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Chemical Evidence for Migration of Deep Formation Fluids into Shallow Aquifers in South Louisiana

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Abstract

Local accumulations of brackish groundwater occur across south Louisiana within shallow, southward-dipping Pleistocene, Pliocene, and Upper Miocene aquifers. Low Br/Cl and K/Cl concentration ratios, high Na/Cl concentration ratios, trace Mg concentrations, and low ^{87}Sr/^{86}Sr ratios in the brackish waters from these aquifers are inconsistent with the saline-water sources being *in situ* marine formation fluids of similar age. The ratios are consistent with the saline-water sources being Lower Miocene or Paleogene marine formation fluids which dissolved recrystallized halite. The region overlies the Jurassic Louann salt and is cut by a series of east-west trending gravity faults with southward-dipping fault planes. Deep formation fluids have dissolved halite in salt diapirs and moved up fault planes to enter shallow aquifers and mix with the in situ groundwaters.

Introduction

This study examines evidence for vertical movement of deep formation fluids into shallow groundwater aquifers in South Louisiana. The purpose was to chemically fingerprint the saltwater sources of brackish groundwaters in shallow aquifers to determine if these were in situ downdip marine pore waters or deeper marine formation fluids with increased salinity due to halite dissolution.

The study involved southward-dipping, Quaternary and Upper Neogene-age sand aquifers (Table 1) in the three regions of South Louisiana shown in Figure 1. The sand aquifers are confined by clay units and were deposited in deltaic sequences with marine pore waters. The aquifers are cut by southward dipping, east-west trending gravity faults and overlie the deep, Jurassic-age Louann salt deposits which are the source of the salt diapirs in South Louisiana (Ewing and Lopez, 1991).

The first two regions of this study are the Lacombe area in St. Tammany Parish (Fig. 2A) and the Baton Rouge area in East and West Baton Rouge Parishes (Fig. 2B), both of which lie just north of the South Louisiana region of salt diapirs (Ewing and Lopez, 1991). The aquifers in both regions are cut by the east-west trending Baton Rouge – Denham Springs (BR-DS) Fault System which extends eastward from Baton Rouge for 100 miles (160 km) across southeast Louisiana and reaches a depth of more than 6 km (Lopez et al., 2002). The third region (Fig. 2C) includes the coastal parishes which overlie the South Louisiana region of salt diapirs.

St. Tammany Parish

Nyman and Fayard (1978) documented brackish waters in the 1,500 ft (460 m) deep Pliocene Big Branch Aquifer in Lacombe in St. Tammany Parish. The Big Branch Aquifer is an artesian aquifer on the updip side of the BR-DS Fault System on the north shore of Lake Pontchartrain (Fig. 2A). The Big Branch is contained within a sequence of freshwater aquifers which are uncontaminated by saltwater intrusion. Nyman and Fayard (1978) suggested recharge into the Big Branch Aquifer occurs by leakage across confining clays because the aquifer lacks surface recharge. Seismic data shows the aquifer may also lack a downdip section to the south under Lake Pontchartrain. Nyman and Fayard proposed the in situ brackish waters represented incomplete flushing in the Lacombe area, presumably of freshwaters which filled the pores of the aquifer in response to lowered sea level during the last Ice Age and have since been flushed by updip moving marine waters.

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Table 1. Stratigraphic and hydrologeologic units, modified from Lovelace and Lovelace (1995).

System	Series	Stratigraphic Unit	Lake Charles Area Aquifers	South Central LA Aquifers	Baton Rouge Area Aquifers	St. Tammany Parish Aquifers	New Orleans Area Aquifers
Quarternary	Recent	Alluvial					
	Pleistocene	Terraces Prairie Montgomery Bentley Williana	Shallow sd “200-ft” sd “500-ft” sd “700-ft” sd	Shallow sd Upper Chicot Lower Chicot	Shallow sd “400-ft” sd “600-ft” sd	Upland Terraces Upper Pontchatoula	Shallow sd Gramercy Norco Gonzales-New Orleans “1,200-ft” sd
Upper Neogene	Pliocene	Fleming	Evangeline		“800-ft” sd “1,000-ft” sd “1,200-ft” sd	Lower Pontchatoula Big Branch	
					“1,500-ft” sd “1,700-ft” sd	Kentwood-Abita Covington Slidell	
	Upper Miocene				“2,000-ft” sd “2,400-ft” sd “2,800-ft” sd	Tchefuncta Hammond Amite	
			Jasper			Ramsay Franklinton	

Specific conductivities of the Big Branch samples from this study (described later and listed in Table 2) are contoured in Figure 2A for St. Tammany Parish to show the extent of the saltwater encroachment. Repeated sampling from 2001 through 2003 indicated a static saltwater front, probably due to present-day low withdrawal of groundwater from the aquifer. Samples were not available downdip of the fault system.

East and West Baton Rouge Parishes

Rollo (1969) described brackish waters in Pleistocene, Pliocene, and Upper Miocene sands at depths of 300 to 2,800 ft (90 to 850 m) in the Baton Rouge area, and Walters and Lovelace (1998) have recently summarized available water quality data. Previous researchers working on saltwater intrusion in the Baton Rouge area (Fig. 2B) have generally assumed that downdip in situ marine pore waters were moving northward (updip) within the aquifers and crossing the BR-DS Fault System in response to freshwater removal exceeding surface recharge (e.g., Rollo, 1969; Whiteman, 1979). Displacement on the fault was assumed to act as a partial barrier to the fluid movement.

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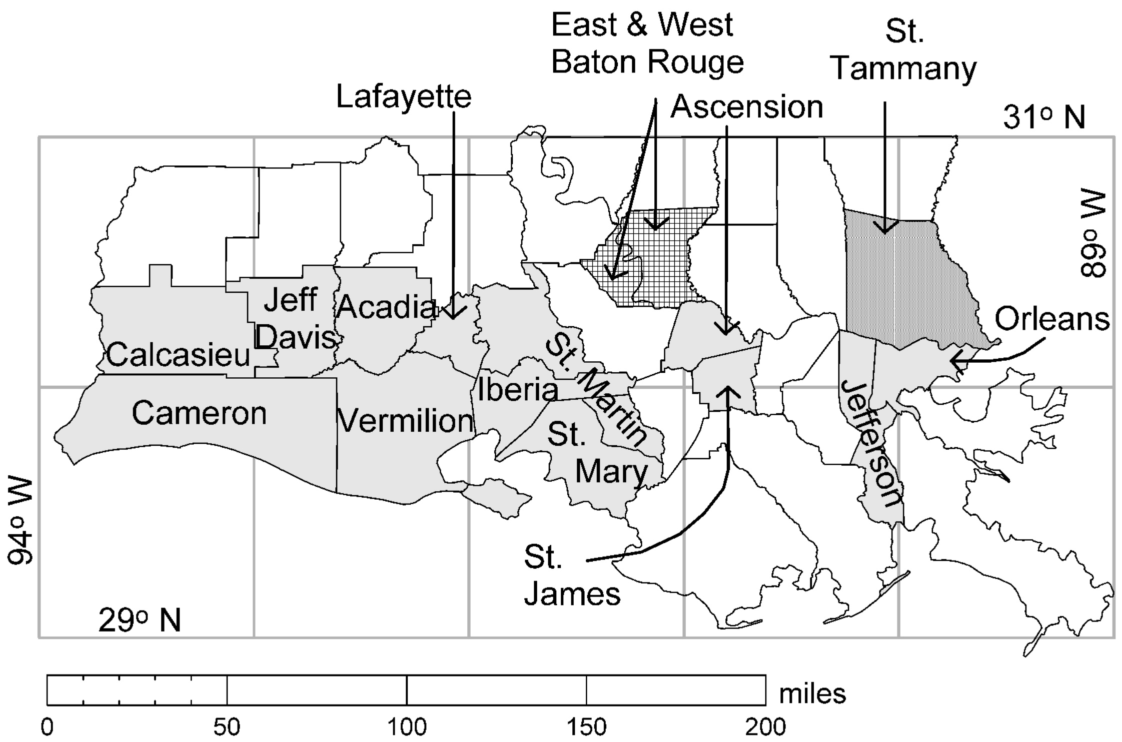

Figure 1. The South Louisiana study region included 3 saline groundwater areas: the Big Branch Pliocene Aquifer in St. Tammany Parish (hatched area); the Pleistocene, Pliocene, and Upper Miocene sands in East and West Baton Rouge Parishes (cross-hatched area); and the Pleistocene sands in 13 coastal parishes (shaded areas).

