Review and Annotated Bibliography of Ancient Lake Deposits (Precambrian to Pleistocene) in the Western States

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By JOHN H. FETH

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REVIEW AND ANNOTATED BIBLIOGRAPHY OF ANCIENT LAKE DEPOSITS (PRECAMBRIAN TO PLEISTOCENE) IN THE WESTERN STATES

By John H. Feth

ABSTRACT

The occurrence of lake deposits in 11 Western States is shown on three maps representing: (1) pre-Tertiary deposits; (2) deposits of Paleocene and Eocene age; and (3) deposits of Oligocene, Miocene, and Pliocene age. A fourth map shows the maximum known or inferred extent of Pleistocene lakes in the same 11-State area.

In this paper, the term "lake" refers to any standing inland body of water having, generally, considerable size. Playa lake is defined as a body of ponded water which temporarily and often repeatedly occupies part or all of a playa, which, in turn, is defined as the lowest part of a closed basin. Lacustrine deposits consist of sediments laid down in both relatively permanent lakes and playa lakes, although the latter are little considered in this paper.

Lacustrine deposits of pre-Tertiary age are concentrated in a few large areas within a zone that extends northward from Arizona into Montana. These deposits are largely of Mesozoic age. The concentration of major areas of lacustrine sediments of Paleocene and Eocene age in much the same region seems to imply that this part of the continent was stable and continental rather than marine during long periods of time and probably was characterized by rather low relief.

Beginning in Oligocene time and continuing through Pliocene time, the lake basins for which we have sedimentary record were characteristically smaller, more numerous, and much more widely distributed than the earlier basins. The distribution of these lake basins suggests a topography similar to that now existing. By Pliocene time, at least, continental conditions dominated over marine throughout the 11 Western States.

A prominent alinement of lacustrine basins, which extends northwestward about 500 miles from Lakes Santa Maria and Guzman in Chihuahua, Mexico, reflects the presence of a major structure coinciding, in part, with the southwest margin of the Colorado Plateau. The structure is probably a grabem in at least some parts of its length. Early evidence of the structure in Arizona is found in the Pliocene lake deposits in the San Simon and Gila Valleys, the San Carlos area, and the Verde Valley.

Search of the literature disclosed very few definitive criteria by which sediments can be identified as lacustrine. Limestone and diatomite that contain fresh-water fossils are considered conclusive evidence of ponded water. Certain assemblages of fossil mollusks—especially the Sphaeriidae, Valvatidae and Amnicolidae, regardless of their enclosing lithology—are also apparently distinctive of lake waters. Among the ostracodes, species of *Cytherissa*, *Limnicythere*, *Cypridea*, *Darwinula*, and *Candona*, where abundant, strongly suggest lacustrine waters. Tabular or broadly lenticular deposits of borate minerals, celestite, trona, and other evaporite minerals and—at places—gypsum suggest the former presence of saline lakes commonly in desert or semiarid surroundings. Of the foregoing, the borates and trona seem to have been deposited without exception in continental environments. The former existence of Pleistocene lakes can be recognized in many places by the presence of shore features. Reconstruction of palegeography may serve as an aid in defining ancient lake basins and in identifying geologic events that disrupted drainage and caused lakes to form.

Suggestive criteria have been discussed by numerous authors. Broad areas occupied by fine-grained laminated clastic rocks of rather uniform lithology, especially where bedding surfaces are flat and individual thin units laterally extensive, have been accepted by some as evidence of lacustrine deposition. Others cite intertonguing of coarse and fine sediments and the saucer shape of the deposits. Individual writers have identified sediments on the basis of bedding and lamination, ripple marks, mud cracks, and similar features; others have made their identification from variations in clay mineralogy, color, and other specific characteristics including the chemistry and isotope variations of the deposits. None of the aforementioned criteria seem broadly applicable as a definitive criterion, although many are suggestive.

An annotated bibliography composes the bulk of the present paper. Included are papers that contain good descriptions of, or maps showing, the lake-sediment areas outlined on the accompanying maps. Also cited are papers that discuss criteria for recognition of lake-deposited materials, and a selected few that provide exceptionally full or useful descriptions of lacustrine sediments.

INTRODUCTION

Since the earliest geologic explorations in the Western conterminous United States, reference has been made to lake-deposited strata, and their inferred presence has been used in reconstructing the paleogeography and paleoenvironments of the region. The present report attempts to compile and annotate the most important literature regarding distribution of ancient lakes, Precambrian through Pleistocene, in 11 Western States, and to list and evaluate various criteria by which lacustrine deposits can be distinguished from those of other origins.

This paper consists mainly of a selected annotated bibliography on lacustrine sediments of the Western conterminous United States, ranging in age from Precambrian to Pleistocene. It also includes a tabular summary (table 1), four maps showing distribution of lake sediments of various geologic ages, and several indexes. The indexes give cross-references to papers on lake deposits grouped by (a) geologic age of the deposits, (b) States in which the deposits occur, (c) criteria for recognition of lake deposits, and (d) economic importance of lacustrine sediments. In addition, the various criteria for the recognition of lake deposits proposed by the authors cited are reviewed in detail and appraised with respect to their general applicability and reliability.

The economic importance of lake deposits is seldom emphasized. In the Western States, they yield or confine large volumes of ground water. In many intermontaine basins it is the presence of ground water in those deposits that has made possible development of housing, industry, and agriculture. Lake deposits not only form large tracts of agricultural land but contain abundant supplies of sand and gravel that are used for construction.

Western lake deposits contain our largest reserves of borate minerals. Much of the brick and the clay tile in the Western States and some refined ceramic products are made from lacustrine clays. Other clays are used as a base for drilling mud which is important in the petroleum industry.

Numerous other deposits of economic importance either are of lacustrine origin or mineralogically replace lacustrine sediments. Among these are sodium chloride and various other salines, magnesite, strontium minerals, gypsum, diatomite, and manganese oxides.

The western lake deposits also contain tremendous resources of oil shale and are the source beds for the significant amounts of petroleum and natural gas produced from continental deposits in Colorado and Utah. Lake deposits also carry less common, but economically valuable, hydrocarbons such as gilsonite, wurtzilite, and ozokerite.

Lake deposits also provide clues to the climates and land forms of the past. For example, a discussion by Bradley (1929a) of the Green River Formation is a classic reconstruction of paleoecology from lacustrine sediments. The size, shape, distribution and lithology of bodies of lake sediments formed during a specific span of geologic time often aid in distinguishing general patterns of geologic structure and geologic history during the time of their deposition.

It is possible to attempt predictions of future events by analogy with the development of lacustrine basins and sediments of the past. Without attempting to carry this procedure too far, one may suggest that the sediments being deposited in parts of the Caspian basin today may in due time resemble some of those now found in the Green River Formation. A succession of formations such as those of Mesozoic age in the Four Corners region (pl. 1) may develop in the Gulf-shore fringes of the Mississippi embayment by closing of barrier bars to form elongate coastal lakes and in the area of the Yellow Sea by growth of an island-arc barrier ultimately rising entirely above the sea.

TABLE 1.—*List of stratigraphic units that are known or believed to consist largely of, or to include, lake-deposited sediments in Western United States*

[Thickness: Figures are given in feet; query indicates author or authors cited did not give thickness of formation or of lacustrine part, where formation thickness is given. Geologic names listed are those of various authors and do not necessarily follow the usage of the U.S. Geol. Survey]

Name of stratigraphic unit	Geologic age	Principal area of occurrence	Thickness		Principal references
			Formation	Lake sediments	
Admiralty Clay	Pleistocene	Puget Sound region, Washington	1,700±	1,700±	Newcomb (1952).
Alamosa Formation	Pliocene or Pleistocene.	San Luis Valley, Colo	>1,000	1,000?	Siebenthal (1910).
Alpine Formation	Pleistocene	Lake Bonneville basin, Utah	25–150	25–150	Hunt, Varnes, and Thomas (1953); Jones and Marsell (1955); Feth and others (1963).
Alturas Formation of Dorf	Pliocene	Northeastern California	(?)	(?)	LaMotte (1936).
American Falls Lake Beds	Pleistocene	Power County, Idaho	150±	150±	Stearns (1936).
Anaverde Formation	Pliocene	Western Mojave Desert, Calif	2,000	1,000	Wallace (1949).
Antero Formation of authors	Oligocene	South Park, Colo	670	100?	Stark and others (1949).
Artillery Formation	Eocene	Artillery Mountains, Mohave County, Ariz.	1,500	(?; individual beds of lacustrine limestone <50 ft thick.)	Lasky and Webber (1949).
Bald Mountain Lake Beds Member of Esmeralda Formation.	Miocene	Manhattan district, Nevada	14,800?	500	Ferguson (1924).
Balfour Formation of authors	Oligocene	South Park, Colo	>1,000?	(?)	Stark and others (1949).
Barstow Formation	Miocene	Mojave Desert region, California	2,000	(?)	Palmer and others (1957).
Bautista Beds of Frick	Pleistocene	Bautista Creek area, southern California.	1,500–2,000	Most of total	Frick (1921).
Bear River Formation	Cretaceous	Southwestern Wyoming, adjacent Idaho.	500–5,000	(?; probably thin)	Yen (1954).
Bidahochi Formation	Pliocene	Navajo country, Arizona	600±	214	Repenning and Irwin (1954).
Bissell Formation	Miocene(?)	Western Mojave Desert, Calif	845	350	Dibblee (1958).
Bonneville Formation	Pleistocene	Lake Bonneville basin, Utah	>20	>20	Hunt, Varnes, and Thomas (1953).
Bopesta Formation	Miocene	Tehachapi Moutains, Calif	3,500	(?)	Buwalda (1954).
Borrego Formation	Pliocene	Imperial Valley, Calif	6,000	6,000	Dibblee (1954).
Bozeman Lake Beds	Tertiary	Gallatin River Valley, Mont	(?)	(?)	Peale (1893).
Brawley Formation	Pleistocene	Imperial Valley, Calif	2,000	2,000	Dibblee (1954).
Brian Head Formation	Miocene(?)	Southwestern Utah	>500	400	Gregory (1945, 1949).
Bridger Formation	Eocene	Southwestern Wyoming and adjacent areas in Utah and Colorado.	2,000±	(?)	Nace (1939); Koenig (1960).
Brule Formation	Oligocene	Eastern Wyoming, central Montana, adjacent areas.	750±	(?)	(*See* White River group).
Brushy Basin Member of Morrison Formation.	Jurassic	Four Corners region	600 max	(?)	Craig and others (1955).

Burley Lake Beds	Pleistocene	Cassia County, Idaho	150	150	Stearns (1936).
Cache Formation	Pliocene or Pleistocene.	Clear Lake area, Lake County, Calif.	1,700	"Some part of" the 1,700 ft.	Becker (1888); Anderson (1936).
Cache Valley Formation of Adamson, Hardy, and Williams.	Miocene-Pliocene	Cache Valley, Utah and Idaho	2,000–7,670	"Mostly of***lacustrine origin***."	Adamson, Hardy, and Williams (1955); Williams (1958).
Camp Davis Formation	Pliocene	Teton County, Wyo	5,600	1,000±	Love (1956a, 1956b).
Cedarville Formation of LaMotte	Miocene(?)-Pliocene.	Northeastern California and adjacent Nevada.	3,500±	70–300	Russell (1928); LaMotte (1936).
Chadron Formation	Oligocene	Eastern Wyoming, central Montana, and adjacent areas.	30–80	(?)	(*See* White River Group.)
Chapin Wash Formation	Pliocene	Artillery Mountains, Mohave County, Ariz.	580–1,350(?)	(?)	Lasky and Webber (1949).
Chemehuevi Formation	Pleistocene	Colorado River Valley below Grand Canyon.	400	(?)	Longwell (1936).
Chinle Formation	Triassic	Four Corners region			Stewart, Poole, and Wilson (1958).
Chuckanut Formation	Eocene(?)	Northwestern Washington	>10,000	? (Thin, scattered)	Weaver (1937).
Church Rock Member of Chinle Formation.	Triassic	Four Corners region	(?)	(?)	Stewart, Poole, and Wilson (1958).
Clarno Formation	Eocene	Central northern Oregon	>400	>400?	Weaver (1945).
Coalmont Formation	do	North Park, Colo	3,500±	Probably >1,000	Beekly (1915).
Colton Formation	do	Central Utah	(?)	(?)	Swain (1949). No map area.
Corcoran Clay Member of Tulare Formation.	Pliocene	San Joaquin Valley, Calif	50–120	50–120	Frink and Kues (1954); Davis and others (1959); Davis and Poland (1957).
Creede Formation	Miocene	Rio Grande Valley near Creede, Colo.	>1,500	>500	Larsen and Cross (1956).
Currant Tuff	Miocene or Pliocene.	White Pine and Nye Counties, Nev	400 max	Nearly all in some places	Faust and Callaghan (1948).
Dalles Formation	do	North-central Oregon and south-central Washington.	1,000±	(?)	Piper (1932).
Danforth Formation	Pliocene	Harney Basin, Oreg	800+	100–200?	Piper, Robinson, and Park (1939).
Dinosaur Canyon Sandstone Member of Moenave Formation.	Triassic(?)	Navajo Indian Reservation, Ariz	28–321	(?)	Harshbarger, Repenning, and Irwin (1957).
Draney Limestone of Gannett Group	Cretaceous (?)	Southeastern Idaho	200±	200±	Mansfield (1927).
Dry Creek Canyon Member of Dakota Sandstone.	Cretaceous	Southeastern Colorado	(?)	7±	Waagé (1953).
Eetza Formation of Lahontan Valley Group.	Pleistocene	Carson Desert, Nev	90	90	Morrison (1959).
Ellensburg Formation	Miocene	Central Washington	About 1,600	(?)	Russell (1900); Weaver (1945).
Esmeralda Formation	do	Southwestern and central Nevada	(?)	"Hundreds of feet"	Turner (1900); Spurr (1905).
Fallon Formation	Recent	Carson Desert, Nev	35	20	Morrison (1959).
Fish Creek Gypsum	Miocene	Fish Creek Mountains, west of Salton Sea, Calif.	100	100	Dibblee (1954).
Flagstaff Limestone	Paleocene and Eocene (?).	Wasatch Plateau, Utah	200–1,000	200–1,000	Spieker (1946).
Florissant Lake Beds	Oligocene	Southeastern Colorado	165	50	MacGinitie (1953).
Fort Union Formation	Paleocene	Powder River region, eastern Montana	(?)	(?)	Swain (1949).

TABLE 1.—*List of stratigraphic units that are known or believed to consist largely of, or to include, lake-deposited sediments in Western United States*—Continued

Name of stratigraphic unit	Geologic age	Principal area of occurrence	Thickness		Principal references
			Formation	Lake sediments	
Fountain Formation	Permian-Pennsylvanian.	Front Range, Colo	200–4,000±	50–100?	Hubert (1958).
Furnace Creek Formation	Pliocene	Death Valley region, Calif	2,500	(?)	Noble and Wright (1954).
Green River Formation	Eocene	25,000 sq mi in Colorado, Wyoming, Utah.	Averages 2,000	Near 2,000	Bradley (1929a).
Green Valley Formation	Pliocene	San Francisco Bay region, California	6,000	(?)	Taliaferro (1951).
Guye Formation	Eocene	Northern Cascade Mountains, Wash	(?)		Weaver (1945).
Hammer Bluff Formation	Miocene (or post-Miocene?).	East of Auburn, Wash	(?)	(?)	Glover (1936).
Hammer Bluff equivalent	Post-Miocene	Lowlands east of Tacoma, Wash	125	15±	Mullineaux, Gard, and Crandell (1959).
Hiawatha Member of Wasatch Formation.	Eocene	Southwestern Wyoming and northwestern Colorado.	4,100	(?)	Nightingale (1930); not separately mapped.
Hoback Formation of Eardley and others.	do	Central western Wyoming	15,000	(?)	Dorr (1958).
Horned Toad Formation	Pliocene	Near Mojave, Calif	1,055	155	Dibblee (1958).
Horse Spring Formation	(Age in much doubt tentatively Paleocene.)	Lake Mead area, Nevada and Arizona	2,800±	2,800±	Longwell (1928, see annotation); Tschanz (1960).
Hualpai Limestone	Pliocene(?)	Lake Mead area, Nevada and Arizona	1,000	1,000	Longwell (1936).
Humboldt Formation	Miocene, Pliocene, or both.	Northeastern Nevada	5,800	1,000	Sharp (1939).
Idaho Group	Pliocene and Pleistocene.	Southwestern Idaho and eastern Oregon.	"Several thousand".	(?)	Lindgren (1900); Kirkham (1931); Baldwin (1959).
John Day Formation	Oligocene and Miocene.	North-central Oregon	1,700–(?)5,000	(?)	Weaver (1945).
Jordan Narrows unit of Salt Lake Group of Slentz.	Miocene(?)	Jordan River Narrows, Utah	>300	>300	Slentz (1955).
Judith River Formation	Cretaceous	Central, northern, southwestern and southern Montana.	250–500	Locally nearly full-thickness of formation.	Stanton and Hatcher (1905).
Kayenta Formation of Glen Canyon Group.	Triassic(?)	Southeastern Utah, northeastern Arizona.	60–180	(?; Thin lenses)	Gregory (1950); Harshbarger, Repenning, and Irwin (1957).
King Lear Formation	Cretaceous	Humboldt County, Nev	200–3,000	"Lenses"	Willden (1958).
Kinnick Formation	Miocene	Tehachapi Mountains, Calif	1,500	"Few hundred"	Buwalda (1954).
Knight Formation	Eocene	Southwestern Wyoming	(?)	(?)	Swain (1949).
Kootenai Formation	Cretaceous	Northern and central Montana	455	10–30	Klepper, Weeks, and Ruppel (1957).

