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The American Southwest and Middle America

The American Southwest (Fig. 14.1) and Middle America, covered in this chapter, is probably the most heterogeneous geographic region considered in this book. The area covers about 25° of latitude and 42° longitude and amounts to more than 3.8 million km^2. Altitudes range from sea level to 5,500 m above sea level, and extremes in climate, edaphic factors, and biotic zones are the rule.

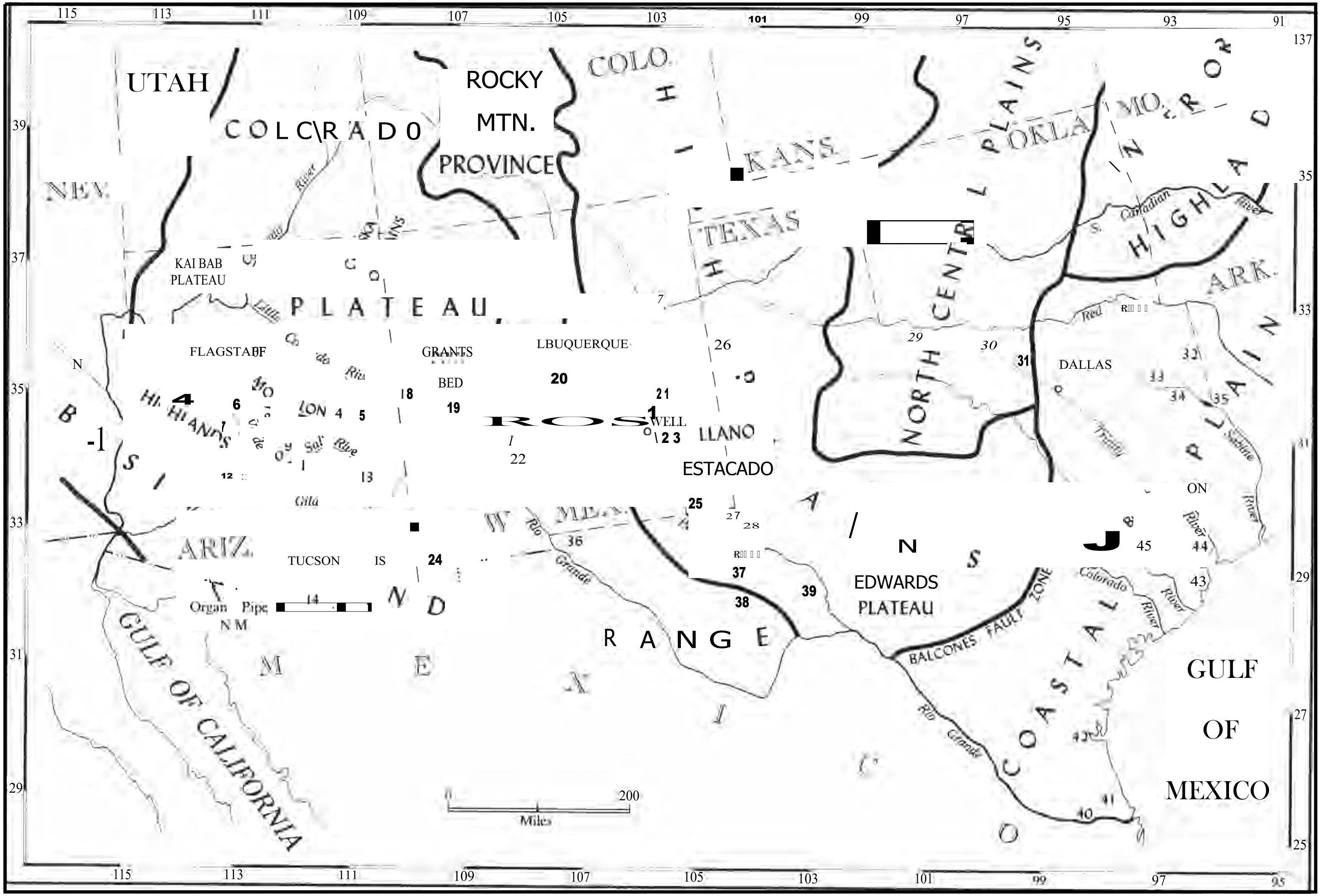
Lakes of this vast area owe their origins to many processes. There is no such thing as one lake district to be considered here. The phrase lake district is used loosely; pond district is the proper terminology in many instances. Furthermore, the region contains unique aquatic habitats: thermal springs, extremely saline waters, lava-collapse ponds, the cenotes of Yucatan, water-containing caves, and ephemeral ponds, to mention a few.

Yet the southwestern states and republics of Middle America are not separate natural entities. They are related climatically and geologically. The Colorado Plateau is shared in part by New Mexico and northern Arizona, and the Texas coastal plain continues far southward into Mexico. The Basin and Range physiographic province is common to Trans-Pecos Texas, southern New Mexico and Arizona, and the northern portion of Mexico to about latitude 18° N. Similarly, Middle American republics share Caribbean and Pacific coastal lowlands, mountain chains, and other geologic features.

Some areas are practically unknown limnologically. Many published data exist for other regions. For this reason, it seems advisable to treat some lakes on an artificial, political basis, and others on the basis of districts of similar origin or location within the same physiographic province. Lack of published studies or exploration of any kind in many areas leaves no alternative except to point out, in such cases, the existence of water bodies and the opportunities for future original research there.

One of the most important single papers on the limnology of the Southwest and Middle America is that of Deevey (1957), who reported on waters from Texas to El Salvador. His publication, though based on hurried visits to the area and a few data from pre-existing literature, is the most valuable summary and synthesis of southwestern and Middle American limnology. To be rewarding, future work in this area should be on a systematic regional and natural basis, concerned with individual lake districts.

Superficially it appears that the arid Southwest has remained practically unchanged since settlement by European man. This is true to a relative extent, but disturbances are far greater than expected. Miller (1961) discussed the modifications of aboriginal aquatic habitats in the Southwest with particular emphasis on the effects on fish faunas. Since 1900, six or seven species have become extinct, and at least 13 additional forms are seriously threatened. Many streams which were permanent during the latter part of the 19th century now flow intermittently, carrying heavy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NORTH CENTRAL PLAINS
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few published data in the realm of limnology, although ichthyologists have collected for a period of many years from Texas waters. Preliminary investigations by Wiebe (1934) on some impoundments represented the beginning of Texas limnology. One of the first comprehensive studies was that of Harris and Silvey (1940), concerned with four reservoirs in the northeastern part of the state. This was followed by the paper of Cheatum *et al.* (1942) on another impoundment farther east. Students of these men have investigated many aspects of Texas fisheries and reservoir limnology since the 1930's. Titles of graduate theses on fishery biology and related subjects in Texas compiled by the Sport Fishing Institute (1959) are abundant, particularly unpublished Masters' theses from North Texas State University. Patterson (1942) includes titles of two other theses in the bibliography of her paper on the plankton of White Rock Lake, Texas.

Furthermore, the Texas Game and Fish Commission, under the direction of Marion Toole, has prepared a series of reports concerning basic investigations of many Texas lakes and streams. Monthly field chemical analyses have been made on most of the big impoundments in the state.

Deevey (1957) briefly reconnoitred some ponds of the Texas coastal plain and the arid Trans-Pecos region. Most other studies of Texas lakes, especially those on the Llano Estacado, have been carried out by geologists and paleoecologists and will be mentioned in a later section.

There is still much to be learned about the lacustrine fauna and flora of Texas, although the lack is not as great as in New Mexico and Arizona. Examples are the paper of Tressler (1954) on ostracods in Texas and reports by several workers, including Comita (1951), on copepods. Comparable papers do not exist for the other southwestern states. Of particular interest are the many papers of Silvey and Roach on the aquatic actinomycetes of Texas (e.g., Roach and Silvey, 1958; Silvey and Roach, 1959).

New Mexico

Four physiographic provinces are represented in New Mexico: the Rocky Mountains extend into the north-central portion; the Great Plains, including a part of the Llano Estacado, lie along the eastern margin; the Colorado Plateau extends across the northwest; and a portion of the Basin and Range province occupies the southwestern third of the state. Because elevations range from 1,000 to 4,600 m above sea level, biotic regions include such extremes as the Chihuahuan desert in the south and the cool, coniferous forest at higher altitudes in the north. More than half the state receives less than 37.5 cm precipitation per annum, and, in the United States, only Connecticut has a smaller total area covered by lakes, ponds, and streams. The most arid region is the southwestern half, although a tongue of aridity extends up the Rio Grande Valley almost to the Colorado state line.

In the Sangre de Cristo Mountains in north-central New Mexico are some small natural lakes which may be the only glacial lakes in the entire area treated in this chapter. Most of these are at elevations between 2,100 m and 3,350 m and seem to be intermediate between cirque and moraine lakes (Koster, personal communication). The formative montane glaciers were small in these mountains. This small lake district is in the headwaters of the South Canadian, Rio Grande, and Pecos rivers.

The largest body of water in New Mexico is Elephant Butte Reservoir, a long, narrow impoundment on the Rio Grande. In general, the most important lakes of the state are man-made.

Many New Mexican waters are characterized by a high sulfate content, a reflection of the widespread and commercially-important gypsum. Some exceptions are seen in the soft waters of the small lake district on the crest of the Chuska Mountains (Megard, 1961) and in the mineralized spring water of Ojo Caliente near Taos. The latter was cited as an example of carbonate water in the classification devised by Clarke (1924), and the dominant cation is sodium. Also, the small trout lakes cursorily surveyed by Gersbacher (1935) in the mountains of north-central New Mexico seem to be soft-water lakes.

One important biological effect, ultimately ascribed to high sulfates, was described by Clark and Greenbank (1936) who investigated the recurring catastrophic fish-kills in Park Lake at an elevation of about 1,430 m near Santa Rosa. The reduction of SO_4 to H_2S following the death and decay of an abundant algal growth was succeeded by sudden strong winds which mixed the waters. Results were disastrous. Those authors compared Park Lake with the nearby Club Lake in which fish-kills had not occurred. Both

4.1.—The American Southwest. Prepare[illegible] ersity of W[illegible] C[illegible] L[illegible].

lett reservoirs,
Verde River.
11. The reservoirs on the Salt River.
12. Lake Carl Pleasant, Agua Fria River.
13. San Carlos Lake, Gila River.
14. Peña Blanca Lake.
15. Willcox Playa.

N[illegible] M[illegible]

16. Clayton Lake, Seneca Creek.
17. Conchas Reservoir, South Canadian River.

8. Montezuma Well.
9. Verde Hot Springs.
10. H[illegible] B[illegible]-

[illegible]

silt loads in flash floods through deeply entrenched arroyos. Many smaller streams and springs are gone, and the freshwater marshy areas known as cienegas have virtually disappeared. Over-grazing, lumbering, pollution, river impoundment, dredging, ditching, pumping ground water, and the introduction of exotic species have been extremely important factors in habitat modification and the resultant alteration of faunas. These factors were combined with the onset of a natural erosional cycle, probably related to increased summer rainfall (Martin *et al.*, 1961). Disturbances in Middle America also have been great because of plantations, lumbering activities, charcoal manufacture, and subsequent erosion.

T[illegible]

Texas, ranging in altitude from sea level to 2,612 m, contains parts of at least four main physiographic provinces, for which numerous subdivisions have been proposed. The [illegible] Coastal Plain, the North Central Plains, the Great Plains, and the Trans-Pecos area (part of the Basin and Range province) are the prominent physiographic features. Of particular interest are the subdivisions of the Great Plains: first, the Southern High Plains or the Llano Estacado, which lies in the panhandle area, extending into eastern New Mexico; and, second, the Edwards Plateau which is south of the Llano Estacado and east of the Pecos River.

On the basis of precipitation, Texas can be divided into zones separated by north-south lines. The most eastern region is characterized by a mean annual rainfall of 109 cm and a low evaporation rate. At the other extreme, precipitation is less than 25 cm in some places west of the Pecos River—the so-called Trans-Pecos area. Water quality of the state can be correlated roughly with these east-to-west regions. There are relatively few permanent natural bodies of water except for rivers, but there are hundreds of man-made ponds and large reservoirs, the latter covering a total area of more than 283,000 ha (Thomas and Harbeck, 1956). Many more are planned (Texas Board [illegible] Water Engineers, 1961.) In general artificial impoundments are the best-known aquatic habitats in Texas.

Much of the work done in Texas has been concerned with estuaries, lagoons, and the littoral marine environments, and there are relatively

(1961) and Hevly and Martin (1961) have studied the sediments of Pluvial Lake Cochise, a playa in southeastern Arizona.

The scarcity of papers dealing with some taxonomic groups of Arizona plants and animals which make up important segments of freshwater communities is apparent in the ensuing discussion. Several phyllopod crustaceans have been recorded (see Dexter, 1959). Edmondson (1935) discussed rotifers from seven ponds and lakes near Flagstaff. Until very recently only three species of calanoid copepods, from a total of seven locations, had been reported (Marsh, 1929; Kincaid, 1953; Wilson, 1955). Now a minimum of seven species is known to occur in Arizona (Cole, 1961). Marsh (1910) described a new cyclopoid from southern Arizona, probably the only one reported from the state. No records of Arizona harpacticoid copepods have been published. Brooks (1957), in a detailed monograph on the genus *Daphnia* in North America, reported three species from two localities in Arizona. There may be no other records of Cladocera from the state. Only one species of the modern ostracod fauna of Arizona is represented in published papers (Dobbin, 1941). Other aquatic crustaceans such as the Amphipoda, Isopoda, and decapods have been neglected completely. There are a few papers on the ichthyofauna of Arizona. Most of these are cited by Miller (1961) in a paper emphasizing the changes wrought by man in the Southwest. Taylor and Colton (1928) published on pond phytoplankton in northern Arizona, and Wien (1958, 1959) studied algae and aquatic seed plants present in irrigation canals near Phoenix. Hevly (1961a, 1961*b*) has summarized and added to our knowledge of Arizona's aquatic flora. Although there may be omissions in the above, in general we know much more about the general limnology and aquatic flora and fauna of Mexico than of Arizona.

Mexico

Mexico, ranging over more than 18° of latitude and 31° of longitude and from sea level to 5,500 m in altitude, is a land of extreme diversity. The physiographic complexity of this republic is surpassed only by variation in climatic and biotic zones, which vary from humid tropical forests to arctic-alpine conditions with perpetual snow cover. It seems advisable to describe the country in the simplest terms to set the stage for discussion of its limnology.

First, a great interior plateau, continuous from the Basin and Range areas of Texas, New Mexico, and Arizona, stretches between the high Sierra Madre Occidental in the west and a shorter, less magnificent range, the Sierra Madre Oriental, on the east (Fig. 14.2). The coastal plain, so conspicuous in South Texas, continues along the Gulf of Mexico, merging into the broad, flat plain which makes up the entire Yucatan Peninsula. On the Pacific side, the coastal plain is narrower and occasionally interrupted by mountain spurs. The State of Baja California is a narrow peninsula bearing a single mountain range which extends nearly its entire length.

We know little about limnology over much of this vast country. Ichthyologists and herpetologists have collected throughout the streams and ponds of Mexico, but limnological explorations have been limited. The lakes of the Rio Lerma system at the southwestern edge of the Mexican plateau have been studied, but on the eastern coastal plain we have information only on the sinks, or cenotes, of Yucatan. On the Pacific coastal plain a very few lagoons have been investigated from a limnological approach.

Summarizing the status of knowledge in Mexico seems to be popular with biologists of that country. Osorio Tafall (1944a) wrote a historical résumé of hydrobiology up to that time, including littoral marine investigations. Alvarez (1949) summarized freshwater ichthyology in Mexico, and several people have assembled historical data on our knowledge of various invertebrate groups, for example, the freshwater sponges (Rioja, 1953) and planktonic rotifers (Osorio Tafall, 1942). One of the most important summarizing documents appeared very recently and too late to be utilized in the preparation of this report. This is a bibliography of Mexican investigations on aquatic biology, oceanography, fish, and related subjects, prepared by the Instituto Mexicano de Recursos Naturales Renovables (Alvarez *et al.*, 1961). This publication contains a bibliography of 1,831 titles and historical summaries of the various subjects. A recent paper by Darnell (1962) has an extensive bibliography of Mexican ichthyology with emphasis on publications relating to the Rio Tamesi drainage and the Tampico Embayment in the east-central part of the country. In summary, there is an extensive literature on the freshwater fauna of Mexico, lakes are fed by underground water high in $CaSO_4$ and are similar in their border vegetation, transparency, and hydrogen-ion concentration. The main differences are morphometric. Park Lake has an area of 3.5 or 4 ha and is no deeper than 4 m, while Club Lake is 20 m deep and has twice the surface area. Profiles from Club Lake show sharp temperature stratification and a marked thermoclinal minimum in dissolved oxygen at about 6 m. There is limited evidence that this corresponded to a level where benthic algae were decaying and H_2S was being produced. The possibility of sudden, wind-generated circulation with resultant fish-kills in such a lake is unlikely.

The history of New Mexican limnology begins in the 1930's when the names of John D. Clark, Hillard L. Smith, John Greenbank, and others appeared on a few University of New Mexico Bulletins concerned with public water supplies. Also, in 1935 Gersbacher's report of a summer's survey of lakes and streams in northern New Mexico was prepared.

The study of Elephant Butte Reservoir (Ellis, 1940) is particularly worthy of note, and the New Mexico Department of Game and Fish has contributed a series of reports on impoundments and streams with emphasis on fishes (Navarre, 1958, 1959, 1960; Little, 1961; Jester, 1960). Wright (1956), Bent (1960), and Megard (1961) have begun what may become a series of reports on the geology, limnology, and paleoecology of a natural lake district in the Chuska Mountains in northwestern New Mexico. Such unusual habitats as saline springbrooks and the water-filled depressions and caves of the Grants Lava Bed have received attention and will be mentioned later.

Other studies largely in the realm of geology and paleoecology will be discussed in a following section. Extinct Lake San Augustin and the deflation basins in the western flank of the Llano Estacado have been under investigation by several people, and there are numerous geological studies of ground-water resources of the state.