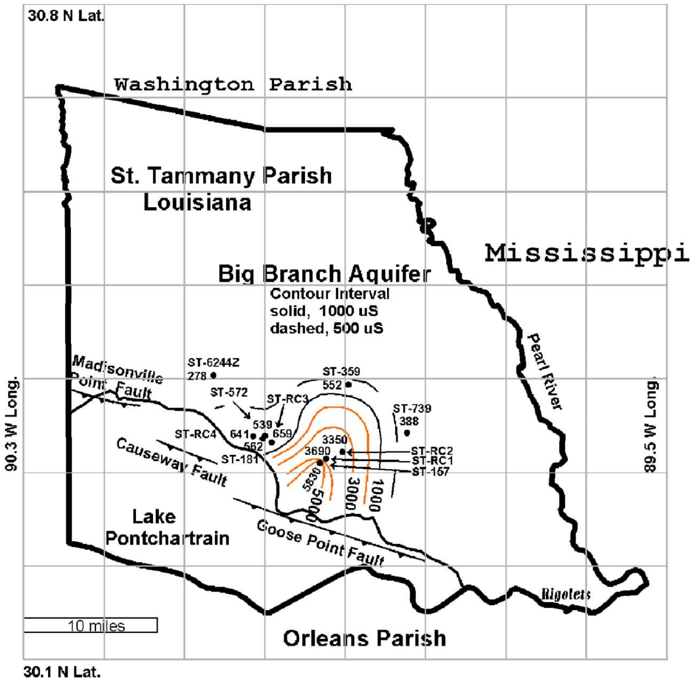

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Figure 2A. Well locations and specific conductivities (Table 2) in the Big Branch Aquifer in the Lacombe area at depths of 1,400-1500 ft (425-460 m). Faults are an extension of the BR-DS Fault System in Figure 2B.

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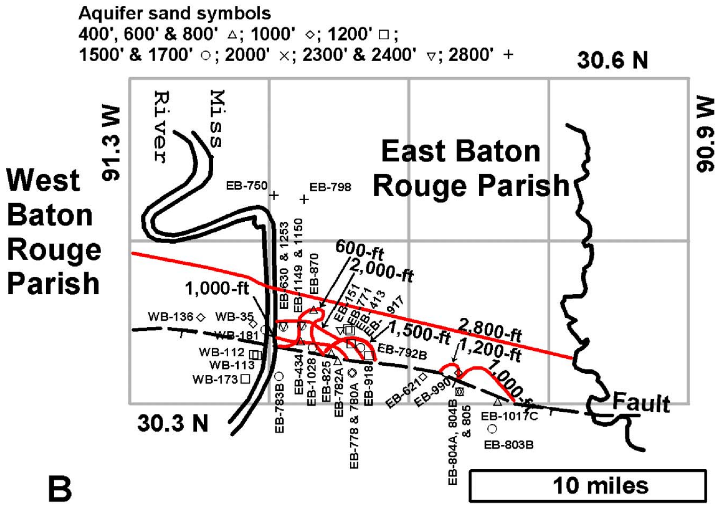

Figure 2B. Baton Rouge area aquifer well locations (Table 2) and 1992 salt-water fronts from Tomaszewski (1996).

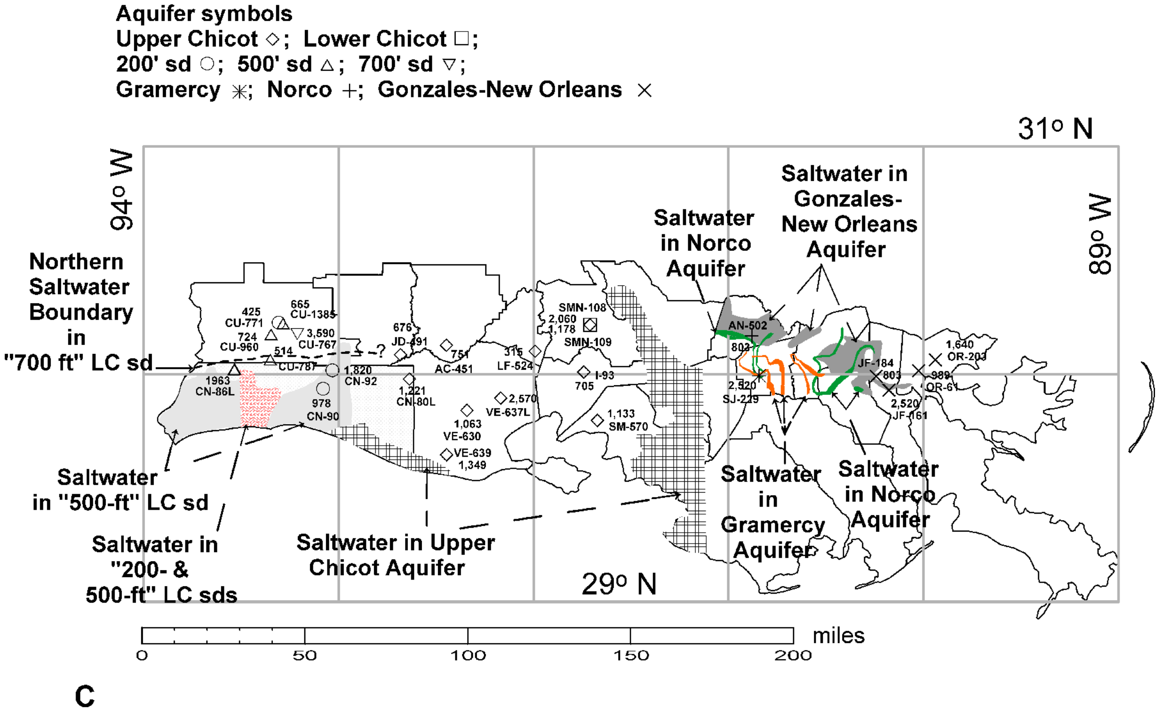

Figure 2C. Aquifer well locations and specific conductivities (Table 2) in coastal parishes with saltwater groundwater areas in Southeast Louisiana from Tomaszewski (2003) and in Southwest Louisiana from Lovelace (1999).

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Table 2. Well and groundwater information. See text for further explanation.