"Kramer Lake Beds"	Miocene	Areas west of Barstow, Calif	2,700	Partly lacustrine	Bowen (1954); Gale (1956).
Lahontan Valley Group	Pleistocene	Carson Desert, Nev	>330	186	Morrison (1959).
Lake Bonneville Group	do	Bonneville Basin, Utah	*See* Alpine, Bonneville, and Provo Formations.		Gilbert (1890); Hunt, Varnes, and Thomas (1963).
Lake Lahontan Beds	do	Northwestern Nevada	>375	>175	Russell (1885).
Lake Missoula Beds of authors	do	West-central Montana	>200	>200	Pardee, (1910); Alden (1932).
Latah Formation	Miocene	Western Idaho and eastern Washington.	350	350	Pardee and Bryan (1926) Kirkham and Johnson; (1929); Kirkham (1931).
Latour Formation of Hershey	do	Coeur d'Alene Valley, Idaho	>500	>500	Hershey (1912).
Livermore Gravel of Clark	Pleistocene(?)	Livermore Valley, Calif	4,000	"May include lacustrine sediments."	Huey (1948).
Manastash Formation	Eocene	Yakima Valley, Wash	200-300	(?; Local, probably thin)	Weaver (1937).
Manix Lake Beds	Pleistocene	Eastern Mojave Desert, Calif	75	75	Buwalda (1914).
Martinez Formation	Paleocene	Western Alameda County, Calif	(?)	(?)	Taliaferro (1951).
Mascall Formation	Miocene	North-central Oregon	800–1,000	(?)	Weaver (1945).
Mint Canyon Formation	do	Ventura basin, California	4,000±	(?)	Jahns (1940).
Moenkopi Formation	Triassic	Little Colorado River region, Arizona	50-300± in this region.	(?)	McKee (1954).
Mohawk Lake Beds	Tertiary	Northern Sierra Nevada, Calif	(?)	(?)	Turner (1896).
Monitor Butte Member of Chinle Formation.	Triassic	Four Corners region	(?)	(?)	Stewart, Poole, and Wilson (1958).
Morales Formation	Pliocene	Cuyama Valley, Calif	5,000	("Partly lacustrine")	Hill, Carlson, and Dibblee (1958).
Morrison Formation, undivided	Jurassic	South Park, Colo	(?)	(?)	Stark and others (1949); no map area.
Morrow Creek Tongue of Green River Group.	Eocene	Red Desert, Wyo	(?)	32	Nace (1939); no map area.
Moss Back Member of Chinle Formation.	Triassic	Four Corners region	(?)	(?)	Stewart, Poole, and Wilson (1958).
Mount Eden Formation of Fraser	Pliocene	San Jacinto Mountains, Calif	1,500	(?)	Frick (1921).
Muddy Creek Formation	Miocene(?)	Lake Mead area, Nevada-Arizona	"Thousands of feet."	Hundreds to thousands of feet.	Longwell (1936).
Nacimiento Formation	Eocene	San Juan Basin, N. Mex. and Colo	2,000	(?)	Simpson (1948).
Navajo Sandstone of Glen Canyon group.	Triassic(?) and Jurassic.	Navajo Country-Four Corners region		Lenses	Harshbarger, Repenning, and Irwin (1957).
Neeley Lake Beds	Pliocene(?)	Power County, Idaho	>100	>100	Stearns (1936).
Newark Canyon Formation	Cretaceous	Vicinity of Eureka, Nev	1,800	(?)	Nolan, Merriam, and Williams (1956).
North Horn Formation	Cretaceous and Paleocene.	Wasatch Plateau region, Utah	2,500 max	>500	Spieker (1946).
North Park Formation	Miocene(?)	North Park, Colo, and Hanna Basin, Wyo.	>1,300	(?)	Beekly (1915), Montagne and Barnes (1957).
Oak Springs Formation	do	AEC Test Site, southern Nevada	2,000	(?)	Johnson and Hibbard, (1957).
Ogallala Formation	Pliocene and Pleistocene.	Staked Plains of southeastern New Mexico.	(?)	(?)	Judson (1950).
Orinda Formation	Pliocene	San Francisco Bay area, California	6,100	(?)	Lawson (1914).
Otero Formation of Herrick	Pleistocene(?)	Southeastern New Mexico	>200	>200	Herrick (1904); Kottlowsk (1958).

TABLE 1.—*List of stratigraphic units that are known or believed to consist largely of, or to include, lake-deposited sediments in Western United States*—Continued

Name of stratigraphic unit	Geologic age	Principal area of occurrence	Thickness		Principal references
			Formation	Lake sediments	
Owl Rock Member of Chinle Formation.	Triassic	Four Corners area	(?)	(?)	Stewart, Poole, and Wilson (1958).
Panaca Formation	Pliocene(?)	Eastern Nevada	"Several hundred feet."	"Several hundred feet" (?).	Westgate and Knopf (1932), Van Houten (1944).
Pantano Formation of authors	Tertiary	South-central Arizona	(?)	(?)	Moore and others (1941).
Parunuweap Formation	Pliocene(?)	Southwestern Utah	(?)	(?)	Gregory (1945).
Paso Robles Formation	Pliocene and Pleistocene(?).	Santa Maria Valley, southwestern California.	200–2,000±	Thin lacustrine limestones near base.	Worts (1951).
Payette Formation	Miocene and Pliocene(?).	Western Idaho–eastern Oregon	>1,000	(?)	Lindgren (1900), Kirkham (1931).
Peace Valley Beds of Crowell	Pliocene	Traverse ranges, northwest of Los Angeles, Calif.	4,000	500–1,000?	Crowell (1950).
Petaluma Formation	do	Bay area north of San Francisco, Calif.	3,500	Near 3,500	Taliaferro (1951); Weaver (1949).
Peterson Limestone	Jurassic(?) or Cretaceous.	Southeastern Idaho	200±	200±	Mansfield (1952).
Petrified Forest Member of Chinle Formation.	Triassic	Zion Park region, Utah, Four Corners region.	950–1,250	400?	Gregory (1950); Stewart, Poole, and Wilson (1958).
Pocatello Formation of Ludlum	Precambrian	East of Pocatello, Idaho	(?)	(?) 350	Ludlum (1942).
Price River Formation	Cretaceous	Central Utah	(?)	Thin, persistent limestone units.	Hail and others (1956).
Provo Formation	Pleistocene	Lake Bonneville basin, Utah	20–80	20–80	Jones and Marsell (1955); Hunt, Varnes, and Thomas (1953).
Quatal Red Clay Member of Santa Margarita Formation.	Miocene	Cuyama Valley, Calif	2,700	"Partly lacustrine"	Hill, Carlson, and Dibblee (1958); Ver Planck (1952).
Raft Lake Beds	Pliocene	Cassia County, Idaho	200±	200±	Stearns, Crandall, and Steward (1938).
Ricardo Formation	do	Mojave Desert, Calif	7,000	2,200	Dibblee (1952).
Ringold Formation	Pleistocene	Pasco basin, Washington	960	800±	Newcomb (1958).
Rock Point Member of Wingate Sandstone.	Triassic	Navajo Indian Reservation, Ariz	202		Harshbarger, Repenning, and Irwin (1957).
Roslyn Formation	Eocene	Northern Cascade Mountains, Wash	2,000–3,500	(?)	Weaver (1937, 1945).
Salt Lake Group	Middle to late Tertiary.	Eastern part of Great Salt Lake Basin, Utah.	>1,200	1,200±	Williams (1958).
San Joaquin Formation	Pliocene-Pleistocene.	Type section is North Dome, Kettleman Hills, Calif.	1,860–3,300	Largest part of total three zones are lacustrine.	Barbat and Galloway (1934); Woodring and others (1940).
San Jose Group	Eocene	San Juan Basin, N. Mex.-Colo	2,000	(?)	Simpson (1948).

Sante Fe Formation	Pliocene	Rio Grande depression, New Mexico	>5,000	4,000± in lower Rio Puerco Valley.	Wright (1946); Bryan (1938).
Sehoo Formation of Lahontan Valley Group.	Pleistocene	Carson Desert, Nev	96	96	Morrison (1959).
Sheep Pass Formation of Winfrey	Eocene	East-Central Nevada	3,500±	3,500±	Winfrey (1958).
Siesta Formation of Berkeley Group	Pliocene	San Francisco Bay region, California	50-700	200?	Lawson (1914); Taliaferro (1951).
Snowy Range Series of Fenton and Fenton.	Precambrian	Snowy Range, Wyo	24,000	(?)450-500	Fenton and Fenton (1957).
Sonoma Volcanics—middle member	Pliocene	Sonoma Valley, Calif	(?)	(?)	Kunkel and Upson (1960).
Swauk Formation	Eocene	Central and north-central Washington	4,000-8,000	(?)	Russell (1900); Weaver (1937).
Sweetwater Group [=? Chadron Formation].	Oligocene	Central Wyoming	1,200-1,400	1,200-1,400?	Hayden (1871).
Tatman Formation of authors	Eocene	Northwestern Wyoming	600	(?)	Van Houten (1944).
Teewinot Formation	Pliocene	Teton County, Wyo	5,000	1,000-2,000	Love (1956b); Merritt (1956).
Tehama Formation	do	San Francisco Bay region, California	(?)	(?)	Taliaferro (1951): Thomasson, Olmsted, and LeRoux (1960).
"Tertiary Lake Beds" of authors	Oligocene-Pliocene.	Central and western Montana	(?)	(?)	Colton and others (1961); Pardee (1925); Alden (1953).
Tibble Formation of Crittenden	Tertiary(?)	American Fork Canyon, Wasatch Mts., Utah.	(?)	(?)	M. D. Crittenden (oral communication, 1959).
Tick Canyon Formation of Jahns	Miocene	Near Saugus, Ventura basin, California.	(?)	(?)	Jahns (1940).
Tipton Tongue of Green River Group.	Eocene	Red Desert, Wyo	167	167	Nace (1939). No map area.
Todilto Limestone	Jurassic	Navajo Country, Ariz.-N. Mex	25±	Lacustrine origin questioned; thickness 25±.	Harshbarger, Repenning, and Irwin (1957).
Touchet Beds of Flint	Pleistocene	Pasco basin, Washington	100	100	Flint (1938).
Tropico Group	Miocene(?) and Pliocene(?).	Western Mojave Desert, Calif	2,800	Part	Dibblee (1958, 1960).
Truckee Formation	Pliocene	Western Nevada	4,000	(?)	Thompson (1956); Morrison (1959).
Tulare Formation	Pliocene and Pleistocene(?).	Southern Central Valley, Calif	"Several thousand feet."	Part	Arnold and Anderson (1908); Woodring, Stewart, and Richards (1940); Davis and Poland (1957).
Uinta Formation	Eocene	Wind River basin, Wyoming	250	Nearly 250	Bauer (1934).
Vasquez Series of authors	Oligocene(?)	Southern California	13,000±	Part	W. P. Irwin (oral communication, 1959).
Verde Formation	Tertiary	Verde Valley, Ariz	>2,000	>2,000	Jenkins (1923); Lehner (1958).
Wasatch Formation	Eocene	Zion Park region, Utah	200+	(?; upper half)	Gregory (1950).
Wayan Formation	Cretaceous	Southeastern Idaho	11,800	? (Contains "Thick fresh-water limestones * * *.")	Mansfield (1952).
Weaverville Formation of Hinds	Oligocene	Trinity River valley, Calif	2,000	(?)	MacGinitie (1937).
White River Group	do	Eastern Wyoming, central Montana and adjacent areas.	>800	(?)	Darton (1901).
White Sage Formation	Eocene	Western Utah	(?)	(?)	Nolan (1935).

TABLE 1.—*List of stratigraphic units that are known or believed to consist largely of, or to include, lake-deposited sediments in Western United States*—Continued

Name of stratigraphic unit	Geologic age	Principal area of occurrence	Thickness		Principal references
			Formation	Lake sediments	
Wilkes Formation	Miocene	Western Washington	760	"Includes lacustrine facies * * *."	Roberts (1958); Snavely and others (1958).
Willamette Silt	Pleistocene	Willamette Valley, Oreg	15	15	Allison (1953).
Willow Tank Formation	Cretaceous	Muddy Mountains, Nev	300±	300±	Longwell (1949).
Yonna Formation	Pliocene	Klamath River basin, Oregon	2,000	Lower part; thickness?	Newcomb and Hart (1958).
Stratigraphic unit named, or name unknown.	Pleistocene	Lake County, Oreg	1,286	1,286	Allison (1945).
Do	do	High Sierra Nevada meadows, California.	(?)	(?)	D. I. Axelrod (written communication, 1961).
Do	do	Eastern Mojave Desert, Calif	>1,000	>1,000	Bassett, Kupfer, and Barstow (1959).
Do	do	Death Valley, Calif	(?)	(?)	Blackwelder (1933).
Do	do	Mojave River Valley, Calif	>1,000	(?)	Bowen (1954).
Do	do	Scabland areas and associated lake basins, Washington.	(?)	(?)	Bretz, Smith, and Neff (1956).
Do	do	Salton Sea region, California	300	300	Brown (1923); Dibblee (1954).
Do	Pliocene	Antelope Valley, southern California	5,000	5,000?	Buwalda (1954); Wiese (1950).
Do	Pliocene(?)-Pleistocene.	Steptoe Valley, Nev	915	915	Clark and Riddell (1920).
Do	Pleistocene	Gila Bend basin, Arizona	800	300	Coates (1952).
Do	Pliocene(?)	Saltdale quadrangle, California	7,000	2,200	Dibblee (1952).
Do	Pliocene; Pleistocene.	Ridge Basin near Gastaic, Calif	18,000, 3,000	13,000, 3,000	Eaton (1939).
Do	Pliocene(?)-Pleistocene.	Tonto and Payson Basins, Ariz	(?)	(?)	Feth and Hem (1963).
Do	do	Lake Bonneville basin, Utah	>6,000	Near total thickness	Feth (this report, unpublished geophysical information).
Do	Pleistocene	Owens Valley, Mojave Desert basins, California.	(?)	(?)	Gale (1914).
Do	Tertiary and Quaternary.	Mojave Desert, Calif	(?)	(?)	Gardner (1940). No map area.
Do	Miocene-Pliocene	Alturas area northeastern California	1,000±	1,000±	Gay and Aune (1959).
Do	Pliocene	San Pedro Valley, Ariz	250	"Part"	Gidley (1926).
Do	Pleistocene	Chelan Valley, Wash	(?)	(?)	Glover (1941).
Do	Quarternary	San Juan Country, Utah	80	80	Gregory (1938).
Do	Pliocene(?)-Pleistocene.	Railroad Valley, Nev	>1,200	100–200 exposed lacustrine; more at depth.	Hance (1914).
Do	Pleistocene	Gentile Valley, Idaho	(Thin—a few tens of feet.)	Same as total	Hewett (1928). No map area.
Do	do	Valley Wells area, California	25	25	Hewett (1956).

Do	do	Lanfair Valley, Calif.-Nev	250	250	Hewett (1956).
Do	do	Spokane Valley, Columbia River Canyon Okenogan Valley, Wash.	(?)	(?)	Hobbs (1945).
Do	do	Yellowstone Lake basin; Hayden Valley Alden Valley, Wyo.	(?)	(?)	Howard (1937).
Do	do	Great Basin			Hubbs and Miller (1948).
Do	Pliocene to Recent.	Owens Valley, Calif	(?)	(?)	Knopf (1918).
Do	Pliocene(?)	South of Prescott, Ariz	(?)	(?)	Medora Krieger (oral communication 1959).
Do	Miocene	Near Wellton, southwestern Arizona	4 000	Part	Lance and Wood (1958).
Do	Pliocene-Pleistocene.	Lake Tahoe region, California	(?)	(?)	Lindgren (1898).
Do	Miocene	Long Valley, northern Boise County, Idaho.	(?)	(?)	Lindgren (1900). No map area.
Do	Pleistocene (pre-Lake Bonneville).	Ogden Valley, Utah	100	100	Lofgren (1955).
Do	Oligocene-Miocene.	Townsend Valley, Mont	4,000–6,000	Most of total?	Lorenz and McMurtrey (1956).
Do	Pleistocene	Homestake Creek, Colo	(?)	(?)	Lovering and Behre (1932).
Do	do	Snake River Valley, Idaho	(?)	(?)	Malde (1960).
Do	do	Yosemite Valley and adjacent areas, California.	(?)	(?)	Matthes (1930, 1960).
Do	do	Southeastern Nevada	50	50	Maxey and Jameson (1948).
Do	do	Long Valley, eastern California	100	100	Mayo (1934).
Do	do	Estancia and Encino Valleys, N. Mex.	(?)	(?)	Meinzer (1911).
Do	do	Near Tonopah, Nev	(?)	(?)	Meinzer (1917).
Do	do	Sulphur Spring Valley, Ariz	(?)	(?)	Meinzer and Kelton (1913).
Do	do	Meteor Crater, Ariz	(?)	(?)	Merrill (1908).
Do	Tertiary(?)	Ranegras Plain, Ariz	(?)	(?)	Metzger (1952).
Do	Pleistocene	Deep Spring Valley, Calif	(?)	(?)	Miller (1928).
Do	Older fill; age uncertain.	Big Sandy Valley, western Arizona	>500	>500	Morrison (1940).
Do	Pleistocene	Yellowstone River Valley and other areas in eastern Montana.	(?)	(?)	Colton and others (1961). Moulder and Kohout (1958).
Do	do	Soda Lake, Calif	950?	950?	Muessig, White, and Byers (1957).
Do	Miocene	East of Tacoma, Wash	60±	20	Mullineaux, Gard, and Crandall (1959).
Do	Pleistocene and Recent.	Death Valley region, Calif	>1,000	>1,000	Noble and Wright (1954).
Do	Pleistocene	Great Falls and Missoula areas, Montana.	(?)	(?)	Pardee (1910); Alden (1932), Fox (1955).
Do	Pliocene(?)	Modoc County, Calif	(?)	(?)	Powers, H. A. (1932). No map area.
Do	Pleistocene	San Agustin Plain, N. Mex	(?)	(?)	Powers, W. E. (1933).
Do	do	Pine Valley, Nev	(?)	(?)	Regnier (1956).
Do	do	Buffalo Valley, Nev	(?)	(?)	Roberts (1951).
Do	do	Mono Lake basin, eastern California	>300	>300	Russell, I. C. (1889)

TABLE 1.—*List of stratigraphic units that are known or believed to consist largely of, or to include, lake-deposited sediments in Western United States*—Continued

Name of stratigraphic unit	Geologic age	Principal area of occurrence	Thickness		Principal references
			Formation	Lake sediments	
Stratigraphic unit named, or name unknown.	Quaternary	Several basins in Cedarville area, northeastern California.	835 (in Surprise Valley).	835	Russell, R. J. (1928).
Do	Pliocene(?)-Pleistocene.	San Simon Valley, Ariz.-New Mex.	1,230	>350	Schwennesen (1917).
Do	Pleistocene	Animas, San Luis, and Playas Valleys, N. Mex.	20?	20?	Schwennesen (1918).
Do	do	Quincy Valley, southern Washington	300±	300±	Schwennesen and Meinzer (1918).
Do	do	Gila and San Carlos Valleys, Ariz.	1,500+	800±	Schwennesen (1919).
Do	Pleistocene and Recent.	Owens, China, Searles, and Panamint basins, California.	375–995 (core holes).	Large parts of total	Smith and Pratt (1957).
Do	Miocene	Centralia-Chehalis district, Washington.	1,000	(?)	Snavely and others (1958).
Do	do	Dardanelle area, Sierra Nevada, Calif.	(?)	(?)	Harold Stager (oral communication, 1959).
Do	Pleistocene	Northern Sandoval County, N. Mex.	500	500	Stearns (1952).
Do	Tertiary	Putah area, Sacramento Valley, Calif.	400	400?	Thomasson, Olmsted, and LeRoux (1960).
Do	Pleistocene	Various basins in Mojave Desert, Calif.			Thompson (1929).
Do	do	Lake County, Oreg.	(?)	(?)	Trauger (1950).
Do	Tertiary; Pleistocene.	Mojave Valley, northeastern California.	(?)	(?)	Turner (1896). No map area.
Do	Oligocene to Pliocene(?).	Middle Park, Colo.	200–500	(?)	Tweto (1957).
Do	Miocene(?)	Near Mackay, Idaho	2,000	2,000	Umpleby (1917).
Do	Tertiary	Various areas in Mojave Desert, Calif.	(?)	(?)	Ver Planck (1952).
Do	Pleistocene	Waucobi embayment, Inyo Mountains, Calif.	150	150	Walcott (1897).
Do	do	Pahrump Valley and adjacent areas, California and Nevada.	>500	50 to hundreds(?)	Waring (1921).
Do	do	Southern Sierra Nevada, Calif.	(?)	(?)	Webb (1952).
Do	Pleistocene(?)	Surprise Valley, northeastern California.	>835	>835	White (1955b).
Do	Pleistocene	Salt River Valley area, Maricopa and Pinal Counties, Ariz.	700	300–700	Wolcott (1952).
Do	Pliocene Pleistocene.	Butte Valley, northern California	1,000± 947	1,000± 850±	Wood (1960).