Although C. L. Herrick lived briefly in Albuquerque during the latter part of the 19th century and performed some taxonomic work on copepods in New Mexico (Herrick, 1895), we know almost nothing about the aquatic invertebrates of the state. Koster (1957) has summarized the status of ichthyology in New Mexico in his *Guide to the Fishes of New Mexico.*

Arizona

Arizona is characterized by two main physiographic provinces with a fairly distinct intermediate area worthy of mention. A section of the Colorado Plateau is in the northern third of the state, its southern boundary marked abruptly in the central area by the Mogollon Rim. Part of the Basin and Range province occupies roughly the southern third of the state and is usually termed the Sonoran desert in this region. Between the two lies a varied mountainous area, sometimes called the Arizona Highlands. Many physical geographers will not agree with the boundaries set forth here.

Altitudes in the state range from about 30 m in the southwest to 3,862 m at the top of the San Francisco Mountains—volcanic cones on the Colorado Plateau above the Mogollon Rim. Extremes in temperature from —36° C to +53° C have been recorded from the state. In the extreme southwest of Arizona precipitation may he as low as 7.6 cm per annum. In the intermediate mountainous area in some places it is ten times greater. Above the Mogollon Rim summer showers and winter snows are common, but precipitation is somewhat less than in the mountainous area below.

Very little limnological work has been done in Arizona if we exclude reports on Lake Mead, which is largely in Nevada. No studies which approach completeness have been made. Some mimeographed summaries of lake and stream surveys by Madsen (1935a, *b, c, d,)* contribute generalities concerning a few physicochemical data and the aquatic life in the National Forests in Arizona. These reports, although sketchy, constitute the most extensive surveys in the state. Hydrographic and water-quality data are being accumulated by various agencies in Arizona, and there are several U.S. Geological Survey publications with information. An example is U.S. Geological Survey Water-Supply Paper No. 1523. These are slanted toward irrigation needs and municipal usage. The Arizona drainage map prepared by Miller (1954) is of merit. Also, the Arizona Game and Fish Department has begun to assemble limnological data, and their publication (1958) includes bathymetric maps and other data for ten important fishing lakes in the state. Work is under way on a desert lake, Peña Blanca, by William J. McConnell (personal communication), with particular emphasis on primary productivity. Martin *et al.*

quite in contrast to the paucity of information concerning the southwestern United States and the Middle American republics south of Mexico.

Serious Mexican fimnological endeavor began with the establishment of the Estación Limnológica de Pátzcuaro on the shores of Lake Pátzcuaro in 1938. In October 1939 Fernando de Buen began directing research there, and within a few years a large number of papers had appeared in the *Informes,* the *Trabajos,* and the *Investigaciones* published by the station. By 1940, a group of taxonomic papers published in Volume 11 of the *Andes del Instituto de Biologia* of the Universidad Nacional de Mexico included more than 80 titles concerned with Lake Pátzcuaro. Also, limnologists from the Pátzcuaro station have made at least reconnaissance investigations of other lakes of the Lerma Valley. Their contributions will be considered later. Deevey's (1957) discussion of Pátzcuaro and Chapala, although based on a relatively short period of study, is meritorious. Two classical papers in Mexican limnology concern the caves and cenotes of Yucatan (Pearse *et al.*, 1936, 1938).

Pioneer work on palynology far south of the limits of continental glaciation began in Mexico with Deevey's (1944) study of Pátzcuaro sediments. Further work on Deevey's cores was performed by Hutchinson *et al.* (1956). Inferences about Pleistocene climate from these studies agree with the results of several investigations from the Valley of Mexico, somewhat farther south (Sears, 1952; Sears and Clisby, 1955; Clisby and Sears, 1955; Foreman, 1955). The pluvial lake which covered this basin lay perhaps 3,000 km beyond the border of continental glaciation.

The peninsula of Baja California in Mexico, with its extensive latitudinal and altitudinal ranges and varied climatic patterns, should be a rewarding area for future regional freshwater studies. The littoral marine faunas indicate a climate ranging from mild temperate to tropical (Soule, 1960). Lacustrine habitats are rare, however, and abrupt escarpments along the eastern coast have worked against the formation of lagoons. Some streams, hot springs, and sloughs are present, from which there have been several ichthyological studies (see Follett, 1960).

Guatemala

Some limnological features of Guatemalan lakes have been reported by Meek (1908), Juday (1916), Holloway (1950), and Deevey (1957), although Meek and Holloway were especially concerned with fish. In addition, there have been occasional plankton studies (Clark, 1908; Tilden, 1908; Peckham and Dineen, 1953).

Lake Amatitlán and the deeper Atitlán stand out as the best-known bodies of water in Guatemala, and bathymetric maps are available for both in Deevey's (1957) paper. Probably the most important contributions to tropical limnology in Middle America have come from study of these lakes.

The large Lake Izabal, at an altitude of 10 m above the Gulf of Honduras and connected to it by the Río Dulce, is an entirely different type of lake. Some data and an incomplete bathymetric map were supplied by Holloway (1950). Calculations made from the map suggest an area of more than 63,700 ha, a maximum length of 46.5 km, a mean breadth of 13.7 km, and a mean depth of about 8-9 m. As is true of many Middle American lakes, Lake Izabal is subjected to strong, daily wind action and is isothermal at these times. Dissolved oxygen values range from 60% of saturation at the bottom to 100% one meter below the surface. Bicarbonate alkalinity data show 76 mg/L at the upper end of the lake and 100 mg/L at the lower.

The Laguna de Petén is a large compound limestone sink, isolated to a great extent, and showing resultant speciation in its fish fauna (Hubbs and Miller, 1948).

El Salvador

The Republic of El Salvador consists of a volcanic highland, which is a southeast continuation of the mountains of Guatemala, bounded by lowlands on either side. This highland is relatively low, and, as a result, most of the country is of the climatic *tierra caliente.* There has been much destruction of the original forests, followed by floods, soil erosion, and dought. The country is well supplied with streams, hot springs, and numerous lakes, but there have been no complete studies of any of them.

For many years the paper of Juday (1916), which contained information on lakes Coatepeque and Ilopango, was the only good account of El Salvador lakes. Since then Deevey (1957) published on these and also, in greater detail, on Lake Güija. Armitage (1958) visited these three

FIG. 14.2.—M[illegible] America. Prepared by the University of Wisconsin Cartographic Laboratory.

TABLE 14.1

Comparison of the waters of Lake Nicaragua and Lake Managua. All values except **pH** are in mg/L.

	Managua	Nicaragua
pH	8.7	7.0
Total dissolved solids	747	151
SiO_2	7	16
Ca	9.4	19
Mg	22.1	3.5
Na	230.8	17.7
	35.9	3.9
CO3	30	0
HCO3	470	82.4
	30.3	9.1
Cl	132.9	15.9
	0.95	0.76
	1.31	0.08
NO3	trace	0.62

E::tensive marginal flats are exposed **to direct** solar radiation during the dry months, and some years the lake is so low that it does not drain into the Rio Tipitata. This probably accounts for the greater salinity in Managua than in the well-drained Nicaragua.

The surface temperature of Lake Managua is 26° C in the early hours of the day, warming to 30° C by noon if the lake is calm. However, during the months from January to May, winds varying from 13 to 16 km/hour destroy stratification, and the lake is uniformly 28° C. These winds bring about the suspension of bottom sediments, and this, coupled with high plankton production, results in a low Secchi disc transparency from 0.5 to 2.0 m.

Puzzling fish-kills occasionally occur in Lake Managua. These have not been explained, but in that region subsurface volcanism might be involved.

The two lakes are extremely rich. About 375 professional fishermen, lacking modern methods and equipment, harvest about 810,000 kg of fish per year. Surveys have suggested, however, that the total annual production of all types of fish is in the neighborhood of 91,370,000 kg.

Lake Nicaragua is remarkable for its land-locked marine fishes, although it is less saline than Managua which lacks them. These include two elasmobranchs and the Atlantic tarpon. One elasmobranch is a dangerous shark, attaining weights of 68 kg and lengths of 2 m or more. The other, a sawfish, grows to more than 300 kg. These animals probably entered the lake by way of the Rio San Juan long before earthquakes created extensive rapids in the river some 300 years ago. The euryhaline shark of the Caribbean, *Carcharhinus leucas,* is undoubtedly the ancestor of the form in Lake Nicaragua. The same three fish species are present also in Lake Izabal, Guatemala (Holloway, 1950).

In both lakes several bizarre cichlids occur. Many are golden-red with strangely humped foreheads. The red fish are sold in the market as *mojarras coloradas* and are also found in some of the other lakes nearby, especially those in deep calderas.

One of the most remarkable lakes in Nicaragua is Lake Apoyo occupying a caldera depression and with a cryptodepression of 110 m. There are many lakes in Nicaraguan calderas, but probably few if any attain this depth.

Armitage (1961) reported some unusual chemical data from a shallow volcanic lake about 5 km west of the city of Managua. This is Lake Nejapa which occupies a closed caldera depression. When visited in December, the lake was only one meter deep, although exposed mud flats implied higher levels during the rainy season. Water temperature was 28.5° C, and the turbidity so great that Secchi disc transparency was only 10 cm. A strong odor of H_2S prevailed, although no tests were performed for sulfur compounds. The pH was in excess of 10, the carbonate alkalinity was 10,440 mg/L, and the bicarbonate alkalinity was 4,390 mg/L. No zooplankters were present, but a bloom of blue-green algae was evident, with species of *Arthrospira, Spindina,* and *Oscillatoria* predominating.

Costa Rica

The limnology of Costa Rica, "the Switzerland of Central America," is practically unknown. Some notes on high-altitude bogs, to be discussed in another section, are present (Reark, 1952; Martin, 1960). Also unexplored volcanic-crater lakes occur. Reark (personal communication) has stated that in the gorge of the Rio Reventazón there are a number of oxbow lakes in various successional stages. No detailed studies have been made of these, but they contain fish, aquatic plants, and probably the invertebrate fauna typical of subtropical ponds.

Panama

The Republic of Panama is a narrow isthmus covering a small area, but it has varied ecological and several other volcanic lakes in the highlands. He also investigated ponds in the Pacific coastal plain (Armitage, 1957) and prepared a report (Fassett and Armitage, 1961) on the aquatic macrophytes of both lake regions, using the posthumous notes of Dr. Norman C. Fassett with whom he worked. Bathymetric maps of at least Ilopango, Coatepeque, and Güija are available (Williams and Meyer-Abich, 1953, 1954; Deevey, 1957).

Honduras

The largest Honduran body of water is the Laguna Caratasca, connected to the Caribbean by a narrow passageway. Until information is available on the salinity and biota of this lagoon on the northeastern coastal plain, it must be considered outside the scope of limnology.

The only other major body of water is Lake Yojoa, a solution lake in east-central Honduras at an elevation of 610 m. Along the precipitous eastern shore a massive Cretaceous limestone is exposed. The area of the lake is about 135 km^2. Carr (1950) writes of incredibly rich avian populations in the shoreline marshes at the northern and southern margins of Lake Yojoa. In spite of the high altitude, many aquatic birds typical of the lowland marshes of Florida are present.

Other aquatic habitats in Honduras are best considered marshes or swamps. On both coastal lowland areas, saline mangrove swamps grade into freshwater marshes. The fresh tidal swamp is a transitional type and offers peculiar habitat conditions. Another lowland habitat mentioned by Carr is the peat swamp composed of gamalote grass *(Paspalum).* At high altitudes *(ca.* 1,830 m) near the cloud forest margins, micromarshes dominated by *Juncus* are present.

British Honduras

British Honduras, a small lowland country, exhibits features typical of neighboring Guatemala and the Yucatan Peninsula. There are several large lagoons near the coast and a few farther inland in the valleys of sluggish rivers. Beard (1953) mentions the "lakes, wooded swamps, undrained sinkhole ponds or aguadas" of that country, but no limnological reports are available.

Nicaragua

The Republic of Nicaragua is a land of volcanoes and lakes, yet little can be said about its limnology. The country consists of three major regions: the highlands through the center of the country, reaching elevations no greater than 2,134 m; the Mosquito Coast along the Caribbean Sea, with many lagoons and slowly flowing rivers and an annual rainfall of 762 cm, hardly to be surpassed anywhere in the world; and the Nicaraguan lowlands, running south from the Gulf of Fonesca along the Pacific coast and then cutting across to the Caribbean at the Costa Rican border. Only the lakes of the third region can be discussed.

The largest lake to be found between Lake Titicaca in South America and the North American Great Lakes of the St. Lawrence drainage is Lake Nicaragua, 19 km from the Pacific and 34 m above it. Unfortunately, little is known concerning the limnology of this body of water or of the closely related and nearby Lake Managua, except for hydrographic data (Davis, 1900), studies of the remarkable fish fauna (Meek, 1907), and a mimeographed summary of work done by Dr. W. H. Shuster and Dr. S. Yen Lin in 1956 and 1960, respectively. The last was supplied by the Ministerio de Agricultura y Ganaderia, Managua, and contains a summary of chemical data from the two lakes which was used to produce Table 14.1.

Geologically the lakes are young, probably formed when post-Tertiary eruptions isolated an elongate basin of the Pacific. Originally, they were a single lake, but marginal erosion and drainage separated the two basins. Today Managua drains into Nicaragua, about 7 m below it, by way of the 26-km Río Tipitata. Lake Nicaragua has a surface area of more than 7,700 km^2 and a maximum depth of about 60 m. Thus, the bottom of the lake lies some 26 m below sea level. Managua is only 1,295 km^2 and has a maximum depth of 30 m, although much of the lake is approximately 8 m deep. The volcanism that originally impounded the lakes reversed the existing hydrographic pattern, so they do not drain toward the nearby Pacific but, by way of the San Juan River, into the distant Caribbean. The salinity of these well-drained lakes, lying in a region where precipitation exceeds evaporation, is greatly reduced, so that in spite of the marine origin of the waters, the lakes are freshwater bodies, especially Lake Nicaragua (Table 14.1).

The surface elevation of Lake Managua varies from 1 to 2.5 m between the dry season (November-April) and the rainy season (May-October) accumulated near a marginal stand of *Scirpus.* This is brown, fibrous material extending below the water surface to some depth. The full extent of this peat bed is not known, but there is a slant to it which suggests it has slipped into deeper water over a period of years and may not imply a rising water level. Further investigation is needed before much can be said, because the plugging of former, lower outlets could have occurred. Montezuma Well is not a closed system and does not seem conducive to peat formation. The peat is not widespread, however, and although the daily flow of water is on the order of one-tenth of the total volume, there may be stagnant conditions where the peat forms at the shore opposite the outlet.

Many montane bogs occur at elevations of 2,300 m and above in the granitic Cordillera de Talamanca of Costa Rica (Reark, 1952; Martin, 1960). Reark (personal communication) has noted at least one below 1.640 m and has theorized the bogs were formed by landslides damming valleys above the elevation of continuous stream flow. In this region of both high precipitation and high relative humidity, slides are common, and the year-long growing season effects rapid stabilization of dams formed across intermittent tributaries. The bogs are found in at least two climatic belts, the upper being characterized by páramo conditions with mean annual temperatures of to 12° C. From the palynological study of a 13-m core, Martin (1960) inferred that two-thirds of the core represented colder climate, and that páramo conditions formerly extended 600-800 m below their present altitudinal limits.

There is a North American aspect to these bogs because of the presence of such familiar genera as *Sphagnum, Vaccinium,* and *Xyris.* The most conspicuous plants show Andean affinities, however, and the bogs have been designated *Puya-Lomaria* types on the basis of the two dominant species, which reach their northern limits here.

Successional stages are probably present among the bogs. The one observed at the lowest elevation by Reark had steep sides, was water filled, and most of the typical plants were missing. Most other bogs had only a little surface water above the peat upon which the *Puya* and *Lomaria* grew. Many of these active bogs are in forests of the huge oak, *Quercus copeyensis,* but older sediments are covered by typical cloud forest species, which seem to be playing an ecological role similar to that of certain spruces, cedars, and tamaracks of northern United States and Canada.

In the volcanic Cordillera Central, to the north of the Talamanca range, there are no such bogs (Reark, personal communication). Topographic and edaphic factors, perhaps combined with the relative frequency of eruptions, have acted against bog formation. The craters of Volcán V. Turrialba, V. Barba, and V. Poás, however, contain cold lakes bordered by oozy margins with sparse plant growth.

Basin and Range playas

The Basin and Range physiographic province is widespread, ranging from far to the north of the area covered by this report to about 18° N latitude in Mexico. Typically it is a region of block faulting, with broad structural valleys and isolated mountain ranges. The valleys are debris-filled basins called bolsons. Much of the Basin and Range province in Arizona, New Mexico, and Trans-Pecos Texas is actually a continuation of the Mexican Plateau, bordered in Mexico by the Sierra Madre Occidental and the Sierra Madre Oriental. Many bolsons have no exterior drainage and contain ephemeral, saline playas, often overlying the sediments of ancient pluvial lakes. Meinzer (1922) mapped many of these Pleistocene lakes, and Hubbs and Miller (1948) discussed and located all the important ones.

New Mexico has more of these ancient lakes than either Arizona or Texas. One of the principal ones is Lake Estancia, 96 km southeast of Albuquerque, which was once 1,166 km^2 in area and 46 m deep. The lake bed is one of the most commercially important sources of NaCl in the state (Phalen, 1919).

Few bolsons in Arizona are closed, with a resulting scarcity of playa lakes. In northwestern Arizona there is an ephemeral lake, 9.6 km in diameter, called Red Lake, which may have been more or less permanent during the Pleistocene. The most important in Arizona is the Willcox Playa in the southeast at an elevation of 1,245 m. This is the site of Pluvial Lake Cochise, which had an area of 311 km^2 and a depth of 14 m. The extremely mineralized waters of Croton Springs, arising from the western edge of the playa, contain a great deal of sodium, chloride, and sulfate. Interesting mounds, some as high as 3 m, are found at the shores of the playa.

conditions. Altitudes range from sea level to 3,850 m, and the Pacific side of the Continental Divide differs climatically from the Atlantic. There is little limnological history to report. The major lakes—Gatun, Madden, and Miraflores-were pooled by construction of the Panama Canal. Gatun Lake is one of the world's largest artificial bodies of water, covering an area of about 423 km^2. Annual temperatures in its waters vary from about 26° to 29° C.