Well # DOTD	Aquifer & Sample Date	Latitude & Longitude	Depth ft	Sp. C. uS/cm	Tds mg/l	$^{87}Sr/^{86}Sr$
LP	Lake Pont., 9/01	N30.34980 W90.06300	1	4,030	2,028	n.m.
BL	B. Lacombe, 9/01	N30.31000 W90.93139	1	540	222	n.m.
St Tammany Parish – Big Branch						
ST-157	Big Branch, 9/01	N30.30972 W89.93111	1,503	5,830	3,165	0.708334
ST-181	Big Branch, 2/02	N30.33611 W90.00222	1,509	553	419	n.m.
ST-359	Big Branch, 11/01	N30.39333 W89.89583	1,253	552	514	n.m.
ST-572	Big Branch, 11/01	N30.33889 W90.00000	1,501	539	402	n.m.
ST-739	Big Branch, 11/01	N30.34194 W89.82333	1,576	388	410	n.m.
ST6244Z	Big Branch, 11/01	N30.40361 W90.06417	1,460	278	283	n.m.
ST-R1	Big Branch?, 7/03	N30.31444 W89.92361	?	3,690	2,186	0.708328
ST-R2	Big Branch, 10/01	N30.32155 W89.90348	1,500	3,350	1,990	0.708269
ST-R3	Big Branch? 11/01	N30.33194 W89.99111	?	659	484	n.m.
ST-R4	Big Branch? 10/01	N30.33862 W90.01442	?	641	461	n.m.
Baton Rouge Area Aquifers						
EB-825	BR 400'sd, 11/03	N30.43139 W91.15556	475	275	290	n.m.
EB1017C	BR 400'sd, 12/03	N30.40167 W91.03667	567	308	300	n.m.
EB-434	BR 600'sd, 11-03	N30.43861 W91.17778	611	441	356	n.m.
EB-870	BR 600'sd, 11-03	N30.45806 W91.16833	692	288	288	n.m.
EB-782A	BR 1000'sd, 1/03	N30.42693 W91.15111	1,189	1,800	1,076	0.707881
EB-805	BR 1000'sd, 11/03	N30.40778 W91.06389	1,072	24,900	14,555	0.708339
WB-35	BR 1200'sd, 12/03	N30.44917 W91.21167	1,290	305	303	n.m.
WB-136	BR 1200'sd, 12/03	N30.45333 W91.24917	1,305	279	286	n.m.
EB-621	BR 1200'sd, 12/03	N30.41667 W91.09028	1,487	545	428	n.m.
EB-780A	BR 1200'sd, 11/03	N30.41917 W91.14083	1,622	3,260	1,749	0.708226
EB-990	BR 1200'sd, 12/03	N30.41917 W91.06472	1,450	317	298	n.m.
WB-112	BR 1500'sd, 12/03	N30.43056 W91.21139	2,205	627	508	n.m.
WB-113	BR 1500'sd, 12/03	N30.42972 W91.20889	2,242	1,135	815	0.708342
WB-173	BR 1500'sd, 12/03	N30.41556 W91.21722	2,194	412	354	n.m.
EB-413	BR 1500'sd, 11/03	N30.44500 W91.14222	1,745	327	328	n.m.
EB-771	BR 1500'sd, 11/03	N30.44611 W91.14389	1,739	315	323	n.m.
EB-917	BR 1500'sd, 11/03	N30.43722 W91.14167	1,736	439	352	n.m.
EB-918	BR 1500'sd, 12/03	N30.42972 W91.12889	1,834	2,740	1,539	0.708372.
WB-181	BR 1700'sd, 12/03	N30.44556 W91.20333	1,900	292	281	n.m.
EB-804A	BR 1700'sd, 1/03	N30.40778 W91.06389	1,950	375	346	n.m.
EB-630	BR 2000'sd, 11/03	N30.44750 W91.19000	2,253	643	509	n.m.
EB-778	BR 2000'sd, 12/03	N30.41917 W91.14083	2,586	1,012	734	0.708408
EB-783B	BR 2000'sd, 12/03	N30.41722 W91.19333	2,675	3,340	2,154	0.708316
EB-792B	BR 2000'sd 11/03	N30.43472 W91.13500	2,286	387	363	n.m.
EB-803B	BR 2000'sd 12/03	N30.38500 W91.04056	2,565	2,270	1,405	0.708524
EB-1028	BR 2000'sd 11/03	N30.43472 W91.16917	2,238	1,156	730	0.70820
EB-1150	BR 2000'sd 11/03	N30.44806 W91.17694	2,242	833	593	n.m.
EB-1253	BR 2300'sd 11/03	N30.44778 W91.19000	2,687	408	401	n.m.

Table 2 cont. on next page

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Table 2. (Cont.) Well and groundwater information. See text for further explanation.

Well # DOTD	Aquifer & Sample Date	Latitude & Longitude	Depth ft	Sp. C. uS/cm	Tds mg/l	$^{87}Sr/^{86}Sr$
WB-151	BR 2400'sd, 11/03	N30.44472 W91.14944	2,658	335	327	n.m.
EB-804B	BR 2400'sd, 11/03	N30.40778 W91.06389	2,762	782	538	n.m.
EB-1149	BR 2400'sd, 11/03	N30.44806 W91.17694	2,694	386	370	n.m.
EB-750	BR 2800'sd, 11/03	N30.52806 W91.19667	2,643	728	612	n.m.
EB-798	BR 2800'sd, 11/03	N30.52583 W91.17528	2,647	1,660	1,011	0.708367
Chicot Aquifers						
SM-57U	U. Chicot sd 3/04	N29.79694 W91.67306	638	1,133	837	n.m.
SMN109	U. Chicot sd 3/04	N30.21778 W91.71111	375	1,178	989	n.m.
SMN108	L. Chicot sd 3/04	N30.21778 W91.71111	505	2,060	1,491	0.70836
I-93	U. Chicot sd 3/04	N30.00972 W91.74250	585	705	642	n.m.
LF-524	U. Chicot sd 3/04	N30.10139 W91.99306	174	315	341	n.m.
VE-630	U. Chicot sd 3/04	N29.8419W92.3422	498	1,063	896	n.m.
VE-637L	U. Chicot sd 3/04	N29.89583 W92.16861	243	2,570	1,751	0.70892
VE-639	U. Chicot sd 3/04	N29.64583 W92.44694	608	1.349	1,036	n.m.
AC-451	U. Chicot sd 3/04	N30.12778 W92.44722	293	751	698	n.m.
JD-491	U. Chicot sd 3/04	N30.08556 W92.68222	377	676	541	n.m.
CN-80L	U. Chicot sd 3/04	N29.97944 W92.63639	481	1,221	860	n.m.
Lake Charles Aquifers						
CN-90	LC 200 ft sd 3/04	N29.93639 W93.08000	396	978	695	n.m.
CN-92	LC 200 ft sd 3/04	N30.01778 W93.03222	443	1,820	1,146	0.70798
CU-771	LC 200 ft sd 3/04	N30.22667 W93.30833	241	425	385	n.m.
CN-86L	LC 500 ft sd 3/04	N30.02222 W93.53556	641	1,963	1,246	0.70788
CN-88L	LC 500 ft sd 9/04	N30.01528 W93.15833	804	2,360	1,397	n.m.
CU-787	LC 500 ft sd 3/04	N30.06472 W93.35056	734	514	437	n.m.
CU-960	LC 500 ft sd 3/04	N30.17528 W93.34694	598	724	512	n.m.
CU-1385	LC 500 ft sd 3/04	N30.22333 W93.28472	580	665	514	n.m.
CU-767	LC 700 ft sd 3/04	N30.17667 W93.21222	850	3,590	2,097	0.70804
New Orleans Area Aquifers						
AN-502	Norco, 9/04	N30.16556 W90.88111	300	803	566	0.70866
OR-61	Gonzales-NO,9/04	N30.01563 W90.02560	653	989	834	n.m.
OR-203	Gonzales-NO,9/04	N30.06382 W89.94002	453	1,640	1,101	n.m.
JF-161	Gonzales-NO,9/04	N29.93028 W90.17806	772	2,520	1,600	n.m.
JF-184	Gonzales-NO,9/04	N29.99103 W90.24280	704	803	602	n.m.
SJ-229	Gramercy, 9/04	N29.99377 W90.84452	345	1,253	1,022	0.70851

tds, from summation of measured concentrations; n.m., not measured; LP (Lake Pontchartrain) and BL (Bayou Lacombe) are open water samples; ST-R1, ST-R2 (drilled by R. Chabreck), ST-R3, and ST-R4 are unregistered wells.