DEFINITIONS

In the many references examined by the author of this paper, the size limits of lakes have not been specified nor have the differences between playas, playa lakes, and short-lived lakes been defined to a degree that usage of the terms is uniform.

For use in this paper the following definitions have been adopted: (1) A lake is any standing body of inland water having, generally, considerable size; (2) a playa is the level or nearly level area in the lowest part of a closed desert basin; it is occupied intermittently by ponded water, a playa lake. Most playas are underlain by stratified fine-grained clastic sediments that generally contain variable amounts of salts in solution or as crystals. Playa deposits may be related wholly or in part to the occupancy of the playa by a lake.

The deposits of Recent playa lakes are not considered in this paper, because most of the basins they occupy were in Pleistocene time the sites of lakes of much larger size. However, as the deposits of the Pleistocene lakes have in many papers been described under titles bearing the term "playa," several references to existing playas appear in the bibliography. The bibliography also contains a few references to deposits that are said to have a playa-lake origin. The occurrence of these deposits implies a closed basin occupied by water, at least intermittently, over a period long enough for a thick sequence of strata to accumulate. An outstanding example of this type of deposit is a section in the Rio Grande Valley, 4,000 feet thick, described by Wright (1946, p. 1213) as "playa deposits."

A variety of phrases, such as lacustrine deposits, lake sediments, lake-deposited sediments, and lacustrine strata, are used interchangeably to designate sediments deposited in lakes.

MAPS

Three maps have been prepared to show the areas underlain by geologic formations known to consist wholly or in part of lake deposits in 11 Western States. Plate 1 shows deposits of pre-Tertiary age; plate 2 shows deposits of Paleocene and Eocene age; and plate 3 shows deposits of Oligocene, Miocene, and Pliocene age. Solid color is used to show the areas underlain wholly or largely by proven lacustrine sediments; hachures denote areas that reportedly include some lacustrine sediments; and a dotted pattern denotes areas which possibly have lacustrine deposits. The boundaries of the areas obviously vary in accuracy with the scale and detail of the source maps.

A fourth map (pl. 4) shows maximum known or inferred extent of Pleistocene lakes whether lake deposits are preserved or not. Dashed

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lines are used to show problematic or doubtful boundaries. For example, the boundary of the large area in the Willamette Valley, Oreg., was drawn to enclose all the ice-rafted erratics mapped by Allison (1935). The text accompanying Allison's map states that the Willamette Valley was flooded with glacial waters when the Columbia River drainage was temporarily interrupted and that the ponding lasted long enough to permit deposition of as much as 15 feet of silt. The extent of most of the lake basins shown, however, was taken from a published source that specifically designates the area as a Pleistocene lake.

Examination of plates 1–4 in sequence discloses certain relationships that have regional geologic significance and that confirm the overall geologic history of the West as interpreted from other evidence.

Three circles shown in the Idaho, Utah, and Wyoming parts of the map for pre-Tertiary time (pl. 1) represent small areas in which lake deposits of Precambrian age have been reported by Fenton and Fenton (1957) and Ludlum (1942). In each of these areas lacustrine conditions are indicated by varved slates closely associated with tillite of Precambrian age. Interpretation of varved slates of Precambrian age as lake deposits has been criticized, but where varved slates are closely associated with glacial debris, this interpretation seems reasonable. A part of the Fountain Formation of Pennsylvanian and Permian age in north-central Colorado is assigned by Hubert (1958, p. 1590) to lacustrine origin. All other formations shown wholly or in part as being lake deposited are of Mesozoic age.

The greatest concentration of large areas underlain by Triassic and Jurassic rocks partly of lacustrine origin is in the general Four Corners area, and the larger areas of lacustrine sedimentation in Cretaceous time are in Montana, southeastern Idaho, and western Wyoming. The implication of this distribution is that a continental mass persisted throughout much of the Mesozoic Era, extending through the areas now occupied by the States of Arizona, New Mexico, Utah, Colorado, Idaho, Wyoming, and Montana. The fact that marine sediments interfinger with continental strata in these areas suggests that the land was only slightly above sea level during much of Mesozoic time.

Much of the West continued to be above sea level throughout Cenozoic time (pl. 2). The North Horn Formation of central Utah, a partly lacustrine formation, spans the boundary between the Mesozoic and Cenozoic (Spieker, 1946, p. 134–135) without a recognizable break in sedimentation, as Cretaceous fossils were found in the lower part and Paleocene forms in the upper part of the formation. During Eocene time, parts of Colorado, Wyoming, and Utah contained the great lake basins in which the Green River Formation and the later Uinta Formation were deposited. Somewhat southwestward, the Flagstaff Limestone (Hunt, 1956, fig. 55, p. 76) was deposited in the general area that earlier was the site of North Horn deposition. Far to the northwest, continental conditions prevailed in Eocene time during deposition of the partly lacustrine Puget Group of western Washington and the Swauk and Clarno Formations of central Oregon and Washington.

The Mesozoic and early Tertiary formations that include lake-deposited strata are extensive. They testify to broad areas of level terrane some of which were near sea level. In all, however, the inference is that the landscape was generally of low relief and that the deposits were characteristically large.

Plate 3, which illustrates lake deposits of Oligocene, Miocene, and Pliocene time, differs markedly from plates 1 and 2. Although several basins of deposition persisted from the Oligocene into the Miocene and from the Miocene into the Pliocene, the dominant tendency in post-Eocene time was for basins of deposition to become smaller, more numerous, and more widely distributed. Apparently the topography became about as rugged and varied as it is today. Among the post-Eocene lake deposits are some of those most noted for their fossil content, such as the Florissant Lake Beds of eastern Colorado with their fossil insects and the Latah Formation of eastern Washington and western Idaho with its plant remains.

The widespread distribution of late Tertiary lake basins in the 11 Western States (pl. 3) shows that the sea had largely withdrawn from the present continental areas of the West by at least the end of Tertiary time. In fact, the geographic spread of recorded lake basins of late Tertiary time is perhaps greater than that for any other time in geologic history. Of course, the numerous lake-sediment areas illustrated in plate 3 mark various sites of deposition that occurred at different times, and simultaneity of occurrence of the lakes is not to be inferred. The cross-reference index at the end of this paper shows that the Oligocene had the fewest post-Eocene Tertiary lakes of record and the Pliocene, the most. It cannot be said to what extent this apparent relationship reflects accidents of preservation and different degrees of completeness of discovery and reporting, but it seems reasonable to assume a progressive transition from the broad lowlands of the early Tertiary to the intricately rugged topography of the present.

Many lake basins apparently existed from the late Tertiary into the Pleistocene. One example is the basin that occupied the lower Snake River Valley in western Idaho and eastern Oregon (pls. 3

and 4). The Payette Formation and Idaho Group, which were deposited in this basin, consist, in part, of lacustrine sediments. Deposition of the Idaho, the younger of the two units, began in the Pliocene and continued into the Pleistocene.

The Great Salt Lake basin, which was occupied by Lake Bonneville in late Pleistocene time, is shown on plate 3 to be underlain, in part, by late Tertiary lacustrine deposits. These deposits are not exposed, but their presence is known from subsurface explorations. Shallow-reflection seismic and gravimeter surveys made in 1955 (U.S. Geological Survey, unpublished data) showed at least 6,000 feet of unconsolidated fill in the area near Ogden, Utah, west of the Wasatch Mountains and possibly 9,000 feet of unconsolidated fill in the deeper parts of the basin east of the Great Salt Lake. It is surmised that origin of a closed basin started not later than Pliocene time and that it was occupied by a lake before the start of Pleistocene time. Drilling, however, has not extended deep enough to demonstrate the presence of Pliocene strata.

Stratigraphic and fossil evidence implies that small lakes occupied the areas of the present San Pedro, San Simon, Gila, and Verde Valleys in Arizona in late Tertiary time. Except for the San Pedro Valley, these valleys were also the sites of Pleistocene lakes. Alinement of these lakes with other Pleistocene lakes in Arizona and southwestern New Mexico and with modern Lakes Guzman and Santa Maria in Chihuahua, Mexico (pl. 4), suggests that in Pleistocene time a topographically low lineament, partly occupied by lakes, extended northwestward about 500 miles from northern Chihuahua to the mouth of the Grand Canyon of the Colorado. Even a 40-mile-long area along the Colorado River extending upstream from Grand Wash Cliffs is part of the lineament, although no implication of structural control of the river's course is known from the literature. This extensive structure, which may be in part a graben, forms part of the southern margin of the Colorado Plateaus.

Nevada and California have by far the greater number of Pleistocene lake basins, although Utah had the largest single Pleistocene lake, Lake Bonneville. The concentration of Pleistocene lakes in Nevada and southeastern California reflects the pattern of interior drainage still characteristic of the Great Basin.

As discussed previously, the outline of the glacial lake in the Willamette Valley, Oreg., (pl. 4), is based on the distribution of ice-rafted erratics. The extent of Lake Chemehuevi in the Colorado River valley between Nevada and Arizona also is poorly known. According to Longwell (oral communication, 1958), the sedimentary record clearly indicates the presence of lake deposits of Pleistocene age; their maximum altitude is about 1,300 feet, but the location of the dam that ponded the waters is unknown. The southern terminus is shown on plate 4 to be at Parker, Ariz., the point farthest downstream where the rock walls on both sides of the valley have the requisite height to back up water to form a lake behind a hypothetical barrier. Outcrops of strata referred to the Chemehuevi Formation, however, are known downstream. The shoreline of Chemehuevi Lake was drawn (pl. 4) closer to 1,200 feet than 1,300 feet because of the spacing of contour intervals on topographic maps of the area. Other Pleistocene lake areas are taken directly from published maps.

The stratigraphic names used in the annotations in this report are those used in the original publication and are not necessarily those used in Geographical Survey publications.

CRITERIA FOR THE RECOGNITION OF LAKE DEPOSITS

Few criteria are by themselves definitive of lake deposits. Several authors, however, have presented lists of criteria that suggest deposition in lakes. Both definitive and suggestive criteria are discussed below, and—where warranted—the differences of opinion regarding the significance of the criteria are given. Divergent points of view have resulted in different interpretations of the origin of some formations. There is even some intimation of recurrent cycles in the interpretations offered.

In the first quarter of the 20th century the earlier postulation of a lacustrine origin for the widespread White River Group and the Fort Union and the Ogallala Formations of the Great Plains region was widely discarded. Davis (1900) was one of the earlier and more influential of those discrediting the hypothesis. For many years thereafter almost nothing on lacustrine sediments appeared in geologic literature. Not until Bradley (1929a, 1931) worked on the Green River Formation was the concept of lacustrine deposition for important stratigraphic units restored to favor. Now many geologists infer lakes as the sites of deposition for widespread formations, where evidence warrants.

DEFINITIVE CRITERIA

FOSSILS

At least two associations of fossil species and enclosing rocks are definitive of fresh-water lacustrine deposition. Limestone that is found in individual beds of large horizontal extent and that contains fossils of fresh-water mollusks or ostracodes, and fresh-water diatomite of widespread distribution, are considered definitive. Powdery marl, consisting almost exclusively of calcium carbonate particles, is included in the present sense with fresh-water limestone. The help of a specialist is often required to determine whether the fossils enclosed in the limestone or the diatomite are fresh-water forms. In limestones barren of fossils, there are only suggestive lines of lithologic or regional evidence. These are discussed later.

If strata, limestone or clastic, contain fairly numerous fossil mollusks, the depositional environment often may be definitely determined. Yen (1951) identifies the habitats of a series of modern and fossil faunal assemblages, stating that a deposit having "well-represented Unionidae, Sphaeriidae, Viviparidae, and Pleuroceritidae, together with a smaller percentage of pulmonates * * * may be considered of fluviatile origin" and that a deposit containing "a large number of Sphaeriidae, Valvatidae, and Amnicolidae, in addition to a well-represented assemblage of aquatic pulmonates, could probably be considered lacustrine."

In the same paper, Yen also states, "A fossil bed that yields an assemblage of a few varieties but with an abundance of individuals, including those of younger stages, may well be taken to represent an original habitat area." Because so few paleontologists are expert in the identification of fresh-water mollusks, Yen's criteria have not been tested or applied as widely as they deserve to be.

If present in sufficient numbers and in suitable varieties, fossils other than mollusks also are a means of proving that the enclosing sediments were deposited in a lake. Diatoms, *Chara*, and ostracodes seem to be more reliable than other forms.

Staplin (1956) cites the presence of the ostracode *Cytherissa lacustris* as definitive of lake deposits, remarking that the species could not live in temporary ponds "because of temperature and extended life cycles." *Darwinula aurea* and other ostracodes not specified are included in the same category. Species of *Cytherissa* close to *C. lacustris* have been found in abundance in some deposits of the Lake Bonneville Group and in deposits of Lake Lahontan (I. G. Sohn, written communication, 1956). Detailed work with fresh-water ostracodes probably would prove rewarding both for additional information about paleoenvironments and for age determinations. The present knowledge of distribution of the forms, in Pleistocene time at least, is inadequate.

The deposits of both Lake Bonneville and Lake Lahontan contain many bedding surfaces covered by shells of ostracodes, notably species of *Candona* and *Limnicythere*. Characteristically these layers separate beds of silt or of clay. Very quiet water is implied by these relations, which clearly indicate lacustrine deposition.

On the other hand, fossil brachiopods, echinoderms, or corals, provided they are not redeposited individuals, are evidence of marine deposition, as they are not known ever to have inhabited lakes (Twenhofel, 1932, p. 174–177).

According to Grabau (1913, p. 717),

> Fresh-water and terrestrial organisms, when exclusively found in a formation, indicates a continental origin. But such remains may be as characteristic of fluviatile as of lacustrine deposits and often more so * * *. Abundant remains of fresh-water mollusks, Crustacea, etc., of Chara and other fresh-water plants, indicate a lacustrine or paludal origin of the formation containing them.

Although remains of terrestrial animals and plants may be preserved in the deposits of any lake, they are commonplace in fluviatile sediments and only under special circumstances can they be considered to be definitive of lacustrine deposition. Some varieties of turtles and of crocodilians are apparently restricted to fluvial deposits, thus providing negative evidence of lacustrine deposition where they are present. Although vertebrate remains deposited in lakes are more likely to be articulated than those deposited in the more turbulent environment of river currents, the vagaries of fossil preservation are so little understood that placing much reliance on the degree of articulation of skeletal remains seems unwarranted.

Interpretation of environments of deposition by means of plant fossils is not easy. According to Twenhofel (1932, p. 825–826) water lilies, cattails, arrowleaf, and sphagnum characteristically occur in lake deposits. These forms seem, however, more likely to be characteristic of sediments deposited in ponds or swamps and less commonly of deposits in large lakes, except as they might occur in relatively isolated shallow-water arms or bays of a lake. David White (in Twenhofel, 1932, p. 389–390) speaks of sapropel as the characteristic organic deposit on the bottoms of ponded waters such as lakes, ponds, lagoons, inland seas, and shallow gulfs where the water is "too deep for vascular plant growth in place, too extensive to permit a considerable contribution of detritus of land origin, and sufficiently protected against tidal scour and aerating currents to favor * * * conservation of humic products." Sapropelic debris consists of spores, pollen, algae, and fungi, with little woody matter.

The fossil leaves of terrestrial plants are not necessarily evidence even of fresh-water deposition much less of lacustrine conditions specifically. For example, Berry (1917) reports that land plants occur with marine invertebrates in the Calvert Formation Miocene on the coastal plain of Maryland, Deleware, and Virginia. Similarly, Brown (1957) shows the rather common occurence of terrestrial plants in marine strata. Diller (1908) also discusses occurrences of fossil land plants with typical marine forms such as *Aucella*, *Inoceramus*, and *Hoplites* but points out in the same locality land plants were also found in association with *Unio*, a pelecypod ordinarily restricted to fresh-water sediments. Either marine and nonmarine conditions must have alternated, or at times, *Unio* was washed into the shallow sea in company with land-plant remains in such abundance that it almost completely dominated the invertebrate fauna in some strata.

Pardee and Bryan (1926, p. 8) conclude that the fossil leaves found in some strata of the Latah Formation of the Columbia Plateau were floated rapidly but gently into place and then deposited flat and well-preserved in quiet ponded water. In contrast, they believe that macerated remains of vegetation indicate accumulation in the bottoms of swamps.

