was not analyzed.
.00x	--------	0	0	x.$^+$	.0x$^-$	.00x$^-$	0	.00x$^-$	.x$^-$	.x$^-$	.0x$^+$	.00x$^+$	.000x$^+$	p	.2	Dolomite.
.000x$^+$	.0x$^+$	0	.0x	0	0	.00x	0	0	.0x$^+$	0	0	0	0	p	----------	Sample was not analyzed.
.00x	x.	.00x	.0x	0	0	.0x	0	.x	xx.	.0x	.0x	.00x	0	p	----------	Do.
.0x	--------	.0x$^-$	.0x$^-$	0	0	.0x	.0x$^-$	.0x$^-$	x.	.0x	.00x$^-$	.00x	.000x	p	.019	Quartz, dolomite.

part of the nodule, although numerous alpha tracks originated from the surrounding organic material.

Another type of fine-sized mineral segregations in the nodules are patchy areas that appear to be made up largely of fine mineral-filled capillaries or pores (fig. 14*A*, *B*). The capillaries are tubular in shape, about a micron in diameter, several microns in length and are systematically arranged. Minute metallic mineral fillings are visible in some of the capillaries, and scratches originating in the vicinity of these areas indicate that polishing has removed minerals from them. Nuclear emulsion exposures indicate that the metallic fillings are radioactive and may be uraninite. These areas resemble the "fingerprint structure" of the nodular thucholite of Boliden, Sweden, described by Grip and Odman (1944), and are similar to features noted by the writers in a botryoidal "thucholite" nodule obtained by Henry Faul from a diamond-drill core of rhyolite from the Sudbury district, Ontario, Canada (fig. 14 *C*, *D*). X-ray diffraction patterns of the Sudbury nodule indicate the mineral inclusions present in the capillary structures of this specimen to be composed of uraninite and coffinite. The capillary structures of the Sudbury nodule are more extensive than those in the Panhandle nodules and occupy nearly the entire volume of the nodule. The uranium content of the Sudbury nodule is also greater, being approximately 6 percent as compared to an uranium content of approximately 0.2 percent in the Panhandle nodules represented by figure 14*A*, *B*.

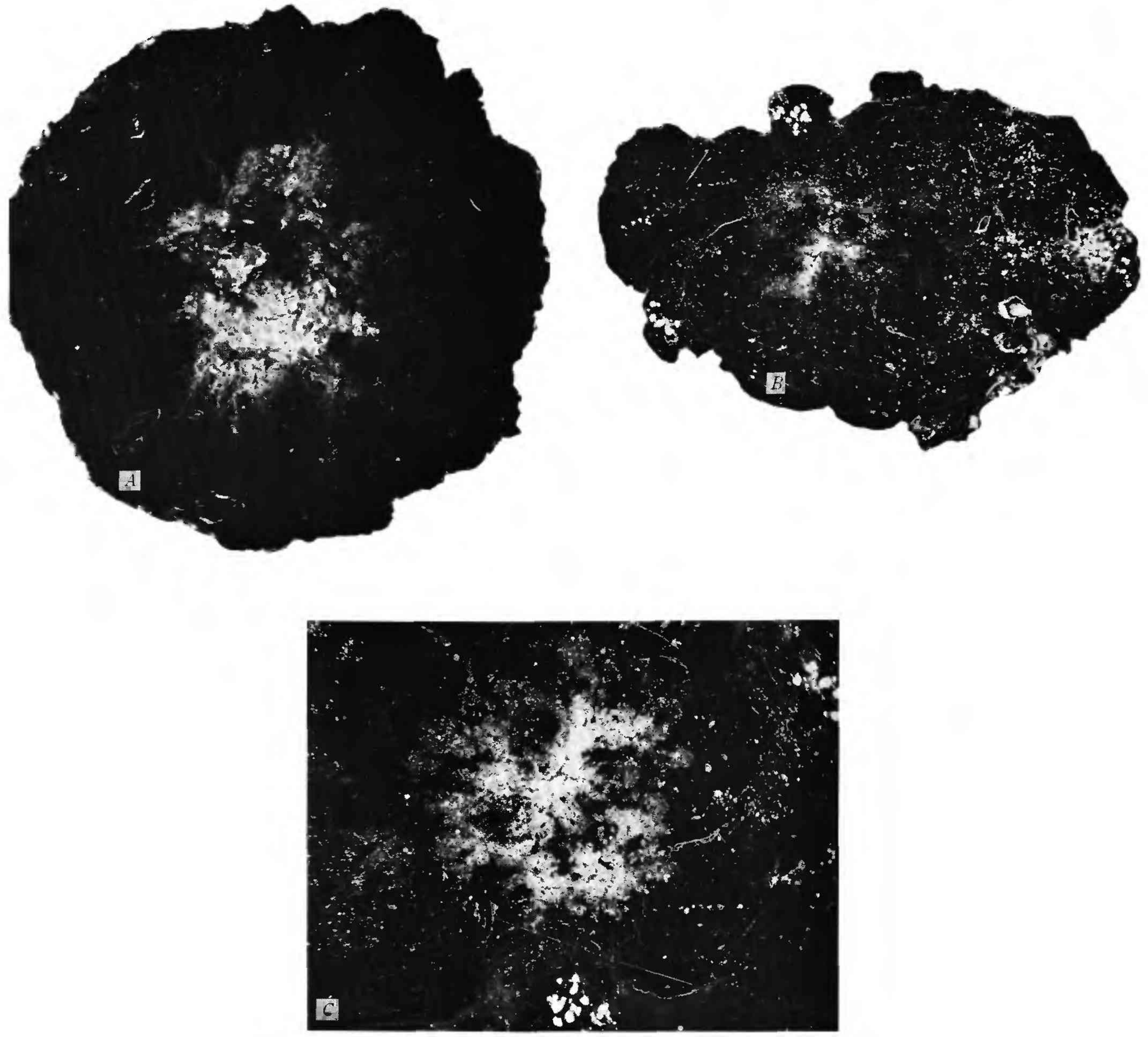
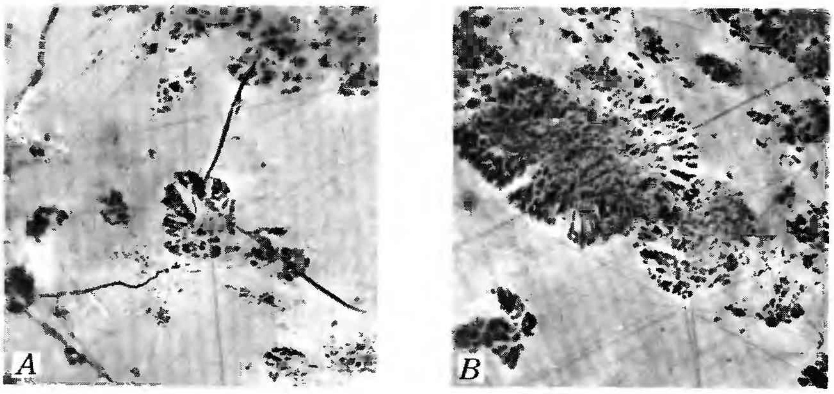


FIGURE 13.—Polished sections of asphaltite nodules showing "nebular" dispersions of smaltite-chloanthite(?). Dark field illumination. *A*, Nodule from "Red Cave," well 825a. × 81. *B*, Nodule from "Panhandle lime," well 897. × 57.7. *C*, Enlargement of a part of *B*. × 94.5.

A third type of mineral inclusion is crystal fragments of pyrite in the peripheral parts of some of the asphaltite nodules. The crystals were fractured and floated apart in the asphaltite prior to its solidification, as is shown on figure 15.

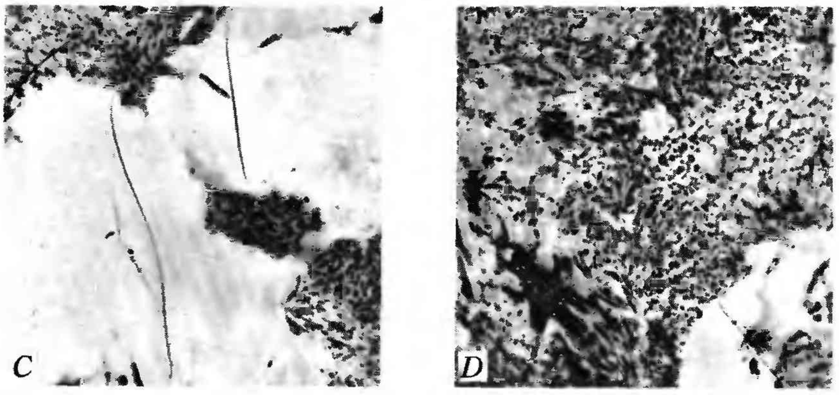
The uraniferous asphaltite nearly always occurs in or is intimately associated with secondary cements including anhydrite, celestite, and to a lesser degree silica, pyrite, residual oil stains, and asphalt. It is most commonly associated with secondary anhydrite which fills pores (fig. 16*A*, *B*) or fractures (fig. 17) or which occurs as intergranular cement in siltstone (fig. 17*B*). The close association of nodular asphaltite with secondary anhydrite suggests that it was formed contemporaneously with the introduction of sulfate-bearing solutions. Both asphaltite and anhydrite fill fractures and solution cavities and thus clearly formed after consolidation of the rocks.

