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Geochemistry of Liquids, Gases, and Rocks From the Smackover Formation

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by

A. Gene Collins[1]

ABSTRACT

The Bureau of Mines conducted a research study of the geochemistry of the Smackover Formation to determine what geochemical relationships are useful in exploration for and production of oil and gas. Samples of oil, gas, brine, and rock were collected and analyzed. The oilfied brines were analyzed by methods recommended by the American Petroleum Institute and by tentative methods of the American Society for Testing and Materials. The crude oils were analyzed by Bureau of Mines methods; the gas, by Bureau of Mines methods; and the rocks, by wet-chemical, atomic absorption, and neutron activation methods. The results were correlated and interpreted, and several geochemical relationships useful in exploration and production were found. These include the type and class of brine, organic constituents in the brine, redox potential, in situ temperature and pressure of brine, degree of sulfate and carbonate saturation of brine, and halide concentrations in the brine.

INTRODUCTION

The Bureau of Mines conducts research related to exploration, production, and conservation of petroleum, natural gas, and other minerals. The objective of this study was to determine some of the geochemical relationships that exist between the waters in a petroleum reservoir and the associated rock, oil, and gas. Knowledge of these relationships should aid exploration and production.

No reports describing the geochemistry of the brine, oil, or gas produced from the Smackover Formation were found; however, several publications concerned with the geology of the Smackover Formation were consulted. Bishop (7)[2] evaluated the environmental controls of the upper Smackover porosity; Dickinson (28-29) described some of the Jurassic stratigraphy, including the Smackover, of Arkansas, Louisiana, and Texas; Rainwater (70) described the geological history of the gulf coast and the potential for oil and gas; and Imlay (52-54) described some of the geology and paleontology of gulf coast Jurassic formations.

[1]Project leader.
[2]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

Numerous geochemical studies of oilfield brines and subsurface waters from various formations have been made, and 19 papers on the geochemistry of subsurface brines were published in a volume edited by Angino and Billings (3). Hitchon (40-42), Hitchon and Friedman (43), and Hitchon and Hays (44) studied the geochemistry and hydrodynamics of subsurface brines in the western Canada basin and the Surat basin. White (81) explored various theories concerning the origin of subsurface saline waters. Rittenhouse (71) studied the geochemistry of bromide in brines and its use in determining their origin. Van Everdingen (79-80) studied the geochemistry and hydrodynamics of formation waters in western Candada and theories of the origin of subsurface brines. Dickey (27) considered the patterns of the chemical compositions of deep formation waters. Chave (16) concluded that the origin of subsurface brines is best explained with respect to their reactions with formation rock. The origin of formation waters in the Illinois basin was studied by Graf (35-36), Clayton (17), and Bond (9). Collins (18-19, 21-23) and Collins and Egleson (24) studied the composition of various formation brines or associated rocks. Many other studies related to the origin of subsurface brines have been reported; for example, those by Bredehoeft (12), Young and Low (83), Egleson and Querio (32), and Schmidt (73).

Numerous studies related to the origin of petroleum also have been made. Some of the trends were outlined by Hodgson (46-47). Hunt published some data concerning hydrocarbons in sedimentary rocks (49) and the origin of petroleum in carbonate rocks (50).

None of the above studies were of brines from the Smackover Formation or of brines that contained the high concentrations of bromide and lithium found in the Smackover. In addition, most of the above studies did not include data for the associated oil, gas, and rock. In this research, the Smackover brines were classified by methods described by Collins (18). The classification indicates that numerous characteristics of the brines are useful genetic indicators of oil and gas accumulations that can be used in exploration.

The concentrations of some constituents in the Smackover brines such as calcium, strontium, barium, bicarbonate, and sulfate indicate that precipitates can form and cause production problems. Pressure drops in the formation or at the wellhead could cause calcium sulfate to precipitate. Mixing the Smackover brine with a waterflood makeup water containing appreciable amounts of sulfate could cause calcium, strontium, and barium sulfates to precipitate.

GENERAL GEOLOGY OF THE SMACKOVER FORMATION

According to Imlay (54), the Smackover Formation was named after the Smackover field in Arkansas. In that area it is composed of 700 feet of oolitic limestone. Smackover time equivalents have been identified in Mexico, Texas, Arkansas, Louisiana, Mississippi, and Alabama and found to be definitely Jurassic age (52) with good paleontological correlations with the late Jurassic Argovian strata in England. Figure 1 illustrates the age of the Smackover with reference to some of the other formations that it overlies or underlies.

System	European Stages	FORMATIONS: North Mexico	FORMATIONS: North Texas, South Arkansas, North Louisiana, Mississippi, Alabama, North Florida
Jurassic	Portlandian	La Casita	Cotton Valley Group
Jurassic	Kimmeridgian		
Jurassic	Kimmeridgian	Olivido	Buckner
Jurassic	Oxfordian	Zuloaga	Smackover
Jurassic	Oxfordian	Minas Viejas	Pre-Smackover including Norphlet
Jurassic	Middle Jurassic		Louann
Jurassic	Middle Jurassic		Werner
Jurassic	Middle Jurassic		Morehouse
Jurassic	Middle Jurassic		Eagle Mills

FIGURE 1. - Correlation chart of Jurassic age formations in Mexico, Texas, Arkansas, Louisiana, Mississippi, Alabama, and Florida.

FIGURE 2. - Approximate geographic location of the Smackover Formation.

The Smackover Formation is the equivalent of the Zuloaga Formation in Mexico (fig. 1). The Zuloaga carbonate outcrops west of the Tamaulipas Peninsula in northwest Mexico. The Smackover in the United States covers a salt dome basin in the western part of the Rio Grande embayment in southwest Texas. It crosses the crest of the San Marcos arch, the northwest part of the east Texas salt basin, the northern portion of the north Louisiana-Arkansas salt basin, then southeast over the north area of the central Mississippi salt basin, and under the Florida panhandle and offshore areas, as illustrated in figure 2. The Smackover Formation does not outcrop anywhere within the continental United States.

The northward boundary of the Smackover Formation follows the approximate updip edge of subcrop of the Jurassic rocks. Regional and local subsidence in the gulf coast geosyncline has caused thousands of fault trends associated with slumpage and folding. Sructural deformation of the Smackover also has been caused by tectonics related to flow of the underlying Louann salt.

The Smackover (Zuloaga) equivalent lies below Cotton Valley (La Casita) or Buckner (Olivido) equivalents in northwest Mexico (fig. 1). The updip limits of the Zuloaga are west of

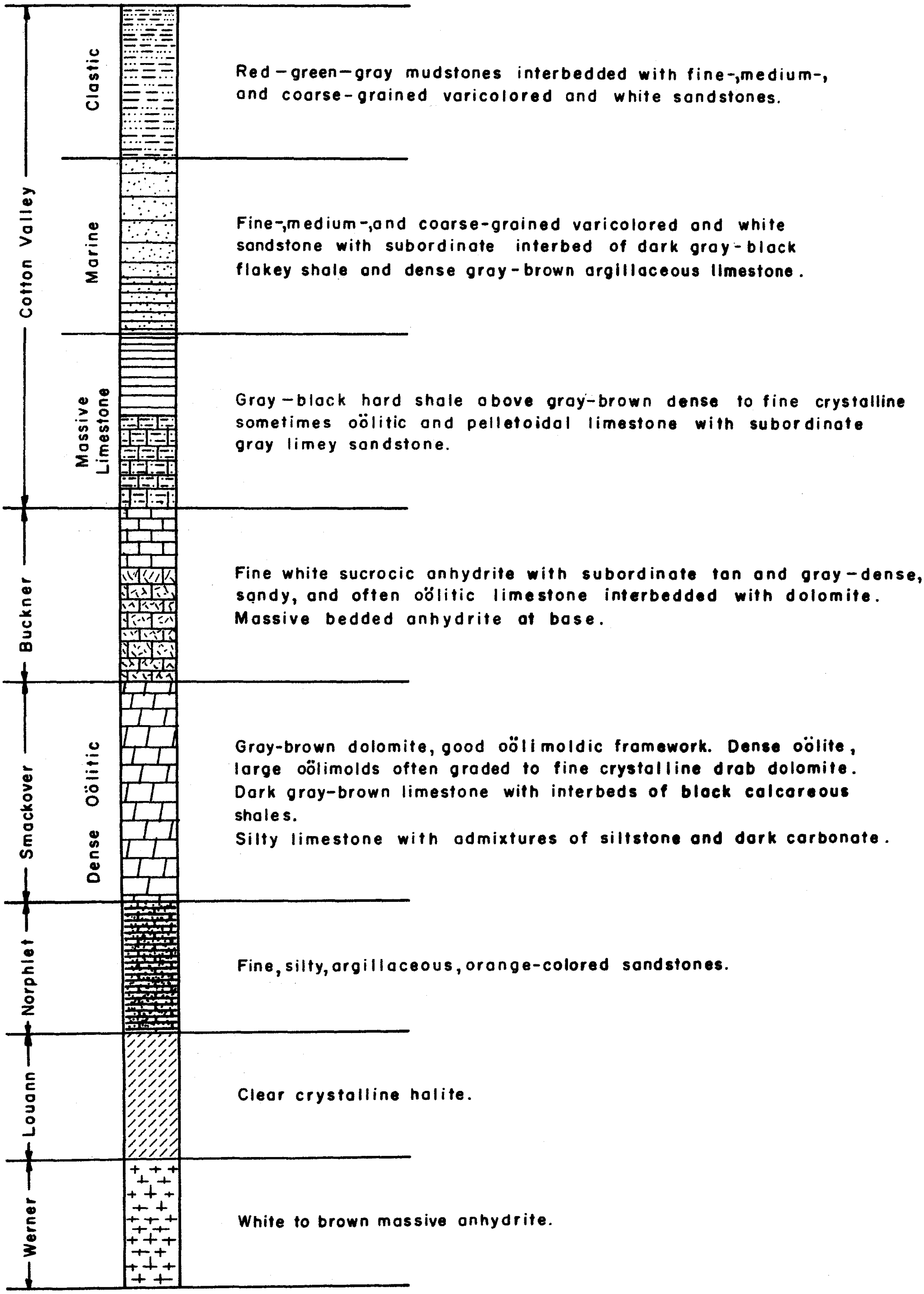

FIGURE 3. - Jurassic section in northeast Texas.

and parallel to the Tamaulipas Peninsula. Surface exposures of Norphlet equivalents (Minas Viejas) are found in the Galena area south of Monterrey and northwest of the Garcia Caves anticline of Sierra del Fraile (30). More than 3,000 feet of anhydrite, salt, and gypsum are found below the 1,400-foot-thick Zuloaga carbonates in the Sabinas basin. The zuloaga thins northeastward or near the northern updip limit of Jurassic sedimentation. The top of the Zuloaga is about 9,600 feet deep near the Mexico-United States border, and the formation is about 600 feet thick.

A pure coarsely crystalline salt (Louann Formation) is found below the Jurassic sediments in Milam County, Tex. The Smackover Formation in Texas usually consists of an arenaceous base, a microcrystalline middle zone, and a top zone of öolitic limestone or dolomite. Figure 3 illustrates types of rocks found in strata in the Werner, Louann, Norphlet, Smackover, Buckner, and Cotton Valley Formations in northeast Texas (30). The upper öolitic zone is recognizable along most of the Upper Gulf Coastal Plain from northwest Texas to Florida and offshore. Giant oilfields probably remain to be found in the southeast Smackover trend including the offshore area (25).

Bishop (7) divided the Smackover into two members: (1) an upper one, deposited in shallow water with various types of agitation and composed of different types of nonskeletal carbonate and mud; and (2) a lower one deposited in a quiet, toxic environment, composed primarily of carbonate mud with pyrite and abundant carbonaceous material. Dickinson (29) divided the Smackover into three informal members, a lower, middle, and upper. In this scheme, the upper member is predominantly öolitic limestone, the middle is usually a dense limestone, while the lower member is predominantly a dark-brown, silty to argillaceous, commonly laminated limestone.

All members of the Smackover are not present in all areas of the formation from northwest Mexico to Florida. The updip areas often are eröded because of uplifting west of the Tamaulipas Peninsula, uplift of the Peninsular arch, and land to the north before the close of the Jurassic period.

ORIGIN OF THE SMACKOVER FORMATION

Near the end of the Triassic period, tectonics produced a trough near southern Mexico and northern Central America, north of an emerging land mass in the regions of Honduras and southern Guatemala, Chiapas, and Oaxaca. Marine waters (Tethys Sea?) spread westward, and an arm of the sea entered the Gulf of Mexico basin. Highly saline water extended into subsiding grabens, and with arid conditions, salt precipitated (70).

The trough, which was the western part of the Antillean geosyncline, received from 2,000 to 3,000 feet of continental deposits along its southern margin during the Lower Jurassic and early Middle Jurassic. Contemporaneously, farther north in the region of eastern Hidalgo and adjoining parts of Veracruz and Puebla, about 1,300 feet of marine clay was deposited (53).

During the Middle Jurassic period, the sedimentation changed from dominantly carbonaceous or coarse littoral to sublittoral and normal marine in the upper part in western Oaxaca and northeastern Guerrero. The littoral and sublittoral character of most of the sediments and the preservation of the flora in them indicate that marine waters occupied little area, occurring mainly as bays and lagoons. The climate during the Lower and Middle Jurassic was hot and humid, at least seasonally, as indicated by the richness of the flora, the presence of considerable coal, and the dark color of the marine sediments (53).

The marine waters covered the southern United States, the northern Antilles, and much of Mexico. Thousands of feet of sediments was deposited during Upper Jurassic time ranging from 3,000 to 7,000 feet in the southern United States; 2,600 to 4,800 feet in northern Mexico; 5,000 feet in southern Mexico; and from 10,000 to 30,000 feet in Cuba.

Marine waters of late Upper Jurassic time were limited landward by highlands formed during the orogeny. The sediments ranged in thickness from a few hundred feet to nearly 4,000 feet and were composed primarily of clays and organic matter, but near shore considerable amounts of terrestial-derived gravel and sand were deposited.

The climate of the later Upper Jurassic probably was more moist than that earlier in the Upper Jurassic because the sediments are much darker and contain more organic matter. At the end of Jurassic time, the marine waters retreated basinward along the northern margins of the Gulf of Mexico and the Mexican geosyncline.

Principal rocks formed during the Upper Jurassic age are sandstone, limestone, dolomite, and evaporites. These suggest that deposition occurred under a variety of environments. As indicated in figure 1, the Smackover Formation overlies the Norphlet Formation in most areas and underlies the Buckner Formation. Generally the Smackover Formation thickens gulfward because of tilting or subsiding of the basin. Uncomformities indicate uplifting and erosion occurred later.

On the Arkansas shelf, the upper Smackover primarily is the "Reynolds Öolite," a "blanket" calcarenite thinning southward toward the shelf slope near the Arkansas-Louisiana border. Active structural growth in the deeper water-shelf slope region gave rise to calcarenite deposition in positive areas in Arkansas and east Texas.

Thin units of calcarenite or sandy limestone interbedded with some shale and sandstone are found in eastern Arkansas and Louisiana and in western Mississippi. A massive clean sandstone was deposited above the shelf in western Mississippi by a stream that probably supplied terrigenous detritus to the Smackover sea.

Massive limestone deposition occurred along a tectonic hingeline on the southern portion of the shelf slope. Gray marine shale is found south of the hingeline in the Smackover.

The Smackover Formation resembles a giant cresent, as illustrated in figure 2. In general, the downdip Smackover thickens, but the precise downdip limits have not been determined because they probably are several miles deep. During Smackover time, the deposition in the deep basin was primarily clays and shales with limestones deposited shelfward.

Several papers have been written in which the main purpose is to compare ancient limestone deposition with the contemporary Bahaman environment (4). Some investigators are certain that significant volumes of carbonate sediments are forming on the Bahama banks by chemical precipitation; others believe that most carbonates are biogenic with only a small portion formed by chemical precipitation. The Reynolds öolites of the upper Smackover were deposited in an environment similar to that of the Bahama Islands (51). On the Bahama banks, öolites, pisolites, pellets, algal lumps, grapestone, and clastic shell material are formed and deposited. The principal deposition is "bahamite" (4), a fine-grained carbonate sand or friable aggregates.

The three principal updip to downdip upper Smackover depositional facies, with respect to decreasing energy level are reservoir, mixed, and pellet-mud (7). According to Bishop (7), the Smackover sea was hypersaline; therefore, the allochems were almost entirely nonskeletal. Deltaic sediments deposited in the eastern area of the Apalachicola embayment probably are the source of the hydrocarbons found in the deep Smackover fields in Florida, Alabama, and offshore. Giant fields probably remain to be found in this area in Jurassic and younger rocks.

ANALYSIS OF SMACKOVER OILFIELD BRINES

Sampling Method

Oilfield brine samples were taken only from wells where reasonable assurance was evident that the formation brine was not contaminated by intrusion of water from other formations. Some drill-stem test samples were taken; however, care was exercised to insure that only bottom samples containing no mud filtrate were used. All of the samples were collected and contained in good-quality polyethylene bottles before transport to the laboratory. Duplicate samples were taken in the field; one sample was not acidified and one sample was acidified to a pH of about 1.5 with reagent-grade hydrochloric acid. The acidified sample was used in the determination of the cations, and the unacidified sample was used in the determination of pH, alkalinity, and the anions.

Analytical Methods

The distances between the points of sampling and the laboratory were several hundred miles; therefore, the time between sampling and analysis often exceeded 3 days. No analyses were made in the field. As soon as the samples reached the laboratory, they were analyzed for pH, alkalinity, and resistivity; therefore, the pH and alkalinity values can be considered only relative and not absolute.

The specific gravity of each sample was determined, so that a correct aliquot size could be estimated for each specific ion determination. A pH meter was used to determine the pH, and a standard acid was used to titrate the carbonate and bicarbonate to a specific pH end point monitored with the pH meter.

Lithium, sodium, potassium, magnesium, calcium, strontium, barium, manganese, iron, copper, zinc, and lead were determined by flame emission or atomic absorption spectroscopy (33). Boron, ammonium, chloride, bromide, and iodide were determined by titrimetric methods, and sulfate was determined by a gravimetric method (1). The organic acids were determined by titration and calculated as acetic acid.

Analyses

Location information is given in table 1 for each sample, and the data are arranged in alphabetical order with reference to the sedimentary basin from which the sample was taken. The number shown in the left column is the sample number, and if oil, brine, and core samples were taken from the same well, the numbers will be the same for all three. Table 1 shows the sample location with respect to State, county, section, township, range, latitude, longitude, and sedimentary basin. Also shown in table 1 is the elevation of the well in feet above sea level, depth of the well in feet, corrected top depth in feet, bottom-hole temperature in ° F, and bottom-hole pressure in pounds per square inch (psi). Subsequent tables in this report show the sample number but not the locations.

The analytical data that were obtained by analyzing brines from the Smackover Formation are shown in table 2. Not all of the Smackover brine samples shown in table 2 were analyzed by the Bureau of Mines; the analytical data for several of the samples were obtained from oil companies. Table 1 indicates where each brine sample was analyzed.

TABLE 1. - Sampling locations, depths, and bottom-hole temperatures and pressures of Smackover samples

Sample	State	County	Section, township, range	Latitude	Longitude	Basin	Elevation, feet	Depth, feet	Corrected depth, feet	Bottom-hole temperature, °F	Bottom-hole pressure, psi
* 1	Mississippi	Smith	4-1N-9E	315800	0892300	East Gulf	370	16,845-17,033	16,475	(1/)	(1/)
* 2	...do.....	Wayne	26-10N-6W	314900	0883400	...do.......	233	12,688-13,488	12,455	(1/)	(1/)
* 3	...do.....	Smith	9-1N-9E	315700	0892300	...do.......	490	15,860-16,845	15,370	284	3,701
* 4	Alabama	Choctaw	35-11N-4W	315300	0882100	Hatchetigbee	156	11,967-11,918	11,811	190	4,694
* 5	...do.....	...do...	4-11N-3W	315700	0881700	...do.......	278	10,486-11,000	10,208	180	3,441
* 6	...do.....	...do...	4-11N-3W	315700	0881700	...do.......	241	10,455-10,480	10,214	180	3,298
* 7	...do.....	...do...	35-11N-4W	315300	0881500	...do.......	155	11,974-11,997	11,819	188	5,014
* 8	Texas	Vanzandt	NAp	324100	0955200	Mexia Talco	394	12,784-12,818	12,390	275	3,520
* 9	Arkansas	Lafayette	9-16S-24W	332300	0993500	Monroe uplift	295	7,030-7,072	6,735	(1/)	2,974
*10	...do.....	Union	30-17S-12W	331300	0922300	...do.......	190	6,049-6,058	5,859	(1/)	(1/)
*11	...do.....	...do...	8-16S-17W	332100	0925300	...do.......	220	6,317-6,479	6,097	(1/)	(1/)
*12	...do.....	Nevada	1-15S-20W	322800	0930800	...do.......	331	5,891-5,897	5,560	(1/)	(1/)
†13	...do.....	Union	15-17S-18W	331600	0925800	North Louisiana	277	7,196-7,200	6,919	(1/)	(1/)
†14	...do.....	...do...	14-15S-24W	332700	0933400	...do.......	244	7,184-7,186	6,940	200	2,700
†15	...do.....	...do...	10-17S-18W	331700	0925700	...do.......	330	7,138-7,143	6,808	200	2,700
†16	...do.....	Lafayette	7-15S-24W	332800	0933800	...do.......	247	7,158-7,282	6,911	200	2,700
†17	...do.....	Union	10-17S-18W	331700	0925700	...do.......	272	7,159-7,165	6,887	200	2,700
†18	...do.....	...do...	10-17S-18W	331700	0925700	...do.......	289	7,184-7,186	6,895	200	2,700
†19	...do.....	...do...	10-17S-18W	331700	0925700	...do.......	244	7,184-7,186	6,940	200	2,700
†20	...do.....	...do...	10-17S-18W	331700	0925700	...do.......	300	7,144-7,186	6,844	200	2,700
†21	...do.....	...do...	15-17S-18W	331600	0925800	...do.......	272	7,788-7,792	7,516	200	2,700
†22	...do.....	...do...	10-17S-18W	331700	0925700	...do.......	283	7,165-7,168	6,882	200	2,700
†23	...do.....	...do...	10-17S-18W	331700	0925700	...do.......	245	7,189-7,191	6,944	200	2,700
†24	...do.....	...do...	10-17S-18W	331700	0925700	...do.......	262	7,140-7,146	6,878	200	2,700
†25	...do.....	...do...	10-17S-18W	331700	0925700	...do.......	282	7,184-7,191	6,902	200	2,700
†26	...do.....	...do...	10-17S-18W	331700	0925700	...do.......	286	7,166-7,194	6,880	200	2,700
†27	...do.....	...do...	10-17S-18W	331700	0925700	...do.......	282	7,184-7,186	6,902	200	2,700
*28	...do.....	...do...	17-17S-17W	331500	0925300	...do.......	215	7,012-7,045	6,797	164	2,724
*29	...do.....	Ouachita	22-15S-18W	332500	0925700	...do.......	209	5,188-5,314	4,979	(1/)	5,314
*30	...do.....	Hemstead	28-14S-23W	333000	0933000	...do.......	279	5,860-5,876	5,581	(1/)	2,132
*31	...do.....	Ouachita	28-15S-15W	332300	0923900	...do.......	129	4,821-4,961	4,692	(1/)	(1/)
*32	...do.....	...do...	13-15S-19W	332600	0930100	...do.......	217	5,837-5,862	5,620	(1/)	(1/)
*33	...do.....	Union	13-17S-13W	331500	0922400	...do.......	263	6,224-6,232	5,961	(1/)	(1/)
*34	...do.....	...do...	28-19S-18W	330300	0925900	...do.......	226	9,287-9,316	9,061	(1/)	2,441
†35	...do.....	Lafayette	18-15S-23W	332700	0933200	Sabine uplift	288	6,450-6,482	6,162	185	2,710
†36	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	310	6,388-6,430	6,078	190	2,710
†37	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	284	6,471-6,489	6,187	180	2,710
†38	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	320	6,372-6,388	6,052	180	2,720
†39	...do.....	...do...	7-15S-25W	332800	0934500	...do.......	302	6,430-6,457	6,128	185	2,710
†40	...do.....	...do...	7-15S-25W	332800	0934500	...do.......	284	6,430-6,457	6,146	185	2,710
†41	...do.....	...do...	7-15S-25W	332800	0934500	...do.......	302	6,430-6,457	6,128	185	2,710
†42	...do.....	...do...	7-15S-25W	332800	0934500	...do.......	288	6,430-6,457	6,142	185	2,710
†43	...do.....	Columbia	15-17S-18W	331600	0925800	...do.......	330	7,138-7,143	6,808	200	2,700
†44	...do.....	...do...	10-17S-18W	331700	0925800	...do.......	275	7,136-7,166	6,861	210	2,700
†45	...do.....	...do...	24-17S-20W	331500	0930800	...do.......	272	7,515-7,525	7,243	210	2,770
†46	...do.....	...do...	23-17S-20W	331500	0930900	...do.......	346	7,626-7,641	7,280	210	2,770
†47	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	266	6,471-6,489	6,205	210	2,770
†48	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	267	6,372-6,388	6,105	210	2,700
†49	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	269	6,388-6,488	6,119	210	2,700
†50	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	266	6,356-6,406	6,090	210	2,700

See footnotes at end of table.

TABLE 1. - Sampling locations, depths, and bottom-hole temperatures and pressures of Smackover samples --Continued

Sample	State	County	Section, township, range	Latitude	Longitude	Basin	Elevation, feet	Depth, feet	Corrected depth, feet	Bottom-hole temperature, °F	Bottom-hole pressure, psi
51	Arkansas	Columbia	10-18S-20W	331200	0931000	Sabine uplift	297	4,283-4,292	3,986	210	2,700
52	...do.....	...do...	24-17S-20W	331500	0930800	...do.......	311	7,603-7,630	7,292	210	2,770
53	...do. ...	...do...	22-17S-20W	331500	0931000	...do.......	340	7,536-7,600	7,196	210	2,770
54	...do.....	...do...	13-17S-20W	331600	0930800	...do.......	327	7,602-7,620	7,275	210	2,720
55	...do.....	...do...	20-18S-19W	331000	0930600	...do.......	320	7,500-7,503	7,180	(1/)	(1/)
56	...do.....	...do...	7-15S-23W	332800	0933200	...do.......	264	6,300-6,314	6,036	(1/)	(1/)
57	...do.....	...do...	13-15S-24W	332700	0933300	...do.......	260	6,258-6,262	5,998	(1/)	(1/)
58	...do.....	...do...	10-15S-24W	332800	0933500	...do.......	265	6,309-6,315	6,044	182	2,429
59	...do.....	...do...	9-15S-24W	332800	0933600	...do.......	268	6,309-6,318	6,041	188	2,748
60	...do.....	...do...	10-15S-24W	332800	0933500	...do.......	264	6,100-6,146	5,836	180	2,963
61	...do.....	...do...	22-17S-20W	331500	0931000	...do.......	354	7,608-7,621	7,254	(1/)	(1/)
62	...do.....	...do...	22-17S-20W	331500	0931000	...do.......	345	7,618-7,626	7,273	(1/)	(1/)
63	...do.....	...do...	22-17S-20W	331500	0931000	...do.......	312	7,573-7,564	7,261	(1/)	(1/)
64	...do.....	Lafayette	7-15S-25W	332800	0934500	...do.......	267	6,430-6,457	6,163	(1/)	(1/)
65	...do.....	Columbia	23-17S-20W	331500	0930900	...do.......	343	7,615-7,645	7,272	210	2,705
66	...do.....	...do...	18-17S-19W	331600	0930700	...do.......	304	7,534-7,55[illegible]	7,230	210	2,770
67	...do.....	...do...	4-18S-20W	331300	0931100	...do.......	293	8,426-8,72[illegible]	8,133	225	2,800
68	...do.....	...do...	15-17S-20W	331600	0931000	...do.......	272	7,628-7,630	7,356	210	2,700
69	...do.....	...do...	16-17S-20W	331600	0931100	...do.......	275	7,624-7,634	7,349	210	2,700
70	...do.....	...do...	19-17S-20W	331500	0931300	...do.......	316	7,533-7,594	7,217	210	2,700
71	...do.....	...do...	24-17S-20W	331500	0930800	...do.......	290	7,630-7,620	7,340	210	2,700
72	...do.....	...do...	23-17S-20W	331500	0930900	...do.......	269	6,183-6,186	5,914	210	2,705
73	...do.....	...do...	23-17S-20W	331500	0930900	...do.......	287	6,750-6,754	6,463	210	2,700
74	...do.....	...do...	23-17S-20W	331500	0930900	...do.......	283	6,238-6,240	5,955	210	2,700
75	...do.....	...do...	21-17S-20W	331500	0931100	...do.......	264	7,614-7,630	7,350	210	2,700
76	...do.....	...do...	21-17S-20W	331500	0931100	...do.......	364	7,619-7,621	7,255	210	2,700
77	...do.....	...do...	22-17S-20W	331500	0931000	...do.......	290	6,190-6,198	5,900	210	2,760
78	...do.....	...do...	22-17S-20W	331500	0931000	...do.......	303	6,470-6,476	6,167	210	2,700
79	...do.....	...do...	22-17S-20W	331500	0931000	...do.......	289	6,232-6,238	5,943	210	2,700
80	...do.....	Lafayette	18-15S-23W	332700	0933200	...do.......	280	6,356-6,364	6,076	180	2,720
81	...do.....	Columbia	18-17S-19W	331600	0930700	...do.......	298	7,534-7,550	7,236	210	2,700
82	...do.....	...do...	13-17S-20W	331600	0930800	...do.......	318	7,602-7,628	7,284	210	2,720
83	...do.....	...do...	13-17S-20W	331600	0930800	...do.......	334	7,575-7,602	7,241	210	2,700
84	...do.....	...do...	19-17S-19W	331500	0930700	...do.......	271	7,530-7,573	7,259	210	2,700
85	...do.....	...do...	18-17S-19W	331600	0930700	...do.......	308	7,534-7,791	7,226	210	2,770
86	...do.....	Lafayette	18-15S-23W	332700	0933200	...do.......	312	6,388-6,430	6,076	180	2,710
87	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	306	6,372-6,388	6,066	180	2,710
88	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	300	6,356-6,406	6,056	180	2,710
89	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	298	6,471-6,489	6,173	180	2,720
90	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	324	6,388-6,430	6,064	180	2,710
91	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	318	6,450-6,482	6,132	185	2,710
92	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	318	6,388-6,430	6,070	180	2,710
93	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	318	6,388-6,430	6,070	180	2,700
94	...do.....	Columbia	23-17S-20W	331500	0930900	...do.......	361	7,614-7,642	7,253	210	2,720
95	...do.....	...do...	23-17S-20W	331500	0930900	...do.......	361	7,446-7,622	7,085	210	2,700
96	...do.....	...do...	23-17S-20W	331500	0930900	...do.......	310	7,615-7,645	7,305	210	2,760
97	...do.....	...do...	22-17S-20W	331500	0931000	...do.......	354	7,605-7,613	7,251	210	2,770
98	...do.....	...do...	22-17S-20W	331500	0931000	...do.......	340	7,536-7,600	7,196	210	2,770
99	...do.....	...do...	22-17S-20W	331500	0931000	...do.......	360	7,618-7,626	7,258	210	2,700
100	...do.....	...do...	22-17S-20W	331500	0931000	...do.......	360	7,520-7,534	7,160	210	2,700

See footnotes at end of table.

TABLE 1. - Sampling locations, depths, and bottom-hole temperatures and pressures of Smackover samples--Continued

Sample	State	County	Section, township, range	Latitude	Longitude	Basin	Elevation, feet	Depth, feet	Corrected depth, feet	Bottom-hole temperature, °F	Bottom-hole pressure, psi
/101	Arkansas	Columbia	22-17S-20W	331500	0931000	Sabine uplift	245	7,573-7,609	7,328	210	2,700
/102	...do.....	...do...	22-17S-20W	331500	0931000	...do.......	312	7,523-7,549	7,211	210	2,700
/103	...do.....	...do...	22-17S-20W	331500	0931000	...do.......	312	7,536-7,600	7,224	210	2,700
/104	...do.....	...do...	22-17S-20W	331500	0931000	...do.......	311	7,618-7,626	7,307	210	2,730
/105	...do.....	...do...	22-17S-20W	331500	0931000	...do.......	310	7,573-7,609	7,263	210	2,700
/106	...do.....	...do...	22-17S-20W	331500	0931000	...do.......	320	7,593-7,606	7,273	210	2,705
/107	...do.....	...do...	19-17S-19W	331500	0930700	...do.......	363	7,530-7,550	7,167	210	2,700
/108	...do.....	...do...	24-17S-20W	331500	0930800	...do.......	309	7,570-7,583	7,261	208	2,524
/109	...do.....	...do...	13-17S-20W	331600	0930800	...do.......	327	6,702-6,720	6,375	210	2,720
/110	...do.....	Lafayette	18-15S-23W	332700	0933200	...do.......	330	6,356-6,406	6,026	180	2,710
/111	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	324	6,450-6,482	6,126	180	2,720
/112	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	289	6,372-6,388	6,083	180	2,710
/113	...do.....	Columbia	10-18S-20W	331200	0931000	...do.......	315	8,283-8,292	7,968	210	2,[illegible]00
/114	...do.....	...do...	17-18S-21W	331100	0931800	...do.......	310	8,916-8,926	8,606	310	2,001
/115	...do.....	...do...	18-18S-21W	331100	0931900	...do.......	320	8,926-8,930	8,606	(1/)	(1/)
/116	...do.....	...do...	21-18S-21W	331000	0931700	...do.......	290	8,003-8,874	7,713	220	2,500
/117	...do.....	...do...	22-18S-21W	331000	0931600	...do.......	255	8,862-8,874	8,607	220	2,500
/118	...do.....	...do...	25-17S-20W	331400	0930800	...do.......	360	7,603-7,620	7,243	210	2,700
/119	...do.....	...do...	25-17S-20W	331400	0930800	...do.......	286	7,603-7,620	7,317	210	2,700
/120	...do.....	...do...	24-17S-20W	331500	0930800	...do.......	289	7,603-7,620	7,314	210	2,700
/121	...do.....	...do...	24-17S-20W	331500	0930800	...do.......	272	7,515-7,525	7,243	210	2,700
/122	...do.....	...do...	24-17S-20W	331500	0930800	...do.......	301	7,510-7,540	7,209	(1/)	(1/)
/123	...do.....	...do...	24-17S-20W	331500	0930800	...do.......	315	7,603-7,620	7,288	210	2,700
/124	...do.....	...do...	24-17S-20W	331500	0930800	...do.......	268	7,510-7,540	7,242	210	2,700
/125	...do.....	...do...	24-17S-20W	331500	0930800	...do.......	275	7,516-7,588	7,241	210	2,700
/126	...do.....	...do...	24-17S-20W	331500	0930800	...do.......	245	7,546-7,588	7,301	210	2,700
/127	...do.....	...do...	24-17S-20W	331500	0930800	...do.......	289	7,515-7,525	7,226	210	2,700
/128	...do.....	...do...	24-17S-20W	331500	0930800	...do.......	324	7,615-7,636	7,291	210	2,700
/129	...do.....	...do...	23-17S-20W	331500	0930900	...do.......	327	7,608-7,621	7,281	210	2,700
/130	...do.....	...do...	23-17S-20W	331500	0930900	...do.......	343	7,615-7,645	7,272	210	2,705
/131	...do.....	...do...	23-17S-20W	331500	0930900	...do.......	352	7,614-7,622	7,262	210	2,720
/132	...do.....	...do...	23-17S-20W	331500	0930900	...do.......	352	7,614-7,622	7,262	210	2,720
/133	...do.....	...do...	23-17S-20W	331500	0930900	...do.......	354	7,605-7,613	7,251	210	2,770
/134	...do.....	...do...	23-17S-20W	331500	0930900	...do.......	361	7,642-7,672	7,281	210	2,730
/135	...do.....	...do...	23-17S-20W	331500	0930900	...do.......	358	7,615-7,645	7,257	210	2,700
/136	...do.....	...do...	23-17S-20W	331500	0930900	...do.......	361	7,609-7,621	7,248	180	2,720
/137	...do.....	Claiborne	25-23N-6W	325700	0925700	...do.......	298	10,156-10,193	9,858	(1/)	(1/)
/138	...do.....	...do...	5-22N-5W	325500	0925500	...do.......	320	10,372-10,416	10,052	(1/)	(1/)
/139	...do.....	...do...	23-23N-6W	325800	0925800	...do.......	250	10,150-10,154	9,900	(1/)	(1/)
*140	...do.....	Columbia	12-18S-21W	331200	0931400	...do.......	322	8,807-9,100	8,485	223	2,800
*141	...do.....	...do...	33-17S-21W	331300	0931700	...do.......	297	8,314-9,284	8,017	225	2,800
*142	...do.....	...do...	23-19S-23W	330500	0932800	...do.......	261	10,913-11,038	10,652	(1/)	(1/)
*143	...do.....	Lafayette	22-19S-24W	330500	0933500	...do.......	236	10,935-10,946	10,699	(1/)	5,197
*144	...do.....	...do...	7-15S-24W	332800	0933800	...do.......	336	6,570-6,614	6,234	182	1,906
*145	...do.....	Columbia	8-18S-20W	331200	0931200	...do.......	328	8,540-8,750	8,212	225	2,800
*146	...do.....	...do...	31-17S-20W	331300	0931300	...do.......	321	8,438-8,732	8,117	223	2,800
*147	...do.....	...do...	2-18S-20W	331300	0930900	...do.......	356	8,345-8,645	7,989	225	2,800
*148	...do.....	...do...	9-18S-20W	331200	0931100	...do.......	266	8,360-8,628	8,094	224	2,800
*149	...do.....	...do...	10-18S-20W	331200	0931000	...do.......	305	8,360-8,650	8,055	223	2,800
*150	...do.....	...do...	11-18S-20W	331200	0930900	...do.......	312	8,310-8,600	7,998	223	2,800

See footnotes at end of table.

TABLE 1. - Sampling locations, depths, and bottom-hole temperatures and pressures of Smackover samples--Continued

Sample	State	County	Section, township, range	Latitude	Longitude	Basin	Elevation, feet	Depth, feet	Corrected depth, feet	Bottom-hole temperature, °F	Bottom-hole pressure, psi
*151	Arkansas	Columbia	7-18S-20W	331200	0931300	Sabine uplift	277	8,656-8,926	8,379	223	2,800
*152	...do.....	Lafayette	7-15S-24W	332800	0933800	...do.......	287	6,495-6,544	6,208	172	1,112
*153	...do.....	Columbia	18-18S-20W	331100	0931300	...do.......	266	8,512-8,792	8,246	223	2,800
/154	...do.....	Lafayette	7-15S-24W	332800	0933800	...do.......	302	6,465-6,502	6,163	182	1,906
*155	...do.....	Columbia	8-17S-20W	331700	0931100	...do.......	274	8,024-8,039	7,750	(1/)	2,852
*156	...do.....	...do...	34-17S-20W	331300	0931000	...do.......	320	8,118-8,400	7,798	224	2,800
*157	...do.....	...do...	3-18S-20W	331300	0931000	...do.......	318	8,352-8,650	8,034	225	2,800
*158	...do.....	...do...	33-17S-20W	331300	0931100	...do.......	304	8,315-8,600	8,011	225	2,800
*159	...do.....	...do...	6-18S-20W	331300	0931300	...do.......	299	8,604-8,908	8,305	224	2,800
*160	...do.....	...do...	4-18S-20W	331300	0931100	...do.......	307	8,417-8,696	8,110	224	2,800
*161	...do.....	...do...	1-18S-21W	331300	0931400	...do.......	317	8,608-8,902	8,291	224	2,800
/162	...do.....	Lafayette	14-15S-24W	332600	0933300	...do.......	260	6,372-6,400	6,112	188	2,722
/163	...do.....	...do...	11-15S-24W	332800	0933400	...do.......	264	6,315-6,362	6,051	(1/)	(1/)
/164	...do.....	...do...	11-15S-24W	332800	0933400	...do.......	268	6,349-6,364	6,081	184	2,190
/165	...do.....	...do...	11-15S-24W	332800	0933400	...do.......	264	6,334-6,350	6,070	184	2,419
/166	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	253	6,402-6,451	6,149	186	1,242
/167	...do.....	...do...	11-15S-24W	332800	0933400	...do.......	262	6,138-6,312	5,876	185	2,692
/168	...do.....	...do...	10-15S-24W	332800	0933500	...do.......	283	6,330-6,333	6,047	186	2,692
/169	...do.....	...do...	10-15S-24W	332800	0933500	...do.......	283	6,330-6,333	6,047	186	2,645
/170	...do.....	...do...	7-15S-23W	332800	0933200	...do.......	264	6,014-6,148	5,750	184	2,419
/171	...do.....	...do...	7-15S-23W	332800	0933200	...do.......	264	6,014-6,148	5,750	179	2,535
/172	...do.....	...do...	14-15S-24W	332600	0933300	...do.......	258	6,282-6,298	6,024	184	1,106
/173	...do.....	...do...	11-15S-24W	332800	0933400	...do.......	267	6,300-6,309	6,033	(1/)	(1/)
/174	...do.....	...do...	11-15S-24W	332800	0933400	...do.......	256	6,345-6,380	6,089	(1/)	(1/)
/175	...do.....	...do...	11-15S-24W	332800	0933400	...do.......	263	6,309-6,313	6,046	185	1,621
/176	...do.....	...do...	11-15S-24W	332800	0933400	...do.......	266	6,309-6,316	6,043	186	1,457
/177	...do.....	...do...	11-15S-24W	332800	0933400	...do.......	263	6,300-6,313	6,037	182	2,884
/178	...do.....	...do...	11-15S-24W	332800	0933400	...do.......	265	6,310-6,315	6,045	170	2,845
/179	...do.....	...do...	14-15S-24W	332600	0933300	...do.......	258	6,082-6,098	5,824	184	1,106
/180	...do.....	...do...	14-15S-24W	332600	0933300	...do.......	259	6,300-6,309	6,041	180	2,633
/181	...do.....	...do...	10-15S-24W	332800	0933500	...do.......	259	6,187-6,309	5,928	186	2,665
/182	...do.....	...do...	10-15S-24W	332800	0933500	...do.......	259	6,187-6,309	5,928	186	2,665
/183	...do.....	...do...	13-15S-24W	332700	0933300	...do.......	254	6,157-6,304	5,903	189	2,770
/184	...do.....	...do...	13-15S-24W	332700	0933300	...do.......	254	6,157-6,304	5,903	189	2,770
/185	...do.....	...do...	13-15S-24W	332700	0933300	...do.......	254	6,157-6,304	5,903	189	2,770
/186	...do.....	...do...	13-15S-24W	332700	0933300	...do.......	269	6,147-6,319	5,878	180	2,595
/187	...do.....	...do...	9-15S-24W	332800	0933600	...do.......	269	6,147-6,319	5,878	180	2,595
/188	...do.....	...do...	14-15S-24W	332700	0933400	...do.......	261	6,300-6,311	6,039	(1/)	(1/)
/189	...do.....	...do...	14-15S-24W	332700	0933400	...do.......	261	6,108-6,311	5,847	(1/)	(1/)
/190	...do.....	...do...	11-15S-24W	332800	0933400	...do.......	262	6,138-6,312	5,876	(1/)	(1/)
*191	...do.....	Columbia	5-18S-20W	331300	0931200	...do.......	310	8,490-8,800	8,180	223	2,800
*192	...do.....	...do...	5-18S-20W	331300	0931200	...do.......	318	8,475-8,777	8,157	223	2,800
*193	...do.....	...do...	32-17S-20W	331300	0931100	...do.......	327	8,396-8,708	8,069	225	2,800
*194	...do.....	...do...	6-18S-20W	331300	0931300	...do.......	330	8,564-8,850	8,234	263	2,800
/195	...do.....	Lafayette	12-15S-24W	332800	0933300	...do.......	260	6,360-6,384	6,100	184	2,667
*196	...do.....	...do...	14-16S-24W	332200	0933300	...do.......	306	6,715-6,715	6,409	190	3,052
*197	...do.....	...do...	11-15S-24W	332800	0933400	...do.......	263	6,198-6,313	5,935	193	3,085
*198	...do.....	Miller	36-16S-27W	331900	0935100	...do.......	296	9,023-9,030	8,727	225	2,800
*199	...do.....	Columbia	21-18S-19W	331000	0930500	...do.......	283	8,431-8,510	8,148	(1/)	(1/)
*200	...do.....	...do...	23-18S-20W	331000	0930900	...do.......	350	8,501-8,575	8,151	(1/)	(1/)

See footnotes at end of table.