Twenhofel (1932, p. 163) suggests that

> deposits with well-preserved leaves of a community of ecologic character suggests the environment of a small lowland lake, lagoon, or bayou; deposits with well-preserved leaves showing mixing of ecologic characters suggests the environment of a mountain lake; and deposits containing plant materials from several environments, with leaves considerably mutilated and with much resistant plant material, suggest the environment of a flood plain or delta.

In wind-deposited sediments, Twenhofel states that leaves tend to occur rolled or curled, hard fruits are found without outer coats, and cones are found with the scales separated. Furthermore, the plant fossils in wind-deposited sediments tend to occur in jumbled masses that are not parallel with bedding.

Two kinds of algae may prove to be useful in recognizing lake deposits but to date they have been studied relatively little. One is the alga *Chara*, several species of which were identified by Peck (1957) in sediments of Mesozoic age in the Western United States. The strata containing *Chara* consist mostly of limestone, which appears to have been deposited in ponded water. The distinction, if any, between species of *Chara* restricted to lake sediments and those characteristic of deposits in river backwaters or small ponds remains to be made.

According to Rezak (1957), the abundant stromatolites used in correlating strata of the Precambrian Belt Series in Glacier National Park show many structural analogies with forms found in lithoid tufa of Pleistocene Lake Lahontan. Algal structures not unlike the Precambrian stromatolites and those found throughout the geologic column are known from fresh-water lakes today. They may also form in saline lakes, but the ecology needs further study.

EVAPORITE DEPOSITS

Tabular or broadly lenticular deposits of gypsum, borate minerals, celestite, trona, and other evaporite minerals may denote the onetime presence of a saline lake, probably in a desert environment. Of the deposits named, only the borates and trona seem to be restricted in origin to continental closed-basin lakes and playa lakes. Gypsum deposits alone are not definitive of either marine or continental conditions, but McKee (1954, p. 51) suggest that the absence of a limestone bed underlying deposits of gypsum in the Moenkopi Formation may result from deposition in lakes fed by streams deficient in calcium carbonate. However, a deposit of gypsum without limestone below would not necessarily indicate that deposition had occurred in a lake because sea water conceivably might have deposited calcium carbonate in one basin and then entered another basin where, upon further concentration, it deposited gypsum.

SHORE FEATURES

In Pleistocene lakes, it is often possible to identify shore features and thus to demonstrate the former presence of a lake. It remains then only to distinguish those strata deposited by the lake waters from those deposited by streams that spilled into the basin during low-water stages of the lake. To do so, however, is often difficult. Gilbert (1890) has dealt with this problem in detail and should be consulted for criteria by which to segregate environments of formation of shore features.

SUGGESTIVE CRITERIA

REGIONAL RELATIONS

Interrelations among isolated sedimentary features, the shape of sedimentary deposits, and the overlap and changes in facies of sediments can be unraveled in many places to demonstrate the lacustrine environment. Lahee (1941, p. 72–73) gives one summary as follows:

> Feeding streams constantly tend to fill a lake, so that the shore sands and pebbles are forced to encroach upon the lake-floor muds. A vertical section through a choked lake exhibits coarser sediments over finer sediments. This is often called the normal lake succession.

According to Twenhofel (1932, p. 824), "a typical lake deposit should consist of an enclosing belt of shore gravels within which is a belt of sandy, marly mud and in the center fine muds or marls essentially free from grit, each belt grading gradually into those adjacent." Longwell (1928), however, cites places in the Virgin River area of southern Nevada where fine silt has accumulated to considerable thicknesses adjacent to Overton Ridge, in places even enclosing talus blocks that have fallen from the ridge. Near the mouth of Weber Canyon, near Ogden, Utah, beds of the Lake Bonneville Group containing 80–100 feet of silt and having scattered thin interbeds of sand, may be seen, in places, within a few tens of feet (laterally) of the Precambrian rock that forms the Wasatch Mountain scarp at the locality. The relationship of lake-laid clay and silt in contact with rock walls of the enclosing basin has been found in other places also (J. F. Lance, oral communication 1958) and, so, apparently is not uncommon.

Lake deposits are believed by Twenhofel (1932, p. 826) to be characteristically small in extent and round or elliptical in plan, except for those in river lakes which are horseshoe-shaped or elongated. Deposits of smaller lakes may display saucer- or lens-shaped cross sections in profile. Deposits are likely to pass vertically and laterally into peat or swamp muck, or, in the case of glacial lakes, into glacial debris. Seashore lakes are difficult to recognize, as the deposits may contain either fresh-water or marine shells and may grade upward from shallow-water marine beds. Elsewhere Twenhofel (1932, p. 493) remarks: "it seems that the deposits of a desiccated salt lake would have lenticular form * * * [with] bordering salts less soluble than [those of] the central portion, and the latter composed of rock salt, but containing a rather wide range of salt minerals."

Bradley (1926) suggests some overall relations, as well as a series of detailed evidences, that indicate near-shore conditions. He says (p. 125) that where shorelines are not marked they "should [going lakeward] probably be placed where cross-bedding in the sandstone lenses becomes greatly reduced in scale * * *. Where the sandstone assumes a lacustrine aspect the lime content increases materially." He also lists the following additional features as suggestive of near-shore environments: Calcareous algal reefs, oolites, pisolites, ostracode-bearing limestone, and mingling of bones of aquatic and terrestrial vertebrates. In Bradley's opinion, however, wood is of doubtful value as a shoreline indicator.

LOCAL EVIDENCE

Pertinent quotations from all the authors who have at one time or another discussed sedimentary features by which lake deposits might be recognized would constitute an imposing compendium. As the usefulness of such a work, however, is open to question only a few of the more valid and useful of the suggested sedimentary features have been selected for consideration in this paper.

A summary of the problem of presenting characteristics definitive of lacustrine deposits has been made by Twenhofel and McKelvey (1941, p. 827), who state, for a group of fresh-water lakes studied in the upper Mississippi Valley, that "the sediments of each lake are to some degree of individual character." The remark is equally applicable to lacustrine sediments in general, because of the complexities introduced by marked variations in salinity of the waters of different lakes, by climate, by vegetation surrounding the lakes, and by varying degrees of solubility of rocks in the drainage areas—to name a few of the variables. (Twenhofel and McKelvey (1941) list 25 or 30) Withal, a high degree of diversity of sedimentary types, bedding, and features on the bedding surfaces is probably the one outstanding trait that characterizes lake deposits as a class, especially those deposited in basins adjacent to country having high relief. This diversity is accompanied by other characteristics that are common to sediments of the continental environment, such as vertical and lateral variations within exceedingly short distances and a broad spectrum of colors. The colors of lacustrine sediments are perhaps more subdued than the more brilliant of the fluviatile strata, but although this criterion may characterize the class, it is not valid for the individual rock or formation.

GRAIN SIZE, BEDDING, AND LAMINATION

Writing about areas in and near the Black Hills of South Dakota, Darton (1901, p. 558) says, "No one who has observed extensive exposures of the finer-grained White River sediments would regard them as other than lake deposits." He speaks also (p. 559) of features he considers to be positive criteria of lake-bed deposition—the presence of chemical deposits, of stream-channel deposits completely enclosed by fine-grained materials, and of very fine-grained sediments "usually spread out in thin beds with perfectly even stratification, in which precisely the same sequence of beds may be traced for miles." The first of the two quotations just given is the essence of the 19th century point of view that was so severely criticized by Davis (1900) and others about the turn of the century (see p. 17).

Nevertheless, the traditional association of fine grain and of delicate lamination with lacustrine deposition persists and has a sound foundation in fact. The major change in point of view between the geologists of the 19th century and their modern counterparts is perhaps recognition of the fact that flood-plain as well as lacustrine sediments may consist of silt and clay and display well-defined lamination. The possibility that grain-size distribution can be estimated on a mathematical basis to distinguish conclusively slack-water lacustrine deposits from fine-grained fluvial deposits is implied in a paper by Stewart (1958). His work, however, was in coastal lagoons and their influent rivers; hence direct applicability can only be surmised.

Buwalda (1914), in describing the Pleistocene beds at Manix Lake, Calif., remarks that the "most striking feature" of the beds is the evenness, persistence, and parallelism of individual layers. Regarding the Latah Formation, Pardee and Bryan (1926, p. 8), as stated earlier, consider fine grain, delicate lamination, and preservation of complete and nearly complete leaf fossils as evidence of deposition beneath lake waters.

According to Twenhofel (1932, p. 828), "Lacustrine clays and silts are typically well sorted and thinly laminated, but the last characteristic is not necessarily present." Carefully restricting his conclusions to Tertiary beds of the Uinta Basin, Picard (1957a) observes, that lacustrine shales are denser, harder, better bedded, more continuous and somewhat thicker and that they contain more limestone and dolomite than the fluvial shales.

Bradley (1931, p. 10) found and remarks on various features within the Green River Formation as follows (the italic does not appear in the original quotation):

> The bedding is regular in general but within the beds and on the bedding planes there are many small irregularities. Ripple marks of both oscillation and current origin are plentiful, but oscillation ripple marks predominate, and *most of the current ripples are nearly symmetrical.* Sandstone and siltstone beds are locally crossbedded through a small vertical range. In a few places ostracode-bearing limestone and oolite beds are also cross-bedded * * *. Mud cracks, curls, and edgewise conglomerate occur * * *. Paper shale with discrete laminae less than 1 millimeter in thickness, many to be measured in a few hundredths of a millimeter, is a characteristic feature of this [Garden City] member of the Green River formation * * *. Outcrops of the paper shale resemble piles of deckle-edge paper. [In the same paper (p. 24) Bradley says,] The leaner beds of dense marlstone with their minute, sharply defined varves, which average about 0.15 millimeter in thickness, must have been deposited in very quiet water.

On the other hand, Twenhofel and McKelvey (1941) found in modern lakes of the upper Mississippi Valley that the lake-deposited sands were laminated but that the silts and clays were not. The absence of lamination in the finer grained materials is considered to have resulted from (1) deposition on deep bottoms where clastic influxes of coarser fractions did not occur and where deposition was virtually continuous, (2) from the fact that the sludge was soft and therefore allowed inorganic materials to sink through it to depths varying with the specific gravity of the particles, and (3) from the fact that the organic mud was continuously worked by organisms.

Commenting on environments of deposition of the Moenkopi Formation of Triassic age, McKee (1954, p. 78–79) says in part:

> Evidence that wide bodies of quiet water, probably lakes or ponds, formed back from the margins of the sea is found in the deposits of deep red-brown, structureless, crumbly claystone * * *. The mud forming these deposits has been accumulated through settling in water so that no bedding or lamination was developed.

Other discussion for and against the significance of laminae as evidence of deposition in a lacustrine environment can be found in many papers, such as those by Knappen and Moulton (1930, p. 21), Bradley (1948, p. 645), Bateman (1956), Malde and Powers (1958), and Wilson (1958).

RIPPLE MARKS, MUD CRACKS, AND SIMILAR FEATURES

Various attempts have been made to find specific physical features of sediments that would permit assignment of the sediments to a specific environment of deposition. In general, results have been disappointing.

Regarding ripple mark, McKee (1954, p. 59) summarizes proposals of others that symmetrical ripple mark is largely a phenomenon of lacustrine deposits because, in the words of Kindle (1917a, p. 48) current action "is generally absent or comparatively rare in lakes." McKee then cites other investigators who found symmetrical ripple mark on tidal flats bordering Long Island and then completes the demolition of ripple mark as a firm criterion by observing that current- and wave-type ripple mark occurs in the Moenkopi Formation not only in the same series of sediments but actually, in some places, on the same rock surface, one type superimposed on the other. Observations by Bradley (1931) were quoted earlier, and further discussion can be found in papers by Kindle (1917a), Knappen and Moulton (1930), Bucher (1919), Feth (1955), and others.

Kindle (1917b) attempts to establish criteria by which the mud cracks and mud curls that form in salt-water sediments can be distinguished from those that form in fresh-water sediments, when both are exposed to drying. He theorizes that shrinkage polygons with flat or convex upper surfaces form in salt-water mud, whereas polygons having concave upper surfaces form in fresh-water mud. He argues that polygons of salt-water mud show no shrinkage or upcurl as the mud expands laterally during drying. Laboratory experiments with salt-water mud yielded polygons with relatively small cracks between them. It was postulated that similar polygons formed in ancient marine sediments would, when exhumed, be less prominent than the grossly curled fresh-water variety. Bradley (1933), however, disagrees with those conclusions, pointing out that the polygon surfaces are concave toward the finer grained side in mud-cracked layers of vertically nonuniform texture regardless of the salinity of the water. Furthermore, Bradley found that fast drying promotes curling, whereas slowly dried mud tends to have polygons with flat surfaces. The differences noted were characteristic only of very fine sediments; the polygons produced in sediment of coarser texture were flattopped regardless of the rate of drying. The only effect of salt observed by Bradley was the tendency for coarser materials in salty water to concentrate toward the top of the mud layer and, consequently, for polygons to curl downward.

Matthew (1883) reports on a method apparently not tried extensively, which involves determination of the specific gravity of air-dried samples of marine shales and of fresh-water shales overlying the marine strata. Some samples from both environments were reddish brown; some were olive gray. Of the small number of samples tested, all from one locality, the fresh-water shale had a lower specific gravity than did the marine. Matthew believes that the fresh-water samples contained enough finely disseminated organic material to explain the difference. When consideration, however, is given to the wide variety of source rocks contributing to both environments and to the abundance of organic clays formed in the marine environment, it seems unlikely that the relationship of the specific gravities would be uniformly the same as that found by Matthew.

MINERALOGY

According to Bradley (1931, p. 31), the predominant clastic constituents of the oil shales in the Green River Formation are clay minerals belonging to the beidellite group. According to Degens, Williams, and Keith (1958, p. 996), illite is more abundant than kaolinite in marine shales, and kaolinite is more abundant than illite in fresh-water shales. The difference did not appear in their analyses of the clay fractions of limestones tested.

Illite, says Keller (1956, p. 2703), is more or less characteristic of marine shales and thus is a possible negative criterion for lake-deposited shales.

Grim (1958) concludes that the mineralogic changes that occur in clay particles when they enter a lake are governed by the chemical character of the lake water. Water that is only slightly mineralized would effect few changes, whereas clay particles in saline lakes would tend to alter to montmorillonite, illite, or both or to chlorite, sepiolite-attapulgite, and zeolites, depending on the chemical character and concentration of the water. Grim expects the three-layer clay minerals, such as illite and montmorillonite, to disappear in highly saline water.

From "thousands of X-ray analyses of clay minerals * * *" Weaver (1958) concludes that any one of the clay minerals can occur in abundance in any major depositional environment and that no selective correlation can be recognized. Clay minerals, according to Weaver, reflect source materials more than the environment of deposition. Rosenqvist (1959) presents electron photomicrographs that show a markedly different structure between samples of fresh-water and marine clay. The sampling is small, however, and the future applicability of the method for distinction of lacustrine clays specifically has not been tested.

Crowley (1939) turns to potash feldspars as a criterion. After studying more than 100 separations each of marine and nonmarine sediments, he concludes that the presence of fresh secondary-growth potash feldspar indicates a marine environment. In nonmarine sediments all potash feldspar grains seen were clearly water-worn or weathered but never fresh. No distinction was made, however, between fluvial and lacustrine sources of sediments.

At this time, mineralogic differences have not been determined sufficiently to solve the problem at hand.

ROCK COLOR

Thompson (1929) writes as follows about his attempt to find criteria by which to distinguish deposits of perennial lakes from those of playa lakes.

> The writer has endeavored to find criteria that may be used in determining whether deposits in the desert basins * * * have been laid down in perennial lakes or in ephemeral lakes * * *. However, unless there is physiographic evidence in the form of wave-cut cliffs or beaches, the only reasonably reliable criterion seems to be the color of the sediment. The prevailing conception is that a greenish or bluish color of the beds indicates deposition beneath water; but the writer has not been able to find any information as to whether this is an infallible indication of deposition in a lake enduring for only a year or several years, or whether it indicates the existence of the lake for many years.

A decade before Thompson, Meinzer (1917, p. 60) reported that in three Nevada valleys the clay deposited in playa lakes is characteristically light yellowish gray to dark brown, whereas the silt and sand are pale yellow to nearly white. He noted, however, that saturated sediments have a bluish hue or are black.

Probably because of the abundance of carbonaceous material, Twenhofel (1932, p. 828) cites the range gray through blue to dark (hue unspecified) as characteristic of lacustrine silt and clay but remarks that red may occur. Strata of the Lake Bonneville Group include the following: Green clay; brown limestone; gray, tan, and pink wave-formed tufa; black muck; yellowish-tan, tan, and salmon-pink silt and clay; and tan and gray sand. In Arizona, lake beds consisting of dead-white limestone form the cliffs across the river from the Indian Agency near San Carlos, and similar limestone characterizes lake deposits near Payson and the lacustrine Verde Formation near Cottonwood. Lacustrine strata in the Tonto Basin, near Roosevelt Lake, Ariz., consist of clay, silt, and sand interbedded with gypsum and display shades of green and red as bright as those of many of the Mesozoic formations of the Colorado Plateaus.

Thus, most, if not all, of the colors that are characteristic of rock strata generally are also found among lacustrine deposits. Even though lighter colors and subdued tones are the general rule, exceptions occur, and color seems to be at best only a suggestive criterion.

LIMESTONE

Geologic literature contains only a few detailed descriptions of fresh-water limestone.

Pettijohn (1957, p. 411) offers the following description:

> Fresh-water limestones of the geologic record are characterized by lack of marine fauna; they contain *Spirorbis*, various ostracodes, and occasional mollusks. Many are algal and show algal structures. Some are nodular. The nodule-like masses show calcite filled syneresis cracks. Under the microscope the rock has a clotted appearance, being made up of rounded clot-like masses of dense fine-grained carbonate held together with clearer coarse-textured carbonate.

Picard (1957a) mentions limestone and dolomite—some coquinoid (in contrast to Pettijohn's "occasional mollusks"), some algal, and some detrital—as being common in lacustrine deposits. He finds limestone represented only by sparse thin beds in fluvial strata of the Uinta Basin.

Krumbein and Sloss (1951) consider fresh-water limestone to be of lacustrine origin and to form from limy mud precipitated, at least in part, as a byproduct of photosynthesis. According to these authors, fresh-water limestone is commonly dense and may be brecciated and show shrinkage cracks. They also consider marl to be a characteristic nonclastic deposit of lakes and to range in composition from relatively pure calcium carbonate to mixtures of calcium carbonate with mud and organic matter.