Many of the asphaltite nodules appear to replace the host rock, particularly the dolomite (figs. 10*A*, 11). The nodules may have formed by a process of molecular replacement of the surrounding rock but more probably were deposited in a cavity that was continuously enlarged by solution around the periphery of the nod-



A, Nodule from the "Panhandle lime", well 897, showing "capillary" structure and shrinkage cracks. × 920.

B, Nodule from the "Panhandle lime", well 897, showing systematic arrangement and tubular shapes of "capillary" structures. × 920.



C, Nodule from a drill core of rhyolite, Sudbury district, Ontario, Canada, showing "capillary" structures and shrinkage cracks. × 920.

D, Nodule from a drill core of rhyolite, Sudbury district, Ontario, Canada, showing systematic arrangement and tubular shapes of capillary structures. × 920.

FIGURE 14.—A comparison of "capillary" structures in asphaltite nodules from the west Panhandle field and the Sudbury district, Ontario.

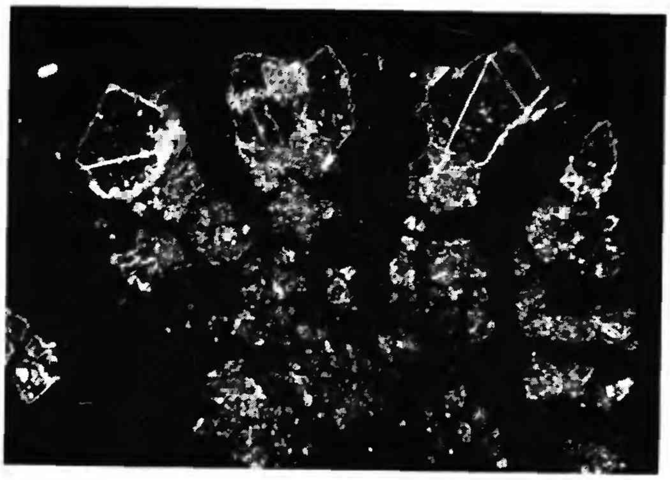


FIGURE 15.—Cataclastic pyrite crystals in an asphaltite nodule from the "Panhandle lime," well 897. Dark-field illumination. × 204.5.

ule. Experiments by Royer (1930) have shown that crystals of dolomite, calcite, and calimine undergo corrosion in the presence of petroleum and several natural organic acids derived from petroleum including naphthenic and phenolic acids. It seems possible that the replacement effects could be the result of a similar process.

Many of the nodules that occur in the shale of the "Red Cave" are surrounded by green halos which contrast sharply with the red shale (figs. 18*A*, *B*). The color change is evidently due to reduction of ferric oxides. Anhydrite nodules surrounded by green halos were also observed in red dolomitic siltstones of the "Red Cave." An X-ray analysis of one sample showed that the rock composing the halo consisted of quartz and clay minerals, whereas the rock beyond the halo contained major amounts of dolomite as well. A small amount of uraninite and uraniferous asphaltite occur at the boundary of the anhydrite nodule. The mineralogic relations suggest that the uraninite and asphaltite were deposited contemporaneously with the anhydrite from solutions that were dissolving dolomite.

Figure 19 shows the association of uraniferous asphaltite with fossiliferous chert. The sample at right contains chalcopyrite in contact with asphaltite and

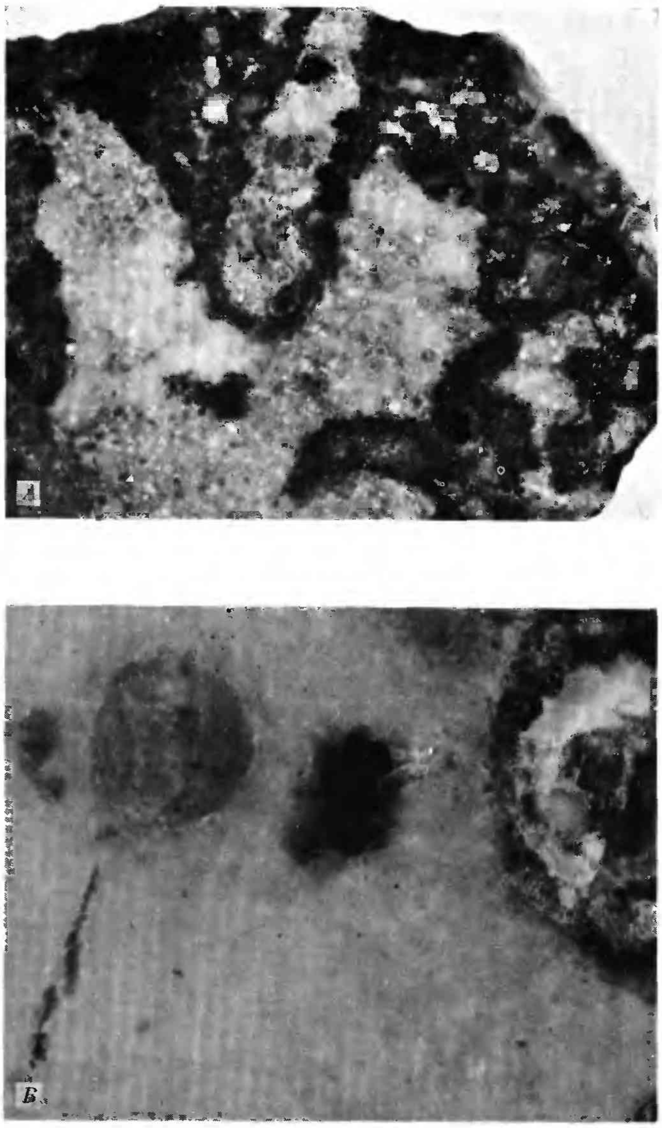


FIGURE 16.—Association of asphaltite with secondary anhydrite in dolomite from the "Panhandle lime," well 783a. *A*, Polished section of mottled gray dolomite containing asphaltite (black) nodules embedded in white crystalline anhydrite. × 12.1. *B*, Polished section of fine-grained dolomite showing asphaltite nodule (black) surrounded by secondary anhydrite (dark gray). × 17.6.

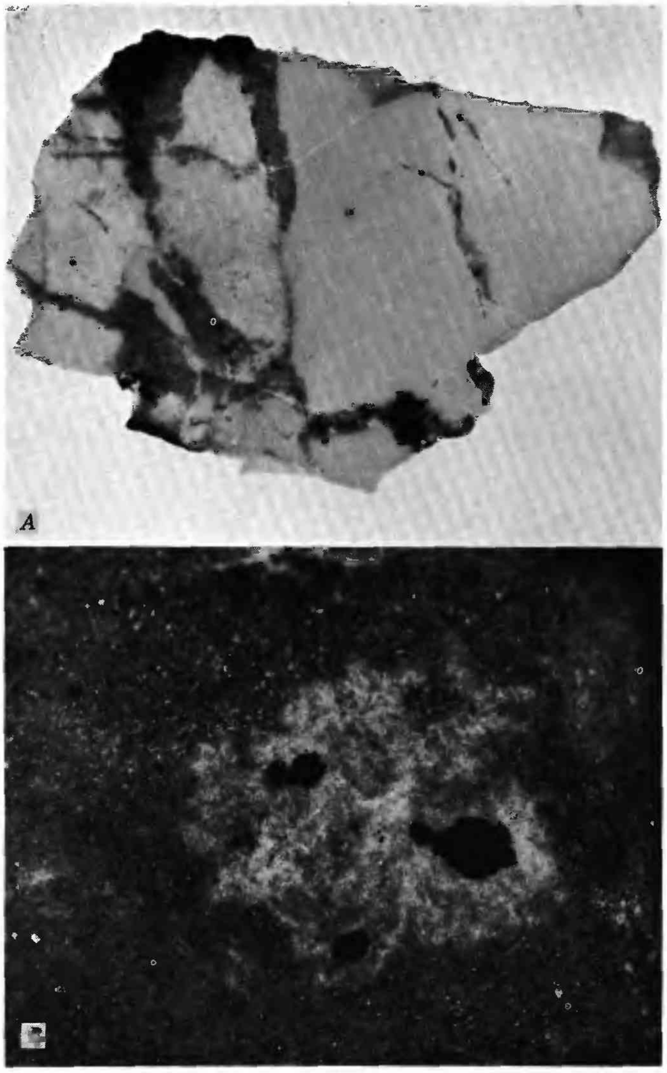


FIGURE 17.—Association of asphaltite with secondary anhydrite in samples from the "Red Cave," well 825a. *A*, Asphaltite (black) and anhydrite (gray) filling fractures in fine-grained dolomite. × 9.4. *B*, Asphaltite (black) and anhydrite (white) in siltstone (gray).

the sample at left contains galena in contact with asphaltite. Pyrite, native copper, and sphalerite are also associated with the asphaltite in these samples.

ORIGIN OF THE ASPHALTITE

The association of the asphaltite with secondary anhydrite and celestite, its occurrence in fractures and solution cavities, its presence in stylolites, and its replacement of the host rock show that the asphaltite is epigenetic. The similarity in physical and chemical properties between the asphaltite and petroleum derivatives as well as the association of the asphaltite with residual oil and natural gas in the Panhandle field suggests that the organic matrix of the asphaltite was derived from petroleum. The uranium and other metals were probably largely introduced by aqueous solutions.

