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PRELIMINARY LIMNOLOGIC INFORMATION ON WATERS OF THE CUATRO CIENEGAS BASIN, COAHUILA, MEXICO

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ABSTRACT. Aquatic habitats in the Cuatro Ciénegas basin, central Coahuila, México, range from springs, through permanent streams and lakes, to ephemeral playas. There has been much disturbance through canalization, but most of the springs originally led *via* streams to closed saline lakes. A sequential change in ionic composition occurs with evaporation and concentration throughout such a series. Most waters are dominated by Ca^{++} and SO_4^{--}, and especially at their spring origins; with evaporation this changes to a dominance of Mg^{++} and SO_4^{--}, and a shift from a sulfato-carbonate water to a sulfato-chloride type. The Ca:Mg ratio is remarkably decreased in the more concentrated water. Total EDTA hardness ranged from 490 to 66,200 mg/liter, indicating the spectrum of chemical habitats represented. Most waters were similar at their spring origins, however, with hardness averaging near 1,200 mg/liter.

Studies of limnology in northern México are scarce (Cole, 1963, 1968), and especially in the Bolsones Region of the Mesa del Norte. Many remnants of large Pluvial lakes became extinct in this part of México during the last 100 years, before having been studied. Laguna de Mayrán, for example, known to occupy part of the basin of a major lake that was partially drained by structural uplift in Pleistocene (Arellano, 1951), held considerable water in 1926 (Goldman, 1951), but was dry when visited by Deevey in 1941 (Deevey, 1957) and when seen by Minckley in 1964 (unpublished). Death of this lake may be partially attributed to irrigation diversions in its drainage (Tamayo and West, 1964), but drying trends and lake recessions certainly occurred in the late 1800 prior to man's impact on the water resources of the region (*see* Meek, 1904). The numerous large lakes of northern México such as lagos de Guzman, Patos, Parras, Santa Maria, and so on (Meek, loc. cit.), probably have recent histories similar to that of Mayrán.

The Cuatro Ciénegas basin in central Coahuila, México, has within an area of a few hundred km^2 a range of aquatic habitats unexcelled in any other desert bolsón known to us. The basin is situated in the

Coahuilan Folded Belt of the Sierra Madre Oriental (West, 1964). Its floor lies about 740 m above mean sea level, and mountains surrounding it rise to more than 3,000 m. The area is climatically arid, with an average annual rainfall of less than 200 mm (Vivó Escoto, 1964).

Water originates mostly from thermal (25°–35° C) springs, which feed seeps, ponds, lakes, and rivers. Most of these now are drained by canals, but in the past they terminated in closed, shallow basins in which playas or permanent, saline lakes occurred. The only such lake that presently remains has an area of between 1 and 2 km². In this paper, preliminary limnologic data on waters of the area are reported. Information included below will hopefully suffice to describe the waters for purposes of this paper. Detailed descriptive information is soon to be published by Minckley. Additional data on aquatic habitats are in publications by Legler (1960), Webb and Legler (1960), Minckley (1962), Webb, *et al.* (1963), Miller and Minckley (1963), and Hubbs and Miller (1965); the last authors also reviewed the rich vertebrate endemism of the area. Taylor (1966) described the unique, aquatic molluscan fauna of the basin, and Cole and Minckley (1966) reported a new species of cirolanid isopod.

COLLECTION LOCALITIES AND METHODS OF STUDY. Localities represented by limnologic data reported here, plus other places mentioned in the text, are plotted on the sketch map (Fig. 1). Samples were collected in one-liter, polyethylene bottles for analyses of principal inorganic constituents. Samples for dissolved O_2 determination were collected by a siphon device in 250-ml, glass-stoppered bottles. Methods of analysis are in Table 1; tabulations of most results are in Table 2.