Bradley (1929b), Eardley (1938), and Russell (1885) deal at length with the more exotic types of carbonate deposition in lakes; namely, algal heads, algal reefs, pisolites, oolites, and various forms of tufa. Rezak (1957) discusses stromatolites and other algal limestone structures.

The exceptional Hualpai Limestone that forms the topmost unit of the Muddy Creek Formation in parts of the Virgin-Detrital trough in the Lake Mead region is described in considerable detail by Longwell (1936, p. 1429–1434). The following excerpts from Longwell's discussion show the variety of colors and textures that characterize this limestone.

> The highest unit of the basin deposits [of Pliocene(?) age] * * * consists chiefly of limestone in thin and rather regular beds, many of which have the porous structure characteristic of travertine. * * *
>
> The color of the limestone ranges from white through gray to pink or light-brown. Between scattered openings the rock is compact and fine-grained.

The degree of porosity varies considerably from bed to bed as well as laterally in any one layer.

* * * Much of the limestone also contains chert nodules and lenses, which litter the ground where they have been liberated by weathering. Commonly, the chert grades from gray to pink or light-brown; some nodules have the translucence of chalcedony. * * *

In the main, however, the formation consists of limestone, nearly aphanitic and with considerably porosity, in beds that are thin and remarkably regular. The original maximum thickness * * * exceeded 1,000 feet.

* * * It appears to represent a lake, or perhaps neighboring connecting lakes, with water highly charged with calcium carbonate. Ordinary playas seem to be out of the question. * * *

In the late Tertiary and Pleistocene lake sediments of Arizona, Utah, Nevada, and parts of Oregon, the present author has observed that marl—in the sense of relatively pure calcium carbonate particles—is generally powdery and incoherent where it occurs in layers at least a few feet thick, is locally richly charged with mollusks, ostracodes, oogonia of *Chara*, or all three, and is typically but not necessarily restricted in areal extent to a few acres rather than to several square miles. Deposition of the marl probably occurred most often in quiet bays in which, at various lake stages, the water of the bays possibly differed chemically from that of the main body of the lake. At times when the bays became supersaturated with respect to calcium carbonate, minute blebs and clots of the mineral formed and rained down with little interruption upon the bay floor. The extensive deposit of marl—Gilbert's (1890) White Marl—of the Bonneville basin is a prominent exception to the generality stated. The conditions in Lake Bonneville that permitted deposition of this widespread marl are not yet understood.

Among the denser carbonate lacustrine beds there is wide variety. The hundreds of feet of lake beds in the San Carlos Indian Reservation, Ariz., are dominated in places by limestone strata. Most of these are white, lithographic in texture, conchoidal or hackly in fracture, and are devoid of fossils save for a few mollusks and equally few pencil-lead thin knobby stems of *Chara*. Some of the limestone beds are liberally spotted with nearly circular concentrations of silica, opaline in appearance and ranging in color from light yellow to molasses brown. Other beds are light gray and a few are brown or pink. The limestone in the Verde Formation and in the lacustrine beds near Payson is similar to the limestone of the San Carlos Reservation, except that siliceous concretions are scarce or absent.

On the other hand, carbonate rocks other than marl are scarce in exposures of the Lake Bonneville Group. In 300 square miles on the east shore of Great Salt Lake and in dozens of individual exposures on the north, east, and south sides of the basin, the author

(Feth, 1955) saw only a few algal structures, wave-formed tufa plastered on older rock at various shorelines, and a single 1-foot bed of brown sugary-textured limestone, enclosed oddly enough above and below by coarse sand and gravel.

In a few basins in Nevada, notably Pahrump Valley and an area north of Las Vegas, Pleistocene lake deposits contain 1-inch-thick layers consisting of highly irregular nodules of calcium carbonate or of sand and carbonate in about equal proportions. The nodules, some discrete and others bound into platelike units, form nearly continuous layers over areas several miles square. In many places they cap surfaces of low relief, from which erosion has removed the less resistant layers of sand and silt that had overlain them. The effect is not dissimilar to that of some deposits of surface caliche. The Manix Lake Beds in the Mojave Desert, Calif., contain at least one prominent layer of white calcareous concretions; some concretions are discrete and some coat pebbles. The layer is one nodule thick and overlies a stratum of gravel.

The layers of calcareous nodules may have been deposited in shallow water that was subject to a high rate of evaporation—that is, an environment like that afforded by a playa lake. On the other hand, the Hualpai Limestone and the thick extensive carbonate beds as those near San Carlos, Ariz., presumably formed over longer periods of time and in deeper water.

CHEMICAL CRITERIA

A few investigators have reported geochemical criteria that, at least in the areas in which they worked, seem to afford a means for distinguishing between marine and nonmarine shales. The depositional environment of the shales used in determining the criteria was known from fossil evidence.

From their work with Carboniferous rocks in the Eastern States, Degens, Williams, and Keith (1957) conclude that boron and rubidium are more abundant in marine than in fresh-water shale. (In the Western States, virtually all known deposits of borate minerals are in saline-lake deposits.) They also found that nickel and vanadium are more abundant in organic fractions of the marine shales and that lead, zinc, copper, and tin are more abundant in the organic fraction of the nonmarine shales. In a second paper, the same authors (1958) report on minerals in the clay fractions from carbonate rocks. They found gallium consistently more abundant in fresh-water than in marine rocks and boron more abundant in marine than in nonmarine rocks. The relationship for rubidium was not conclusive. Plotted on trilinear coordinates, their data show overlap of fields of marine and fresh-water sediments but permit separation of marine and nonmarine samples in 80 percent of the samples tested.

Silverman and Epstein (1958) report on their studies of the stable isotopes of carbon. The ratio $C^{13}:C^{12}$ was studied in petroleum, in modern plant constituents, and in other organic materials including marine invertebrates and natural gas. In marine organisms and in petroleum from marine strata, the ratio shows that the concentration of C^{13} in marine substances is greater than in nonmarine materials. The nonmarine samples, however, were taken largely from the Green River Formation and wide sampling would seem to be necessary before the method could be considered reliable.

Deposition of iron oxides, mainly limonite, is cited by various authors, among them Krumbein and Sloss (1951, p. 183), as a characteristic of some lakes. And Bradley (1931, p. 31) says,

> Pyrite occurs in various amounts in all the oil shale of the Green River formation. The greater part of it is in subspherical or irregular grains that range from 0.002 to about 0.05 millimeter in diameter * * * there are numerous discoid aggregates of microgranular pyrite from 0.5 to 3 millimeters across * * * the pyrite so formed [in organic lacustrine oozes] seems to have a distinctive microgranular or rather microspheritic habit.

Although the abundant segregations of silica in the lacustrine limestone on the San Carlos Indian Reservation have not been observed to weather out as nodules, chert nodules from the Hualpai Limestone locally "litter the ground," according to Longwell (1936, p. 1430). These examples of the occurrence of siliceous masses in fresh-water limestone do not substantiate the statement of Twenhofel (1932, p. 534) that where the environment of a deposit containing significant amounts of flint and chert has been determined, the deposit has been shown to be marine. Within limits, then, flint and chert in nodules that weather from the enclosing rock without losing identity may signify marine deposition, but more disseminated concentrations of silica within a limestone apparently do not indicate specifically that deposition occurred in a marine or nonmarine environment.

Dense deposits of soil-formed caliche, some of considerable thickness, occur in the intermontane basins of Arizona and New Mexico. These carbonate deposits are locally of considerable purity and extent and might be mistaken for fresh-water limestone. It is probable, however, that they can be properly identified by their common association with veins of caliche extending below the base of the bedded carbonate, by mapping, or by the character of the enclosing strata. Characteristically they are devoid of fossils but irregular tubes or rods of carbonate may mark former plant roots.

CHECKLIST OF CRITERIA

Positive identification of lake deposits from observation of a single criterion is exceptional. But a reasonable assemblage of criteria from the following list strongly suggests—or even proves—the lacustrine environment of deposition. The list is derived from the more extensive discussion given on the preceding pages.

Checklist of criteria for the identification of lake sediments

[Criteria marked (*) appear to be the most definitive]

Paleontology

*Species of *Chara*.
Arborescent or concretionary algal structures (calcium carbonate).
Tufa in masses resembling stromatolites. (*See* Rezak, 1957.)
*Abundant fresh-water mollusks of lacustrine habitat: among those mentioned (see Yen, 1946a, 1946b, 1951) are species of *Pisidium, Valvata, Amnicola, Brannerillus, Lymnea, Physa, Armiger, Vorticifex, Carinifex, Planorbifex, Papyrotheca, Charydrobia, Australorbis, Anisus, Menetus.*
Abundant fresh-water ostracodes, especially *Darwinula aurea* and **Cytherissa lacustris;* also mentioned (see Swain, 1949) are species of *Candona, Cypridea, Cyprois, Erpetocypris?, Ilyocypris, Lymnicythere, Scottia.*
*Any coquina consisting of fresh-water forms of mollusks or ostracodes, or bedding surfaces generally covered by tests of fresh-water ostracodes.
Flat well-preserved leaves or leaf imprints; not rolled or macerated.
NOTE.—Brachiopods, corals, conodonts, and echinoderms are restricted entirely to marine waters.

Mineralogy

*Tabular or lenticular bodies of saline deposits, especially borates, celestite and trona; borates and trona in the Western States are apparently limited entirely to lacustrine deposits.
Gypsum where not underlain by limestone.
Saline deposits grading outward from central halite to progressively less-soluble salts.

Petrology

*Powdery marl.
*Limestone containing fresh-water fossils, especially where widespread and occurring in flat beds; locally, limestone-pebble conglomerate may represent lacustrine limestone reworked in wave zone.
*Diatomite containing fresh-water species.
Lithographic limestone; clotted limestone; algal limestone fringing a basin.
*Pure white or yellowish-white limestone. Varved sediments, paper shale, and oil shale are suggestive.
*Tufa where formation by wave action on rock surfaces may reasonably be inferred. Although this is a shore feature, it is more likely to be preserved than features formed in unconsolidated materials.

Bedding and other sedimentary structures

[See Stewart and others, 1959; Malde and Powers, 1958, for useful discussion]

*Persistent fine lamination, even and parallel.

Noteworthy reduction of cross-bedding scale in one sedimentary unit; reduction marks transition from shore to lake environment.
Nearly symmetrical current ripple mark.

Regional relations

*Fine-grained sediments that grade laterally in all directions into coarser sediments; grade vertically upward into coarser sediments especially toward center of the basin of deposition.
*Gradation laterally or vertically from clastic sediments to muck or peat.
*Areal evidence of continental environment of deposition. For example, any chemical sediment of Tertiary age in Idaho is reasonably considered to be lacustrine because the Tertiary history of the region implies absence of marine waters.

***Shore features**

Shore features are, of course, definitive but are restricted almost entirely to Pleistocene, characteristically later Pleistocene, occurrences. (See Gilbert, 1890.)

BIBLIOGRAPHY

In the pages that follow, an attempt has been made to list at least one definitive publication for each occurrence of lake deposits or for each Pleistocene lake basin shown on the maps (pls. 1–4). This has not always been possible, because definitive descriptions simply do not exist for many localities shown. The bibliography, however, does include nearly all the publications that contain the maps showing the distribution and outcrop areas of lake deposits and from which plates 1–4 were compiled. Also included in the bibliography are publications containing criteria suggested for the recognition of lake deposits, discussions of the economic importance of lake-deposited materials, or exceptionally good descriptions of individual lacustrine sequences.

Many more references were scanned than are included. Some were not included because they largely duplicate earlier publications that remain adequate; some because they are superseded by later interpretations based on more complete information. The greater majority of those not included, however, were omitted because they contained but passing reference to lacustrine formations and provided neither useful descriptions nor maps showing distribution of the lacustrine deposits. Unquestionably some significant items in the literature on lake sediments of the West have been missed, but the bibliography probably provides references for more than 75 percent of all occurrences of lake sediments that have been recorded in the geologic literature on the area.

Geologic names listed in this bibliography are those of various authors and do not necessarily follow the usage of the U.S. Geological Survey.

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Alden, W. C.

1932. Physiography and glacial geology of eastern Montana and adjacent areas: U.S. Geol. Survey Prof. Paper 174, 133 p.

Map shows shoreline of Great Falls glacial lake and of other ice-dammed water bodies. Text reconstructs Pleistocene drainage patterns and extent of ice cover, ponded waters, lake sediments, and moraines.

1953. Physiography and glacial geology of western Montana and adjacent areas: U.S. Geol. Survey Prof. Paper 231, 200 p.

Lake and stream deposits of Oligocene age underlie Quaternary stream terraces in valleys of Missouri River and its tributaries. Individual valleys are described in citations from older publications and from personal study. The descriptions cover most of the Tertiary lake-bed areas of central and western Montana that are shown on the "Geologic Map of Montana" compiled by Ross, Andrews, and Witkind (1955). No evidences are cited for older lake beds. Shorelines for Glacial Lake Missoula (Pleistocene) are mentioned and partly mapped.

Allen, J. E.

1954. (and Balk, Robert). Mineral resources of Fort Defiance and Tohatchi quadrangles, Arizona and New Mexico: New Mexico Bur. Mines and Mineral Resources Bull. 36, 192 p.

Chinle Formation (Late Triassic) contains fresh-water bivalves and includes limestone and other calcareous deposits probably deposited in fresh-water basins.

Allison, I. S.

1935. Glacial erratics in Willamette Valley [Oreg.]: Geol. Soc. America Bull., v. 46, no. 4, p. 615–632.

Map shows distribution of glacial erratics of Pleistocene age, the outer limits of which were used (by J. H. Feth) to reconstruct the outline of the glacial lake in the valley. See Allison (1953) for discussion.

1945. Pumice beds at Summer Lake, Oregon: Geol. Soc. America Bull., v. 56, no. 8, p. 789–808.

A late pluvial lake in Summer Lake basin was originally 215 ft deep. Highest shoreline (Lake Chewaucan) is at an altitude of 4,500 ft and is considered correlative with Bonneville stage. Lower shoreline (Winter Lake) at altitude of 4,275–4,360 ft is probably equivalent to Provo stage. Driller at Lakeview, Oreg., reported soft blue lake muds penetrated almost continuously to 960 ft in one well and to 1,286 ft in another.

1953. Geology of the Albany quadrangle, Oregon: Oregon Dept. Geology and Mineral Industries Bull. 37, 18 p.

Willamette silts, as much as 15 ft thick, underlie most of Willamette Valley lowland to about 400 ft above sea level. They probably were deposited in a short-lived lake of Wisconsin-stage age that received water and numerous ice-rafted erratics from the Columbia River. Outer limits of erratics are inferred by J. H. Feth to represent maximum extent of the lake and were used to reconstruct the approximate shoreline (Allison, 1935).

1954. Pluvial lake levels of south-central Oregon [abs.]: Geol. Soc. America Bull., v. 65, no. 12, pt. 2, p. 1331.

Pluvial lakes in the intermontane basins of south-central Oregon (Summer Lake, Chewaucan Marsh, and Abert Lake) show a long and complicated history. Summer Lake basin shows main shorelines at 4,190 ft, 4,225 ft, 4,260–4,280 ft, 4,325–4,350 ft (a swarm), 4,365–4,370 ft, 4,400 ft, 4,455 ft, 4,470 ft, 4,485 ft, and 4,520 ft. Eruption of Crater Lake (Mount Mazama) 6,450 years ago is marked by pumice sand at the 4,260–4,280-ft shoreline. At least some of the higher shorelines are probably of pre-Wisconsin age.

Anderson, C. A.

1936. Volcanic history of the Clear Lake area, California: Geol. Soc. America Bull., v. 47, no. 5, 632–639.

Some parts of a 1,700-ft sedimentary section are lacustrine, others fluviatile. Becker (1888, p. 219–221) calls the section all lacustrine and believes that the basin of Cache Lake is the same as that of present Clear Lake. Anderson believes the Cache Formation of Pliocene or Pleistocene age was tilted and eroded before Clear Lake basin formed. The Cache Formation is best exposed west of North Fork of Cache Creek and includes fresh-water diatomite and limestone.

Anderson, F. M.

1905. A stratigraphic study in the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., v. 2, p. 181.

This paper establishes name Tulare Formation for fresh-water gypsiferous sands and clays exposed along the west border of the Great Valley of California. Age of the formation is Pliocene and Pleistocene (?).

Andrews, D. A.

1948. (and Hunt, C. B.). Geologic map of eastern and southern Utah: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 70.

Distribution is shown for the Flagstaff Limestone (Paleocene and Eocene?), North Horn Formation (Cretaceous and Paleocene), and Green River Formation (Eocene).

Antevs, Ernst

1948. Climatic changes and pre-white man, *in* The Great Basin, with emphasis on glacial and postglacial time: Utah Univ. Bull., v. 38, no. 20, p. 168–191.

Occurrence of pluvial lakes is probably caused by the southward displacement of North Pacific storm tracks (p. 170). It is suggested that the maximum size of Lake Bonnville occurred during Iowan (Tahoe) time, some 70,000 years ago, and that Provo Pluvial stage was correlative with the Mankato advance, some 25,000 years ago.

Postglacial climates suggested by Antevs are as follows:

Ages and general temperature	*Moisture conditions in Great Basin and contiguous areas*
Present: Medithermal — moderately warm.	Arid and semiarid, but some Great Basin lakes reborn.
2500 B.C.: Altithermal—warmer than at present.	Arid. Lakes and glaciers disappeared.
5000 B.C.: Anathermal—at first as today, but growing warmer.	Probably subhumid and semiarid. Lakes in Great Basin.
7000 B.C.	

Arnold, Ralph

1908. (and Anderson, Robert). Preliminary report on the Coalinga oil district, Fresno and Kings Counties, California: U.S. Geol. Survey Bull. 357, 142 p.

First detailed description is given of the Paso Robles Formation (Pliocene and Pleistocene?) in the Central Valley of California (now called the Tulare Formation, a reversion to the original usage of Anderson (1905). The formation includes beds of limestone containing abundant fresh-water fossils.

1910. (and Anderson, Robert). Geology and oil resources of the Coalinga district, California: U.S. Geol. Survey Bull. 398, 354 p.