Most of the shallow Baton Rouge sand aquifers contain some brackish waters updip (north) of the BR-DS fault system. These include the Pleistocene "400- and 600-foot" sands; the Pliocene "800-, 1,000-, 1,200-, and 1,500-foot" sands; and the Upper Miocene "2,000- and 2,800-foot" sands (Table 1). The two most heavily pumped aquifers with the saltwater front near the fault are the "1,500- and 2,000-foot" sands in which the front is moving northward, respectively, at estimated rates of about 100 ft/yr (Whiteman, 1979) and 930 ft/yr (Rollo, 1969).

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The saltwater fronts north (updip side) of the BR-DS Fault System sketched in the Baton Rouge area in Figure 2B are for 1992 (Tomaszewski, 1996). The Pliocene and Upper Miocene aquifers south of the fault are thought to contain primarily saltwater; however, the limited available water-quality data does not preclude occurrences of freshwater in these aquifers south of the fault.

Coastal parishes

Shallow Pleistocene aquifers in coastal parishes across South Louisiana (Fig. 2C) make up the third region of this study. These aquifers are part of the regional Chicot Aquifer System in southwest and south-central Louisiana and the New Orleans Aquifer System in southeast Louisiana (Table 1). Areas of saltwater intrusion shown in Figure 2C are from Nyman (1984) and Lovelace (1999) in southwest and south-central Louisiana, and from Tomaszewski (2003) in the New Orleans area of southeast Louisiana. The entire region is cut by numerous east-west trending gravity faults and includes numerous salt diapirs (Ewing and Lopez, 1991).

Brackish waters occur in the “200- 500- and 700-foot” Lake Charles sands in southwest Louisiana, the Upper and Lower Chicot sands in south-central Louisiana, and in the Gramercy, Norco, and the Gonzales-New Orleans Aquifers in southeast Louisiana. From west to east, the “200-foot” and “700-foot” sands grade into the Upper and Lower Chicot sands, respectively, and the “500-ft” sand pinches out, just east of the Calcasieu Parish Boundary. Continuity of these Pleistocene sands with those in the New Orleans Aquifer System further east is unknown.

Nyman (1984) attributed the in situ brackish waters in the Chicot Aquifer System to a combination of updip movement of marine pore waters within an aquifer, vertical leakage from underlying aquifers containing saltwater, e.g., from the “700-foot” Lake Charles sand into the “500-foot” Lake Charles sand, and saltwater coning from the base of an aquifer. These processes are driven by the discharge of freshwater in wells at a rate faster than surface aquifer recharge of the freshwater. The saltwater front in the most heavily pumped aquifer in southwest Louisiana, the “500-foot” sand, may be slowly moving northward from the border of Calcasieu and Cameron Parishes (Lovelace, 1999).

Unlike the Baton Rouge and Lacombe areas, the saltwater encroachments in the New Orleans area and in the southwest and south-central coastal parishes are not associated with one specific regional fault system. In Figure 2C, the brackish specific conductivities in several of the well samples from this study (described later and listed in Table 2) north of the saltwater aquifer fronts, indicate further updip movement of the fronts is occurring, e.g., CN-92 in the “200-ft” sand; CN-86L in the “500-foot” sand, CU- 767 in the “700-foot” sand, VE-637L in the Upper Chicot Sand; SMN-108 in the Lower Chicot Sand, and OR-203 in the Gonzales Aquifer.

Methods

Well locations

Sample well locations in the vicinities of Lacombe, Baton Rouge, and in the coastal Pleistocene aquifers across South Louisiana are shown, respectively, in Figs. 2A, 2B, and 2C. The longitude and latitude of each well location, together with the available LA DOTD well registration number at http://www.dotd.la.us/intermodal/wells/select_wells.asp are listed in Table 2. Samples from the mouth of Bayou Lacombe and Lake Pontchartrain area also listed in Table 2.

Ten artesian Big Branch wells in St. Tammany Parish (Fig. 2A) were sampled in 2001 through 2003. Four of these wells were unregistered and were identified by completion depth by Richard Chabreck, a Lacombe water-well driller. Samples from these wells are listed in Table 2 with well numbers ST-RC1 through ST-RC4. The 33 USGS monitor wells in East and West Baton Rouge Parishes (Fig. 2B, Table 2) and the 27 USGS monitor wells in the coastal Pleistocene aquifers (Fig. 2C, Table 2) were sampled, respectively, in 2003 and in 2004, during USGS sampling trips with Frank Glass.

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Field and laboratory procedures

The well-sampling procedure on non-artesian wells used either a permanently-mounted turbine pump or injection of compressed air through tubing below the water level to force the water to the surface. A minimum of two well-bore volumes was allowed to flow before taking samples. A Hydrolab Quanta G probe was used to measure specific conductivity, Eh, temperature, dissolved oxygen, and pH in artesian and pump wells and to measure specific conductivity in air-lift wells. Some of the samples had traces of H2S, and field iodometric titrations with thiosulfate indicated concentrations less than one mg/l.

Water samples were taken in 250 ml acid-washed bottles in the field and gravity-filtered through #42 micron Whatman filters in the laboratory. Alkalinity was measured on each filtered sample using a standard acid titration to a pH of 4.5. The remaining filtered sample was split into two 60 ml aliquots (one acidified) and refrigerated. The filtration, measurement of alkalinity, and acidification of field samples were generally completed within 8 hours of field collection.

Measurements of aqueous component concentrations were completed within six weeks of collection using Dionix 100 and Dionix 1000 ion chromatographs (IC) for cations (acidified aliquot) and anions (non-acidified aliquot). Aqueous silicon concentrations were measured colorimetrically by the molybdenum blue method on a Turner 690 UV-VIS spectrograph. Isotopic ratios of 87Sr/86Sr in 20 brackish-water samples were measured in filtered samples using a Finnigan MAT 262 mass spectrometer within nine months of collection. Analytical precisions were 1 mg l-1 HCO3 for alkalinities, 0.05 mg l-1 for cations, other anions, and aqueous SiO2, and 0.00001 for 87Sr/86Sr ratios. Analytical results are reported in Tables 2 and 3, and additional data such as pH, aqueous O2, N, and P concentrations are available from the senior author by request.

Procedures to identify and place age restrictions on the saltwater sources

The components commonly used as chemical fingerprints of saltwater sources are Br, Cl, Na, and K, e.g., see Carpenter (1978), Land and Prezbindowski (1981), Stoessell and Moore (1983), and Stoessell (1997). Linear mixing trends are determined by plotting the concentrations of one conserved component versus a second conserved component, e.g., Br versus Cl, and by plotting the concentration ratio of the two conserved components versus the reciprocal of the concentration of the component in the denominator, e.g., Br/Cl versus Cl-1. The first plot focuses on the more saline samples, and the second plot expands the dilute region to show how well the dilute samples fit a linear mixing relationship. The intercept on the second plot accurately delineates the slope of a trend line on the first plot, useful because of scatter in the mixing line. The intercept is usually close to the value of the ratio in the saltwater end member because its salt composition dominates the mixture.

Aqueous 87Sr/86Sr ratios can help set minimum age limits for marine Cenozoic formation fluids which have acted as saltwater end members. Since Late Eocene, the isotopic ratio has steadily increased in seawater due to decay of 87Rb to 87Sr and its subsequent input into the oceans through weathering reactions (Faure, 1998), making this a convenient fluid dating tool. However, if the marine formation fluid subsequently moves upward through other formations, the isotopic ratio may be elevated by mixing with a younger marine fluid and/or by picking up additional 87Sr generated from 87Rb decay in clays and feldspar, producing an apparent younger age. If Sr is conserved, plotting the 87Sr/86Sr ratios against the reciprocal of the total Sr concentrations produces a linear mixing line in which the intercept is an estimate of the Sr isotope ratio in the saltwater end member. Generally, the mixing line is expected to have a positive slope because younger pore waters are expected to have higher isotope ratios.