TABLE 1. - Sampling locations, depths, and bottom-hole temperatures and pressures of Smackover samples--Continued

Sample	State	County	Section, township, range	Latitude	Longitude	Basin	Elevation, feet	Depth, feet	Corrected depth, feet	Bottom-hole temperature, °F	Bottom-hole pressure, psi
*201	Arkansas	Lafayette	12-15S-25W	332800	0934000	Sabine uplift	334	6,552-6,556	6,218	(1/)	2,679
*202	...do.....	Columbia	10-17S-19W	331700	0930400	...do.......	265	7,368-7,370	7,103	(1/)	(1/)
*203	...do.....	Union	28-19S-18W	330300	0925900	...do.......	266	9,287-9,316	9,021	(1/)	(1/)
†204	...do.....	Lafayette	7-15S-24W	332800	0933800	...do.......	319	6,523-6,565	6,204	185	808
†205	...do.....	...do...	14-15S-24W	332700	0933400	...do.......	259	6,400-6,412	6,141	181	1,978
†206	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	256	6,353-6,404	6,097	182	2,323
†207	...do.....	...do...	12-15S-24W	332800	0933300	...do.......	258	6,300-6,308	6,042	178	2,716
†208	...do.....	...do...	10-15S-24W	332800	0933500	...do.......	265	6,309-6,315	6,044	176	2,850
†209	...do.....	...do...	11-15S-24W	332800	0933400	...do.......	276	6,320-6,326	6,044	184	2,368
†210	...do.....	...do...	7-15S-23W	332800	0933200	...do.......	257	6,147-6,307	5,890	184	2,630
†211	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	257	6,150-6,307	5,893	188	2,625
†212	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	261	6,147-6,311	5,886	178	3,060
†213	...do.....	...do...	13-15S-23W	332700	0932700	...do.......	257	6,187-6,307	5,930	184	3,147
†214	...do.....	...do...	9-15S-24W	332800	0933600	...do.......	269	6,147-6,319	5,878	180	2,658
†215	...do.....	...do...	13-15S-24W	332700	0933300	...do.......	255	6,072-6,305	5,817	182	2,742
†216	...do.....	...do...	13-15S-24W	332700	0933300	...do.......	255	6,072-6,305	5,817	182	2,108
†217	...do.....	...do...	18-15S-23W	332700	0933200	...do.......	253	6,187-6,303	5,934	180	2,630
*218	...do.....	Claiborne	4-22N-6W	330700	0930000	...do.......	277	10,322-10,329	10,045	241	1,231
*219	...do.....	Webster	18-23N-9W	325900	0932000	...do.......	238	10,700-10,900	10,462	218	1,710
*220	...do.....	Claiborne	10-23N-6W	330000	0925900	...do.......	208	10,000-11,000	9,792	204	4,763
*221	...do.....	Webster	10-23N-9W	330000	0931700	...do.......	325	10,000-11,030	9,675	(1/)	1,107
*222	...do.....	Claiborne	26-23N-6W	325700	0925800	...do.......	223	10,000-11,000	9,777	220	1,896
*223	...do.....	...do...	19-23N-6W	325800	0930200	...do.......	314	9,500-10,200	9,186	212	2,325
*224	Texas	Cass	NAp	331500	0942900	...do.......	312	10,493-10,506	10,181	263	2,763
*225	...do.....	...do...	NAp	331200	0942100	Tyler	238	9,868-9,893	9,630	(1/)	(1/)
*226	...do.....	Wood	NAp	325200	0953600	...do.......	422	12,765-12,797	12,343	280	6,275
227	Arkansas	Columbia	5-17S-19W	331800	093070	Sabine uplift	(1/)	7,388-7,430	(1/)	(1/)	(1/)
228	...do.....	Union	5-18S-17W	331200	092530	...do.......	(1/)	7,636-7,655	(1/)	(1/)	(1/)
229	...do.....	Lafayette	5-15S-24W	332800	093360	...do.......	(1/)	6,304-6,372	(1/)	(1/)	(1/)
230	...do.....	Miller	5-16S-25W	332300	093430	...do.......	(1/)	7,343-7,450	(1/)	(1/)	(1/)
231	...do.....	Columbia	5-18S-19W	331200	093070	...do.......	310	8,239-8,294	7,929	(1/)	(1/)
232	...do.....	...do...	5-18S-19W	331200	093070	...do.......	(1/)	8,284-8,287	(1/)	(1/)	(1/)
233	...do.....	...do...	5-18S-19W	331200	093070	...do.......	200	8,155-8,164	7,955	(1/)	(1/)
234	...do.....	...do...	5-18S-19W	331200	093070	...do.......	(1/)	(1/)	(1/)	(1/)	(1/)
235	...do.....	...do...	22-17S-20W	331500	093100	...do.......	361	7,392-7,570	7,031	(1/)	(1/)
236	...do.....	Lafayette	35-17S-24W	331400	093340	...do.......	264	9,302-9,306	9,038	(1/)	(1/)
237	...do.....	...do...	13-15S-24W	332700	093330	...do.......	270	6,200-	5,930	(1/)	(1/)
238	...do.....	...do...	7-15S-24W	332800	093380	...do.......	352	6,580-6,595	6,228	(1/)	(1/)
239	...do.....	Columbia	5-17S-21W	331800	093180	...do.......	274	8,024-8,115	7,750	(1/)	(1/)
240	...do.....	Union	2-17S-18W	331800	092570	...do.......	246	7,149-7,241	6,903	(1/)	(1/)
241	...do.....	Columbia	18-16S-22W	332200	093250	...do.......	259	7,195-7,258	6,936	(1/)	(1/)
242	...do.....	...do...	18-18S-19W	331100	093070	...do.......	340	8,328-8,338	7,988	(1/)	(1/)
243	...do.....	Ouachita	9-15S-19W	332700	093040	...do.......	264	5,889-5,907	5,625	(1/)	(1/)
244	...do.....	Lafayette	17-15S-24W	332700	093370	...do.......	352	6,583-6,589	6,231	(1/)	(1/)
245	...do.....	...do...	5-17S-23W	331800	093310	...do.......	(1/)	8,113-8,118	(1/)	(1/)	(1/)
246	Louisiana	Claiborne	23-23N-6W	330100	092580	...do.......	233	10,308-10,357	10,075	(1/)	(1/)
247	...do.....	Webster	17-23N-9W	325900	093190	...do.......	253	10,730-10,738	10,477	(1/)	(1/)
248	...do.....	...do...	8-23N-9W	330000	093190	...do.......	(1/)	10,820-10,835	(1/)	(1/)	(1/)
249	...do.....	Claiborne	23-23N-7W	325800	093040	...do.......	318	9,894-10,116	9,576	(1/)	(1/)
250	...do.....	Webster	8-23N-9W	330000	093190	...do.......	203	10,952-11,010	10,749	(1/)	(1/)

See footnotes at end of table.

TABLE 1. - Sampling locations, depths, and bottom-hole temperatures and pressures of Smackover samples--Continued

Sample	State	County	Section, township, range	Latitude	Longitude	Basin	Elevation, feet	Depth, feet	Corrected depth, feet	Bottom-hole temperature, °F	Bottom-hole pressure, psi
251	Louisiana	Webster	7-23N-9W	330000	093200	Sabine	226	10,936-10,956	10,710	(1/)	(1/)
252	...do.....	Claiborne	21-23N-7W	325800	093050	...do.......	270	10,160-10,170	9,890	(1/)	(1/)
253	...do.....	Webster	3-23N-8W	330100	093110	...do.......	325	11,032-11,052	10,707	(1/)	(1/)
254	...do.....	Claiborne	34-23N-6W	325600	092590	...do.......	277	10,159-10,188	9,882	(1/)	(1/)
255	...do.....	Webster	7-23N-9W	330000	093200	...do.......	226	10,640-10,660	10,414	(1/)	(1/)
256	...do.....	Claiborne	34-23N-6W	325600	092590	...do.......	261	10,142-10,184	9,881	(1/)	(1/)
257	...do.....	...do...	21-23N-7W	325800	093050	...do.......	305	10,020-10,170	9,715	(1/)	(1/)
258	...do.....	Webster	5-23N-9W	330100	093190	...do.......	289	10,706-10,746	10,417	(1/)	(1/)
259	...do.....	Claiborne	26-23N-7W	325700	093040	...do.......	290	10,160-10,334	9,870	(1/)	(1/)
260	...do.....	...do...	23-23N-7W	325800	093040	...do.......	277	10,322-	10,045	(1/)	(1/)
261	...do.....	...do...	33-23N-6W	325600	093000	...do.......	254	10,213-10,272	9,959	(1/)	(1/)
262	...do.....	Webster	8-23N-9W	330000	093190	...do.......	253	11,056-11,066	10,803	(1/)	(1/)
263	...do.....	...do...	5-23N-8W	330100	093130	...do.......	266	10,650-10,680	10,384	(1/)	(1/)
264	...do.....	Claiborne	25-23N-6W	325700	092570	...do.......	(1/)	9,000-10,000	(1/)	(1/)	(1/)
265	...do.....	...do...	25-23N-7W	325700	093030	...do.......	(1/)	(1/)	(1/)	(1/)	(1/)
266	...do.....	...do...	23-23N-8W	325800	093100	...do.......	351	2,790-2,830	2,439	(1/)	(1/)
267	...do.....	...do...	23-23N-8W	325800	093100	...do.......	345	4,560-4,590	4,215	(1/)	(1/)
268	...do.....	...do...	22-23N-7W	325800	093050	...do.......	301	4,445-4,455	4,144	(1/)	(1/)
269	...do.....	Webster	1-23N-11W	330100	093270	...do.......	238	3,085-3,133	2,847	(1/)	(1/)
270	...do.....	...do...	3-23N-9W	330100	093170	...do.......	325	11,030-11,170	10,705	(1/)	(1/)
271	...do.....	Claiborne	1-23N-6W	330100	093000	...do.......	208	9,950-10,045	9,742	(1/)	(1/)
272	...do.....	Webster	18-23N-9W	325900	093200	...do.......	238	10,700-10,900	10,462	(1/)	(1/)
273	...do.....	Claiborne	27-23N-6W	325700	092590	...do.......	256	10,140-10,270	9,884	(1/)	(1/)
274	Arkansas	Ouachita	5-15S-15W	332700	092410	North Louisiana	207	4,938-4,944	4,731	(1/)	(1/)
275	...do.....	...do...	5-15S-15W	332700	092410	...do.......	729	4,822-4,852	4,093	(1/)	(1/)
276	...do.....	...do...	5-15S-15W	332700	092410	...do.......	99	4,792-4,803	4,693	(1/)	(1/)
277	...do.....	Union	5-17S-18W	331700	093000	...do.......	232	7,166-7,373	6,934	(1/)	(1/)
278	...do.....	...do...	28-17S-17W	331300	092520	...do.......	293	7,826-7,858	7,533	(1/)	(1/)
279	...do.....	Ouachita	14-15S-18W	332600	092560	...do.......	188	5,866-5,878	5,678	(1/)	(1/)
280	...do.....	...do...	22-15S-18W	332500	092570	...do.......	204	5,866-5,876	5,662	(1/)	(1/)
281	Louisiana	Claiborne	-20N-4W	324300	092460	...do.......	(1/)	10,270-10,393	(1/)	(1/)	(1/)
282	Mississippi	Smith	5-1N-9E	315700	089240	Jackson Dome	(1/)	15,570-15,585	(1/)	(1/)	(1/)
283	...do.....	Rankin	18-5N-5E	321600	089490	...do.......	(1/)	17,816	(1/)	(1/)	(1/)
284	...do.....	Smith	17-11N-9E	315600	089240	...do.......	(1/)	15,675-15,701	(1/)	(1/)	(1/)
285	...do.....	...do...	17-11N-9E	315600	089240	...do.......	(1/)	14,017-14,045	(1/)	(1/)	(1/)
286	...do.....	...do...	4-11N-9E	315700	089230	...do.......	(1/)	16,794-16,814	(1/)	(1/)	(1/)
287	...do.....	Scott	18-5N-8E	321700	089310	...do.......	(1/)	(1/)	(1/)	(1/)	(1/)
288	...do.....	Wayne	22-10N-6W	314900	088340	...do.......	233	12,754-12,771	12,521	(1/)	(1/)
289	Texas	Franklin	NAp	330200	095090	Van Dome	506	12,180-12,383	11,674	(1/)	(1/)
290	...do.....	Hopkins	NAp	331700	095320	Mexia Talco	(1/)	(1/)	(1/)	(1/)	(1/)
291	...do.....	...do...	NAp	331500	095340	...do.......	(1/)	(1/)	(1/)	(1/)	(1/)
292	Florida	Santa Rosa	9-5N-29W	305700	086450	Hatchetigbee Anticline	(1/)	15,470-15,524	(1/)	(1/)	(1/)
293	Arkansas	Columbia	16-18S-20W	331100	093110	Sabine uplift	(1/)	8,584-9,703	(1/)	(1/)	(1/)
294	...do.....	...do...	2-18S-20W	331300	093090	...do.......	(1/)	8,385-8,541	(1/)	(1/)	(1/)
295	...do.....	...do...	19-18S-20W	331000	093130	...do.......	(1/)	9,024-9,112	(1/)	(1/)	(1/)
296	...do.....	...do...	9-18S-20W	331200	093110	...do.......	(1/)	8,430-8,475	(1/)	(1/)	(1/)
297	...do.....	...do...	12-18S-20W	331200	093080	...do.......	(1/)	8,414-8,566	(1/)	(1/)	(1/)
298	Texas	Van Zandt	NAp	(1/)	(1/)	Mexia Talco	(1/)	12,152-12,193	(1/)	(1/)	(1/)
299	...do.....	Bowie	NAp	(1/)	(1/)	...do.......	(1/)	9,540-9,572	(1/)	(1/)	(1/)
300	...do.....	Van Zandt	NAp	(1/)	(1/)	...do.......	(1/)	12,887-13,149	(1/)	(1/)	(1/)

See footnotes at end of table.

TABLE 1. - Sampling locations, depths, and bottom-hole temperatures and pressures of Smackover samples--Continued

Sample	State	County	Section, township, range	Latitude	Longitude	Basin	Elevation, feet	Depth, feet	Corrected depth, feet	Bottom-hole temperature, °F	Bottom-hole pressure, psi
301	Texas	Van Zandt	NAp	(1/)	(1/)	Mexia Talco	(1/)	12,923-12,960	(1/)	(1/)	(1/)
302	...do.....	Hopkins	NAp	(1/)	(1/)	...do.......	(1/)	9,305-9,339	(1/)	(1/)	(1/)
303	Louisiana	Ouachita	36-17N-1E	322500	092200	North Louisiana	(1/)	10,222-10,262	(1/)	(1/)	(1/)
304	Texas	Navarro	NAp	(1/)	(1/)	Mexia Talco	(1/)	9,364-9,654	(1/)	(1/)	(1/)
305	Mississippi	Wayne	26-10N-6W	314800	088330	East Gulf Embayment	(1/)	12,718-12,778	(1/)	(1/)	(1/)
306	...do.....	Clark	6-1N-18E	315700	088300	...do.......	(1/)	11,568-11,718	(1/)	(1/)	(1/)
307	Louisiana	Union	10-20N-1W	324400	092270	North Louisiana	(1/)	10,476-10,502	(1/)	(1/)	(1/)
308	...do.....	Ouachita	36-17N-1E	322500	092200	...do.......	(1/)	10,241-10,262	(1/)	(1/)	(1/)
309	Mississippi	Wayne	26-10N-6W	314800	088330	East Gulf Embayment	(1/)	12,738-12,778	(1/)	(1/)	(1/)
310	Texas	Van Zandt	NAp	(1/)	(1/)	Mexia Talco	(1/)	13,008-13,149	(1/)	(1/)	(1/)
311	...do.....	Navarro	NAp	(1/)	(1/)	...do.......	(1/)	9,651-9,669	(1/)	(1/)	(1/)
312	...do.....	Bowie	NAp	(1/)	(1/)	...do.......	(1/)	9,553-9,573	(1/)	(1/)	(1/)
313	Mississippi	Clarke	22-2N-14E	310800	089480	East Gulf Embayment	(1/)	13,058-13,098	(1/)	(1/)	(1/)

* Designates those brines analyzed at Bartlesville Energy Research Center.
/ Designates those brines not analyzed at Bartlesville Energy Research Center.
NAp Not applicable.
1/ Not available.

TABLE 2. - Analyses of Smackover oilfield brines

Sample	County	Field	Specific gravity, 60°/60° F	Resistivity, ohm-meters, 80°F	pH	Li^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}	Mn^{2+}	Fe^{2+}	Cu^{2+}	Zn^{2+}	B^{3+}	Pb^{2+}	NH_4^+	HCO_3^-	CO_3^{2-}	Cl^-	Br^-	I^-	SO_4^{2-}	Organic acid as acetic
					Milligrams per liter																					
1	Smith ...	Tallahala Creek	1.211	0.039	6.1	48	55,200	7,560	4,240	45,200	1,410	33	52	9	2	3	167	(1/)	247	202	0	185,500	2,1[illegible]	13	95	21
2	Wayne ..	Cypress Creek	1.210	.044	2.0	80	74,500	650	2,000	48,800	4,020	47	25	5	1	2	150	(1/)	130	0	0	188,900	2,000	8	0	80
3	Smith ...	Tallahala Creek	1.188	.040	5.0	67	55,200	4,260	2,500	34,600	1,960	16	3	203	1	14	137	3	225	18	0	173,300	1,500	18	146	26
4	Choctaw	Choctaw Ridge	1.222	.043	3.6	56	68,700	5,530	1,690	55,300	2,600	30	75	70	1	2	109	(1/)	200	0	0	205,200	1,750	37	131	220
5	...do...	Toxey	1.215	.038	3.8	49	75,700	2,730	2,110	40,900	1,910	11	3	6	1	2	25	(1/)	196	0	0	186,300	2,040	35	33	300
6	...do...	...do.......	1.211	.040	6.0	50	75,100	12	4,160	41,000	2,220	36	60	50	1	2	225	(1/)	112	40	0	190,300	1,440	23	165	220
7	...do...	Choctaw Ridge	1.222	.040	2.0	61	75,400	8,000	1,720	41,000	2,560	9	30	12	0	2	282	(1/)	190	0	0	203,100	1,880	22	77	260
8	Van Zandt	Edgewood ...	1.081	.099	6.5	100	25,300	2,860	2,900	9,100	1,720	28	3	9	1	0	274	(1/)	164	110	0	71,200	980	7	0	200
9	Lafayette	Lewisville, N.	1.213	.040	5.3	72	58,800	1,870	2,560	44,000	2,050	38	81	30	1	92	66	13	69	56	0	186,800	4,110	11	420	100
10	Union ..	New London, N.	1.148	.048	5.9	35	47,500	470	3,400	24,900	1,150	12	8	73	1	2	66	(1/)	76	103	0	120,000	4,210	21	432	120
11	...do...	Bear Creek ..	1.171	.046	1.5	21	68,900	740	3,290	23,700	1,300	6	1	8	1	1	44	(1/)	100	0	0	171,300	3,890	20	406	75
12	Nevada.	Stephens	1.135	.053	3.0	15	47,300	520	2,650	18,200	700	2	7	307	1	7	143	2	264	0	0	121,100	2,000	19	222	336
13	Union ..	Mt. Holly...	1.180	.050	5.7	(1/)	63,200	(1/)	4,100	29,500	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	96	0	161,700	(1/)	(1/)	203	(1/)
14	...do...	...do.......	1.191	.051	6.0	(1/)	66,500	(1/)	3,700	31,100	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	157	0	168,100	(1/)	(1/)	258	(1/)
15	...do...	...do.......	1.191	.051	5.5	(1/)	64,900	(1/)	3,060	32,200	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	166	0	165,600	(1/)	(1/)	247	(1/)
16	...do...	...do.	1.193	.051	5.9	(1/)	66,000	(1/)	3,780	37,300	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	193	0	168,800	(1/)	(1/)	231	(1/)
17	...do...	...do.......	1.189	.050	5.9	(1/)	68,900	(1/)	3,200	31,100	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	174	0	170,300	(1/)	(1/)	200	(1/)
18	...do...	...do.......	1.192	.048	6.1	(1/)	68,300	(1/)	4,000	31,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	171	0	173,000	(1/)	(1/)	216	(1/)
19	...do...	...do.......	1.193	.051	6.0	(1/)	64,800	(1/)	3,200	31,000	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	188	0	163,800	(1/)	(1/)	240	(1/)
20	...do...	...do.......	1.193	.051	5.9	(1/)	61,300	(1/)	3,700	32,100	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	116	0	161,200	(1/)	(1/)	219	(1/)
21	...do...	...do.......	1.192	.050	5.9	(1/)	64,900	(1/)	4,300	32,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	154	0	170,600	(1/)	(1/)	305	(1/)
22	...do...	...do.......	1.192	.049	6.1	(1/)	68,600	(1/)	3,100	33,000	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	182	0	173,000	(1/)	(1/)	223	(1/)
23	...do...	...do.......	1.191	.049	6.0	(1/)	67,700	(1/)	3,500	32,000	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	198	0	171,000	(1/)	(1/)	181	(1/)
24	...do...	...do.......	1.190	.049	6.0	(1/)	65,500	(1/)	3,370	35,700	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	182	0	174,200	(1/)	(1/)	219	(1/)
25	...do...	...do.......	1.192	.050	5.9	(1/)	68,200	(1/)	4,100	31,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	167	0	172,700	(1/)	(1/)	329	(1/)
26	...do...	...do.......	1.186	.051	5.9	(1/)	68,100	(1/)	3,390	33,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	191	0	170,200	(1/)	(1/)	284	(1/)
27	...do...	...do.......	1.185	.049	5.8	(1/)	70,200	(1/)	2,450	29,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	198	0	167,800	(1/)	(1/)	237	(1/)
28	...do...	West Lisbon..	1.181	.042	5.9	5	77,600	20	3,900	28,500	1,720	6	2	18	1	1	45	(1/)	100	55	0	154,400	3,850	13	166	210
29	Quachita	Gum Creek ..	1.141	.044	7.0	22	42,900	5,190	2,900	20,300	598	4	5	3	1	5	15	(1/)	140	79	0	117,700	3,880	18	314	98
30	Hempstead	Patmos	1.152	.044	4.1	26	59,300	774	3,170	25,100	1,025	2	3	113	1	1	22	(1/)	214	0	0	132,500	3,100	26	329	120
31	Quachita	Smackover ..	1.109	.065	6.0	12	50,900	307	2,080	18,750	885	7	1	26	1	1	124	(1/)	589	79	0	117,900	5,580	79	325	168
32	...do...	Wesson	1.149	.050	5.5	24	58,200	716	2,630	17,500	770	1	2	6	1	1	42	(1/)	286	41	0	129,400	2,050	36	320	228
33	Union ..	El Dorado, E.	1.157	.040	3.0	50	55,500	614	2,780	26,400	1,070	2	4	58	1	2	75	(1/)	646	0	0	133,700	2,080	16	325	180
34	...do...	Tubal	1.082	.084	4.1	34	21,900	204	1,470	16,900	168	11	21	12	1	1	144	(1/)	735	0	0	61,200	1,010	10	166	80
35	Lafayette	Midway.....	1.181	.051	5.9	(1/)	51,600	(1/)	3,370	35,300	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	144	0	151,400	(1/)	(1/)	290	(1/)
36	...do...	...do.......	1.198	.051	5.8	(1/)	59,500	(1/)	3,820	37,400	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	62	0	188,800	(1/)	(1/)	255	(1/)
37	...do...	...do.......	1.197	.051	5.8	(1/)	60,300	(1/)	4,000	37,400	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	73	0	170,500	(1/)	(1/)	270	(1/)
38	...do...	...do.......	1.201	.050	6.0	(1/)	60,900	(1/)	4,300	38,700	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	76	0	174,500	(1/)	(1/)	212	(1/)
39	...do...	...do.......	1.134	.050	5.6	(1/)	57,300	(1/)	4,000	33,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	123	0	159,200	(1/)	(1/)	439	(1/)
40	...do...	...do.... ..	1.184	.050	6.1	(1/)	56,700	(1/)	4,150	34,800	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	39	0	164,200	(1/)	(1/)	261	(1/)
41	...do...	...do......	1.185	.050	5.5	(1/)	55,900	(1/)	3,970	37,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	16	0	163,800	(1/)	(1/)	231	(1/)
42	...do...	...do.......	1.185	.051	6.0	(1/)	53,000	(1/)	3,730	35,400	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	100	0	155,000	(1/)	(1/)	278	(1/)
43	Columbia	Magnolia	1.186	.053	5.8	(1/)	68,500	(1/)	3,370	31,800	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	187	0	167,400	(1/)	(1/)	279	(1/)
44	...do...	...do..	1.187	.055	5.8	(1/)	67,100	(1/)	3,000	30,100	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	193	0	166,000	(1/)	(1/)	290	(1/)
45	...do...	...do.......	1.188	.054	6.1	(1/)	69,800	(1/)	2,220	32,300	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	146	0	170,900	(1/)	(1/)	200	(1/)
46	...do...	...do.......	1.214	.052	5.8	(1/)	73,400	(1/)	4,100	38,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	114	0	193,600	(1/)	(1/)	172	(1/)
47	Lafayette	Midway	1.200	.054	5.7	(1/)	63,100	(1/)	3,560	37,800	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	59	0	174,500	(1/)	(1/)	246	(1/)

See footnote at end of table.

TABLE 2. - Analyses of Smackover oilfield brines--Continued

Sample	County	Field	Specific gravity, 60°/60° F	Resistivity, ohm-meters, 80° F	Milligrams per liter: pH	Li^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}	Mn^{2+}	Fe^{2+}	Cu^{2+}	Zn^{2+}	B^{3+}	PB^{2+}	NH_4^+	HCO_3^-	CO_3^{2-}	Cl^-	Br^-	I^-	SO_4^{2-}	Organic acid as acetic
48	Lafayette	Midway.....	1.195	.054	5.6	(1/)	62,900	(1/)	3,950	35,300	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	41	0	172,700	(1/)	(1/)	260	(1/)
49	...do...	...do.......	1.197	.054	5.8	(1/)	63,500	(1/)	3,220	35,300	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	84	0	169,500	(1/)	(1/)	216	(1/)
50	...do...	...do.......	1.195	.054	5.7	(1/)	62,500	(1/)	3,820	36,800	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	29	0	172,300	(1/)	(1/)	239	(1/)
51	Columbia	Calhoun	1.226	.049	5.8	(1/)	78,000	(1/)	3,100	39,800	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	231	0	199,300	(1/)	(1/)	134	(1/)
52	...do...	Magnolia ...	1.207	.052	5.8	(1/)	75,700	(1/)	3,300	37,800	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	176	0	193,900	(1/)	(1/)	230	(1/)
53	...do...	...do.......	1.215	.052	5.8	(1/)	73,600	(1/)	3,650	48,200	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	229	0	195,000	(1/)	(1/)	213	(1/)
54	...do...	...do.......	1.157	.056	4.9	(1/)	57,800	(1/)	2,220	26,000	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	26	0	141,500	(1/)	(1/)	166	(1/)
55	...do...	...do.......	1.204	.046	4.3	(1/)	66,500	(1/)	3,300	37,800	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	179,000	(1/)	(1/)	124	(1/)
56	Lafayette	Midway.....	1.184	(1/)	5.5	(1/)	60,800	(1/)	5,300	29,800	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	12	0	161,700	(1/)	(1/)	602	(1/)
57	...do...	...do.......	1.135	(1/)	4.5	(1/)	42,200	(1/)	3,800	21,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	114,400	(1/)	(1/)	887	(1/)
58	...do...	...do.......	1.201	(1/)	4.3	(1/)	53,900	(1/)	8,600	37,500	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	1	0	174,500	(1/)	(1/)	1,830	(1/)
59	...do...	...do.......	1.199	(1/)	6.1	(1/)	67,200	(1/)	8,600	25,100	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	35	0	173,000	(1/)	(1/)	615	(1/)
60	...do...	...do.......	1.182	(1/)	6.0	(1/)	60,300	(1/)	5,300	32,200	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	27	0	160,800	(1/)	(1/)	474	(1/)
61	Columbia	Magnolia	1.213	.052	5.8	(1/)	74,300	(1/)	4,400	39,400	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	196	0	189,400	(1/)	(1/)	149	(1/)
62	...do...	...do.......	1.216	.052	5.7	(1/)	70,900	(1/)	4,100	33,000	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	222	0	190,100	(1/)	(1/)	189	(1/)
63	...do...	...do.......	1.216	.052	5.7	(1/)	77,200	(1/)	3,700	37,000	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	207	0	195,000	(1/)	(1/)	199	(1/)
64	Lafayette	Midway	1.184	.054	5.7	(1/)	60,100	(1/)	3,400	33,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	44	0	161,700	(1/)	(1/)	340	(1/)
65	Columbia	Magnolia ...	1.214	.051	5.8	(1/)	72,100	(1/)	3,400	40,300	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	211	0	199,000	(1/)	(1/)	218	(1/)
66	...do...	...do.......	1.208	.058	5.8	(1/)	84,800	(1/)	5,000	43,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	229	0	223,000	(1/)	(1/)	264	(1/)
67	...do...	Kerlin	1.232	.040	5.9	391	71,000	6,380	3,840	45,000	2,470	20	46	10	1	2	230	1/	170	191	0	211,000	5,250	10	632	80
68	...do...	Magnolia ...	1.218	.054	5.7	(1/)	76,600	(1/)	2,600	37,500	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	224	0	190,200	(1/)	(1/)	242	(1/)
69	...do...	...do.......	1.210	.059	5.8	(1/)	79,000	(1/)	2,300	38,200	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	294	0	196,600	(1/)	(1/)	217	(1/)
70	...do...	...do.......	1.208	.050	5.8	(1/)	82,400	(1/)	5,540	44,100	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	290	0	221,100	(1/)	(1/)	270	(1/)
71	...do...	...do.......	1.206	.048	5.8	(1/)	67,300	(1/)	4,570	36,500	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	234	0	181,500	(1/)	(1/)	202	(1/)
72	...do...	...do.......	1.211	.051	6.2	(1/)	70,200	(1/)	3,630	39,200	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	167	0	188,000	(1/)	(1/)	311	(1/)
73	...do...	...do.......	1.208	.049	5.8	(1/)	76,700	(1/)	2,670	36,700	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	245	0	190,800	(1/)	(1/)	198	(1/)
74	...do...	...do.......	1.210	.050	5.0	(1/)	74,300	(1/)	2,670	37,700	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	216	0	189,000	(1/)	(1/)	224	(1/)
75	...do...	...do.......	1.215	.051	5.7	(1/)	75,900	(1/)	2,860	37,700	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	222	0	193,000	(1/)	(1/)	171	(1/)
76	...do...	...do.......	1.207	.049	5.8	(1/)	68,900	(1/)	2,900	36,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	240	0	190,000	(1/)	(1/)	180	(1/)
77	...do...	...do.......	1.085	.077	6.5	(1/)	36,800	(1/)	1,140	7,310	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	112	0	72,400	(1/)	(1/)	782	(1/)
78	...do...	...do.......	1.211	.052	5.8	(1/)	73,400	(1/)	2,900	38,200	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	240	0	189,800	(1/)	(1/)	220	(1/)
79	...do...	...do.......	1.204	.050	5.8	(1/)	69,200	(1/)	3,320	36,700	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	204	0	181,200	(1/)	(1/)	173	[illegible]
80	Lafayette	Midway	1.194	.051	5.6	(1/)	55,500	(1/)	4,480	37,800	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	62	0	165,200	(1/)	(1/)	261	[illegible]
81	Columbia	Magnolia	1.208	.052	6.2	(1/)	69,400	(1/)	3,300	38,400	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	151	0	185,100	(1/)	(1/)	188	(1/)
82	...do...	...do.......	1.145	.054	6.1	(1/)	55,400	(1/)	2,850	29,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	92	0	145,100	(1/)	(1/)	212	(1/)
83	...do...	...do.......	1.199	.047	5.8	(1/)	65,200	(1/)	3,790	36,200	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	154	0	175,500	(1/)	(1/)	70	(1/)
84	...do...	...do.......	1.211	.051	6.4	(1/)	84,700	(1/)	3,470	49,300	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	233	0	227,600	(1/)	(1/)	230	(1/)
85	...do...	...do.......	1.205	.047	6.2	(1/)	70,000	(1/)	4,330	36,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	163	0	175,100	(1/)	(1/)	181	(1/)
86	...do...	...do.......	1.196	.050	4.6	(1/)	63,800	(1/)	3,780	37,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	1/	(1/)	(1/)	7	0	185,900	(1/)	(1/)	154	(1/)
87	Lafayette	Midway	1.199	.048	4.6	(1/)	65,200	(1/)	3,410	39,400	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	179,400	(1/)	(1/)	997	(1/)
88	...do...	...do.......	1.194	.049	5.2	(1/)	60,900	(1/)	3,280	38,200	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	21	0	170,900	(1/)	(1/)	244	(1/)
89	...do...	...do.......	1.200	.043	4.6	(1/)	68,700	(1/)	2,620	37,300	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	7	0	179,400	(1/)	(1/)	200	(1/)
90	...do...	...do.......	1.192	.055	5.3	(1/)	62,700	(1/)	3,370	37,700	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	32	0	173,000	(1/)	(1/)	227	(1/)
91	...do...	...do.......	1.183	.053	5.1	(1/)	56,300	(1/)	4,120	33,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	67	0	158,500	(1/)	(1/)	484	(1/)
92	...do...	...do.......	1.193	.055	3.8	(1/)	62,600	(1/)	4,130	37,100	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	174,100	(1/)	(1/)	213	(1/)
93	...do...	...do.......	1.192	.050	5.5	(1/)	64,000	(1/)	4,050	34,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	142	0	171,300	(1/)	(1/)	379	(1/)
94	Columbia	Magnolia ...	1.155	.053	5.7	(1/)	57,100	(1/)	1,360	24,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	73	0	135,800	(1/)	(1/)	262	(1/)

See footnote at end of table.

TABLE 2. - Analyses of Smackover oilfield brines--Continued

Sample	County	Field	Specific gravity, 60°/60° F	Resistivity, ohm-meters, 80° F	Milligrams per liter: pH	Li^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}	Mn^{2+}	Fe^{2+}	Cu^{2+}	Zn^{2+}	B^{3+}	Pb^{2+}	NH_4^+	HCO_3^-	CO_3^{2-}	Cl^-	Br^-	I^-	SO_4^{2-}	Organic acid as acetic
95	Columbia	Magnolia....	1.205	.048	5.9	(1/)	70,500	(1/)	3,130	36,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	171	0	182,300	(1/)	(1/)	156	(1/)
96	...do...	...do.......	1.215	.050	5.8	(1/)	72,000	(1/)	3,130	39,200	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	211	0	189,400	(1/)	(1/)	219	(1/)
97	...do...	...do.......	1.209	.048	5.4	(1/)	69,200	(1/)	3,620	38,700	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	101	0	195,500	(1/)	(1/)	231	(1/)
98	...do...	...do.......	1.217	.047	6.0	(1/)	73,200	(1/)	3,620	42,000	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	20	0	196,100	(1/)	(1/)	165	(1/)
99	...do...	...do.......	1.212	.049	6.0	(1/)	72,500	(1/)	4,520	38,300	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	204	0	192,900	(1/)	(1/)	179	(1/)
100	...do...	...do.......	1.209	.047	5.7	(1/)	71,200	(1/)	3,000	38,200	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	163	0	186,000	(1/)	(1/)	184	(1/)
101	...do...	...do.......	1.215	.048	5.8	(1/)	72,300	(1/)	4,000	39,300	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	216	0	192,200	(1/)	(1/)	402	(1/)
102	...do...	...do.......	1.210	.050	5.3	(1/)	72,800	(1/)	3,690	36,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	771	0	187,900	(1/)	(1/)	252	(1/)
103	...do...	...do.......	1.215	.051	6.2	(1/)	70,800	(1/)	3,640	39,400	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	170	0	189,400	(1/)	(1/)	264	(1/)
104	...do...	...do.......	1.217	.046	5.8	(1/)	77,400	(1/)	2,160	38,700	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	210	0	194,000	(1/)	(1/)	230	(1/)
105	...do...	...do.......	1.215	.047	5.9	(1/)	76,400	(1/)	2,400	39,000	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	168	0	194,600	(1/)	(1/)	189	(1/)
106	...do...	...do.......	1.213	.047	5.7	(1/)	68,900	(1/)	4,940	38,700	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	200	0	188,000	(1/)	(1/)	315	(1/)
107	...do...	...do.......	1.209	.048	6.2	(1/)	70,700	(1/)	3,580	37,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	105	0	186,400	(1/)	(1/)	305	(1/)
108	...do...	...do.......	1.213	.048	5.8	(1/)	87,400	(1/)	2,500	40,100	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	215	0	212,000	(1/)	(1/)	212	(1/)
109	...do...	...do.......	1.200	.048	5.8	(1/)	77,700	(1/)	4,280	44,000	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	172	0	209,800	(1/)	(1/)	444	(1/)
110	Lafayette	Midway.....	1.194	.050	6.0	(1/)	63,800	(1/)	3,500	38,400	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	23	0	176,200	(1/)	(1/)	414	(1/)
111	...do...	...do.......	1.186	.052	5.7	(1/)	61,600	(1/)	3,600	35,700	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	26	0	168,400	(1/)	(1/)	255	(1/)
112	...do...	...do.......	1.195	.051	5.2	(1/)	64,900	(1/)	3,800	37,200	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	28	0	177,000	(1/)	(1/)	237	(1/)
113	Columbia	Calhoun	1.230	.047	5.5	(1/)	78,200	(1/)	4,200	41,000	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	131	0	205,300	(1/)	(1/)	169	(1/)
114	...do...	Magnolia ...	1.120	.060	3.6	(1/)	44,800	(1/)	1,580	15,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	101,800	(1/)	(1/)	122	(1/)
115	...do...	...do.......	1.218	.047	5.7	(1/)	78,700	(1/)	2,450	39,100	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	168	0	197,500	(1/)	(1/)	244	(1/)
116	...do...	...do.......	1.211	.049	5.1	(1/)	74,400	(1/)	3,150	35,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	107	0	186,900	(1/)	(1/)	576	(1/)
117	...do...	...do.......	1.208	.047	4.7	(1/)	74,300	(1/)	3,230	36,300	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	17	0	187,900	(1/)	(1/)	198	(1/)
118	...do...	...do.......	1.209	.050	6.0	(1/)	73,200	(1/)	2,480	38,100	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	138	0	188,300	(1/)	(1/)	195	(1/)
119	...do...	...do.......	1.210	.051	6.7	(1/)	71,700	(1/)	3,690	38,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	157	0	189,400	(1/)	(1/)	174	(1/)
120	...do...	...do.......	1.209	.048	6.1	(1/)	69,200	(1/)	4,090	38,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	151	0	186,500	(1/)	(1/)	261	(1/)
121	...do...	...do.......	1.210	.052	6.2	(1/)	66,900	(1/)	4,000	40,300	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	143	0	185,800	(1/)	(1/)	160	(1/)
122	...do...	...do.......	1.182	.050	6.3	(1/)	60,900	(1/)	3,680	31,800	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	123	0	160,600	(1/)	(1/)	123	(1/)
123	...do...	...do.......	1.211	.049	5.7	(1/)	68,700	(1/)	3,080	38,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	173	0	183,300	(1/)	(1/)	257	(1/)
124	...do...	...do.......	1.191	.048	5.9	(1/)	67,700	(1/)	3,720	34,300	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	177	0	175,500	(1/)	(1/)	267	(1/)
125	...do...	...do.......	1.125	.063	7.0	(1/)	42,400	(1/)	2,030	21,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	146	0	109,200	(1/)	(1/)	261	(1/)
126	...do...	...do.......	1.152	.054	5.8	(1/)	50,500	(1/)	2,680	26,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	159	0	133,000	(1/)	(1/)	226	(1/)
127	...do...	...do.......	1.214	.048	6.2	(1/)	78,600	(1/)	3,650	38,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	151	0	190,000	(1/)	(1/)	344	(1/)
128	...do...	...do.......	1.209	.046	6.2	(1/)	69,600	(1/)	3,650	38,100	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	166	0	186,900	(1/)	(1/)	190	(1/)
129	...do...	...do.......	1.212	.052	6.1	(1/)	70,300	(1/)	3,880	40,400	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	165	0	191,000	(1/)	(1/)	181	(1/)
130	...do...	...do.......	1.212	.048	6.2	(1/)	77,300	(1/)	3,670	40,200	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	170	0	191,400	(1/)	(1/)	170	(1/)
131	...do...	...do.......	1.057	.104	6.6	(1/)	23,600	(1/)	1,040	4,680	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	109	0	47,500	(1/)	(1/)	64	(1/)
132	...do...	...do.......	1.152	.053	6.6	(1/)	60,400	(1/)	3,870	22,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	120	0	108,700	(1/)	(1/)	144	(1/)
133	...do...	...do.......	1.212	.048	6.2	(1/)	72,900	(1/)	3,320	38,800	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	154	0	190,400	(1/)	(1/)	239	(1/)
134	...do...	...do.......	1.219	.047	5.7	(1/)	73,800	(1/)	3,800	40,000	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	174	0	195,400	(1/)	(1/)	190	(1/)
135	...do...	...do.......	1.214	.046	5.9	(1/)	70,700	(1/)	3,700	41,100	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	189	0	192,500	(1/)	(1/)	171	(1/)
136	...do...	...do.......	1.214	.047	6.0	(1/)	73,900	(1/)	2,640	40,300	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	179	0	192,500	(1/)	(1/)	233	(1/)
137	Claiborne	Colquitt.....	1.199	.037	5.4	(1/)	59,600	(1/)	5,320	38,100	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	85	0	174,500	(1/)	(1/)	277	(1/)
138	...do...	Mt. Sinai ...	1.188	.045	5.6	(1/)	67,700	(1/)	725	40,300	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	329	0	177,300	(1/)	(1/)	311	(1/)
139	...do...	Colquitt	1.201	.036	4.8	(1/)	58,200	(1/)	7,000	38,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	49	0	178,700	(1/)	(1/)	145	(1/)
140	Columbia	Kerlin	1.232	.040	6.0	445	71,400	8,340	2,970	45,700	2,980	45	50	35	1	2	206	(1/)	170	245	0	196,100	5,850	14	548	110
141	...do...	...do.......	1.230	.040	6.0	331	70,700	5,950	1,860	46,900	3,440	40	40	12	1	2	300	(1/)	220	224	0	219,600	5,670	11	640	85

See footnote at end of table.