The Tulare Formation of Pliocene and Pleistocene(?) age consists of bedded gravel, sand, and clay. A few scattered layers are indurated. Associated beds include fresh-water shells, marl, and limestone at base. The Tulare was deposited partly in fresh-water lakes, partly in shallow ocean water, and partly in subaerial environment. The formation is best exposed in Kettleman Hills where basal sand has many fresh-water fossils and where its thickness is "several thousand feet."

Axelrod, D. I.

1958. The Pliocene Verdi flora of western Nevada: California Univ., Dept. Geol. Sci. Bull., v. 34, p. 91–160.

Author briefly describes the geologic occurrence of the plant fossils and a few vertebrate remains, which were deposited on a flood plain that had local lakes in areas near present town of Verdi, Nev.

Baker, C. L.

1911. Notes on the later Cenozoic history of the Mojave Desert region in southeastern California: California Univ., Dept. Geol. Sci. Bull., v. 6, p. 333–383.

Early nondefinitive discussion of the (then) Rosamond series (upper Miocene) of Hershey is given; map shows a few localities. The series probably had an origin in playa lakes. Hot-spring origin of borate minerals limestone and gypsum is also considered possible, but 35-ft thickness of some colemanite beds implies fairly deep water.

Baldwin, E. M.

1959. Geology of Oregon: Oregon Univ. (Eugene) Cooperative Book Store, 136 p.

The terms "Payette Formation" and "Idaho Group" are extended to include basin deposits of comparable type and origin that underlie many basins in eastern Oregon. Distribution of these Tertiary lacustrine deposits is shown on a map (pl. 28).

Barbat, W. F.

1934. (and Galloway, John). San Joaquin clay, California: Am. Assoc. Petroleum Geologists Bull., v. 18, no. 4, p. 478–499.

San Joaquin Clay of Pliocene and early Pleistocene age is 1,860 ft thick at type section and includes at least three zones that contain fresh-water lacustrine fossils. Well cores suggest a thickness of 3,300 ft including probably six zones of lacustrine sediments. The outlet of a Pliocene lake was probably near Coalinga. The lake drained to the ocean via the Priest Valley area.

The Tulare Formation (Pleistocene) shows evidence of two advances and intervening retreat, as well as possible desiccation of an ancient lake far larger than modern Tulare Lake. Authors suggest correlation with glacial and interglacial stages.

Bassett, A. M.

1957. (and Muessig, Siegfried). Possible high shore lines of a Pleistocene lake in eastern Mojave Desert, California [abs.]: Geol. Soc. America Bull., v. 68, no. 12, pt. 2, p. 1818.

Topographic benches, green sediments, and sand ridges in the area near Crucero occur at elevations of 1,096 and 1,111 ft, well above Lake Mojave spillway level of 946 ft. Either an area of 1,500 sq mi was flooded or crustal uplift occurred after Lake Mojave was drained.

1959. (and Kupfer, D. H., and Barstow, F. C.) Core logs from Bristol, Cadiz, and Danby dry lakes, San Bernardino County, California: U.S. Geol. Survey Bull. 1045–D, p. 97–138.

Detailed logs of four core holes from the named basins are reported. A map shows locations and outlines of the basins. The fact that both fresh-water and marine fossils were recovered suggests that brackish-water environments existed during deposition of the clay, salt, and gypsum cut by drilling. It is inferred (p. 111) that deposition took place in ephemeral lakes, because strata cannot be correlated from one core hole to another as would be possible had deposition occurred in permanent water bodies.

Bateman, P. C.

1956. Economic geology of the Bishop tungsten district, California: California Div. Mines Special Rept. 47, 87 p.

Near the north end of Owens Valley, Calif., angular pumice of Pleistocene age grades from fine at base to coarse at top—an upside-down criterion, as this gradation is opposite to that normally found elsewhere. Regional relations prove that the strata are not inverted. This inverse gradation may have resulted because pumice floats until saturated and because small fragments become saturated sooner than the larger ones and hence sink first. This condition would prevail if the deposit was formed in ponded water. Alternatively, the inverse gradation may have resulted from deposition on dry land of pumice discharged from a volcanic vent at which explosive force increased progressively with time. The latter assumption better explains observed distribution of accidental fragments of metamorphic and granitic rock in the pumice which are also size graded from small (lower) to larger (higher).

Bauer, C. M.

1934. Wind River Basin [Wyo.]: Geol. Soc. America Bull., v. 45, no. 4, p. 665–696.

The Uinta Formation of Eocene age is more than 250 ft thick and is dominantly lacustrine as is evidenced by the fine texture and clearly defined bedding.

Becker, G. F. *See also* Anderson, C. A., 1936.

1888. Geology of the quicksilver deposits of the Pacific slope, with an Atlas: U.S. Geol. Survey Mon. 13, 486 p.

The "great thickness" of gravel, sand, and calcareous beds exposed along the north fork of Cache Creek, near Clear Lake, Calif., was deposited in a lake (p. 219–221). Fresh-water shells and vertebrate remains are sparse and fragmentary but suggest late Pliocene age. Fossils occur in "light-colored, calcareous, soft and excessively fine-grained material, manifestly a lake deposit."

Beekly, A. L.

1915. Geology and coal resources of North Park, Colo.: U.S. Geol. Survey Bull. 596, 121 p.

The Coalmont Formation of Eocene age was deposited in fresh water, within "inconstant lake and marsh areas." The lower 3,500± feet consists of sandstone, shale, and coal and is light yellow, light gray, and chocolate colored. The principal coal bed is about 30 ft above the base of the formation. The upper 2,000± feet consists of coarse gray sandstone and conglomerate.

The North Park Formation of Miocene(?) age consists of interbedded sandstone and shale alternating with volcanic materials. Hard white calcareous sandstone and marl are prominent and characteristic. Formation is 500–1,000 ft thick. No fossils are reported.

Berry, E. W.

1916. The physical conditions indicated by the flora of the Calvert formation: U.S. Geol. Survey Prof Paper 98–F, p. 61–73.

Because fossils of land plants sometimes occur with marine invertebrate faunas, they do not necessarily indicate that the enclosing sediments were deposited in a continental environment. (Comment relates to criteria in general; example is drawn from Atlantic seaboard.)

Bissel, H. J.

1952. Stratigraphy of Lake Bonneville and associated Quaternary deposits in Utah Valley, Utah [abs.]: Geol. Soc. America Bull., v. 63, no. 12, pt. 2, p. 1358. [Abstract, quoted in full; one of the first of a series of reinterpretations of histories of Great Basin lakes.]

Mapping in the Utah Valley shows the following Quaternary stratigraphic section, which requires substantial revision of Gilbert's classic interpretation of Lake Bonneville history:

1. Basal thick fan gravel, grading basinward to lake sediments; very strong soil profile on the gravel.
2. Sediments of four high lake cycles (substages), which are Gilbert's ancient Lake Bonneville:
   a. First lake substage: mainly silt and clay, some sand and gravel, to 5,100 ft in maximum altitude.
   b. Local disconformity, eolian sand, alluvium, and (or) weak soil profile demonstrating lake recession to at least 4,600 ft.
   c. Second lake substage: mainly gravel, grading basinward to sand, silt, and clay; maximum level, 5,135 ft, was Lake Bonneville's highest shoreline (Gilbert's Bonneville shoreline).
   d. Local disconformity, eolian sand, alluvium, and (or) strong soil profile, demonstrating desiccation to at least 4,500 ft (almost to bottom of Utah valley).
   e. Third lake substage: gravel, sand, clay; major still stand at highest level, level, 4,800 ft, marked by large deltas and other shore features (Gilbert's Provo shoreline).
   f. Local disconformity, alluvium, volcanic ash, and (or) weak soil profile, demonstrating lake recession to at least 4,700 ft.
   g. Fourth lake substage: gravel, sand, and clay to about 4,760 ft; final recession to below 4,500 ft.
3. Deposits of three low post-Bonneville lakes, with intervening alluvium, weak soils, and (or) disconformities suggesting practically complete desiccation following fourth substage of Lake Bonneville and between each low-lake substage.

This record reveals that Lake Bonneville had four high cycles with partial recession between the first two and between the second and third.

Blackwelder, Eliot

1931. Pleistocene lakes of Basin Range province [abs.]: Geol. Soc. America Bull., v. 42, no. 1, p. 313.

Where shorelines are evident, such as those of Greater Mono Lake and Lake Bonneville, the lake probably is late Pleistocene (Wisconsin, perhaps). Early Pleistocene lakes (as in the Las Vegas area, for example) are known only by deposits and in some areas are difficult to distinguish from lakes of Miocene and Pliocene age.

1933. Lake Manly, an extinct lake of Death Valley: Geog. Review, v. 23, no. 3, p. 464–471.

Pleistocene Lake Manly in Death Valley reached a maximum elevation of 310 ft, and at least 12 recognizable terraces were cut. Scanty tufa deposits occur locally. Lake deposits include marl, limestone, and pale-olive-gray silt. At maximum size, the lake was 90 miles long, 11 miles wide, and 585 ft. deep.

Blackwelder, Eliot

1936. Pleistocene Lake Tecopa [abs.]: Geol. Soc. America Proc. (1935), p. 333.

In pre-Wisconsin Pleistocene time, a lake occupied part of the Amargosa River valley east of Death Valley.

1939. Pleistocene mammoths in Utah and vicinity: Am. Jour. Sci., v. 237, no. 12, p. 890–894.

Proboscidian fossils found in Utah and nearby parts of Idaho are listed, but no age conclusions are drawn. A suggestion is made, however, that *Elephas columbi* and *E. imperator* lived in the Bonneville Basin in Provo and post-Provo to near-Recent times. Early-Recent climates were mild and semiarid, perhaps during Antevs' 5500–2000 B.C. Altithermal.

1936. (and Ellsworth, E. W.). Pleistocene lakes of the Afton Basin, California: Am. Jour. Sci., 5th ser., v. 31, no. 186, p. 453–463.

The Afton Basin in the Mojave Desert successively records three lakes in an eastward extension of Manix basin along the Mojave River: (1) An undrained lake (=Tahoe?) in mid-Pleistocene time; (2) a lake (=Tioga?) which was refilled after desiccation and which was drained as its outlet was eroded; (3) a Recent lake, whose outlet was temporarily plugged; the origin and direct evidence of the plug, however, could not be found. Shorelines are evident.

Bode, F. D.

1937. Geology of Lake Mojave outlet channel, *in* The archeology of Pleistocene Lake Mojave, a symposium: Los Angeles, Southwest Mus. Paper 11, p. 108–118.

This paper shows how occurrences of stone artifacts found in the Mojave River valley south of Death Valley, Calif., give evidence of human life on ancient shorelines of Pleistocene Lake Mojave, illustrates types of flint chips that are interpreted as artifacts, and discusses the age, outlet channel, and shore features of the lake.

Bowen, O. E., Jr.

1954. Geology and mineral deposits of the Barstow quadrangle, San Bernardino County, Calif.: California Div. Mines Bull. 165, p. 1–185.

Kramer Hills Lake Beds of Miocene(?) age, whose total thickness is nearly 2,700 ft, include about 740 ft of lacustrine clays, thin-bedded carbonates, magnesite, opaline shales, and jasperoid shales. Folded lake beds of thin-bedded shales and limestones crop out in several places north of Barstow.

Pleistocene deposits cover considerable area in Mojave River valley and include thin-bedded opaline shales, carbonate rocks and tuffaceous(?) sands (*all* of lacustrine origin), and playa deposits of limy clays that commonly contain salines and alkalies; these deposits intertongue with flood-plain clays, silts, sands, and fanglomerate. Maximum thickness is probably less than 1,000 ft, of which lake beds make up an unknown part.

Bradley, W. H.

1926a. Shore phases of the Green River formation in northern Sweetwater county, Wyo.: U.S. Geol. Survey Prof. Paper 140–D, p. 121–131.

Where shorelines are not marked, they "should probably be placed where cross-bedding in the sandstone lenses becomes greatly reduced in scale * * *. Where the sandstone assumes a lacustrine aspect the lime content increases materially."

Criteria suggesting near-shore environment of deposition include (1) calcareous algal reefs, (2) oolites, (3) pisolites, (4) ostracode-bearing limestones, and (5) mingling of bones of aquatic and terrestrial vertebrates. Value of wood as an indicator of shorelines is doubtful. Other evidences of near-shore deposition are abundant larval cases of insects, beds 1–3 ft thick consisting almost exclusively of ostracode tests, carbonized plant remains, and broken algal-reef material suggesting wave action.

1929a. The varves and climate of the Green River epoch: U.S. Geol. Survey Prof Paper 158–E, p. 87–110.

Green River Formation is of middle Eocene age, averages 2,000 ft in thickness, and underlies 25,000 sq mi in Colorado, Utah, and Wyoming. Varves occur in marlstone, oil shale, and fine-grained sandstone. The predominant type consists of a pair of laminae, one richer in organic matter than the other. Varves range in thickness from 0.014 mm in richest oil shale to 9.8 mm in fine sandstone. Weighted average thickness is about 0.18 mm.

More or less continuous sedimentation is assumed. The peak of carbonate production occurred early in summer, and the peak of plankton occurred later in summer; organic material settled more slowly. Preservation of varves implies thermal stratification and maximum depth of water 75 to 100 ft where varves accumulated.

Three sedimentary cycles of greater length than varve cycles are found: 12-yr cycle, correlated with the cycle of sunspot members; 50-yr cycle, correlation not known; and 21,000-yr cycle, correlated with the precession of the equinoxes.

Varves indicate that the Green River epoch lasted 5 million to 8 million years. Duration of the Eocene (Wasatch, Bridger, and Uinta time plus Green River) was 13 million to 33 million years, the average estimate being about 23 million. These estimates agree more or less with estimates based on radioactivity.

1929b. Algae reefs and oolites of the Green River formation: U.S. Geol. Survey Prof. Paper 154–G, p. 203–223.

Algal reefs are restricted (p. 203 and pl. 31) to shore phases of the formation and to basal member of formation elsewhere. Nowhere are reefs associated with even moderately rich oil shale. Thick reefs required relatively stable conditions of water level, circulation, and sedimentation for their growth and suggest that lakes had outlets during, at least, parts of their existence. The Green River reefs were lenticular and were formed largely by deposition of lime by *Chlorellopsis coloniata* Reis. Field occurrences, hand specimens, and microscopic structures of reefs are described and illustrated.

Oolites are considered largely or entirely inorganic in origin, resulting from a balance of favorable water chemistry and some agitation. Nuclei are scarce. Growth is related to, and considered limited by, the availability of ferric hydroxide, which is concentrated in the oolites at the expense of the matrix in which oolites occur.

1930. The occurrence and origin of analcite and meerschaum beds in the Green River formation of Utah, Colorado, and Wyoming: U.S. Geol. Survey Prof. Paper 158–A [1929], p. 1–7.

Thin beds of analcite crystals occur at five or more horizons in the Green River Formation (Eocene) in association with minor amounts of apophyllite. Analcite also is disseminated in many oil-shale beds.

Field and microscopic evidence are interpreted to mean that analcite and apophyllite crystals formed "in place on the lake bottom as a result of interactions between salts dissolved in the lake water and the dissolution products of volcanic ash that fell into the lake."

Meerschaum (fibrous sepiolite) occurs in several thin beds near top of formation in Duchesne County, Utah, and was probably formed in place.

1931. Origin and microfossils of the oil shale of the Green River formation of Colorado and Utah: U.S. Geol. Survey Prof. Paper 168, 58 p.

Of the literature on lacustrine sediments, this report, in conjunction with two other reports by Bradley (1926a and 1929b), is probably the most definitive. The Green River Formation was studied as a unit. Although the significance of its distribution is discussed, the detailed treatment of microstructures, bedding-surface features, lamination, and microfossils is more useful to the student of lake deposits. Accumulation of paper shale whose laminae are as thin as 1 mm requires very quiet water. In places the paper shale is 20–70 ft thick. The requirement for an environment of deposition free from organisms that would destroy bedding is not discussed, although Bradley (1948) pointed out this requirement in a later paper.

Transition from one type of deposition to another (as from oil shale to dense varved "marlstone") is probably caused by fluctuations in source materials or changes in conditions of deposition. A sedimentary cycle correlated with the 21,000-year precession cycle of the equinox is postulated, and the probable relation of lenticular and irregular bedding to low lake stages is suggested.

Detailed consideration is given to minor features such as laminae, contorted beds, shale breccias (intraformational conglomerates), and mud cracks.

Saline minerals, largely concentrated in the upper part of the formation, suggest a change toward greater aridity in later Green River time and a tendency toward playa environment. The nature of the salts is described and the puzzle of "molds of an unknown salt of bladed habit" is discussed.

Much attention is given to the microflora, which consists of bacteria, fungi, algae, the spores of mosses and ferns, and a few seeds and pollen grains of higher orders of plants. The presence of abundant remains of fungi is taken to mean periodic exposure of organic oozes to the air. The dominant blue-green algae imply warmth and prevalence of foul, stagnant waters. No diatoms are recorded, perhaps because lakes were too saline or possibly because fresh-water diatoms did not exist in Eocene time.

The extremely abundant remains of large larvae of flies and habits of related modern species seem to imply prevalance of shallow-lake waters.

The hydrocarbons of the oil shales probably were derived from the abundant microflora and microfauna.

1933. Factors that determine the curvature of mud-cracked layers: Am. Jour. Sci., 5th ser., v. 26, no. 151, p. 55–71.

Regardless of the salinity of the water, the surfaces of mud-cracked layers of vertically nonuniform texture are concave toward the finer grained side.

1948. Limnology and the Eocene lakes of the Rocky Mountain region: Geol. Soc. America Bull., v. 59, no. 7, p. 635–648.

The Rocky Mountain area at end of Cretaceous time is visualized as a region having basin floors several hundred, perhaps 1,000 ft above sea level. The basins originated mainly by intermittent downwarp. Lake Uinta occupied a basin

south of the Uinta Mountains in Utah and adjacent parts of Colorado; Gosiute Lake occupied the largest basin in west-central Wyoming, and an unnamed lake occupied a small basin in extreme western Wyoming.

Preservation of organic matter (as in oil shales) in the deposits of Gosiute Lake implies that the lake water was chemically stratified and that organic debris accumulated in a "saline hypolimnion that persisted for thousands of years" (p. 644). As oil shale also occurs without saline minerals, thermal stratification probably prevailed at some of the higher lake stages. Even wing-scales of mosquitoes are preserved. Nonglacial varves are restricted to the hypolimnion, which is devoid of oxygen and bottom fauna; consequently, scavengers do not disturb the delicate lamine after deposition and before consolidation.