Springs and lakes in the area are canalized and interconnected; thus interpretation of drainage systems and relationships between springs is difficult. Of the waters samples, only the Churince Laguna-Río Churince-Laguna Grande drainage is scarcely disturbed by man. This system represents the original condition for most of the others: 1) a subterranean water source; 2) a stream draining it and leading through marshy terrain to; 3) a closed lake where extreme concentration *via* evaporation occurs. A resultant sequential change in relative ionic proportions can best be seen in such basins. The other systems have been altered markedly and the closed lakes terminating them are no longer connected with water sources and are dry except following rainy periods. The most concentrated body of water studied so far is Laguna Salada which no longer receives water from its original source, but is occasionally supplied *via* Julio's Canal.

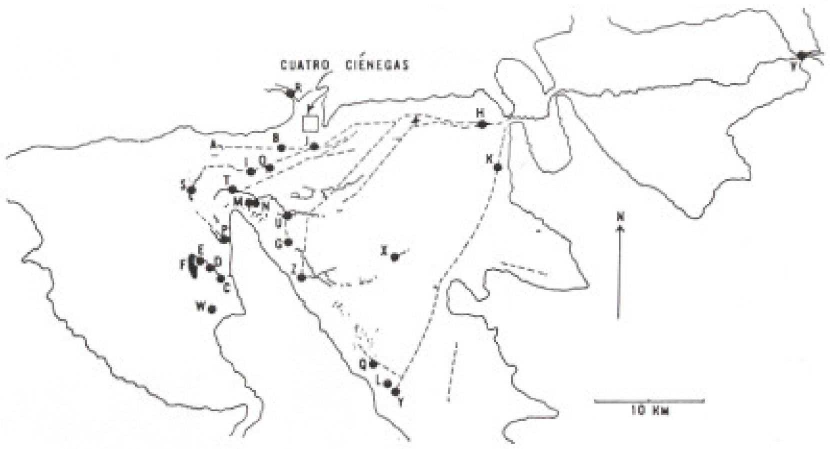

Fig. 1. Sketch map of the Cuatro Ciénegas basin, Coahuila, México, showing localities mentioned in text; the distance from Tio Candido (Z) to the center of Cuatro Ciénegas is 13 km.

a. Anteojo	n. El Mojarral (East)
b. Anteojo Canal	o. Laguna Salada
c. Churince(= Posos Bonitos)	p. Posos De La Becerra
d. Unnamed Laguna	q. Quintero
e. Mouth of Rio Churince	r. Rio Canon
f. Laguna Grande	s. El Garabatal
g. Escobeda	t. Rio Mesquites
h. Ferriño's Canal	u. Rio Puente Colorado
i. La Angostura Canal (12/64)	v. Rio Salado De Los Nadadores
j. La Angostura Canal (4/65)	w. San Marcos
k. La Polilla Canal	x. San Pablo
l. Los Fresnos	y. Santa Tecla
m. El Mojarral (West)	z. Tio Candido

The Río Mesquites system, separated in Table 2 as a major series of aquatic habitats, is connected directly by canals to the Río Salado de los Nadadores (Fig. 1). La Angostura Canal drains marshes and springs associated with the Río Garabatal (Hubbs and Miller, 1965). Anteojo is relatively isolated, but probably also belongs to the Río Garabatal complex. Lagunas in the southeastern lobe of the basin appear distinctive. On the basis of faunal evidence (Miller and Minckley, 1963; Minckley, unpublished data), and field examination of sills and other topographic features (Hubbs and Miller, 1965), they are more closely related to the Río Salado drainage than to the formerly-internal drainage of the part of the Cuatro Ciénegas basin lying immediately west.

RESULTS. Our few data on dissolved O_2 are from nine samples gathered in April 1961. Six of the samples were from open water in the

TABLE 1

Methods of analysis of water samples from Cuatro Ciénegas, Coahuila México.