Prescott (1951) found significant differences between the algal floras of Gatun and Lake Mirafibres. Gatun is in the Atlantic drainage, whereas Miraflores is close to the Pacific Ocean. Prescott suggested that waters draining into the Atlantic reaches of the Panama Canal may differ chemically from those west of the Divide.

Extinct lake basins

Bogs

Many extinct lakes are present in southwestern United States, adjacent Mexico, and perhaps far more than suspected in the mountainous areas of the other republics of Middle America. In arid regions they are conspicuous as ephemeral playas or extensive salt flats. In forested regions they are either rare or have escaped attention. With the relatively recent interest in past climatic conditions south of the limits of continental glaciation, research literature is accumulating rapidly. The bulk of recent limnological work in the Southwest has been geological or in the realm of paleolimnology.

Bog lakes and large accumulations of peat are associated most often with formerly glaciated regions, although a few have been reported from the Southwest and Middle America. Several acid peat bogs occur in east-central Texas, in a southwest-northeast strip from Guadalupe and Gonzales counties to Polk and Houston counties (Chelf, 1941; Plummer, 1941, 1945; Shafer, 1941). Many of these peat accumulations occupy various poorly drained depressions such as old meander scars, impounded tributary valleys, and closed basins near ancient natural levees. Others are not fluviatile in origin but owe their existence to perched-water conditions. Water seeping from sands and gravels spreads over impermeable clay areas, collecting in depressions not subjected to frequent flooding and drainage which would preclude peat accumulation. Some of these depressions in Texas are surrounded by trees and shrubs and are called "bay galls." Sphagnum is present in many of the bogs, some of which are domed. The occurrence of sphagnum in Gonzales County, Texas, may mark its southwestern limit in the United States. In general, this is a moist, relict area characterized by disjunct floral and faunal elements (Raun, 1959). Several ericaceous plants around the bay galls are rather far from their normal range, and Raun considered that more than 50% of the vertebrates in the peat bogs of Gonzales County show eastern affinities.

Some Texas peat bogs in three different counties were studied by Potzger and Tharp (1943, 1947, 1954), and pollen profiles were presented. On the basis of palynological data, they proposed a four-phase climatic oscillation for that part of Texas. Since then commercial peat mining has destroyed their bogs, except for the lower 1.5 m of Gause Bog in Milam County. Graham and Heimsch (1960) reinvestigated the peat remnants in this bog and studied the pollen fossils in a fourth, Soefje Bog. Their data show essentially unmodified vegetation throughout the entire history of the 4.7-m deep sediments, and radiocarbon dating places the age of the bog at about 8,000 years. Probably the lower level of Soefje Bog correlates with the 3-m level in Gause Bog. Below this the sediments of the latter contain some *Picea* pollen, implying a moister and cooler climate, but Graham and Heimsch see no evidence above this for climatic oscillations. The age of these bottom sediments in Gause Bog is estimated to be a little more than 12,000 years.

A case of incipient bog formation may have been described in Texas by Cheatum *et al.* (1942). In a shallow, artificial reservoir, 160 km east of Dallas, there is an encroaching mat of *Zizania* and *Typha,* on which *Cephalanthus, Alnus, Hypericum, Salix,* and some ferns grow. The open-water pH is from 6.4 to 7.0, but in the marginal mats it is 6.1 or 6.2. The lake is partly fed by acid springs.

Some solution basins below the limits of continental glaciation contain peat, but none has been reported from Texas. In the Arizona sink, Montezuma Well,* some well-defined peat has

*Studies on Montezuma Well, Arizona, have been made possible by National Science Foundation Grant G 1316 and the cooperation of the National Park Service.

These were considered of recent origin by Meinzer and Kelton (1913), who postulated trapping of lake-bed deflation materials by aquatic vegetation at artesian seeps. Hevly and Martin (1961) have shown by pollen analyses that the knolls are of pluvial age and probably represent erosional remnants.

Most studies on bolson playas have been in the realm of geologic, ground-water, or salt-resource reports. The papers of Hevly and Martin (1961) and Martin *et al.* (1961) on Lake Cochise and other sites are largely palynological. For data on the modern limnology of bolson lakes, we must turn to Deevey's (1957) short discussion of playas in the so-called Salt Basin of Trans-Pecos Texas. This is an extensive graben bounded on the east by the Guadalupe Mountains and extending north into New Mexico. Deevey's discussion makes it plain that Grable's Salt Works and Fort Stockton Lake are greatly modified, but Toyah Lake appears to be a good example of a playa. The waters of Toyah are about 3‰ total salinity. Grable's Salt Works is extremely concentrated and very high in chloride. Fort Stockton and Toyah have relatively more sulfate, but in all three magnesium is surprisingly low, and the dominant cation is sodium.

One feature of these lakes, which may apply generally to turbid waters in arid regions, is the high percentage *(ca.* 85%) of phosphorus in sestonic form. Total phosphorus is not especially high, and the N/P ratio is normal.

The Valley of Mexico is a bolson which contained a large, but shallow, pluvial lake, much of which remained until early 16th century when drainage operations began. Seven remnants are present now, the largest of which is saline Lake Texcoco. Apparently this bolson was closed by volcanic mountain building. Deevey (1957) gives a good account of the known history of the lake, including Aztec usage. Osorio Tafall (1942) classified Texcoco as a brackish habitat and *Brachionus pterodinoides* as a rotifer typical of it.

Lake San Augustin

Sediments derived from former pluvial lakes, now entirely dry or, at the most, ephemeral in nature, have been studied by several workers in the Southwest. Most of these playa basins lie within the Basin and Range physiographic province, but an important exception is extinct Lake San Augustin now represented by the San Augustin Plains in west-central New Mexico. This is an intermontane basin, probably a graben (Stearns, 1956), within the Colorado Plateau physiographic province. It lies at elevations from 2,050 to 2,100 m, with surrounding mountains 1,000 m higher. Powers (1939) described the lake as having been 50 m deep with a surface area of 660 km^2. Descriptions of the modern aspect of the San Augustin Plains and evidence for the relatively recent existence of the lake have been published by Potter (1957) and Potter and Rowley (1960). Core studies by Clisby, Foreman, and Sears (1957) have suggested that the rate of deposition was about 30 cm per 1,000 years, and below a depth of 165 m the sediments are probably Pliocene. Recent drillings to a subsurface level of 600 m are probably well into the Pliocene. A new 15-m core collected for radiocarbon dating contains *Pediastrum* microfossils between 1.3 and 10 m depth (Clisby, personal communication). This implies a freshwater lake, perhaps high enough to overflow, thus precluding marked accumulation of salts. The levels of *Pediastrum* abundance coincide roughly with the *Picea* pollen maximum first shown by Clisby and Sears (1956).

Basins of meteoritic origin

Some of the now-extinct pluvial lakes of the Southwest are known to have had their origins in meteoritic impact and explosion. They are, at present, anomalous basins in lake districts of entirely different genesis. The most famous of these is the dry crater at Coon Butte on the Colorado Plateau in Arizona. The crater lies in a region of volcanism, and Darton (1910) believed it was formed by volcanic explosion. Blackwelder (1946) seems to have established clearly the meteoritic origin. Barringer (1905) wrote that the floor of the crater contains about 30 m of lacustrine sediments.

In Ector County, Texas, there are several meteoritic pits. At least one of these, Odessa Meteor Crater, 16 km east of the Monahans Dunes, contains 20 m of eolian and lacustrine deposits, representing former pond stages (Green, 1961). The crater is a small, flat-bottomed depression, its impact ring rising 4 m above the floor. It is situated in a district of deflation basins at the southern edge of the Llano Estacado.

High-altitude lakes of Arizona and New Mexico

Volcanic lakes of the Colorado Plateau

In a strip 120 km long from Williams, Arizona, southeast past Flagstaff, on the southern edge of the Colorado Plateau, are many small lakes which are volcanic in origin. An exception is Lake Mary, near Flagstaff, which occupies a limestone valley and is artificially impounded. Probably none is deeper than 7 or 8 m, and all are above 2,135 m in elevation. The lakes of this district are worthy of study, but few data have been assembled concerning them.

Most of these lakes have no permanent source of water, and only seasonal runoff fills them. During dry periods many are empty. The natural lakes of this district are characterized by a rich and varied flora and fauna, with luxuriant emergent vegetation bounding their shallows in spite of fluctuations in water level. Taylor and Colton (1928) pointed out that the natural tanks and lakes of northern Arizona are much more likely to have rich algal flora than are the artificial ones, and the occurrence of a varied green-alga and diatom population is practically limited to natural bodies of water. This seems to apply to the emergent and submerged aquatics also, for most man-made impoundments on Arizona rivers have barren shores. Of course this may be caused by morphometric features. Lakes on large Arizona rivers were formed within steep-walled canyons, while natural lakes above the Mogollon Rim occupy relatively shallow, saucer-like depressions. Fluctuations in water level are probably more drastic in the large, dammed lakes because of irrigation requirements.

Mormon Lake, the largest natural lake in Arizona (2,590 ha), lies in an intercone basin dammed by lava flows and Mormon Mountain. At least one spring enters the lake, but during periods of reduced precipitation the lake is dry (Colton, personal communication). Madsen (1935a) reported accounts of Mormon Lake's having been formed by the trampling of cattle and sheep. According to ranchers, the lake was originally a grassy meadow surrounded by dry hills, into which livestock was turned to graze. Trampling made the basin watertight and created the lake. One is inclined to believe a longer lacustrine history with only occasional interruptions.

Stoneman Lake occupies a small caldera (Colton, 1957), and this is probably true also of Crater Lake and Walker Lake. Five small springs feed Stoneman Lake, but in spite of this it has been dry occasionally in recent years. It is especially rich in aquatic macrophytes. Others such as Kinnikinick, Ashurst, Marshall, and Vail lakes occupy depressions in Pliocene or early Pleistocene lava flows (Colton, personal communication). Some of these lakes have been deepened by dams to increase their fishing potential. Thus, Kinnikinick formerly had a maximum depth of 5 m. This shallowness, combined with strong winds and the volcanic-ash sediments, resulted in extreme turbidity. A dam constructed in 1956 raised the level 3 m, and the lake now covers 54.6 ha with a total volume of 3.1 million m^3. There is some summertime thermal stratification, but oxygen is abundant at all depths. Because of the altitude and low winter temperatures, this is a dimictic lake. Water chemistry data are scarce, but all these volcanic, high-altitude lakes are probably remarkably soft for closed-basin waters. They are characterized by high pH values and a mean methyl orange alkalinity of about 57 mg/L (as $CaCO_3$). An exception is the caldera lake, Stoneman, with recorded alkalinity values from 210 to 280 mg/L.

An interesting volcanic lake, quite different from those in Arizona, lies to the east in New Mexico, 67 km south by east from the Pueblo of Zuñi (Darton, 1905). This is Zuñi Salt Lake, which Darton considered of solution origin, but which Hutchinson (1957) classified as a caldera basin. According to Darton, the lake is 1.6 km in diameter surrounded by high walls of Cretaceous sandstone capped by lava and volcanic ejecta. The floor contains some water with marginal flats of mud and a white saline evaporite which the Indians collect. In the main basin are two secondary volcanic cones, one of which contains a pool of water 50 m in diameter and has a NaCl percentage of 26.

Chuska Mountain lake district

A small lake district may be seen in the Chuska Mountains, which extend for 95 km across the northern portion of the Arizona-New Mexico border, attaining elevations from 2,700 to 3,000 m. The mountains are capped by Tertiary sandstones of eolian origin (Wright, 1956). This

Chuska sandstone contains hundreds of small basins, some of which contain water permanently, others only temporarily. All are shallow and occupy closed basins. In spite of poor drainage, they are rather low in salt content and can be characterized as calcium carbonate-bicarbonate waters with little sulfate and chloride. The permanent ponds contain luxuriant growths of aquatic macrophytes. Cores to a depth of 8 m from Deadman Lake, one of the largest of these ponds (*ca.* 11 ha), have been studied by Bent (1960). Apparently all the sediment was deposited during the Pleistocene except for the uppermost 20 or 30 cm. Remains of *Pediastrum* are absent in the upper strata but are common throughout the core below 60 cm. The disappearance of *Pediastrum* is not easily reconciled with the present water quality of the lake which is neither hard nor saline. Perhaps morphometric changes and the great increase in macrophytes, implied by Bent's pollen diagram, were related in some way to the *Pediastrum* decline. Megard (1961) demonstrated the formation of a daytime microstratification which is destroyed by nocturnal density currents in Deadman and in the larger (21 ha) Whiskey Lake. Both are less than 1.5 m deep. Also, Megard estimated rates of carbon fixation during summer days in the two lakes on the basis of dissolved oxygen and apparent CO_2 changes uncorrected for atmospheric exchanges. Mean net productivity was 364 mg O_2/m^2 per hr or approximately 1 g C/m^2 per day.

Other high-altitude and sub-Mogollon Arizona lakes

In the eastern mountainous area of Arizona in an area bounded roughly by Springerville, St. Johns, and Show Low, there are several artificial impoundments, some of which occupy basins which may have been cienegas. Most of these lakes are over 2,000 m in elevation. They are soft-water lakes with calcium and bicarbonate the principal ions. One of the most important of these is Big Lake, 40 km southwest of Springerville and originally impounded in the 1930's. Trout growth in this lake has been excellent, but the shallowness of the basin, coupled with luxuriant vegetation and ice cover, resulted in an almost annual winter-kill. The dam was raised later to make a lake of 228 ha with a capacity of more than 11 million m^3.

Just below the Mogollon Rim in Arizona there are several small, shallow lakes in addition to abundant stock tanks. Many of these are 1,500 m above sea level in rolling grassland dotted with junipers and pinyon pines. Most are characterized by high summer pH values. An anomalous lake in this region is Peck Lake at about 1,000 m in the Verde Valley. It is a shallow oxbow relict of the Verde River receiving its waters from a spring and from a conduit from the river. Its area of 36 ha is almost compelely choked with *Myriophyllum,* and pH values up to 10 have been recorded from the surface waters.

Stehr Lake, elevation 1,586 m, in Yavapai County, is a 10-ha body of water with a maximum depth of 4 m. All but 2.5 ha are grown with aquatic macrophytes. The lake was impounded for power generation and receives its water ultimately from several sources known collectively as Fossil Spring3. Their flow approaches constancy at about 75 m^3/minute. These are mineralized waters high in bicarbonates, and as they splash on nearby objects, incrustations form, creating the appearance of fossils. These waters flow into Fossil Creek and hence via flume to Stehr Lake. Methyl orange alkalinities up to 375 mg/L (as $CaCO_3$) have been determined in its waters, a reflection of its rheocrene source. However, apparently much carbonate is lost from the creek water before it reaches the lake.

A few small, isolated, man-made lakes are found at high altitudes on peaks of the Basin and Range province in Arizona and in the mountainous area. These serve as trout lakes. Two are Riggs Flat Lake at 2,623 m on Mount Graham in the Pinaleno Mountains and Rose Canyon Lake at 2,135 m on Mount Lemmon.

An interesting artificial lake above the Mogollon Rim, southeast of the Arizona volcanic lakes, is dimictic Woods Canyon Lake, impounded in 1956. It is an elongate lake of 20.6 ha, with a maximum depth of about 11 m. It occupies a basin in a narrow canyon bordered by mature stands of ponderosa pine, fir, and aspen at an altitude of 2,272 m. At present the total solids are only about 51 mg/L, and methyl orange alkalinity is usually under 20 mg/L.

Deflation basins

Wind is a major erosional agent in arid regions, and therefore many Southwestern lake basins are believed to be of eolian origin. Along the Texas coastal plain there are ponds which may be of this type. Deevey (1957) has discussed a possible series, starting with small depressions seldom deeper than 0.3-0.6 m, in the Beaumont Clay formation of the humid coastal plain near Houston, and terminating in large salt lakes, La Sal Vieja and La Sal del Rey, in the semiarid southern extreme of the Texas coastal plain 480 km away. Although these basins seem unrelated, the occurrence of a group of ponds in Kleberg County, intermediate in character and geographic position, suggested to Deevey a transitional series and a common origin for the three districts.

Launchbaugh (1955) has described the microtopography of the San Antonio Prairie, a little more than 160 km northwest of the small depressions on the coastal plain near Houston and at a mean elevation of about 100 m. The majority of the fields studied by Launchbaugh exhibited an undulating surface relief in the form of what he called "hog wallows." These are depressions 3 to 10 m wide and 0.3 to 0.5 m deep, which seem similar to the dimple basins near Houston that Deevey discussed. About 480 km northwest of the San Antonio depressions, the lakes of the Llano Estacado begin. Although several theories have been advanced for the origin of the High-Plains basins, the consensus is that they are deflation products, with assistance rendered by ungulates not ruled out. A description of basins geographically intermediate between the San Antonio Prairie "hog wallows" and the so-called playa lakes of northwestern Texas was published by Van Siclen (1957). East of the Llano Estacado in the Osage Plains of Texas are many shallow basins. However, in Van Siclen's opinion there is no reason to believe them of eolian origin, and he considered them sinkholes formed by solution of calcareous Pleistocene sediments and underlying beds. Thus, the basins of the Llano Estacado are the best examples of a deflation-lake district in the Southwest.

There are thousands of these basins, ranging in size from the small, shallow type called "buffalo wallows" to large, deep lakes extending down through several formations and 115 m below the surface of the surrounding area. In Potter County, Texas, 238 km^2 are covered by playa lakes. This represents one-tenth of the total county area. Cedar Lake, one of the largest, has some puzzling islands near the southeast margin. These are probably composed of windblown materials, because prevailing winds are from the west. Parker and Whitfield (1941) have described three distinct parts to the larger lakes: a central low flat making up one-fourth to one-half the total area; a surrounding, concentric, and poorly drained flat known as the "second bottom"; and an outer somewhat eroded slope 0.2-0.4 km wide. Germond (1939) described Guthrie Lake as typical, composed of a large shallow basin and a modern, smaller, deeper one, the latter definitely eolian. In this lake there are 6 m of lacustrine sediments overlying Edwards limestone which shows no evidence of displacement, as would be the case if the lake occupied a solution basin.