TABLE 2. - Analyses of Smackover oilfield brines--Continued

Sample	County	Field	Specific gravity, 60°/60° F	Resistivity, ohm-meters, 80° F	Milligrams per liter																				
					pH	Li^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}	Mn^{2+}	Fe^{2+}	Cu^{2+}	Zn^{2+}	B^{3+}	Pb^{2+}	NH_4^+	HCO_3^-	CO_3^{2-}	Cl^-	Br^-	I^-	SO_4^{2-}	Organic acid as Acetic
142	Columbia	Walker Creek	1.197	.039	3.7	108	66,100	163	244	37,000	2,810	12	7	51	1	39	63	12	211	0	0	161,500	2,350	8	207	200
143	Lafayette	Dooley Creek	1.039	.174	4.4	91	15,800	218	123	1,840	230	8	4	246	0	0	0	(1/)	515	0	0	31,100	350	12	508	0
144	...do...	Midway, W.	1.184	.043	5.7	(1/)	54,300	1,070	1,160	33,700	1,690	0	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	138,200	(1/)	(1/)	118	(1/)
145	Columbia	Kerlin	1.231	.040	5.8	358	70,200	4,670	4,230	50,400	2,180	30	48	22	1	5	178	(1/)	200	96	0	210,600	4,980	25	288	180
146	...do...	...do.......	1.231	.041	5.8	386	77,900	6,950	3,500	43,900	2,290	16	48	15	1	4	220	(1/)	148	100	0	212,900	5,720	20	320	180
147	...do...	...do.......	1.229	.041	5.8	331	78,400	5,640	4,110	43,300	2,060	44	34	19	1	4	200	(1/)	126	104	0	210,600	5,650	17	254	190
148	...do...	...do.......	1.231	.041	5.8	357	78,300	5,810	3,280	48,600	2,460	32	54	45	1	3	200	(1/)	170	96	0	208,500	5,450	18	306	180
149	...do...	...do.......	1.230	.038	5.9	365	73,300	4,230	3,360	43,500	4,480	30	36	25	1	3	210	(1/)	130	424	0	218,700	5,300	10	500	225
150	...do...	...do.......	1.229	.041	5.9	329	75,700	5,330	3,760	40,800	3,570	24	39	17	1	3	212	(1/)	150	455	0	190,200	4,980	9	836	200
151	...do...	...do.......	1.230	.041	5.8	403	73,800	5,260	6,820	44,000	2,450	29	45	14	1	4	200	(1/)	124	384	0	200,200	4,900	9	800	180
152	Lafayette	Midway, W. .	1.188	.045	5.6	(1/)	54,400	1,070	2,180	31,100	1,690	0	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	138,900	(1/)	(1/)	104	(1/)
153	Columbia	Kerlin	1.230	.038	5.8	341	76,500	7,000	2,230	45,400	2,350	34	48	15	1	3	200		150	441	0	217,600	5,340	11	513	120
154	Lafayette	Midway, W. .	1.164	.046	5.7	(1/)	56,100	90	2,830	28,100	1,420	0	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	11	0	131,300	(1/)	(1/)	136	(1/)
155	Columbia	Kerlin	1.228	.040	5.0	160	87,100	2,730	4,240	43,500	2,260	21	20	16	1	2	122	(1/)	512	94	0	207,500	4,100	12	201	120
156	...do...	...do.......	1.229	.039	5.9	276	76,500	4,090	3,960	43,400	2,460	35	27	30	1	3	210	(1/)	98	415	0	201,600	4,790	9	805	190
157	...do...	...do.......	1.230	.039	5.8	343	77,000	5,960	9,540	43,600	3,000	39	47	14	2	3	136	(1/)	112	428	0	210,200	4,500	10	590	210
158	...do...	...do.......	1.230	.040	5.8	329	76,400	5,330	6,900	50,000	1,970	36	40	26	1	2	168	(1/)	142	479	0	214,200	5,410	9	554	120
159	...do...	...do.......	1.231	.038	5.8	425	78,600	4,770	3,590	45,200	2,970	26	52	15	2	3	175	(1/)	120	443	0	200,200	4,770	8	398	190
160	...do...	...do.......	1.231	.040	5.9	440	69,600	4,360	3,470	45,100	2,860	40	39	20	1	2	220	(1/)	130	204	0	203,200	5,540	16	406	120
161	...do...	...do.......	1.231	.040	5.9	412	73,000	7,460	2,600	45,100	1,890	23	49	12	1	2	210	(1/)	148	244	0	228,200	5,660	16	889	170
162	Lafayette	Midway	1.102	.061	6.1	(1/)	28,100	535	1,400	16,600	614	0	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	39	0	81,400	(1/)	(1/)	579	(1/)
163	...do...	...do.......	1.189	.045	6.4	(1/)	49,000	(1/)	2,230	32,800	1,300	0	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	140,100	(1/)	(1/)	75	(1/)
164	...do...	...do.......	1.198	.044	4.2	(1/)	56,800	1,190	3,490	32,400	1,530	0	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	147,600	(1/)	(1/)	117	(1/)
165	...do...	...do.......	1.167	.046	4.7	(1/)	48,400	1,000	2,750	29,500	1,330	0	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	133,700	(1/)	(1/)	161	(1/)
166	...do...	...do.......	1.135	.051	4.3	(1/)	58,300	1,040	2,550	29,900	1,540	0	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	111,100	(1/)	(1/)	235	(1/)
167	...do...	...do.......	1.187	(1/)	5.9	(1/)	83,200	(1/)	3,690	32,500	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	192,000	(1/)	(1/)	6,480	(1/)
168	...do...	...do.......	1.187	(1/)	4.8	(1/)	54,900	(1/)	6,440	34,500	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	12	0	163,600	(1/)	(1/)	1,360	(1/)
169	...do...	...do.......	1.188	(1/)	5.5	(1/)	58,900	(1/)	4,570	33,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	13	0	163,900	(1/)	(1/)	504	(1/)
170	...do...	...do.......	1.186	(1/)	4.2	(1/)	72,400	(1/)	6,300	18,200	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	12	0	161,900	(1/)	(1/)	760	(1/)
171	...do...	...do.......	1.180	(1/)	4.5	(1/)	50,500	(1/)	5,400	38,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	49	0	159,900	(1/)	(1/)	3,660	(1/)
172	...do...	...do.......	1.121	(1/)	6.0	(1/)	39,300	(1/)	2,190	22,800	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	24	0	207,000	(1/)	(1/)	442	(1/)
173	...do...	...do.......	1.164	.054	6.1	(1/)	52,400	(1/)	3,740	30,800	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	63	0	146,000	(1/)	(1/)	297	(1/)
174	...do...	...do.......	1.201	.043	6.3	(1/)	51,500	(1/)	3,100	34,500	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	149,400	(1/)	(1/)	69	(1/)
175	...do...	...do.......	1.152	(1/)	4.5	(1/)	44,300	(1/)	4,740	27,700	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	7	0	130,600	(1/)	(1/)	976	(1/)
176	...do...	...do.......	1.192	.059	4.2	(1/)	59,700	(1/)	5,400	34,700	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	75	0	169,000	(1/)	(1/)	502	(1/)
177	...do...	...do.......	1.199	(1/)	5.9	(1/)	65,100	(1/)	4,800	35,400	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	17	0	175,900	(1/)	(1/)	1,660	(1/)
178	...do...	...do.......	1.202	(1/)	5.5	(1/)	67,700	(1/)	5,480	31,200	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	173,500	(1/)	(1/)	3,080	(1/)
179	...do...	...do.......	1.074	(1/)	5.4	(1/)	30,200	(1/)	1,890	13,200	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	73	0	61,800	(1/)	(1/)	4,500	(1/)
180	...do...	...do.......	1.187	(1/)	5.4	(1/)	59,700	(1/)	4,110	35,100	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	164,300	(1/)	(1/)	2,930	(1/)
181	...do...	...do.......	1.193	(1/)	4.9	(1/)	63,000	(1/)	5,030	33,700	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	4	0	171,200	(1/)	(1/)	667	(1/)
182	...do...	...do.......	1.194	(1/)	6.1	(1/)	63,600	(1/)	4,050	34,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	26	0	171,400	(1/)	(1/)	565	(1/)
183	...do...	...do.......	1.203	(1/)	6.0	(1/)	80,800	(1/)	8,600	39,000	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	173,000	(1/)	(1/)	297	(1/)
184	...do...	...do.......	1.202	(1/)	4.4	(1/)	62,700	(1/)	5,630	36,500	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	176,800	(1/)	(1/)	1,430	(1/)
185	...do...	...do.......	1.201	(1/)	5.8	(1/)	80,700	(1/)	4,800	24,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	181,800	(1/)	(1/)	1,328	(1/)
186	...do...	...do.......	1.197	(1/)	4.9	(1/)	63,000	(1/)	9,700	24,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	13	0	170,900	(1/)	(1/)	587	(1/)
187	...do...	...do.......	1.199	(1/)	4.5	(1/)	84,500	(1/)	3,840	23,200	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	24	0	180,000	(1/)	(1/)	3,670	(1/)
188	...do...	...do.......	1.199	(1/)	4.5	(1/)	72,600	(1/)	5,900	26,900	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	175,900	(1/)	(1/)	1,300	(1/)

See footnote at end of table.

TABLE 2. - Analyses of Smackover oilfield brines--Continued

					Milligrams per liter																					
Sample	County	Field	Specific gravity, 60°/60° F	Resistivity, ohm-meters, 80° F	pH	Li^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}	Mn^{2+}	Fe^{2+}	Cu^{2+}	Zn^{2+}	B^{3+}	Pb^{2+}	NH_4^+	HCO_3^-	CO_3^{2-}	Cl^-	Br^-	I^-	SO_4^{2-}	Organic acid as acetic
189	Lafayette	Midway	1.196	(1/)	4.5	(1/)	61,000	(1/)	5,200	35,100	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	171,200	(1/)	(1/)	556	(1/)
190	...do...	...do.......	1.197	(1/)	4.2	(1/)	67,500	(1/)	3,640	33,800	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	172,900	(1/)	(1/)	3,112	(1/)
191	Columbia	Kerlin	1.128	.040	4.0	378	71,400	5,550	3,600	45,700	3,180	38	48	10	1	2	236	(1/)	150	0	0	201,800	(1/)	(1/)	841	(1/)
192	...do...	...do.......	1.230	.040	5.8	367	74,000	4,410	4,340	44,400	3,050	42	46	21	1	2	240	(1/)	150	96	0	202,100	5,730	14	276	120
193	...do...	...do.......	1.231	.038	5.8	340	64,900	6,230	3,970	46,700	2,760	35	47	11	1	3	213	(1/)	190	103	0	202,700	5,730	15	234	180
194	...do...	...do.......	1.230	.039	5.7	382	64,200	11,100	3,250	44,600	2,450	29	51	9	1	3	250	(1/)	180	101	0	200,000	5,440	26	241	100
195	Lafayette	Midway, W. .	1.184	.051	5.5	(1/)	50,800	(1/)	2,960	29,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	11	0	139,400	(1/)	(1/)	223	(1/)
196	...do...	Lewisville ...	1.157	.043	6.3	46	46,800	1,230	4,530	22,700	1,270	3	32	10	1	94	10	(1/)	202	54	0	125,200	1,940	14	166	150
197	...do...	...do.......	1.174	.045	6.3	62	43,900	1,240	4,140	27,600	371	15	8	6	1	54	94	14	120	48	0	143,900	2,320	22	156	200
198	Miller	Fouke	1.067	.068	7.2	28	20,500	500	2,280	22,400	125	12	6	92	1	2	24	(1/)	190	84	0	43,300	98	15	158	80
199	Columbia	Pine Tree	1.227	.042	4.7	277	63,000	3,020	2,120	39,800	2,760	23	3	10	1	1	174	(1/)	647	55	0	201,500	5,640	13	184	83
200	...do...	Brister	1.221	.045	4.9	241	84,400	5,790	3,620	39,200	2,780	18	26	16	1	1	191	(1/)	657	99	0	198,200	5,630	17	189	87
201	Lafayette	Palm	1.183	.049	3.5	99	59,400	720	3,670	35,600	1,330	5	7	49	1	4	126	(1/)	386	0	0	184,900	4,670	12	209	180
202	Columbia	Village	1.195	.049	5.2	7	68,900	1,310	5,240	32,200	1,620	8	2	15	3	2	109	(1/)	376	43	0	174,600	4,740	12	246	330
203	Union...	Tubal	1.119	.048	5.2	52	36,300	514	1,950	33,200	1,130	18	22	5	0	1	207	(1/)	249	104	0	194,300	1,430	17	369	202
204	Lafayette	Midway, W. .	1.192	.044	4.8	(1/)	54,800	1,330	1,540	33,500	1,610	0	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	142,800	(1/)	(1/)	147	(1/)
205	...do...	Midway	1.195	.044	4.3	(1/)	56,100	1,160	3,230	30,800	1,580	0	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	143,900	(1/)	(1/)	122	(1/)
206	...do...	...do.......	1.188	.044	5.5	(1/)	54,100	1,100	3,040	31,400	1,560	0	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	20	0	142,900	(1/)	(1/)	93	(1/)
207	...do...	...do.......	1.197	(1/)	4.0	(1/)	72,700	(1/)	3,760	32,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	178,000	(1/)	(1/)	4,024	(1/)
208	...do...	...do.......	1.155	(1/)	6.3	(1/)	51,700	(1/)	2,980	26,800	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	360	0	135,400	(1/)	(1/)	623	(1/)
209	...do...	...do.......	1.191	(1/)	4.3	(1/)	55,600	(1/)	5,030	35,400	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	4	0	162,600	(1/)	(1/)	877	(1/)
210	...do...	...do.......	1.187	(1/)	5.1	(1/)	50,000	(1/)	5,440	33,700	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	2	0	162,500	(1/)	(1/)	1,630	(1/)
211	...do...	...do.......	1.182	(1/)	4.4	(1/)	50,800	(1/)	4,210	39,200	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	159,000	(1/)	(1/)	1,070	(1/)
212	...do...	...do.......	1.199	(1/)	4.5	(1/)	62,300	(1/)	4,880	38,300	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	177,400	(1/)	(1/)	1,150	(1/)
213	...do...	...do.......	1.198	(1/)	6.3	(1/)	60,300	(1/)	4,720	35,700	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	24	0	169,100	(1/)	(1/)	1,540	(1/)
214	...do...	...do.......	1.208	(1/)	5.2	(1/)	63,900	(1/)	4,820	39,600	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	182,100	(1/)	(1/)	1,170	(1/)
215	...do...	...do.......	1.202	(1/)	4.4	(1/)	62,600	(1/)	5,630	36,500	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	176,800	(1/)	(1/)	1,430	(1/)
216	...do...	...do.......	1.202	(1/)	4.6	(1/)	60,400	(1/)	4,800	40,100	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	177,400	(1/)	(1/)	1,280	(1/)
217	...do...	...do.......	1.200	(1/)	4.3	(1/)	62,400	(1/)	4,870	36,700	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	(1/)	0	0	174,500	(1/)	(1/)	1,500	(1/)
218	Claiborne	Colquitt	1.025	.222	5.3	3	5,000	188	257	6,820	199	10	3	15	0	0	18	(1/)	29	21	0	21,200	74	7	0	216
219	Webster..	Shongaloo ...	1.222	.038	5.7	69	70,700	1,170	365	44,800	4,700	61	9	9	1	2	45	(1/)	36	114	0	203,200	1,380	61	187	298
220	Claiborne	Lick Creek ...	1.186	.040	4.2	100	87,400	1,090	389	33,400	189	9	1	84	0	12	100	(1/)	276	0	0	171,600	2,070	40	150	196
221	Webster	Red Rock	1.227	.039	3.9	68	82,800	616	316	44,600	4,320	68	22	312	1	136	27	(1/)	84	0	0	221,000	2,030	41	363	220
222	Claiborne	Colquitt	1.170	.046	4.9	80	59,900	908	1,300	32,000	2,510	28	4	31	1	8	66	8	24	177	0	179,200	1,680	88	13	206
223	...do...	...do.......	1.191	.044	5.2	80	82,800	1,380	1,290	33,000	2,540	13	5	80	1	25	95	6	36	32	0	182,200	1,730	65	166	120
224	Cass	Byron Mills ..	1.211	.038	6.2	404	69,300	6,390	2,730	28,300	2,500	5	24	20	1	2	383	(1/)	220	81	0	170,700	2,370	39	123	668
225	...do...	Frost	1.105	.069	2.8	473	26,800	282	6,910	25,300	2,290	37	233	20	1	2	100	(1/)	190	0	0	105,300	939	23	589	300
226	Wood ...	Yantis, W. ..	1.210	.045	5.9	505	75,400	7,430	4,510	26,900	2,670	36	140	10	1	2	78	(1/)	305	96	0	192,000	3,080	13	202	668

1/ Not determined.

CLASSIFICATION OF SMACKOVER WATERS

Classification of waters provides a basis for grouping closely related waters. Because the grouping is chemical, it is dependent upon the dissolved constituents found in the waters. Most of the classification systems developed to date have considered only the dissolved major inorganic constituents and have ignored the minor and trace inorganic constituents (18). Portions of three classification systems (67, 74, 77) and Bojarki's modification of Sulin's system (8) were applied to the Smackover Formation waters.

Waters as related to the earth are meteoric, surface, and subsurface. Surface waters can be fresh or saline if the amounts of dissolved constituents in the water are used to classify them as fresh or saline. For example, water from melting snow on a mountain top usually will contain small amounts of dissolved mineral matter and can be classified as fresh water, whereas water in an ocean will contain 35,000 milligrams per liter or more of dissolved minerals and is classified as saline. Waters found in rivers connecting the mountain stream to the ocean may contain varying amounts of dissolved constituents and, depending upon the amounts, can be classified as fresh or saline. In a similar manner, subsurface waters are classified as fresh or saline. Merely classifying a water as either fresh or saline will not provide a sufficiently useful classification. The dissolved constituents that are used in many classification systems depend upon the amounts or ratios of sodium, magnesium, calcium, carbonate, bicarbonate, sulfate, and chloride found in the water.

The amounts and ratios of these constituents in subsurface waters are dependent upon the origin of the water and what has occurred to the water since entering the subsurface environment. For example, some subsurface waters found in deep sediments were trapped during sedimentation, but other subsurface waters have infiltrated from the surface through outcrops. Some waters are mixtures of the infiltration water and trapped ancient seawater. Also, the rocks containing the waters often contain soluble constituents that dissolve in the waters or contain chemicals that will exchange with chemicals dissolved in the waters, causing alterations of the dissolved constituents.

The amounts of dissolved constituents found in subsurface waters can range from a few milligrams per liter to more than 350,000 milligrams per liter. This salinity distribution is dependent upon several factors, including hydraulic gradients, depth of occurrence, distance from outcrops, mobility of the dissolved chemical elements, soluble material in the associated rocks, ion-exchange reactions, and clay membrane filtration.

Table 3 shows the results that were obtained by classifying 226 Smackover brine samples. The ion concentrations are given in equivalents per million (epm); column 18 illustrates the type of brine. Note that all 226 of the Smackover brines classified are of the chloride-calcium type.

TABLE 3. - Classification of Smackover oilfield brines

Sample	State	Basin	Depth, feet	Concentration, equivalents per million (epm) Li	K	Na	Mg	Ca	Sr	Ba	HCO_3	SO_4	Cl	Br	I	Total	Type (77)	Class (77)	Cl 1/ (74)	SO_4 2/ (74)	$\sqrt{Ca \times SO_4}$	$\sqrt[3]{(HCO_3 + CO_2)^2(Ca)}$	IBE 3/	Na/Cl	Cl/Br	SO_4/Cl	Na/Ca+Mg	Ca/Mg
1	Miss.	East Gulf	16,845	6	160	1,982	288	1,861	26	0.4	2.7	1.6	4,319	22	0.1	8,669	Cl-Ca	$S_2S_1S_3$	VH	N	55.1	24.1	0.5	0.5	199	0.0	1.0	6.6
2	do.	...do.......	12,688	10	14	2,678	136	2,013	76	.6	0.0	0.0	4,402	21	.1	9,349	Cl-Ca	$S_1S_2A_2$	VH	N	.2	.0	.4	.6	215	.0	1.2	15.4
3	do.	...do.......	15,860	8	92	2,021	172	1,451	38	.2	.3	2.6	4,114	16	.2	7,915	Cl-Ca	$S_1S_2S_3$	VH	N	60.9	4.5	.5	.5	260	.0	1.3	8.7
4	Ala.	Hatchetigbee	11,967	7	116	2,445	114	2,258	49	.4	.0	2.2	4,735	18	.2	9,744	Cl-Ca	$S_1S_2A_2$	VH	N	71.0	.0	.5	.5	264	.0	1.1	20.3
5	do.	...do.......	10,486	6	58	2,711	143	1,680	36	.1	.0	.6	4,323	21	.2	8,978	Cl-Ca	$S_1S_2A_2$	VH	N	30.8	.0	.4	.6	206	.0	1.5	12.0
6	do.	...do.......	10,455	6	0	3,417	283	1,689	42	.4	.5	2.8	4,431	15	.2	9,886	Cl-Ca	$S_1S_2A_2$	VH	N	69.2	7.9	.2	.8	298	.0	1.7	6.1
7	do.	...do.......	11,974	7	168	2,683	116	1,673	48	.1	.0	1.3	4,686	19	.1	9,402	Cl-Ca	$S_1S_2S_3$	VH	N	46.8	.0	.4	.6	244	.0	1.6	14.9
8	Tex.	Mexia Talco	12,784	13	68	1,018	222	420	36	.4	1.7	.0	1,857	11	.1	3,647	Cl-Ca	$S_1S_2S_3$	VH	N	.1	10.6	.4	.6	165	.0	1.6	2.1
9	Ark.	Monroe	7,030	9	40	2,109	173	1,810	39	.5	.8	7.2	4,344	42	.1	8,574	Cl-Ca	$S_2S_1S_3$	VH	A	114.2	10.1	.5	.5	103	.0	1.1	10.7
10	do.	...do.......	6,049	4	11	1,798	244	1,083	23	.1	1.5	7.8	3,687	46	.1	6,905	Cl-Ca	$S_2S_1S_3$	VH	A	92.1	13.3	.5	.5	80	.0	1.3	4.5
11	do.	...do.......	6,317	3	16	2,561	231	1,010	25	.1	.0	7.2	4,126	42	.1	8,021	Cl-Ca	$S_1S_2S_3$	VH	A	85.4	.0	.4	.6	99	.0	2.0	4.5
12	do.	...do.......	5,891	2	12	1,811	192	798	14	.0	.0	4.1	3,010	22	.1	5,864	Cl-Ca	$S_1S_2S_3$	VH	N	57.0	.0	.4	.6	139	.0	1.8	4.2
13	do.	North Louisiana	7,196	(4/)	(4/)	2,330	285	1,246	(4/)	(4/)	1.3	3.6	3,864	(4/)	(4/)	7,731	Cl-Ca	$S_1S_2S_3$	VH	N	66.8	13.0	.4	.6	(4/)	.0	1.5	4.3
14	do.	...do.......	7,184	(4/)	(4/)	2,427	257	1,304	(4/)	(4/)	2.2	4.5	3,980	(4/)	(4/)	7,974	Cl-Ca	$S_1S_2A_2$	VH	N	76.7	18.3	.4	.6	(4/)	.0	1.6	5.1
15	do.	...do.......	7,140	(4/)	(4/)	2,370	211	1,348	(4/)	(4/)	2.3	4.3	3,921	(4/)	(4/)	7,857	Cl-Ca	$S_1S_2A_2$	VH	N	76.2	19.2	.4	.6	(4/)	.0	1.5	6.4
16	do.	...do.......	7,158	(4/)	(4/)	2,397	259	1,553	(4/)	(4/)	2.6	4.0	3,973	(4/)	(4/)	8,189	Cl-Ca	$S_1S_2A_2$	VH	N	78.9	22.1	.4	.6	(4/)	.0	1.3	6.0
17	do.	...do.......	7,159	(4/)	(4/)	2,521	221	1,306	(4/)	(4/)	2.4	3.5	4,039	(4/)	(4/)	8,093	Cl-Ca	$S_1S_2A_2$	VH	N	67.8	19.6	.4	.6	(4/)	.0	1.7	5.9
18	do.	...do.......	7,184	(4/)	(4/)	2,492	276	1,334	(4/)	(4/)	2.4	3.8	4,094	(4/)	(4/)	8,202	Cl-Ca	$S_1S_2A_2$	VH	N	70.9	19.5	.4	.6	(4/)	.0	1.6	4.8
19	do.	...do.......	7,184	(4/)	(4/)	2,363	221	1,297	(4/)	(4/)	2.6	4.2	3,872	(4/)	(4/)	7,760	Cl-Ca	$S_1S_2A_2$	VH	N	73.7	20.5	.4	.6	(4/)	.0	1.6	5.9
20	do.	...do.......	7,189	(4/)	(4/)	2,234	254	1,341	(4/)	(4/)	1.6	3.8	3,810	(4/)	(4/)	7,391	Cl-Ca	$S_1S_2A_2$	VH	N	71.6	15.1	.4	.6	(4/)	.0	1.4	5.3
21	do.	...do.......	7,788	(4/)	(4/)	2,369	296	1,379	(4/)	(4/)	2.1	5.3	4,035	(4/)	(4/)	8,087	Cl-Ca	$S_1S_2A_2$	VH	N	85.7	18.4	.4	.6	(4/)	.0	1.4	4.7
22	do.	...do.......	7,165	(4/)	(4/)	2,503	216	1,383	(4/)	(4/)	2.5	3.9	4,094	(4/)	(4/)	8,202	Cl-Ca	$S_1S_2A_2$	VH	N	73.4	21.0	.4	.6	(4/)	.0	1.6	6.4
23	do.	...do.......	7,189	(4/)	(4/)	2,471	242	1,342	(4/)	(4/)	2.7	3.2	4,047	(4/)	(4/)	8,107	Cl-Ca	$S_1S_2A_2$	VH	N	65.1	21.5	.4	.6	(4/)	.0	1.6	5.6
24	do.	...do.......	7,140	(4/)	(4/)	2,394	233	1,498	(4/)	(4/)	2.5	3.8	4,128	(4/)	(4/)	8,027	Cl-Ca	$S_1S_2S_3$	VH	N	75.7	21.1	.4	.6	(4/)	.0	1.4	6.4
25	do.	...do.......	7,184	(4/)	(4/)	2,489	283	1,323	(4/)	(4/)	2.3	5.7	4,085	(4/)	(4/)	8,189	Cl-Ca	$S_1S_2A_2$	VH	N	87.1	19.1	.4	.6	(4/)	.0	1.6	4.7
26	do.	...do.......	7,166	(4/)	(4/)	2,497	235	1,414	(4/)	(4/)	2.6	5.0	4,047	(4/)	(4/)	8,200	Cl-Ca	$S_1S_2A_2$	VH	N	83.9	21.4	.4	.6	(4/)	.0	1.5	6.0
27	do.	...do.......	7,184	(4/)	(4/)	2,576	170	1,246	(4/)	(4/)	2.7	4.2	3,993	(4/)	(4/)	7,992	Cl-Ca	$S_1S_2S_3$	VH	N	72.0	21.1	.4	.7	(4/)	.0	1.8	7.3
28	do.	...do.......	7,012	1	0	2,859	272	1,205	33	0.1	.8	2.9	3,687	41	.1	8,103	Cl-Ca	$S_1S_2A_2$	VH	N	59.4	8.9	.2	.8	90	.0	1.9	4.6
29	do.	...do.......	5,188	3	6	1,633	208	886	12	0.1	1.1	5.7	2,901	42	.1	5,698	Cl-Ca	$S_1S_2S_3$	VH	N	71.1	10.4	.4	.6	68	.0	1.5	4.3
30	do.	...do.......	5,860	3	17	2,239	227	1,086	20	0.0	.0	5.9	3,244	34	.2	6,876	Cl-Ca	$S_1S_2A_2$	VH	N	80.3	.0	.3	.7	97	.0	1.7	4.9

See footnotes at end of table.

TABLE 3. - Classification of Smackover oilfield brines--Continued

Sample	State	Basin	Depth	Concentration, equivalents per million (epm) Li	K	Na	Mg	Ca	Sr	Ba	HCO_3	SO_4	Cl	Br	I	Total	Type (77)	Class (77)	Cl 1/ (74)	SO_4 2/ (74)	$\sqrt{Ca \times SO_4}$	$\sqrt[3]{(HCO_3 + CO_2)^2(Ca)}$	IBE 3/	Na/Cl	Cl/Br	SO_4/Cl	Na/Ca+Mg	Ca/Mg
31	Ark.	North Louisiana	4,821	2	7	1,482	154	844	18	0.1	1.2	6.1	2,997	63	0.1	5,575	Cl-Ca	$S_2S_1S_3$	VH	A	71.7	10.5	0.5	0.5	48	0.0	1.5	5.6
32	do.	...do.......	5,837	3	16	2,205	188	761	15	.0	.6	5.8	3,176	22	.3	6,393	Cl-Ca	$S_1S_2S_3$	VH	N	66.4	6.4	.3	.7	142	.0	2.3	4.1
33	do.	...do.......	6,224	6	14	2,086	198	1,139	21	.0	.0	5.8	3,258	23	.1	6,749	Cl-Ca	$S_1S_2A_2$	VH	N	81.6	0.0	.4	.6	145	.0	1.6	5.9
34	do.	...do.......	9,287	5	5	927	112	831	4	.2	.0	3.2	1,602	12	.1	3,502	Cl-Ca	$S_1S_2A_2$	VH	N	51.5	.0	.4	.6	128	.0	1.0	7.4
35	do.	Sabine	6,450	(4/)	(4/)	1,899	235	1,490	(4/)	(4/)	2.0	5.1	3,615	(4/)	(4/)	7,246	Cl-Ca	$S_1S_2A_2$	VH	N	87.2	18.1	.5	.5	(4/)	.0	1.1	6.4
36	do.	...do.......	6,388	(4/)	(4/)	2,161	263	1,556	(4/)	(4/)	.9	4.4	4,444	(4/)	(4/)	8,429	Cl-Ca	$S_2S_1S_3$	VH	N	83.0	10.4	.5	.5	(4/)	.0	1.2	5.9
37	do.	...do.......	6,471	(4/)	(4/)	2,190	276	1,560	(4/)	(4/)	1.0	4.7	4,018	(4/)	(4/)	8,049	Cl-Ca	$S_1S_2A_2$	VH	N	85.5	11.6	.5	.6	(4/)	.0	1.2	5.7
38	do.	...do.......	6,372	(4/)	(4/)	2,205	292	1,606	(4/)	(4/)	1.0	4.2	4,097	(4/)	(4/)	8,205	Cl-Ca	$S_1S_2A_2$	VH	N	81.7	12.0	.5	.5	(4/)	.0	1.2	5.5
39	do.	...do.......	6,430	(4/)	(4/)	2,199	291	1,479	(4/)	(4/)	1.8	8.1	3,959	(4/)	(4/)	7,938	Cl-Ca	$S_1S_2A_2$	VH	A	109.1	16.7	.4	.6	(4/)	.0	1.2	5.1
40	do.	...do.......	6,430	(4/)	(4/)	2,158	289	1,468	(4/)	(4/)	0.5	4.6	3,911	(4/)	(4/)	7,831	Cl-Ca	$S_1S_2S_3$	VH	N	82.1	7.5	.5	.6	(4/)	.0	1.2	5.1
41	do.	...do.......	6,430	(4/)	(4/)	2,053	276	1,582	(4/)	(4/)	0.2	4.1	3,899	(4/)	(4/)	7,814	Cl-Ca	$S_1S_2A_2$	VH	N	80.1	4.3	.5	.5	(4/)	.0	1.1	5.7
42	do.	...do.......	6,430	(4/)	(4/)	1,952	259	1,492	(4/)	(4/)	1.4	4.9	3,697	(4/)	(4/)	7,407	Cl-Ca	$S_1S_2A_2$	VH	N	85.5	14.2	.5	.5	(4/)	.0	1.1	5.8
43	do.	...do.......	7,130	(4/)	(4/)	2,512	234	1,316	(4/)	(4/)	2.6	4.9	3,980	(4/)	(4/)	8,049	Cl-Ca	$S_1S_2A_2$	VH	N	80.3	20.7	.4	.6	(4/)	.0	1.6	5.6
44	do.	...do.......	7,136	(4/)	(4/)	2,458	209	1,265	(4/)	(4/)	2.7	5.1	3,943	(4/)	(4/)	7,883	Cl-Ca	$S_1S_2S_3$	VH	N	80.2	20.8	.4	.6	(4/)	.0	1.7	6.1
45	do.	...do.......	7,515	(4/)	(4/)	2,555	154	1,356	(4/)	(4/)	2.0	3.5	4,057	(4/)	(4/)	8,127	Cl-Ca	$S_1S_2A_2$	VH	N	68.9	17.7	.4	.6	(4/)	.0	1.7	8.8
46	do.	...do.......	7,626	(4/)	(4/)	2,629	277	1,598	(4/)	(4/)	1.5	3.0	4,497	(4/)	(4/)	9,005	Cl-Ca	$S_1S_2A_2$	VH	N	68.6	15.6	.4	.6	(4/)	.0	1.4	5.8
47	do.	...do.......	6,471	(4/)	(4/)	2,288	244	1,574	(4/)	(4/)	0.8	4.3	4,100	(4/)	(4/)	8,211	Cl-Ca	$S_1S_2A_2$	VH	N	81.9	10.1	.4	.6	(4/)	.0	1.3	6.5
48	do.	...do.......	6,372	(4/)	(4/)	2,289	272	1,476	(4/)	(4/)	0.6	4.5	4,076	(4/)	(4/)	8,118	Cl-Ca	$S_1S_2S_3$	VH	N	81.7	7.8	.4	.6	(4/)	.0	1.3	5.4
49	do.	...do.......	6,388	(4/)	(4/)	2,309	221	1,471	(4/)	(4/)	1.2	3.8	3,993	(4/)	(4/)	7,999	Cl-Ca	$S_1S_2A_2$	VH	N	74.3	12.5	.4	.6	(4/)	.0	1.4	6.7
50	do.	...do.......	6,356	(4/)	(4/)	2,274	263	1,535	(4/)	(4/)	0.4	4.2	4,067	(4/)	(4/)	8,144	Cl-Ca	$S_1S_2A_2$	VH	N	79.9	6.2	.4	.6	(4/)	.0	1.3	5.8
51	do.	...do.......	4,283	(4/)	(4/)	2,766	207	1,618	(4/)	(4/)	3.1	2.3	4,584	(4/)	(4/)	9,180	Cl-Ca	$S_1S_2A_2$	VH	N	60.7	24.9	.4	.6	(4/)	.0	1.5	7.8
52	do.	...do.......	7,603	(4/)	(4/)	2,729	222	1,564	(4/)	(4/)	2.4	4.0	4,530	(4/)	(4/)	9,052	Cl-Ca	$S_1S_2S_3$	VH	N	78.7	20.8	.4	.6	(4/)	.0	1.5	7.1
53	do.	...do.......	7,536	(4/)	(4/)	2,635	247	1,978	(4/)	(4/)	3.1	3.7	4,527	(4/)	(4/)	9,394	Cl-Ca	$S_1S_2A_2$	VH	N	84.9	26.6	.4	.6	(4/)	.0	1.2	8.0
54	do.	...do.......	7,602	(4/)	(4/)	2,172	158	1,123	(4/)	(4/)	0.4	3.0	3,448	(4/)	(4/)	6,905	Cl-Ca	$S_1S_2A_2$	VH	N	57.9	5.3	.4	.6	(4/)	.0	1.7	7.1
55	do.	...do.......	7,500	(4/)	(4/)	2,403	226	1,567	(4/)	(4/)	0.0	2.1	4,193	(4/)	(4/)	8,390	Cl-Ca	$S_1S_2A_2$	VH	N	57.9	.0	.4	.6	(4/)	.0	1.3	7.0
56	do.	...do.......	6,300	(4/)	(4/)	2,235	368	1,254	(4/)	(4/)	0.2	10.6	3,851	(4/)	(4/)	7,720	Cl-Ca	$S_1S_2S_3$	VH	A	115.2	3.3	.4	.6	(4/)	.0	1.4	3.4
57	do.	...do.......	6,258	(4/)	(4/)	1,616	276	964	(4/)	(4/)	0.0	16.3	2,842	(4/)	(4/)	5,714	Cl-Ca	$S_1S_2S_3$	VH	A	125.2	.0	.4	.6	(4/)	.0	1.3	3.5
58	do.	...do.......	6,309	(4/)	(4/)	1,951	412	1,559	(4/)	(4/)	0.0	31.7	4,097	(4/)	(4/)	8,052	Cl-Ca	$S_2S_1S_3$	VH	H	222.3	.7	.5	.5	(4/)	.0	1.0	3.8
59	do.	...do.......	6,309	(4/)	(4/)	2,437	593	1,046	(4/)	(4/)	0.5	10.7	4,069	(4/)	(4/)	8,157	Cl-Ca	$S_1S_2S_3$	VH	A	105.7	6.2	.4	.6	(4/)	.0	1.5	1.8
60	do.	...do.......	6,100	(4/)	(4/)	2,218	294	1,337	(4/)	(4/)	0.0	68.0	3,847	(4/)	(4/)	7,765	Cl-Ca	$S_1S_2S_3$	VH	VH	301.6	.0	.4	.6	(4/)	.0	1.4	4.5

See footnotes at end of table.