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Table 3. Aqueous Compositions. See text for further explanation.

Well # DOTD	Na	K	Mg	Ca	Sr	SiO_2	Br	Cl	SO_4	HCO_3
					Mmolarity					
LP	27.6	0.563	2.72	0.699	0.0035	0.115	0.0462	30.7	1.45	0.62
BL	2.91	0.043	0.197	0.107	0.0006	0.186	0.0035	3.05	0.125	0.21
St Tammany Parish – Big Branch										
ST-157	47.9	0.069	0.424	0.699	0.0049	0.331	0.0229	47.4	b.a.p	5.24
ST-181	5.31	0.011	b.a.p	0.018	b.a.p	0.451	0.0009	1.64	0.108	3.28
ST-359	6.05	0.007	0.002	0.022	b.a.p	0.313	b.a.p	0.080	0.123	5.57
ST-572	5.05	0.012	0.003	0.015	b.a.p	0.368	0.0010	1.59	0.107	3.21
ST-739	4.78	0.006	0.002	0.013	b.a.p	0.461	b.a.p	0.070	0.126	4.21
ST6244Z	3.06	0.004	0.002	0.042	b.a.p	0.519	b.a.p	0.080	0.096	2.75
ST-R1	33.6	0.059	0.253	0.432	0.0034	0.323	0.0148	29.9	0.017	5.00
ST-R2	29.1	0.043	0.140	0.294	0.0025	0.318	0.0120	27.8	0.002	4.87
ST-R3	6.26	0.011	0.005	0.027	b.a.p	0.384	0.0014	2.85	0.088	3.38
ST-R4	5.83	0.010	0.005	0.027	b.a.p	0.374	0.0011	2.34	0.101	3.44
Baton Rouge Area Aquifers										
EB-825	2.79	0.027	0.042	0.075	0.0007	0.800	b.a.p	0.107	0.072	2.65
EB1017C	3.13	0.009	0.004	0.012	b.a.p	0.572	b.a.p	0.104	0.078	2.98
EB-434	3.86	0.039	0.046	0.153	0.0015	0.581	0.0009	1.35	0.043	2.80
EB-870	2.66	0.033	0.034	0.107	0.0009	0.672	b.a.p	0.081	0.102	2.74
EB-782A	16.2	0.041	0.048	0.255	0.0027	0.323	0.0068	12.8	0.016	3.51
EB-805	195	0.270	9.71	18.5	0.1058	0.366	0.1110	251	b.a.p	2.23
WB-35	3.23	0.010	0.004	0.011	b.a.p	0.473	b.a.p.	0.079	0.111	3.05
WB-136	2.96	0.010	0.004	0.010	b.a.p	0.639	b.a.p.	0.096	0.098	2.72
EB-621	5.17	0.013	0.008	0.105	0.0007	0.479	0.0009	1.73	0.109	3.33
EB-780A	27.1	0.076	0.170	1.01	0.0182	0.111	0.0130	26.7	b.a.p	2.00
EB-990	3.15	0.009	0.003	0.033	b.a.p	0.456	b.a.p.	0.069	0.116	3.00
WB-112	5.99	0.022	0.008	0.045	b.a.p	0.817	0.0011	2.23	0.083	3.79
WB-113	10.7	0.028	0.013	0.135	0.0006	0.656	0.0029	6.13	0.057	4.90
WB-173	4.07	0.011	0.003	0.020	b.a.p	0.463	b.a.p.	0.828	0.091	3.16
EB-413	3.60	0.010	0.003	0.013	b.a.p	0.479	b.a.p.	0.271	0.105	3.21
EB-771	3.57	0.011	0.004	0.022	b.a.p	0.524	b.a.p.	0.120	0.099	3.18
EB-917	4.21	0.014	0.003	0.016	b.a.p	0.409	0.0008	1.22	0.100	2.88
EB-918	23.5	0.059	0.172	1.10	0.0054	0.370	0.0109	21.9	0.063	2.33
WB-181	3.08	0.010	0.001	0.012	b.a.p	0.398	b.a.p.	0.082	0.091	2.85
EB-804A	4.00	0.012	0.002	0.016	b.a.p	0.399	b.a.p,	0.055	0.109	3.54
EB-630	6.49	0.019	0.005	0.053	b.a.p	0.404	0.0012	2.49	0.089	3.87
EB-778	9.81	0.026	0.006	0.035	b.a.p	0.393	0.0020	4.20	0.028	5.41
EB-783B	32.5	0.072	0.016	0.046	0.0009	0.348	0.0105	20.8	b.a.p	10.5
EB-792B	3.98	0.013	0.002	0.025	b.a.p	0.411	b.a.p.	0.077	0.104	3.82
EB-803B	21.5	0.067	0.082	0.239	0.0047	0.343	0.0074	16.6	0.006	4.70
EB-1028	10.1	0.027	0.021	0.143	0.0010	0.606	0.0032	6.86	0.067	3.33
EB-1150	7.72	0.024	0.013	0.147	0.0008	0.408	0.0020	4.18	0.096	3.70

Table 3 cont. on next page

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Table 3. (Cont.) Aqueous Compositions. See text for further explanation.

Well #	Na	K	Mg	Ca	Sr	SiO_2	Br	Cl	SO_4	HCO_3
DOTD	Mmolarity									
EB-1253	4.43	0.018	0.002	0.028	b.a.p	0.398	b.a.p.	0.089	0.113	4.24
WB-151	3.68	0.013	0.002	0.030	b.a.p	0.411	b.a.p.	0.073	0.108	3.33
EB-804B	7.31	0.023	0.003	0.072	b.a.p	0.393	0.0015	3.78	0.089	3.51
EB-1149	4.07	0.015	0.001	0.035	b.a.p	0.373	b.a.p	0.078	0.112	3.90
EB-750	7.52	0.024	0.003	0.033	b.a.p	0.418	0.0010	1.87	0.045	5.59
EB-798	14.6	0.052	0.021	0.189	0.0030	0.362	0.0042	8.74	0.022	5.41
Chicot Aquifers										
SM-57U	5.44	0.069	1.23	1.92	0.0040	0.575	0.0030	5.39	0.001	6.16
SMN109	6.96	0.069	1.14	1.94	0.0121	0.619	0.0022	3.53	b.a.p	9.13
SMN108	15.5	0.092	1.23	2.06	0.0128	0.549	0.0057	11.5	b.a.p	9.42
I-93	2.93	0.044	0.888	1.63	0.0048	0.653	b.a.p	1.12	b.a.p	6.67
LF-524	2.45	0.095	0.211	0.352	0.0008	0.758	b.a.p	0.217	0.024	3.38
VE-630	6.18	0.062	1.17	1.66	0.0059	0.525	0.0029	5.22	b.a.p	7.19
VE-637L	15.1	0.078	1.81	4.09	0.0059	0.569	0.0093	22.0	b.a.p	6.18
VE-639	9.00	0.072	1.04	1.70	0.0110	0.456	0.0052	8.89	b.a.p	6.38
AC-451	4.92	0.068	0.551	1.14	0.0068	0.514	0.0012	1.13	0.001	7.41
JD-491	3.80	0.043	0.477	1.05	0.0027	0.680	0.0024	2.85	b.a.p	4.20
CN-80L	7.61	0.067	0.810	1.45	0.0086	0.425	0.0042	7.78	b.a.p	4.95
Lake Charles Aquifers										
CN-90	7.66	0.042	0.342	0.609	0.0029	0.438	0.0030	4.85	b.a.p	4.69
CN-92	13.0	0.065	0.621	1.27	0.0081	0.467	0.0064	11.6	0.016	5.49
CU-771	2.42	0.045	0.332	0.676	0.0035	0.394	b.a.p	0.494	0.020	4.08
CN-86L	16.8	0.048	0.229	0.556	0.0043	0.478	0.0069	14.4	b.a.p	4.74
CN-88L	18.8	0.073	0.402	0.936	0.0083	0.468	0.0091	16.3	0.002	5.03
CU-787	3.36	0.043	0.232	0.686	0.0029	0.565	0.0010	1.31	0.001	4.00
CU-960	3.04	0.085	0.588	1.26	0.0087	0.909	0.0023	3.78	0.001	3.02
CU-1385	4.36	0.062	0.351	0.998	0.0025	0.836	0.0022	3.02	0.004	3.36
CU-767	24.8	0.141	1.39	2.99	0.0136	0.704	0.0155	29.9	b.a.p	4.29
New Orleans Area Aquifers										
AN-502	5.44	0.047	0.389	0.654	0.0031	0.466	0.0025	4.09	0.002	3.79
OR-61	9.83	0.102	0.091	0.125	0.0008	0.429	0.0025	2.71	0.012	7.75
OR-203	14.9	0.102	0.183	0.091	b.a.p	0.367	0.0060	10.0	0.001	6.01
JF-161	23.3	0.116	0.302	0.465	0.0035	0.468	0.0095	17.3	0.002	6.44
JF-184	7.48	0.046	0.066	0.104	b.a.p	0.481	0.0026	3.89	0.002	4.18
SJ-229	6.12	0.086	1.31	2.16	0.0097	0.549	0.0036	5.58	0.001	8.64