The estimated average concentration of uranium and other metals in asphaltite, crude oil, and brine (table 15) and the ratio of percent metal (the percent of each metal among the sum of all the metals present) in the oil and asphaltite to percent metal in the brine (table 16) show that the asphaltite and the crude oil tend to be selectively enriched in the same group of metals with reference to the brine. Uranium, arsenic, and cobalt, however, are preferentially concentrated in the asphaltite while vanadium is preferentially concentrated in the oil; for this reason the two organic materials, although probably of common origin, seem to have been segregated and mineralized separately.

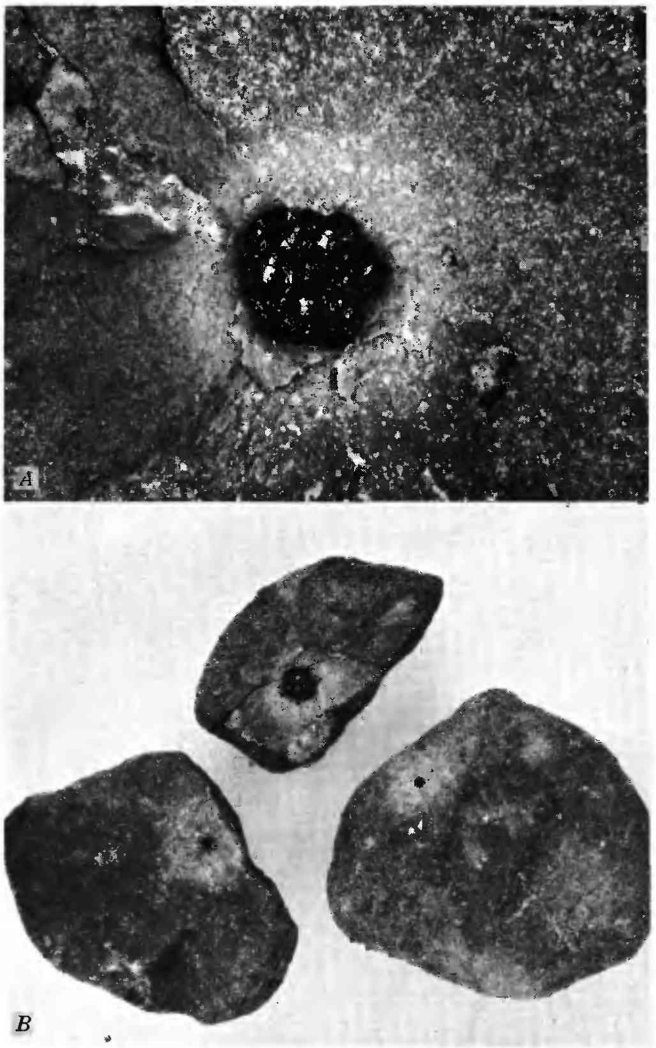


FIGURE 18.—Asphaltite nodules surrounded by halos, in shale. *A*, Botryoidal nodule in "Red Cave" shale, well 832. × 5.6. *B*, Asphaltite nodules in shale samples from the "Panhandle lime," well 139. × 4.7.

TABLE 15.—*Estimated average concentration of metals in brine, crude oil, and asphaltite from the Panhandle field*

Metal	Concentration, in parts per million, in—		
	Brine (30 samples)	Crude oil (25 samples)	Asphaltite (26 samples)
Na	44, 000	10	3, 000
Ca	2, 760	4	30, 000
Mg	1, 340	. 5	4, 000
K	470	. 5	5, 000
Sr	140	. 1	200
Fe	70	. 5	4, 000
Si	20	. 8	4, 000
B	15	. 03	40
Zn	7	. 01	300
Ba	5	. 005	100
Al	4	. 3	3, 000
Cu	2	. 06	300
Ti	2	. 01	200
Cr	2	. 005	20
V	1	. 7	300
Ni	1	. 7	3, 000
Zr	1	. 03	50
As	1	. 5	30, 000
Mn	. 5	. 01	40
Pb	. 1	. 005	50
Co	<. 1	. 005	2, 000
U	. 0015	. 0015	4, 000

TABLE 16.—*Comparison of ratios of percent metal in crude oil and asphaltite to percent metal in brine from the Panhandle field*

Metal	Metal in oil	Metal in asphaltite
	Metal in brine	Metal in brine
Na	0. 5	0. 04
Sr	3	. 7
B	10	1
Mg	2	2
K	5	6
Ca	7	6
Ba	5	10
Zn	5	20
Zr	100	30
Ti	10	30
Fe	30	30
Mn	100	40
Cu	100	80
Si	200	100
V	3, 000	200
Pb	200	300
Al	400	400
Ni	3, 000	2, 000
Co	>200	10, 000
As	2, 000	20, 000
U	4, 000	1, 000, 000

Segregation of the asphaltite from petroleum may have occurred in several ways. The asphaltite may represent water-soluble organic material that was dissolved from petroleum or its source rocks by associated connate brines, and was later precipitated from saturated brines during cementation of the reservoir rocks. Or it may represent a surface-active fraction of petroleum that was adsorbed at oil-mineral and oil-water interfaces. Adsorption of metal-bearing fractions of petroleum at oil-water and oil-mineral interfaces has been demonstrated by Denekas, Carlson, Moore, and Dodd (1951) and by Dunning, Moore, and Denekas (1953).

The transformation of the organic material into asphaltite is probably the result of polymerization and dehydrogenation caused by radiations from decay of uranium and its daughter products. Lind (1928) and others have demonstrated experimentally that alpha bombardment of liquid and gaseous organic compounds converts them to insoluble solids. Such materials are highly crosslinked and may resemble synthetic ion exchange resins in their ability to extract metals from solutions. It is possible that initial adsorption of small amounts of uranium by asphaltite may in time have enhanced its ability to pick up more.

The relation of asphaltite to the host rocks show that it, as well as anhydrite, celestite, and rarely silica, is present as a secondary cement. The secondary anhydrite characteristically replaces dolomite in samples of the carbonate rocks. Uranium and other metals in the asphaltite seem to have been derived from the same cementing solutions as the secondary anhydrite. The interval of rocks near the top of the "Panhandle lime" and the base of the "Red Cave" contains oolitic dolomites and siltstones that in many places are completely cemented with asphaltite-bearing anhydrite and have

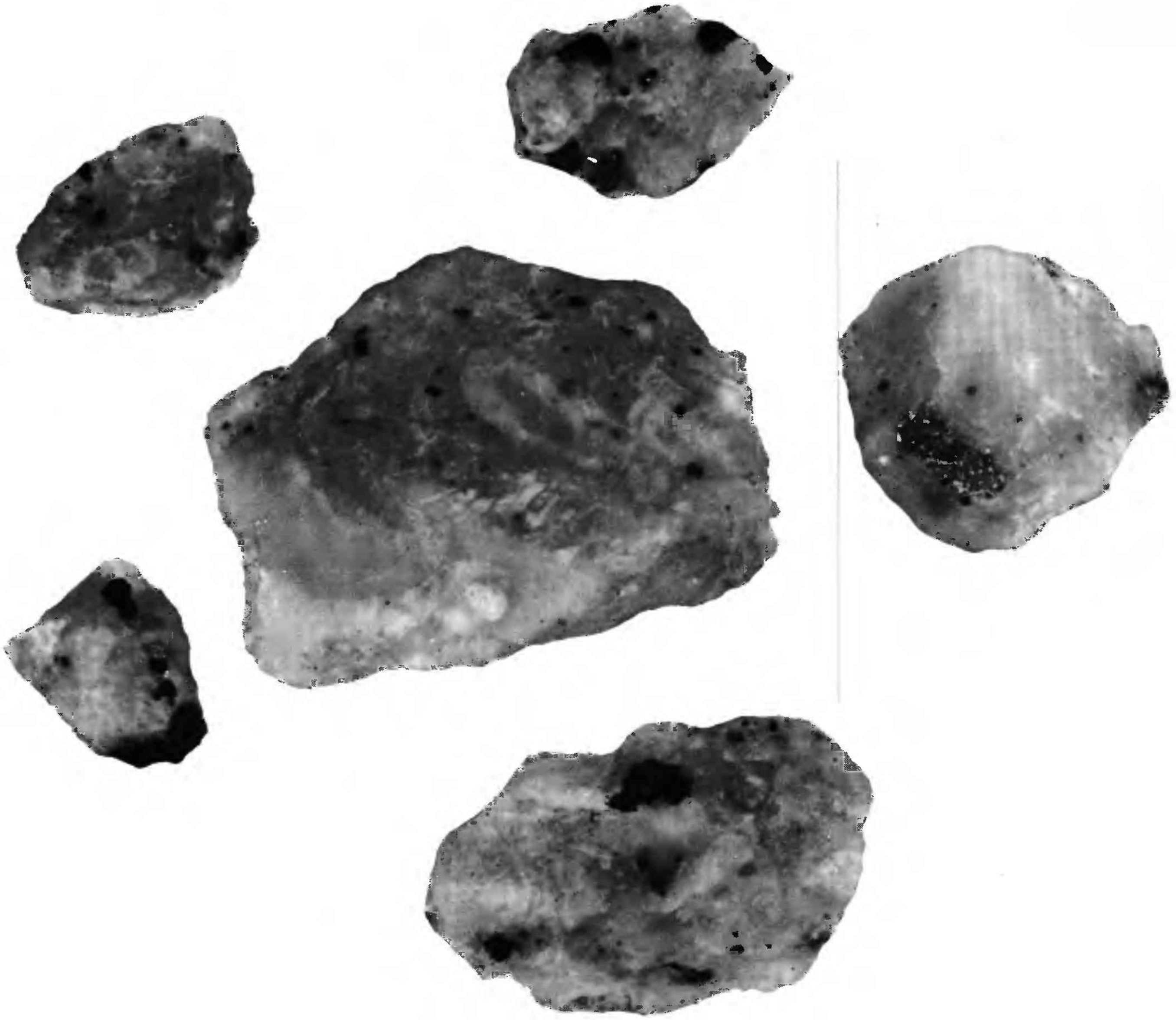


FIGURE 19.—Fossiliferous chert containing disseminated asphaltite from the "Brown dolomite," well 825a. × 2.4.