TABLE 3. - Classification of Smackover oilfield brines--Continued

Sample	State	Basin	Depth	Concentration, equivalents per million (epm) Li	K	Na	Mg	Ca	Sr	Ba	HCO_3	SO_4	Cl	Br	I	Total	Type (77)	Class (77)	Cl 1/ (74)	SO_4 2/ (74)	$\sqrt{Ca \times SO_4}$	$\sqrt[3]{(HCO_3 + CO_2)^2(Ca)}$	IBE 3/	Na/Cl	Cl/Br	SO_4/Cl	Na/Ca + Mg	Ca/Mg
61	Ark.	Sabine uplift	7,608	(4/)	(4/)	2,666	301	1,619	(4/)	(4/)	2.7	2.6	4,402	(4/)	(4/)	8,993	Cl-Ca	$S_1S_2A_2$	VH	N	64.3	22.5	0.4	0.6	(4/)	0.0	1.4	5.4
62	do.	...do.......	7,618	(4/)	(4/)	2,536	280	1,354	(4/)	(4/)	3.0	3.2	4,408	(4/)	(4/)	8,583	Cl-Ca	$S_1S_2S_3$	VH	N	66.2	23.0	.4	.6	(4/)	.0	1.6	4.8
63	do.	...do.......	7,573	(4/)	(4/)	2,763	248	1,520	(4/)	(4/)	2.8	3.4	4,523	(4/)	(4/)	9,060	Cl-Ca	$S_1S_2A_2$	VH	N	71.9	22.8	.4	.6	(4/)	.0	1.6	6.1
64	do.	...do.......	6,430	(4/)	(4/)	2,207	238	1,414	(4/)	(4/)	0.6	6.0	3,851	(4/)	(4/)	7,717	Cl-Ca	$S_1S_2A_2$	VH	N	91.9	8.1	.4	.6	(4/)	.0	1.3	5.9
65	do.	...do.......	7,615	(4/)	(4/)	2,582	230	1,656	(4/)	(4/)	2.9	3.7	4,622	(4/)	(4/)	9,096	Cl-Ca	$S_1S_2S_3$	VH	N	78.6	23.8	.4	.6	(4/)	.0	1.4	7.2
66	do.	...do.......	7,534	(4/)	(4/)	3,054	343	1,812	(4/)	(4/)	3.1	4.6	5,200	(4/)	(4/)	10,416	Cl-Ca	$S_1S_2A_2$	VH	N	90.8	26.0	.4	.6	(4/)	.0	1.4	5.3
67	do.	...do.......	8,426	46	133	2,502	257	1,817	46	0.2	2.5	10.7	4,823	53	0.1	9,689	Cl-Ca	$S_1S_2S_3$	VH	A	139.2	22.7	.5	.6	91	.0	1.3	7.3
68	do.	...do.......	7,628	(4/)	(4/)	2,737	177	1,536	(4/)	(4/)	3.0	4.1	4,404	(4/)	(4/)	8,862	Cl-Ca	$S_1S_2A_2$	VH	N	79.7	24.1	.4	.6	(4/)	.0	1.6	8.7
69	do.	...do.......	7,624	(4/)	(4/)	2,839	158	1,575	(4/)	(4/)	4.0	3.7	4,582	(4/)	(4/)	9,162	Cl-Ca	$S_1S_2S_3$	VH	N	76.7	29.3	.4	.6	(4/)	.0	1.6	10.0
70	do.	...do.......	7,589	(4/)	(4/)	2,968	377	1,822	(4/)	(4/)	3.9	4.7	5,161	(4/)	(4/)	10,337	Cl-Ca	$S_1S_2A_2$	VH	N	92.0	30.5	.4	.6	(4/)	.0	1.4	4.8
71	do.	...do.......	7,680	(4/)	(4/)	2,426	312	1,510	(4/)	(4/)	3.2	3.5	4,244	(4/)	(4/)	8,499	Cl-Ca	$S_1S_2A_2$	VH	N	72.5	24.8	.4	.6	(4/)	.0	1.3	4.8
72	do.	...do.......	6,183	(4/)	(4/)	2,522	246	1,617	(4/)	(4/)	2.3	5.3	4,376	(4/)	(4/)	8,770	Cl-Ca	$S_1S_2A_2$	VH	N	92.9	20.2	.4	.6	(4/)	.0	1.4	6.6
73	do.	...do.......	6,750	(4/)	(4/)	2,762	182	1,516	(4/)	(4/)	3.3	3.4	4,454	(4/)	(4/)	8,920	Cl-Ca	$S_1S_2A_2$	VH	N	71.9	25.6	.4	.6	(4/)	.0	1.6	8.4
74	do.	...do.......	6,238	(4/)	(4/)	2,672	183	1,555	(4/)	(4/)	2.9	4.9	4,405	(4/)	(4/)	8,823	Cl-Ca	$S_1S_2A_2$	VH	N	87.4	23.7	.4	.6	(4/)	.0	1.5	8.5
75	do.	...do.......	7,614	(4/)	(4/)	2,718	194	1,552	(4/)	(4/)	2.7	2.9	4,480	(4/)	(4/)	8,949	Cl-Ca	$S_1S_2S_3$	VH	N	67.4	22.6	.4	.6	(4/)	.0	1.6	8.0
76	do.	...do.......	7,619	(4/)	(4/)	2,484	200	1,526	(4/)	(4/)	3.3	3.1	4,439	(4/)	(4/)	8,655	Cl-Ca	$S_1S_2S_3$	VH	N	68.8	25.3	.4	.6	(4/)	.0	1.4	7.6
77	do.	...do.......	6,190	(4/)	(4/)	1,475	87	336	(4/)	(4/)	1.7	15.0	1,882	(4/)	(4/)	3,796	Cl-Ca	$S_1S_2A_2$	VH	A	71.0	9.9	.2	.8	(4/)	.0	3.5	3.9
78	do.	...do.......	6,470	(4/)	(4/)	2,635	197	1,574	(4/)	(4/)	3.3	3.8	4,401	(4/)	(4/)	8,815	Cl-Ca	$S_1S_2A_2$	VH	N	77.1	25.5	.4	.6	(4/)	.0	1.5	8.0
79	do.	...do.......	6,232	(4/)	(4/)	2,500	227	1,521	(4/)	(4/)	2.8	3.0	4,244	(4/)	(4/)	8,498	Cl-Ca	$S_1S_2A_2$	VH	N	67.4	22.7	.4	.6	(4/)	.0	1.4	6.7
80	do.	...do.......	6,356	(4/)	(4/)	2,023	309	1,578	(4/)	(4/)	.9	4.6	3,903	(4/)	(4/)	7,818	Cl-Ca	$S_1S_2A_2$	VH	N	84.7	10.5	.5	.5	(4/)	.0	1.1	5.1
81	do.	...do.......	7,534	(4/)	(4/)	2,501	225	1,585	(4/)	(4/)	2.1	3.2	4,321	(4/)	(4/)	8,636	Cl-Ca	$S_1S_2S_3$	VH	N	71.6	18.8	.4	.6	(4/)	.0	1.4	7.1
82	do.	...do.......	7,602	(4/)	(4/)	2,103	205	1,289	(4/)	(4/)	1.3	3.9	3,573	(4/)	(4/)	7,174	Cl-Ca	$S_1S_2A_2$	VH	N	70.5	13.1	.4	.6	(4/)	.0	1.4	6.3
83	do.	...do.......	7,575	(4/)	(4/)	2,367	260	1,506	(4/)	(4/)	2.1	1.2	4,128	(4/)	(4/)	8,265	Cl-Ca	$S_1S_2A_2$	VH	N	42.8	18.8	.4	.6	(4/)	.0	1.3	5.8
84	do.	...do.......	7,530	(4/)	(4/)	3,043	235	2,030	(4/)	(4/)	3.2	4.0	5,300	(4/)	(4/)	10,616	Cl-Ca	$S_1S_2A_2$	VH	N	89.6	27.2	.4	.6	(4/)	.0	1.3	8.6
85	do.	...do.......	7,534	(4/)	(4/)	2,557	295	1,515	(4/)	(4/)	2.2	3.1	4,332	(4/)	(4/)	8,705	Cl-Ca	$S_1S_2A_2$	VH	N	68.8	19.5	.4	.6	(4/)	.0	1.4	5.1
86	do.	...do.......	6,388	(4/)	(4/)	2,322	260	1,569	(4/)	(4/)	.1	2.7	4,147	(4/)	(4/)	8,301	Cl-Ca	$S_1S_2A_2$	VH	N	64.8	2.4	.4	.6	(4/)	.0	1.3	6.0
87	do.	...do.......	6,372	(4/)	(4/)	2,365	234	1,640	(4/)	(4/)	.0	17.3	4,220	(4/)	(4/)	8,476	Cl-Ca	$S_1S_2A_2$	VH	A	168.4	0.0	.4	.6	(4/)	.0	1.3	7.0
88	do.	...do.......	6,356	(4/)	(4/)	2,219	226	1,598	(4/)	(4/)	.3	4.3	4,037	(4/)	(4/)	8,084	Cl-Ca	$S_1S_2A_2$	VH	N	82.4	5.1	.5	.6	(4/)	.0	1.2	7.1
89	do.	...do.......	6,471	(4/)	(4/)	2,491	180	1,551	(4/)	(4/)	.1	3.5	4,217	(4/)	(4/)	8,442	Cl-Ca	$S_1S_2A_2$	VH	N	73.3	2.4	.4	.6	(4/)	.0	1.4	8.6
90	do.	...do.......	6,388	(4/)	(4/)	2,287	232	1,580	(4/)	(4/)	.4	4.0	4,094	(4/)	(4/)	8,198	Cl-Ca	$S_1S_2A_2$	VH	N	79.1	6.7	.4	.6	(4/)	.0	1.3	6.8

See footnotes at end of table.

TABLE 3. - Classification of Smackover oilfield brines--Continued

Sample	State	Basin	Depth	Concentration, equivalents per million (epm) Li	K	Na	Mg	Ca	Sr	Ba	HCO_3	SO_4	Cl	Br	I	Total	Type (77)	Class (77)	Cl 1/ (74)	SO_4 2/ (74)	$\sqrt{Ca} \times SO_4$	$\sqrt[3]{(HCO_3 + CO_2)^2(Ca)}$	IBE 3/	Na/Cl	Cl/Br	SO_4/Cl	Na/Ca + Mg	Ca/Mg
91	Ark.	Sabine uplift	6,450	(4/)	(4/)	2,072	287	1,431	(4/)	(4/)	0.9	8.5	3,778	(4/)	(4/)	7,577	Cl-Ca	$S_1S_2A_2$	VH	A	110.3	10.7	0.5	0.6	(4/)	0.0	1.2	5.0
92	do.	...do.......	6,388	(4/)	(4/)	2,282	285	1,554	(4/)	(4/)	.0	3.7	4,116	(4/)	(4/)	8,240	Cl-Ca	$S_1S_2A_2$	VH	N	76.0	0.0	.5	.6	(4/)	.0	1.2	5.5
93	do.	...do.......	6,388	(4/)	(4/)	2,334	280	1,448	(4/)	(4/)	2.0	6.6	4,052	(4/)	(4/)	8,122	Cl-Ca	$S_1S_2A_2$	VH	A	97.9	17.7	.4	.6	(4/)	.0	1.4	5.2
94	do.	...do.......	7,646	(4/)	(4/)	2,151	97	1,064	(4/)	(4/)	2.5	4.7	3,316	(4/)	(4/)	6,635	Cl-Ca	$S_1S_2S_3$	VH	N	70.9	18.6	.4	.7	(4/)	.0	1.9	11.0
95	do.	...do.......	7,614	(4/)	(4/)	2,545	213	1,514	(4/)	(4/)	2.3	2.7	4,265	(4/)	(4/)	8,542	Cl-Ca	$S_1S_2A_2$	VH	N	63.8	20.2	.4	.6	(4/)	.0	1.5	7.1
96	do.	...do.......	7,615	(4/)	(4/)	2,580	212	1,612	(4/)	(4/)	2.9	3.8	4,395	(4/)	(4/)	8,805	Cl-Ca	$S_1S_2A_2$	VH	N	77.7	23.6	.4	.6	(4/)	.0	1.4	7.6
97	do.	...do.......	7,605	(4/)	(4/)	2,490	246	1,596	(4/)	(4/)	1.4	4.0	4,559	(4/)	(4/)	8,897	Cl-Ca	$S_1S_2S_3$	VH	N	79.7	14.4	.5	.6	(4/)	.0	1.4	6.5
98	do.	...do.......	7,536	(4/)	(4/)	2,616	244	1,723	(4/)	(4/)	.3	2.8	4,544	(4/)	(4/)	9,130	Cl-Ca	$S_1S_2A_2$	VH	N	69.7	5.0	.4	.6	(4/)	.0	1.3	7.1
99	do.	...do.......	7,618	(4/)	(4/)	2,603	307	1,578	(4/)	(4/)	2.8	3.1	4,488	(4/)	(4/)	8,982	Cl-Ca	$S_1S_2S_3$	VH	N	69.6	22.9	.4	.6	(4/)	.0	1.4	5.1
100	do.	...do.......	7,605	(4/)	(4/)	2,563	203	1,577	(4/)	(4/)	2.2	3.2	4,338	(4/)	(4/)	8,687	Cl-Ca	$S_1S_2A_2$	VH	N	70.7	19.8	.4	.6	(4/)	.0	1.4	7.8
101	do.	...do.......	7,573	(4/)	(4/)	2,589	271	1,612	(4/)	(4/)	2.9	6.9	4,461	(4/)	(4/)	8,943	Cl-Ca	$S_1S_2A_2$	VH	A	105.3	23.9	.4	.6	(4/)	.0	1.4	6.0
102	do.	...do.......	7,523	(4/)	(4/)	2,616	251	1,522	(4/)	(4/)	2.3	4.3	4,380	(4/)	(4/)	8,775	Cl-Ca	$S_1S_2A_2$	VH	N	81.2	20.1	.4	.6	(4/)	.0	1.5	6.1
103	do.	...do.......	7,536	(4/)	(4/)	2,541	246	1,616	(4/)	(4/)	2.3	4.5	4,395	(4/)	(4/)	8,805	Cl-Ca	$S_1S_2A_2$	VH	N	85.5	20.4	.4	.6	(4/)	.0	1.4	6.6
104	do.	...do.......	7,618	(4/)	(4/)	2,768	146	1,588	(4/)	(4/)	.0	3.9	4,495	(4/)	(4/)	9,001	Cl-Ca	$S_1S_2A_2$	VH	N	79.0	.0	.4	.6	(4/)	.0	1.6	10.9
105	do.	...do.......	7,573	(4/)	(4/)	2,734	162	1,602	(4/)	(4/)	2.3	3.2	4,517	(4/)	(4/)	9,021	Cl-Ca	$S_1S_2S_3$	VH	N	72.0	20.2	.4	.6	(4/)	.0	1.6	9.9
106	do.	...do.......	7,593	(4/)	(4/)	2,469	335	1,591	(4/)	(4/)	2.7	5.4	4,372	(4/)	(4/)	8,775	Cl-Ca	$S_1S_2A_2$	VH	N	92.7	22.7	.4	.6	(4/)	(4/)	1.3	4.8
107	do.	...do.......	7,530	(4/)	(4/)	2,985	270	1,962	(4/)	(4/)	3.1	4.3	5,240	(4/)	(4/)	10,464	Cl-Ca	$S_1S_2S_3$	VH	N	91.9	26.7	.4	.6	(4/)	(4/)	1.3	7.3
108	do.	...do.......	7,570	(4/)	(4/)	3,134	170	1,648	(4/)	(4/)	2.9	3.6	4,929	(4/)	(4/)	9,888	Cl-Ca	$S_1S_2A_2$	VH	N	77.4	24.1	.4	.6	(4/)	(4/)	1.7	9.7
109	do.	...do.......	6,702	(4/)	(4/)	2,684	279	1,743	(4/)	(4/)	2.2	7.3	4,695	(4/)	(4/)	9,411	Cl-Ca	$S_1S_2A_2$	VH	A	113.0	20.6	.4	.6	(4/)	(4/)	1.3	6.2
110	do.	...do.......	6,356	(4/)	(4/)	2,325	241	1,605	(4/)	(4/)	.3	7.2	4,162	(4/)	(4/)	8,341	Cl-Ca	$S_1S_2A_2$	VH	A	107.6	5.4	.4	.6	(4/)	(4/)	1.3	6.7
111	do.	...do.......	6,450	(4/)	(4/)	2,259	250	1,502	(4/)	(4/)	.4	4.5	4,005	(4/)	(4/)	8,021	Cl-Ca	$S_1S_2A_2$	VH	N	82.0	5.8	.4	.6	(4/)	(4/)	1.3	6.0
112	do.	...do.......	6,372	(4/)	(4/)	2,363	263	1,555	(4/)	(4/)	.4	4.1	4,176	(4/)	(4/)	8,362	Cl-Ca	$S_1S_2A_2$	VH	N	80.1	6.1	.4	.6	(4/)	(4/)	1.3	5.9
113	do.	...do.......	8,283	(4/)	(4/)	2,767	281	1,666	(4/)	(4/)	1.8	2.9	4,707	(4/)	(4/)	9,425	Cl-Ca	$S_1S_2A_2$	VH	N	69.0	17.2	.4	.6	(4/)	(4/)	1.4	5.9
114	do.	...do.......	8,916	(4/)	(4/)	1,740	116	709	(4/)	(4/)	.0	2.3	2,562	(4/)	(4/)	5,130	Cl-Ca	$S_1S_2A_2$	VH	N	40.1	.0	.3	.7	(4/)	(4/)	2.1	6.1
115	do.	...do.......	8,926	(4/)	(4/)	2,812	165	1,603	(4/)	(4/)	2.3	4.2	4,573	(4/)	(4/)	9,160	Cl-Ca	$S_1S_2A_2$	VH	N	81.7	20.2	.4	.6	(4/)	(4/)	1.6	9.7
116	do.	...do.......	8,003	(4/)	(4/)	2,672	214	1,479	(4/)	(4/)	1.5	9.9	4,352	(4/)	(4/)	8,728	Cl-Ca	$S_1S_2A_2$	VH	A	121.0	14.6	.4	.6	(4/)	(4/)	1.6	6.9
117	do.	...do.......	8,862	(4/)	(4/)	2,674	220	1,498	(4/)	(4/)	.2	3.4	4,387	(4/)	(4/)	8,783	Cl-Ca	$S_1S_2A_2$	VH	N	71.5	4.3	.4	.6	(4/)	(4/)	1.6	6.8
118	do.	...do.......	7,603	(4/)	(4/)	2,634	169	1,572	(4/)	(4/)	1.9	3.4	4,392	(4/)	(4/)	8,771	Cl-Ca	$S_1S_2S_3$	VH	N	72.6	17.7	.4	.6	(4/)	(4/)	1.5	9.3
119	do.	...do.......	7,603	(4/)	(4/)	2,578	251	1,591	(4/)	(4/)	2.1	3.0	4,413	(4/)	(4/)	8,838	Cl-Ca	$S_1S_2A_2$	VH	N	69.0	19.3	.4	.6	(4/)	(4/)	1.4	6.3
120	do.	...do.......	7,603	(4/)	(4/)	2,489	278	1,591	(4/)	(4/)	2.1	4.5	4,351	(4/)	(4/)	8,716	Cl-Ca	$S_1S_2A_2$	VH	N	84.5	18.8	.4	.6	(4/)	(4/)	1.3	5.7

See footnotes at end of table.

TABLE 3. - Classification of Smackover oilfield brines--Continued

Sample	State	Basin	Depth	Concentration, equivalents per million (epm): Li	K	Na	Mg	Ca	Sr	Ba	HCO_3	SO_4	Cl	Br	I	Total	Type (77)	Class (77)	Cl 1/ (74)	SO_4 2/ (74)	$\sqrt{Ca \times SO_4}$	$\sqrt[3]{(HCO_3 + CO_2)^2(Ca)}$	IBE 3/	Na/Cl	Cl/Br	SO_4/Cl	Na/Ca + Mg	Ca/Mg
121	Ark.	Sabine uplift	7,515	(4/)	(4/)	2,404	272	1,660	(4/)	(4/)	1.9	2.8	4,330	(4/)	(4/)	3,672	Cl-Ca	$S_1S_2A_2$	VH	N	67.6	18.4	0.4	0.6	(4/)	(4/)	1.2	6.1
122	do.	...do.......	7,510	(4/)	(4/)	2,241	256	1,341	(4/)	(4/)	1.7	4.3	3,832	23	0.0	7,699	Cl-Ca	$S_1S_2S_3$	VH	N	75.6	15.8	.4	.6	165	0.0	1.4	5.2
123	do.	...do.......	7,603	(4/)	(4/)	2,466	209	1,602	(4/)	(4/)	2.3	4.4	4,269	(4/)	(4/)	8,553	Cl-Ca	$S_1S_2A_2$	VH	N	84.1	20.6	.4	.6	(4/)	(4/)	1.4	7.7
124	do.	...do.......	7,510	(4/)	(4/)	2,472	257	1,436	(4/)	(4/)	2.4	4.7	4,156	(4/)	(4/)	8,328	Cl-Ca	$S_1S_2A_2$	VH	N	81.8	20.4	.4	.6	(4/)	(4/)	1.4	5.6
125	do.	...do.......	7,516	(4/)	(4/)	1,638	149	959	(4/)	(4/)	2.1	4.8	2,738	(4/)	(4/)	5,490	Cl-Ca	$S_1S_2A_2$	VH	N	68.0	16.3	.4	.6	(4/)	(4/)	1.5	6.5
126	do.	...do.......	7,546	(4/)	(4/)	1,908	191	2,189	(4/)	(4/)	2.3	4.1	3,255	(4/)	(4/)	7,550	Cl-Ca	$S_1S_2A_2$	VH	N	94.5	22.4	.4	.6	(4/)	(4/)	.8	11.5
127	do.	...do.......	7,515	(4/)	(4/)	2,815	247	1,601	(4/)	(4/)	2.0	5.9	4,414	(4/)	(4/)	9,085	Cl-Ca	$S_1S_2A_2$	VH	N	97.1	18.8	.4	.6	(4/)	(4/)	1.5	6.5
128	do.	...do.......	7,615	(4/)	(4/)	2,504	248	1,572	(4/)	(4/)	2.3	3.3	4,359	(4/)	(4/)	8,689	Cl-Ca	$S_1S_2S_3$	VH	N	71.7	20.0	.4	.6	(4/)	(4/)	1.4	6.3
129	do.	...do.......	7,608	(4/)	(4/)	2,522	263	1,665	(4/)	(4/)	2.2	3.1	4,443	(4/)	(4/)	8,898	Cl-Ca	$S_1S_2A_2$	VH	N	71.9	20.3	.4	.6	(4/)	.0	1.3	6.3
130	do.	...do.......	7,615	(4/)	(4/)	2,775	249	1,656	(4/)	(4/)	2.3	5.4	4,454	(4/)	(4/)	9,142	Cl-Ca	$S_1S_2A_2$	VH	N	94.3	20.6	.4	.5	(4/)	.0	1.5	6.6
131	do.	...do.......	7,614	(4/)	(4/)	970	81	221	(4/)	(4/)	1.7	1.3	1,268	(4/)	(4/)	2,542	Cl-Ca	$S_1S_2A_2$	VH	N	16.7	8.6	.2	.8	(4/)	.0	3.2	2.7
132	do.	...do.......	7,614	(4/)	(4/)	2,279	276	979	(4/)	(4/)	1.7	2.6	2,661	(4/)	(4/)	6,199	Cl-Ca	$S_1A_2S_2$	VH	N	50.4	14.2	.1	.9	(4/)	.0	1.8	3.5
133	do.	...do.......	7,605	(4/)	(4/)	2,616	226	1,597	(4/)	(4/)	2.1	4.1	4,431	(4/)	(4/)	8,875	Cl-Ca	$S_1S_2A_2$	VH	N	80.9	19.1	.4	.6	(4/)	.0	1.4	7.1
134	do.	...do.......	7,642	(4/)	(4/)	2,633	257	1,637	(4/)	(4/)	2.3	3.3	4,520	(4/)	(4/)	9,053	Cl-Ca	$S_1S_2A_2$	VH	N	74.0	20.8	.4	.6	(4/)	.0	1.4	6.4
135	do.	...do.......	7,615	(4/)	(4/)	2,533	255	1,690	(4/)	(4/)	2.6	2.9	4,473	(4/)	(4/)	8,956	Cl-Ca	$S_1S_2A_2$	VH	N	70.4	22.3	.4	.6	(4/)	.0	1.3	6.6
136	do.	...do.......	7,609	(4/)	(4/)	2,647	179	1,655	(4/)	(4/)	2.4	4.0	4,473	(4/)	(4/)	8,960	Cl-Ca	$S_1S_2A_2$	VH	N	81.3	21.3	.4	.6	(4/)	.0	1.4	9.2
137	do.	...do.......	10,156	(4/)	(4/)	2,054	365	1,585	(4/)	(4/)	1.2	4.8	4,103	(4/)	(4/)	8,113	Cl-Ca	$S_1S_2S_3$	VH	N	87.3	12.9	.5	.5	(4/)	.0	1.1	4.3
138	do.	...do.......	10,372	(4/)	(4/)	2,480	50	1,692	(4/)	(4/)	4.5	5.5	4,209	(4/)	(4/)	8,441	Cl-Ca	$S_1S_2A_2$	VH	N	96.0	32.7	.4	.6	(4/)	.0	1.4	33.7
139	do.	...do.......	10,150	(4/)	(4/)	2,107	480	1,615	(4/)	(4/)	0.7	2.5	4,196	(4/)	(4/)	8,402	Cl-Ca	$S_1S_2A_2$	VH	N	63.7	9.0	.5	.5	(4/)	.0	1.0	3.4
140	do.	...do.......	8,807	52	173	2,521	199	1,850	55	0.5	3.3	9.3	4,031	59	.1	8,953	Cl-Ca	$S_1S_2A_2$	VH	A	130.8	27.0	.3	.7	68	.0	1.3	9.6
141	do.	...do.......	8,314	39	124	2,499	124	1,902	64	.5	3.0	10.8	5,036	58	.1	9,860	Cl-Ca	$S_1S_2S_3$	VH	A	143.5	25.7	.5	.5	87	.0	1.3	15.8
142	do.	...do.......	10,913	13	3	2,404	17	1,541	54	.2	.0	3.6	3,806	25	.1	7,865	Cl-Ca	$S_1S_2A_2$	VH	N	74.4	0.0	.4	.6	155	.0	1.5	95.0
143	do.	...do.......	10,935	13	5	768	10	88	5	.1	.0	10.2	844	4	.1	1,748	Cl-Ca	$S_1S_2A_2$	VH	A	30.0	.0	.1	.9	201	.0	7.6	9.6
144	do.	...do.......	6,570	(4/)	23	1,997	81	1,422	32	.0	.0	2.1	3,291	(4/)	(4/)	6,848	Cl-Ca	$S_1S_2A_2$	VH	N	54.3	.0	.4	.6	(4/)	.0	1.3	18.1
145	do.	...do.......	8,540	42	118	2,481	283	2,043	40	.4	1.3	4.9	4,824	51	.2	9,888	Cl-Ca	$S_1S_2A_2$	VH	N	99.7	15.0	.5	.5	95	.0	1.1	7.4
146	do.	...do.......	8,438	45	145	2,753	234	1,780	42	.2	1.3	5.4	4,877	58	.1	9,941	Cl-Ca	$S_1S_2A_2$	VH	N	98.1	14.7	.4	.6	84	.0	1.4	7.8
147	do.	...do.......	8,345	39	117	2,775	275	1,758	38	.5	1.4	4.3	4,833	57	.1	9,899	Cl-Ca	$S_1S_2A_2$	VH	N	86.9	15.0	.4	.6	84	.0	1.4	6.5
148	do.	...do.......	8,360	42	121	2,767	219	1,970	45	.4	1.3	5.2	4,776	55	.1	10,002	Cl-Ca	$S_1S_2A_2$	VH	N	100.9	14.8	.4	.6	86	.0	1.3	9.2
149	do.	...do.......	8,360	43	5	2,592	225	1,765	83	.4	5.7	8.5	5,013	54	.1	9,794	Cl-Ca	$S_1S_2S_3$	VH	A	122.2	38.4	.5	.5	93	.0	1.3	8.2
150	do.	...do.......	8,310	39	111	2,679	191	1,899	66	.3	6.1	14.2	4,364	51	.1	9,323	Cl-Ca	$S_1S_2A_2$	VH	A	159.7	40.5	.4	.6	86	.0	1.4	9.8

See footnotes at end of table.

TABLE 3. - Classification of Smackover oilfield brines--Continued

Sample	State	Basin	Depth	Concentration, equivalents per million (epm) Li	K	Na	Mg	Ca	Sr	Ba	HCO_3	SO_4	Cl	Br	I	Total	Type (77)	Class (77)	Cl 1/ (74)	SO_4 2/ (74)	$\sqrt{Ca \times SO_4}$	$\sqrt[3]{(HCO_3 + CO_2)\ (Ca)}$	IBE 3/	Na/Cl	Cl/Br	SO_4/Cl	Na/Ca + Mg	Ca/Mg
151	Ark.	Sabine uplift	8,656	47	110	2,610	456	1,784	45	0.3	5.1	13.5	4,590	50	0.1	9,711	Cl-Ca	$S_1S_2A_2$	VH	A	155.3	36.0	0.4	0.6	92	0.0	1.2	4.0
152	do.	...do.......	6,495	(4/)	(4/)	1,990	151	1,308	32	.0	0.0	1.8	3,298	(4/)	(4/)	6,781	Cl-Ca	$S_1S_2A_2$	VH	N	48.8	0.0	.4	.6	(4/)	.0	1.3	8.9
153	do.	...do.......	8,512	40	146	2,705	149	1,842	43	.4	6.8	8.7	4,988	54	0.1	9,984	Cl-Ca	$S_1S_2S_3$	VH	A	126.4	44.2	.4	.6	92	.0	1.4	12.6
154	do.	...do.......	6,465	(4/)	2	2,095	200	1,205	28	.0	.2	2.4	3,180	(4/)	(4/)	6,713	Cl-Ca	$S_1S_2A_2$	VH	N	54.1	3.1	.3	.7	(4/)	.0	1.5	6.2
155	do.	...do.......	8,024	19	57	3,084	284	1,766	42	.3	1.3	3.4	4,766	42	0.1	10,064	Cl-Ca	$S_1S_2A_2$	VH	N	77.5	14.1	.3	.7	114	.0	1.5	6.4
156	do.	...do.......	8,118	32	85	2,708	265	1,760	46	.4	5.5	13.6	4,625	51	0.1	9,592	Cl-Ca	$S_1S_2A_2$	VH	A	154.9	37.8	.4	.6	91	.0	1.4	6.8
157	do.	...do.......	8,352	40	124	2,723	638	1,767	56	.5	5.7	10.0	4,820	46	0.1	10,231	Cl-Ca	$S_1S_2A_2$	VH	A	132.8	38.6	.4	.6	104	.0	1.2	2.9
158	do.	...do.......	8,315	39	111	2,702	464	2,024	36	.4	6.4	9.4	4,912	55	0.1	10,359	Cl-Ca	$S_1S_2A_2$	VH	A	137.7	43.6	.4	.6	89	.0	1.1	4.4
159	do.	...do.......	8,604	50	99	2,778	240	1,832	55	.3	5.9	6.7	4,587	48	0.1	9,702	Cl-Ca	$S_1S_2A_2$	VH	A	111.0	40.0	.4	.6	95	.0	1.4	7.9
160	do.	...do.......	8,417	52	155	2,577	232	1,826	53	.5	2.7	6.9	4,654	56	0.1	9,615	Cl-Ca	$S_1S_2A_2$	VH	A	111.9	23.8	.4	.6	83	.0	1.3	8.1
161	do.	...do.......	8,608	48	155	2,581	174	1,826	35	.3	3.3	15.0	5,228	58	0.1	10,124	Cl-Ca	$S_1S_2S_3$	VH	A	165.6	26.8	.5	.5	91	.0	1.4	10.7
162	do.	...do.......	6,372	(4/)	12	1,111	107	750	13	.0	.6	10.9	2,084	(4/)	(4/)	4,088	Cl-Ca	$S_1S_2S_3$	VH	A	90.5	6.3	.5	.5	(4/)	.0	1.3	7.2
163	do.	...do.......	6,315	(4/)	(4/)	1,794	154	1,378	25	.0	.0	1.3	3,323	(4/)	(4/)	6,675	Cl-Ca	$S_1S_2A_2$	VH	N	42.5	.0	.5	.5	(4/)	.0	1.2	9.1
164	do.	...do.......	6,349	(4/)	25	2,063	239	1,351	29	.0	.0	2.0	3,475	(4/)	(4/)	7,184	Cl-Ca	$S_1S_2A_2$	VH	N	52.4	.0	.4	.6	(4/)	.0	1.3	5.8
165	do.	...do.......	6,334	(4/)	22	1,805	194	1,264	26	.0	.0	2.9	3,234	(4/)	(4/)	6,548	Cl-Ca	$S_1S_2A_2$	VH	N	60.3	.0	.4	.6	(4/)	.0	1.2	6.6
166	do.	...do.......	6,402	(4/)	23	2,199	182	1,292	30	.0	.0	4.2	2,704	(4/)	(4/)	6,434	Cl-Ca	$S_1A_2S_2$	VH	N	74.0	.0	.2	.8	(4/)	.0	1.5	7.3
167	do.	...do.......	6,138	(4/)	(4/)	3,049	256	1,366	(4/)	(4/)	.0	113.6	4,561	(4/)	(4/)	9,346	Cl-Ca	$S_1S_2S_3$	VH	VH	393.9	.0	.3	.7	(4/)	.0	1.9	5.3
168	do.	...do.......	6,330	(4/)	(4/)	2,012	446	1,449	(4/)	(4/)	.2	23.8	3,887	(4/)	(4/)	7,818	Cl-Ca	$S_1S_2S_3$	VH	A	185.8	3.4	.5	.5	(4/)	.0	1.1	3.3
169	do.	...do.......	6,330	(4/)	(4/)	2,157	317	1,422	(4/)	(4/)	.2	8.8	3,890	(4/)	(4/)	7,795	Cl-Ca	$S_1S_2S_3$	VH	A	112.0	3.6	.5	.6	(4/)	.0	1.2	4.5
170	do.	...do.......	6,014	(4/)	(4/)	2,655	437	3,291	(4/)	(4/)	.2	13.3	3,850	(4/)	(4/)	10,247	Cl-Ca	$S_1A_2S_2$	VH	A	209.5	4.5	.3	.7	(4/)	.0	.7	7.5
171	do.	...do.......	6,014	(4/)	(4/)	1,862	376	1,645	(4/)	(4/)	.7	64.5	3,821	(4/)	(4/)	7,769	Cl-Ca	$S_2S_1S_3$	VH	VH	325.8	9.1	.5	.5	(4/)	.0	.9	4.4
172	do.	...do.......	6,282	(4/)	(4/)	1,525	161	1,015	(4/)	(4/)	.4	8.2	2,692	(4/)	(4/)	5,401	Cl-Ca	$S_1S_2A_2$	VH	A	91.2	5.0	.4	.6	(4/)	.0	1.3	6.3
173	do.	...do.......	6,300	(4/)	(4/)	1,958	264	1,320	(4/)	(4/)	.0	5.3	3,537	(4/)	(4/)	7,085	Cl-Ca	$S_1S_2A_2$	VH	N	83.7	.0	.5	.6	(4/)	.0	1.2	5.0
174	do.	...do.......	6,345	(4/)	(4/)	1,866	212	1,433	26	0.0	.0	1.2	3,508	(4/)	(4/)	7,045	Cl-Ca	$S_1S_2A_2$	VH	N	41.4	.0	.5	.5	(4/)	.0	1.1	6.9
175	do.	...do.......	6,309	(4/)	(4/)	1,672	339	1,201	(4/)	(4/)	.1	17.6	3,197	(4/)	(4/)	6,426	Cl-Ca	$S_1S_2S_3$	VH	A	145.5	2.3	.5	.5	(4/)	.0	1.1	3.6
176	do.	...do.......	6,309	(4/)	(4/)	2,177	373	1,453	(4/)	(4/)	1.0	8.8	3,998	(4/)	(4/)	8,010	Cl-Ca	$S_1S_2S_3$	VH	A	112.8	11.6	.5	.5	(4/)	.0	1.2	3.9
177	do.	...do.......	6,300	(4/)	(4/)	2,361	330	1,473	(4/)	(4/)	.2	28.8	4,137	(4/)	(4/)	8,330	Cl-Ca	$S_1S_2S_3$	VH	H	206.0	4.3	.4	.6	(4/)	.0	1.3	4.5
178	do.	...do.......	6,310	(4/)	(4/)	2,450	375	1,295	(4/)	(4/)	.0	53.3	4,070	(4/)	(4/)	8,244	Cl-Ca	$S_1S_2S_3$	VH	H	262.8	.0	.4	.6	(4/)	.0	1.5	3.5
179	do.	...do.......	6,082	(4/)	(4/)	1,223	145	3,401	(4/)	(4/)	1.1	87.2	1,623	(4/)	(4/)	6,480	Cl-Ca	$A_2S_1S_2$	VH	VH	544.4	16.2	.3	.8	(4/)	.0	.3	23.5
180	do.	...do.......	6,300	(4/)	(4/)	2,189	285	1,476	(4/)	(4/)	.0	51.3	3,903	(4/)	(4/)	7,904	Cl-Ca	$S_1S_2S_3$	VH	H	275.2	.0	.4	.6	(4/)	.0	1.2	5.2

See footnotes at end of table.