b.a.p. below analytical precision; LP (Lake Pontchartrain) and BL (Bayou Lacombe) are open water samples; ST-R1, ST-R2 (drilled by R. Chabreck), ST-R3, and ST-R4 are unregistered wells.

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Results and Discussion

Chemical fingerprints

Millimolarity (mM) plots are shown in the A and B plots in Figures 3, 4, and 5, respectively, for Br, Na, and K. In each figure, the mMi of a component is plotted versus mMCl in the A plot, and the mM ratio of the component to Cl is plotted versus (mMCl)-1 in the B plot, The dashed seawater-mixing line in the figures was computed using the freshwater sample in Table 3 from Bayou Lacombe (which flows into Lake Pontchartrain, an estuary of the Gulf of Mexico) and seawater (from Pytkowicz, 1985). Linear mixing trends in the figures were sketched (when possible) to qualitatively fit the samples. The seawater ratio and the average South Louisiana Miocene formation fluid ratio (Collins, 1970) are also plotted on the B plot in each figure to indicate, respectively, the expected ratio for a Quaternary marine formation fluid and for a Neogene marine formation fluid that dissolved halite.

Br and Cl

The linear mixing trend in Figure 3A for mM of Br versus Cl fits the samples from all the aquifers. Two trends occur in Figure 3B in which the molar ratio of Br/Cl is plotted versus the reciprocal of Cl concentration. The trends indicate the dilute waters in the coastal Pleistocene aquifers are enriched (for unknown reasons) in Br relative to those in the Baton Rouge sands and the Big Branch Aquifer. The common intercept in Figure 3B for both trends gives the molar Br/Cl ratio in the saltwater source. This ratio is about 0.0005, close to the ratio in the average South Louisiana Miocene formation fluid (Collins, 1970) and a factor of 3 less than the ratio in seawater. This ratio “fingerprints” the saltwater source(s) as having increased salinity due to halite dissolution. The ratio can be explained by a marine formation fluid dissolving more than 70 grams of diagenetically recrystallized halite per liter of seawater, the halite containing an average of 50 mg Br/kg (Stoessell and Carpenter, 1986).

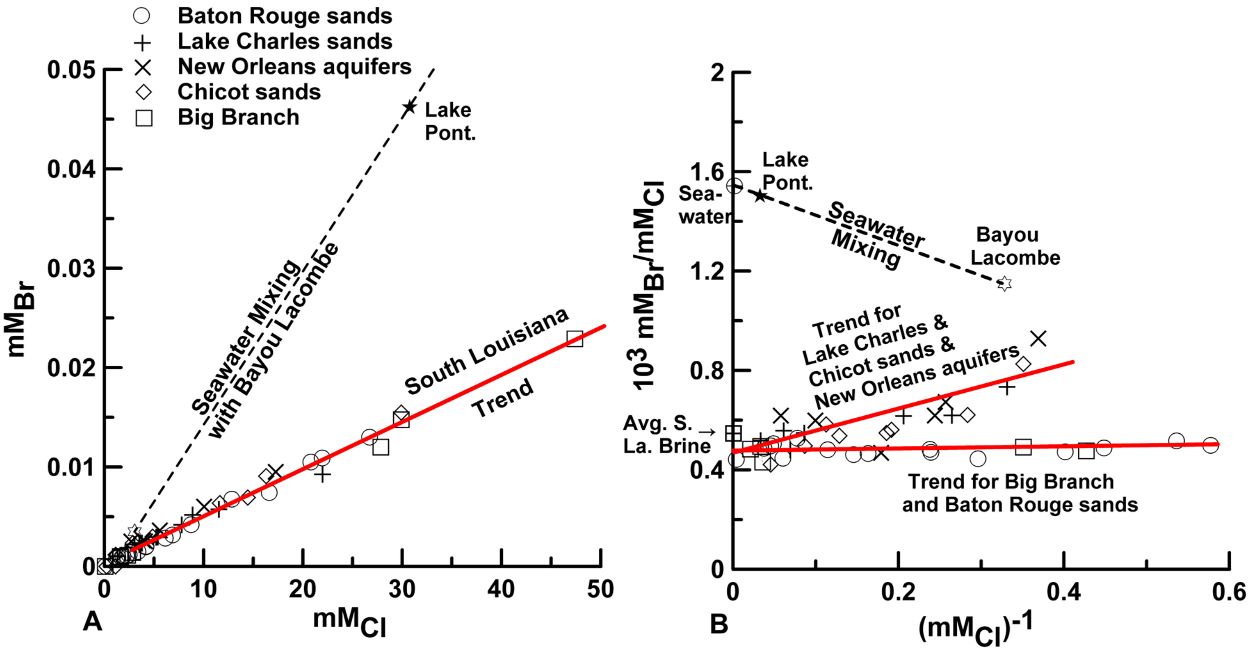

Figure 3. (A) mM_{Br} versus mM_{Cl} and (B) 10^3 mM_{Br}/mM_{Cl} versus $(mM_{Cl})^{-1}$ (Table 3).