a uranium content of 20 to 200 ppm uranium, most of which is in the uraniferous asphaltite. Inasmuch as the rocks contain about 20 percent secondary anhydrite, the uranium content of the anhydrite plus asphaltite must be in the range of 100 to 1,000 ppm. The solubility of calcium sulfate ranges from about 2 to 6 g per liter of water, depending on salinity (Seidell, 1940). The upper limit for the uranium content of the original cementing solutions must, therefore, have been about 0.2 to 6.0 ppm. It is known that concentrated, highly oxidized saline brines tend to be enriched in uranium relative to other natural waters (Bell, 1960.) It may be postulated that if such a brine migrated through the evaporite sequence into the underlying rocks where it was subjected to a reducing environment, the uranium and other metallic ions would be precipitated as stable minerals. The uranium may have been introduced into the Panhandle field in this manner.

The abundance of hydrogen in the Panhandle field gases allows an estimate of the reducing potential. The partial pressure of hydrogen in the gasfield, as calculated from the hydrogen contents, ranges from about 0.003 to 0.06 atmospheres, and the pH of the brines, as measured at the well head, ranges from 5 to 7 (A. S. Rogers, written communication, 1956). The Eh of the environment as calculated from the hydrogen half-cell reaction is, then, about -0.2 to -0.4 volts, and is sufficient to cause reduction of uranyl, arsenate, and sulfate ions, resulting in the formation of uraninite arsenides, and sulfides (for example, see Garrels, 1960).

It has been noted that secondary anhydrite replaces dolomite in the carbonate rocks. This replacement and the fact that the rocks are part of an evaporite sequence indicate that the original cementing solutions were mildly acid magnesium sulfate bitterns and that the magnesium sulfate reacted with calcium carbonate in the original rock to form dolomite and calcium sulfate. As the calcium sulfate solubility product was exceeded, anhydrite was precipitated. Oxidation potentials may have been such that the change in pH due to the above reaction was sufficient to result in reduction of uranyl ions by organic materials that were already present in the rock pores.

The evidence and assumptions discussed above suggest that asphaltite and secondary anhydrite deposition occurred under more oxidizing conditions than now exist in these rocks, but occurred later than lithification and fracturing. It is estimated on the basis of data obtained from sample logging that 10 to 30 percent compaction of the shales and siltstones in "Red Cave" and "Panhandle lime" would release a sufficient volume of brine, saturated with magnesium sulfate, to explain the amounts of secondary anhydrite cement now present in the intervening and underlying carbonate rocks. According to the density studies made by Athy (1930a, b) of red beds of Permian age in the Garber, Okla., area, a 10- to 30-percent compaction of shale would occur by the time the thickness of overburden reached about a thousand feet. Inasmuch as 1,000 to 2,000 feet of Permian rocks overlie the "Red Cave," this process could have been completed by the end of Permian time.

The uraniferous asphaltite in the lower part of the Clear Fork Group and the upper part of the "Panhandle lime" is distributed over such a large area that it seems probable that these rocks, particularly the red shales and siltstones among the evaporite beds, were syngenetically enriched in uranium. The arsenic, cobalt, and nickel that are enriched along with uranium in the asphaltite nodules were also probably derived from the same hematitic red shales and siltstones. Conspicuous concentrations of these elements, especially arsenic, are known to result from their coprecipitation with ferric hydroxide in oxidate sediments of evaporite deposits (Rankama and Sahama, 1950).

In summary, it appears that uranium has been redistributed and concentrated within the interstices of rocks through which petroleum and brine have migrated or in which they have accumulated. The redistribution and concentration of uranium has been associated in time with structural and diagenetic events including compaction, fracturing and cementation of the rocks, and concentration of metals in organic materials derived from petroleum or petroleum waters. The result has been that uranium and its daughter products have been concentrated in the pore spaces where they are easily accessible to fluids and gases.

RADON IN THE NATURAL GAS

The radon content of the gas in the western part of the Panhandle field as measured by Henry Faul and others (pl. 1) ranges from less than 5 to 1450×10^{-12} curies per liter, and averages about 100×10^{-12} curies per liter (STP). These measurements have been discussed previously by Faul and others (1954) and by Sakakura and others (1959). From the study made by Sakakura and others, the above radon concentrations can be explained by reservoir rocks containing 0.1 to 30 ppm uranium and averaging about 2 ppm uranium.

A contour map showing the relation of the radon and helium content of gas to structure (pl. 1) shows that there is no direct relation between the positions of the radon and helium anomalies. Radon in excess of 100×10^{-12} curies per liter is concentrated in the natural gas in an extensive area along the north flank of the uplift, and conforms roughly to the configuration of the structure contours. The extremely high, but isolated, radon anomalies are related to the structurally more complex areas on both the north and south flanks of the uplift.

Because of its short half life, the occurrence of radon must correspond to the distribution of its source. The distribution of the uraniferous asphaltite and its association with radon in gas-producing rocks (pl. 2) show that concentrations of radon in excess of about 100×10^{-12} curies Rn^{222} per liter (STP) are restricted to gas wells in which the generalized interval of rock that is mineralized with uraniferous asphaltite overlaps the generalized interval of gas-producing rocks. This relation indicates that the source of the anomalous radon is uraniferous asphaltite.

HELIUM IN THE NATURAL GAS

Few studies on the geologic occurrence of helium have been made since that of G. S. Rogers (1921). Since that time, the increasing volume of data accumulated on the radioactivity of rocks has resulted in the general acceptance of Rogers' assumption that most of the helium of natural gas is radiogenic, having been formed since the beginning of earth history. However, this assumption cannot be fully proved because escape of helium from the earth's atmosphere prevents an estimation of the primordial helium abundance in the earth. Next to hydrogen, helium is the most abundant cosmic element and large amounts of primordial helium could conceivably have been trapped in rocks of the earth's interior and crust. If so, we would expect helium to be greatly enriched in the earth with respect to other inert gases. The available evidence, however, suggests that there is no such enrichment. For example, the cosmic-abundance ratio of helium to argon is about 10^4 (Green, 1959), whereas natural gas from rocks have a mean helium to argon ratio of about 10 (Pierce, 1955; see also data in Boone, 1958). This difference might be interpreted as the result of preferential loss of helium at the time of the earth's formation, but an alternate explanation of the proportions of helium to argon is suggested by a comparison of their ratio in natural gas with the amounts that would be formed in average rocks by nuclear processes.

The calculated helium-4 to argon-40 ratios resulting from the decay of the uranium, thorium, and potassium present in average carbonate rock, shale, and sandstone are about 50, 7, and 1, respectively, on the basis of the geochemical data given by Green (1959). The ratio for an average igneous rock presumably is close to that of shale because of the similar uranium, thorium, and potassium contents. The helium to argon ratio of 10 to 20 in the gas of the Panhandle and Cliffside fields (table 17) is within the range of ratios calculated for the above rocks and suggests that the helium and argon are of radiogenic origin.

The average ratio of the helium isotopes, He^3 to He^4, in the Panhandle field is about 1.5×10^{-7} (table 17), as compared to an average of 1.7×10^{-7} for the helium in the natural gas fields that have been investigated (Aldrich and Nier, 1948) and to a calculated ratio of 2×10^{-7} for helium originating from nuclear reactions in rocks of the earth's crust (Morrison and Beard, 1949). The comparatively close agreement between the measured and calculated proportions of argon, helium-3, and helium-4 that should be present in common rocks suggests that the major part of the helium in the gas of the Panhandle field is radiogenic.

TABLE 17.—*Composition of natural gas from the western part of the Panhandle field, the Cliffside field, and the Quinduno field*

[Analyses by the U.S. Bureau of Mines (Boone, 1958)]

	Western part of Panhandle field [1]	Cliffside field	Quinduno field
Volume percent			
Methane	71.6	67.1	80.2
Ethane	5.4	3.6	7.7
Higher hydrocarbons	4.3	2.8	5.5
Carbon dioxide	.3	.7	.1
Hydrogen	.1	.2	.1
Nitrogen	17.4	24.8	6.3
Argon	.05-.1	.1-.2	Tr.
Helium	1.11	1.79	.14
Oxygen	Tr.	Tr.	Tr.
Ratio			
He:A	10	20	------------
He^3:He^4	------------ [3] 1.5×10^{-7}	[2] 1.73×10^{-7} [3] 1.5×10^{-7}	------------ ------------
Pounds per square inch			
Initial pressure	440	730	883

[1] Average of analyses from 10 wells having highest helium content.
[2] From Coon (1949).
[3] From Aldrich and Nier (1948).