TABLE 3. - Classification of Smackover oilfield brines--Continued

Sample	State	Basin	Depth	Concentration, equivalents per million (epm) Li	K	Na	Mg	Ca	Sr	Ba	HCO_3	SO_4	Cl	Br	I	Total	Type (77)	Class (77)	Cl 1/ (74)	SO_4 2/ (74)	$\sqrt{Ca \times SO_4}$	$\sqrt[3]{(HCO_3 + CO_2)\ (Ca)}$	IBE 3/	Na/Cl	Cl/Br	SO_4/Cl	Na/Ca + Mg	Ca/Mg
181	Ark.	Sabine uplift	6,300	(4/)	(4/)	2,297	347	1,409	(4/)	(4/)	0.0	11.6	4,047	(4/)	(4/)	8,112	Cl-Ca	$S_1S_2S_3$	VH	A	128.0	0.0	0.4	0.6	(4/)	0.0	1.3	4.1
182	do.	...do.......	6,300	(4/)	(4/)	2,318	279	1,444	(4/)	(4/)	.0	9.8	4,048	(4/)	(4/)	8,100	Cl-Ca	$S_1S_2S_3$	VH	A	119.2	.0	.4	.6	(4/)	.0	1.4	5.2
183	do.	...do.......	6,157	(4/)	(4/)	2,920	338	1,029	(4/)	(4/)	.0	5.1	4,055	(4/)	(4/)	8,347	Cl-Ca	$S_1S_2A_2$	VH	N	72.7	.0	.3	.7	(4/)	.0	2.1	3.0
184	do.	...do.......	6,157	(4/)	(4/)	2,267	385	1,515	(4/)	(4/)	.0	24.8	4,148	(4/)	(4/)	8,340	Cl-Ca	$S_1S_2S_3$	VH	H	193.6	.0	.5	.6	(4/)	.0	1.2	3.9
185	do.	...do.......	6,157	(4/)	(4/)	2,921	332	1,035	(4/)	(4/)	.0	23.0	4,269	(4/)	(4/)	8,579	Cl-Ca	$S_1S_2S_3$	VH	A	154.3	.0	.3	.7	(4/)	.0	2.1	3.1
186	do.	...do.......	6,147	(4/)	(4/)	2,288	667	1,078	(4/)	(4/)	.2	10.2	4,026	(4/)	(4/)	8,070	Cl-Ca	$S_1S_2S_3$	VH	A	104.9	3.3	.4	.6	(4/)	.0	1.3	1.6
187	do.	...do.......	6,147	(4/)	(4/)	3,065	264	966	(4/)	(4/)	.3	63.7	4,234	(4/)	(4/)	8,591	Cl-Ca	$S_1S_2S_3$	VH	VH	247.9	4.7	.3	.7	(4/)	.0	2.5	3.7
188	do.	...do.......	6,300	(4/)	(4/)	2,632	404	1,120	(4/)	(4/)	.0	22.6	4,137	(4/)	(4/)	8,316	Cl-Ca	$S_1S_2S_3$	VH	A	158.9	.0	.4	.6	(4/)	.0	1.7	2.8
189	do.	...do.......	6,300	(4/)	(4/)	2,219	358	1,466	(4/)	(4/)	.0	9.7	4,037	(4/)	(4/)	8,089	Cl-Ca	$S_1S_2S_3$	VH	A	119.1	.0	.5	.6	(4/)	.0	1.2	4.1
190	do.	...do.......	6,138	(4/)	(4/)	2,453	250	1,409	(4/)	(4/)	.0	54.1	4,073	(4/)	(4/)	8,240	Cl-Ca	$S_1S_2S_3$	VH	H	276.0	.0	.4	.6	(4/)	.0	1.5	5.6
191	do.	...do.......	8,490	44	116	2,528	25	1,856	59	0.5	.0	14.2	4,635	58	0.1	9,336	Cl-Ca	$S_1S_2S_3$	VH	A	162.6	.0	.4	.6	80	.0	1.4	77.0
192	do.	...do.......	8,475	43	92	2,617	290	1,803	57	.5	1.3	4.7	4,632	58	.1	9,598	Cl-Ca	$S_1S_2A_2$	VH	N	91.7	14.4	.4	.6	80	.0	1.3	6.4
193	do.	...do.......	8,396	40	130	2,293	265	1,893	51	.4	1.4	4.0	4,781	58	.1	9,517	Cl-Ca	$S_1S_2S_3$	VH	N	86.5	15.3	.5	.5	82	.0	1.1	7.3
194	do.	...do.......	8,564	45	230	2,343	218	1,811	45	.3	1.4	4.1	4,586	55	.2	9,340	Cl-Ca	$S_1S_2A_2$	VH	N	85.9	14.9	.4	.6	83	.0	1.3	8.5
195	do.	...do.......	6,360	(4/)	(4/)	1,868	205	1,250	0	.2	.2	3.9	3,319	(4/)	(4/)	6,647	Cl-Ca	$S_1S_2S_3$	VH	N	70.0	3.1	.4	.6	(4/)	.0	1.3	6.1
196	do.	...do.......	6,715	6	27	1,761	322	980	25	.0	.8	3.0	3,050	21	.1	6,196	Cl-Ca	$S_1S_2A_2$	VH	N	54.1	8.3	.4	.6	146	.0	1.4	3.1
197	do.	...do.......	6,920	8	27	1,628	290	1,171	7	.2	.7	2.8	3,656	25	.2	6,816	Cl-Ca	$S_2S_1S_3$	VH	N	56.9	8.1	.6	.5	148	.0	1.1	4.1
198	do.	...do.......	9,023	4	12	836	175	1,049	3	.2	1.3	3.1	1,143	1	.1	3,228	Cl-Ca	$A_2S_1S_2$	VH	N	56.8	12.1	.3	.7	996	.0	0.7	6.0
199	do.	...do.......	8,431	33	63	2,232	142	1,620	51	.3	.7	3.1	4,631	57	.1	8,834	Cl-Ca	$S_2S_1S_3$	VH	N	71.1	9.6	.5	.5	81	.0	1.3	11.7
200	do.	...do.......	8,501	28	121	3,005	244	1,602	52	.2	1.3	3.2	4,577	58	.1	9,693	Cl-Ca	$S_1S_2A_2$	VH	N	71.8	14.2	.3	.7	79	.0	1.7	6.8
201	do.	...do.......	6,552	12	37	2,184	255	1,508	26	.1	.0	3.7	4,409	49	.1	8,484	Cl-Ca	$S_1S_2S_3$	VH	N	74.5	.0	.5	.5	89	.0	1.3	6.0
202	do.	...do.......	7,368	1	28	2,509	361	1,345	31	.1	.6	4.3	4,120	50	.1	8,449	Cl-Ca	$S_1S_2A_2$	VH	N	75.9	7.8	.4	.6	83	.0	1.5	3.8
203	do.	...do.......	9,287	7	12	1,411	144	1,479	23	.2	1.5	6.9	4,897	16	.1	7,997	Cl-Ca	$S_2S_3S_1$	VH	A	100.7	15.1	.7	.3	308	.0	.9	10.5
204	do.	...do.......	6,523	(4/)	28	2,001	106	1,402	31	.0	.0	2.6	3,379	(4/)	(4/)	6,950	Cl-Ca	$S_1S_2A_2$	VH	N	60.0	.0	.4	.6	(4/)	.0	1.3	13.5
205	do.	...do.......	6,400	(4/)	25	2,041	223	1,287	30	.0	.0	2.1	3,397	(4/)	(4/)	7,004	Cl-Ca	$S_1S_2A_2$	VH	N	52.3	.0	.4	.6	(4/)	.0	1.3	5.9
206	do.	...do.......	6,353	(4/)	15	1,246	132	831	19	.0	.2	1.0	2,135	(4/)	(4/)	4,379	Cl-Ca	$S_1S_2A_2$	VH	N	29.2	2.9	.4	.6	(4/)	.0	1.3	6.4
207	do.	...do.......	6,300	(4/)	(4/)	2,641	259	1,359	(4/)	(4/)	.0	7.0	4,193	(4/)	(4/)	8,459	Cl-Ca	$S_1S_2A_2$	VH	A	97.4	.0	.4	.6	(4/)	.0	1.6	5.3
208	do.	...do.......	6,309	(4/)	(4/)	1,948	212	1,158	(4/)	(4/)	5.1	11.2	3,306	(4/)	(4/)	6,640	Cl-Ca	$S_1S_2A_2$	VH	A	114.0	31.2	.4	.6	(4/)	.0	1.4	5.5
209	do.	...do.......	6,320	(4/)	(4/)	2,030	348	1,483	(4/)	(4/)	.1	15.3	3,850	(4/)	(4/)	7,726	Cl-Ca	$S_1S_2S_3$	VH	A	150.7	1.7	.5	.5	(4/)	.0	1.1	4.3
210	do.	...do.......	6,300	(4/)	(4/)	1,869	377	1,416	(4/)	(4/)	.0	28.6	3,861	(4/)	(4/)	7,552	Cl-Ca	$S_2S_1S_3$	VH	H	201.1	1.0	.5	.5	(4/)	.0	1.0	3.8

See footnotes at end of table.

TABLE 3. - Classification of Smackover oilfield brines—Continued

Sample	State	Basin	Depth	Concentration, equivalents per million (epm) Li	K	Na	Mg	Ca	Sr	Ba	HCO_3	SO_4	Cl	Br	I	Total	Type (77)	Class (77)	Cl 1/ (74)	SO_4 2/ (74)	$\sqrt{Ca \times SO_4}$	$\sqrt[3]{(HCO_3 + CO_2)(Ca)}$	IBE 3/	Na/Cl	Cl/Br	SO_4/Cl	Na/Ca + Mg	Ca/Mg
211	Ark.	Sabine uplift	6,300	(4/)	(4/)	1,868	293	1,645	(4/)	(4/)	0.0	18.8	3,793	(4/)	(4/)	7,619	Cl-Ca	$S_2S_1S_3$	VH	A	176.0	0.0	0.5	0.5	(4/)	0.0	1.0	5.6
212	do.	...do.......	6,300	(4/)	(4/)	2,258	335	1,594	(4/)	(4/)	.0	20.0	4,172	(4/)	(4/)	8,379	Cl-Ca	$S_1S_2S_3$	VH	A	178.3	.0	.5	.5	(4/)	.0	1.2	4.8
213	do.	...do.......	6,300	(4/)	(4/)	2,190	324	1,489	(4/)	(4/)	.3	26.7	3,980	(4/)	(4/)	8,010	Cl-Ca	$S_1S_2S_3$	VH	H	199.5	5.4	.5	.6	(4/)	.0	1.2	4.6
214	do.	...do.......	6,300	(4/)	(4/)	2,301	329	1,637	(4/)	(4/)	.0	20.2	4,251	(4/)	(4/)	8,537	Cl-Ca	$S_1S_2S_3$	VH	A	186.6	.0	.5	.5	(4/)	.0	1.2	5.0
215	do.	...do.......	6,300	(4/)	(4/)	2,267	385	1,515	(4/)	(4/)	.0	24.8	4,148	(4/)	(4/)	8,340	Cl-Ca	$S_1S_2S_3$	VH	H	193.6	.0	.5	.6	(4/)	.0	1.2	3.9
216	do.	...do.......	6,300	(4/)	(4/)	2,186	329	1,664	(4/)	(4/)	.0	22.2	4,162	(4/)	(4/)	8,363	Cl-Ca	$S_1S_2S_3$	VH	A	192.0	.0	.5	.5	(4/)	.0	1.1	5.1
217	do.	...do.......	6,300	(4/)	(4/)	2,263	334	1,525	(4/)	(4/)	.0	26.0	4,101	(4/)	(4/)	8,248	Cl-Ca	$S_1S_2S_3$	VH	H	199.1	.0	.5	.6	(4/)	.0	1.2	4.6
218	La.	...do.......	10,322	0	5	228	27	502	4	0.1	.3	0.0	606	1	0.1	1,373	Cl-Ca	$S_2S_1A_2$	M	N	0.1	3.8	.6	.4	672	.0	0.4	19.0
219	do.	...do.......	10,700	8	25	2,521	25	197	88	.7	2.5	3.2	4,689	14	.4	7,573	Cl-Ca	$S_1S_2S_3$	VH	N	25.0	10.7	.5	.5	332	.0	8.2	11.6
220	do.	...do.......	10,000	12	24	3,206	27	142	4	.1	.0	2.6	4,081	22	.3	7,520	Cl-Ca	$S_1S_2S_3$	VH	N	19.3	.0	.2	.8	187	.0	18.8	5.4
221	do.	...do.......	10,000	8	13	2,936	21	188	80	.8	.0	6.2	5,078	21	.3	8,352	Cl-Ca	$S_1S_2S_3$	VH	A	34.0	.0	.4	.6	245	.0	10.2	12.7
222	do.	...do.......	10,000	10	20	2,225	91	1,364	49	.4	2.5	.2	4,319	18	.6	8,100	Cl-Ca	$S_1S_2S_3$	VH	N	17.8	20.3	.5	.5	240	.0	1.5	15.5
223	do.	...do.......	10,000	10	30	3,024	89	1,384	49	.2	.4	2.9	4,314	18	.4	8,922	Cl-Ca	$S_1S_2A_2$	VH	N	63.3	6.5	.3	.7	238	.0	2.0	16.1
224	Tex.	...do.......	10,493	48	135	2,490	185	1,166	47	.1	1.1	2.1	4,107	24	.3	8,207	Cl-Ca	$S_1S_2S_3$	VH	N	49.6	11.2	.4	.7	168	.0	1.9	6.6
225	do.	Tyler	9,868	62	7	1,053	515	1,141	47	.5	.0	11.1	2,687	11	3.0	5,537	Cl-Ca	$S_2S_1A_2$	VH	A	112.5	.0	.6	.4	253	.0	.7	2.3
226	do.	...do.......	12,765	60	157	2,710	307	1,110	50	.4	.0	5.0	4,474	32	.1	8,905	Cl-Ca	$S_1S_2S_3$	VH	N	74.6	.0	.4	.7	140	.0	2.0	3.8

1/ epm Cl is >700, very high
epm Cl is 420-700, marine
epm Cl is 140-420, high
epm Cl is 40-140, average
epm Cl is 10-40, low
epm Cl is <10, normal

2/ epm SO_4 is >58, very high
epm SO_4 is 24-58, high
epm SO_4 is 6-24, average
epm SO_4 is <6, normal

3/ IBE is index of base exchange; ratio between exchanged ions and same ions as they originally existed.

4/ Not determined.

According to Sulin (77), there are four basic environments of natural water distribution: (1) Continental (terrestrial) conditions that promote the formation of sulfate waters. Such conditions supply soluble sulfate constituents to the water, and the genetic type of such a water is "sulfate-sodium;" (2) continental conditions that promote the formation of sodium bicarbonate waters. The genetic type is "bicarbonate-sodium;" (3) marine conditions and the formation of a "chloride-magnesium" type of water; and (4) deep subsurface conditions within the earth's crust and the formation of a "chloride-calcium" type of water. The first two types are characteristic of meteoric and/or artesian waters; the third, of marine environments and evaporite sequences; and the fourth, of deep stagnant conditions.

The water type is expressed by use of a formula representing decreasing values of the Palmer (67) characteristics. For example, $S_1 S_2 A_2$ indicates that primary salinity is predominant and is followed by secondary salinity and secondary alkalinity. Therefore, the classes are subdivided into subclasses, and class S_1 can include the subclass $S_1 S_2 A_2$, $S_1 A_2 S_2$, and S_1. Table 3, column 19, gives the class of water according to its degree of salinity and alkalinity. Most of the Smackover brines fall in the $S_1 S_2 A_2$ class. Collins (18) classified about 4,000 oilfield waters from sedimentary basins and found that the most of them were of the chloride-calcium type and in the $S_1 S_2 A_2$ class.

In table 3, column 20 illustrates the degree of chloride concentration in waters, and there are six possible types according to Schoeller (74). If the chloride concentration is greater than 700 epm it is very high; 420 to 700 epm, it is marine; 140 to 420 epm, it is high; 40 to 140 epm, it is average; 10 to 40 epm, it is low; and less than 10 epm is normal (for fresher waters).

All of the Smackover brines that were classified were very highly concentrated in chloride except for sample 218, which fell in the marine category. This sample was taken in August 1969 from a well that was completed in October 1967; therefore, the sample should not be contaminated from drilling fluids. The initial oil and gas production of the well was 220 barrels per day (bbl/d) and 372,000 cubic feet per day (ft^3/d), respectively. At the time of sampling the production was down to 22 bbl/d and 81,000 ft^3/d, respectively. The sample appears to have been diluted by a fresher water.

Column 21, table 3, indicates the degree of sulfate concentration in the waters. A very high concentration of sulfate is present if the epm is greater than 58 as shown at the bottom of the table.

The concentrations of sulfate in most of the samples are less than 6 epm, indicating that they are normally sulfated. There are a few samples that contain more than 58 epm, but have a ratio $SO_4 \times 100/Cl$ of less than 1, and they, therefore, are characteristic of a brine associated with a hydrocarbon accumulation.

Column 22, table 3, indicates the degree that the water is saturated with calcium sulfate, Schoeller (74) used an arbitrary value of 70 for $\sqrt{SO_4 \times Ca}$ to indicate that a water is saturated with $CaSO_4$. This is not necessarily true because some waters, depending upon their concentrations of other dissolved constituents, can contain smaller or larger amounts.

Schoeller (74) observed $CaSO_4$ saturation only in very-high-chloride waters. The Ca concentration always is very high (150 to 1,100 epm) in high-chloride waters that have $SO_4 > 58$ epm and usually is less than 150 epm in high-chloride waters where $SO_4 < 58$ epm. All petroleum waters, even if saturated with $CaSO_4$, have a low SO_4/Cl ratio that is attributed to reduction of sulfates and high concentrations of chloride. The ratio never exceeds 1 except in low or normal chloride waters.

The data in table 3 indicate that many of the Smackover brines are saturated with calcium sulfate using an arbitrary value of 70. The elevated pressures, temperatures, and high concentrations of chloride and other ions can account for this saturated condition (66). This saturated condition merits attention by producers because any changes in pressure temperature or mixing with other waters could cause precipitation of calcium sulfate (34). Other likely precipitates are the sulfates of strontium and barium.

Column 23, table 3, indicates the amount of bicarbonate and carbonate in the waters and the formula $\sqrt[3]{(HCO_3 + CO_3)^2(Ca)}$ is proportional to the gaseous pressure of CO_2 in equilibrium with $CaCO_3$ in the water. As the Cl concentration increases, the tendency is for Ca concentration to increase and HCO_3 concentration to decrease; however, because the Ca concentration increases, the product of $\sqrt[3]{(HCO_3 + CO_3)^2(Ca)}$ does not vary greatly.

The $\sqrt[3]{(HCO_3 + CO_3)^2(Ca)}$ was used by Schoeller (74) to determine if a water was saturated with calcium carbonate, and such a water should have a value greater than 7. This is not entirely accurate, but the formula does indicate whether the water contains an excess of calcium which decreases the carbonate concentration. Many of the Smackover brines evaluated had values greater than 7. A distilled water thus saturated would deposit precipitated calcium carbonate, but the activities of other ions dissolved in a brine cause the solubility product to be different in the brine.

As the waters move in their subsurface environment, their dissolved ions have a tendency to exchange with those in the rocks. Two extreme types of adsorption can be noted in addition to intermediate types of adsorption. The extreme types are a physical adsorption or Van der Waals adsorption with weak bonding between the adsorbent and the constituent adsorbed and a chemical adsorption with strong valence bonds. Both of these adsorptions can act simultaneously.

Cations can be fixed at the surface and in the interior of the associated minerals. These fixed cations can exchange with the cation in the water. When the exchange occurs, there is an exchange of bases. With the right physical conditions of the adsorbent, similar exchange can occur with the anions. Some of the constituents in sedimentary rocks, which are capable of exchange and adsorption, are argillaceous minerals, zeolites, ferric hydroxide, and certain organic compounds.

Particle size influences the exchange rates and capacities if the solids are clays such as illite and kaolinite. The rate increases with decreasing particle size. However, if a larger mineral has a lattice the exchange can easily occur on the plates. The concentration of exchangeable ions in the adsorbent and in the water is important. More exchange usually occurs when the solution is highly concentrated.

The formula $$(a - x) = k \left(\frac{x}{a-x} \right)^{\frac{1}{p}} \tag{1}$$

indicates the relationship that exists between the initial concentration a of the cations in milliequivalents in the unreacted water, and x the final concentration of the cations in milliequivalents in the water after equilibrium or reaction with the rocks. The amounts of cations exchanged by passing from the liquid to the rock or clay is (a-x), and the index of base exchange (IBE) = $\left(\frac{a-x}{a} \right)$. By substitution,

$$IBE = \frac{k}{a} \left(\frac{x}{a-x} \right)^{\frac{1}{p}} \quad \text{(Schoeller (74))}. \tag{2}$$

The IBE column 24, table 3, indicates the ratio between the exchanged ions and the same ions as they originally existed. For example, assume that in the original water there were as many equivalents of Cl as (Na + K), and when the Na and K of the water exchanged with the alkaline earths in the rocks alkaline exchange occurs, then

$$IBE = \frac{Cl - (Na + K)}{Cl}, \tag{3}$$

and this value is positive if the equivalents are Cl > (Na + K). Theoretically all the halides should be included as Cl and all the alkalies as Na or (Na + K).

However, when the alkaline earth ions in the water exchange for alkali metal ions on the rocks, then

$$IBE = \frac{Cl - (Na + K)}{SO_4 + HCO_3 + NO_3}, \tag{4}$$

and this value is negative if the equivalents are Cl < (Na + K). The lack of equilibrium between the halides and the alkalies is not always a characteristic of base exchange because seawater has a positive value without the occurrence of base exchange. Negative values usually are observed for water coming from altered crystalline rocks.

According to Schoeller (74), only those waters with an IBE equal to or greater than 0.129 can be true connate petroleum reservoir waters. Waters with a negative IBE are waters of meteoric origin that have infiltrated into marine sediments.

Comparison of petroleum reservoir waters with other types of subsurface waters revealed that the other waters have most of the same characteristics but generally have a much higher SO_4 concentration and a lower $\sqrt[3]{(HCO_3{}^2 (Ca)}$ or

(Kr). Waters that are in contact with organic matter (other than petroleum such as bitumens, lignites, and coals, resemble petroleum reservoir water, but the frequency of a Kr above normal is greater in petroleum-associated waters. Waters related to magmatic reactions commonly possess high concentrations of HCO_3.

Schoeller's study (74) of petroleum reservoir waters indicated that a positive IBE is more frequent as the Cl increases. A negative IBE is more frequent as the Cl decreases, and a negative value is predominant in low and normal chloride waters associated with petroleum. In fact, he observed that this characteristic appears specific for petroleum reservoir waters since in other subsurface waters a positive index occurs as frequently as a negative index.

Ancient seawater (connate water) deposited with the sediments usually has an IBE > 0.129 and a Cl/Na > 1.17. Intruding meteoric water in sedimentary marine rock has an IBE < 0.129 and Cl/Na < 1.17. Petroleum reservoir waters with an IBE greater than seawater 0.129 also have the characteristics Cl/Na > 1.17, Cl/Ca < 26.8, Cl/Mg > 5.13, Mg/Ca < 5.24; a very high value for $\sqrt[3]{(HCO_3)^2(Ca)}$ indicating sulfate reduction; low concentrations of HCO_3; and frequent high concentrations of NH_4. Petroleum reservoir waters made up of infiltrating meteoric water and with ancient seawater have an IBE less than that of contemporary seawater, 0.129, and the characteristics Cl/Na < 1.17, the ratio Mg/Ca increases and approaches but never equals 5.24, and the ratios Na/Ca and Na/Mg decrease as the dissolved solids increase.

The data in column 24, table 3, show that the IBE for all of the Smackover brines was positive, indicating that the exchange was alkali metals in the waters for alkaline earth metals on the clays. If the IBE were negative, the indication would be exchange of alkaline earth metals for alkali metals on the clays. In addition the IBE for all of the samples exceeded 0.129, which could indicate that the brines were derived from ancient seawater deposited with the sediments.

Bojarski (8) distinguished waters as follows:

1. Waters of the bicarbonate-sodium type, which occur in the upper zone of a sedimentation basin, with "intense water exchange," that is, a hydrodynamic situation where the waters are moving at a relatively fast geological rate, which promote unfavorable conditions for the preservation of petroleum and natural gas deposits. The waters are defined by the ratio $(Na - Cl)/SO_4 > 1$. If the ratio Na/Cl in epm is greater than 1, the water contains more sodium than chloride, and the excess sodium can react with sulfate or bicarbonate ions. Therefore, such waters belong to the bicarbonate-sodium or sulfate-sodium types. If the ratio $(Na-Cl)/SO_4$ is greater than 1, it indicates an excess of sodium with respect to both chloride and sulfate.

2. Waters of the sulfate-sodium type with $(Na - Cl)/SO_4 < 1$. If less than 1, this ratio indicates that all of the sodium will react with chloride or sulfate.

3. Waters of the chloride-magnesium type with (Cl - Na)/Mg < 1. A ratio of this type indicates that all of the chloride will react with sodium and magnesium. Such a water is characteristic of the transition zone between a hydrodynamic area, which is becoming more hydrostatic in the deeper part of the basin, and the amount of dissolved bromide increases directly with the (Cl - Na)/Mg ratio.

4. Waters of the chloride-calcium type with (Cl - Na)/Mg > 1. This ratio indicates an excess of chloride with respect to sodium and magnesium, and the excess will react with calcium. This type of water occurs in deeper zone, which are isolated from the influence of infiltration waters and are hydrostatic or almost hydrostatic.

The chemical compositions in the chloride-calcium type of water can be subdivided as follows:

1. The first class, chloride-calcium with Na/Cl > 0.85, characterizes an active hydrodynamic zone with considerable water movement. It is considered a zone in which hydrocarbons are not likely to accumulate.

2. The second class, chloride-calcium II with Na/Cl = 0.85 to 0.75, characterizes the transition zone between an active hydrodynamic zone and a more stable hydrostatic zone of the sedimentation basin, which is generally considered a poor zone for hydrocarbon preservation.

3. The third class, chloride-calcium III with Na/Cl = 0.75 to 0.65 (0.060), characterizes favorable conditions for the preservation of hydrocarbon deposits. It is designated as a fairly favorable environment for the preservation and accumulation of hydrocarbons.

4. The fourth class, chloride-calcium IV with Na/Cl = 0.65 to 0.50, is characterized by complete isolation of the hydrocarbon accumulations as well as by the presence of residual waters. It is considered a good zone for the preservation and accumulation of hydrocarbons.

5. The fifth class, chloride-calcium V with Na/Cl < 0.50, is characterized by the presence of ancient residual seawater which has been highly altered since original deposition both in the concentration of dissolved solids and in the ratios of the dissolved constituents. Bojarski (8) considers a zone of this type to be one of the most likely areas for the accumulation of hydrocarbons. Additional characteristics of water associated with hydrocarbon accumulations are as follows:

(a) Iodide concentration above 1 mg/l.

(b) Bromide concentration above 300 mg/l. Increasing iodide and bromide concentrations may point to a hydrocarbon accumulation.

(c) Ratio Cl/Br below 350.

(d) $SO_4 \times 100/Cl < 1$.

In addition to indicating the degree of alteration, bromide and iodide as biophile constituents play a decisive role. This follows because of the increased concentration of biophile elements in the waters accompanying a petroleum deposit. The concentration of iodide in the ground waters depends mainly on the organic substances, whereas the concentration of bromide up to a certain limit takes place in an inorganic medium, but an increase in bromide must be evaluated as a positive indication. In many waters accompanying petroleum deposits, large amounts of bromide and smaller amounts of iodide are detected, or vice versa. This is related to the types of bituminous substances that absorb the individual biophile elements in different amounts.

The data in columns 25-29 of table 3 are ratios useful in comparing the Smackover brines to seawater to determine the extent of alteration of the waters. Collins (18) found that the ratio Na/Ca + Mg tends to decrease as the dissolved solids increase in some waters from the east Texas basin. This depletion of sodium with respect to calcium + magnesium was attributed to diagenesis of the waters and it correlated with the IBE, indicating that the alkali metals in the waters exchanged with alkaline earth metals on the clays to decrease the dissolved alkali metals and increase the dissolved alkaline earth metals.

Collins (18) found that the ratio Ca/Mg tends to increase as the dissolved solids concentration in the waters increase in some waters from the east Texas basin. This trend also is related to diagenesis of the waters and the increase in dissolved calcium as the dissolved magnesium decreases may be related to the formation of the minerals such as chlorite or dolomite, or to exchange reactions with argillaceous minerals. It is not a result of the solubility products because most magnesium compounds are more soluble than calcium compounds.

ORIGIN OF SMACKOVER FORMATION WATERS

The origin of oilfield waters is related to many complex natural processes. Some of the mechanisms that cause oilfield waters to differ in composition from the water originally deposited with the sediments include ion exchange, infiltrating waters, sediment leaching, mineral formation, sulfate, reduction, and ultrafiltration through clay-shale membranes.

Reactions With Minerals

Most of the Smackover brines are deficient in magnesium relative to an evaporite-formed brine, as illustrated in figure 4. Table 4 illustrates the approximate amounts of calcium, magnesium, bromide, and sulfate that could exist in a water before and after precipitation of gypsum.

TABLE 4. - Approximate seawater composition before and after gypsum precipitation, mg/l

Ion	Before precipitation	After precipitation
Calcium..........	390	0
Magnesium........	1,300	1,300
Bromide..........	65	65
Sulfate..........	2,580	1,644

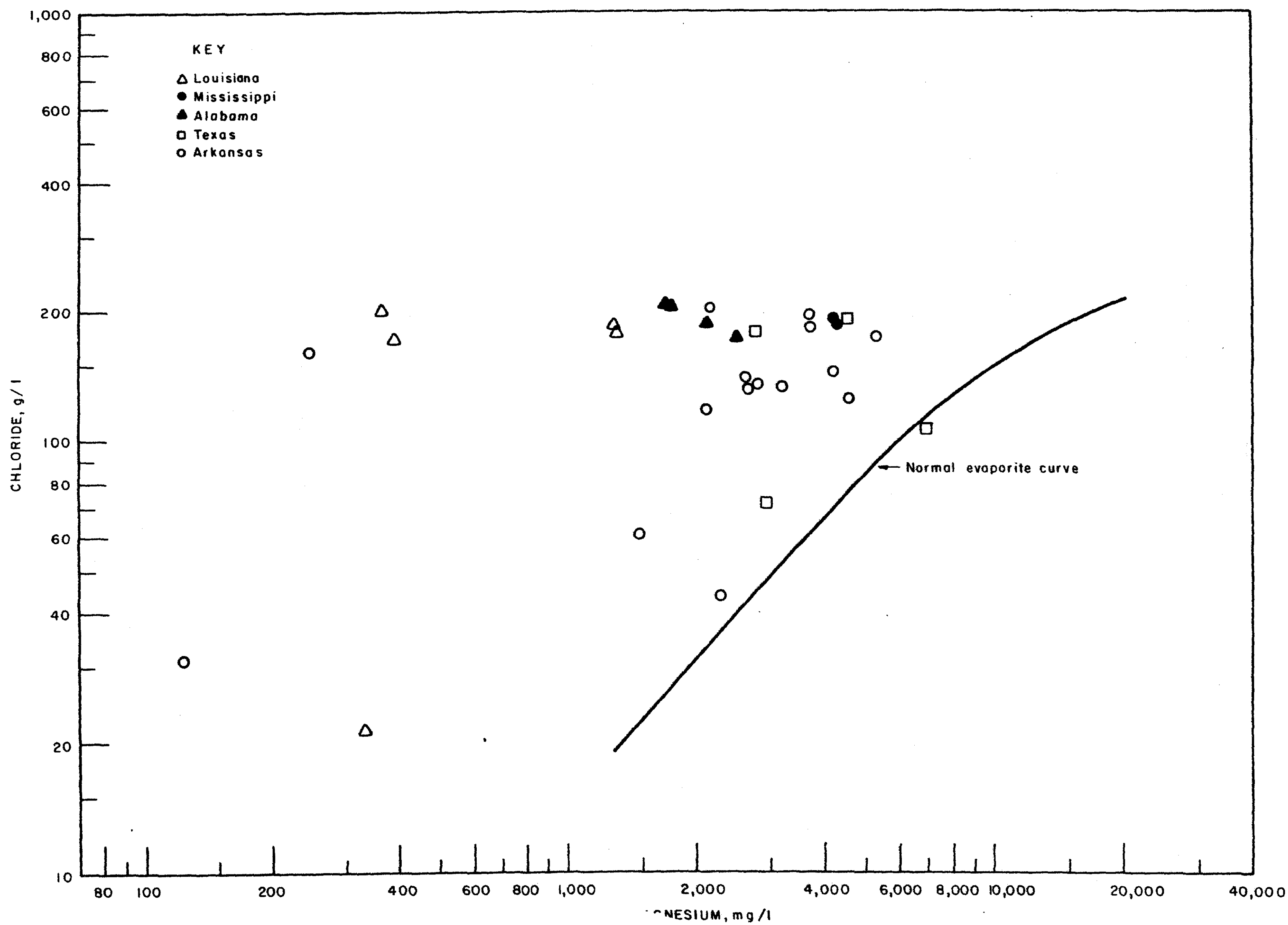

FIGURE 4. - Comparison of the chloride versus magnesium concentrations of some Smackover oilfield brines to that of evaporating seawater.

Assuming that the residual sulfate 1,644 mg/l was removed by the dolomitization reaction,

$$\cancel{MgCl_2} + 2CaCO_3 \longrightarrow \cancel{CaCl_2} + CaMg(CO_3)_2 \tag{5}$$

$$\cancel{CaCl_2} + MgSO_4 \longrightarrow CaSO_4 + \cancel{MgCl_2} \tag{6}$$

$$MgSO_4 + 2CaCO_3 \longrightarrow CaSO_4 + CaMg(CO_3)_2 , \tag{7}$$

then the Mg/Br ratio would be about 883/65 = 13.6, as illustrated by the data in table 5.

TABLE 5. - Approximate seawater composition after dolomitization or bacterial reduction, mg/l

Ion	After dolomitization	After bacterial reduction
Calcium............	0	0
Magnesium..........	883	1,300
Bromide............	65	65
Sulfate............	0	0

However, if the residual sulfate was removed by bacterial reduction,

$$CnHm + Na_2SO_4 \longrightarrow Na_2CO_3 + H_2S + CO_2 + H_2O, \tag{8}$$

the Mg/Br ratio would be about 1,300/65 = 20.

Magnesium will react with $CaCO_3$ (calcite) to form dolomite; thus, the concentration of calcium is increased in the brine, and the Smackover brines are enriched in calcium, as shown in figure 5. However, the total calcium plus magnesium in the brine should remain constant; this can be calculated as

$$\frac{24.31}{40.08} \times \text{mg/l calcium} + \text{mg/l magnesium} = \text{total equivalent magnesium or Mg'}.$$

The ratio Mg'/Mg will vary, depending upon the availability of calcite, and the ratio should be indicative of the degree of dolomotization.

For example, brines in equilibrium with sandstones should have a relatively low Mg'/Mg ratio; those in equilibrium with dolomite should have higher ratios; and those in equilibrium with limestone should have the highest ratios. The average Mg'/Mg ratio for the Smackover brines studied is 7, which indicates that the brines were in equilibrium with limestone and dolomite. Previous studies (19-20) have shown that the average ratio in sandstones is about 2.5 and in limestones about 9.5.

The formation of chlorite from montmorillonite requires about 9.2 moles of MgO per mole of chlorite, as follows:

$$1.7\ Al_2O_3,\ 0.9\ MgO,\ 8SiO_2,\ 2H_2O + 9.2\ MgO + 6H_2O \longrightarrow$$

$$10.1\ MgO,\ 1.7\ Al_2O_3,\ 6.4\ SiO_2,\ 8H_2O + 1.6\ SiO_2\ (31,\ 39). \tag{9}$$

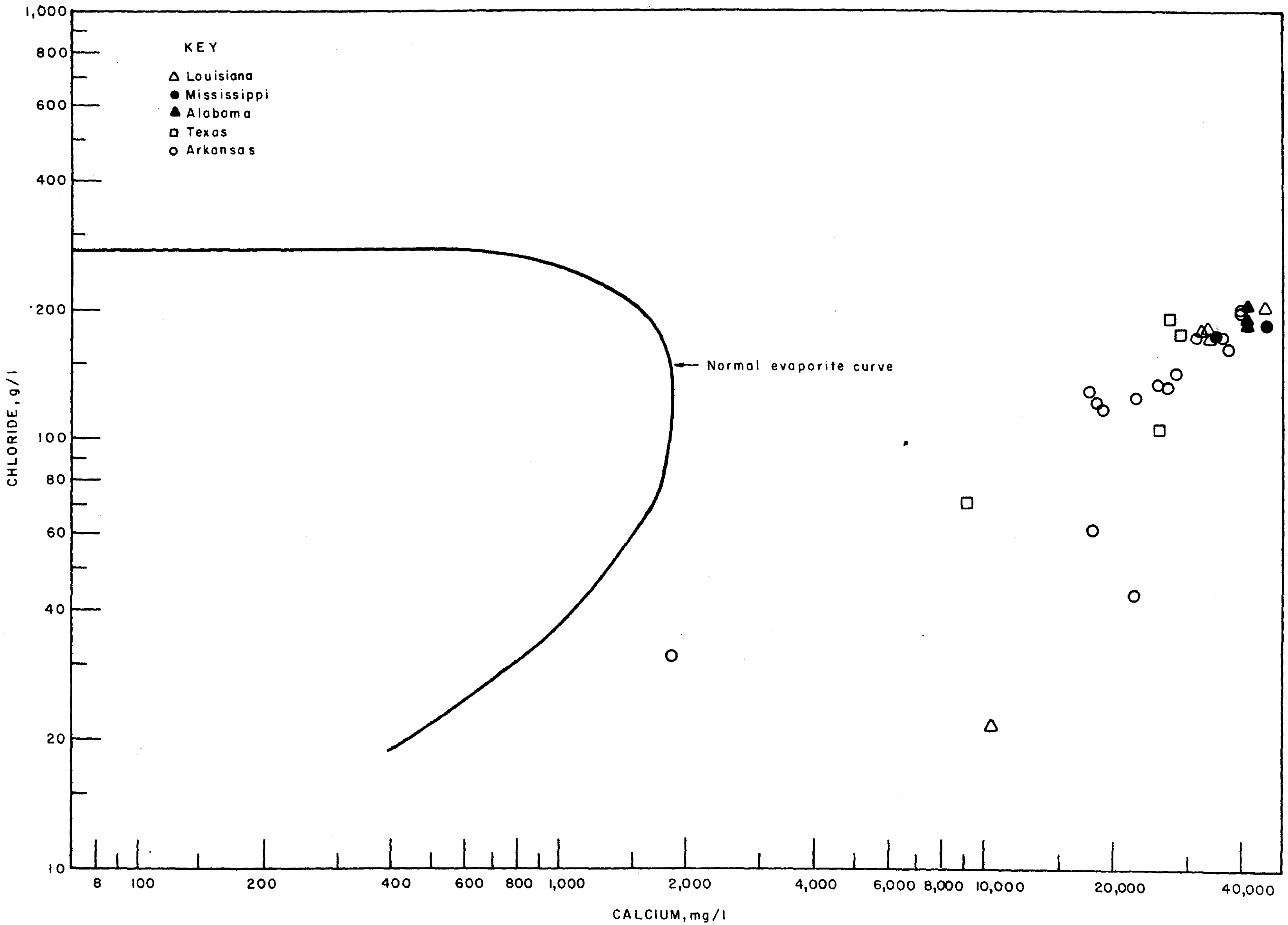

FIGURE 5. - Comparison of the chloride versus calcium concentrations of some Smackover oilfield brines to that of evaporating seawater.

Such a reaction can remove large amounts of magnesium from waters. Hiltabrand (39) has shown that contemporary argillaceous sediments can remove 100 mg/l of magnesium from seawaters.

As evaporites form, bromide is accommodated in the halite crystal lattice and replaces chloride in solid solution (10). The weight percentage of bromide in solid solution in the halite lattice is related to its weight percentage in the parent brine as

$$C = \frac{\text{wt-pct Br (in halite)}}{\text{wt-pct Br (in solution)}}, \tag{10}$$

where C is the partition coefficient. In most natural environments for halite, C = 0.14 (11).

The bromide relationships to chloride in saline deposition sequences are relatively constant. The relative weight proportion of bromide in halite, sylvite, carnallite, and bischofite of paragenetic crystallization is $1_{halite}:10\pm1_{sylvite}:7\pm1_{carnallite}:9\pm1_{bischofite}$ at 25° C, respectively. The bromide concentration within a given halite sequence theoretically should increase from the bottom to the top.

Bromide does not form its own minerals when seawater evaporates. Some of it is lost from solution because it forms an isomorphous admixture with chloride in the halite precipitate. However, more bromide is left in solution than is entrained in the precipitate. Therefore, relative to chloride, the bromide concentration in the brine increases exponentially. Because of this, the bromide concentration in the brine is a good indicator of the degree of seawater concentration, assuming that appreciable quantities of biogenic bromide have not been introduced.

Table 6 presents data obtained by comparing the average composition of the Smackover brines that were analyzed to seawater. The concentration ratio was calculated by taking the mean average for a given constituent in the Smackover brines and dividing it by the amount of the constituent found in normal seawater. The excess factor was determined by dividing the concentration ratio of a constituent by the concentration ratio of bromide. The calculation for Mg' or total equivalent magnesium was previously explained, and the number of Smackover samples indicates how many samples were used in the calculation. For example, 71 Smackover brines were analyzed for lithium, whereas 283 were analyzed for sodium.

The concentration ratios indicate that with the exception of sulfate, all of the determined constituents in the Smackover brines were enriched with respect to seawater. The excess factor ratios, however, indicate that sodium, potassium, magnesium, boron, chloride, sulfate, and total equivalent magnesium generally were depleted in the Smackover brines, while lithium, calcium, strontium, barium, copper, iron, manganese, and iodide were enriched. Furthermore, these ratios indicate that the Smackover brines have been altered considerably if it is assumed that they originally were seawater.

TABLE 6. - Concentration ratios and excess factor ratios for some constituents in Smackover brines

Constituent	Average composition, mg/l		Concentration ratio[1]	Excess factor[2]	Number of Smackover samples
	Seawater	Smackover brines			
Lithium.............	0.2	174	870	18.1	71
Sodium..............	10,600	66,973	6	.1	283
Potassium...........	380	2,841	8	.2	82
Calcium.............	400	34,534	86	1.8	284
Magnesium...........	1,300	3,465	3	.1	280
Strontium...........	8	1,924	241	5	85
Barium..............	.03	23	767	16	73
Boron...............	4.8	134	28	.6	71
Copper..............	.003	1.1	359	7.5	64
Iron................	.01	41	4,049	84.2	90
Manganese...........	.002	30	14,957	311	69
Chloride............	19,000	171,686	9	.2	284
Bromide.............	65	3,126	48	1	74
Iodide..............	.05	25	501	10.4	73
Sulfate.............	2,690	446	.2	.003	271
Mg'[3]...............	1,543	24,362	16	.3	284

[1]Amount in brine/amount in seawater.
[2]Concentration ratio of a given constituent/concentration of bromide.
[3]Mg' = (24.31/40.08) X mg/l calcium + mg/l magnesium.

The concentration ratio 48 for bromide is one of the highest we have seen. For example, bromide concentration ratios of 1.2, 4.4, 8.8, and 7.2 were found for brines from Tertiary, Cretaceous, Pennsylvanian, and Mississippian age rocks in previous studies (19-20). Figure 6 illustrates the enrichment of bromide in the Smackover brines relative to brine formed by evaporation of seawater.