The larger lakes have a lunette of sand on the leeward side which is of lesser volume than the basin. Parker and Whitfield (1941) described a lake of 20 ha near Amarillo with a shore 5 m higher on the side opposite prevailing winds. This is a region where winds attain a velocity of 30 or 40 mph nearly every month and a mean annual velocity from 12 to 15 mph. These salt lakes, or alkali lakes as they are often termed, extend from northwestern Texas into eastern New Mexico (Judson, 1950), and similar lakes are known from the Northern High Plains. Hutchinson (1957) has pointed out the great similarity between many of these depressions and the "pans" of the Transvaal. There is little evidence of active deflation today, and most geologists (e.g., Germond, 1939; Evans and Meade, 1945) believe the basins of the Llano Estacado were wind-excavated during drier periods of the Pleistocene. The best source of information concerning late Pleistocene environmental changes in this region, the Southern High Plains, is the series of papers compiled by Wendorf (1961). Among the exposed deflation basins there are many extinct lakes and ponds no longer recognizable except when dissected (Evans, 1943). These are represented now by diatomite sediments up to 23 m thick deposited in freshwater lakes and ponds. Some pond basins were buried by the sands of the Monahans Dunes which lie across a part of the southwest margin of the Llano Estacado.

Probably all but the largest of the playas in northwestern Texas and eastern New Mexico are ephemeral, although many are always moist from ground-water sources. When dry, many are dazzling with a white evaporite, and some are of commercial importance as sources of brine. Reed (1930) listed analyses of the dry lake-bed material which showed $NaCl$ and $MgSO_4$ the most abundant compounds. Meigs *et al.* (1922) considered the brine to be derived from underlying sediments of Permian seas, and they found marked differences in pump-water brine concentrations from different lakes.

The origin of the salt in the waters of La Sal Vieja and La Sal del Rey, on the coastal plain, is more of a problem. Deevey (1957) suspects the salt is derived, via summer trade winds, from salt flats surrounding Laguna Madre about 48 km away. Percentages of chloride, sodium, and potassium in La Sal Vieja and La Sal del Rey are relatively higher than in sea water. This could be explained by selective enrichment during evaporation, transport, and redeposition.

Published limnological studies of the ephemeral eolian lakes of the Llano Estacado are scarce. Reed (1930) mentioned that algae were scanty in them. Mitchell (1956) reported on winter invertebrates from a modified basin, Goose Lake in Bailey County, a playa lake which has been dammed so that it dries up only in extremely arid years. The fauna, therefore, may be somewhat different from those basins which have at least one annual dry period. Unfortunately Mitchell presented very few physicochemical data. The lake has an area of less than 4.5 ha and a maximum depth of 1.5 m. It lies in a gypsum basin, and the mean winter pH values are 8.34. Floating blue-green algae flourish, and diatoms are present. *Brachionus rubens* and *Keratella valga* are common planktonic rotifers, and blood-red tendipedid larvae abound in the sediments. The fauna contains *Diaptomus clavipes*, *D. siciloides,* a daphnid, and *Cyclops vernalis*. This is a combination one might expect in some large stock tanks in Arizona, and it may be a widespread association in the arid West. Comita (1951) reported it from a turbid pond in Trans-Pecos Texas.

The life of the saline deflation basins of the southern Texas coastal plain is known only through Deevey's (1957) contributions. Because of their high salinity, their faunas and floras are probably rather specialized, although not necessarily endemic, even though Deevey collected an undescribed species of blue-green alga. Fiddler crabs referable to *Uca subcylindrica* (Stimpson) were found at the margins of both La Sal Vieja and La Sal del Rey. Tendipedid larvae and some gastropods were present in the bottom sediments of La Sal Vieja, but in the more saline La Sal del Rey only ephydrid fly larvae occurred.

Solution basins

Cenotes and Montezuma Well

The northern part of the Yucatan Peninsula in Mexico is characterized by a lack of surface drainage and a number of limestone sinks, termed cenotes, which in many instances connect with ground waters. Thirty cenotes ranging from 0.5 to 54 m in depth were studied by Pearse *et al.* (1936). More recently Cárdenas Figueroa studied the hydrology and fauna of the cenotes and caves of Yucatan as well as the epigean fauna in that region. His results are published in a monograph edited by De la O Carreño (1950). Surfaces of the large cenotes near Chichen Itza lie 20 m below the ground level. Nearer the coast the water is closer to the land surface, and the cenotes are shallow. Some cenotes are cavelike; others are open with steep vertical walls. Eroded and presumably older cenotes occupy saucer-like depressions. Thus, the cenotes grade into two other Yucatan aquatic habitats: water-containing caves and shallow water holes called aguadas.

Several cenotes show evidence of circulation probably brought about by water entering and leaving through subsurface porous fissures of some sort. Others are stagnant and presumably have lost connection with the ground water. The role of water flow in circulation is emphasized by the following data. Although Scan Yui cenote is 54 m deep and bounded by steep cliffs rising 20 m above the surface, its temperature, pH, CO_2, alkalinity, and dissolved oxygen are practically uniform from top to bottom. By contrast, Xtolok and Xanaba II are relatively shallow, 15.4 m and 20.7 m, respectively, and yet exhibit stratification. The thermal gradients from top to bottom involve a difference of about 5° C. Below 6 m there is no detectable oxygen, and H_2S is present. Similarly, pH, CO_2, and bicarbonates are stratified. Maximum surface temperature of the cenotes was found to be 28.5° C, minimum bottom temperature 21.9° C, and the mean temperature was 25.45° C. Each cenote has its own characteristic temperature, varying little during the summer months at least. The oxygen tension in the cenote waters is about one-half of saturation. Highest *p*H values are associated with the presumed isolation from ground water and are found in Xtolok and Xanaba II. The pH of most cenotes is circumneutral, 6.8 being the lowest. Similarly, surface waters of Xtolok and Xanaba II contain the lowest concentration of CO_2, with the exception of two cenotes less than 2 m deep. Sodium chloride ranged from 70 to 560 mg/L, and $CaCO_3$ from 144 to 460 mg/L. However, although physicochemical conditions are similar in all the cenotes, the variations show no correlation with geographic position. Thus, the highest concentration of NaCl is found in Scan Yui at Chichen Itza, and the lowest in Pisté cenote which is about 5 km away. Chemical analyses of "Lake Chichen-Kanab, Yucatan" shown by Clarke (1924) presumably refer to a cenote. These show a relatively high sulfate content, and, although a carbonate value is not given, Clarke classified it as an example of sulfato-chloride water.

Pearse emphasized the successional aspect, from cave to aguada, of the cenotes and their included biota. The fauna of young, steep-walled cenotes is relatively impoverished, but it increases until in an old cenote it becomes aguada-like. The young cenotes contain some animals found also in the Yucatan caves, but these are gone by the time the old cenotes approach the aguada stage. Catfishes referable to *Rhamdia* are present in all caves and natural cenotes. Cichlid fishes are present in many cenotes, but there is evidence that in many cases these do not survive and are continuously replaced from ponds near the coast. *Macrocyclops albidus, Tropocyclops prasinus,* and *Mesocyclops tenuis* are widely distributed cyclopoid copepods in the cenotes. In Yucatan caves cirolanid isopods, two species of blind shrimps, and a schizopod crustacean are found. These animals, suggestive of marine ancestry, do not extend into the cenotes. However, the leech, *Cystobranchus*, probably with marine relationships, is found in caves and young cenotes. Two other leeches are found only in older cenotes. Dragonflies and damselflies appear in young, open cenotes, although one species, *Telebasis salvo,* is limited to old cenotes and aguadas. Similarly, among the cenote mollusks one gastropod is restricted to older cenotes. Aquatic hemipterans and coleopterans are common in older cenotes, although the corixids are represented by only two species, and no members of *Notonecta* are present. The reported chironomid fauna of the cenotes consists of only three species. Only one taxonomic group, the Ostracoda, seems to be well represented by many species in the Yucatan sinks.

The plankton of some cenotes is rather abundant. Several cladocerans and cyclopoids and two species of *Diaptomus* are present. Although several new species have been described from the cenotes, there is little or no evidence of endemism. On the whole, Yucatan aquatic fauna consists of widely distributed species, which occur also to the south and west and to a lesser extent in the islands to the north.

A habitat which is best compared with the Yucatan cenotes is Montezuma Well (Fig. 14.3) in Yavapai County, Arizona (Cole, unpublished). This is a limestone sink much like the young, open-type cenote. It is surrounded by vertical walls 21 m high, and the maximum water depth is 17 m, except for at least two deep fissures through which water enters, which have been sounded to about 40 m. The well is very nearly circular in outline with a diameter of about 100 m. However, Montezuma Well combines features of a cenote and a warm spring and is essentially a limnocrene habitat. There is a well-marked subterranean outlet through which water leaves at an approximate rate of 5,600 m^3/day, emerging outside the cliffs which bound the well. The entering water approaches physical and chemical constancy throughout the year at about 23.7° C, although the entire body of water cools and warms with the seasons. There is a lack of stratification in the well, reminiscent of Scan Yui cenote, and this lends strength to the theory that gentle currents are circulating through the latter. Chemically Montezuma Well differs from the cenotes. The pH ranges from 6.2 at night and on some cloudy days to 6.9 on bright sunny days. The total alkalinity, which is due entirely to bicarbonate, varies from 565 to 600 mg/L. There is no residual acidity, and aeration of samples raises the pH to 8.3 or more. This indicates a free CO_2 content far higher than that found in any of the Yucatan cenotes and accounts for the absence of fishes. Dissolved oxygen is from 70% to 98% of saturation and is usually uniform throughout. There is usually no detectable turbidity in Montezuma Well waters, and the euphotic zone extends to approximately 9.5 or 10 m. Secchi disc readings average about 3 m.

The fauna of Montezuma Well is represented by relatively few species, although total numbers are high. The absence of fish may account for the extreme abundance of the amphipod, *Hyalella azteca,* in the plankton as well as in the marginal weedbeds and to a lesser extent in the benthos. Only three of the Yucatan cenotes contain this crustacean. Surprisingly, there are no chironomids in the soft organic sediments of the deeper parts, although a few species are found in its weedbeds. The commonest benthic animals are oligochaetes which are present in numbers up

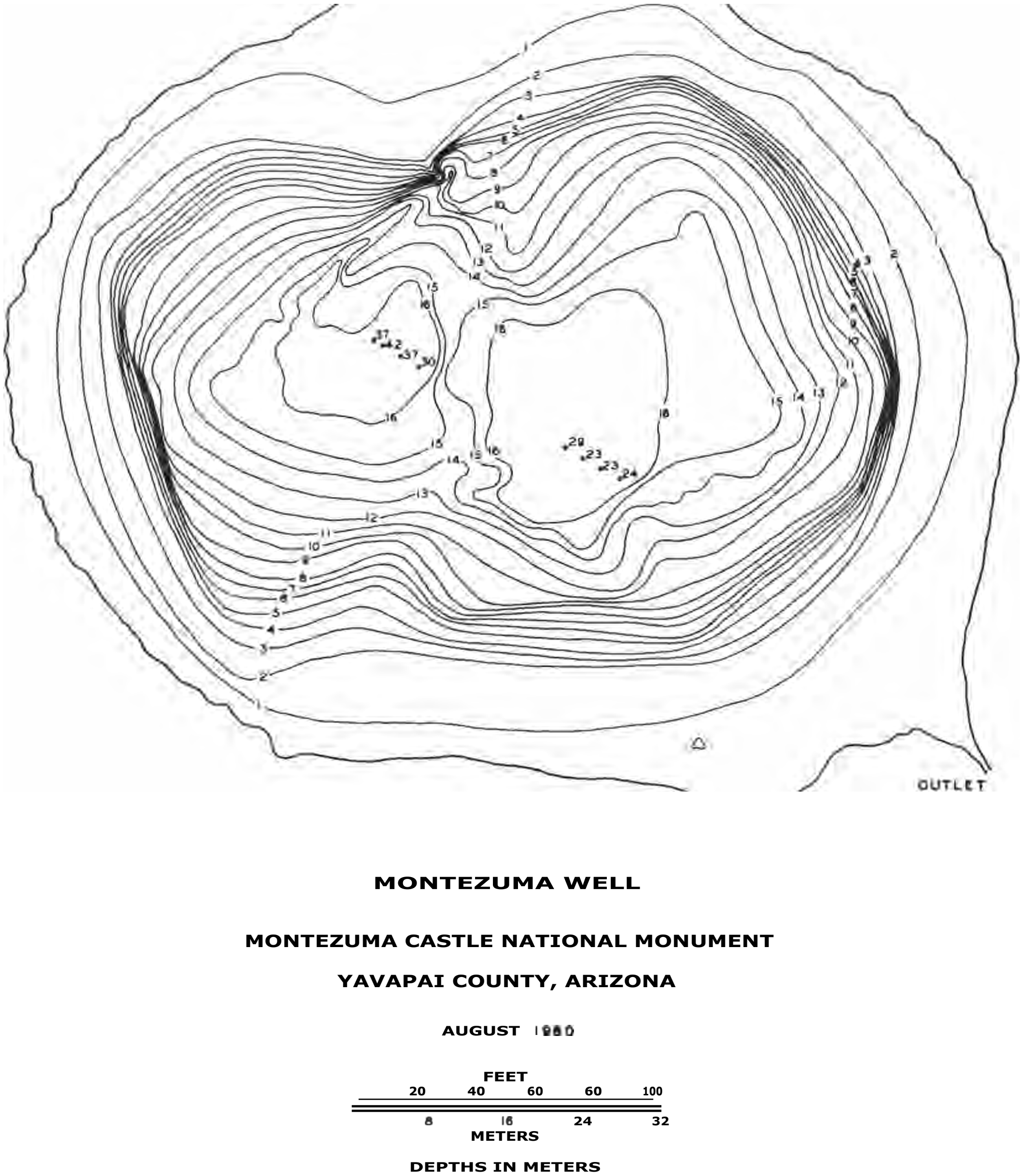

Fig. 14.3.—Bathymetric map of Montezuma Well, Arizona, a large limnocrene and solution-basin environment.

to 10,000 per m^2. The more abundant of the two oligochaetes is an undetermined species. Leeches, probably referable to *Erpobdella punctata annulata*, are present in some numbers in the benthos but are more typical of the plankton. *Tropocyclops prasinus mexicanus* is an extremely abundant plankter; presumably this is the same subspecies present in the cenotes. *Macrocyclops albidus* is also present in the plankton. There are no calanoid copepods and no planktonic Cladocera or rotifers. The only other crustaceans are some cosmopolitan ostracods, an undetermined species of harpacticoid copepod from *Chara* beds in the shallows, and chydorid cladocerans in the extensive marginal stand of *Potamogeton illinoensis.*

Diurnal migration is conspicuous in the plankton of Montezuma Well. During bright days more than 90% of the plankton is found between 3 and 8 m below the surface. At night, however, the leeches, amphipods, and copepods rise to the surface.

In addition to the lack of calanoids, rotifers, and cladocerans in the plankton of Montezuma Well, there is another unique feature: there are almost no net phytoplankters; the holophytic members of the plankton must be classed as nannoplankton.

The molluscan fauna includes two gastropods and at least the shells of the sphaeriid, *Pisidium.* Hemipterans in the well are represented abundantly, but almost exclusively, by the water scorpion *(Ranatra quadridentata), Abedus breviceps,* and microveliid water striders. The beetles are *Cybister, Hydrophilus,* and *Hydroscapha natans. Telebasis salva* is probably the only member of the Odonata which reproduces in the well, although several other damselflies and dragonflies from adjacent Beaver Creek oviposit there.

Bottomless Lakes, New Mexico

East of the Pecos River about 16 km from Roswell, New Mexico, is an interesting group of solution lakes. They lie in a chain along the base of gypsum bluffs at an elevation of 1,054 m and are called the Bottomless Lakes. Seven of these which are within the boundaries of Bottomless Lakes State Park have been studied by the New Mexico Department of Game and Fish. Their report (Navarre, 1959) includes good bathymetric maps (Fig. 14.4). Apparently these lakes are all monomictic, although certain morphometric and chemical features suggest the possibility of meromixis. Total depletion of summer oxygen occurs in the deeper waters of some lakes, but the data are not uniform, and it is impossible to state conditions in all of them.

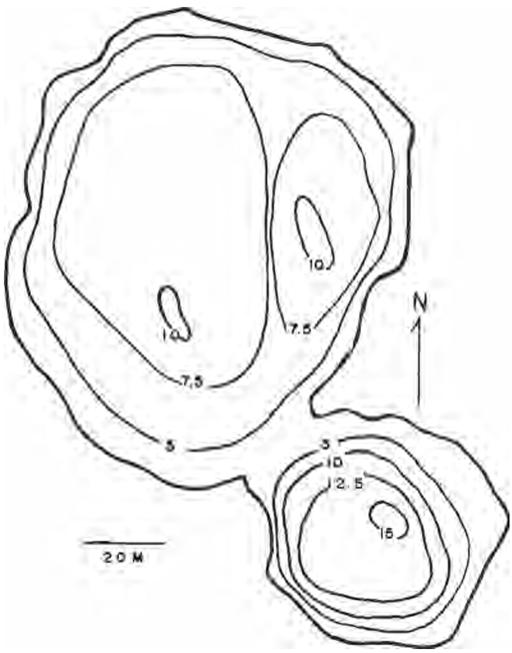

Fig. 14.4.—Bathymetric map of Mirror Lake, Bottomless Lakes State Park, New Mexico, a compound sink in gypsum deposits. Modified from Navarre, 1959.