Radiogenic helium presents the problem of determining the distribution of the uranium and (or) thorium sources. The average helium content of the gas in the Panhandle field is about 0.5 percent. Calculation shows that this amount of helium would be generated since Permian time in reservoir rocks containing either 0.02 percent uranium or 0.1 percent thorium. Although uraniferous asphaltite has been observed in drill samples from the gas reservoir rocks, most of the samples contain no uraniferous asphaltite, only from 2 to 4 ppm uranium, and probably not more than three times that amount of thorium. It is likely, therefore, that the helium was derived from an external source.

An investigation of the isotopic composition of argon in gas from the western part of the Panhandle field by Wasserburg (1957) has shown it consists mainly of argon-40, the decay product of potassium-40. Explaining the radiogenic argon (0.1 percent by volume) in the Panhandle field presents a problem similar to that of helium. Calculation shows that the reservoir rock would have to be about 100 percent potassium to supply the argon present; the argon, therefore, also must have been derived from an external source.

The distribution and concentration of helium in the Panhandle field are indicative of the direction from which the helium-rich gas has migrated (pl. 1; fig. 20). The helium content increases from about 0.1 percent in the gas along the eastern end of the field to about 1.9 percent in the zone of en echelon faults which in general constitute the southwestern boundary of commercial gas production. The helium content of gas from approximately the same stratigraphic units continues to increase southward 20 miles beyond the boundaries of the field and reaches a maximum of 2.24 percent (figs. 9, 20). Northward in the Anadarko basin the gas from the "Brown dolomite" in the Quinduno field, however, contains only about 0.15 percent helium (fig. 20). The reservoir pressure in the Quinduno field is about 885 psi and the pressure in the Cliffside field is about 730 psi; the Panhandle field, which has an initial pressure of only 440 psi, is therefore, a "pressure sink" into which gases of the Anadarko and Palo Duro basins can migrate.

The Panhandle field is at about one-third the normal hydrostatic pressure gradient for a field of its depth, but is at nearly normal hydrostatic pressure with respect to the ground-water table in the Wichita Moun-

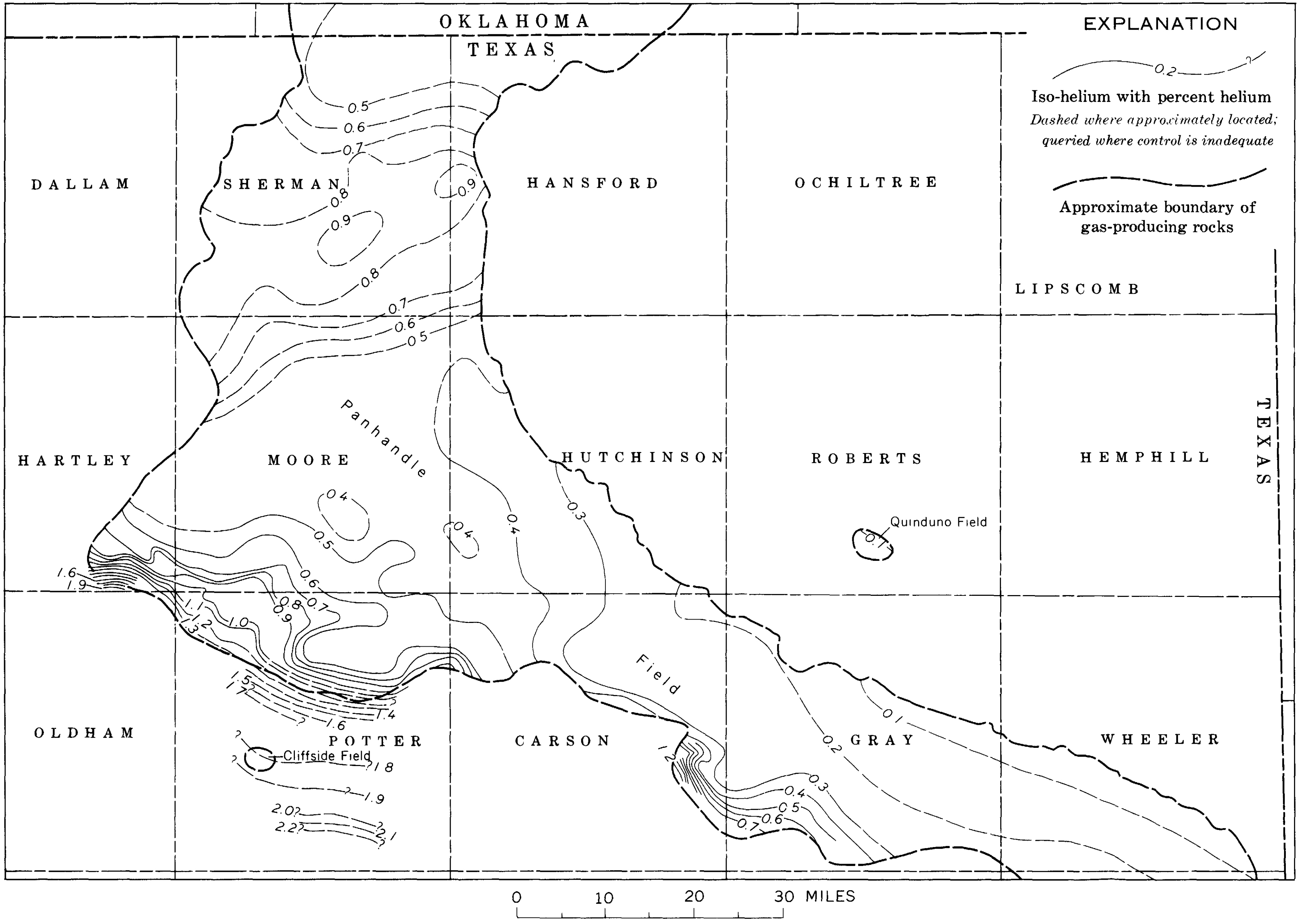


FIGURE 20.—Distribution of helium in the Panhandle field, Texas, and adjacent areas. (Analyses are from Anderson and Hinson, 1951; Boone, 1958; and G. B. Shelton, U.S. Bureau of Mines, written communication, 1958.)

tains where the igneous rocks of the Amarillo-Wichita uplift crop out (Levorsen, 1954). Deficient reservoir pressures also exist in satellitic oil and gas fields along both sides of the uplift, including the Cliffside and Quinduno fields. Interestingly, the latter fields, although deficient in pressure with respect to their depths, are at nearly normal hydrostatic pressure with respect to the water table of the vast Panhandle field. During Late Cretaceous time when the overlying surface was at or below sea level, the reservoir pressures of most of these gas fields were two or three times greater. Epeirogenic uplifting since that time has been accompanied by erosion and drainage of waters from the elevated rocks and would have caused the reservoir volumes of the satellite fields (if they were filled with gas) to expand and to spill their excess gas into the structurally higher Panhandle field. The uplifting must also, because of lessening pressures, have been accompanied by a general degassing of formation waters throughout the rocks of the basins and uplifts, a process that is capable of supplying large quantities of gas and one which may still be going on. Such a process could result in mixing of gas migrating from either side of the uplift.

The helium, nitrogen, and hydrocarbon content of the gas of the Panhandle field is intermediate to that of the Cliffside and Quinduno gas, as shown on figure 21, and thus can be explained as the result of mixing of gas derived from the Palo Duro and Anadarko basins. The relative amounts of other gas constituents in the Panhandle field can also be explained as the products of mixing. For example, a mixture composed of 60 percent Cliffside-type gas (table 17) and 40 percent Quinduno-type gas (table 17) would contain about 72 percent methane, 5 percent ethane, 4 percent higher hydrocarbons, 17 percent nitrogen and 1.1 percent helium; this is the same as the actual composition of the helium-rich gas in the western Panhandle field (table 17). The average helium content of Panhandle field gas is about 0.5 percent and corresponds to a helium mixture composed of about one-fourth from Quinduno-type gas and three-fourths from Cliffside-type gas. Figure 21 shows that the overall helium-nitrogen-hydrocarbon distribution in the gas of these three fields could also be explained by systematic dilution of a nearly pure hydrocarbon gas with nonhydrocarbon gas, such as might be derived from basement rocks, containing nitrogen and helium in proportions of about 10 to 1.

A more detailed picture of the helium distribution in relation to the structure of the gas-producing rocks is shown in plate 1. The highest helium concentration of 1.9 percent occurs structurally in the lowest part of the field and indicates that helium is actively flowing into the gas field at this point. The helium source, therefore, must be either in the deep igneous and metamorphic rocks associated with the faults or in the downfaulted sedimentary formations to the south. These two possible sources are discussed below.