Strontium is also enriched in the Smackover brines relative to seawater, as shown in figure 7 and table 6, and reactions that can aid in this are

$$2SrCO_3 + MgCl_2 \longrightarrow SrMg(CO_3)_2 + SrCl_2 \qquad (11)$$

and

$$SrMg(CO_3)_2 + MgCl_2 \longrightarrow 2MgCO_3 + SrCl_2. \qquad (12)$$

The concentration of potassium is depleted relative to seawater in some of the Smackover brines as indicated by the K/Br ratio and in figure 8. Some reactions of brines to form silicates that can account for the depletion of alkali metals are

$$3Al_2Si_2O_5(OH)_4 + 2K^+ \longrightarrow 2KAl_3Si_3O_{10}(OH)_2 + 3H_2O + 2H^+, \qquad (13)$$

$$KAl_3Si_3O_{10}(OH)_2 + 6SiO_2 + 2K^+ \longrightarrow 3KAlSi_3O_8 + 2H^+, \qquad (14)$$

and

$$Al_2Si_2O_5(OH)_4 + 4SiO_2 + 2Na^+ \longrightarrow 2NaAlSi_3O_8 + H_2O + 2H^+. \qquad (15)$$

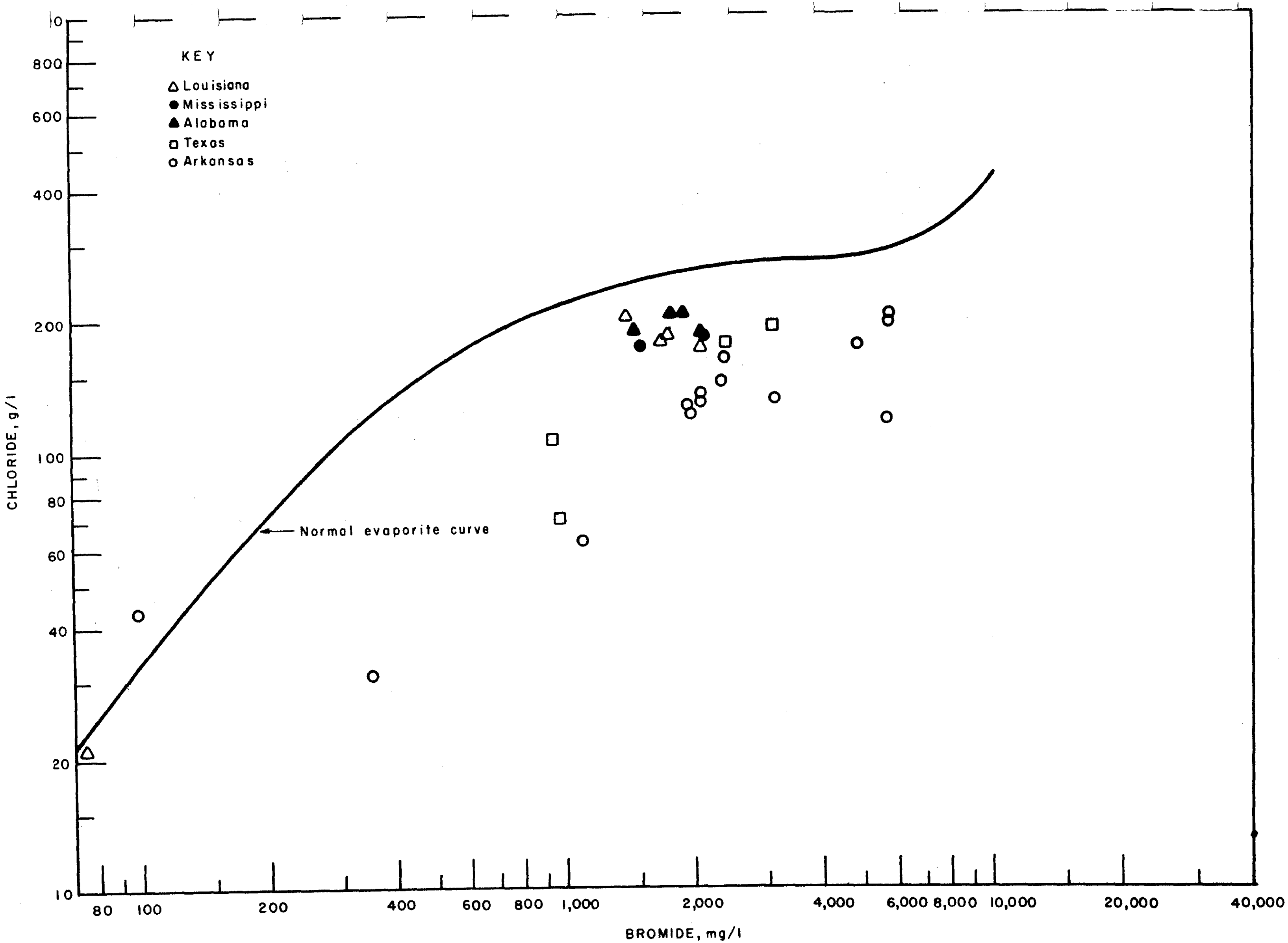

FIGURE 6. - Comparison of the chloride versus bromide concentrations of some Smackover oilfield brines to that of evaporating seawater.

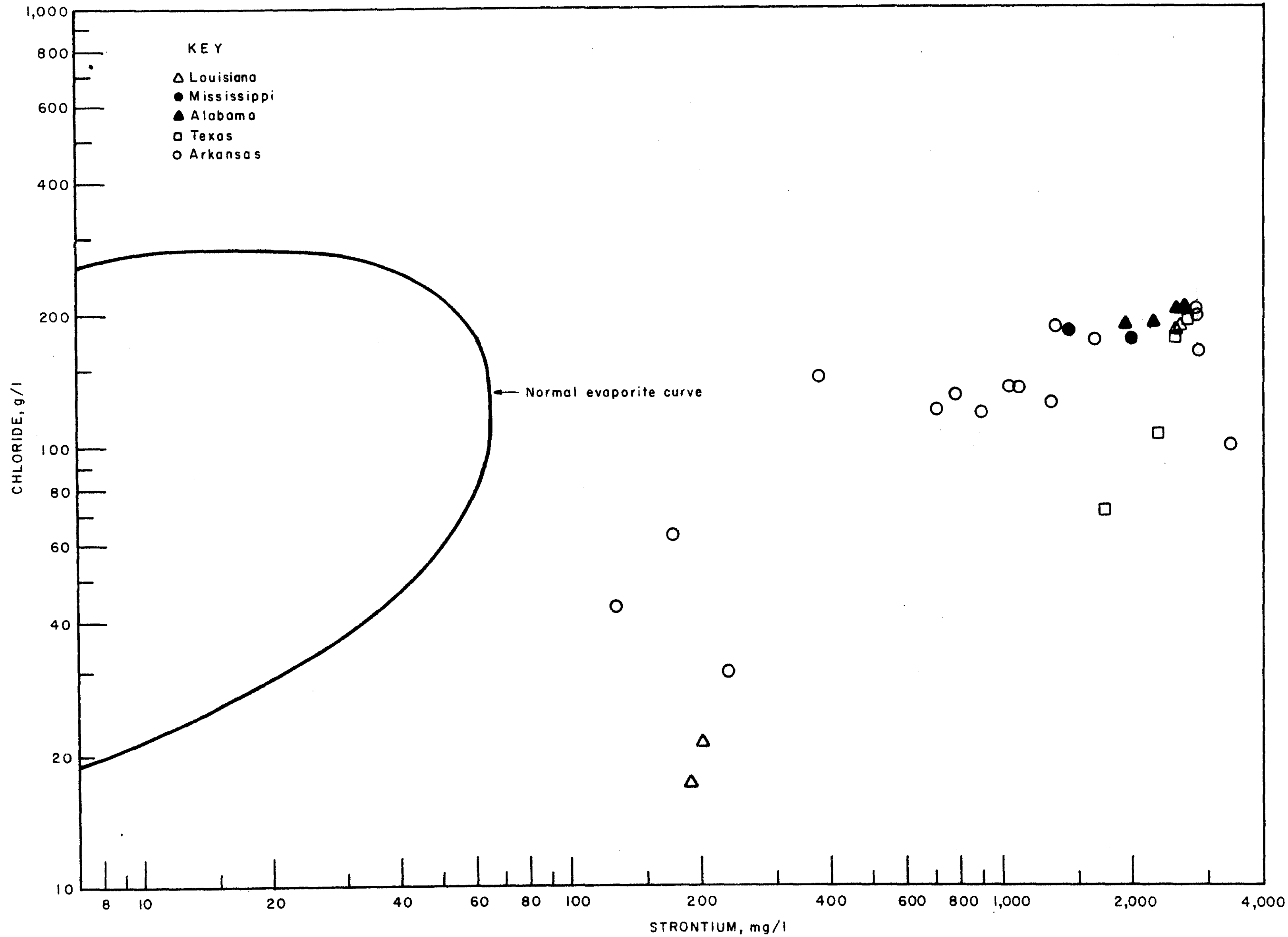

FIGURE 7. - Comparison of the chloride versus strontium concentrations of some Smackover oilfield brines to that of evaporating seawater.

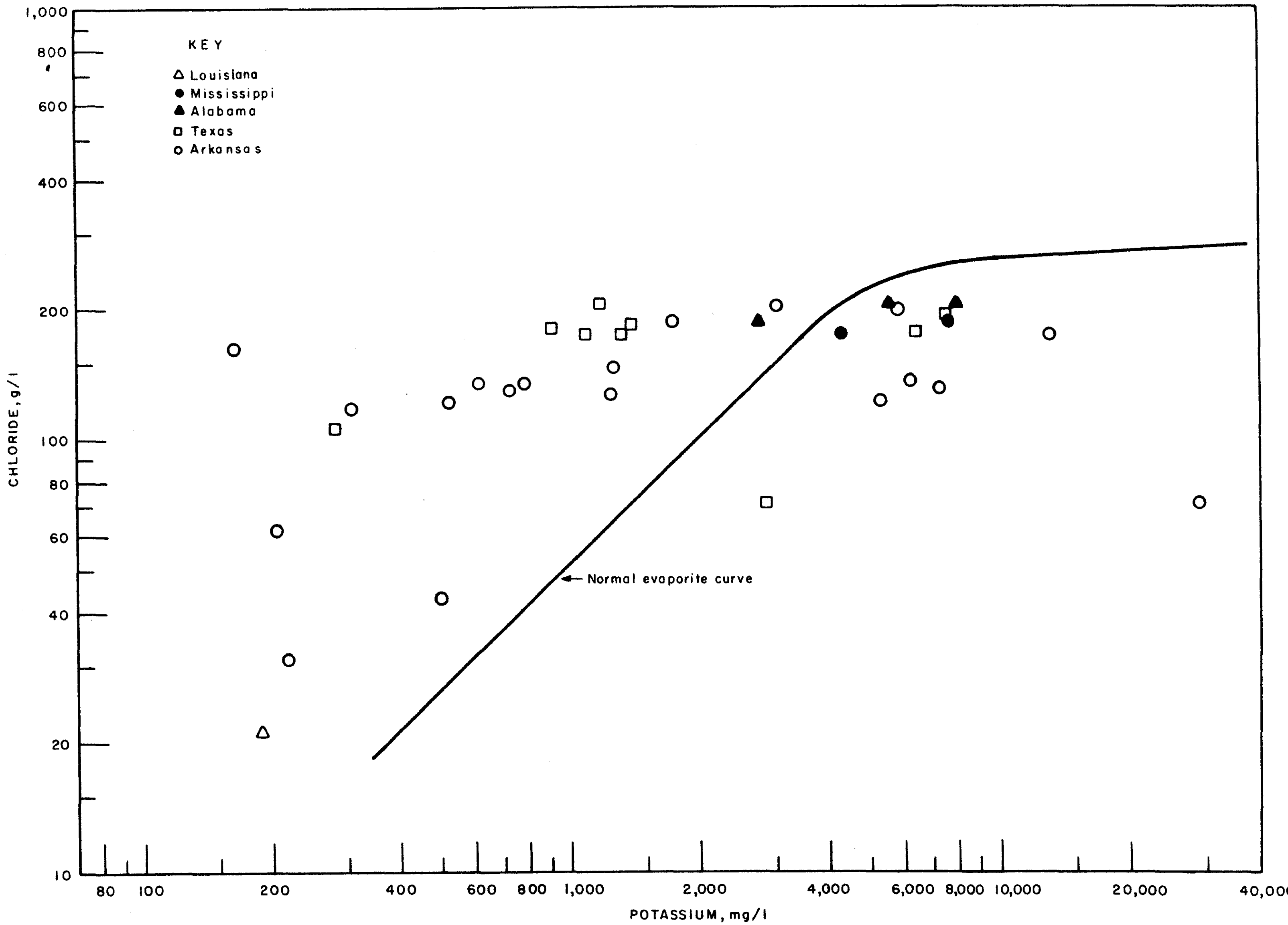

FIGURE 8. - Comparison of the chloride versus potassium concentrations of some Smackover oilfield brines to that of evaporating seawater.

These reactions can account not only for the depletion of potassium or sodium, but also for a decrease in pH because of the release of hydrogen ions. The decrease in pH enables the waters to dissolve metallic metals, to convert bicarbonate to carbon dioxide, or to convert bisulfide to hydrogen sulfide. The Smackover brines often contain relatively high concentrations of hydrogen sulfide.

Exchange Reactions

Figure 5 indicates that calcium is enriched relative to the normal evaporite curve in all of the Smackover waters. In addition to the dolomitization reaction, cation exchange reactions with clays can account for some of this enrichment:

$$2Na^{+}(\text{solution}) + Ca(\text{clay}) \longrightarrow Ca^{+2}(\text{solution}) + 2Na(\text{clay}). \qquad (16)$$

This type of reaction also can help explain the sodium depletion relative to normal evaporite associated water, as shown in figure 9.

Kozin (57) wrote about a "reverse" exchange of anions when the cations exchange on clays:

$$Cl^{-}(\text{solution}) + Br(\text{clays}) \longrightarrow Br^{-}(\text{solution} + Cl(\text{clay}). \qquad (17)$$

Such a reaction can account for some of the bromide enrichment in the Smackover brines, as illustrated in figure 6. A similar reaction for iodide,

$$Cl^{-}(\text{solution}) + I(\text{clay}) \longrightarrow I^{-}(\text{solution}) + Cl(\text{clay}), \qquad (18)$$

can help explain the enrichment of iodide in the brines shown in figure 10.

Krejci-Graf (58) believes that solutions predominantly concentrated in chloride can force an exchange of calcium and bromide from clay minerals for sodium and chloride from the solution. This type of reaction may have occurred in the Smackover brines and can explain their enrichment of calcium and bromide, as illustrated in figures 5 and 6. Collins and Egleson (24) postulated that the adsorption of iodide by clays is decreased in the presence of concentrated brines containing high concentrations of calcium chloride and organic acid salts. This can account for some of the tremendous enrichment of iodide in the Smackover brines illustrated in figure 10.

Table 7 contains data concerning the radii of the nonhydrated ions, of the hydrated ions, the ionic potential, and the polarization of the brine constituents. The size of the ions is of interest concerning the mobilities or the relative transport coefficient of a given ion through a clay/shale membrane system or the replacement coefficient in a clay ion-exchange system. The ionic potential is of interest because elements with low ionic potentials are the most likely to remain in true solution. The polarization, which is equivalent to the valency divided by the ion radius, is of interest because the larger the polarization the lower the replacing power in an exchange system.

TABLE 7. - Radii, valence, ionic potentials, and polarization of Smackover brine constituents[1]

Constituent	Nonhydrated radius, A	Valence	Hydrated radius, A	Ionic potential	Polarization
Lithium.............	0.60	+1	3.82	0.60	1.67
Sodium..............	.65	+1	3.58	.95	1.05
Potassium...........	1.33	+1	3.31	1.33	.75
Calcium.............	.99	+2	4.12	.50	2.02
Magnesium...........	.65	+2	4.28	.33	3.08
Strontium...........	1.13	+2	4.12	.57	1.77
Barium..............	1.35	+2	4.04	.68	1.48
Boron...............	.23	+3	-	.08	-
Chloride............	1.81	-1	3.32	1.81	.55
Bromide.............	1.95	-1	3.30	1.95	.51
Iodide..............	2.16	-1	3.31	2.16	.46
Sulfate.............	2.90	-2	3.79	1.45	.69

[1]See reference 65.

The lithium concentration is enriched relative to the normal evaporite curve in all of the Smackover brines (fig. 11). In fact, lithium concentrations in excess of 200 mg/l are evident in some of the samples from east Texas and west Arkansas. These concentrations may be the highest on record in an oilfield water.

It can be postulated that lithium enrichment results at least in part from exchange reaction on clays. Lithium has a small radius, a low atomic number, a larger hydrated radius than sodium, and a larger polarization than sodium (table 7). Because of these factors, its replacing power in the lattices of clay minerals is low (56). Other ions, such as barium, strontium, calcium, magnesium, cesium, rubidium, potassium, and sodium, will preferentially replace lithium in clay minerals, thus releasing lithium to solutions. Furthermore, the solubility products of most lithium compounds are higher than those of other alkalies and alkaline earths. Therefore lithium tends to stay in solution.

According to Grim (37), the replacing power of some ions in clays is as follows:

1. In NH_4, kaolinite:

$$Cs > Rb > K > Ba > Sr > Ca > Mg > H > Na > Li;$$

2. In NH_4, montmorillonite:

$$Cs > Rb > K > H > Sr > Ba > Mg > Ca > Na > Li.$$

These two clays often are present in sedimentary rocks, and the replacing order could account for the lithium enrichment in solutions.

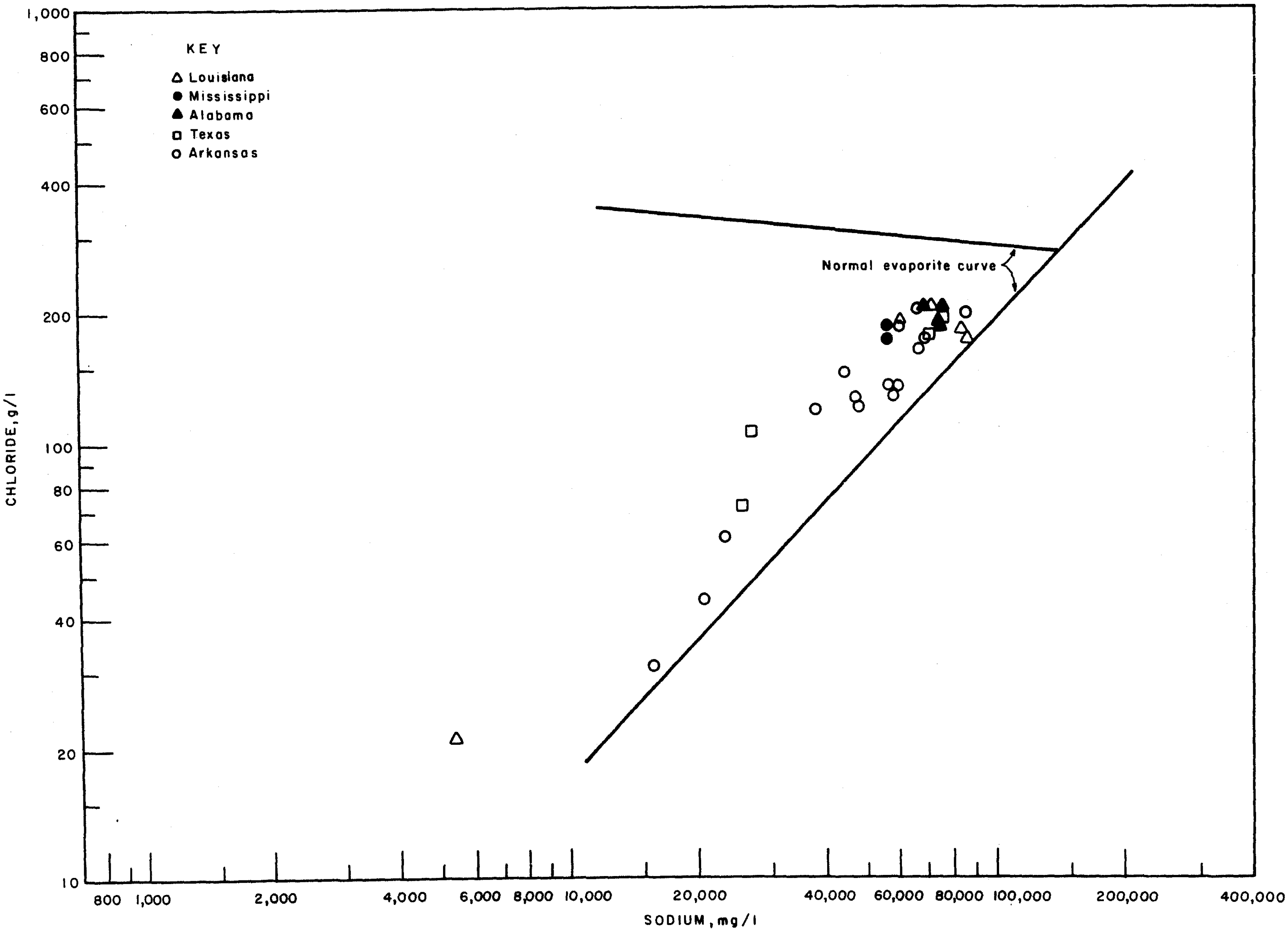

FIGURE 9. - Comparison of the chloride versus sodium concentrations of some Smackover oilfield brines to that of evaporating seawater.

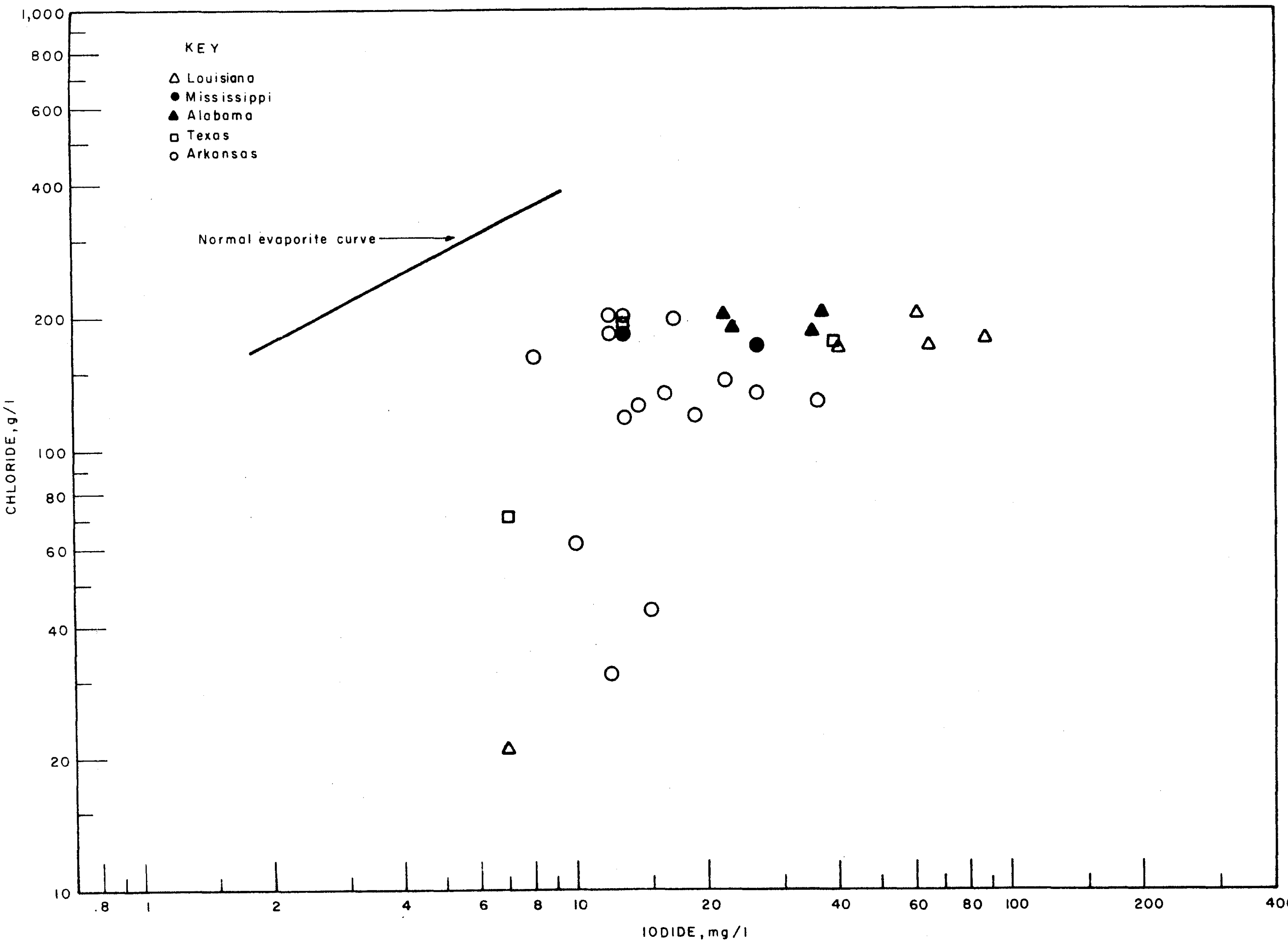

FIGURE 10. - Comparison of the chloride versus iodide concentrations of some Smackover oilfield brines to that of evaporating seawater.

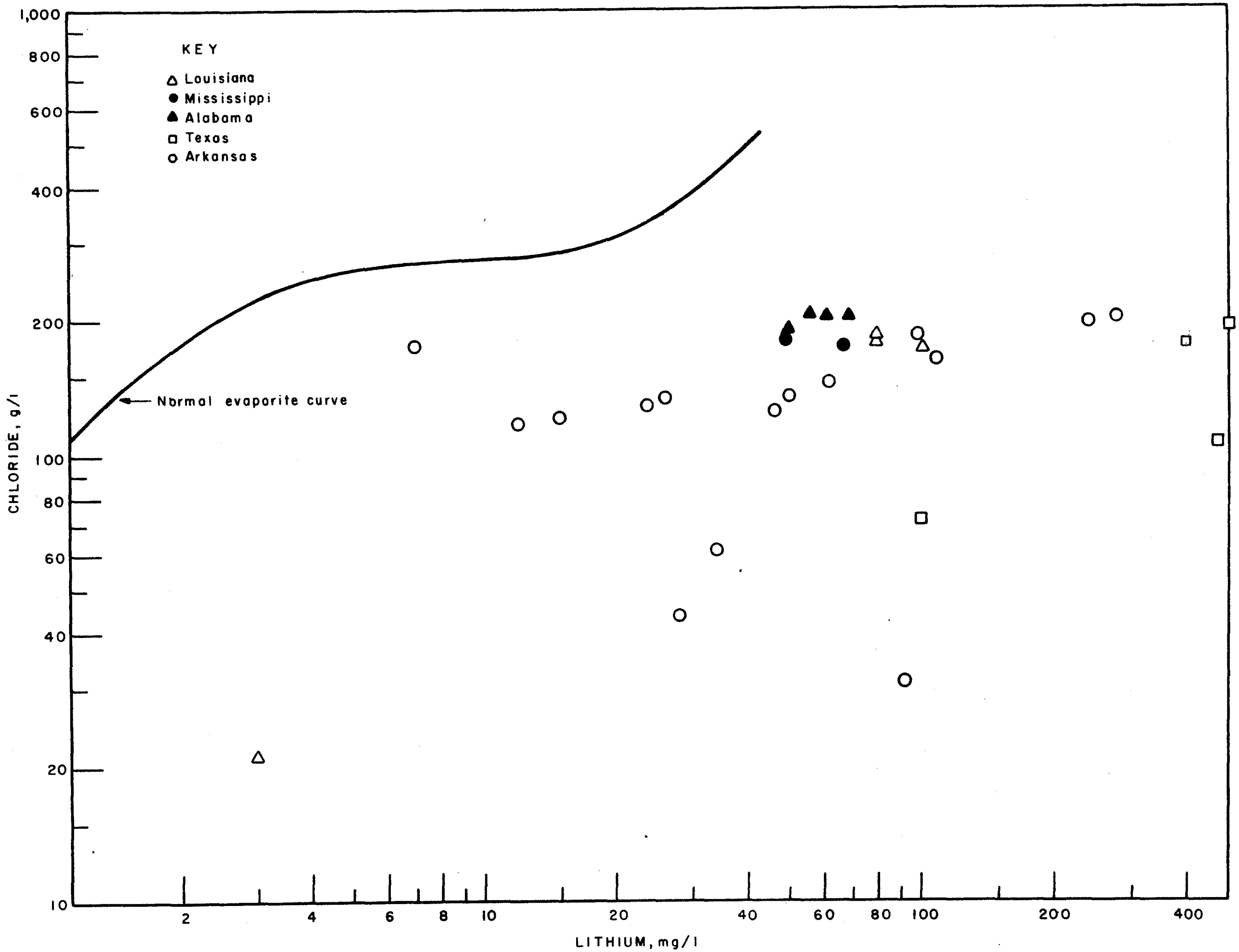

FIGURE 11. - Comparison of the chloride versus lithium concentrations of some Smackover oilfield brines to that of evaporating seawater.

Boron also usually is enriched relative to the normal evaporite curve in the Smackover brines, as shown in figure 12. Table 7 shows that it, like lithium, has a small radius, a low atomic number, and a large polarization; therefore, its replacing power in the lattices of clay minerals is low. Furthermore, boron does not have a tendency to enter silicate lattices of the common rock-forming minerals, and because of this, boron usually remains in solution until late-stage crystallization.

The data in table 6 and the plots shown in figures 4 through 12 indicate that the Smackover brines have been altered considerably with respect to a brine formed only by the evaporation of seawater. If the Smackover brine were the result of concentration by membrane filtration, it would appear that the ions in the brine should follow the concentration order of ions formed in systems subjected to osmosis or reverse osmosis.

Membrane-Concentrated Brines

Essentially, the postulate that clays and shales act as membranes to filter dissolved solids from waters results from the fact that synthetic membranes are used to desalinate waters by reverse osmosis. Conceivably, compacted clays and shales may perform as imperfect semipermeable membranes. Solutions of salts of different concentrations separated by a semipermeable membrane will cause water from the lower salt concentration side to move through the membrane to the higher concentration side, producing a greater pressure on the high concentration side. The pressure differential is the osmotic pressure of the system and can account for abnormal pressures found in some reservoirs.

Reverse osmosis occurs when hydraulic pressure in excess of the osmotic pressure is applied to the high concentration side, which forces water through the membrane to the low concentration side. The system is not 100 percent effective, and some dissolved solids move through the membrane.

Such a system requires rather high pressure differentials in nature to produce the highly concentrated brines found in some formations. The osmotic pressure could produce pressure differentials in formations, but the pressure comes to equilibrium as the two solutions equilibrate. The reverse osmosis system works only as long as the excess hydraulic pressure is applied. In the absence of the excess hydraulic pressure, the system comes to equilibrium.

Larson (60) reported some desalination results for waters with reverse osmosis using cellulose-acetate membranes. With a brackish water containing about 4,300 mg/l of dissolved solids, input pressure of 600 psi, and temperature of 15.9° C, the ion-injection rates were as high as 99.9 percent. The rejection order based on the percent rejected was

$$Ca^{+2} + Mg^{+2} > HCO_3^{-2} + SO_4^{-2} > Cl^- > Na+ > NO_3^-.$$

Assuming that this mechanism operates in a shale filtration system, the order of ion concentrations on the high-brine-concentration side would be the same.

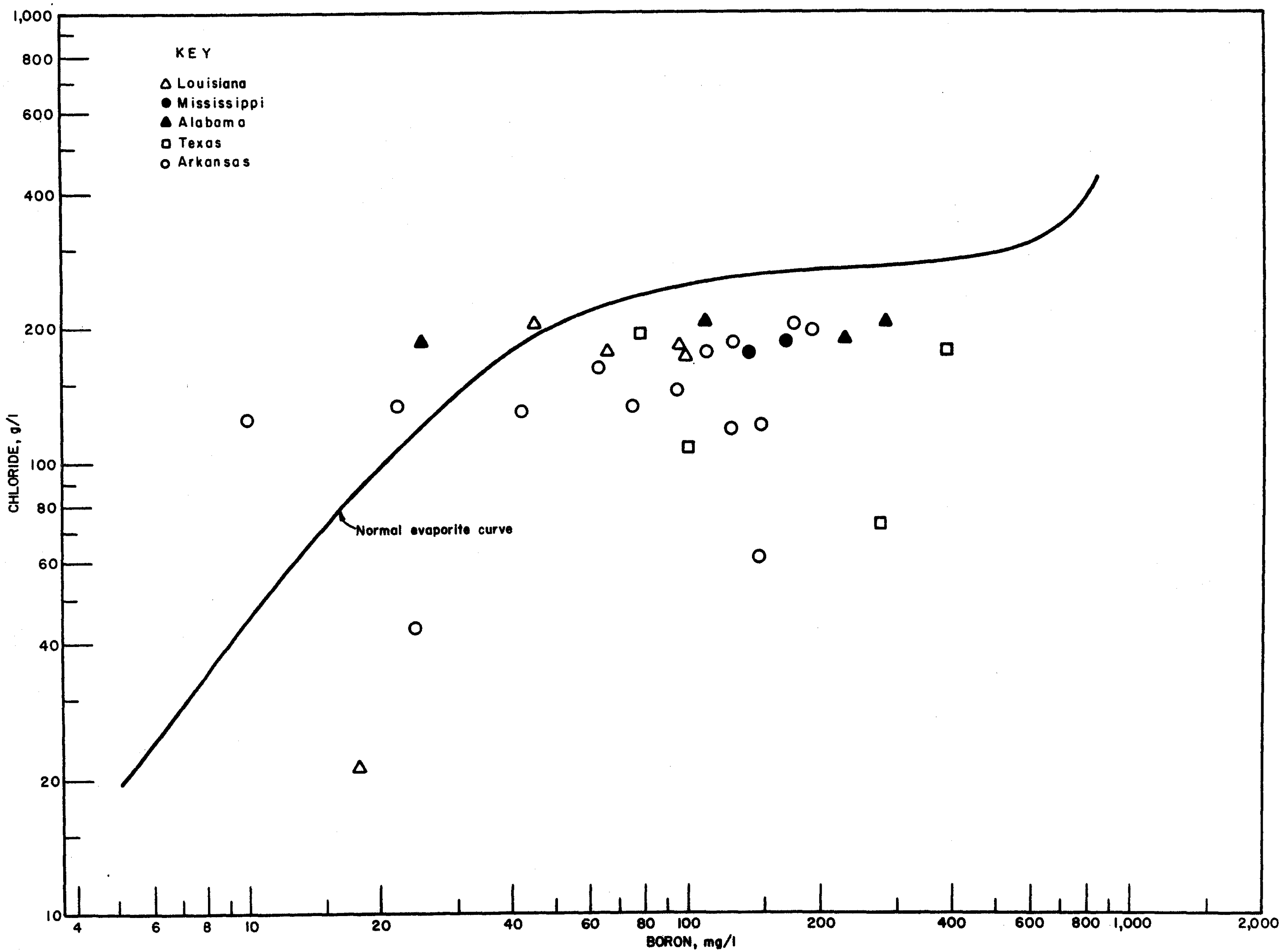

FIGURE 12. - Comparison of the chloride versus boron concentrations of some Smackover oilfield brines to that of evaporating seawater.

The ion concentrations on the fresher water side would be the reverse, or

$$NO_3^- > Na^+ > Cl^- > SO_4^{-2} + HCO_3^{-2} > Ca^{+2} + Mg^{+2}.$$

Other investigations have obtained similar results. For example, Loeb and Manjikian (61) found a rejection order of

$$SO_4^{-2} > Mg^{+2} > Ca^{+2} > Na^+ > HCO_3^- > Cl^- > NO_3.$$

Michaels (63) found a rejection order of $Ca^{+2} > Li^+ > Na^+ > K^+$ for the pressure independent portion of salt transport in cellulose acetate reverse-osmosis desalination membranes. This correlates with the size of the hydrated ion radii (table 7) because calcium is the largest and potassium, the smallest. Further, this indicates that the pore size of the membrane is a controlling factor.

The data of Larson (60) showed that sulfate and carbonate scale formed on the high-pressure side of the membrane and if not removed would cause flow to decrease or stop. The pH on the output or fresh-water side of the membrane decreased.

Berry (5) postulated that the selectivity of hyperfiltration for the halogens is Cl > Br > I > F, and in water thus concentrated, the Ca/Na, Na/Li, Sr/Ca, Cl/Br, Br/I, and I/F ratios should increase. Using the data in table 6, we calculated the ratios in table 8.

TABLE 8. - Comparison of the ratios of some constituents in seawater to the average ratios found for the Smackover brines

Ratio	Seawater	Smackover brine
Ca/Na........................	0.038	0.516
Na/Li........................	53,000	385
Sr/Ca........................	.02	.056
Cl/Br........................	292	55
Br/I........................	1,300	125

The ratios shown in table 8 indicate that the Ca/Na ratio and the Sr/Ca ratio did increase in the Smackover brine compared to seawater. However, the ratios Na/Li, Cl/Br, and Br/I decreased--some quite significantly. Therefore, it might be reasoned that the Smackover brines might not owe their origin to hyperfiltration.

Billings (6) found a membrane-concentrated brine with a relative concentration pattern of Rb > K > Na > Li. The data in table 6 indicate that the Smackover concentration pattern is Li > K > Na, giving further weight to the possibility that they do not owe their origin entirely to membrane filtration.

Figure 13 shows how the concentrations of calcium and sodium in the Smackover brines compare with the concentrations of calcium and sodium in some altered relict bitterns. The sodium and calcium concentrations in the

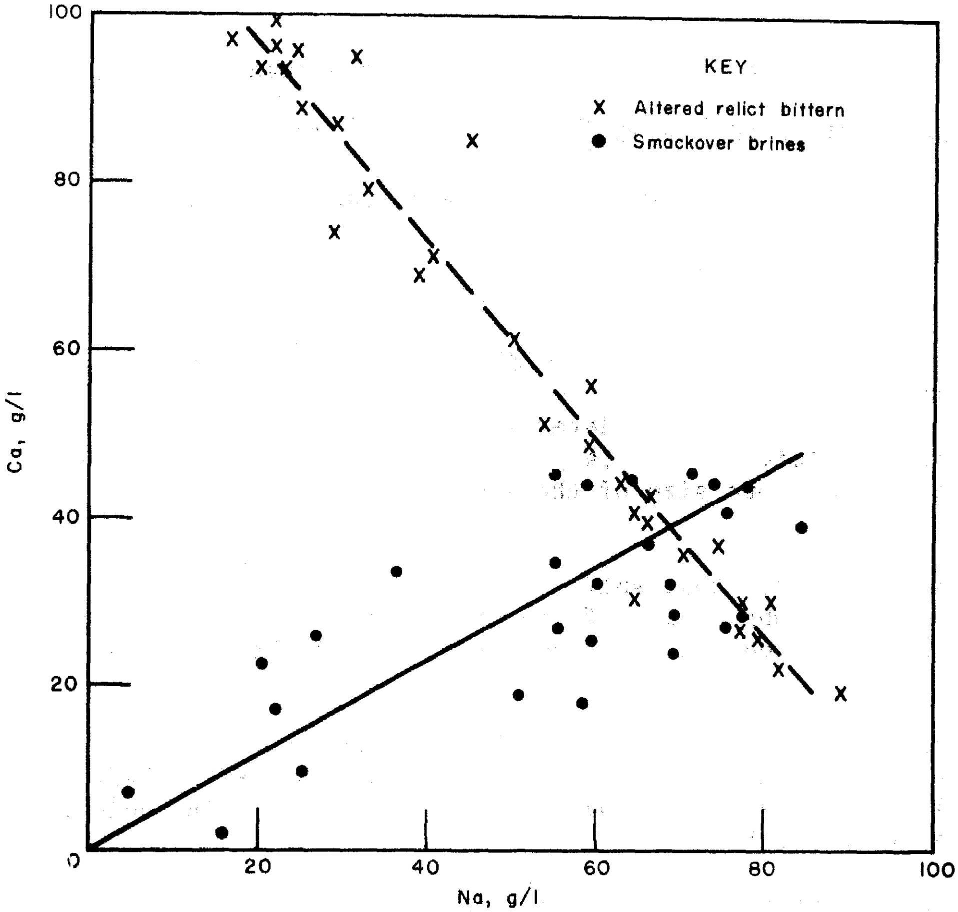

FIGURE 13. - Comparison of calcium and sodium concentrations of some Smackover brines to those of some altered relict bitterns.

bitterns are dependent upon the solubilities of their respective compounds, and the plot in figure 13 is indicative of this. In contrast, the calcium concentration increases as the sodium concentration increases in the Smackover brines (fig. 13), which indicates that the increased calcium probably results from cation exchange or perhaps mineral formation.

Figure 14 is a plot of Na' versus Br for the Smackover brines, an altered relict bittern, evaporating seawater, and evaporite salt dissolved in water. The $\text{Na}' = \text{mg/l Na} + \frac{46}{40}\,\text{mg/l Ca}$ because in an exchange reaction, 2 moles of sodium are exchanged for 1 mole of calcium. The assumption is that the sodium in the brine exchanges for calcium in the clay thus increasing the calcium concentration in the brine. Na' plotted versus Br because the bromide concentration should be proportional to the amount of salt redissolved. The Smackover brines contain some iodide, which indicates bioconcentration; therefore, some biogenic bromide is present and this accounts for some of the point scatter.

The plots on figure 14 indicate that the Smackover brine is altered relative to evaporated seawater; however, it appears to be an alteration that differs from the altered relict bittern. The high bromide content in the Smackover brines indicates that the Smackover brines may have reached the bittern state at one or more times. However, it is possible that biogenic bromide may account for the higher bromide concentrations. Some of the Smackover samples obviously were diluted by fresh water; that is, those that fall to the left of the evaporating seawater line.