Analysis or Measurement	Technique
pH	Battery-operated, "pocket" pH-meter
Temperatures	Standard, pocket thermometer in °F, converted to °C
Dissolved oxygen	Sodium-azide modification of Winkler method
EDTA hardness	Titration, EDTA
Ca^{++} hardness	Titration, EDTA following precipitation of Mg^{++} as $Mg(OH)_2$
Mg^{++} hardness	Calculated by subtraction
Ca^{++}	Calculated from Ca^{++} hardness
Mg^{++}	Calculated from Mg^{++} hardness
Total dissolved solids	By evaporation at 105°C after membrane filtration
Na^{+}	Flame photometry
K^{+}	Flame photometry
SO_4^{--}	Turbidimetric analysis following method of Hach Chemical Co., Ames, Iowa
CO_3^{--}	Titration, total alkalinity as $CaCO_3 \times 0.6$
Cl^{-}	Titration, Hach Chemical Co. modification of Clarke Mercuric-Nitrate method
SiO_2	Spectrophotometry, heteropoly-blue method

lagunas and were near 100% of O_2 saturation, ranging from 6.6–7.6 mg/liter. One sample from an inflow spring of Posos de la Becerra had only 4.1 mg/liter, about 53% of saturation. Fishes and other animals living in the inflows of this and other large springs attest to the adequate oxygenation of subterranean waters in the basin. Supersaturation of dissolved oxygen was recorded in Ferniños Canal (150%, 13.3 mg/liter) and in a flood pool of the Rio Garabatal (130%, 12.4 mg/liter); both sites had dense beds of *Chara*. During times of high insolation, bubbles are abundant on the undersides of floating waterlily leaves (*Nymphaea* sp.) and thin trails of bubbles rise from the extensive submerged beds of the same plant, or from algae on relatively open bottoms. Extensive flotation of sediments also occurs in shallower waters, as a result of algal activity. Transparency in the basin waters is remarkably great and productivity must be unusually high.

Hydrogen-ion concentration varies with habitat and time of day.

TABLE 2

Principal inorganic constituents in mg/liter (total dissolved solids in g/liter) of water from the Cuatro Ciénegas basin, Coahuila, México, collected December 1964 and April 1965; see text for further explanation and Fig. 1 for localities.

Localities	Date	EDTA Hardness	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	SO_4^{--}	CO_3^{--}	Cl^{-}	SIO_2	TDS	Ca/Mg	Na/K
Churince—Laguna Grande System													
Churince Laguna	4/65	1324	440	54	140	9.3	1250	178	108	21.3	2.42	8.1	15.1
Río Churince	4/65	1506	435	102	160	9.3	1525	144	121	27.0	2.72	4.3	17.2
Laguna Grande	4/65	2480	624	225	350	20.2	2700	121	291	62.0	4.64	2.8	17.3
Laguna Grande	12/64	2610	552	299	395	39.5	3100	125	322	...	...	1.9	10.0
Unnamed Laguna	4/65	1296	349	103	160	8.0	1275	70	110	21.0	4.78	3.4	20.0
San Marcos Laguna	4/65	1304	342	109	150	11.3	1125	182	58	26.3	2.32	3.1	13.3
Río Mesquites System													
Posos de la Becerra	12/64	1270	360	105	142	14.8	1262	156	104	...	...	3.4	9.6
Río Mesquites	12/64	1720	440	151	213	22.5	1750	162	157	...	...	2.9	9.4
El Mojarral (west)	4/65	1284	347	101	160	8.9	1225	178	110	29.3	2.28	3.4	18.0
El Mojarral (east)	4/65	1208	316	101	160	7.5	1065	154	105	21.3	2.10	3.1	21.3
Escobeda	12/64	1310	360	100	152	14.8	600	126	101	...	...	3.6	10.3
Escobeda	4/65	1250	345	100	80	8.4	400	255	112	25.0	...	3.5	9.5
Tio Candido	12/64	1220	320	102	130	14.0	1200	164	96	...	...	3.1	9.3
Tio Candido	4/65	1204	350	80	160	8.7	800	163	142	20.5	...	4.4	18.4
Rio Garabatal System													
La Angostura Canal	12/64	1560	400	136	175	20.5	1125	136	142	...	...	2.9	8.5
La Angostura Canal	4/65	1500	389	128	200	11.7	1025	144	144	28.8	2.85	3.0	17.1
Anteojo Laguna	12/64	840	232	63	29	5.3	706	119	17	...	...	3.7	5.5
Southeastern lobe													
Laguna Santa Tecla	12/64	490	128	41	38	3.5	225	156	29	...	...	3.1	10.7
Laguna de los Fresnos	12/64	600	168	44	85	5.5	281	156	48	...	...	3.8	15.5
Laguna Tio Quintero	12/64	860	240	63	85	9.3	625	157	68	...	...	3.8	9.1
Miscellaneous													
Laguna Salada	4/65	62400	1232	14414	6000	1250.0	66500	252	10200	1.3	309.41	0.1	4.8
Río Cañon	12/64	550	128	41	36	3.0	253	187	22	...	...	3.1	12.1
Río Salado de los Nadadores	12/64	1112	258	114	230	10.0	1325	197	138	21.3	2.14	2.3	23.0