The deepest is Lea Lake with a maximum depth of about 30 m. The largest is No Name Lake, 10.6 ha in area and with a maximum depth of 21 m. The smallest is Devil's Inkwell, 10 m deep, with an area of 0.145 ha. This lake is reminiscent of some Yucatan cenotes and Montezuma Well, for it has vertical banks, and the water surface lies 6.1 m below the surrounding terrain. The same may be said to a lesser degree of nearby Cottonwood Lake which is surrounded by vertical cliffs and lies more than 3 m below the adjacent land.

The dissolved solids in the waters of the Bottomless Lakes are extremely high, with estimates of 25,538 mg/L; conductivities are as high as 2,850 x 10 mhos at 25° C. They are best characterized as sulfato-chloride waters. Very few analyses of sodium are available, but it appears to be the dominant cation even though calcium values approach 1,000 mg/L. An unusually high fluoride content of 9.5 mg/L was found in one of the lakes. Their silica values are not available.

It is not surprising that such hard-water plants as *Ruppia maritima* and *Chaetophora incrassata* thrive here, and that fish-kills commonly decimate introduced game species, although *Cyprinodon* populations maintain themselves in several of the lakes.

The linear orientation of this group of lakes may be typical of solution basins lying in gypsum deposits. Olive (1955) described many narrow subsidence troughs in the Castile anhydrite south of the Bottomless Lakes. The troughs run parallel to the dip, about 3° E in this case. Sinkholes as deep as 10 m occur in and near the troughs.

Kaibab Plateau of Arizona

A small lake district in the Colorado Plateau province of Arizona is seen in the Kaibab Plateau north of the Grand Canyon. Rasmussen (1941) has discussed the general ecology of this area, which covers 2,980 km^2 and reaches altitudes of 2,800 m. It is surprisingly level and composed of a thick layer of Permian sediment, the Kaibab limestone, in which there are many solution basins. Some are sealed and permanent, ranging in size from 3 m in diameter to those, such as Jacob Lake and three or four others, which cover areas greater than a hectare. The fauna of many of the sinks include anostracan crustaceans, reflecting their ephemeral nature. Also, one high-altitude copepod of the West, *Diaptomus shoshone,* is present in these temporary ponds. In both permanent and temporary sinks, *D. nudus* occurs. This calanoid is typical of the lakes and ponds of Arizona north of the Mogollon Rim (Cole, 1961).

Lakes of the Río Lerma System, Mexico

A series of related lakes occurs at the southwestern edge of the Mexican Plateau in the states of Guanajuato, Michoacán, and Jalisco. They range in elevation from 2,120 to 1,525 m in a region typified by marked summer rains and winter drought. The important lakes of this system are Zirahuén, Pátzcuaro, Cuitzéo, and the largest in Mexico, Chapala. The first three seem to be successive compartments of a river system in the Lerma basin separated by volcanic materials. Lake Chapala is a relic of an extensive Tertiary or Pleistocene lake. De Buen (1943) considered the lakes fragmented from the Rio Lerma system to be a series showing relative degrees of aging. Zirahuén, the youngest, is at the highest elevation and about 46 m deep; Pátzcuaro follows at a lower level, and with a maximum depth of 15 m; Cuitzéo, at a still lower elevation, De Buen termed decadent. Chapala is only 1,525 m above sea level and is probably no deeper than 9.8 m. The extreme shallowness of this large lake has precluded the preservation of a Tertiary fauna, and it may not have had a continuous lacustrine history. Several characin fishes of the family Goodeidae and atherinids of the genus *Chirostoma* are present in these lakes and the Rio Lerma. Zirahuén has the fewest, while the river and Chapala have the greatest number of species. A basic similarity among Lerma basin lakes may be reflected in Osorio Tafall's (1942) attempt to relate the brachionid rotifer fauna of Mexico with physicochemical factors. Chapala, Pátzcuaro, and Zirahuén he considered typical of the *habitat alcalino,* with similar faunas. Chemical data approaching completeness are available only from the first two lakes, however, and no bathymetric maps exist.

The Estación Limnológica was established on the shores of Pátzcuaro in 1938, and subsequently numerous publications were concerned with that lake and others of the Lerma system. Both Mexicans and foreigners have contributed studies, and, as a result, Pátzcuaro is one of the best-known lakes in Mexico—perhaps in all Middle America. Many of the data from adjacent waters, even those from lagoons and streams, have been compared with conditions in Lake Pátzcuaro (De Buen, 1945).

Lake Pátzcuaro, elevation 2,035 m, is a C-shaped body of water with an area of 111 km^2 and a maximum depth of 15 m. There is no outlet, and the water level fluctuates about a meter during the year, the rise occurring during summer months when precipitation exceeds evaporation. Suspended volcanic materials impart extreme turbidity to the lake; the mean monthly Secchi disc transparencies are between 1 and 2 m. The temperature data presented by De Buen (1944) and Deevey (1957) for winter and summer indica`e a lack of permanent stratification thrcughout the year.

Pátzcuaro is much like Lake Chapala chemically, although Deevey's (1957) analyses cf inorganic constituents show s-me differences. The chief discrepancies between the two are a total concentration of dissolved solids in Pátzcuaro more than 1.6 times greater than Chapala, much more sulfate and less carbonate in Chapala, and almost four times as much silica in Chapala. Diatoms are the predominant phytoplankters in Pátzcuaro (Osorio Tafall, 1944b). Both are essentially carbonate lakes with an unusually high concentration of sodium for such a type, Deevey reporting 41% Na+K for each. Calcium and magnesium values, on the other hand, are extremely low, being less than 2% of the principal ions. Surface chlorophyll values determined by Deevey in the summer of 1941 were about the same for both lakes (12.5 to 15 mg/m), but certain nutrient substances were quite different. Total phosphorus was four times greater in Chapala, although the seston fraction was roughly 50% in both. Nitrates have not been assayed, but without these the N/P ratio is 61.7 in Pátzcuaro and 5.9 in Chapala.

The fauna and flora of Lake Pátzcuaro are well known. The biological survey of the lake published in Volume 11 of *Anales del Instituto de Biologia,* 1940, as "Prospecto Biológico del Lago de Pátzcuaro," is one of the major references, but there have been other contributions. A few animal species have been described originally from the lake, although they are not necessarily endemic. Osorio Tafall (1944b) published a paper on the biodynamics of Lake Pátzcuaro following Lindeman (1941) with emphasis on the central position of the ooze. No quantitative data were presented, but the list of plants and animals with their presumed trophic roles is extensive.

Deevey (1957) examined eleven Ekman-dredge samples from Pátzcuaro and five from Chapala. The total weights were rather low, 1.77 g/m^2 in the former and 0.472 g/m^2 in Chapala. An unusual feature was the presence of hirudineans in the deeper areas of these lakes. Deevey found this to be true for Lake Amatitlán in Guatemala also, and the occurrence of many leeches in the cenotes of Yucatan and in the deep sediments of Montezuma Well is worthy of note. To the limnologist familiar with the profundal benthos of temperate lakes, this is an anomalous situation.

Lake Chapala has been described by De Buen (1945) and Deevey (1957). It is a shallow lake with the deepest known point 9.8 m near the western end and a surface area of 1,685 km^2. It circulates throughout the year. The lake is extremely turbid as evidenced by Secchi disc transparencies as low as 25 cm. The Rio Lerma enters its eastern tip, where it has built a broad delta, and the Rio Grande de Santiago drains the lake from a nearby point. De Buen's (1945) paper describes the method by which limnologists under his direction have studied the lakes near the Pátzcuaro station. In April 1943 a concerted attack was made on Chapala. The lake was divided into sectors, and concurrent samples were taken by different teams. The data from this synoptic approach showed the western end of the lake characterized by nearly horizontal isotherms and some degree of regularity in the oxygen and, particularly, pH profiles. This region which is not under the influence of currents of external origin De Buen called the *zona eulimnica.* At the eastern end of the lake the influences of the entering Rio Lerma and the effluent Rio Santiago were clearly shown. River water, denser, more highly oxygenated, and with a high pH, caused much more irregularity in the various profiles. This region of the lake De Buen termed the *zona pseudolimnica.*

At least exploratory work has been performed on Lake Zirahuén, the deepest in the Lerma system (De Buen, 1943). The waters are clear and blue, with a color of VII on the Forel-Ule scale. The profiles constructed from synoptic temperature and oxygen analyses show considerable influence of currents from the Arroyo de la Palma. De Buen considered the lake almost totally *pseudolimnica* because of the irregularity of these profiles. De Buen's temperature profiles, however, suggest some degree of stability in Zirahuén, and it may be a monomictic lake.

Zirahuén is not rich in plankton. The phytoplankers make up from 87 to 98% of total numbers and are predominantly of the Chlorophyceae, with *Staurastrum* and other desmids particularly abundant.

Lakes Amatitlán and Atitlán, Guatemala

Atitlán and Amatitlán lie in a tropical humid region on the Pacific slope of the Guatemalan highlands, the former at 1,555 m elevation, the latter at 1,189 m. Both are impounded by volcanic dams. The maximum depth of Amatitlán is about 34 m, and Atitlán is 10 times deeper. The areas are a little more than 8 km^2 for Amatitlán and 136.8 km^2 for Atitlán. Amatitlán is composed of two quite distinct basins and probably should be considered two lakes.

Lake Atitlán seems to occupy a closed basin.

It has no visible outlet, although there are reasons to suspect subterranean exits. At least one small hot spring enters it from the north, but its influence is not great in such a large lake. On the other hand, the Río Lobos entering Amatitlán brings in much silt which has built a large delta at the north and northeast end. Numerous saline, thermal springs along the south shore have influenced the water quality of Amatitlán markedly. It is drained by the Rio Michatoya.

The threefold greater silica content and eight times higher chlorinity in Amatitlán waters when compared with those of Atitlán can be attributed to influent river and saline-spring water in a relatively small lake. The lake water has a greater salinity than the Rio Lobos, and probably most of it is derived from the springs. No significant increase in the salinity of the water occurred during the 40 years separating Meek's (1908) and Deevey's (1957) analyses. Apparently a rough equilibrium exists between the influent sources. Meromixis has not occurred in the lake because of the high temperatures of the spring water. Although extremely saline, the water does not flow immediately to the bottom but spreads out over the surface and is gradually mixed as it cools and sinks.

Sulfate values are not available, but it would appear that Lake Atitlán is surprisingly fresh for a closed system and is probably a carbonate lake. In Amatitlán, however, chlorides are sub-equal to the carbonates.

Deevey assayed phosphorus in the two lakes, finding the totals to be not unusual and in a mesotypic range. This is true of the lakes of other Middle American republics with the exception of Ilopango in El Salvador, a special case. The proportion of sestonic phosphorus appeared normal, although somewhat low in Atitlán. An interesting comparison here is the difference between Amatitlan and Lake Güija, El Salvador, and two similar shallow, turbid lakes to the north, Chapala and Pátzcuaro. The two Mexican lakes have a higher percentage of sestonic phosphorus than the two to the south. Deevey attributed the lack of association between turbidity and relatively high seston phosphorus in the latter to more intense metabolism under more nearly tropical conditions. One peculiarity of the lakes of Guatemala and those of El Salvador is the unusually low N/P ratio, supposedly caused by a terrestrial nitrogen deficiency.

Some thermal calculations, based on available morphometric and temperature data, were made by Deevey (1957) for Amatitlán and Atitlán. Probably both lakes are monomictic, but because the stability is not great in Amatitlán, occasional summer isothermy cannot be ruled out. The stability of Atitlán is great, however. A most remarkable feature is the high summer heat income in Atitlán, which is far greater than expected for a tropical lake. Hutchinson (1957) has pointed out that the winter heat content above 4° C in Atitlán is of the same order as in deep lakes of tropical Sumatra, but at the same time Atitlán exhibits an annual heat budget comparable to those of temperate dimictic lakes. Daily high-velocity winds sweep on Atitlán, and the work of the wind in distributing an average calorie is 0.169 g·cm.

Atitlán data contradict the generalization that all tropical lakes have small heat budgets, but the inference that such lakes should be unusually productive was confirmed by Deevey (1957). Dark-light bottle experiments in Amatitlán indicated a primary-productivity rate of 0.514 mg $0_2/cm^2$ per day and a probable yearly mean two or three times that of such productive temperate lakes as Mendota. Calculated hypolimnetic oxygen deficits in Atitlán suggest the same magnitude.

The summer plankton of Amatitlán consists largely of green algae, particularly desmids (Peckham and Dineen, 1953), but surface scums of blue-green algae are present at times (Clark, 1908). During February Juday (1916) found diatoms, especially *Melosira,* to be predominant in both Amatitlán and Atitlán. There is nothing unusual about the zooplankton in these lakes, although, inexplicably, no calanoid copepods were collected from Atitlán by either Juday or Deevey.

The Amatitlán bottom fauna sampled from various depths had a mean weight of 3.9 g/m^2, which is relatively low when compared to productive temperate lakes (Deevey, 1957). This is probably an outcome of intense metabolism and nutrient regeneration in upper waters, as would be expected in a tropical lake, thus in part depriving sediments of an energy source. Deevey's samplings revealed what may have been an atypical "azoic" zone below 25 m and the familiar concentration zone of tendipedid larvae at about 15 m.

The fauna of Lake Amatitlán contains two common decapod crustaceans: a large prawn and a brachyuran crab. This emphasizes one aspect of Middle American aquatic biology that is unique to the North American limnologist—the presence of large crustaceans in what seem most unlikely habitats. For example lobster-like shrimps called *camarones* occur in rocky, freshwater streams on the eastern slopes of Honduran mountains, and, in the mountainous cloud forests of the same country, crabs are found in small turbulent streams. An inland shrimp fishery is present here (Mercado Sanchez, 1961) as in many other tropical countries.

Volcanic lakes of El Salvador

Volcanic activity, tectonic events, and combinations of these forces produced many lakes which lie in the humid highlands of El Salvador. This is still a region of marked geologic activity, and some of the lakes were formed relatively recently, while others have been destroyed in late years. The large Lake Güija, lying in the Department of Santa Ana on the Guatemalan boundary at an elevation of 426 m, has been estimated to be less than 500 years old. It occupies a valley obstructed by a lava flow, and recent volcanism has produced several small craters nearby. By contrast Lake Zapotitlán has been drained by the Rio Sucio and now consists of marsh and saline pools (Armitage, 1958). Formerly it may have been as large as Coatepeque, now the second largest lake of El Salvador. Also, a body of water known formerly as Las Ranas and occupying a crater depression has drained through its eroded walls and contained no water when visited by Armitage in 1953.

The lakes vary in their aspect, some with precipitous margins and little vegetation, others with extensive shallow areas choked with hyacinths and water lilies. Human activity has modified the shores of many. Others are relatively undisturbed. At least one, Lago Verde de Metapán, lying in a small crater at an altitude of 450 m, is so isolated it contains a population of caimans (Armitage, 1958).

At higher altitudes the lakes occupying volcanic basins have a northern aspect, on the basis of their aquatic plants, and appear to be more typical ecologically of temperate regions than of the tropics (Fassett and Armitage, 1961). This is true, for example, of Lago Las Ninfas and Lago Verde de Apaneca, at altitudes of 1,670 and 1,650 m, respectively. Their November surface temperatures were 18° C, which is about 10° lower than that of the other lakes. Certain aquatic macrophytes reach the southern limits of their range in Middle America in these lakes, of which *Nymphaea odorata, Proserpinaca palustris, Potamogeton pusillus,* and *Brasenia schreberi* are examples. Conversely, *Eleocharis sellowiana is* a South American species that attains its northern limit in these high-altitude lakes of El Salvador.

Continuous temperature data are lacking for the volcanic lakes of El Salvador, but probably most of them are monomictic with circulation occurring during January and February. In some cases polymixis may apply. Temperature profiles from Ilopango and Coatepeque were obtained during February by Juday (1916) and in October by Armitage (1958). Lake Güija temperatures were recorded in January or February by Hildebrand (1925), in October by Deevey (1957), and in October and November by Armitage (1958). In addition, Armitage presented single temperature profiles for six other lakes. Thus, only enough data exist to calculate the thermics of Lake Güija which is relatively shallow (maximum depth 26 m). Unfortunately, seasonal temperature changes in lakes Coatepeque and Ilopango, with depths of 120 m and 248 m, respectively, are little known, although bathymetric maps are available for both. Deevey (1957) calculated some thermal properties of Lake Giiija, which show it to be not unlike the similarly shallow Amatitlán in Guatemala.

Temperature data presented by Juday (1916) for lakes Coatepeque and Ilopango during February show a very weak thermal stratification. Armitage's (1958) October data reveal a curve very similar to Juday's for Ilopango, but Coatepeque's is sharper. Deevey's (1957) October profile for Güija shows pronounced stratification, and this is also true of Armitage's temperature curve for this lake. Some profiles from the six other volcanic lakes, which Armitage graphed, show marked thermoclines between temperatures of 29° and 24° C, which imply considerable changes in density.

In the El Salvador lakes studied, deep-water oxygen deficiencies usually occurred, with total depletion in some cases. An exception was Coatepeque: Juday observed only a slight decrease in the dissolved oxygen between the surface and 110 m, with a slight, and perhaps insignificant, increase at 10 m. Armitage (1958) analyzed only surface and 15-m water in this lake; dissolved oxygen amounted to 6.6 mg/L at the surface and 8.0 at 15 m. The latter value he considered questionable, but it may have been valid.

There are conspicuous variations in certain physical features of the volcanic lakes of El Salvador. Some are extremely turbid, while others are relatively clear. Lake Güija and several of the smaller lakes are turbid, while the two largest, Ilopango and Coatepeque, have reported Secchi disc values of 10.5 and 12.5 m, respectively. Seasonal variations occur within individual lakes, however. For example, following summer rains, the waters of Ilopango carry suspended substances derived from severe erosive activity of the Río Guaye. At those times Secchi disc transparencies are reduced to 6.5 m.