Little is known about the igneous and metamorphic rocks underlying the Panhandle field. Their uranium and thorium content, however, should be at least as great as that of the overlying sedimentary rocks and, because of their greater ages, their radiogenic helium content should be as large or larger. A part of their helium, however, must have been lost to the atmosphere

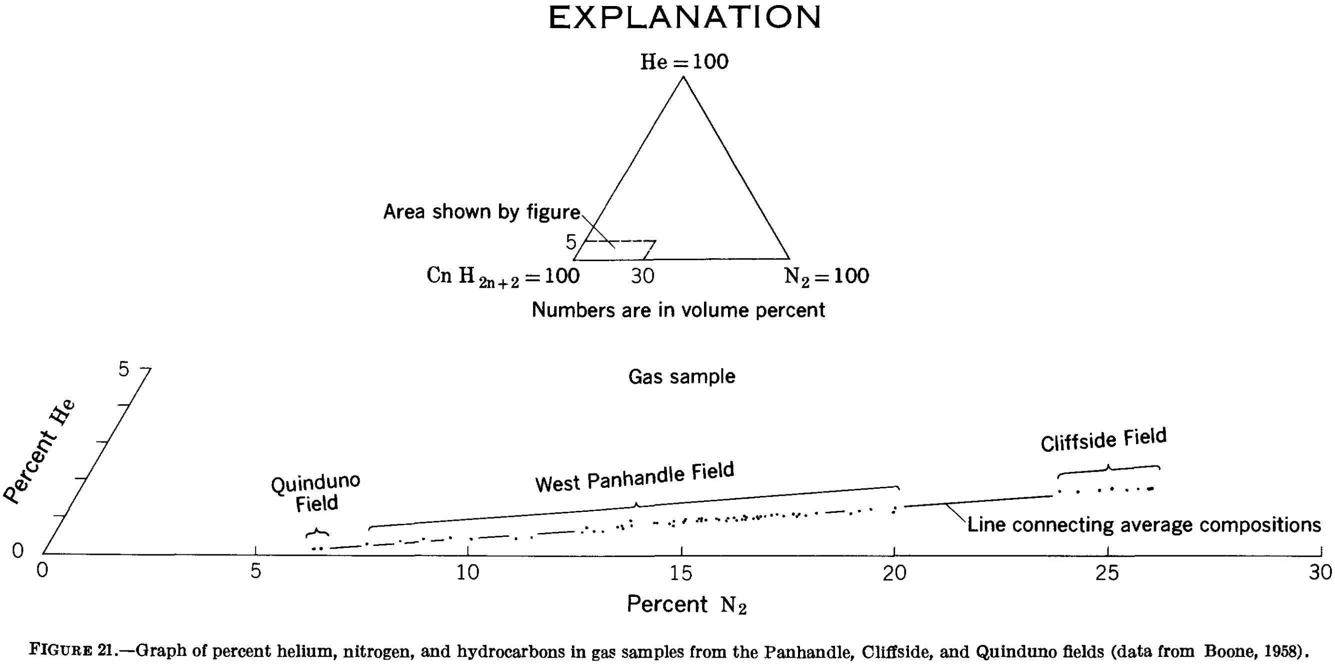


FIGURE 21.—Graph of percent helium, nitrogen, and hydrocarbons in gas samples from the Panhandle, Cliffside, and Quinduno fields (data from Boone, 1958).

before the uplift was finally covered by sediments during Late Pennsylvanian time.

The Amarillo uplift, which underlies the principal helium accumulation in the western Panhandle field (see pl. 1), is about 40 miles long and 20 miles wide; it has an average relief of about 2,000 feet and, in all, a volume of about 300 cubic miles. The igneous rocks of at least the upper part of the uplift are permeable and produce gas in some of the wells which penetrate them (pl. 2). The uplift was exposed to the atmosphere until it was covered by sediments during the Permian Period. If there is a mean uranium content of 4 ppm, a 50 percent retentivity, and a thorium to uranium ratio of 3.6, the total amount of helium generated in the uplift since Permian time would be about one-eighth of the amount that has accumulated in this part of the gas field. Calculations indicate that a comparable amount of helium could have been generated by the "buried mountains" in Sherman, Carson, and Gray Counties where the reservoir rocks also contain anomalous concentrations of helium (fig. 20).

If the helium was derived from igneous rocks, then, it seems likely that the main source would be deeper than the "buried mountains." Helium escaping from deep igneous rocks would probably tend to migrate upward through major tensional fault zones. The helium concentrated in gases along the Potter County fault zone (pl. 1) and in the adjacent Cliffside area (fig. 1) could have been derived from such a source. If it is assumed that the deep basement rocks in this fault zone are 10^9 years in age, contain 4 ppm uranium and have a thorium to uranium ratio of 3.6, and a helium retentivity of 50 percent, then calculation shows that about 790 cubic miles of rock would be required to generate the helium of the Panhandle field. This amount of rock would be equivalent, for example, to that in a fault zone 30 miles long, 15 miles deep, and about 9,000 feet wide. Very little is known about the nature of such deep fault zones and whether the effective porosity and permeability necessary to degas these rocks could exist under the high geostatic pressures in such a region.

The hydrocarbon gas of the Panhandle field was probably derived from sedimentary rocks of the basins and probably migrated laterally into the reservoir rocks. The enormous quantity of gas in the field indicates that the sedimentary rocks from which it migrated must be very permeable. If these sedimentary formations are also the helium source, the rocks extending downdip from the Amarillo uplift must contain quantities of uranium and thorium capable of supplying the helium existing in the Panhandle area.

It has previously been shown that the reservoir rocks in the Panhandle field contain from 2 to 4 ppm uranium and probably not more than three times that amount of thorium. Data described elsewhere in this report (p. 26), however, indicate that the upper part of the "Panhandle lime" and the basal part of the Clear Fork Group contain from 10 to 20 ppm uranium through a 200- to 300-foot-thick interval. Most of the uranium in these rocks occurs in asphaltite. Exploratory holes drilled south of the Panhandle field have encountered limited volumes of natural gas in the uraniferous rocks that contain high concentrations of helium (pl. 3; figs. 9, 20). The uraniferous and helium-rich rocks have been faulted against the gas-producing formations along the south side of the Panhandle field. (See pl. 2, section between wells 825a and 825b.) The structure, therefore, is such that the gas can migrate from the most uraniferous rocks across the fault zone and into the gas reservoir. It would be informative, therefore, to examine the total volume of helium these rocks could supply.

The potential "gathering area" for the natural gas that has migrated into the Panhandle field can be estimated from the Tectonic Map of North America (Longwell, 1944) by drawing lines normal to the structure contours that define the Amarillo uplift. When this is done, the potential "gathering area" extending eastward to the center of the Anadarko basin is about 6,000 square miles, while the potential "gathering area" extending south of the Panhandle field through the Palo Duro basin to the Midland basin is about 5,000 square miles.

The most probable source rocks of gas from the Anadarko basin are those of Wolfcamp age, whereas the source rocks of gas from the Palo Duro basin are probably those of Leonard age, particularly the "Panhandle lime" which is known to contain helium-rich gas in this area. (See fig. 9.)

Average thicknesses of the potential gas-source rocks in these two areas can be estimated from isopach maps by Roth (1955). The average thickness of the rocks of Wolfcamp age in the Anadarko basin is about 3,000 feet, and the average thickness of the rocks of Leonard age in the area of the Palo Duro and Midland basins is about 2,000 feet. If it is assumed that the rocks are 250 million years in age, contain 4 ppm uranium, and have a thorium to uranium ratio of 3.6 and a helium retentivity of 50 percent, then calculation shows that the rocks of Wolfcamp age in the Anadarko basin could supply about 10×10^{15} cc helium, whereas those of Leonard age in the Palo Duro basin could supply about 6×10^{15} cc helium. In comparison, the amount of helium in the Panhandle field is about 4×10^{15} cc, on the basis of an original gas reserve of 30 trillion cubic feet and an average helium content of 0.5 percent. If it is assumed that the average helium content represents a mixture (discussed above) composed of about one-fourth of the helium from the Anadarko basin and about three-fourths from the Palo Duro basin, the respective source rocks could have supplied 10 and 2 times the amounts of helium attributed to them.

Although this calculation shows that sufficient radiogenic helium is potentially available, a further calculation (given below) indicates that the partial pressure of helium generated in rocks with 4 ppm uranium may not be great enough to explain the observed partial pressures of helium in the Cliffside field and western part of the Panhandle field. Results of this calculation suggest that about 10 ppm uranium in the source rocks is necessary to account for the helium present in these areas.