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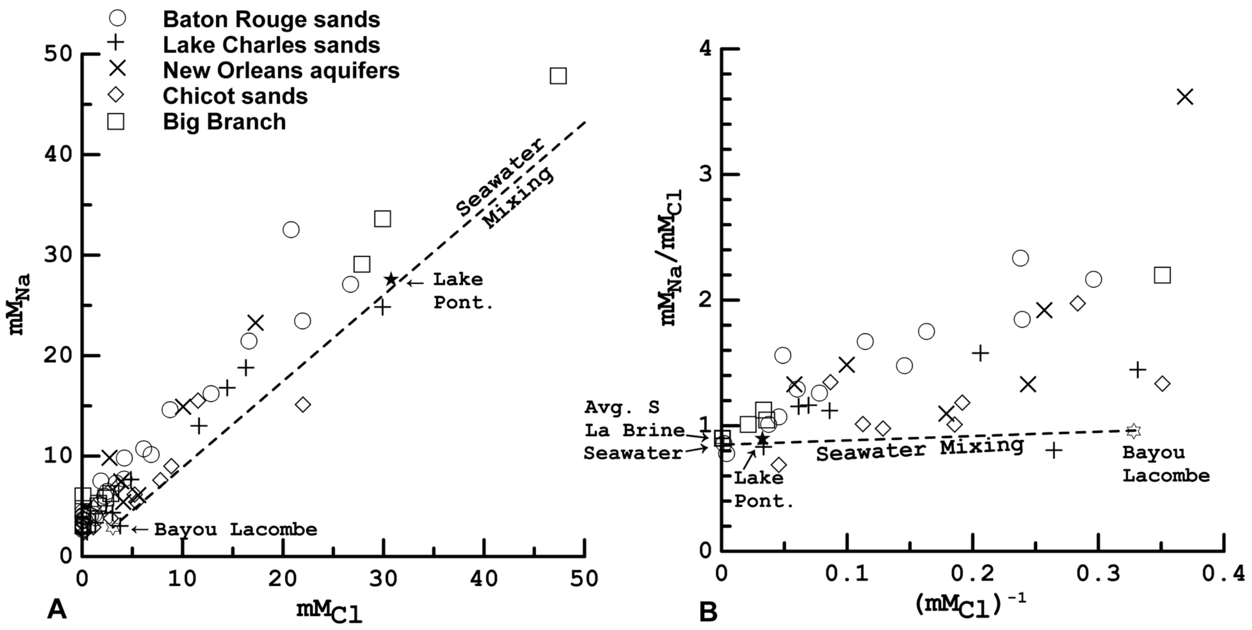

Figure 4. (A) mM_{Na} versus mM_{Cl} and (B) mM_{Na}/mM_{Cl} versus $(mM_{Cl})^{-1}$ (Table 3).

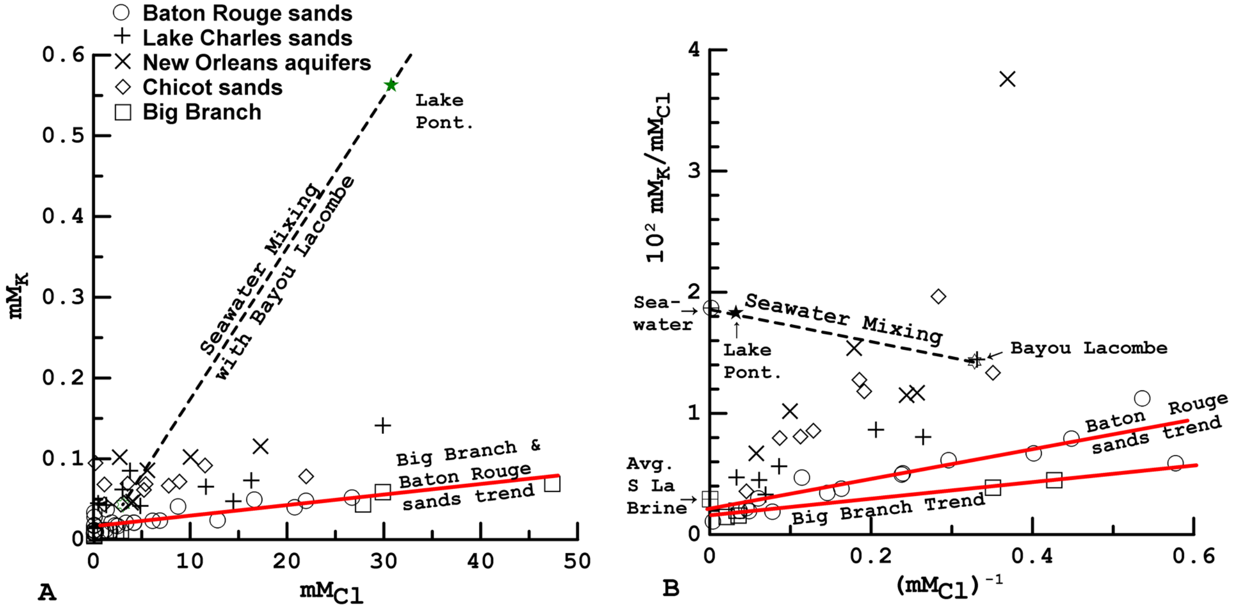

Figure 5. (A) mM_K versus mM_{Cl} and (B) mM_K/mM_{Cl} versus $(mM_{Cl})^{-1}$ (Table 3).

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Na and Cl

Halite dissolution will produce a molar Na/Cl ratio approaching one in the saltwater source, larger than the 0.86 ratio in seawater. The dissolution of 70 grams of halite dissolution per liter of marine pore fluids (mentioned above) would produce an aqueous molar Na/Cl ratio of 0.94. With the exceptions of 4 samples mentioned below, Na concentrations and molar Na/Cl ratios, respectively, plot above above the seawater-mixing line in Figures 4A and 4B, supporting halite dissolution as the salinity source.

The scatter in the data in Figures 4A and 4B is probably due to water-rock interactions. In freshwaters at near-surface temperatures, Na is input from weathering feldspars and exchanged with calcium on clays (Berner, 1971). Na is commonly removed by albitization of Ca feldspar during diagenesis in deeper formations (Land and Prezbindowski, 1981). Three of the four exceptions (EB-805, VE-637L, and CU-767) are saline with high molar Ca/Na ratios, consistent with Na removal by albitization of Ca feldspar, and the fourth sample (CU-960) is predominantly freshwater in which the Na concentration reflects near-surface weathering reactions.

K and Cl

The linear mixing trend for the saline samples in Figure 5A for mM of K plotted versus Cl fits the samples from the Big Branch Aquifer and the Baton Rouge sands. The samples from the coastal Pleistocene aquifers in the figure have more scatter and higher K concentrations and do not form a linear mixing trend. The linear trend in Figure 5A splits into two trends in Figure 5B in which the molar K/Cl ratio is plotted against the reciprocal of Cl concentration. The trends indicate the dilute waters in the Baton Rouge sands are slightly enriched in K (for unknown reasons) relative to those in the Big Branch Aquifer. The samples in Figure 5B from the coastal Pleistocene aquifers have higher molar K/Cl ratios and have too much scatter to define a linear mixing trend. However, with increasing chlorinity, the molar K/Cl ratios of all samples converge towards a common intercept in Figure 5B ranging from 0.0015 to 0.003, bracketing the ratio of 0.0029 for the average South Louisiana Miocene formation fluids (Collins, 1970). These ratios for the saltwater sources are more than a factor of 6 lower than in seawater. Removal of K from pore waters by illitization of smectites is a common diagenetic reaction in deeply-buried formations (Stoessell and Moore, 1983), making the ratio consistent with the saltwater source being a deep formation fluid.

SO_4 and Mg

Only minor to trace concentrations of Mg and SO4 are present in the groundwater samples in Table 3, consistent with the saltwater source being dissolution of halite by a formation fluid. However, the lack of SO4 is not diagnostic because it is removed by both biogenic SO4 reduction at near-surface temperatures and by thermal SO4 reduction at higher temperatures. But the low concentrations of Mg support the saltwater source being a deep formation fluid. Mg is expected to be removed at higher diagenetic tempertures by dolomitization of calcium carbonate and transformation of kaolinite and other 7A clays into 14A chlorite (Berner, 1971; Carpenter, 1978; Stoessell and Moore, 1983).