Analyses approaching completeness are not available for the volcanic lakes of El Salvador, but chemically the lakes are not unusual and are similar with certain exceptions. Chloride content varies from 5 to 50 mg/L in most of them, but in Ilopango and Coatepeque this ion concentration was 635 and 494 mg/L, respectively, in 1953 (Armitage, 1958). Coatepeque owes much of its salinity to a hot spring influent, and there appears to have been a chloride increase since Renson's 1910 report (Juday, 1916) of 301.5 mg/L. By contrast, Deevey (1957) found that the hot, saline springs entering Lake Amatitlán, Guatemala, did not raise the chlorides appreciably in 40 years, probably a reflection of the fact that this lake has an outlet, whereas Coatepeque occupies a closed basin. Combining the data of Renson and Armitage, one may conclude that, in terms of Clarke's (1924) classification, Coatepeque is a *triple* lake, with chloride slowly gaining ascendancy over carbonate and sulfate. The principal cation is sodium. This is probably not true of the other lakes, with the possible exception of Ilopango. In most of the others carbonates are well ahead of chlorides, but no data are available for sulfates. Much of the salinity of Ilopango is caused by materials brought in by streams, but it is also significant that subsurface eruptions have occurred in this lake, which may have added much. Certainly the unusually high phosphorus content of 646 mg/m reported by Deevey (1957) for Ilopango suggests a contribution from underwater volcanic activity. Calcium is low, however, in both Ilopango and Coatepeque. One would expect high acidity in Ilopango, and, on the basis of what would be considered improper analyses today, Juday reported its waters to show an acid reaction at all depths in 1910. Armitage in 1953, however, found a pH of 8.4 at the surface and 8.3 at a depth of 15 m.

Of the 18 volcanic lakes studied by Armitage (1958), only the nearly extinct Zapotitlán approached Ilopango and Coatepeque in chlorinity. However, Lago Chanmico had more than twice the chloride content of the remaining 15 lakes, with 51 mg/L, and its flora was considered halophytic by Fassett and Armitage (1961). The importance of sulfate must not be overlooked, although no data are available on the concentration of this ion. Fish-kills in Chanmico are said to be an annual event, usually in January, because of sulfurous gases. Parenthetically, Chanmico is of interest because it is a good example of a parasitic maar on the flank of Volcán de San Salvador (Hutchinson, 1957, p. 28).

Najas marina, Ruppia maritime, Chara zeylanica, and *Potamogeton pectinatus,* plants typical of brackish waters, are present only in the four lakes with the highest chlorides mentioned above. These, except for the *Chara* species, are common at North American latitudes, but their presence in the El Salvador lakes from 470 to 750 m elevation and their absence in the less saline high-altitude lakes points to salinity as a very important factor in their distribution.

An interesting lake, from a chemical viewpoint, is Laguna de Alegría situated in a crater at an altitude of 1,220 m in the center of the Department of Usulután. Several sulfurous fumaroles and springs situated along the shore have brought the pH of this lake down to values as low as 2.0, and the only aquatic macrophyte present is *Eleocharis sellowiana.* The other lakes are circumneutral or slightly alkaline.

Some net plankton collections from lakes Ilopango and Coatepeque were studied by Juday (1916). Deevey (1957) reported on collections from Ilopango, Güija, and a small, closed pond near Chalchuapa. Phytoplankters seemed to be scarce, especially in Ilopango. Traces of chlorophyll were found at a 12-m depth in Güija by Deevey, although surface values were only about 12 mg/m . The zooplankton does not appear unusual and, with the possible exception of the rotifer *Keratella stipitata,* consists of species found in many North American lakes, if we are to rely on lists presented by Juday. However, the taxonomic status of *K. stipitata is* confused (Edmondson, 1959), and it may well be *K. americana* Carlin *(gracilienta* Ahlstrom), which is not rare in the United States.

Ponds and lagoons of Pacific coastal lowlands

The Pacific lowlands of Middle America contain many lagoons and shallow ponds of varied origins, but there are few limnological data concerning them. Nine shallow lakes situated in the coastal lowlands of El Salvador have been studied by Armitage (1957), and the aquatic plants of these and two additional lakes by Fassett and Armitage (1961). Armitage considered none of these basins volcanic in origin, but lava flows partially bound some of them. They share several features: all occupy closed basins; none is deeper than 2.5 m, although fluctations in level are marked; they are wind-swept and turbid; their temperatures are about 30° C; their floras are relatively poor in species and characterized by floating types. Salinities are low in spite of the closed basins; chloride values obtained by Armitage ranged from 8 to 81 mg/L and total alkalinities 36 to 244 mg/L. All were circumneutral with the exception of the only one which showed phenolphthalein alkalinity and had a pH of 9.4.

Two lagoons on the Pacific Coast of Mexico near Acapulco were studied by Ramirez Granados (1952) who presented bathymetric maps and some data on physicochemical and biotic factors. These bodies are quite different from the lakes of the El Salvador coastal plain. They are shoreline lakes, each separated from the sea by a barrier sand bar and fed by a freshwater stream. One of these, Laguna de Tres Palos, has an area of 5,500 ha and a maximum depth of about 5 m. The other, Laguna de Coyuca, is only 2,800 ha but is 18 m deep. Ramirez Granados found Secchi disc transparencies of less than a meter, water temperatures of 28°-29° C, and chloride values ranging from near zero by the influent Rio Coyuca up to 900 mg/L in Tres Palos. Although these data imply the lagoons are oligohaline, Osorio Tafall (1942) stated that Laguna de Coyuca's salinity surpasses that of the sea during dry periods, and he classed it as a saline, rather than brackish, habitat. The rotifer, *Brachionus plicatilis,* is found abundantly throughout the year in this lagoon, and Osorio Tafall considered it an indicator species for this type water. Rawson and Moore (1944) found it in only the most saline of Saskatchewan lakes they studied and mentioned literature reports of it in other extremely saline bodies of water.

Although Ramirez Granados was especially concerned with fish in the two lagoons, he also reported luxuriant aquatic vegetation, a phytoplankton predominantly myxophycean, and a varied invertebrate fauna which included such unrelated forms as green tendipedid larvae, cladocerans, and the brachyuran decapod, *Callinectes.*

Unusual habitats

Irrigation ditches

To quote Pennak (1958), the West is "densely crisscrossed with an extensive system of irrigation ditches" which have been important in changing distribution patterns of many aquatic organisms. Despite the ubiquity of the ditches, they have not attracted attention of limnologists, and there are few studies to report. In Mexico, the official organ of the National Commission of Irrigation, *Irrigacion en Mexico,* contains material on the hydrology, including some biological data, of canals as well as of artificial impoundments, lakes, and rivers.

Irrigation canals in the Salt River Valley in the Phoenix region of Arizona were studied by Wien (1958, 1959). Some of these ditches carried water from the diversion dam below the confluence of the Verde and Salt rivers; others carried pump water from underground sources; one contained water from Lake Carl Pleasant, an impoundment on the Agua Fria River north of Phoenix. Chemical data from the canals receiving their waters from the Verde and Salt rivers reflect the mixture. The chlorides, derived largely from the Salt River, range from 300 to 400 mg/L, and the bicarbonates originating mainly, although not exclusively, from the Verde River range from 250 to 300 mg/L. In the Salt River the mean chloride is about five times the bicarbonate.

Marine or brackish-water affinities are shown by the flora and fauna of these irrigation canals. For example, two red algae, *Compsopogon coeruleus* (Balbis) and *Thorea ramosissima* Bory, and the green alga, *Enteromorpha intestinalis* (L.), are present. Also, the introduced oriental clam *Corbicula fluminea* (O.F.M.), first reported from the Phoenix area by Dundee and Dundee (1958), is abundant. Some species of *Corbicula* show brackish-water affinities, but this may not apply to *C. fluminea.* The plants and mollusk mentioned above, are also present in some canals which carry mineralized, subsurface pump water, but they do not occur in a canal deriving its water from Lake Carl Pleasant. It is tempting to attribute this to lower salt content. Of the principal anions in the lake, bicarbonate is about 74%, sulfate 17%, and chloride 9%. Total soluble salts are only 374 mg/L. Another factor must be considered, however: because of water shortages, releases to the main canal from Carl Pleasant have been made only during the summer in recent years, and the canal is dry most of the time.

Lying below certain Salt-Verde River canals are a series of small, artificial ponds, termed the Papago Ponds. They have been used as experimental ponds for rearing fish and can be considered permanent for all practical purposes. These ponds and others nearby make up a small, but unique, lake district. Chlorides have accumulated in them from canal influents and evaporation. Their chloride content is about 950 mg/L and conductivity values are 1,900 micromhos at 25° C. *Najas marina,* a plant typical of salt springs and brackish waters, is here. Also, in these ponds the calanoid copepods are represented only by *Diaptomus dorsalis* Marsh. This marks the known western limit for this species, which is essentially a West Indies form. It has not been collected in any other bodies of water in Arizona.

Irrigation "drains" from the Rio Grande in New Mexico at altitudes from 1,360 to 1,556 m are somewhat different (Clark and Mauger, 1932; Clark and Smith, 1935). Few biological data are available, but physicochemical assays have been made. In these canals carbonates are only slightly in excess of sulfates, but the relative chlorinity is about the same as in the canals from Lake Carl Pleasant, Arizona. Mean total solids are near 500 mg/L. At such altitudes there might be a possibility of trout survival if drains were shaded, because periods of high water temperatures are brief.

Stock tanks

Pennak (1958) pointed out the rich invertebrate fauna to be found in the stock tanks of the arid West and emphasized the fact that these habitats have been neglected by aquatic biologists. In Arizona earthen tanks are common in all physiographic provinces. Most of them are probably not permanent and exhibit environmental extremes. Many shallow tanks above the Mogollon Rim freeze completely. All are characterized at times by extreme turbidity. High temperatures are pronounced in those at low altitudes in the Sonoran desert. It would seem that real contributions to population ecology could be made through studies of these tanks, because their faunas and floras appear simple. A few comments concerning the planktonic microcrustaceans of Arizona tanks will illustrate this.

In most stock ponds one species of calanoid copepod is present, although in rare instances two occur (Cole, 1961). There is some evidence that congeneric coexistence is a feature of new tanks, but that one species will disappear in time. There are usually one or two species of *Daphnia* and one cyclopoid copepod, the latter most often being *Cyclops vernalis.* Some remarks concerning a Texas pond by Comita (1951) imply the above situation may apply rather generally. In late summer, notonectid nymphs become prevalent, and crustacean populations are decimated. Anomalous situations prevail at times: some tanks have been found to contain tremendous populations of ostracods, referable to *Cyprinotus,* and diaptomids are absent. In some short-lived, shallow tanks various species of *Moina* occur, and *Daphnia* and *Diaptomus* are rare or absent.

An interesting situation was observed in a small Arizona tank that contained *Daphnia pulex* as the sole member of the genus. Immediately below the dam was a small, water-filled depression fed by seepage from the tank. In this pool *Daphnia similis* was abundant, and only a few *D. pulex* occurred.

These preliminary observations suggest excellent opportunities for studying the dynamics of interspecific competition and for answering some questions concerning indicator species. Moreover, it should be emphasized that problems of sampling environmental factors are insignificant compared to the situation in a large lacustrine habitat.

Natural ephemeral waters

Ponds.—Small, ephemeral ponds of the arid Southwest have been neglected to a great extent. They are characterized by extremes of turbidity and temperatures. Many species of phyllopod crustaceans occur in such habitats, the notostracan, *Triops longicaudatus,* being one of the most interesting forms. Large populations of these can be found occasionally in muddy puddles no deeper than 5 cm. Cladocerans of the genus *Moina* and ostracods referable to *Cyprinotus* are also typical inhabitants of seasonal desert pools.

Weise (personal communication) studied a small, desert depression filled by summer showers near Phoenix, Arizona (altitude *ca. 333* m). The entire life span of this pond was 12 days, during which time a large population of conchostracans hatched and matured. Chemical data were sketchy but suggested that sequential changes in relative anions occurred similar to those which take place over many years in closed basins of arid regions (cf. Hutchinson, 1957, pp. 566-567).

Tinajas.—An interesting aquatic microhabitat in the mountainous areas of the Southwest is the tinaja. This is a cylindrical pothole worn in the rocks of steep washes. Hensley (1954) mentions some in Organ Pipe National Monument in southwestern Arizona. Schwarz (1914) described the "Four Tanks" in a steep, rocky gorge above Castle Hot Springs, Arizona. These are typical, being from 1 to 2 m deep and lying in series one above the other. It is possible that some protected tinajas contain some water throughout the year, although most are not permanent. It is tempting to postulate meromixis in those which approach permanency, but no studies have been made on them. Many contain abundant algal and microcrustacean elements. The ostracod, *Cyprinotus,* is common in some almost inaccessible tinajas of Arizona canyons.

A diminutive counterpart of the tinaja, although of different origin, is the "etched pothole" described by Udden (1925) in calcareous Texas rocks. Some of these tinajitas contain water at times but must be considered extremely ephemeral.

Springs and springbrooks

Permanent limnocrene habitats in the Southwest are relatively common, but there are few data concerning them. Listing the many known springs is prohibitive, but there are tremendous opportunities for future study among them.

Some of the most conspicuous of these are the Big Springs of Texas arising along the Balcones fault line at the southern and eastern border of the Edwards Plateau. Edwards limestone is over 90% $CaCO_3$, affecting the quality of the water issuing from the springs.

Some bolsons have large springs. Balmorhea Springs, south of Pecos, Texas, is one of these, yielding great quantities of water from a porous limestone. In general, the many springs in the Basin and Range physiographic province of Texas, New Mexico, and Arizona are located near or in ancient lake beds and are extremely mineralized. In the United States the water table has been lowered drastically in such areas, but in parts of northern Mexico, particularly in Coahuila and Chihuahua, there are many closed bolsons with high water tables. The bodies of water in these are marked by a high degree of endemism in their faunas and warrant increased attention by biologists.

Springs that would be most appealing to limnologists and other aquatic biologists are those isolated oases in extremely arid areas. Quitobaquito Springs in Organ Pipe National Monument, Arizona, is such a habitat. It flows at the rate of 163 L per minute and has been impounded, covering an area of 0.1 ha (Hensley, 1954). In it occurs a distinct subspecies of *Cyprinodon macularis,* probably endemic to the spring and the Sonoyta River, a recently disrupted segment of the Colorado River drainage (Hubbs and Miller, 1948).

Abbott and Hoese (1960) attempted a study of energy flow in a small, brick spring chamber, Minter Spring, in Brazos County, Texas. The poorly oxygenated and acid water, probably from Pliocene strata, had a mean flow of 7 L a minute, and other physical and chemical conditions approached constancy. Because the chamber had a volume of only about 1,100 L, the mean flushing time was 2.6 hr, precluding establishment of a plankton community. Primary productivity appeared to be derived entirely from encrusting mats of filamentous green algae, but no satisfactory method of measuring it could be devised. Trophic relations were simple, with ostracods and snails serving as primary consumers. Dytiscid larvae were the tertiary consumers. The chlorophyll A content of the entire system during mid-December was 0.53 g/m^2.

Springbrooks of the Southwest have received little attention, although they are another of the unusual aquatic environments of the region. Noel (1954) reported a year's investigation of Lander Springbrook, arising from a rheocrene spring in the Roswell Artesian Basin of New Mexico. The water was extremely mineralized, with a total residue of 4,400 mg/L, and best characterized as sulfato-chloride in quality. Temperatures were nearly constant throughout the year at about 18° C. There were no sphaeriids, isopods, trichopterans, simuliids, hirudineans, or water cress, which are species typical of many springbrook communities. Presumably these were absent because of the high salinity. Although the fauna was depauperate, a few species were abundant, predominantly *Gammarus,* coleopterans referable to *Zaitzevia parvula* (Horn), gastropods, flatworms, tendipedids, and tubificids.

Similar springbrooks, differing mainly in water quality, found in other parts of the Southwest would lend themselves to comparative study. Fossil Creek in Arizona is one such habitat. Another is the ancient Indian canal which carries the effluent from Montezuma Well, Arizona. Within the first kilometer there are conspicuous changes in the water chemistry, resulting chiefly from loss of CO_2 to the atmosphere with ensuing precipitation of $CaCO_3$ and relative enrichment of other ions.

Schwarz (1914) commented on the fauna of Castle Hot Springs, Yavapai County, Arizona. The springs are at an elevation of 600 m near the southern edge of the Wickenburg Mountains. Water temperature is 46° C at the source, cooling to 35° C at the bottom of the gorge. At the source Schwarz collected a mite and two beetles, including the unusual coleopteran *Hydroscapha natans.*

The stream issuing from Verde Hot Springs in Arizona represents another opportunity for study of a western springbrook. It is 41° C and may differ chemically from the last.

Grants Lava Bed, New Mexico

The Grants Lava Bed in west-central New Mexico contains unique aquatic habitats which have been described by Lindsey (1949, 1951). These are lava sinkhole ponds and lava-tube caves which contain water. According to Lindsey, this is the only American lava flow containing permanent water. More than 100 such ponds in collapse depressions and caves exist in an extensive region of 570 km^2. They receive their waters from Zuñi Mountain and from several large springs at Horace, New Mexico. As is true of so many New Mexican waters, these are high in calcium sulfate.

The ponds are at altitudes of more than 1,800 m. As a result, they freeze over during winter. At that time stored heat in the lava accounts for unusual circulation and temperature relations. In some cases water 77 cm below the ice is 6° C.

Lindsey (1951) described a plant succession in these bodies of water, starting with a floating film of *Chlorella* and culminating in a shrubby swale. Of particular interest is the optical effect produced by *Chlorella* cells in the dim cave pools, as they orient their chloroplasts opposite the light (Lindsey, 1949). Many pools are lavender-colored because of the presence of the sulfur bacterium, *Lamprocystis roseo-persicina* (Kutz). Of special biogeographical interest is a relict population of an arctic-alpine moss, *Homomallium incurvatum* (Schrad.), on northeast facing walls in some of the ice caves.