The helium partial pressure of a gas field can be estimated from the physical properties of the source rocks (Pierce, 1960). The pores of the helium source rocks, which extend downdip from the Amarillo uplift, are mainly filled with water. Because helium is only slightly soluble in water, the minute amounts of it that are slowly produced in the rock by radioactive decay and that escape into the water-filled pores will exert a significant partial pressure in associated gas fields. If it is assumed that the radiogenic helium in the source rocks can migrate into a gas field at a rate that is rapid enough to maintain an equilibrium concentration, then the partial pressure of the helium in the gas phase can be calculated from Henry's Law:

$$P_{\mathrm{He}}=Kx,$$

where P_{He} is the partial pressure of the helium in the gas phase, K is an equilibrium constant which varies with temperature, and x is the mole fraction of helium in solution. x can be calculated from average rock properties, and the expression for the helium partial pressure becomes:

$$P_{\mathrm{He}}=K\mathrm{U}f[8(e^{\lambda t}-1)+7R'(e^{\lambda' t}-1)+6R''(e^{\lambda'' t}-1)]\frac{d}{w}$$

Where U is the uranium content of the source rock; f is the fraction of radiogenic helium that escapes into (and is retained by) the effective porosity; λ, λ', and λ'' are the decay rates of U^{238}, U^{235}, and Th^{232}, respectively; R' is the present ratio of U^{235} to U^{238}; R'' is the ratio of Th^{232} to U^{238} in the rock; d is the rock density; w is the water content of the rock as calculated from the rock porosity (water saturated); t is the absolute age of the rock; and K is the Henry's Law equilibrium constant. Typical values for these parameters as applied to the possible helium source rocks (discussed above) of the Panhandle field are as follows:

$\mathrm{U}=1$–4 ppm$=0.4$–1.7×10^{-8} moles per g rock for "Brown dolomite" source rocks in the Anadarko basin
$\mathrm{U}=10$–20 ppm$=4.3$–8.5×10^{-8} moles per g rock for "Panhandle lime" and basal part of the Clear Fork source rocks in the Palo Duro basin
$K=1.9\times10^{6}$ psia
$f=0.50$
$\lambda=1.54\times10^{-10}$ per yr
$\lambda'=9.72\times10^{-10}$ per yr
$\lambda''=0.49\times10^{-10}$ per yr
$t=250\times10^{6}$ yrs
$R'=0.0071$
$R''=0.40$
$d=2.6$ g rock per cc rock
$w=0.050$ cc pores (water saturated) per cc rock $=2.75\times10^{-3}$ moles $\mathrm{H_2O}$ per cc rock

The value of K, the equilibrium constant, is taken from the work of Pray and others (1952). The value of this constant does not vary greatly in the range of 32° to 200° F, and the value adopted is an average of those given. The value for f, the fraction of radiogenic helium that escapes into (and is retained by) the rock pores, is estimated to be 50 percent after Hurley (1954). The value for t is the absolute age for early Permian rocks as given by the time scale prepared by Kulp (1959). The value for R' is a constant in nature. The value for R'' is based on the isotopic composition of radium in brines from wells (table 9). The value for w is calculated on the basis of rock porosities (water saturated) from the extensive study made by Katz and others (1952) of the properties of the gas-producing dolomites in Sherman County, Tex., immediately north of the area covered by this report. The value of 5 percent porosity corresponds to a permeability of about 0.02 millidarcy on the empirical porosity-permeability diagram given by Katz and others, and represents the average lower limit of porosity of the gas-producing dolomites which contain the gas reservoir.

As applied to the Panhandle field, calculation shows that the helium partial pressures that would exist in gas originating from the assumed source rocks are:

$P_{\mathrm{He}}=1$ to 5 psi for helium in gas migrating from the "Brown dolomite" in the Anadarko basin
$P_{\mathrm{He}}=10$ to 30 psi for helium in gas migrating from the "Panhandle lime" and basal part of the Clear Fork in the Palo Duro basin

As compared with these calculated pressures, the initial maximum partial pressure of helium in the Panhandle field was about 8.2 psi, that in the Cliffside field was about 13.0 psi, and that in the Quinduno field was about 1.4 psi.

In summary, the helium partial pressure in the Quinduno field could be explained by rocks containing normal amounts of uranium, but the helium partial pressures in the Cliffside field—nearly 10 times that in the Quinduno field—would require source rocks having either a higher uranium content (as was assumed in the above calculation), lower helium retentivity, lower porosity, a greater age, or a combination of these factors. It has already been shown that the "Panhandle lime" and the basal part of the Clear Fork probably contain from 10 to 20 ppm uranium through a 200- to 300-foot-thick interval. Much of the uranium in these rocks may be present in uraniferous asphaltite. The asphaltite, because of its amorphous structure, probably has a negligible helium retentivity and is a more effective helium source than would be an equivalent amount of uranium distributed through the crystal lattices of rock-forming minerals.

CONCLUSIONS

Studies and calculations indicate that the sedimentary rocks could be the source of the helium in the Panhandle gas field. An undetermined part of the argon and helium in the gas may have been added from igneous rocks associated with the deeper parts of the fault zones bounding the uplift, but the decrease in permeability with depth due to the high geostatic pressures may be a limiting factor.

In contrast to the igneous rocks, most of the possible sedimentary source rocks have relatively high permeability and their structure is such that the helium generated in them can migrate into the gas field. These rocks also occur at comparatively shallow depths and their formation waters have been subject to extensive degassing as the result of greatly lessened hydrostatic pressures due to post-Cretaceous uplifting, erosion, and drainage of overlying rocks. The major sources in sedimentary rocks from which gas could migrate into the uplift are in the Anadarko and Palo Duro basins.

Data on the distribution and composition of the natural gas suggest that about three-fourths of the helium in the Panhandle field was derived from helium-rich hydrocarbon gas that has migrated into the field from sources in the Palo Duro basin. The relation of the helium accumulation to the geologic structure and to the distribution of known uranium-bearing material suggests that the helium in this gas was derived from uraniferous rocks that are faulted against the gas-producing reservoir rocks along the western boundary of the Panhandle field. Available information about these rocks indicates that uranium was remobilized and deposited with asphaltic residues in the interstices of the rocks where it is accessible to migrating fluids and gases. Helium generated under these circumstances would have easy access to the gas field. The low solubility and high diffusivity of the gases in the formation water, together with decrease of pressure during uplift, probably explain the migration of the helium and other inert gases into the gas field.

About one-fourth of the helium in the Panhandle field appears to have been derived from the relatively low concentrations of helium present in the large volumes of hydrocarbon gas that have migrated into the Panhandle field from sedimentary rocks of the Anadarko basin. The helium in this gas was probably derived from traces of uranium and thorium inherent in the same rocks as gave rise to the hydrocarbon gas.

SELECTED BIBLIOGRAPHY

Abraham, Herbert, 1945, Asphalts and allied substances: New York, D. Van Nostrand Co., v. 1, 887 p.

Adams, J. E., 1932, Anhydrite and associated inclusions in the Permian limestones of west Texas: Jour. Geology, v. 40, no. 1, p. 30–45.

Aldrich, L. T., and Nier, A. O., 1948, The occurrence of He^3 in natural sources of helium: Phys. Rev., v. 74, p. 1590–1594.

Anderson, C. C., and Hinson, H. H., 1951, Helium-bearing natural gases of the United States—analysis and analytical methods: U.S. Bur. Mines Bull. 486, 141 p.

Athy, L. F., 1930a, Density, porosity and compaction of sedimentary rocks: Am. Assoc. Petroleum Geologists Bull., v. 14, no. 1, p. 1–24.

——— 1930b, Compaction and oil migration: Am. Assoc. Petroleum Geologists Bull., v. 14, no. 1, p. 25–35.

Ball, M. W., Vary, J. A., Knight, G. L. Traver, J. H., and Lamb, W. E., 1950, Diagrammatic cross-section, southern Kansas to western Texas: Washington, D.C., Federal Power Comm., Exhibit 53, Docket G–1302, March 1950.

Bartell, F. E., and Niederhauser, D. O., 1946, Film-forming constituents of crude petroleum oils, Proj. 27 *of* Fundamental research on the occurrence and recovery of petroleum, 1946–1947: New York, Am. Petroleum Inst., p. 57–80.

Bell, K. G., 1960, Deposition of uranium in salt-pan basins: U.S. Geol. Survey Prof. Paper 354–G, p. 161–169.

Boone, W. J., Jr., 1958, Helium-bearing natural gases of the United States: U.S. Bur. Mines Bull. 576, 117 p.

Bowie, S. H. U., 1958, Helium in natural gas in the Witwatersrand: Nature, v. 182, p. 1082–1083.

Carter, G. E. L., 1931, An occurrence of vanadiniferous nodules in the Permian beds of South Devon: Mineralog. Mag., v. 22, p. 609–613.

Clark, G. L., 1955, Applied X-rays: 4th ed., New York, McGraw-Hill Book Co., 843 p.

Coon, J. H., 1949, Helium-3 isotopic abundance: Phys. Rev., v. 75, p. 1355–1357.

Cotner, Victor, and Crum, H. E., 1933, Geology and occurrence of natural gas in Amarillo district, Texas: Am. Assoc. Petroleum Geologists Bull., v. 17, no. 8, p. 877–906.

Davidson, C. F., and Bowie, S. H. U., 1951, On thucholite and related uraninite complexes, with a note on the origin of the Witwatersrand Au ores: London, Great Britain Geol. Survey Bull. 3, p. 1–19.

Denekas, M. O., Carlson, F. T., Moore, J. W., and Dodd, C. G., 1951, Materials adsorbed at crude petroleum-water interfaces—isolation and analysis of normal paraffins of high molecular weight: Indus. Eng. Chemistry, v. 43, p. 1165–1169.

Dunning, H. N., Moore, J. W., and Denekas, M. O., 1953, Interfacial activities and porphyrin contents of petroleum extracts: Indus. Eng. Chemistry, v. 45, p. 1759–1765.

Dunning, H. N., Moore, J. W., and Myers, A. T., 1954, Properties of porphyrins in petroleum: Indus. Eng. Chemistry, v. 46, p. 2000–2007.

Ellsworth, H. V., 1928a, Thucholite, a remarkable primary carbon mineral from the vicinity of Parry Sound, Ontario [pt. 1]: Am. Mineralogist, v. 13, no. 8, p. 419–439.