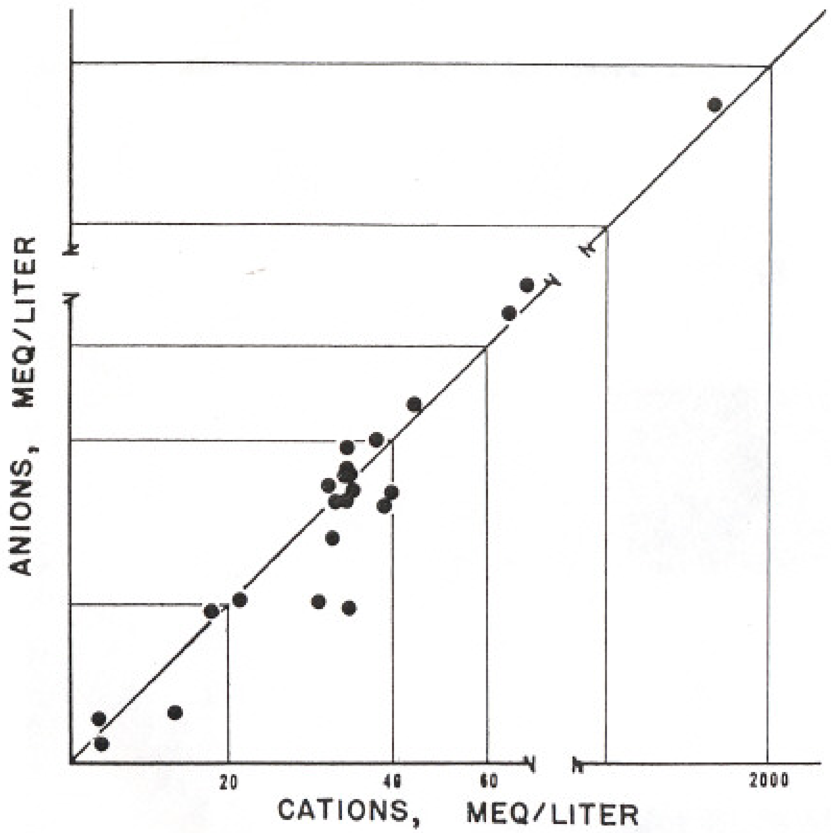

Fig. 2. Cation-anion balance in 23 water samples from the Cuatro Ciénegas basin, Coahuila, México; see text for further explanation.

There is no residual acidity, aerated samples rapidly attaining the phenolphthalein end-point (ca. pH 8.3). Most spring inflows are circumneutral (pH 7.0–7.2, six samples). Waters of open lagunas, into which springs enter directly, range from pH 7.3–7.8 (eight samples), but the pH shifts to more than 8.0 in most effluent streams and quiet, lateral lagunas fed by surface streams (pH 7.7–9.0, 15 samples); most are between 7.8 and 8.4. Drying habitats experience the highest pH values, ranging from 8.0–9.7 (eight samples), with most exceeding 8.7.