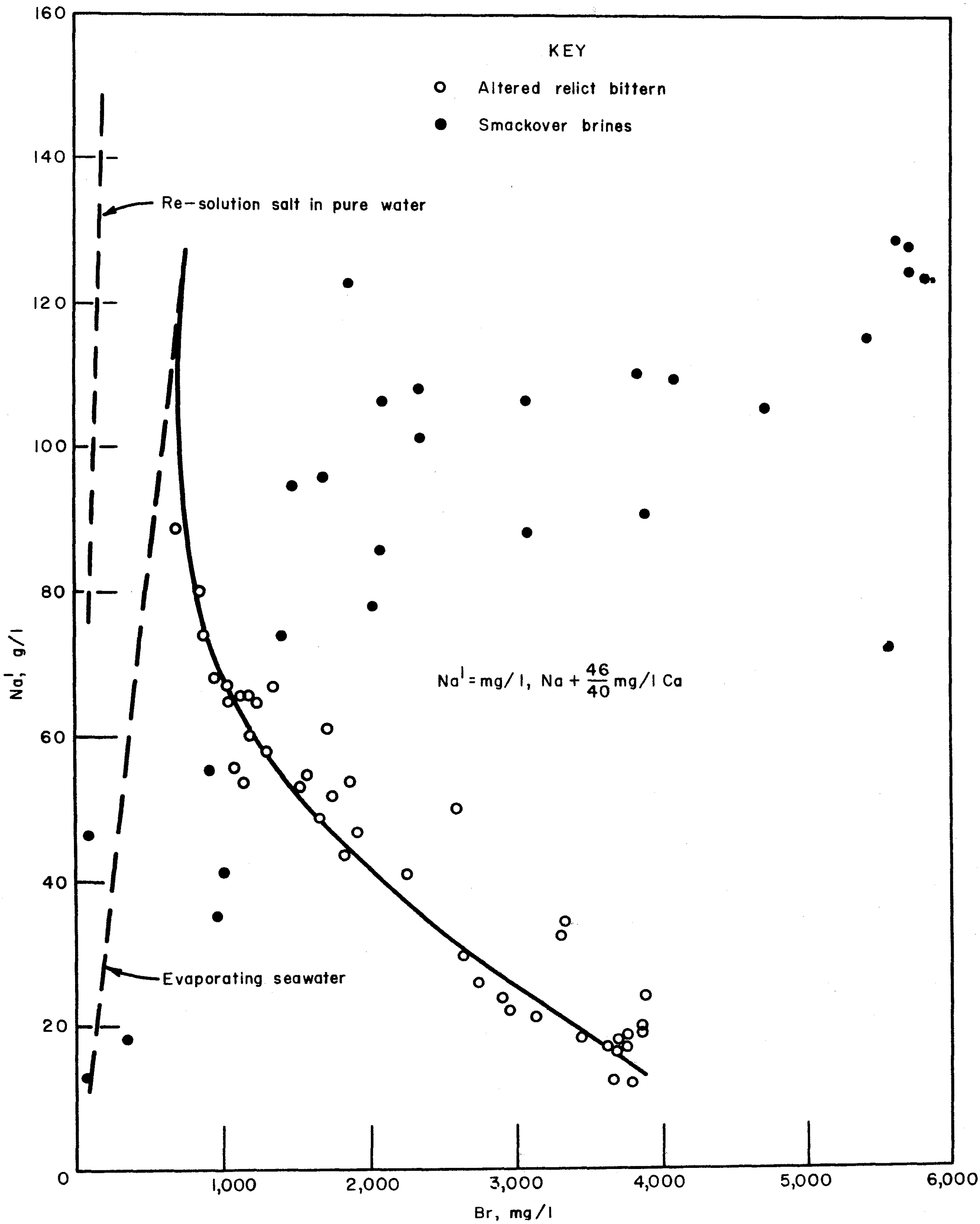

FIGURE 14. - Comparison of Na' and Br concentrations of some Smackover brines to those of an altered relict bittern, evaporating seawater, and redissolved salt.

The concentration of Na' decreases as the Br increases in the altered relict bittern, whereas the reverse is characteristic of the Smackover brines. It is therefore postulated that the Smackover brine is an altered seawater that has at one or more times approached or reached the bittern stage. Probably bitterns from the Louann salt mixed with the Smackover brines; however, this study provides no proof of this.

LOUANN SALT

A sample of Louann salt was obtained from the Kerlin field, Columbia County, Ark., and analyzed for sodium, potassium, lithium, calcium, magnesium, barium, strontium, iron, manganese, zinc, copper, chloride, bromide, iodide, and sulfate. The amount of salt available was limited; however, the analyses were made with techniques which should produce high degrees of confidence. The only exceptions were the techniques used to determine iodide and bromide. Wet-chemical methods were used to determine these two anions, and the general method is highly reliable; however, because of the small sample size, it was impossible to take detailed precautions to insure that all of the possible interferences were removed, or to take several replicate samples. Atomic absorption methods were used to determine all of the cations. The analytical results are shown in table 9.

Plots were made of the concentrations of the constituents found versus depth. Figure 15 illustrates a plot for chloride, sodium, sulfate, and calcium. The curves show a tendency for parallel codeposition of chloride, sodium, and sulfate. The calcium curve from 10,000 feet to about 9,900 feet appears independent and probably is related to deposition of calcium carbonate; however, above 9,900 feet it parallels the sulfate curve.

Figure 16 illustrates the concentrations of magnesium, iron, barium, strontium, and calcium in the Louann salt versus stratigraphic depth. The curves indicate that codeposition of all of these elements occurred as the Louann formed, except for calcium during the early stages and also to some extent for strontium. Again the heavier deposition of calcium during the early precipitation from the Louann sea probably was as the carbonate. Iron carbonate is less soluble than calcium carbonate, and if the Louann sea contained a sufficiently high concentration of it during the early stages of deposition, it should more closely follow the calcium deposition. The fact that the amount of barium deposition peaked twice and then decreased to about 20 ppm is interesting. None of the anions gave a similar curve; it is quite likely that all of the barium deposited as the sulfate.

TABLE 9. - Analyses of some samples of Louann salt[1/]

Depth, feet	Amount soluble, ppm of original salt														Relative amount insoluble
	2/ Na	K	Li	Ca	Mg	Ba	Sr	Fe	Mn	Zn	Cu	3/ Cl	3/ Br	3/ I	2/ SO_4	
9,370- 9,380	390,000	259	<0.4	379	174	20.3	20.1	12.0	4.1	12.6	2.7	662,000	80	31	1,430	Small.
9,380- 9,390	384,000	382	<.4	317	153	20.1	2.1	14.5	4.8	14.0	2.4	599,000	378	0	3,220	Do.
9,390- 9,400	380,000	744	<.4	239	120	14.4	1.4	7.8	4.1	11.0	2.6	612,000	322	8	3,150	Do.
9,960- 9,980	376,000	29.2	<.4	252	76.7	768	17.3	8.1	4.9	9.4	2.5	633,000	144	0	3,280	Do.
9,980-10,000	390,000	35.4	<.4	546	56.1	385	10.5	11.9	4.3	11.0	2.6	618,000	327	0	3,880	Do.
10,040-10,060	316,000	66.5	<.4	340	826	516	267	713	38.8	44.4	5.4	550,000	405	23	833	Medium.
10,420-10,440	319,000	46.5	<.4	330	439	121	191	314	24.6	33.5	3.5	496,000	105	43	650	Do.
10,680-10,700	385,000	51.9	<.4	580	314	67.0	72.0	155	157	26.8	3.1	602,000	213	0	1,870	Small.

1/ Sample 141 from Kerlin field, Columbia County, Ark., Calvert SWD, 33-17S-20W, Latitude 331300, Longitude 0931100. The amount of sample available was limited, therefore duplicate analyses were not made for all constituents. A stoichiometric balance was not obtained for all of the samples. Possibly this was caused because separate portions were used for the various constituents; furthermore, the sample may not have been completely homogeneous.

2/ Cations and sulfate salt dissolved in 1:5 HCl for analysis.

3/ Halides-salt dissolved in distilled water for analysis.

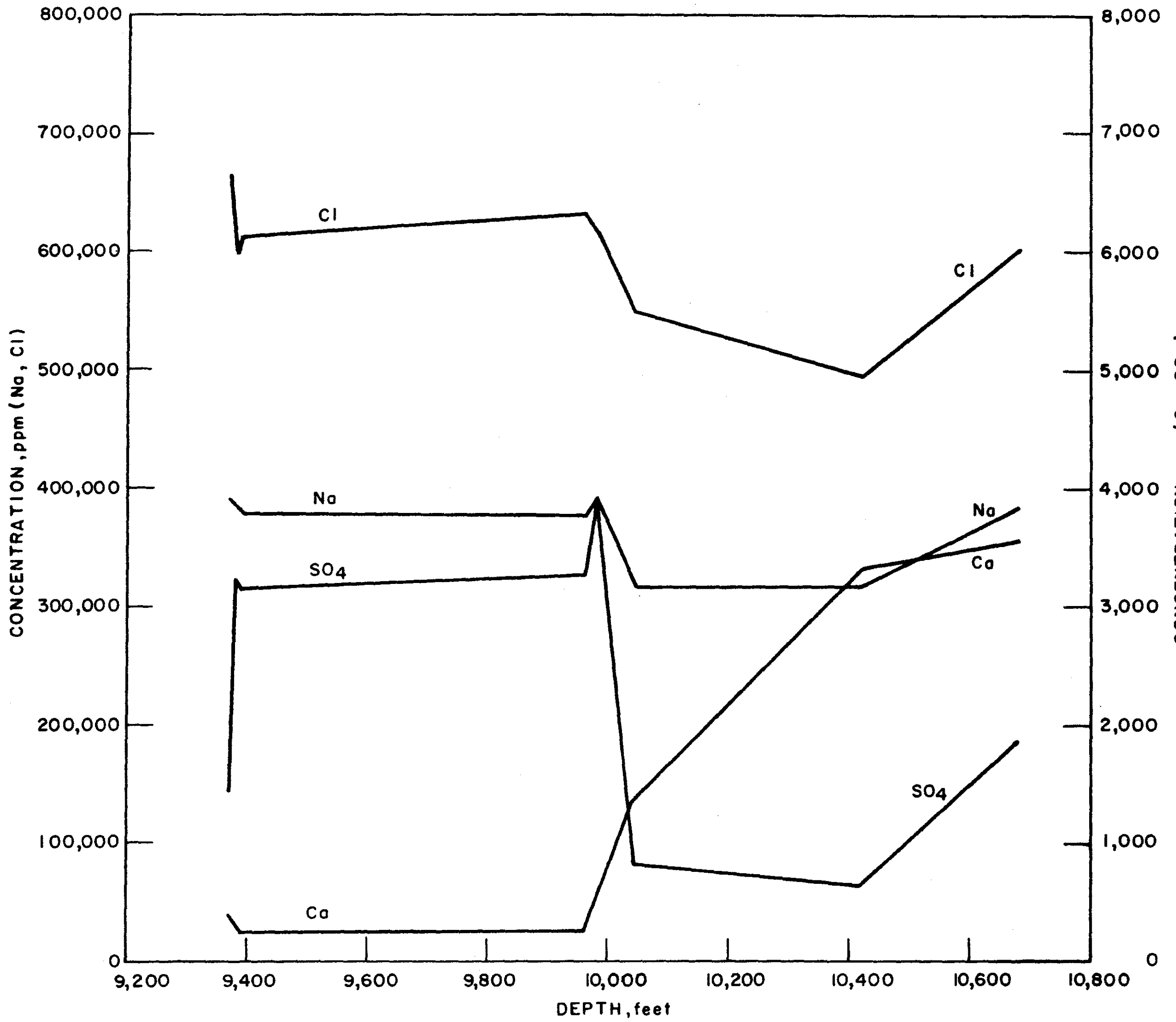

FIGURE 15. - Concentrations of sodium, chloride, calcium, and sulfate found in the Louann salt versus depth.

Figure 17 illustrates the concentration of magnesium, zinc, copper, iodide, and manganese in the Louann salt versus stratigraphic depth. The deposition of zinc parallels not only that of magnesium but also that of iron, barium, and strontium, as shown in figure 16. The deposition of copper, iodine, and manganese appears to be independent until the 10,000-foot level is reached. Manganese could have precipitated as the carbonate during the early stages of deposition, and it, along with copper, probably precipitated as sulfur compounds during the later stages. The iodide values go to zero several times and this could be related to oxidation or no deposition.

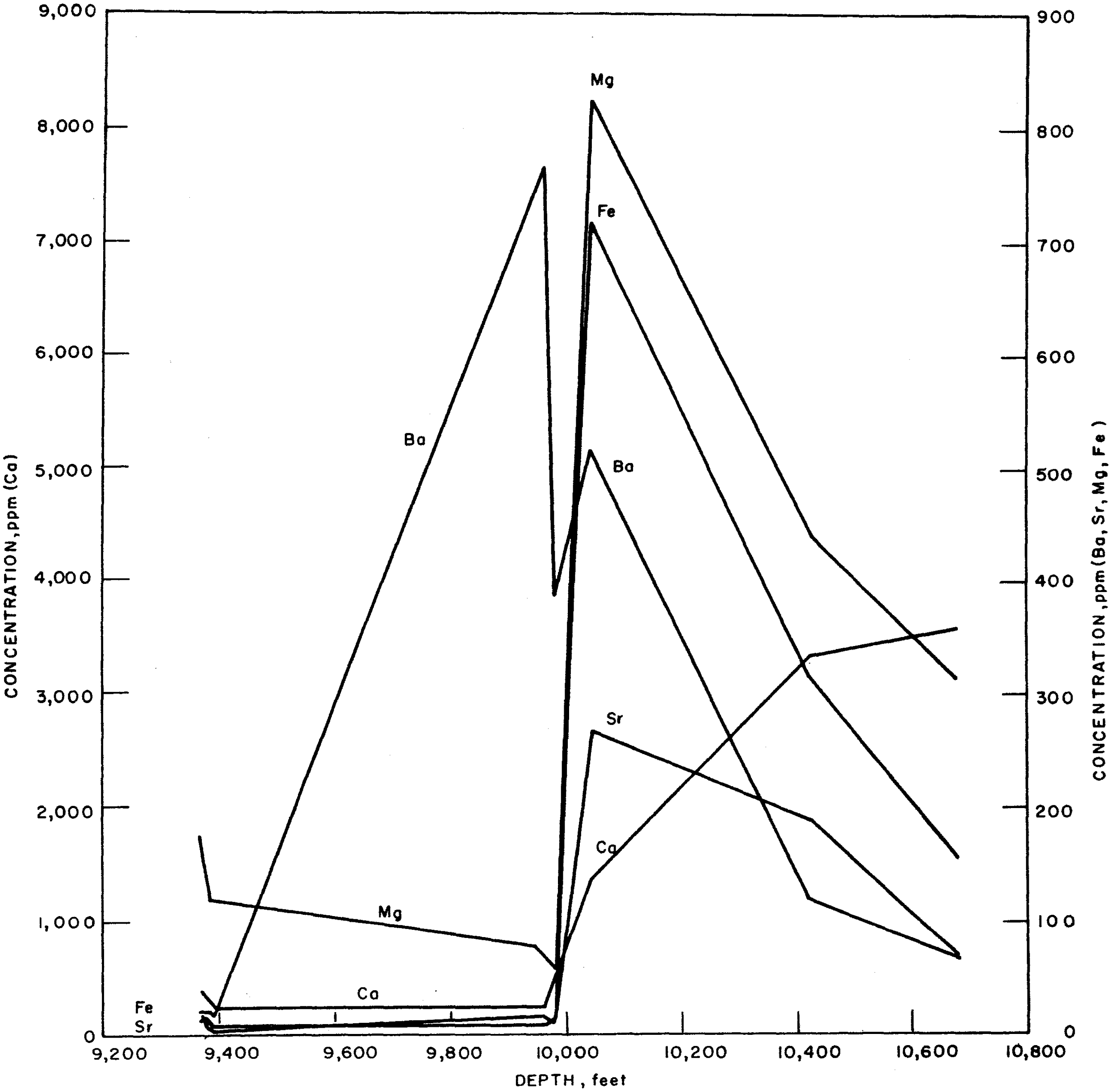

FIGURE 16. - Concentrations of calcium, barium, strontium, magnesium, and iron found in the Louann salt versus depth.

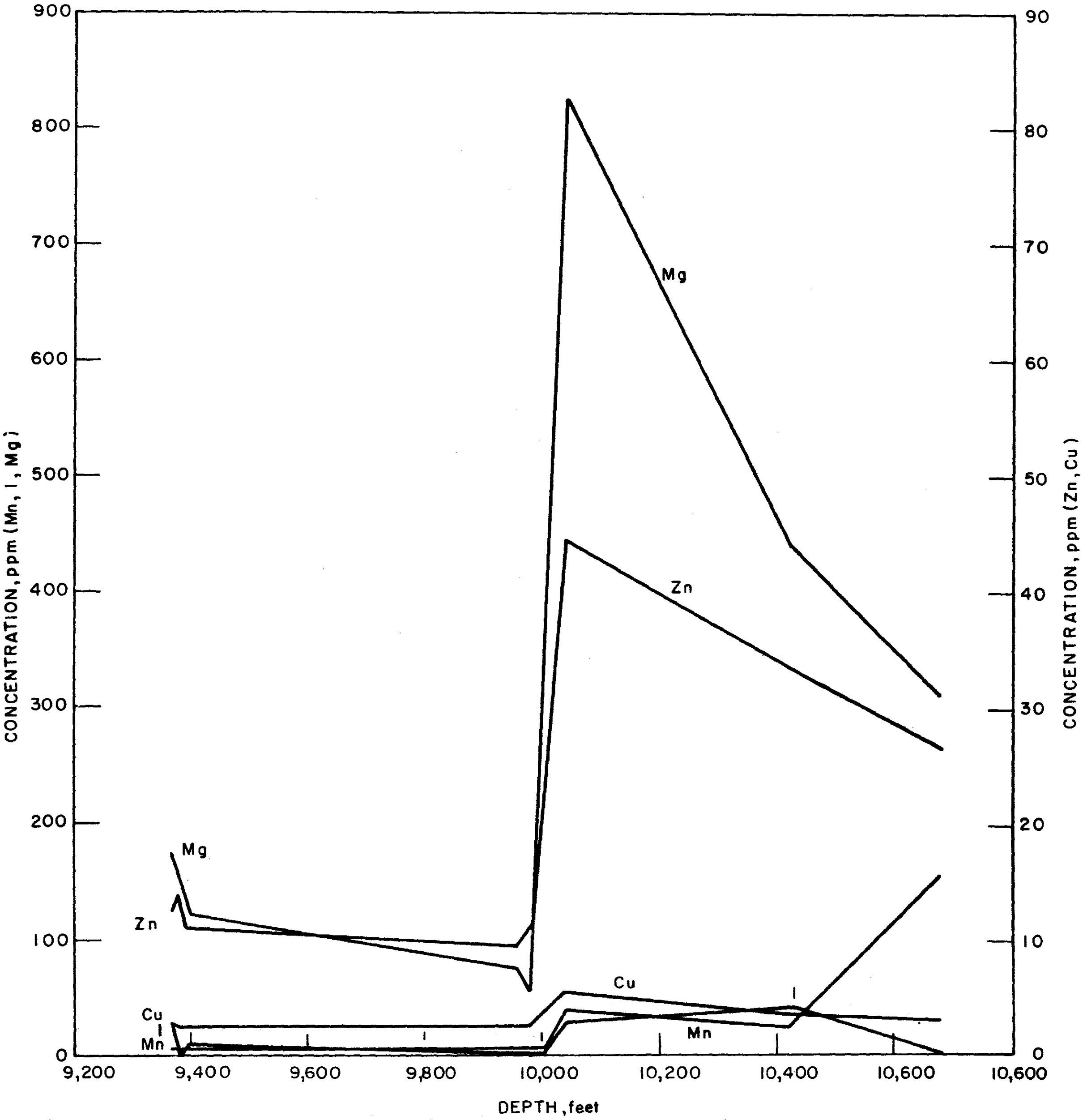

FIGURE 17. - Concentrations of manganese, magnesium, zinc, copper, and iodine found in the Louann salt versus depth.

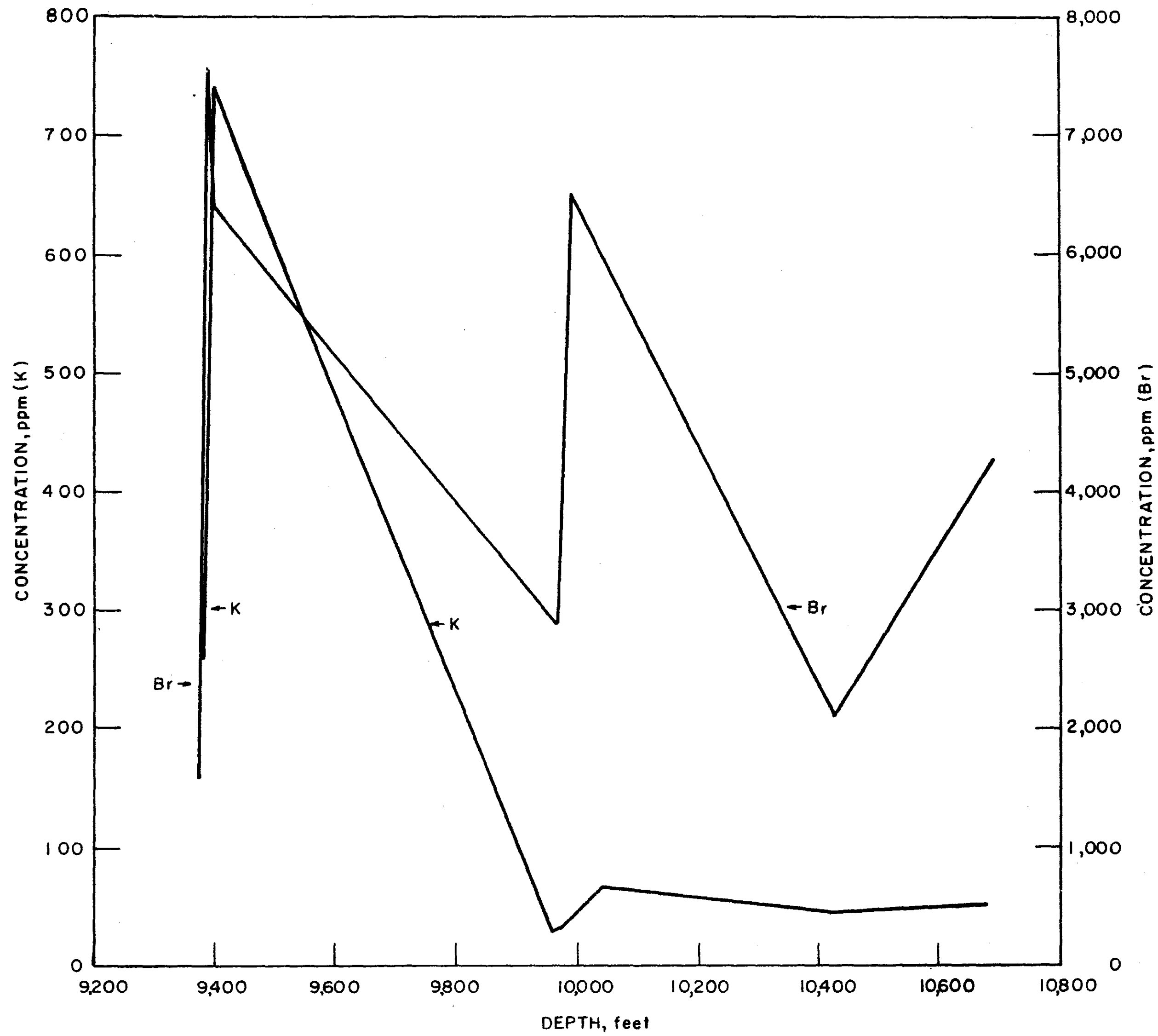

FIGURE 18. - Concentrations of potassium and bromide found in the Louann salt versus depth.

Figure 18 shows the concentration of potassium and bromide in the Louann salt versus stratigraphic depth. The curves indicate no parallel deposition.

SMACKOVER OILS

Oil and gas were discovered in the Smackover Formation in southeast Ouachita County, Ark., in 1936. Since that time, exploration for additional accumulations has extended through south Arkansas, north Louisiana, east Texas, Mississippi, Alabama, and the panhandle of Florida. Several south Arkansas fields were discovered and developed in the 1940's; the Louisiana fields in the 1950's; and in 1963 in Smith County, Miss., sweet oil was found in dolomitic Smackover limestone. In 1967, in Choctaw County, Ala., oil was found in the Smackover at an average depth of 11,500 feet; and in 1970, in Santa Rosa County, Fla., a discovery was made that flowed 1,710 barrels of 50° API gravity oil per day and 2,145,000 cubic feet per day of gas from a well drilled to about 15,500 feet in Smackover dolomite.

Several of the Smackover fields are major fields with estimated primary recoveries in excess of 50 million barrels of oil or gas condensate. The Jay field in Santa Rosa County, Fla., contains recoverable reserves exceeding 300 million barrels of oil and 300 billion cubic feet of gas. The production occurs on the south plunge of a large anticline. The updip trap consists of a facies change from porous dolomite to dense micritic limestone.

The Smackover oils used in this study were analyzed by the Bureau of Mines routine method (76). The correlation index (Cl) (75) is related to the type of hydrocarbons in the distillate fractions. The index number is small if the distillation fraction contains predominantly paraffins, while fractions containing larger percentages of naphthenes and/or aromatics have larger Cl numbers.

The data in table 10 summarize the general characteristics of the samples, and the sampling location and other sample description data are given in table 1 corresponding to the number given in column 1 of table 10. Column 2, table 10, shows for each sample the API gravity. Most of the samples have high API gravities corresponding to low specific gravities.

Column 3, table 10, gives the characteristic color of the crude oils; column 4 gives the amount of sulfur found in the oils. The sulfur content of several of the Smackover oils is relatively high, and the correlation coefficients shown in table 11 indicate an inverse correlation of -0.9398 for sulfur in the oil to the API gravity, which is a high degree of correlation.

Table 10, column 5, shows the amounts of nitrogen contained in the crude oils, and it too gives an inverse correlation to the API gravity indicating that the poorer quality oils contain more nitrogen compounds. The correlation coefficient for API gravity to nitrogen is -0.9510 (table 11). Crude oils that contain relatively large amounts of sulfur, nitrogen, and oxygen compounds sometimes are classified as immature oils.

Column 6, table 10, presents the carbon residue data for the Smackover samples, and these data also exhibit an inverse relationship to the degrees API as shown by a correlation coefficient of -0.8824 in table 11. The carbon residue reflects the amount of heavy organic compounds in the crude oil or compounds which do not easily distill. Such compounds often contain sulfur, nitrogen, and oxygen. Relatively high correlation coefficients were found for carbon residue to sulfur 0.8802 and nitrogen 0.7878, as shown in table 11.

TABLE 10. - General characteristics and correlation indexes of some Smackover oils

Oil	General characteristics					Volume-percent					Correlation index		Characteristics of residuum	
	Gravity, ° API	Color[1]	Sulfur, weight-percent	Nitrogen, percent	Carbon residue, Conradson weight-percent	Fractions 1-3 (light gasoline)	Fractions 4-7 (naphtha)	Fractions 8-12 (kerosine and gas oil)	Fractions 13-15 (lubricating oil)	Residuum	Average of fractions 4-7	Average of fractions 13-15	Percent on gasoline-free basis	Specific gravity, 60°/60° F
1	44.1	GB	0.29	0.006	0.6	11.8	33.2	28.3	15.6	10.4	23	36	19	0.940
2	30.6	BB	1.70	.067	2.9	6.6	18.5	21.6	16.1	34.7	25	46	48	.993
3	44.1	Green	.35	.005	.6	12.5	30.0	30.2	17.2	8.4	23	39	15	.939
4	37.6	GB	1.08	.028	2.0	11.2	27.3	25.3	16.5	18.2	26	47	30	.975
5	19.4	BB	4.59	.187	6.2	5.9	12.4	19.1	15.6	45.7	20	57	57	1.068
6	17.0	BB	5.03	.204	6.6	4.7	11.8	21.7	17.0	44.2	22	61	53	1.089
7	38.2	GB	1.07	.027	2.1	11.7	26.2	27.8	14.4	17.8	27	50	30	.981
8	57.9	NPA 1-1/2	.49	.002	.3	48.0	38.8	([2])	([2])	12.0	38	-	12	.923
9	38.4	BB	.80	.034	1.8	11.3	23.1	29.3	15.4	18.1	23	48	29	.968
10	11.1	BB	5.96	.317	7.1	1.0	5.3	16.1	16.0	61.3	30	66	66	1.058
11	26.1	BB	2.16	.115	4.4	4.4	16.9	25.1	15.6	37.6	23	51	48	1.010
12	32.5	BB	1.79	.079	2.8	9.5	19.1	28.4	14.7	26.5	24	52	38	.994
30	28.4	BB	2.16	.094	3.2	6.5	16.6	28.9	12.9	33.2	22	54	44	1.015
31	35.2	BB	1.35	.048	3.1	6.9	24.8	27.4	17.2	23.5	22	44	35	.979
32	32.8	BB	1.63	.054	3.6	8.6	19.4	24.8	15.5	29.8	23	47	43	.980
33	23.1	BB	3.30	.166	5.2	5.5	12.4	18.9	13.5	47.3	22	52	59	1.021
34	44.3	Green	.19	.005	.2	9.0	26.5	29.7	19.4	15.0	19	26	23	.895
142	46.0	do.	.20	.004	.3	11.0	28.4	29.7	17.7	12.0	19	27	20	.890
143	46.0	do.	.27	.006	.3	8.3	25.8	31.4	16.9	16.0	13	26	25	.896
153	41.5	do.	.57	.009	.5	3.9	34.7	35.5	13.7	12.0	23	35	20	.932
198	63.1	NPA 1-1/2	.16	.001	.0	36.9	44.2	4.9	-	9.6	22	-	66	.836
199	44.9	BG	.62	.004	.5	12.7	28.6	28.1	16.4	13.0	20	34	23	.911
200	45.2	BG	.55	.005	.5	12.5	28.0	30.6	13.8	12.9	21	35	23	.912
201	21.6	BB	2.95	.126	5.2	3.0	12.9	19.0	17.1	47.3	24	50	57	1.021
202	36.0	BB	.64	.028	2.3	4.1	24.8	28.1	17.6	25.1	22	38	35	.949
218	47.4	NPA 5	.10	.004	.1	12.4	28.0	31.4	18.4	9.0	18	24	15	.896
222	41.5	BG	.22	.005	.6	3.6	21.2	33.1	25.7	15.4	16	24	21	.907
223	46.3	BG	.14	.005	.3	12.6	24.6	30.6	17.6	13.2	16	24	21	.897
224	52.3	NPA 1-1/2	.44	.001	.0	21.8	42.5	22.5	-	11.2	24	-	33	.898
225	47.6	NPA 6	.30	.004	.2	18.1	30.8	28.9	11.9	8.1	24	36	17	.923
226	65.6	NPA 1	.31	.000	.0	44.8	37.4	-	-	7.0	35	-	100	.907
227	41.1	BG	.80	([3])	1.5	14.1	24.9	19.8	19.5	19.9	22	40	34	.948
228	36.8	GB	.91	([3])	2.1	10.0	22.3	26.1	15.8	24.6	25	41	37	.956
229	36.6	BG	1.36	([3])	2.8	10.0	20.8	25.4	16.8	24.9	20	43	37	.975
230	71.2	NPA 2-1/2	<.1	([3])	<.1	56.8	33.7	2.4	-	2.8	22	-	54	.843
231	51.1	NPA 6	.37	([3])	.3	21.8	28.5	23.9	13.0	10.0	23	30	21	.910
232	49.0	BG	.43	([3])	.5	16.6	28.1	26.8	13.7	11.0	23	31	21	.914
233	45.2	BG	.54	([3])	.4	12.6	23.9	29.0	16.8	14.2	23	31	24	.912
234	41.9	BG	.52	.015	.3	7.0	27.4	31.6	18.3	15.6	24	29	24	.911
235	38.4	BG	.90	.023	1.6	8.6	23.6	27.4	16.7	20.5	22	44	32	.951
236	50.6	NPA 4	.43	.022	Nil	20.6	33.8	24.8	11.8	4.8	24	35	12	.924
237	36.6	GB	1.33	.041	4.7	10.2	20.9	25.2	15.8	25.2	22	44	38	.976
238	33.2	BB	1.57	.049	2.7	8.2	21.0	25.0	17.1	27.5	22	46	40	.984
239	31.9	BB	1.40	.034	3.2	5.7	12.5	29.4	16.4	32.1	24	42	41	.969
240	35.8	BB	.87	.028	1.7	3.0	27.0	28.3	18.3	23.2	23	39	33	.947
241	31.3	GB	1.90	.075	3.9	7.5	19.5	24.2	14.1	32.0	24	49	46	.996
242	43.8	BG	.50	.004	.4	9.8	27.1	30.7	17.4	13.7	23	32	22	.991
243	33.6	GB	1.54	.051	3.6	8.4	20.0	23.8	16.7	28.1	24	48	41	.980
244	33.4	GB	1.41	.053	3.6	9.3	20.0	25.0	17.1	27.7	22	46	40	.983
245	71.8	NPA <0.5	.09	.002	.0	58.6	28.3	-	-	7.6	19	-	8	.784

See footnotes at end of table.

TABLE 10. - General characteristics and correlation indexes of some Smackover oils--Continued

Oil	General characteristics					Volume-percent					Correlation index		Characteristics of residuum	
	Gravity, ° API	Color[1]	Sulfur, weight-percent	Nitrogen, percent	Carbon residue, Conradson weight-percent	Fractions 1-3 (light gasoline)	Fractions 4-7 (naphtha)	Fractions 8-12 (kerosine and gas oil)	Fractions 13-15 (lubricating oil)	Residuum	Average of fractions 4-7	Average of fractions 13-15	Percent on gasoline-free basis	Specific gravity, 60°/60° F
246	54.4	NPA 5	<0.10	0.017	0.1	24.1	37.6	20.8	9.5	7.1	17	23	19	0.894
247	64.5	NPA 0	.01	.000	.0	28.6	56.8	-	-	6.6	15	-	100	.780
248	60.8	NPA 0	.01	.000	.0	24.9	53.3	9.1	-	10.7	22	-	54	.794
249	58.4	NPA 2	.05	.001	.0	17.4	64.6	4.6	-	12.5	15	-	73	.834
250	70.1	NPA 1	.13	.052	.0	64.1	25.4	-	-	8.6	12	-	10	.781
251	61.5	NPA 1	.05	.034	.0	19.7	67.8	-	-	9.5	13	-	100	.806
252	67.5	NPA 1-1/2	.06	.039	.0	51.2	34.4	-	-	10.6	15	-	11	.796
253	56.2	NAP 3	.11	.023	.1	20.1	44.8	18.7	3.9	10.0	15	24	31	.876
254	52.3	NPA 4-1/2	.10	.031	.7	19.1	29.1	24.0	3.6	20.9	14	-	43	.874
255	61.8	NPA 1	.01	.008	.0	22.2	70.2	-	-	7.2	13	-	100	.791
256	53.7	NPA 4	.07	.008	.1	20.0	29.8	24.1	13.0	8.8	16	23	19	.894
257	59.2	NPA 1-1/2	.02	.010	.0	14.4	74.9	-	-	10.6	15	-	100	.811
258	67.5	NPA 2	.01	.009	.0	48.7	39.0	-	-	10.1	15	-	100	.824
259	60.8	NPA 1	.04	.005	.0	18.6	72.8	-	-	8.0	16	-	100	.791
260	66.4	NPA 1	.03	.013	.0	44.4	40.0	-	-	13.9	15	-	14	.773
261	49.7	NPA 5	.11	.008	.2	19.7	23.4	23.9	16.9	13.2	18	22	24	.895
262	62.1	NPA 1	.02	.005	.0	20.4	68.1	-	-	10.1	13	-	100	.781
263	65.9	NPA 1	.00	.000	.0	35.7	56.1	-	-	4.7	13	-	5	.725
264	45.6	Green	.17	.005	.4	12.3	28.8	28.4	16.6	12.5	19	27	22	.906
265	61.8	do.	.05	.001	.1	32.4	48.9	6.4	-	10.1	15	-	61	.832
266	36.0	BB	.20	.027	2.4	4.5	18.7	28.0	21.0	26.7	22	30	35	.941
267	38.4	BB	.36	.022	2.1	1.4	17.4	31.4	21.4	28.2	8	25	35	.926
268	35.6	BB	.55	.039	3.8	1.5	15.1	28.8	20.3	33.8	6	23	41	.949
269	39.4	BG	.22	.019	1.9	4.3	22.5	32.2	19.6	21.2	15	30	29	.934
270	54.2	BG	.09	.003	.0	19.1	40.2	20.1	7.3	9.0	17	21	25	.887
271	41.5	BG	.18	.008	.5	5.8	25.1	31.7	20.5	16.8	21	29	24	.904
272	53.5	NPA 4	.08	.002	.0	9.3	48.2	32.6	-	9.3	14	-	22	.853
273	44.7	Green	.22	.011	.3	10.8	21.5	27.7	23.1	14.8	17	24	23	.898
274	36.2	GB	1.08	(3)	2.6	6.7	24.9	28.8	16.6	22.9	22	41	34	.967
275	36.6	GB	1.29	(3)	3.0	8.8	24.6	26.3	16.2	23.1	22	42	35	.979
276	36.0	GB	1.24	(3)	2.5	6.6	23.7	28.8	15.8	24.2	22	41	35	.968
277	41.7	BG	.74	(3)	1.8	13.1	26.8	25.2	14.4	18.9	23	39	32	.944
278	35.4	BB	1.00	.032	2.3	7.4	23.3	28.7	16.2	23.2	25	45	34	.964
279	21.3	BB	4.24	.146	4.5	4.6	13.4	19.5	17.3	44.8	23	52	55	1.038
280	21.6	BB	4.22	.155	4.7	3.5	13.5	23.1	16.6	41.9	20	57	51	1.042
281	55.0	NPA 1	<.10	(3)	Trace	22.5	34.2	27.6	10.3	5.2	15	15	12	.871
282	43.4	BG	.44	.007	.7	10.5	35.7	28.2	14.4	10.2	26	38	19	.937
283	48.1	BG	.10	.004	.2	12.0	37.2	29.8	13.2	7.7	20	25	15	.909
284	45.6	Green	.28	.007	.5	14.5	29.6	27.3	15.0	11.3	24	35	21	.929
285	41.9	DG	.54	.021	1.6	12.4	23.9	25.7	17.1	18.0	18	38	30	.950
286	44.9	GB	.26	.010	.7	12.7	29.5	25.4	16.0	13.1	24	35	24	.931
287	39.4	BB	.62	.022	1.2	11.4	24.7	29.6	18.6	12.8	26	50	21	.977
288	36.2	BB	1.23	.053	2.5	7.2	22.0	26.3	8.0	33.1	20	43	49	.963
289	56.9	NPA 1	.43	.001	.0	33.3	48.8	4.5	-	11.2	30	-	63	.870
290	50.4	BG	.60	.010	.5	26.6	35.0	19.8	5.8	9.4	26	47	27	.948
291	38.8	BG	.87	.027	1.6	12.9	24.7	27.4	14.7	18.9	26	47	31	.965

[1] Colors of crude oils in this table are designated as follows: Brownish black, BB; brownish green, BG; dark green, DG; greenish black, GB; green, no abbreviation, but NPA numbers.
[2] Distillation discontinued.
[3] Not determined.

TABLE 11. - Oil data correlation coefficients

	Depth	Gravity, °API	Sulfur	Nitrogen	Carbon residue	Fractions 1-3(1/)	Fractions 4-7(2/)	Fractions 8-11(3/)	Fractions 12-15(4/)	Residuum	Gasoline-free residuum
Depth	1.0000	--	--	--	--	--	--	--	--	--	--
Gravity, °API	-.0435	1.0000	--	--	--	--	--	--	--	--	--
Sulfur	.0793	-.9398	1.0000	--	--	--	--	--	--	--	--
Nitrogen	.0701	-.9510	.9198	1.0000	--	--	--	--	--	--	--
Carbon residue	.0576	-.8824	.8802	.7878	1.0000	--	--	--	--	--	--
(1/)Fractions 1-3	.0120	.7034	-.5175	-.5519	-.6625	1.0000	--	--	--	--	--
(2/)Fractions 4-7	.0332	.9159	-.8107	-.8477	-.8370	.7333	1.0000	--	--	--	--
(3/)Fractions 8-11	-.1409	.4782	-.5556	-.6499	-.3908	-.0299	.3624	1.0000	--	--	--
(4/)Fractions 12-15	-.2477	-.2681	.0864	.0556	.2496	-.5309	-.4190	.4649	1.0000	--	--
Residuum	.0123	-.8821	.8335	.7768	.9341	-.7635	-.8943	-.3374	.3357	1.0000	--
Gasoline-free residuum	-.0046	-.6238	.6432	.5964	.6877	-.4737	-.6436	-.3998	.0497	.7423	1.0000

1/ Light gasoline.
2/ Naphtha.
3/ Kerosine and gas oil.
4/ Lubricating oil.

The volume percent of light gasoline, naphtha, kerosine and gas oil, lubricating oil, and residuum are shown in columns 7, 8, 9, 10, and 11 of table 10. The data in these columns generally correlate with the API gravity. The first fraction distills at about 95° to 122° F and contains hydrocarbons up to C_7, while the 10th fraction distills at 482° to 527° F and contains paraffin hydrocarbons in the range of C_{32}, C_{33}, and C_{34}, as shown in table 12. Fractions 11 through 15 are collected by vaccum distillation.

TABLE 12. - Approximate relationship of boiling point and number of carbon atoms in paraffins

Fraction	Boiling point, ° F	Hydrocarbon, C numbers
1..............	95-122	C_7.
2..............	122-167	C_8.
3..............	167-212	C_9, C_{10}.
4..............	212-257	C_{11}, C_{12}.
5..............	257-302	C_{13}, C_{14}, C_{15}, C_{16}.
6..............	302-347	C_{17}, C_{18}.
7..............	347-392	C_{19}, C_{20}, C_{21}.
8..............	392-438	C_{22}, C_{23}, C_{24}, C_{25}.
9..............	437-482	C_{26}, C_{27}, C_{28}, C_{29}, C_{30}, C_{31}.
10..............	482-527	C_{32}, C_{33}, C_{34}.

Table 11 indicates high correlation coefficients for API gravity to percent of light gasoline 0.7034 and percent of naphtha 0.9159. The percent residuum shows high negative correlations to API gravity, light gasoline, and naphtha; and high positive correlations to sulfur, nitrogen, and carbon residue.

Columns 12 and 13, table 10, show the average C1 for the combined distillation fractions of 4 through 7 and 13 through 15. Column 14 shows the characteristics of the residuum as a percent on a gasoline-free basis and was obtained by calculating the percent residuum as that portion of the crude oil that distills above 392° F. Column 15 shows the specific gravity.

Figure 19 shows plots of the C1 versus fraction number for the Smackover oils in Texas, Arkansas, Louisiana, Mississippi, Alabama, and Florida. The plots indicate the composition of the Smackover oils vary somewhat along the trend.

The composition of the Smackover crude oils is different in various fields. Probably the compositional variations result from alteration of the oils in the reservoirs rather than from different organic source materials. However, even the protopetroleum entering from the source bed at various time intervals may vary in composition (2).