Caves

Water-containing caves in the Southwest and Middle America include lava-tube caves and many solution caverns in calcareous regions. The caves of the Yucatan Peninsula grade into open cenotes but were considered in a separate report by Pearse *et al.* (1938). Some other caves in Mexico are relatively well known; these are La Cueva Chica and La Cueva de los Sabinos in the state of San Luis Potosi. Breder (1942) described the ecology of the former with particular emphasis on the blind characin, *Anoptichthys.* Osorio Tafall (1943) recorded 37 species of aquatic animals from the two caves but considered only the following to be typical troglophiles: *Anoptichthys,* a cirolanid isopod, and, surprisingly, the calanoid copepod *Diaptomus cokeri* which he had described previously. Both caves contain ostracods assigned to the genus *Candona* and an harpacticoid possibly referable to *Attheyella pilosa* Chappuis. Probably Osorio Tafall should have included these with the true cave species.

A series of escarpments and faults, known as the Balcones fault zone, forms a curve from southwest to north-central Texas. To the north and west of the fault line lies the Edwards Plateau containing remarkably pure limestone. There are water caves in the Edwards limestone near the faults. They have been little studied, although probably they contain a unique fauna (Maguire, 1961).

Reservoirs of southwestern United States

The impoundments of the arid Southwest are similar in many respects to natural lakes, but

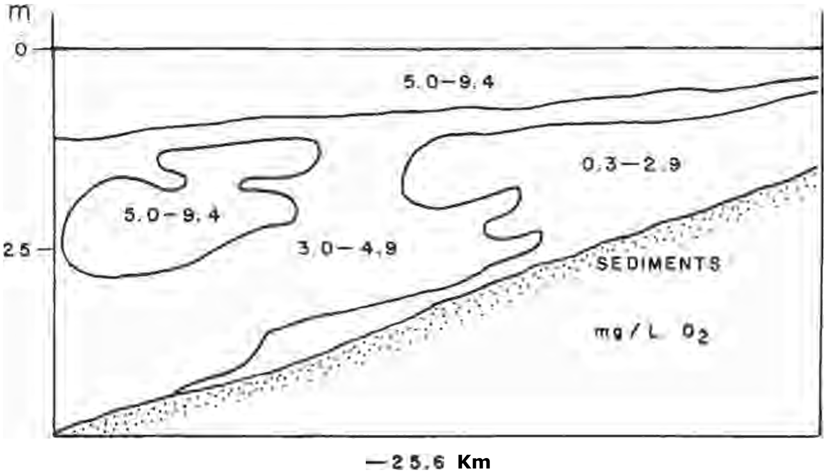

Fig. 14.5.—Mid-channel section of Elephant Butte Reservoir, New Mexico, showing unusual distribution of dissolved oxygen, July 13-17, 1938. Modified from Ellis, 1940.

there are some important departures from natural conditions which preclude accurate calculations of oxygen deficits and heat budgets. At unpredictable intervals, flash floods suddenly introduce turbid waters which profoundly alter existing thermal and oxygen relations. In Elephant Butte Reservoir, New Mexico, a large area of shallow water in the upper part of the lake is either much warmer or much colder than the main body of water, depending on the season. Intrusions of this water mass into the lower lake following floods strikingly alter pre-existing conditions (Ellis, 1940).

Ellis diagrammed some unusual oxygen conditions in Elephant Butte where draw-off for irrigation demands also complicates the normal course of physicochemical events (Fig. 14.5). Moreover, in many impounded waters of the West, such as Elephant Butte, there are unusual subsurface contours, which complicate the flow patterns of density currents. Also stratification in the adclaustral region, which is the term Ellis applied to the portion of lake near the dam, is modified by the interaction of the perpendicular dam surface and wind-generated currents.

Such a problem confronted McConnell (personal communication), who could find no reliable method of measuring the flash-flood import of organic material which entered Peña Blanca Lake in southern Arizona but estimated roughly more than 300 thousand kg a year, which is on the order of 15,000 kg/ha per year. These floods, therefore, not only alter temperature stratification and hypolimnion oxygen concentrations but interfere seriously with a compete assay of the lake's economy.

Arizona

Four large impoundments are present on the Salt River of Arizona, formed from tributaries arising in the mountainous areas to the east. The largest and oldest of these is Roosevelt Lake, impounded 50 years ago at an altitude of a little more than 635 m. Below it lie Apache, Canyon, and Saguaro lakes, the last with a spillway crest about 450 m above sea level. Apache Lake is about 80 m deep, and the rest are at least 30 m deep. They have a combined area of 8,979 ha. Except for Roosevelt Lake, they occupy basins bounded abruptly by steep cliffs. Fluctuations in water level are pronounced, and their shores are bare and rocky.

A few data kindly supplied by members of the Arizona Game and Fish Department, the Salt River Valley Water Users' Association, and the Maricopa Water District make possible a sketchy limnological appraisal of these bodies of water. They are warm monomictic lakes which stratify from, at latest, early July until November. Annual surface temperatures range from 31° to 11° C. There is some evidence of density currents entering the upper ends of these lakes and flowing beneath the surface in summer months, but this is not conspicuous in winter. This could be a reflection of the almost daily summer rains in the highlands to the north and east, as opposed to winter months when precipitation in the watershed is largely snow. More reasonably, however, much of the turbidity in the lower lakes is caused by letdown from lake to lake to supply increased irrigation and power demands at this time.

Few chemical data are available for these lakes, although water quality of the Salt River above Roosevelt Lake is well known. This river has salt beds along its course, and this is reflected in its high chloride content which ranges from 330 mg/L, when diluted in early spring, to well over 1,000 mg/L during the low water periods. Sodium is usually the dominant cation, although sometimes calcium surpasses it during periods of high runoff. The lakes themselves are dilute chloride waters, with bicarbonate the second most abundant anion. Sulfates probably attain values up to 100 mg/L at times, and a strong odor of H_2S is present at the outlet of each lake during summer stagnation.

Summer oxygen depletion is complete in the lower waters of the four lakes. Total alkalinities range from 75 to 192 mg/L (as $CaCO_3$) and pH from 6.2 to 9.2.

Plankton usually is scanty in all the lakes, although conspicuous blooms of *Ceratium hirundinella* have been noted occasionally during late summer. There is a similarity in the dominant zooplankters from each lake. *Diaptomus clavipes* and *D. siciloides* are present, and this coexistence is probably typical also of the low-altitude impoundments on the Verde, Gila, and Agua Fria rivers. *Daphnia ambigua* is the common cladoceran, although *Diaphanosoma brachyurum, Ceriodaphnia lacustris,* and *Bosmina* also occur. Large spongillid colonies are found on rocks in the shallows.

Horseshoe and Bartlett lakes are impoundments on the Verde River at elevations of 610 and 533 m, respectively. Waters leaving Bartlett Lake enter the Salt River below Saguaro Lake and are diverted into large canals serving the Phoenix-Mesa area. There are several data available for Bartlett Lake but few for Horseshoe. The former is more than 30 m deep, but summer thermal stratification is not pronounced as it is in the Salt River lakes. Summer records show surface temperatures of about 29° C and 23° C at 24 m, the sharpest dines being 0.5°/m. In spite of this, waters at 15 m and below lack oxygen during the summer months.

Total alkalinities in Bartlett Lake and the Salt River impoundments reflect differences in the drainage systems of the Verde and Salt rivers. In Bartlett Lake methyl orange alkalinities are higher, ranging from 138 to 266 mg/L (as $CaCO_3$), and annual pH values range from 6.8 to 8.9 at the surface. The Salt River arises largely in igneous rocks, whereas most of the Verde River flow originates in the Verde Valley and the calcareous Verde Formation. The dominant compound in the Verde River is calcium bicarbonate; chloride is relatively low.

Lake Carl Pleasant, northwest of Phoenix on the boundary of Yavapai and Maricopa counties, was formed by the impoundment of the Agua Fria River. The headwaters of the Agua Fria lie east of Prescott, Arizona, and the river flows approximately parallel to the Verde River in a different valley. The lake has a maximum depth of 52 m. However, water shortages are common, and these dimensions were attained several years ago. It is a warm monomictic lake, stratifying in summer months, with oxygen depletion occurring in the hypolimnion. Some chemical analyses are available for the waters of this lake, and they show sulfates (50 mg/L) and bicarbonates (202 mg/L) as principal anions. Chlorides are 24 mg/L. Sodium (45 mg/L) and calcium (38 mg/L) are the dominant cations. Plankton has been scanty in collections from the lake.

San Carlos Lake, a large impoundment on the Gila River at an elevation of 790 m, has been at low levels in recent years. It owes its high chloride and sulfate content at least in part to Clifton Hot Springs which empties into a tributary of the Gila River. The daily contribution of salt from these springs ranges from 22 to 63 thousand kg.

New Mexico

The large reservoirs of New Mexico, like those of Arizona, are warm monomictic bodies of water even though situated at higher elevations. The Arizona impoundments are somewhat warmer than their New Mexican counterparts. There are smaller New Mexican lakes, however, which are dimictic. For example, Clayton Lake (Navarre, 1960) in the northeastern corner of the state at about 36° 30' N latitude and at an elevation of 1,570 m is dimictic. The lake covers only 31.6 ha and is usually no deeper than 15 m, although a maximum depth of 21 m is possible.

The largest body of water in New Mexico is

Elephant Butte Reservoir, a long narrow impoundment on the Rio Grande which covers a maximum of 15,783 ha with a depth of more than 30 m. The lake lies in a region of semi-desert flora with piñon pine, juniper, cactus, and mesquite. The fishes are typically warm-water fauna, although trout are found below the dam. Like most impoundments of the Southwest, the water level fluctuates considerably, and much of the shoreline is bare of aquatic plants. During summer stagnation complete oxygen depletion is rare. Greenbank (1937), Clark (1938), and Ellis (1940) have contributed papers on this impoundment making it one of the best known in the Southwest.

Willow Lake in southeastern New Mexico originally occupied a solution depression in bedrock of Permian gypsum (Navarre, 1958). In 1920, however, the first of two dams was built to enlarge the lake, and water from the Black River was diverted by canal to fill the basin. The lake covers 145.7 ha but is only 6.5 m deep. In spite of this it stratifies effectively at high temperatures during the summer when bottom waters become as warm as 26°, and there is no dissolved oxygen below 4.8 m. Mean total solids in the lake are 3,465 mg/L, and pH values are usually above 8. The category *apatotrophic*, proposed by Swain and Meader (1958) for alkaline lakes with high total dissolved solids and relatively low sedimentary nitrogen and carbon, does not apply to Willow Lake. Analyses of its hydrosoils show a high nitrogen content.

The fishes of Willow Lake show a higher rate of growth than those of most other New Mexican reservoirs. In all of these lakes benthic production seems to be low, but it is difficult to make comparisons. Data are presented in numbers and volume per unit area, but no weights are given. In Willow Lake the means of Ekman-dredge samples are about 92 organisms per m^2 having a total volume of 0.86 cm^3/m^2. In New Mexican impoundments plankton feeders such as *Dorosoma* are used as forage fish. In Arizona the similar thread-fin shad *Signalosa* has proven a successful forage species (Haskel, 1959).

Texas

In most reports on Texas reservoirs either there are incomplete chemical analyses or morphometric details are lacking. Most investigation has been concerned largely with fish inventory. Limnological information is incidental. Harris and Silvey (1940) reported unpublished generalizations from A. H. Wiebe which seem to apply. East Texas reservoirs have a pH varying from 5.8 to 7.1 and are low in total alkalinity. Some of these lakes, for example those in the Cypress Creek Basin such as the natural Caddo Lake, have highly stained waters. That region of Texas bears forests of pine and cypress. Reservoirs of northeastern Texas farther west, where Harris and Silvey worked, have *p*H values from 7.0 to 8.4, while still farther west many waters show phenolphthalein alkalinity much of the time.

Edaphic and climatic factors interact to bring about these contrasts. Rainfall decreases and evaporation rate increases from east to west. The geologic formations in the state are such that, as one moves from east to west, bedrock changes coincide with precipitation-evaporation changes.

Along the upper half of the eastern border of Texas, reservoirs lie in Eocene sediments and contain relatively high chloride content. In Lake Murvaul, Panola County (Dorchester, 1959), the mean bicarbonate/chloride ratio during the first year following impoundment was about 1.6, the concentrations being 44 mg/L of bicarbonate and 27.56 mg/L of chloride. In Striker Creek Reservoir, Rusk County (Dorchester, 1960), chlorides are higher, and the same ratio is 0.14, the chlorinity being 170 mg/L in contrast to 26 mg/L of bicarbonate. The increased chlorinity in Striker Lake, which lies to the west of Murvaul, might be attributed to subterranean waters derived from the Woodbine Sand, which does not extend eastward into Panola County (Plummer and Sargent, 1931). Although this Cretaceous formation is found farther west in Texas, the chloride content of its waters increases markedly in an eastward direction. Nearby shallow Upper Ellis Lake in Wood County, lying in similar Eocene sediments, was studied by Cheatum *et al.* (1942). Chlorides were not assayed, but surface methyl orange alkalinity was usually less than 20 mg/L (as $CaCO_3$) although concentrations up to 54 mg/L occurred at lower levels during summer. Because this lake is fed in part by acid springs, it rarely attains a pH as high as 7.0. A mat of littoral vegetation is encroaching upon the lake. Apparently, sphagnum is not involved in its formation. Parts of this mat break off and float about during summer. These drifting islands sink during winter but reappear in spring.

TABLE 14.2

Comparison of four Texas reservoir lakes. From Harris and Silvey, 1940.

Name	Year impounded	Number of macrophyte species	Organic material total plankton (mg/L)	Organic material total plankton (kg/ha)
Lake Worth	1914	54	3.956	126.5
Dallas Lake	1927	52	5.035	167.2
Eagle Mountain	1934	16	2.935	134.9
Bridgeport Lake	1935	9	4.603	276.2

Harris and Silvey (1940) published on four shallow reservoirs of the Trinity River basin in Jack, Wise, Tarrant, and Denton counties. All lie in Cretaceous sediments, except for Lake Bridgeport located farther west in Pennsylvanian deposits. The report includes excellent data on the plankton, aquatic plants, and physicochemical factors. There is no information on the benthos, and morphometric details also are incomplete. The lakes are usually monomictic, but the authors cite weather bureau records that two of them froze the winter of 1929. These were Lake Dallas and Lake Worth. The former is 12 m deep, 160 m above sea level, and at 33° 20' N latitude. Lake Worth is 9 m deep, 180 m above sea level, and at 32° 47' N latitude. Also Harris and Silvey (1948) described thick ice on Lake Dallas during February 1939. This may represent one of the lowest latitudinal limits for dimictism at such altitudes in North America.

The four reservoirs are typical freshwater bodies with bicarbonates making up about 75% of the principal anions and calcium the most abundant cation. Summation of chemical analyses shows the lakes have a mean total salinity of about 240 mg/L. Lake Dallas has a slightly higher chloride content, perhaps because its basin lies in the Woodbine Sand.

In the same drainage system, but farther east in Dallas County, is White Rock Lake (Patterson, 1942). Chemical analyses are incomplete, but this reservoir seems to be similar to those studied by Harris and Silvey. It lies in Cretaceous sediments, and total alkalinities range from 70 to 121 mg/L.

Harris and Silvey approached their study of artificial lakes with an eye to the effects of aging on productivity. They found a direct correlation between age and the number of aquatic macrophyte species present in each lake, but most other data did not show the same relationship. Perhaps the most instructive data were in gravimetric determinations, based on ignition, of the organic content of mean total seston, which are shown in Table 14.2.

Lake Wichita, about 80 km northwest of Lake Bridgeport in Archer and Wichita counties, is 60 years old at this time (Lewis and Dalquest, 1957). Its drainage area is within the Red Beds of the Texas Permian. These marine sediments are high in NaCl and $CaSO_4$, and this is reflected in the water quality. The waters contain more sodium than calcium, and the relative anions are Cl > SO_4 > CO_B. According to Lewis and Dalquest, plankton is "extremely rich." No quantitative data are given, but the benthos also "is rich, especially in *Chironomus* larvae."

Small, turbid reservoirs, largely used for irrigation and stock watering, are present in the Salt Basin of Trans-Pecos Texas. These are quite different from the impoundments farther east. Deevey's (1957) account of Fort Stockton Lake and Balmorhea Lake may typify many of them. Both are sulfato-chloride waters with a total salinity of about 2,000 mg/L. Magnesium is remarkably low in these lakes, especially when compared to many of the saline lakes of New Mexico. A further feature which may prove typical of desert lakes is the high percentage of sestonic phosphorus, although there are no comparable data on others outside Trans-Pecos Texas.

Deevey examined one Ekman-dredge sample from Balmorhea Lake, but this does not warrant generalizing about the benthic productivity of desert impoundments. It contained only tendipedid larvae and tubificids in amounts implying 78.58 kg/ha. This is six times less than the mean crop for productive Lake Mendota but about twice the value reported from the lakes of Connecticut's Eastern Highland (Deevey, 1941).

Thermics

In most lakes of the American Southwest the temperature regime is not unusual. Warm monomictic lakes are common, but at high altitudes in New Mexico and Arizona dimixis occurs regularly. The possibility of intermittent ice cover is great, however, and there may be more polymixis than suspec ted.