——— 1928b, Thucholite and uraninite from Wallingford Mine, near Buckingham, Quebec: Am. Mineralogist, v. 13, no. 8, p. 442–448.

Erickson, R. L., Myers, A. T., and Horr, C. A., 1954, Association of uranium and other metals with crude oil, asphalt, and petroliferous rock: Am. Assoc. Petroleum Geologists Bull., v. 38, no. 10, p. 2200–2218.

Faul, Henry, Gott, G. B., Manger, G. E., Mytton, J. W., and Sakakura, A. Y., 1954, Radon and helium in natural gas: Internat. Geol. Cong., 19th, Algiers 1952, Comptes rendus, sec. 9, pt. 9, p. 339–348.

Flawn, P. T., 1954, Texas basement rocks—a progress report: Am. Assoc. Petroleum Geologists Bull., v. 38, no. 5, p. 900–912.

Garrels, R. M., 1960, Mineral equilibria at low temperature and pressure (Harpers geoscience series): New York, Harper & Bros., 254 p.

Gott, G. B., and Erickson, R. L., 1952, Reconnaissance of uranium and copper deposits in parts of New Mexico, Colorado, Utah, Idaho, and Wyoming: U.S. Geol. Survey Circ. 219, 16 p.

Green, Jack, 1959, Geochemical table of the elements for 1959: Geol. Soc. America Bull., v. 70, p. 1123–1184.

Grigoriev, P. K., 1935, Materialy po pegmatitam Severnoi Karelii [Materials in the pegmatites of northern Karelia]: Trudy. Tzentr. Nauchno. Issl. Geol. Rasved. Inst., no. 37, p. 1–103.

Grip, E., and Odman, O. H., 1944, On thucholite and natural gas from Boliden: Stockholm, Sveriges Geol. Undersok. Arsb., v. 38, no. 6, 14 p.

Hess, F. L., 1922, Uranium-bearing asphaltitic sediments of Utah: Eng. Mining Jour., v. 114, p. 272–276.

Hurley, P. M., 1954, The helium age method and the distribution and migration of helium in rocks, *in* Faul, Henry ed., Nuclear Geology: New York, John Wiley & Sons, 413 p.

Katz, D. L., Turner, C. E., Grimm, R. D., Elenbaas, J. R., and Vary, J. A., 1952, Sample grading method of estimating gas reserves: Am. Inst. Mining Metall. Engineers Trans., v. 195, p. 207–212.

Katz, J. J., and Rabinovitch, Eugene, 1951, The chemistry of uranium: New York, McGraw-Hill Book Co., 609 p.

Kimura, K., and Iimuri, T., 1937, On uraninite, monazite and thucholite from Amaki, Fukuoka prefecture: Chem. Soc. Japan Jour., v. 58, p. 1135–1143.

King, P. B., 1937, Geology of the Marathon region, Texas: U.S. Geol. Survey Prof. Paper 187, 148 p.

Kulp, J. L., 1959, Geological time scale [abs.]: Geol. Soc. America Bull., v. 70, no. 12, pt. 2, p. 1634.

Labout, J. W. A., 1950, Constitution of asphaltic bitumin, *in* Pfeiffer, J. P., The properties of asphaltic bitumen: Amsterdam Elsevier, p. 13–48.

Labuntzov, A. N., 1939, Pegmatites of northern Karelia and their minerals [pt. 2], *in* Pegmatites of the U.S.S.R.: Moscow-Lenigrad, Acad. Sci.

Lang, A. H., 1952, Canadian deposits of uranium and thorium; Canada Geol. Survey Econ Geology Ser., no. 16, 173 p.

Lang, W. B., 1937, The Permian formations of the Pecos Valley of New Mexico and Texas; Am. Assoc. Petroleum Geologists Bull., v. 21, no. 7, p. 833–898.

Levorsen, A. I., 1954, Geology of petroleum: San Francisco, W. H. Freeman & Co., 703 p.

Lind, S. C., 1928, The chemical effects of alpha particles and electrons: New York, Chemical Catalog Co., 260 p.

Longwell, C. R., ed., 1944, Tectonic map of the United States: Am. Assoc. Petroleum Geologists Bull., v. 28, no. 12, p. 1767–1774.

Moeller, Therald, 1952, Inorganic chemistry: New York, John Wiley & Sons, 966 p.

Morrison, P., and Beard, D. B., 1949, He^3 and the origin of terrestrial helium: Phys. Rev., v. 75, p. 1332–1333.

Perutz, Max, 1939, Radioactive nodules from Devonshire, England: Mineralog. Petrog. Mitt., v. 51, nos. 1–2, p. 141–161.

Pierce, A. P., 1955, Radon and helium studies, *in* Geologic investigations of radioactive deposits, semiannual progress report, Dec. 1, 1954 to May 31, 1955 U.S. Geol. Survey TEI–540, p. 234–237, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

———1960, Studies of helium and associated natural gases, *in* Short papers in the Geological Sciences: U.S. Geol. Survey Prof. Paper 400–B, p. B77–B79.

Pierce, A. P., Mytton, J. W., and Barnett, P. R., 1958, Geochemistry of uranium in organic substances in petroliferous rocks, *in* United Nations Survey of raw material resources: Internat. Conf. Peaceful Uses Atomic Energy, 2d, Geneva, Sept. 1958 Proc., v. 2, p. 192–198.

Ponsford, D. R. A., 1954, Note on the occurrence of uranium at certain horizons in the Enville beds: Great Britain Geol. Survey Bull. 5, p. 59–60.

———1955, Radioactivity studies of some British sedimentary rocks: Great Britain Geol. Survey Bull. 10, p. 24–44.

Pray, H. A., Schweickert, C. E., and Minnich, B. H., 1952, Solubility of hydrogen, oxygen, nitrogen, and helium in water at elevated temperatures: Indus. Eng. Chemistry, v. 44, p. 1146–1151.

Rankama, Kalervo, and Sahama, T. G., 1950, Geochemistry: Chicago Univ. Press, 911 p.

Rogers, A. F., 1937, Introduction to the study of minerals: 3d ed., New York, McGraw-Hill Book Co., 626 p.

Rogers, G. S., 1921, Helium-bearing natural gas: U.S. Geol. Survey Prof. Paper 121, 113 p.

Rosholt, J. N., Jr., 1954, Quantitative radiochemical method for determination of major sources of natural radioactivity in ores and minerals: Anal. Chemistry, v. 26, p. 1307–1311.

Roth, Robert, 1955, Paleogeology of Panhandle of Texas: Am. Assoc. Petroleum Geologists Bull., v. 39, no. 4, p. 422–443.

Royer, M. L., 1930, Sur la décroissance du cristal dans un milieu isotrope actif [On the etching of crystals in an isotropic active media]: Soc. Française Minéralogie et Cristallographie Bull., v. 53, p. 350–374.

Sakakura, A. Y., Lindberg, Carolyn, and Faul, Henry, 1959, The equation of continuity in geology with applications to the transport of radioactive gas: U.S. Geol. Survey Bull. 1052–I, p. 287–305.

Sanders, J. M., 1928, Microscopic examination of crude petroleum: Jour. Inst. Petroleum Technology, v. 23, p. 525–573.

Schreiter, R., 1925, Vanadiumoxyde im sachsischen Rotliegenden und ihre Bleichungswirkung [Vanadium oxide in the Saxony red beds and their bleaching action]: Sachsen, Jahrbuch Berg- und Huttenwerk, v. 101, p. A49–A69.

Seidell, Atherton, 1940, Solubilities of inorganic and metal organic compounds; a compilation of quantitative solubility data from the periodical literature: New York, D. Van Nostrand Co., v. 1, 1698 p.

Senftle, F. E., and Keevil, N. B., 1947, Thorium-uranium ratios in the theory of genesis of lead ores: Am. Geophys. Union Trans., v. 28, no. 5, p. 732–738.

Simard, G. L., and Warren, B. E., 1936, X-ray study of amorphous rubber: Am. Chem. Soc. Jour., v. 58, p. 507–509.

Sloss, L. L., 1953, The significance of evaporites: Jour. Sed. Petrology, v. 23, no. 3, p. 143–161.

Spence, H. S., 1930, A remarkable occurrence of thucholite and oil in a pegmatite dike, Parry Sound district, Ontario: Am. Mineralogist, v. 15, no. 11, p. 499–520.

Stewart, F. H., 1951, The middle evaporite bed, pt. 2 *of* The petrology of the evaporites of the Eskdale, No. 2 boring, east Yorkshire: Mineralog. Mag., v. 29, no. 212, p. 445–475.

Tanton, T. L., 1948, Radioactive nodules in sediments of the Sibley series, Nipigon, Ontario: Royal Soc. Canada Trans., 3d ser., v. 42, sec. 4, p. 69–75.

Wahl, A. C., and Bonner, N. A., 1951, Radioactivity applied to chemistry: New York, John Wiley & Sons, 666 p.

Wasserburg, G. J., 1957, a discussion *in* Cosmological and geological implications of isotope ratio variations; Natl. Acad. Sci.-Natl. Research Council Pub. 572, p. 156–158; Washington, D.C., Nuclear Science Series Rept. 23.

Young, R. B., 1917, The Rand Banket; a study of the auriferous conglomerates of the Witwatersrand and the associated rocks: London, 125 p.

U.S. GOVERNMENT PRINTING OFFICE: 1964 O—690-464