It can be postulated that the Smackover petroleums originated from organic source material deposited within the Smackover Formation. Progressive metamorphism of the organic matter occurred as the sediments became more deeply buried as a result of increased temperature and time (68). The deep

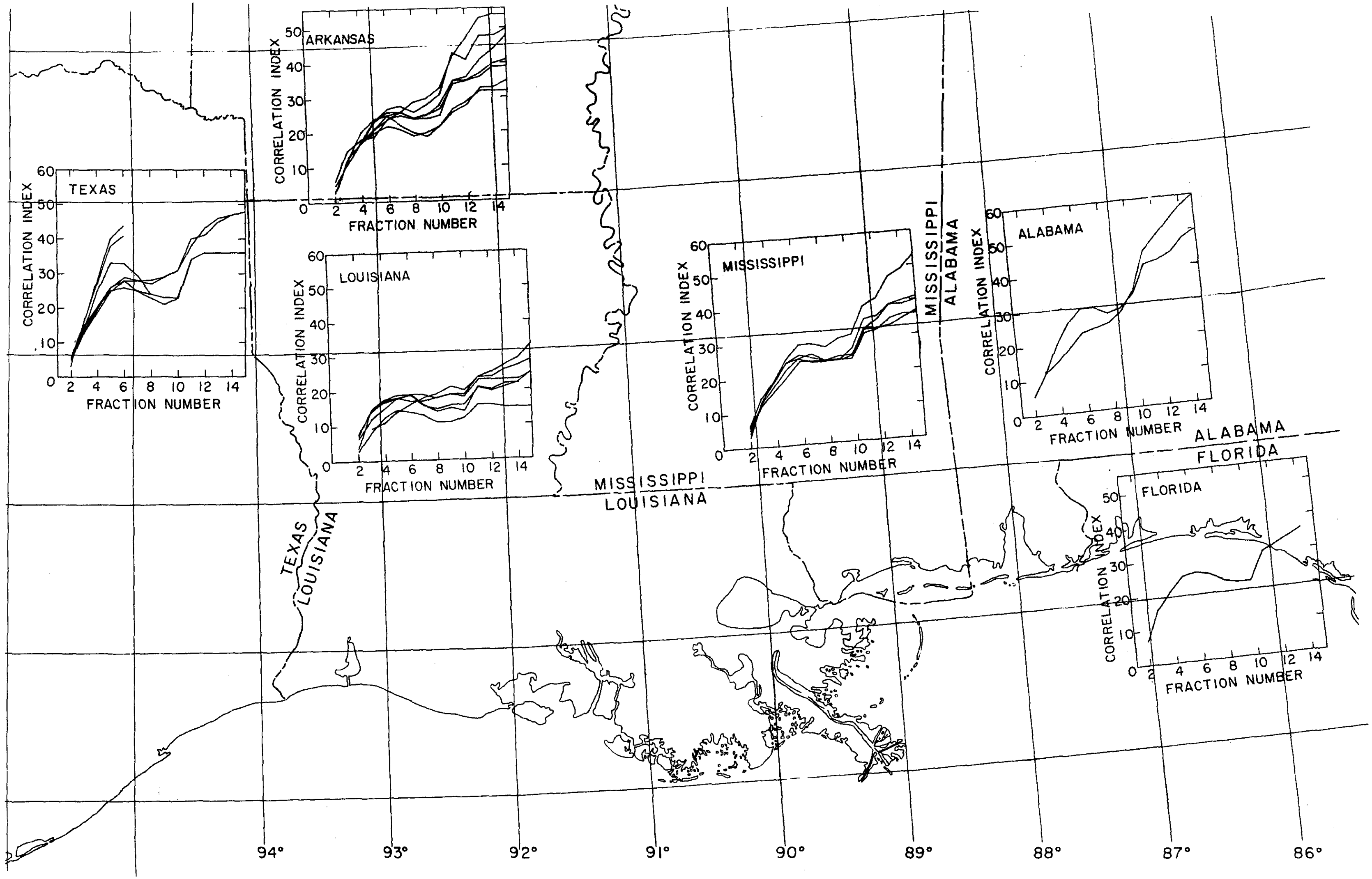

FIGURE 19. - Compositional variations in Smackover oils.

burial also caused water to be released from the sediments as a result of the alteration of minerals and because of sediment compaction (14-15).

The released water along with other formation water moved the released protopetroleum to the reservoir. The first move often is called primary migration. Various theories have been postulated concerning primary migration (64). They include the movement of discrete oil globules through water-wet rocks, and migration as molecular solution or a micellar dispersion in the water. The movement of the protopetroleum in a water solution appears to be the more plausible.

Assuming that this mechanism operated in the Smackover Formation, the water and the protopetroleum moved within the formation until they reached a reservoir with a trap. Nagy and Colombo (64) discuss traps, and noted that most traps are partly open and partly shut. This concept appears reasonable, because a completely closed trap would not allow water displacement, whereas if it were completely open no accumulation could occur.

After the fluids reach the trap and a more hydrostatic environment, they would tend to segregate. The protopetroleum could separate from the water because of density differences or because of possible mixing of the water with more saline waters causing the organic molecules to coagulate. Many subsurface waters contain organic acid salts; note for example, the amount of organic acids found in the Smackover Formation waters (table 2). These salts convert to organic acid as the pH decreases; therefore, a release mechanism also could be a decrease in pH.

After the protopetroleum is released from the water phase, it is subject to additional alteration within the reservoir. Rogers (72) postulated that three processes cause the greatest alteration: (1) thermal alteration (maturation), (2) gas deasphalting and gravity-segregation, and (3) water washing and biodegradation.

The thermal alteration occurs because of increased temperature and time (68). A basic temperature of about 115° C and above is required for the generation of petroleum hydrocarbons through abiogenic reactions. The quality of the generated petroleum increases with increasing temperature; however, at higher temperatures the liquid petroleum is converted to methane, and finally to graphite (59).

The better quality higher API gravity Smackover oils are found in the deeper reservoirs, indicating that temperatures found at depth allowed them to mature more than the Smackover oils found in more shallow reservoirs.

Deasphalting also occurs with deeper burial as a result of increasing pressure and temperature (72). The thermally altered petroleum dissolves the light gases that it generates because the increased pressure causes its equilibrium to change and asphalt to precipitate. This in turn causes the API gravity to rise.

Water washing occurs when infiltrating fresher waters contact the hydrocarbon accumulation and dissolve the lighter ends up to about C_6 hydrocarbons.

In a hydrodynamic environment, the accumulation can be severely altered to heavy oil of low economic value. Some of the Smackover oils of low API gravity may have been altered by this mechanism; however, we have not as yet documented a specific example. The Smackover Formation does not outcrop in the United States, and any infiltrating meteoric water would need another entry mechanism.

Biodegradation also occurs when infiltrating fresh waters containing bacteria come in contact with the petroleum accumulation (82). Here again, we have found no specific example of this occurring to the Smackover oils.

SMACKOVER GAS

In the previous section, the mode of origin of hydrocarbon gas was discussed. Table 13 shows the composition of some Smackover gas from the Jay field, Florida. In addition to hydrocarbons, the gas contains nitrogen, oxygen, argon, hydrogen, hydrogen sulfide, carbon dioxide, and helium.

TABLE 13. - Analysis of a sample of Smackover gas from Jay field, Florida, depth 15,500 feet

Constituent	Percent	Constituent	Percent
Methane	69.2	Hexanes plus	0.2
Ethane	10.9	Nitrogen	2.7
Propane	4.3	Oxygen	.0
n-Butane	1.0	Argon	.0
Iso-Butane	.7	Hydrogen	.1
n-Pentane	.4	Hydrogen sulfide	7.2
Iso-Pentane	([1])	Carbon dioxide	3.3
Cyclopentane	([1])	Helium	.02

[1] Trace.

Hosler and Kaplan (48), using sulfur-isotope data, calculated that large shifts in the concentration of sulfate in the sea occurred during various geologic ages. The calculations indicated that the early Paleozoic seas contained about 25 percent less sulfate than the modern seas, while the late Paleozoic seas contained about 45 percent more. Sedimentation of sulfate exceeded the influx of soluble sulfate to the sea during the Mesozoic. Therefore, the Jurassic sediments should be enriched in sulfate. The Smackover Formation contains some anhydrite; however, some of the other Jurassic age formations such as the Buckner contain relatively larger amounts. Reduction of the sulfates produces the sulfides that are associated with the Smackover oils, gases, and waters.

Almost all high-sulfur gases are confined to sulfate and carbonate rock complexes. Hydrogen sulfide at depths is related to thermocatalytic dissociation of sulfur-containing organic compounds of oils and bitumens.

The other gases in the Smackover gas can be attributed to the end products produced by the thermal alteration of the liquid hydrocarbons with the exception of argon and helium. The analysis shown in table 13 indicates that no argon was found in this particular gas; however, traces of argon often are found, and the origin of argon usually is attributed to the radioactive decay of K^{40} in rocks to Ar^{40} (85). Helium is generated by radioactive decay of U^{238} and Th^{232} to Pb^{206} and Pb^{208}, respectively. The alpha particles given off in these reactions take on two electrons each and become helium (26).

SMACKOVER ROCKS

Smackover Formation core samples were obtained from several wells. Portions of 10 of the cores from basins in Alabama, Arkansas, Louisiana, Mississippi, and Texas were analyzed for sodium, magnesium, calcium, strontium, vanadium, manganese, copper, aluminum, chloride, and bromide. The depths from which the samples were taken varied from about 8,300 feet to more than 13,000 feet, as shown in tables 14 and 15. The analytical results shown in table 14 were obtained by use of neutron activation techniques. Additional location data for the samples in tables 14 and 15 are in table 1.

Two samples from different depths were analyzed by neutron activation for each of 10 core samples as shown in table 14. The concentrations of some of the constituents vary dramatically along relatively short distances of the stratigraphic column, indicating different environments of deposition or subsequent diagenesis.

Samples 308 and 310, from Louisiana and Texas, respectively, contain relatively high concentrations of aluminum, which possibly can be attributed to the presence of bentonites. Montmorillonite and illite also contain aluminum. The alumino-silicates are important catalysts and significantly accelerate reactions such as alkylation, isomerization, polymerization, dealkylation, depolymerization, cracking, and hydrogen disproportionation. Because of their catalytic importance they can play an important role in the transformation of organic matter into petroleum (2).

The bromide and chloride contents of the Smackover rocks, as shown in table 14, indicate that halite is present, and the concentration of bromide above 100 ppm indicates a late-stage bittern. The calcium concentration indicates limestone, while the magnesium concentration indicates some dolomite.

Table 15 contains analyses for some Smackover rock samples. The rock samples were dissolved in hydrochloric acid and then analyzed with an atomic absorption spectrophotometer for the cations. The anions were determined by wet-chemical analysis. Only samples 28 and 194, both from Arkansas, included a sample of the brine and the rock.

The analytical data in table 15 indicate that most of the samples are limestone with some dolomite and gypsum or anhydrite. Sample 305 contains appreciable amounts of dolomite.

TABLE 14. - Neutron activation analysis of some Smackover rock samples

Sample	State	County	Section, township, range	Latitude	Longitude	Basin	Depth, feet	Concentration, ppm									
								Sodium	Magnesium	Calcium	Strontium	Vanadium	Manganese	Copper	Aluminum	Chloride	Bromide
4	Alabama....	Choctaw..	35-11N-4W	315300	0882100	Hatchetigbee	12,000-	1,000	190	156,000	50,000	2.9	67	47	2,260	2,600	13
4	...do......	...do....	35-11N-4W	315300	0882100	.....do.....	12,024-	1,150	680	120,000	11,000	2.1	96	37	740	2,100	49
150	Arkansas...	Columbia.	11-18S-20W	331200	0930900	Sabine Uplift.	8,319- 8,388	1,260	88	178,000	610	4.2	260	32	950	1,800	76
150	...do......	...do....	11-18S-20W	331200	0930900	.....do.....	8,438- 8,498	820	89	161,000	<100	6.7	230	41	2,200	710	20
254	Louisiana..	Claiborne	33-23N-6W	325600	0930000	.....do.....	10,650-10,660	1,600	250	160,000	1,100	7.2	450	59	1,900	2,000	19
254	...do......	...do....	33-23N-6W	325600	0930000	.....do.....	10,680-10,691	960	570	155,000	940	6.3	2,400	80	1,100	2,300	34
291	Texas......	Hopkins..	NAp	331500	0953400	Mexia Talco.	9,319- 9,322	1,170	280	155,000	4,200	7.2	430	32	4,460	758	<3
291	...do......	...do....	NAp	331500	0953400	.....do.....	9,287- 9,292	1,300	280	143,000	800	1.9	490	67	700	2,000	29
308	Louisiana..	Ouachita.	36-17N-1E	322500	0922000	North Louisiana.	10,241-10,245	1,800	170	125,000	2,700	26	63	110	15,500	800	33
308	...do......	...do....	36-17N-1E	322500	0922000	.....do.....	10,258-10,262	2,480	220	66,000	1,200	47	90	150	30,000	630	5.8
309	Mississippi	Wayne....	26-10N-6W	314900	0883400	East Gulf Embayment.	12,738-12,758	600	1,700	82,000	780	4.1	250	52	2,300	1,600	65
309	...do......	...do....	26-10N-6W	314900	0883400	.....do.....	12,768-12,778	1,060	2,600	96,000	<100	7	305	65	2,600	1,400	<3
310	Texas......	Van Zandt	NAp	([1])	([1])	Mexia Talco.	13,008-13,019	5,200	330	11,500	2,200	23	90	110	34,000	960	67
310	...do......	...do....	NAp	([1])	([1])	.....do.....	13,146-13,149	1,900	180	91,000	<100	23	150	110	18,000	4,700	120
311	...do......	Navarro..	NAp	([1])	([1])	.....do.....	9,666- 9,669	1,520	740	165,000	1,900	5.1	173	41	1,840	660	34
311	...do......	...do....	NAp	([1])	([1])	.....do.....	9,651- 9,654	1,000	730	170,000	5,700	1.4	190	65	730	1,900	120
312	...do......	Bowie....	NAp	([1])	([1])	.....do.....	9,553- 9,556	400	26	180,000	600	.6	460	42	270	870	50
312	...do......	...do....	NAp	([1])	([1])	.....do.....	9,570- 9,573	2,300	75	180,000	<100	.9	316	37	230	910	12
313	Mississippi	Clarke...	22-2N-14E	310800	0894800	East Gulf Embayment.	13,058-13,078	1,700	750	120,000	<100	6.6	110	55	6,700	790	16
313	...do......	...do....	22-2N-14E	310800	0894800	.....do.....	13,088-13,098	2,600	670	125,000	<100	10.3	110	61	9,300	1,900	48

NAp Not applicable.
[1]Not available.

TABLE 15. -Atomic absorption and wet-chemical analysis of some Smackover rock samples

Sample	Depth, feet	Concentration, ppm														
		Bromide	Iodide	Sulfate	Calcium	Magnesium	Sodium	Potassium	Lithium	Barium	Strontium	Iron	Zinc	Manganese	Copper	Lead
28	7,017-7,019	(1/)	(1/)	5,000	303,000	3,290	717	30	2	110	480	438	37	298	5	0 (2/)
28	7,028-7,030	(1/)	(1/)	2,600	396,000	3,720	785	108	2	60	347	553	45	70	6	0
28	7,040-7,043	(1/)	(1/)	1,200	366,000	3,710	808	25	2	60	267	365	36	57	5	0
141	8,363-8,367	(1/)	(1/)	8,000	375,000	3,000	908	35	2	40	246	288	49	173	7	0
141	8,443-8,447	18	<0.2	18,200	367,000	1,300	1,640	51	2	60	261	320	124	161	7	0
141	8,513-8,516	(1/)	(1/)	39,700	360,000	3,200	1,090	78	6	60	286	195	105	142	6	0
194	8,560-8,565	(1/)	(1/)	8,200	391,000	2,400	809	38	2	70	247	336	47	233	6	0
194	8,637-8,641	(1/)	(1/)	13,600	367,000	2,500	1,041	26	1	60	239	169	73	249	6	0
194	8,710-8,715	(1/)	(1/)	9,800	484,000	4,600	725	52	3	60	351	258	56	128	7	0
288	13,038-13,048	20	< .02	5,600	166,000	3,500	567	195	1	30	170	347	22	85	4	0
288	13,058-13,078	(1/)	(1/)	7,200	210,000	32,400	344	87	1	40	132	373	32	72	4	0
288	13,088-13,098	(1/)	(1/)	3,500	258,000	32,600	655	153	2	50	159	373	30	77	4	0
293	8,584-8,585	37	< .2	5,500	196,000	2,300	1,039	32	3	90	300	222	48	322	8	0
293	9,627-9,632	(1/)	(1/)	9,200	182,000	2,600	854	24	3	70	247	245	3,860	249	7	0
293	9,668-9,703	(1/)	< .04	9,400	206,000	3,200	560	29	3	70	256	236	203	227	7	.4
294	8,385-8,386	(1/)	(1/)	2,600	165,000	7,400	1,900	83	5	70	286	498	115	220	10	1.8
294	8,440-8,441	(1/)	(1/)	17,200	188,000	4,100	1,190	36	2	60	299	392	42	184	7	0
294	8,540-8,541	33	< .04	7,900	164,000	11,900	942	52	4	70	233	574	39	304	6	0
295	9,024-9,025	(1/)	(1/)	14,800	206,000	3,200	1,880	85	7	80	255	459	38	232	7	0
295	9,076-9,079	(1/)	(1/)	35,900	169,000	3,900	826	62	4	40	322	489	57	273	6	0
295	9,110-9,112	(1/)	(1/)	20,400	153,000	21,600	603	45	2	40	270	3,240	45	193	8	0
296	8,430-8,431	(1/)	(1/)	1,200	177,000	3,100	1,201	73	6	70	243	215	75	185	7	0
296	8,450-8,451	(1/)	(1/)	11,700	367,000	2,700	1,311	88	7	30	262	232	41	191	7	0
296	8,474-8,475	(1/)	(1/)	2,300	335,000	4,500	784	74	3	40	249	352	37	180	7	0
297	8,414-8,415	(1/)	(1/)	10,000	363,000	3,100	2,145	60	3	40	275	318	37	177	6	0
297	8,495-8,496	(1/)	(1/)	3,500	300,000	6,000	422	170	3	50	240	495	40	144	7	0
297	8,565-8,566	(1/)	(1/)	3,000	381,000	3,000	1,589	73	6	60	271	188	82	112	6	0
298	12,152-12,156	(1/)	(1/)	13,400	316,000	7,160	1,480	35	1	170	453	110	42	42	7	0
298	12,172-12,175	(1/)	(1/)	7,900	253,000	27,400	718	36	1	130	4,330	159	28	60	5	C
298	12,189-12,193	(1/)	< .04	15,500	259,000	7,300	8,200	67	1	120	5,590	147	25	85	5	0
299	9,540-9,543	(1/)	(1/)	12,800	432,000	2,160	4,110	61	5	90	1,430	214	135	433	8	0
299	9,553-9,556	(1/)	(1/)	12,300	401,000	1,950	1,570	61	3	50	420	181	35	394	6	0
299	9,570-9,572	(1/)	(1/)	4,800	440,000	3,480	1,940	50	2	90	283	178	36	325	7	0
300	12,887-12,896	(1/)	(1/)	61,800	111,000	928	1,950	138	1	34	332	713	15	31	4	0
300	13,008-13,019	(1/)	(1/)	6,700	258,000	2,670	6,030	805	6	250	455	1,740	54	40	2	0
300	13,146-13,149	(1/)	(1/)	3,500	213,000	5,800	1,400	587	4	230	427	1,400	24	98	5	0
301	12,923-12,926	(1/)	(1/)	11,100	215,000	12,500	1,080	106	2	40	81	388	32	65	4	0
301	12,934-12,937	(1/)	(1/)	13,400	230,000	12,700	1,640	190	3	80	131	345	29	72	4	0
301	12,957-12,960	(1/)	(1/)	17,900	317,000	6,410	1,620	70	1	60	131	150	29	68	6	0
302	9,305-9,308	(1/)	(1/)	14,800	341,000	4,200	7,070	36	1	60	144	1,510	3,400	968	6	0
302	9,320-9,323	50	< .02	10,800	413,000	3,780	2,410	51	1	80	273	286	926	450	7	0
302	9,336-9,339	(1/)	< .02	5,900	422,000	2,960	2,550	71	2	130	4,570	327	327	602	7	0
303	10,222-10,224	53	(1/)	8,600	12,700	5,540	2,920	1,150	32	50	54	15,100	37	84	11	0
303	10,241-10,245	(1/)	(1/)	4,400	300,000	3,600	1,180	152	2	180	480	2,170	39	101	7	0
303	10,258-10,262	(1/)	(1/)	2,300	88,000	2,410	744	275	2	230	358	1,720	99	63	7	0
304	9,364-9,388	(1/)	(1/)	3,000	319,000	9,580	1,160	95	2	120	1,840	203	26	131	7	0
304	9,666-9,667	(1/)	(1/)	4,800	299,000	39,900	1,400	214	2	40	1,270	392	39	170	6	0
304	9,651-9,654	(1/)	(1/)	11,200	325,000	37,500	1,280	71	2	90	3,960	276	27	201	6	0
305	12,718-12,728	(1/)	(1/)	3,800	190,000	102,400	447	93	1	20	158	1,400	26	182	5	0
305	12,738-12,758	(1/)	(1/)	4,200	149,000	86,300	435	74	1	40	326	1,470	20	210	4	0
305	12,768-12,778	(1/)	(1/)	12,800	192,000	111,000	4,370	100	1	40	87	2,400	25	293	4	0
306	11,568-11,588	(1/)	(1/)	12,000	318,000	9,700	846	39	2	110	194	35	30	106	4	0
306	11,588-11,608	(1/)	(1/)	6,000	344,000	6,400	1,161	45	2	150	4,210	121	32	119	5	0
306	11,680-11,718	(1/)	(1/)	8,000	354,000	26,400	1,100	49	2	130	2,640	38	30	152	5	0
307	10,476-10,480	(1/)	(1/)	1,200	341,000	34,600	265	83	1	150	311	2,080	81	196	7	0
307	10,487-10,490	(1/)	(1/)	3,900	192,000	19,000	378	83	1	40	203	1,440	79	127	4	0
307	10,500-10,502	(1/)	(1/)	2,800	309,000	3,210	706	16	1	60	268	1,470	125	172	6	0

1/ Not determined.
2/ Less than 0.2 ppm.

ORIGIN OF HYDROCARBON ACCUMULATIONS IN THE SMACKOVER FORMATION

Rapid deposition of sediment with abundant organic matter is a prerequisite of hydrocarbon source rocks. Such conditions are associated with carbonate rock depositions in rapidly subsiding areas with shallow, restricted marine environments where rapid deposition of organic-rich carbonate sediments occurs. Deltas depositing into a subsiding seabed contain abundant organic matters; rapid deposition tends to preserve considerable organic matter; and slow compaction can allow any generated hydrocarbons to escape from the surrounding fine-grained sediments into more porous sediments.

An indigenous origin of the Smackover hydrocarbons can be postulated because of the common presence of carbonaceous material in the Smackover Formation and because of the improbability that the overlying red anhydritic Buckner shale or the underlying Norphlet sandstone and red beds or the Louann salt are source rocks. According to Malek-Aslani (62), the generation of petroleum in carbonate rocks is controlled by conditions such as depositional environment, diagenesis, tectonics, and fluid mechanics.

Facies present in the Smackover are representative of those capable of hydrocarbon generation. Some of these are öolite bars, biostromal carbonates, organic banks, algal mats, and mud islands. According to Dickinson (28), the lower member of the Smackover Formation was deposited in relatively deep water in a stagnant basin. The stagnant environment is suggested by the preservation of organic matter and the lack of fossils. The middle member contains pelletoidal micritic limestone and locally is anhydritic, stylotic, fossiliferous, öolitic, or silty. Shoaling in the shelf areas occurred when the middle member was depositing. A shoal is an extensive submarine ridge of carbonate sand (69). Shoals often are up to 1 mile wide and 10 to 15 miles long and exist on a shallow sea floor with unobstructed tidal flow. Continued shoaling in the shelf areas occurred as the upper member was deposited in a high-energy shallow-water environment. The upper member often is an öolitic limestone containing intraclasts, pisolites, and pellets.

Bishop (7) divided the Smackover into two members, and according to him the lower members are composed of carbonate muds, pyrite, and carbonaceous material, which was deposited in a quiet, toxic environment. This type of an environment is conducive to the preservation of organic material that can serve as a source for the generation of hydrocarbons. The upper member contains nonskeletal types of carbonate grains and muds deposited in a shallow-water environment.

Until Triassic time, the gulf basin probably was a part of the Llanoria-Appalachia continental land mass. Widespread rifting occurred, and the Tethys Sea spread westward into a newly formed gulf basin during early Jurassic times (fig. 20). The basin subsided and Terrigenous clastics from emerging land areas to the north were deposited in deltas. The southern Appalachians were a prime source of such materials (70).

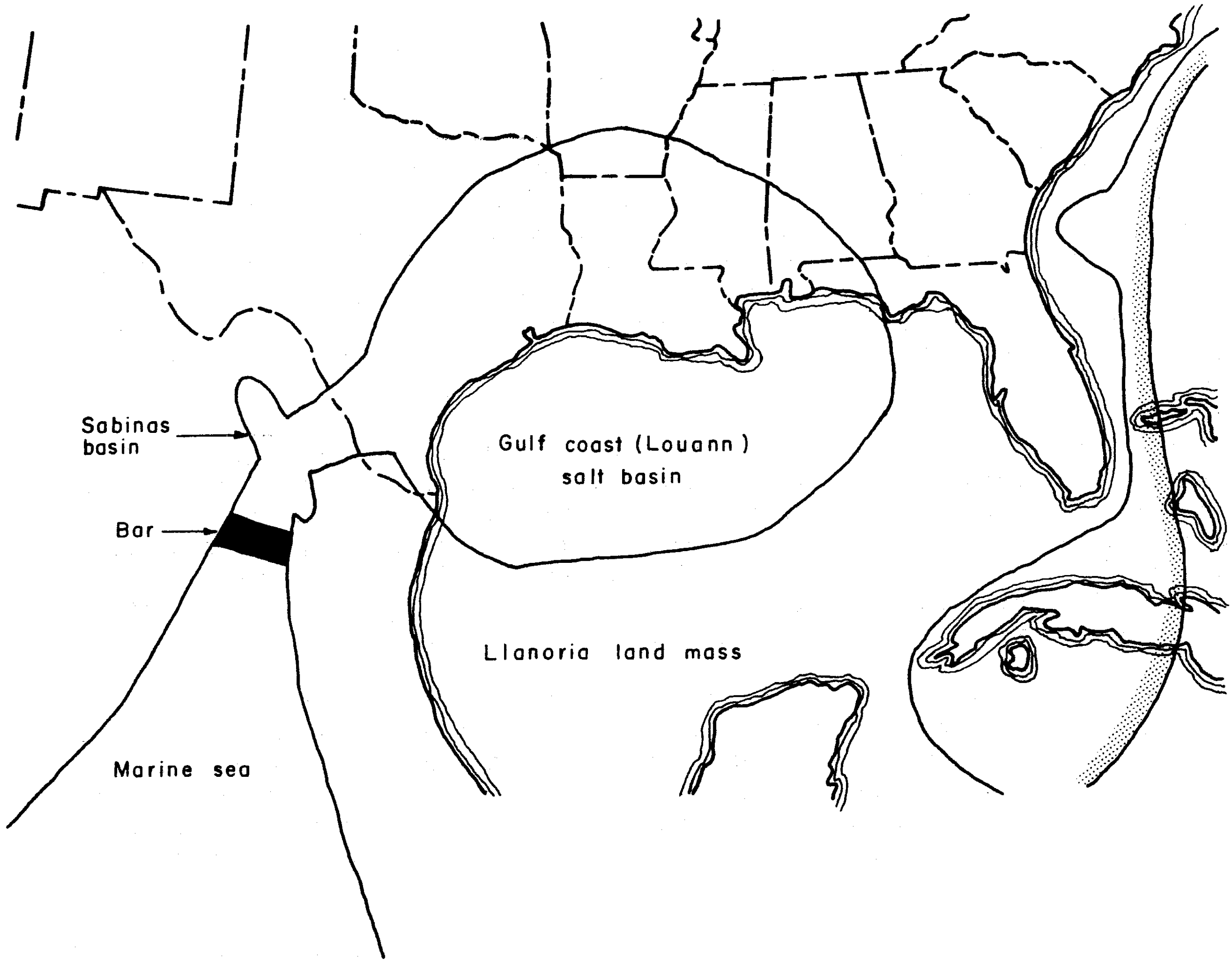

FIGURE 20. - Gulf coast basin during late Paleozoic and early Mesozoic time, modified after Halbouty (38).

The gulf coast basin may have been an epeiric (inland) sea during Jurassic time, and shallow shelves of epeiric seas are a preferred habitat for prolific benthonic life (Malek-Aslani (62)). Such a dense, bottom-dwelling community can produce a favorable habitat for the generation of hydrocarbons.

The sedimentation conditions that prevailed during Smackover Jurassic time were favorable for the generation and preservation of large amounts of organic material, which later could form petroleum hydrocarbons. Large quantities of these organic materials were deposited in alluvial, deltaic-lagoonal, deltaic, and shallow marine environments.

Traps

Much of the Smackover exploration has been for closed structures, as reflected by the data in table 16. Increased well control has provided data that indicates that stratigraphy is an important factor in Smackover traps. The regressive depositional setting of various regions of the Smackover is responsible for the formation of several stratigraphic traps, many of which probably remain undiscovered. For example, many stratigraphic traps were never drilled into because no structural closure was found by seismology or by structural mapping.

The problem, of course, is to find the numerous undiscovered oil and gas accumulations in stratigraphic and stratigraphic-structural traps in the Smackover and other formations in the favorable facies of carbonate and terrigenous strata. Formation water maps and oilfield water classification data are of value in locating stratigraphic traps. For example, the brines in or near the hydrocarbon accumulations in stratigraphic traps will be characteristic of the stagnant hydrostatic environments associated with such a trap. Also, they are likely to contain increased concentrations of dissolved hydrocarbons and related organic salts (18).

TABLE 16. - Types of hydrocarbon traps in the Smackover Formation

State	Field	Type of trap
Arkansas	Atlanta	Anticline.
	Bear Creek	Do.
	Brister	Monocline.
	Calhoun	Anticline.
	Cario	Do.
	Catesville	Do.
	Dooley Creek	Do.
	El Dorado, E.	Do.
	Gum Creek	Anticline-fault.
	Haynesville	Anticline.
	Lewisville	Fault-anticline.
	Lewisville, W.	Anticline-fault.
	Mt. Zion	Anticline.
	Page City, E.	Anticline-fault.
	Spirit Lake	Do.
	Welcome	Do.
	Wesgum	Do.
Florida	Jay	Combination structural-stratigraphic.
Louisiana	Anitoch	Anticline.
	Arkana	Do.
	Caterville	Do.
	Colquitt	Do.
	Cotton Valley	Do.
	Haynesville	Fault-dome.
	Haynesville, E.	~~Anticline-fault~~.
	Ivan	Anticline.
	Monroe	Monocline.
	Mt. Sinai	Anticline-fault.
	Rodessa	Do.
	Sarepta, S.	Anticline.
	Shongaloo, N. Red Rock.	Do.

TABLE 16. - Types of hydrocarbon traps in the Smackover Formation--Continued

State	Field	Type of trap
Mississippi	Barber Creek	Anticline.
	Bienville Forrest	Stratigraphic-general.
	Black Creek	Anticline.
	Clara, W.	Do.
	Cypress Creek, S.	Do.
	Davis	Anticline-fault.
	Double Creek	Anticline.
	Goodwater	Do.
	Harmony	Anticline-fault.
	Nancy	Stratigraphic-general.
	.....do	Anticline.
	Pachuta Creek	Low-relief salt roller.
	Paulding, E.	Anticline-fault.
	Pool Creek	Dome.
	Prairie Ranch	Anticline.
	Shangelo Creek	Fault-dome.
	Shubuta, N.	Structural-fault.
	Stafford Springs	Anticline.
	Tallahala Creek	Fault-dome.
	Tallahala Creek, E.	Anticline-fault.
	Tinsley, W. Segment	Do.
	Watts	Anticline.
	Winchester	Do.
Texas	Flower Acers	Dome.
	Mexia	Monocline.
	New Hope	Anticline.
	Powell	Monocline

Indicators of Hydrocarbon Accumulations

Certain constituents dissolved in oilfield waters are called favorable indicators of hydrocarbon accumulations. Iodide, ammonium, organic acid salts, ethane, butane, low sulfate concentrations, and type of brine are important, according to Sulin (77) and Kartsev (55).

Zarrella (84) found that the amount of benzene in formation waters directly reflects the occurrence of a petroleum accumulation and can be used to estimate its proximity. Furthermore, he postulated that vertical migration of hydrocarbons between aquifers probably does not occur and that lateral migration is limited. Buckley (13) found that gases diffuse laterally through water for only a few miles and that vertical diffusion through strata does not occur.

Recently Hitchon and Horn (45) used a statistical technique, discriminant analysis, to show that formation waters associated with large hydrocarbon

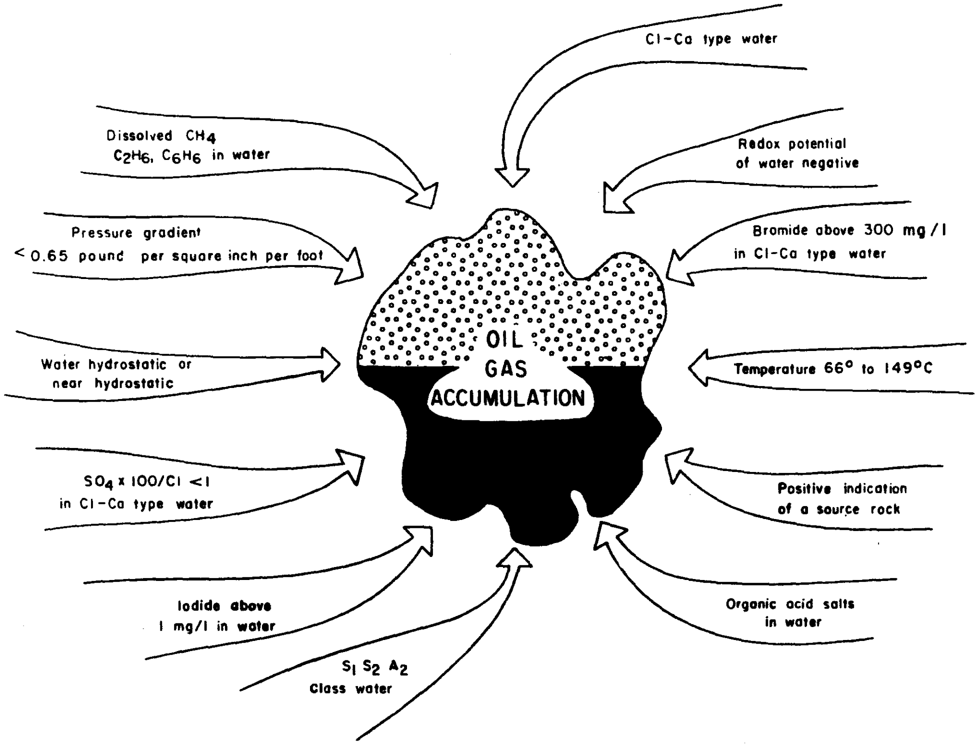

FIGURE 21. - Genetic indicators in a brine associated with an oil and gas accumulation.

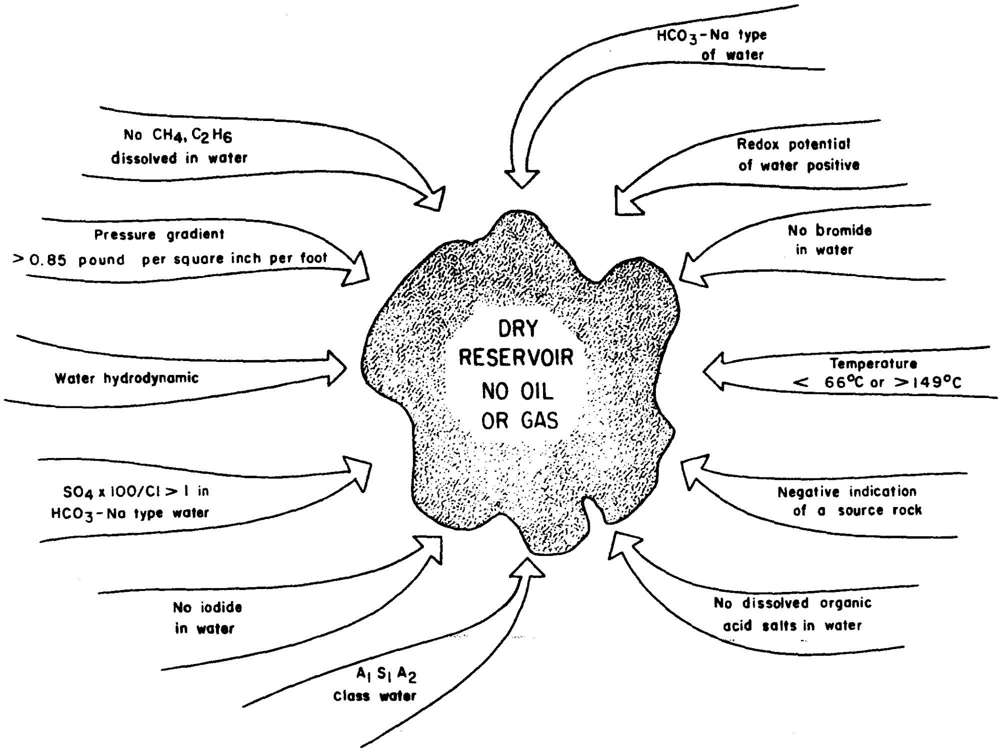

FIGURE 22. - Genetic indicators in a brine associated with a reservoir containing no oil or gas.

accumulations. They found that iodide and magnesium were important discriminators in waters taken from Paleozoic age rocks, while chloride and sodium were the discriminators for waters from Mesozoic age rocks. Their study did not include organic acid salts or ammonium.

Organic acid salts, petroleum hydrocarbons, and other organic compounds are soluble in water. The ionic composition, the pH, and the Eh of the water influence the solubilities of the organic compounds. The aqueous solubility of petroleum hydrocarbons increases with increasing temperature and pressure and decreases with increasing water salinity. The aqueous solubility of organic acid salts increases with increasing pH.

A vehicle for the migration of petroleum or petroleum precursors, therefore, is water. It is known that petroleum hydrocarbons are generated from organic-rich rocks. The organic material in the petroleum source rocks is transformed by physicochemical reactions into petroleum precursors and/or hydrocarbons, which are solubilized by water. The water phase moves the solubilized organics from the source to the reservoir where, because of salinity, pH, filtration, or organic salting-out phenomena, the organic phase separates from the water.

In the reservoir the petroleum precursors and/or hydrocarbons mature to crude oil and gas primarily because of temperature and time. Thermal alteration proceeds both in the fine-grained source rock and in the reservoir at temperatures above 115° C by abiogenic reactions (68). With increasing temperature the quality of the crude oil improves; however, at higher temperatures the crude oil is destroyed, leaving methane and pyrobitumen (59).

According to Timko and Fertl (78), commercial hydrocarbon accumulations are not likely to be found in reservoirs with pressure gradients greater than 0.85 psi/ft. Commercial hydrocarbon accumulations are more likely to be found when the pressure gradient is less than 0.65 psi/ft.

The primary mechanism in the migration of petroleum involves water; therefore, it follows that knowledge of certain characteristics of the water are useful in exploration for oil and gas. Some of the characteristics related to waters that are likely to indicate an oil or gas accumulation are shown in figure 21. In contrast, figure 22 illustrates characteristics related to waters that are likely to indicate a dry reservoir.

CONCLUSIONS

The Smackover Formation consists primarily of carbonates and shales deposited under a variety of environmental conditions during Jurassic time. The Smackover brine is highly enriched in manganese, iron, lithium, barium, copper, iodide, strontium, calcium, bromide, and boron. It is a commercial source of bromine. The brine is an altered seawater that has approached a bittern stage at one or more times.

Classification of the Smackover brines indicated that all of those found near a hydrocarbon accumulation were a Cl-Ca type, most were in the $S_1 S_2 A_2$

class, were very highly concentrated in chloride, were normally sulfated, and were saturated with calcium sulfate, and all had positive base-exchange indexes. The positive index indicated that alkali metals in the water exchanged for alkaline earth metals in the rocks.

Correlation indexes indicate that the composition of the Smackover oils vary somewhat from one field to another. These differences are caused by different degrees of maturation or alteration within the reservoir. Correlation coefficients indicate negative correlations of sulfur and nitrogen in the oils to the quality of the oils. The oils originated from organic matter deposited within the Smackover Formation and were transported to the reservoir in aqueous solution.

The Smackover gas contains about 70 percent methane and 11 percent ethane. The hydrogen sulfide content often is more than 5 percent and is formed by thermocatalytic dissociation of sulfur containing compounds. The hydrocarbon gases are the end products produced by the thermal alteration of the liquid hydrocarbons.

The Smackover rocks contain limestone, dolomite, gypsum, anhydrite, and shale. Appreciable quantities of aluminum and strontium compounds are present in some of the rocks.

Most of the discovered hydrocarbon traps in the Smackover are structural. It is believed that many large stratigraphic traps remain to be discovered, and that some hydrocarbon indicators related to the brine will be useful in locating these traps.

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