A feature of deep Middle American lakes is the considerable stability despite small temperature gradients. This is, of course, consistent with

TABLE 14.3
Thermics of Southwestern and Middle American lakes

				Depth (m)		Heat incomes (g-cal/cm^2)		
	Lat. (N)	Alt. (m)	Area (ha × 10)	Max.	Mean (š)	Summer (0 bs)	Winter (0 bw)	Annual heat budget (0 ba)
Dimictic lakes								
Clayton Reservoir, New Mexico	36°37'	1,569	0.315	15	6	10,475		
Woods Canyon, Arizona	34°18'	2,294	0.206	11	6.1	7,714		
Monomictic lakes								
Conchas Reservoir, New Mexico	35°23'	1,289	64.87	50	14		+[illegible]1,871	
Alamogordo Reservoir, New Mexico	34°39'	1,300	18.82	23	13	16,686	0	16,686
Apache Lake, Arizona	33° 31'	576	10.75	77	28		−21,600	
Elephant Butte, New Mexico	33° 20'	1,341	148.81	47	18		−[illegible]7,246	
Pena Blanca Lake, Arizona	31° 22'	1,219	0.198	18.3	6.6	8,386	−[illegible]3,056	8,386
Lake Atitlán, Guatemala[a]	14°40'	1,555	13,686	341	183	22,110	−288,300	22,110
Lake Amatitlán, Guatemala[a]	14° 25'	1,189	822.6	33.6	18.8	8,510	−29,670	8,510
Lake Güija, El Salvador[a]	14° 13'	426	4,475	26	16.5	5,410	−32,090	5,410

From Hutchinson, 1957, Table 53. The symbols for depth and heat income are those proposed by Hutchinson.

the high temperatures that prevail. The gradient from 29° C to 24° C in some lakes of El Salvador (Armitage, 1958) represents a change in density roughly equal to that between 19° and 9.3° C. Some large impoundments of Arizona, New Mexico, and Texas attain surface temperatures comparable to those of Middle American lakes and perhaps higher at times. Harris and Silvey (1948) report an August temperature of 37° C from Lake Dallas, for example. The main differences are in hypolimnion temperatures, which are reflections of winter conditions. Elephant Butte, New Mexico, is 8° C in winter, while Apache Lake, Arizona, at an altitude 765 m lower, has winter temperatures from 11° to 12° C. The Guatemalan and El Salvadoran lakes have winter temperatures near 20° C.

Calculations for Atitlán, Amatitlán, and Güija show large negative winter heat budgets as expected in tropical lakes (Hutchinson, 1957, Table 53). Because of incomplete data, comparisons with reservoirs of the Southwest have to be made on the basis of this parameter. In many of the dimictic lakes the minimum winter temperatures are not known, and in such large lakes as Apache, summer records are available only to a depth of 24 m, which is more than 50 m above the bottom. Therefore, it is impossible to calculate maximum summer heat content, even though adequate morphometric data exist for Apache. Moreover, many reservoirs are drastically altered during summer by the release of large subsurface volumes and the disturbances caused by density currents.

In Table 14.3 some thermal data are presented for a few Southwestern and Middle American lakes. These are not all valid, because flash floods dramatically change such small lakes as Peña Blanca (McConnell, personal communication).

Chemistry

Several generalizations about the chemistry of Southwestern and Middle American waters have been made in this chapter. Most of these have come from Deevey's (1957) paper, because since its publication there has been almost no other comparable research. However, the unusually low magnesium content Deevey found in some ponds of Trans-Pecos Texas is certainly not typical of many Basin and Range waters.

Silica is high throughout the region. Some summaries and comparative data are presented in Table 14.4. The East Texas reservoirs and the dilute Chuska Mountain lakes are low in silica. Also, the two most saline lakes Deevey studied, La Sal del Rey and Grable's Salt Works, had a small silica content. Most Southwestern lakes and springs of intermediate salinity are moderately high in silica, but the content of the Mexican, Guatemalan, and El Salvadoran lakes averages about 43 mg/L.

Graphic representations of relative concentrations of the three major anions in Texan, New Mexican, and Arizona waters are shown in Figures 14.7, 14.8, and 14.9. The method employed in plotting these by triangular coordinate diagram is explained by Figure 14.6 and its legend.

Arizona waters are the least varied (Fig. 14.7). Most are essentially the carbonate type, even when fairly concentrated. Sulfate is not important, although the issue from Croton Springs is best described as triple water in the classification of Clarke (1924). The Salt River impoundments contain chloro-carbonate waters.

An interesting trend is seen in New Mexican waters (Fig. 14.8). The high-altitude lakes and springs are carbonate waters. With increasing salinity, sulfato-carbonate waters develop, as shown by the three large impoundments on New Mexican rivers—Elephant Butte on the Rio Grande, Conchas on the South Canadian, and Alamogordo on the Pecos River. Most lakes lying in gypsum deposits can be categorized as sulfato-chloride waters. The most concentrated of these, No Name, is a chloro-sulfate lake.

There are no sulfato-carbonate waters plotted for Texas (Fig. 14.9). The playas of Trans-Pecos Texas can be classified as sulfato-chloride waters, and the saline lakes of the South Texas coastal plain fall into the chloride category.

The Mexican lakes, Chapala and Pátzcuaro, plotted in Figure 14.9, appear to be typical carbonate waters, but their dominant cation is sodium. Thus, they are quite different from the reservoirs of eastern Texas, which, although plotted nearby, are calcium lakes.

Productivity

Knowledge of productivity in Southwestern and Middle American waters is based almost entirely on Deevey's (1957) work. This leaves important areas for future investigations in these regions.

High primary productivity in Amatitlán and the hypolimnetic oxygen deficit in Atitlán have been discussed. Here productivity is high, but benthic fauna production is low, a characteristic which may be typical of tropical and semi-tropical lakes. Other data from Deevey apply to

TABLE 14.4

Amounts of silica present in some Southwestern and Middle American waters, with comparative data

Water	Authority	mg/L
Ojo Caliente, New Mexico	Clarke, 1924	60.2
Verde Hot Springs, Arizona	USGS, Phoenix	60.0
Lake Amatitlán, Guatemala	Deevey, 1957	58.7
Lake Chapala, Mexico	Deevey, 1957	50.0
Lake Güija, El Salvador	Deevey, 1957	50.0
Rio Grande Drains, New Mexico (mean)	Clark and Mauger, 1932	39.0
Owl Spring, New Mexico	Megard, 1961	35.0
La Sal Vieja, Texas	Deevey, 1957	25.0
Lake Atitlán, Guatemala	Deevey, 1957	25.0
Bartlett Lake, Verde River, Arizona	Salt R. Valley Water Users' Assoc.	25.0
Montezuma Well, Arizona	Cole, unpublished	22.0
Lake Carl Pleasant, Agua Fria River, Arizona	Maricopa County, Water District No. 1	20.0
Reservoirs on Salt River, Arizona (mean)	Salt R. Valley Water Users' Assoc.	19.0
Eight Trans-Pecos Texas lakes (mean)	Deevey, 1957	18.1
Soda Springs, Arizona	USGS, Phoenix	18.0
Fossil Springs, Arizona	USGS, Phoenix	14.0
Lake Pátzcuaro, Mexico	Deevey, 1957	14.0
Four northeastern Texas reservoirs (mean)	Harris and Silvey, 1940	5.13
La Sal del Rey, Texas	Deevey, 1957	4.0
Chuska Mountains lakes (mean)	Megard, 1961	3.4
Five most saline lakes, Saskatchewan (mean)	Rawson and Moore, 1944	21.0
Sea water	Clarke, 1924	*ca.* 4.0
Geysers, Yellowstone National Park, Wyoming (mean)	Clarke, 1924	356.0

benthic standing crops and chlorophyll values in Texas waters as well. Neither is high, but of course turnover rates are not known.

Numbers of benthic organisms reported in fisheries surveys from New Mexican reservoirs and the Bottomless Lakes are even smaller. Also, a scanty plankton in the big Arizona impoundments is implied by data supplied by the Arizona Game and Fish Department.

The only adequate data on primary productivity in desert lakes are those supplied by McConnell (personal communication), who studied gross primary productivity in Pella Blanca Lake, Arizona. This is a warm monomictic lake impounded in a narrow canyon in the Pajarito Mountains. It is 1,220 m above sea level and 9.6 km north of Nogales and the Mexican border. Peña Blanca was formed in 1957 and has a total solids content of about 130 mg/L. McConnell estimated the

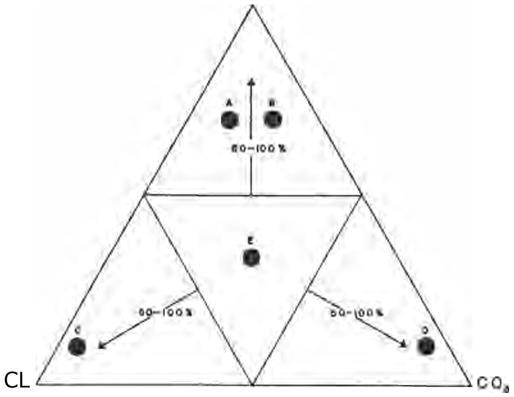

Fig. 14.6.—Triangular coordinate method of portraying relative composition of major anions in natural waters.

Circle	*CO*	*SO₄*	*Cl*
A	10%	70%	20%
	20	70	10
	5	10	85
	85	10	5
	33.3	33.3	33.3

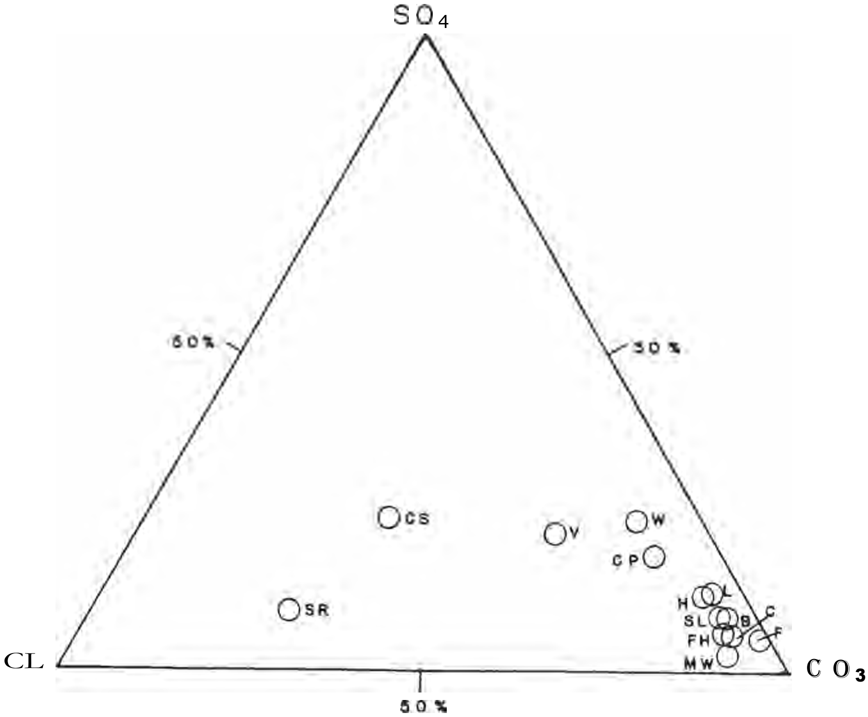

Fig. 14.7.—Relative anionic composition of som e Arizonan lakes and streams. Figure following name is sum of principal anions in mg/L.

Large impoundments on rivers

SR	Lakes on the Salt River	520
CP	Lake Carl Pleasant, Agua Fria River	276
	Horseshoe Lake, Verde River	205

Springs

CS	Croton Springs, Willcox Playa	1066
	Fossil Springs	513
MW	Montezuma Well	640
V	Verde Hot Springs	2604

Small lakes on southeastern rim of Colorado Plateau

	Big Lake	67
	Concho Lake	106
FH	Fools Hollow Lake	133
	Luna Lake	121
SL	Show Low Lake	120
	Woods Canyon Lake	25.6

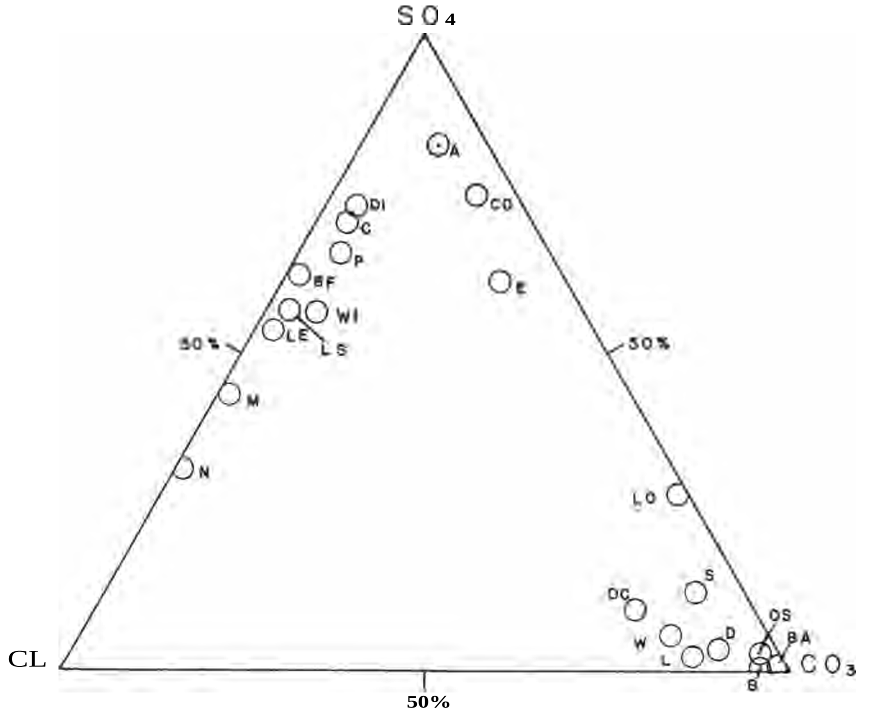

Fig. 14.8.—Relative anionic composition of some New Mexican waters. Figure following name is sum of principal anions in mg/L.

Large impoundments on rivers		
A	Alamogordo Reservoir, Pecos River	941
CO	Conchas Reservoir, South Canadian River	590
	Elephant Butte Reservoir, Rio Grande	286
Waters of the Chuska Mountains		
	Boot Lake	122
BA	Basalt Lake	127.4
	Deadman Lake	54
	Landslide Lake	48.1
LO	Long Lake	75
	Wide Lake	50.9
OS	Owl Spring	234.9

Waters in gypsum deposits of southeast N.M. (Bottomless Lakes)		
	Cottonwood Lake	2900
DI	Devils Inkwell	2939
LE	Lea Lake	4866
	Mirror Lake	8578
	No Name Lake	16532
	Pasture Lake	2798
8F	Figure Eight Lake	8183
Waters in gypsum deposits of southeast N.M. (others)		
WI	Willow Lake	1282
LS	Lander Springbrook	2782
Springs of the Rocky Mountain Province of N.M.		
OC	*Ojo* Caliente	1478.3
	Spring, 1.6 km west of Santa Fe	162.4

rather high mean daily oxygen production by pelagic algae of 0.31 mg/cm^2. This was based on analyses of diurnal oxygen changes in a mean water column. Further calculations, based on a chlorophyll-photosynthesis ratio, yielded a higher figure, 0.41 mg/cm^2. The mean assimilation number, 3.12, was used for this, following a few simultaneous measurements of chlorophyll and oxygen.

Megard's (1961) data for the Chuska Mountain lakes apply largely to the productivity of littoral macrophytes. His values, which he considered net productivity, are equivalent to 0.29 mg O_2/cm per day.

I.

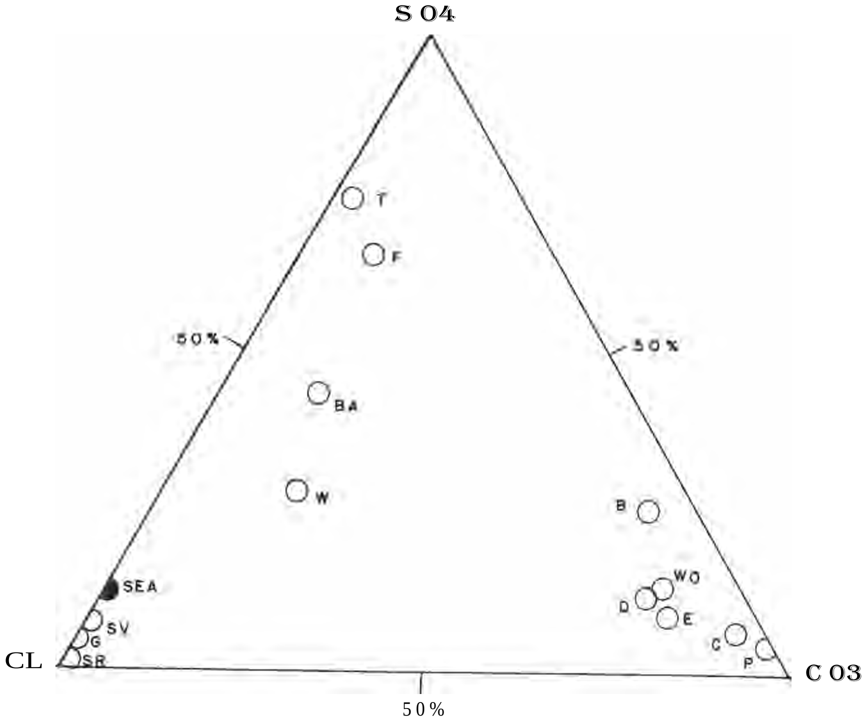

Fig. 14.9.—Relative anionic composition of some Texan lakes and Lake Patzcuaro and Chapala, Mexico, compared with sea water. Figure following name is sum of principal anions in mg/L.

Mexican lakes		
	Lake Chapala	471
	Lake Pátzcuaro	276
Northeastern Texas reservoirs		
	Bridgeport Lake	141
	Lake Dallas	183
	Eagle Mountain Lake	171
WO	Lake Worth	168
North-central Texas		
	Lake Wichita	669

Lakes and playas of Trans-Pecos Texas		
BA	Balmorhea Lake	1270
F	Fort Stockton Lake	1479
	Grable's Salt Works	41752
	Toyah Playa Lake	2078
Salt lakes of south Texas coastal plain		
SV	La Sal Vieja	14238
SR	La Sal del Rey	108325
SEA	Sea Water	*ca.* 22000

Data for calculating areal oxygen deficits are either lacking for most Southwest lakes or are rendered meaningless by flash-flood import and/or drawdown for irrigation. The small, soft-water Woods Canyon Lake, Arizona, however, is relatively undisturbed. The Arizona Game and Fish Department has supplied some temperature and oxygen values for a period from May 27 to June 13. The rate of oxygen decrease below 4.8 m during this time was 0.057 mg 0_2/cm^2 per day, which puts the lake in a low eutrophic category.

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