Bradley, W. W.

1925. Magnesite in California: California Div. Mines Bull. 79, p. 47–50; 72–75.

Bedded magnesite of Tertiary age and probably of lacustrine origin occurs with clay, clayshale, and massive ledges of limestone three-quarters of a mile northeast of Bissell station in the Mojave Desert.

Bretz, J. H.

1956. (and Smith, H. T. U., and Neff, G. E.). Channeled scabland of Washington, new data and interpretations: Geol. Soc. America Bull., v. 67, no. 8, p. 957–1049.

The authors review and revise Bretz' longstanding interpretation of the origin of scabland features, placing emphasis on constructional land forms disclosed by aerial photographs and by numerous excavations for irrigation works. Of major present interest, however, is a map showing the maximum extent of Pleistocene Lakes Lewis and Missoula.

Broecker, W. S.

1958. (and Orr, P. C.). Radiocarbon chronologies of Lake Lahontan and Lake Bonneville: Geol. Soc. America Bull., v. 69, no. 8, p. 1009–1032.

Radiocarbon measurements show that modern tufas contain an equilibrium amount of radiocarbon; hence, age determinations on fossil tufas should be reliable.

Methods for evaluating reliability of radiocarbon measurements of fresh-water carbonates (tufas) are suggested. Errors resulting from exchange or from low initial C^{14} concentrations are not greater than 10 percent.

A series of samples from Lake Lahontan and Lake Bonneville suggests that low water levels characterized the period 34,000–25,000 yr ago and that high water levels characterized the period 25,000–14,000 yr ago; it also suggests that the water level declined between 14,000 and 13,000 yr ago, rose to a maximum height about 11,700 yr ago, and then declined rapidly.

Brown, J. S.

1923. The Salton Sea region, California, a geographic, geologic and hydrologic reconnaissance with a guide to desert watering places: U.S. Geol. Survey Water-Supply Paper 497, 292 p.

The history of Pleistocene and Recent Lake Cahuilla is given (p. 58–59) and shorelines and lakes deposits including tufa are described (p. 47–48).

Brown, R. W.

1957. Nonalgal megascopic marine plants, *in* Treatise on marine ecology and paleoecology, volume 2 of Paleoecology: Geol. Soc. America Mem. 67, p. 729–730.

Because fossil terrestrial plants commonly are found in marine strata, the remains of terrestrial plants do not necessarily imply nonmarine deposition.

Brown, W. H.

1939. Tucson Mountains, an Arizona basin range type: Geol. Soc. America Bull., v. 50, no. 5, p. 697–760.

Tertiary(?) lake beds are exposed in local areas in the Tucson Mountains west of Tucson, Ariz.

Bryan, Kirk

1938. Geology and ground-water conditions of the Rio Grande depression in Colorado and New Mexico, *in* The Rio Grande Joint Investigations (Regional Planning, pt. 6): Natl. Res. Comm., v. 1, pt. 2, p. 197–225.

Author describes the Santa Fe Formation of Pliocene age and implies that it is partly lacustrine (p. 207), stating that closed basins "have a central or axial lake or playa * * *" and that "* * * the Santa Fe Formation was deposited in both drained and undrained basins."

Bucher, W. H.

1919. On ripples and related sedimentary surface forms and their paleogeographic interpretation: Am. Jour. Sci., 4th ser., v. 47, p. 241–269.

"Ripples cannot * * * be used to distinguish marine and lacustrine sediments," because oscillation ripple marks form on sea bottoms in places where no currents occur. Where tides are small (p. 243), as in the Baltic, Black, Mediterranean, and Caribbean Seas, currents are negligible.

"A sediment like the Berea sandstone, which consists largely of fine-grained, almost pure quartz sand, abounds in oscillation-ripples without a trace of current ripples, may therefore have originated either in a lake or in a sea free from tidal currents."

Buwalda, J. P.

1914. Pleistocene beds at Manix in the eastern Mohave Desert region: California Univ., Dept. Geol. Sci. Bull., v. 7, p. 443–464.

Manix strata underlie an area of 200–300 sq mi and are best exposed in the valley of the Mojave River about 2 miles southeast of Manix station. They consist of about 75 ft of sandy clay and argillaceous fine sand, both grayish green, and contain a few veins of gypsum but no other evaporites. Evenness, persistence, and parallelism of individual beds is the most striking feature. The fact that the beds of fine-grained sediment are separated by several feet of coarser material suggests temporary recession of lake waters.

"Besides the evidence afforded by the remarkably even and persistent bedding, the fine texture, and the green deoxidized condition of the sediments, further proof of the lacustrine origin of the Manix Beds lies in the abundance at more than one horizon of fresh-water organisms (p. 449)."

1954. Geology of the Tehachapi Mountains, California: California Div. Mines Bull. 170, chap. 2, no. 9, p. 131–142.

The Kinnick Formation (Miocene) underlies 25 sq mi north of Monolith and is more than 1,500 ft thick. Most of the formation consists of volcanic materials, but the upper few hundred feet consist of gray sandy clay interbedded

with fresh-water diatomite and gray and yellow chert. These strata, their fine grain size, and the presence of fossil leaves suggest playa deposition. The Bopesta Formation, also of Miocene age, is at least 3,500 ft thick and widely exposed northeast of Monolith. An unstated thickness within the Bopesta is inferred to be lacustrine in origin, although the greater part was deposited as coalescing alluvial fans adjacent to country having high relief.

Along the southeast base of the Tehachapi Mountains, "Pliocene fresh-water lake beds, mainly siltstone, clay and marl," are exposed along about 8 miles of the foothills and have a maximum thickness of about 5,000 ft. These strata are not named, but it is indicated that in Pliocene time a fresh-water lake occupied the area now partly included in Antelope Valley.

Caplan, Allan

1935. The Miocene lake of Creede, Colo.: Rocks and Minerals, v. 10, no. 10, p. 152–154.

A popular decription is presented of the lacustrine Creede Formation at an elevation of 9,000 ft and its Miocene plants and insects. These sediments were deposited in a lake that was at least 2 by 20 miles. No evidence of lacustrine origin is cited.

Clark, W. O.

1920. (and Riddell, C. W.). Exploratory drilling for water and use of ground water for irrigation in Steptoe Valley, Nev.: U.S. Geol. Survey Water-Supply Paper 467, 70 p.

Pleistocene shore features and drainage in the valley north of Ely, Nev., are described briefly. One test hole penetrated 915 ft of clay and fine sand inferred to be lacustrine and of Pliocene or early Pleistocene age. A small-scale map shows the Pleistocene lakes of Nevada known as of 1918.

Clements, T. D.

1951. (and Clements, Lydia). Evidence of Pleistocene man in Death Valley, Calif. [abs.]: Geol. Soc. America Bull., v. 62, no. 12, pt. 2, p. 1498–1499.

For a long time the level of a Pleistocene lake in Death Valley was 300–400 ft below highest level reached, and the shores were inhabited by man. This lower stage is tentatively correlated with the Provo stage of Lake Bonneville.

Coates, D. R.

1952. Gila Bend basin, Maricopa County, *in* Halpenny, L. C., and others, Ground water in the Gila River Basin and adjacent areas, Arizona—a summary: U.S. Geol. Survey open-file report (duplicated), p. 171–176.

In the Gila Bend basin much of the older fill of undetermined age was deposited when basin had no outlet. In the western part, the older fill consists of "800 ft of lake-bed clays" and is overlain by about 300 ft of nonlacustrine sand and gravel. No lake clays are known in the eastern part of Gila Bend area.

Colton, R. B.

1961. (and Lemke, R. W., and Lindvall, R. M.). Glacial map of Montana east of the Rocky Mountains: U.S. Geol. Survey Misc. Geol. Inv. Map I–327.

Several large and small Pleistocene lake areas are shown in Montana east of the Rocky Mountains. Elevations of maximum shorelines are given, and names are suggested for the major lakes.

713–182—64——4

Craig, L. C.

1955. (and others). Stratigraphy of the Morrison and related formations, Colorado Plateau region, a preliminary report: U.S. Geol. Survey Bull. 1009–E, p. 125–168.

The Brushy Basin member of the Morrison Formation (Jurassic) is considered to be fluvial and lacustrine in origin and is as much as 600 ft thick. Lower Cretaceous rocks overlying Morrison are also in part lacustrine. The strata are composed of variegated claystone, impure bentonitic clay, and lenses of conglomeratic sandstone. Thin discontinuous limestone beds occur sparsely. Fresh-water snails and algae are sparse, but dinosaur bones and wood are common. Sandstone structures and textures indicate fluviatile deposition; limestone and clay are stated to be probably lacustrine, but no direct evidence is given.

Crawford, A. L.

1949. Gilsonite and related hydrocarbons of the Uinta Basin, Utah, *in* Hansen, G. H., and Bell, M. M., The oil and gas possibilities of Utah: Salt Lake City, Utah Geol. and Mineralog. Survey p. 235–260.

Author discusses occurrences, chemistry, uses, and possible origins of solid hydrocarbons in and related to the Paleocene and Eocene formations in the Uinta Basin, many of which are lacustrine. A useful bibliography is included.

Crowell, J. C.

1950. Geology of the Hungry Valley area, southern California: Am. Assoc. Petroleum Geologists Bull., v. 34, no. 8, p. 1623–1646.

The Peace Valley beds of Crowell are about 4,000 ft thick in an area 55 miles northwest of Los Angeles. A formational name was not proposed, as no base to the sequence was discovered. Thin-bedded greenish siltstone and fine sandstone carrying fresh-water mollusks and ostracodes suggest that a fresh-water lake existed during deposition of parts of the Peace Valley beds. The deposits are considered to be of middle Pliocene age on the basis of plant fossils found in the strata in a nearby area and because they conformably underlie the Hungry Valley Formation which carries fossil vertebrates of upper Pliocene age.

Crowley, A. J.

1939. Possible criterion for distinguishing marine and nonmarine sediments: Am. Assoc. Petroleum Geologists Bull., v. 23, no. 11, p. 1716–1720.

Study of more than 100 separations each of marine and nonmarine sediments suggests that secondary-growth potash feldspars are restricted to marine sediments; no fresh secondary-growth potash feldspars were found in nonmarine sediments. In marine sediments, the accretions occur as (1) cement in aggregates of grains of feldspars and quartz, (2) as euhedral crystals, and (3) as secondary growths on clastic feldspar grains. Potash feldspar where seen in nonmarine sediments, was clearly water worn or weathered and never fresh.

Dane, C. H.

1954. Stratigraphic and facies relationships of upper part of Green River formation and lower part of Unita formation in Duchesne, Uintah, and Wasatch Counties, Utah: Am. Assoc. Petroleum Geologists Bull., v. 28, no. 3, p. 405–425.

Strata of lacustrine, playa, and mud-flat origin in an area centered near Indian Canyon, Utah, are now believed to be basal Uinta Formation (Eocene) rather than a saline facies of the Green River Formation (Eocene), as had been believed earlier. Reinterpretation is based on tracing of persistent time-equivalent beds of tuff and on examination of facies changes. The strata appear to be fluviatile

near the Colorado-Utah border and grade westward to a lacustrine-playa-mud flat facies (p. 405) ; lacustrine deposition is suggested by the abundance of limestone, marl, and marly shale, which are analogous to the types of rocks found in the Green River.

Darton, N. H.

1901. Preliminary description of the geology and water resources of the southern half of the Black Hills and adjoining regions in South Dakota and Wyoming: U.S. Geol. Survey 21st Ann. Rept., pt. 4, p. 489–599.

"No one who has observed extensive exposures of the finer grained White River sediments [Oligocene] would regard them as other than lake deposits" (p. 558). Criteria of lake-bed deposition are (p. 559) very fine grained sediments "usually spread out in thin beds with perfectly even stratification, in which precisely the same sequence of beds may be traced for miles," the presence of chemical deposits, and—where still detectable—shorelines. Stream-channel deposits completely enclosed by fine-grained materials also occur within lacustrine sequences.

Davis, G. H.

1957. (and Poland, J. F.). Ground-water conditions in the Mendota-Huron area, Fresno and Kings Counties, California: U.S. Geol. Survey Water-Supply Paper 1360-G, p. 409–588.

Diatomaceous lake-deposited clay of Pliocene age, the "blue clay" of common usage in the area, occurs in subsurface of Central Valley. It ranges from 20 to 120 ft in thickness and separates ground waters of markedly different chemical character. Some of the strata below the clay—in the Tulare Formation of Pliocene and Pleistocene(?) age and in the upper part of the underlying San Joaquin Formation of Pliocene age—are also of lacustrine origin (p. 420–426). Diatom assemblages have been identified as lacustrine.

1959. (and Green, J. H., Olmsted, F. H., and Brown, D. W.), Ground-water conditions and storage capacity in the San Joaquin Valley, California: U.S. Geol. Survey Water-Supply Paper 1469, 287 p.

Much of the southern part of the Central Valley of California is underlain by 10–160 ft of diatomaceous clay. Identified locally in outcrop and mostly in logs of wells, the clay has a known length of 200 miles and widths ranging from 10 to 40 miles. The lake in which it formed was presumably somewhat wider. The northern boundary of the deposit is not known, as well data from the delta area of the Sacramento River are scarce.

Referred to as the Corcoran Clay Member of the Tulare Formation, the clay is of late Pliocene age, dark greenish gray, silty, and notably free from sand. The diatom flora indicates deposition in a dominantly fresh-water lake. Of the 113 species and varieties identified from the Corcoran, 37 also occur in a 12-foot bed of diatomaceous clay at the base of the Tulare Formation in exposures in the Kettleman Hills. The flora is not listed.

Davis, W. M.

1900. The fresh-water Tertiary formations of the Rocky Mountain region: Am. Acad. Arts and Sci. Proc., v. 35, p. 345–373.

This report gives one of the earlier discussions stating that the Tertiary sediments west of the Mississippi and east of the Rockies are largely of fluviatile origin. Previously King, Hayden, Newberry, and others had postulated a lacustrine origin.

Facies changes from the shore toward the center of the basin are important criteria for identification of lake deposits. "Coarse and variable sediments" are excluded from the lake facies. Tree stumps standing in place are evidence of subaerial deposition, as are crossbedded strata, conglomerates, and disarticulated vertebrate remains.

Vermilion Cliff Group (Utah) and Denver and Arapahoe Formations (Colorado) are examples of fluviatile strata erroneously regarded as having been deposited in lakes. European and Asiatic analogies in modern fluviatile plains are given.

Degens, E. T.

1957. (and Williams, E. G., and Keith, M. L.). Environmental studies of Carboniferous sediments, pt. 1—Geochemical criteria for differentiating marine from fresh-water shales: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 11, p. 2427–2455.

Occurrence of characteristic fossils and gross lithologic aspect remain principal methods of environmental interpretation; however, work with cyclothems in coal-bearing sequences of Pennsylvanian age indicates chemical distinctions that may be useful.

Boron and rubidium are more abundant in marine than in fresh-water shales; nickel and vanadium are concentrated in organic fractions of marine shales; but lead, zinc, copper, and tin are concentrated in organic fractions of fresh-water shales.

These characteristics are of interest in defining the chemical characteristics of environments of deposition and might be applicable to identification of lake deposits where shales are nonfossiliferous.

1958. (and Williams, E. G., and Keith, M. L.). Environmental studies of Carboniferous sediments, pt. 2—Application of geochemical criteria: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 5, p. 981–997.

Fossils indicate alternation of fresh-water and marine sequences of Pennsylvanian age in western Pennsylvania. Spectrographic determinations of trace elements were made in the clay fraction of carbonate rocks and of sandstones from both sequences. Gallium was consistently more abundant in fresh-water sediments; rubidium was not found to be useful for determining environments; boron was significantly more abundant in rocks of marine origin; illite was more abundant than kaolinite in most, but not all fresh-water limestones. Spectrochemical data plotted on trilinear diagrams show overlap of marine and fresh-water sediments but make clear separation in 80 percent of samples tested. Relations hold for shales and clay fractions of limestones (fig. 3), for sandstones and shales (fig. 4), and for underclays (fig. 5).

These methods might be applied to identification of environments of deposition of limestones in the absence of fossils.

Dibblee, T. W., Jr.

1952. Geology of the Saltdale quadrangle, California: California Div. Mines Bull. 160, p. 7–43.

The Ricardo Formation of Pliocene(?) age has a maximum thickness of 7,000 ft. Lacustrine members consist of thin bedded calcareous sandstone, silicified mud and ash, and impure limestone and opaline chert. Members 4 and 5 contain lake deposits; member 7 is entirely lacustrine. Lake deposits in the Ricardo aggregate 2,200 ft in thickness where measured in the northwestern Mojave Desert.

In Pleistocene time, the basin of Koehn Lake contained a permanent body of water below the 2,000 ft contour. A prominent sandbar existed at the northeast margin.

1954. Geology of the Imperial Valley region, California: California Div. Mines Bull. 170, chap. 2, no. 2, p. 21–28.

In the western Fish Creek Mountains, the Fish Creek Gypsum of Miocene age is as much as 100 ft thick, white, and bedded. It consists of gypsum and anhydrite and is described as a playa deposit. In northwestern Imperial Valley, the Borrego Formation of Pliocene age has a maximum thickness of 6,000 ft and is considered by Dibblee to be lacustrine facies of the terrestrial Palm Springs Formation. The Borrego consists of gray claystone and interbedded sandstone. The claystone contains a lacustrine fauna of mollusks, ostracodes, and rare Foraminifera. In the same area, the Brawley Formation (Pleistocene) is lithologically and faunally similar to the Borrego. Dibblee considers the Brawley to be lacustrine and the continental equivalent of the Ocotillo Conglomerate. The Brawley has a maximum thickness of 2,000 ft. In northwestern Imperial Valley and in northeastern Coachella Valley, the strata formed in Pleistocene Lake Coahuila overlie the older materials in many places and have a maximum thickness of 300 ft.

1958. Tertiary stratigraphic units of western Mojave Desert, Calif.: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 1, p. 135–144.

Dibblee proposes the term Tropico Group to include several thick and scattered sedimentary and igneous formations of Miocene(?) and Pliocene age in areas near Rosamond, Mojave, and Boron. The proposed group would include Gem Hill Formation, Fiss Fanglomerate, Bissell Formation, Saddleback Basalt, and Red Buttes Quartz Basalt. Near Mojave are 1,055 ft of conglomerate, sandstone, and clay of the Horned Toad Formation of middle or early Pliocene age.