Our data on principal inorganic constituents of the waters (Table 2; Figs. 2–3) show an average, gross error in cation-anion balance of 6.2%. Exclusion of data from Escobeda and La Angostura Canal (see below) reduces this estimate to 4.0%. Net analytical error, derived by subtraction of the percentage error when cations cause the excess from

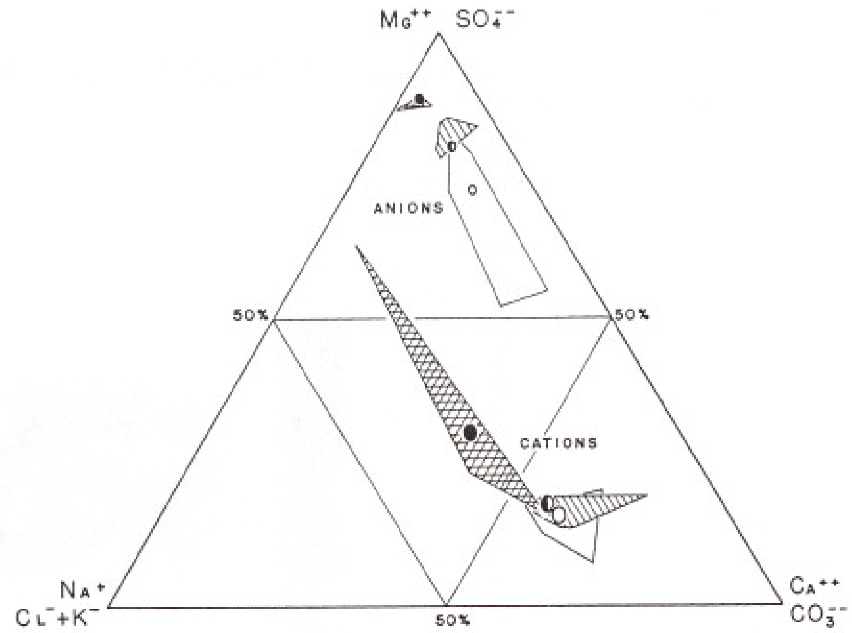

Fig. 3. Relative abundance by weight of principal ions in water samples from Cuatro Ciénegas basin, Coahuila, México. The three apices represent 100% of the cation or anion there indicated, with the bases representing 0% of the ions at the opposite apex. Enclosed areas include all data from three kinds of habitat: cross-hatched = terminal downflow lakes; lined = canals or streams; and blank = springs and directly spring-fed lagunas. Dots, half-shaded circles, and circles are the mean values for the three kinds of habitats, respectively.

that of indicated anionic excess, averages 1.8% in favor of anions. High amounts of certain constituents, especially SO_4^{--} (Table 2), necessitated extreme dilution of most samples; this may introduce variation in results. However, we have rarely encountered perfect ionic balance in analytical data on natural hard waters of the concentrated type discussed here.

Analytical errors indicated for waters of Escobeda and La Angostura Canal (Table 2) are consistent in each sample pair. We assume an unknown ion(s) in each instance, or interference from unknown factors. La Angostura waters are unbalanced toward the anions, but relative proportions of ions are similar. Escobeda waters have an apparent excess of cations, and the errors are similar in magnitude on the two sampling dates. Relative and absolute amounts of ions vary more than is indicated by visible variations in physical characteristics of the spring, and additional samples are needed to interpret this situation.

Variation existing between samples in Laguna Grande and in Laguna Tío Candido (Table 2) are explicable by different points of sampling. The December sample from Laguna Grande was from open water, near shore, 200 m from the inlet. Water level was high, sparse beds of halophytes around the lake were inundated by 5 to 15 cm. By the time of the April sample the water had receded to the visible, distinct shoreline (down about 20 cm). The collection was obtained about 0.5 km from the inlet, again in open water about 10 m from shore. Wind action was severe and the shore was lined by precipitated salts. Waves carried these salts back into the water to form a "slush line" about 75 cm wide along the shoreline, and dried salts were being blown into a dune area at the northwest side. The dunes associated with Laguna Grande exceed seven m in height, and are composed of nearly pure (95+%) gypsum, $CaSO_4 2H_2O$.

At Laguna Tío Candido, the April water sample was obtained directly from a spring inflow three m beneath the surface. The December sample was from open water of the laguna, about 100 m from the point sampled in April. More than 15 spring inflows are in the bottom of the laguna, and variations of the magnitude observed might be expected from spring to spring.