Age of salt-water source

$^{87}Sr/^{86}Sr$

The expected 87Sr/86Sr ratios from Faure (1998) for marine formation fluids range from 0.7089 (late Miocene) to 0.7090 (Pliocene) to 0.7092 (Quaternary). The measured ratios (from Table 2) of 19 out of 20 samples in this study are plotted versus the reciprocal of total strontium concentrations in Figure 6 with the one unplotted sample being off scale. The ratios are grouped by aquifer or group of adjacent aquifers and 6 mixing trends are shown in the figure. The mixing trends have to be used with caution since two trends involve only two samples each. Nevertheless, the intercepts provide an estimate of the expected ratios in the saltwater sources. These ratios range from 0.7080 to 0.7085, corresponding to seawater ages of Middle Oligocene to Early Miocene, consistent with the saltwater

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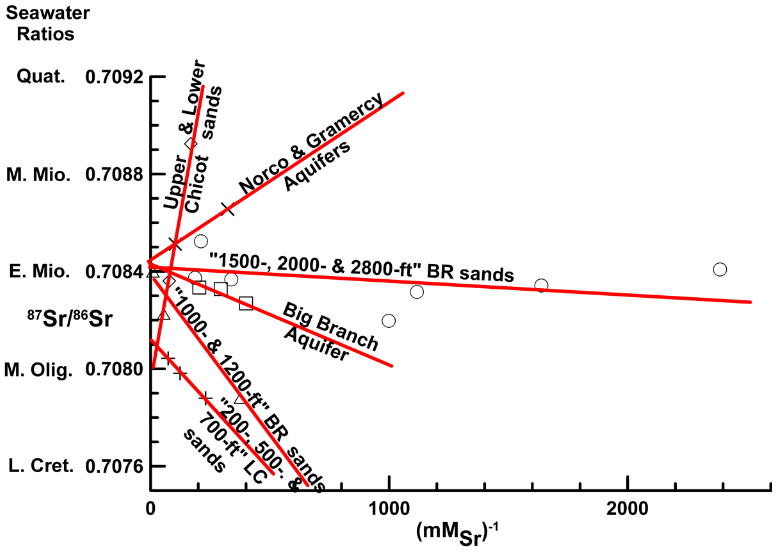

Figure 6. $^{87}Sr/^{86}Sr$ **versus** $(mM_{Sr})^{-1}$ **for different aquifer groups (Tables 2 and 3).**

sources being older formation fluids than in situ marine fluids in the Late Miocene to Pleistocene-age aquifers. The negative slopes of some of the mixing trends are unexpected. We can only hypothesize that earlier saltwater sources were deeper (older) formation fluids and their lower isotope ratios are reflected in the brackish groundwaters.

Summary and Conclusions

A simple chemical profile of formation fluids in deep Cenozoic Gulf Coast formations occurs due to diagenetic reactions and halite dissolution (Stoessell and Moore, 1983). These brines have low molar Br/Cl ratios, molar Na/Cl ratios approaching one, low molar K/Cl ratios, and are depleted in SO4 and Mg concentrations. These are also the chemical profiles in this study delineated for the saltwater sources in the brackish waters in the shallow South Louisiana aquifers.

The only known halite sources are deeper salt diapirs, suggesting the saltwater sources were deep migrating formation fluids. The 87Sr/86Sr ratios imply the minimum age of these formation fluids are Early Miocene. These fluids dissolved halite, entered the fault systems, migrated up the fault planes and entered some of the Upper Neogene and Quaternary aquifers.

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The research began with the serendipitous sampling of a brackish, artesian Big Branch well in Lacombe on property owned by Judy and Bill Wilson. The field aspects of the project could not have been completed without the help of Richard Chabreck of Lacombe and Frank Glass and Dan Tomaszewski of the USGS. The $^{87}Sr/^{86}Sr$ ratios were measured at LSU in Lui-Heung Chan's laboratory and the 2 Dionix ion chromatographs were purchased with Louisiana LEQSF/8(G) grants to RKS.

References

Berner, R.A., 1971, Principles of Chemical Sedimentology: New York, N.Y., McGraw Hill, 240 p.

Carpenter, A.B., 1978, Origin and chemical evolution of brines in sedimentary basins, J.S. Johnson and J.R. Russell, eds. 13th Industrial Minerals Forum: Oklahoma Geological Survey Circular 79, p. 60-77.

Collins, A.G., 1970, Geochemistry of some petroleum-associated waters from Louisiana: United States Department of the Interior, Bureau of Mines, Report of Investigations 7326, 31 p.

Ewing, T.E. and R.F. Lopez, 1991, Principal structural features, Gulf of Mexico Basin, A. Salvador, ed., The Gulf of Mexico Basin: The Geological Society of America, The Geology of North America v. J, plate 2.

Faure, G., 1998, Principles and Applications of Inorganic Geochemistry: 2nd edition, Upper Saddle River, New Jersey, Prentice Hall, 600 p.

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Land, L.S. and D.R. Prezbindowski, 1981, The origin and evolution of saline formation water, Lower Cretaceous carbonates, south-central Texas, U.S.A: Journal of Hydrology v. 54, p. 51-74.

Lopez, J., S. Penland, P. Connor Jr, J. Kindinger and J. Williams, 2002, Baton Rouge-Denham Springs Fault System, Lake Pontchartrain, S. Penland, A. Beall and J. Waters, eds. Environmental Atlas of the Lake Pontchartrain Basin: Lake Pontchartrain Basin Foundation, p. 55.

Lovelace, J.K. and W.M. Lovelace, 1995, Hydrogeologic unit nomenclature and computer codes for aquifers and confining units in Louisiana. State of LA, Office of Public Works, Water Resources Special Report No. 9, 12 p.

Lovelace, J.K., 1999, Distribution of saltwater in the Chicot Aquifer System in the Calcasieu Parish Area, Louisiana, 1995-96: State of LA, Water Resources Section, Water Resources Technical Report No. 66, 61 p.

Nyman, D.J. and L.D. Fayard (1978) Groundwater resources of Tangipahoa and St. Tammany Parishes, southeastern Louisiana: State of LA, Office of Public Works, Water Resources Technical Report No. 15, 76 p.

Nyman, D.J., 1984 The occurrence of high concentrations of chloride in the Chicot Aquifer System of southwestern Louisiana: State of LA. Office of Public Works, Water Resources Technical Report No. 33, 75 p.

Rollo, J.R., 1969, Saltwater encroachment in aquifers of the Baton Rouge Area, Louisiana: State of LA, Office of Public Works, Water Resources Bulletin No. 13, 45 p.

Pyktowicz, R.M., 1983, Equilibria, Nonequilibria, and Natural Waters, Vol 1: New York, N.Y., John Wiley, 351 p.

Stoessell, R.K., 1997, Delineating the chemical composition of the salinity source for saline groundwaters: An example from east-central Concordia Parish, Louisiana: Ground Water, v. 35, p. 409-417.

Stoessell, R.K. and A.B. Carpenter, 1986, Stoichiometric saturation tests of $NaCl_{1-x}Br_x$ and $KCl_{1-x}Br_x$: Geochimica et Cosmochima Acta, v. 50, p. 1465-1474.

Stoessell, R.K. and C.H. Moore, 1983, Chemical constraints and origins of four Gulf Coast reservoir fluids: American Association of Petroleum Geologists, v. 67, p. 896-906.

Tomaszewski, D.J., 1996, Distribution and movement of saltwater in aquifers in the Baton Rouge area, Louisiana, 1990-92: State of LA, Office of Public Works, Water Resources Technical Report No. 59, 44 p.

Tomaszewski, D.J., 2003, Ground-water resources along the lower Mississippi River, southeastern Louisiana: State of LA, Office of Public Works, Water Resources Technical Report No. 69, 23 p.

Walters, D.J. and W.M. Lovelace, 1998, Groundwater quality for East and West Baton Rouge, East and West Feliciana, and Pointe Coupee Parishes, Louisiana, water years 1944-97: State of LA, Office of Public Works, Water Resources Basic Records Report No. 21, 54 p.

Whiteman, C.D. Jr., 1979, Saltwater encroachment in the “600-foot” and “1,500” foot sands of the Baton Rouge area, Louisiana, 1966-78, including a discussion of saltwater in other sands: Louisiana Department of Transportation and Development, Office of Public Works Water Resources Technical Report No. 19, 49 p.