The general similarity of most of the spring waters is striking. Most range between 1,100 and 1,300 mg/liter EDTA hardness (Table 2). Streams and canals that drain the springs had slightly higher values, about 1,500 to 1,700 mg/liter. Exceptions to this are found in springs of the southeast lobe of the basin, however (Fig. 1; Table 2), and in Anteojo Canal and Río Cañon. Anteojo springs, and those of the southeast lobe, flow into their lagunas from the side, as opposed to entering from the bottom. We propose that differences in water chemistry result from the springs of the central basin rising through thick lake deposits, many of which are gypsum, before coming to the surface. The other springs and the Río Cañon enter the epigean environment from a shorter or more direct route through the deposits, perhaps being diluted by seepage water through the bajada slopes, and have less contact with sulfate-bearing beds. Quintero spring, lying between the springs of the central basin and those near the southeast end (Fig. 1), also is somewhat intermediate in its chemical constituents (Table 2), and perhaps in provenance of its water. Río Cañon heads high above the basin floor, and its water is not closely related to that of the other areas.

Our single sample from the Río Salado de los Nadadores (Table 2; Fig. 1), at a point a few miles outside the entrance to the Cuatro Ciénegas basin, appears somewhat diluted when compared with the waters that presumably feed it. This reflects inflow from springs in the river bed, dilution by waters from the southeast lobe of the basin, and perhaps inflow of a yet-to-be-visited stream that reportedly enters the Río Salado from the north, just east of the exit from the Cuatro Ciénegas system.

None of the 23 waters had less than 50% (by weight) of their total anions represented by SO_4^{--} (Fig. 3). Relatively small amounts of Cl^- are present, with CO_3^{--} comprising the second-most abundant anion in most samples. Cations are dominated by Ca^{++}, with $Na^+ + K^+$ being less abundant than Mg^{++} in most of the waters.

One of the more interesting samples in the series is from Laguna Salada (Fig. 1; Table 2), with more than 62,000 mg/liter EDTA hardness and 309.4 g/liter total dissolved solids. This shallow habitat was about 100 m broad, roughly circular, and had a ring of ice-like, crystalline salt 2 to 3 m wide around its shoreline. A few clumps of *Ruppia* sp. were in the center of the pond, and a harpacticoid copepod, *Cletocamptus albuquerquensis* (Herrick), a common inhabitant of brackish and saline waters elsewhere (Wilson and Yeatman, 1959), was abundant. The water and the visible lake bottom had a distinct reddish color, perhaps resulting from sulfatophilic bacteria (*see* Butlin and Postgate, 1954).

There is a strong tendency for waters of the Cuatro Ciénegas basin to change from sulfato-carbonate type (using the terminology of Clarke, 1924), to a sulfato-chloride type, upon concentration. This may be seen in Fig. 3, and is indicated by the relative changes of the three principal anions in the Churince-Laguna Grande system. These constituents, SO_4^{--}, CO_3^{--}, and Cl^-, respectively, occur in the April series of samples as follows: Churince Laguna, 81.4%–11.6%–7.0%; inlet of Río Churince to Laguna Grande, 85.2%–8.0%–6.8%; and Laguna Grande, 86.7%–3.9%–9.4%. One also may include in this series, as intermediate between Río Churince and Laguna Grande, the unnamed laguna (Fig. 1), which is directly connected to Río Churince and has no other known source of water, at 87.6%–4.8%–8.0%.

Water from Laguna Salada, representing a terminal stage of evaporation in our series of samples, had 86.4%–0.3%–13.3% of the three principal anions. It seems unlikely that waters of the basin, in spite of extreme evaporation, would change to a dominance of Cl^- in the presence of such great amounts of SO_4^{--}. The sample from Laguna Salada was the most concentrated of waters analyzed. It is obvious from this, and the sequence in the Churince-Laguna Grande series (Table 2), that the calcium/magnesium ratio decreases remarkably with concentration of the Cuatro Ciénegas waters.

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