The Bissell Formation is 845 ft thick and consists of sandstone, conglomerate, siltstone, and clay shale interbedded with magnesite, limestone, dolomite, chert, siliceous shale, and clay shale. It may be in part a lacustrine facies of the Fiss Fanglomerate. Horned Toad Formation, not included in Tropico Group, is a sequence of stream-laid and lacustrine sediments, the carbonate rocks signifying lacustrine deposition.

1960. Geologic map of the Hawes quadrangle, San Bernadino County, California: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–226.

The Tropico Group (Miocene? to Pliocene?) is exposed in the Kramer Hills and is at least 2,800 ft thick. Part of the section consists of basalt, the remainder of fluviatile and lacustrine sedimentary rocks. Included are clay shale, sandstone, chert, limestone, and dolomite suggestive of lacustrine deposition.

In the area, light greenish-gray clay and interbedded white calcareous marl of probable Pleistocene age underlie areas in the southeastern part of the quadrangle. A lake or playa origin is inferred. These deposits have a maximum thickness of 100 ft.

Diller, J. S.

1908. Strata containing the Jurassic flora of Oregon: Geol. Soc. America Bull., v. 19, p. 367–402.

Occurrences are cited from Oregon and California in which numerous plant fossils were found in association with typical marine invertebrate forms.

Dorr, J. A., Jr.

1958. Early Cenozoic vertebrate paleontology, sedimentation, and orogeny in central western Wyoming: Geol. Soc. America Bull., v. 69, no. 10, p. 1217–1244.

The Hoback Formation is reviewed and its origin assigned to fluviatile, paludal, and lacustrine environments in the rapidly subsiding orogenic trough during part of Paleocene and during early Eocene time. The total thickness of the formation is about 15,000 ft. Map shows area of Hoback outcrops. Partial lacustrine deposition is inferred from the presence of pyritic limestone containing fossil mollusks and fishes.

Durrell, Cordell

1953. Geological investigations of strontium deposits in southern California: California Div. Mines Spec. Rept. 32, 48 p.

Strontianite or celestite replace Tertiary sediments, some or all of which are lacustrine in origin, at five Mojave Desert localities. Mechanisms of replacement and hydrothermal or connate-water source of strontium minerals are discussed. The enclosing and partly replaced strata are characteristic of arid-region lake deposits, such as halite, gypsum, and salt-impregnated clastic sediments or thin-bedded tuff, sand, silt and clay, and algal or nonalgal limestone. All deposits are inferred to be, or to include closed-basin lake deposits of Tertiary to Recent age.

Eardley, A. J.

1938. Sediments of Great Salt Lake, Utah: Am. Assoc. Petroleum Geologists Bull., v. 22, no. 10, p. 1305–1411.

Desiccation of sediments deposited in the Great Salt Lake reduces their volume by about 1:300. There has been an accumulation of dissolved solids content derived from the rivers since outflow from the lake basin ceased. "For some time past, carbonate deposition has been the outstanding chemical process" (p. 1322). The rate of deposition of $CaCO_3$ by the lake was calculated to be 14.4 billion lb per year, or 0.038 lb per year per sq ft of lake surface (p. 1329).

Clay is the most widely distributed sediment on the floor of the Great Salt Lake. In August 1933 the floor of the western half of the lake was composed of clay where the water was more than 12 ft deep and of sandy clay loam and clay where the water was less than 12 ft deep (p. 1334). The color of the clay ranges from black to light tan but gray is predominant. Plasticity is retained even where clay is buried under hundreds of feet of sediment.

Oolites are formed near the shores, especially those facing the open lake. Oolites extend lakeward to water depths of 3–12 ft and are invariably associated with well-formed ripple marks. Algal bioherms are confined to shallow-water and shore areas, mostly in the western part of the lake, and are estimated to have an areal extent of 100 sq mi.

1957. (and Gvosdetsky, Vasyl, and Marsell, R. E.). Hydrology of Lake Bonneville and sediments and soils of its basin [Utah]: Geol. Soc. America Bull., v. 68, no. 9, p. 1141–1201.

Man-made cuts through lake sediments in the Basin and Range province have revealed a much more complicated history of lake levels than was apparent to Gilbert (1890) from his study of natural exposures and shorelines. The spread of lake waters over thresholds into subsidiary basins probably accounts

for stillstands of lake level long enough to permit development of major shorelines. An estimated 39 billion tons of salts has been removed from the basin in the last 25,000 yr (20 billion in the past 8,000 yr) by wind action.

Soil development before and during Lake Bonneville time is described in detail, and the value of soil science as an important tool in the study of Pleistocene lake histories is emphasized.

Authors interpret the data as follows: Alpine (first high-level lake) as Kansan in age; Bonneville-Provo I as Tazewell-Iowan; unnamed low stage as equivalent to Brady; Provo II stage as Cary; subsequent low stages as Two Creeks; Standsbury as equivalent to Mankato; and "Gilbert," the last major stillstand of Lake Bonneville, as a stage that occurred 10,000 to 8,000 yr ago (either a minor pluvial maximum or a halt in desiccation of the lake).

1952. (and Stringham, B. F.). Selenite crystals in the clays of Great Salt Lake: Jour. Sed. Petrology, v. 22, no. 4, p. 234–238.

Selenite crystals 2–6 inches long occur in "soft sodium clays of the lake bottom" at a few places only. Crystals are in clusters or pockets a few to 18 inches below the lake floor. The larger crystals are oriented vertically; the smaller (often twinned or intergrown), occur near top of clay and are randomly oriented.

Eaton, J. E.

1939. Ridge Basin, California: Am. Assoc. Petroleum Geologists Bull., v. 23, no. 4, p. 517–558.

An area about 10 by 20 miles in extent, lying between Castaic and Gorman in southern California, may contain the thickest section of lacustrine beds in the world. The site of deposition is a fault trough bounded on the northeast by the San Andreas rift and on the southwest by the San Gabriel fault.

The remaining rocks include a marine sequence of Miocene age, over which was deposited 18,000 ft of nonmarine strata in Pliocene time, the upper 13,000 ft of which are lacustrine. In addition, about 3,000 ft of Lower(?) Pleistocene lake beds were deposited.

The San Gabriel fault apparently formed the southwest margin of the basin throughout the period of accumulation of the 23,000 ft of nonmarine sediments in Pliocene and Pleistocene time. Adjacent to the fault throughout the section is characteristically a "shapeless mass of cobbles and boulders * * * as if the material had fallen * * * where it now lies. * * * Less than one mile from the San Gabriel fault most of the post-Miocene part grades to lacustrine shale having the monotonously even perfect, and persistent bedding characteristic of such still-water deposits."

Pliocene and Pleistocene fresh-water forms consisting of ostracodes and, less commonly, of mollusks are abundant throughout the section. The Pleistocene rocks are coarser in texture and suggest a shallowing of lake waters after Pliocene time.

Faust, G. T.

1948. (and Callaghan, Eugene). Mineralogy and petrology of the Currant Creek magnesite deposits and associated rocks of Nevada: Geol. Soc. America Bull., v. 49, no. 1, p. 11–74.

Deposits of magnesite occur as alteration products in the Currant Tuff, a lake-deposited and lake-reworked tuff having interbeds of tuffaceous fresh-water limestone. Fragments of snails and ostracodes also occur in many beds. Area

of outcrop is 30–40 miles southwest of Ely on U.S. Highway 6. The age of the tuff is Miocene or Pliocene. Sedimentary structural features in parts of the sequence, the limestone, and the contained fossils, which include diatoms, suggest a fresh-water lake environment.

Fenton, C. L.

1957. (and Fenton, M. A.). Paleoecology of the Precambrian of northwestern North America, *in* Treatise on marine ecology and paleoecology, volume 2 of Paleoecology: Geol. Soc. America Mem. 67, p. 103–116.

The Snowy Range Series, considered by the authors to be of late Precambrian age, is 24,000 ft thick. Phyllites 450 and 500+ ft thick are interpreted to be varved deposits of glacial lakes (p. 105), but no specific criteria are listed. Metaquartzites in the series contain mudballs which may imply either lacustrine or marine-littoral origin.

Ferguson, H. G.

1924. Geology and ore deposits of the Manhattan district, Nevada: U.S. Geol. Survey Bull. 723, 162 p.

Beds of conglomerate, sandstone, and shale about 500 ft thick lie about 700 ft below top of the Esmeralda Formation (Miocene) in central Nevada. Termed the Bald Mountain Lake Beds Member of the Esmeralda Formation, these beds overlie the Diamond King Member and underlie the quartz latite member. Two deposits of rhyolitic tuff are intercalated with the Bald Mountain Lake Beds. Small grain size, thin regular bedding, fresh-water snails, and the alternations of finer- and coarser-grained sediments suggest lacustrine deposition.

Feth, J. H.

1955. Sedimentary features in the Lake Bonneville group in the East Shore area, near Ogden, Utah, *in* Utah Geol. Soc. Guidebook no. 10, p. 45–69.

Lake beds in basins with adjacent high relief are heterogeneous. Sediments are divided into following categories: (1) Deposits from actively moving water such as stream currents, lake currents, and turbidity currents; (2) deposits, such as the greater part of the "Weber Delta," from still or sluggishly moving water; (3) subaerial deposits, such as mudrock flows, talus, and landslide debris which are all closely related to the lake beds in the area; and (4) chemical precipitates, which are scarce in the area and consist predominantly of wave-formed algal head or algal reef(?) tufa. A lake environment is suggested by thin regular bedding, fine grain, contained fossils (especially the ostracodes), and relations to shore features.

1963. (and Hem, J. D.). Reconnaissance of headwater springs in the Gila River Drainage Basin, Arizona: U.S. Geol. Survey Water-Supply Paper 1619–H, p. H1–H54.

Map shows lake basins of Pliocene and Pleistocene age marginal to the Mogollon Rim. Lake deposits in San Carlos, Verde, Tonto, and Payson basins are described briefly.

Fisher, C. A.

1909. Geology and water resources of the Great Falls region, Montana: U.S. Geol. Survey Water-Supply Paper 221, 89 p.

Two series of late Pleistocene glacial-lake deposits of undetermined thickness occupy river valleys where water was ponded against terminal moraine. Younger sediments yield water of good quality. Glacial history of area suggests that the sediments are of lacustrine origin.

Fox, P. P.

1955. Lower Glacial Lake Missoula sediments in Montana [abs.]: Geol. Soc. America Bull., v. 66, no. 12, p. 1713.

More than 200 ft of previously undescribed strata are added to lakebed sequence. Drilling showed "brown, fat, varved clay having a liquid limit of 42 to 63 percent," with only minor interbeds of silt and sand. Silts and fine sands characteristic of exposed Missoula beds overlie the clay sequence.

Frick, Childs

1921. Extinct vertebrate faunas of the badlands of Bautista Creek and San Timoteo Cañon, Southern California: California Univ. Dept. Geol. Sci. Pub., v. 12, no. 5, p. 277–424.

The Eden beds (Mount Eden Formation of Fraser) consist of two members. The upper member is about 1,500 ft thick and includes an unspecified thickness of fine sands and muds derived from erosion of adjacent granitic and metamorphic highlands and deposited "over what was then a region of shallow brackish lakes and plains." Contained fossils indicate Pliocene age.

The Bautista beds of Frick are 1,500–2,000 ft thick and of Pleistocene age. They are made up in large part of "minutely classified strata of fine lacustrine sands and lustrous clays." These sediments contain vertebrate fossils.

Frink, J. W.

1954. (and Kues, H. A.). Corcoran clay—a Pleistocene lacustrine deposit in San Joaquin Valley, Calif.: Am. Assoc. Petroleum Geologists Bull., v. 38, no. 11, p. 2357–2371.

The Corcoran Clay [Member of Tulare Formation] 50–120 ft thick underlies at least 4,000 sq mi in San Joaquin Valley at a depth of 200–800 ft. Abundant diatoms and a few vertebrate fossils suggest an age between extreme late Pliocene and middle Pleistocene. The diatoms consist mostly of fresh-water lacustrine types. This unit is massive silty dark-greenish-gray clay, which is locally carbonaceous, pyritic, or both.

Gale, H. S.

1914. Salines in the Owens, Searles, and Panamint basins, southeastern California: U.S. Geol. Survey Bull. 580–L, p. 251–323.

Owens, Searles, and Panamint basins are described as a chain of lakes at successively lower elevations that fed down one to another. Overflow from Panamint basin to Death Valley is considered probable (p. 252) but evidence is not conclusive. Paper includes discussions of old lake areas and volumes and mineralogy of Searles Lake deposits.

1946. Geology of the Kramer borate district, Kern County, California: California Jour. Mines and Geology, v. 42, no. 4, p. 325–378.

The Kramer borate deposit is contained in a sequence of playa or lake sediments of late Tertiary age. Three parts are recognized. At the base is the "footwall shale" consisting of 7–50 ft of dark-greenish-gray to nearly black slaty shale, locally including sandstone and conglomerate. Fine-grained cream-colored limestone is found locally, and ulexite and ostracodes are scattered throughout the shales.

Next above the "footwall shale" is the ore-bearing zone, 200–250 ft thick. In addition to the main body of sodium borates, there are peripheral deposits of less soluble calcium borate minerals, and interfingering with the borates and peripheral to all are shaly lake deposits which occupy the remainder of the former lake basin. These "blue shales" of local terminology are soft and dark bluish gray when wet; they include nodules and lumps of carbonate minerals and of the calcium borate minerals ulexite and colemanite. Hardly any of the common desert saline minerals such as chlorides and sulfates are found. The borates were probably deposited from magmatic waters accumulating in the lake basin, because the "footwall shales" conformably overlie volcanic rocks. These relations suggest that the borate-rich lake waters occupied the basin almost as soon as the volcanic flows cooled.

The sodium borate ore body occupies a known area of at least 500 acres. The thickness of nearly pure sodium borate reportedly ranges from 31 to 226 ft and averages about 75 ft. The estimated ore reserves were 92,250,000 short tons, about half of which was assumed to be recoverable.

Overlying the ore-bearing sequence is 30–50 ft of green shale, also of probable lacustrine origin. Ostracodes, algal remains, and fresh-water mollusks have been recovered from the Kramer Lake Beds. The Kramer is considered probably correlative to part of the Ricardo Formation of Pliocene age.

Gardner, D. L.

1940. Geology of the Newberry and Ord Mountains, San Bernardino County, California: California Jour. Mines and Geology, v. 36, no. 3, p. 257–292.

About 640 ft of sand, clay, limestone, and tuffaceous sand displaying thin continuous even bedding crops out along Daggett Ridge in the western part of the Newberry Mountains, south of Daggett, and along the south side of the ridge in Stoddard Valley. Although the outcrops cannot be traced one into the other, it is inferred that the strata are equivalent to each other, at least in part. The assigned age is late Tertiary or Quaternary.

Gay, T. E., Jr.

1959. (and Aune, Q. A.). Geologic reconnaissance of Alturas area, northeastern California [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 1, p. 255–256.

Diatomaceous tuffaceous sediments 1,000 ft thick occur beneath a nearly horizontal volcanic sheet in a broad area in northeastern California. Sediments are lacustrine, range in age from Miocene to Pleistocene, and crop out in the larger present-day lake basins and river valleys.

Gidley, J. W.

1926. Fossil Proboscidea and Edentata of the San Pedro Valley, Ariz.: U.S. Geol. Survey Prof. Paper 140–B, p. 83–95.

Fossils were found in 250-ft thickness of valley fill, part of which was deposited in lakes that desiccated to saline lakes. Valley deposits extend from the Mexican border to near the Gila River. Animals whose bones are preserved are inferred to have been bogged in mud near fresh-water springs adjacent to the saline lakes. Fossils show late Pliocene age. Existence of lakes is suggested by basinal outlines of the region, fine-grained sediments, presence of limestone, and evidence of fresh-water springs peripheral to the lakes.

Gilbert, G. K.

1875. Report on the geology of portions of Nevada, Utah, California, and Arizona: U.S. Geog. Surveys west of the one hundredth meridian, v. 3, chap. 3, The glacial epoch, p. 88–100.

The name Bonneville Beds[1] is applied to all deposits formed in Lake Bonneville from the highest to the present shoreline, including lake beds and beach deposits. The term Bonneville Group is applied to deeper water facies consisting of clay and marl and of fine sand.

1890. Lake Bonneville: U.S. Geol. Survey Mon. 1, 438 p.

There are two outstanding features in this classic discussion of the lake basin. First, is the completeness of treatment, from tectonic events causing a basin to form through the various stages of occupancy—overflow and desiccation—to warping of the lake shorelines as the result of rebound due to unloading of the floor of the basin. Second, is the extensive and complete illustration of shore features and of the lacustrine and fluvial processes that caused them to form. Among the shore features suggesting lake occupancy of a basin are sea cliffs, spits, bars, embankments, terraces, ridges, and deltas. Each is discussed in relation to comparable land forms with which it might be confused. The single best criterion of former lake occupation indicated is horizontality, both with reference to details of the shapes (tops and bases) of individual features and with reference to the suggestion of a broad plane surface that meets the eye of the observor as he reaches the altitude of the highest stand of water in the basin.

It was inferred that lacustrine deposition occurred in the region at least three times prior to occupancy by Lake Bonneville; the earliest lake deposits were referred to the Eocene. The older history, however, is retained only in scattered patches of lake sediments and was merely mentioned in passing. The history of Lake Bonneville was divided into three principal events as follows: Flooding of the basin and deposition of the Yellow Clay; desiccation and deposition of coarser alluvial materials; and reflooding accompanied by deposition of the White Marl. It was during the latter flood that the waters rose to the Bonneville shoreline, overtopped the barrier at Red Rock Pass in northern Cache Valley, and thereafter eroded the outlet to the Provo level where a long stillstand occurred and major shore features were formed throughout the basin. The Stansbury level, marked by sparse shore features in the basin, occurs about midway, vertically, between the Provo level and the shore of Great Salt Lake, marking a pause in desiccation of the main water body.

The foregoing outline of events was tied to the concept of two epochs of glaciation—the high-water periods coinciding with glacial advances and the intervening desiccation representing the interglacial period. At the time the monograph was written, two glacial advances were all that had been determined.

Glover, S. L.

1936. Hammar Bluff formation of western Washington [abs.]: Pan-Am. Geologist, v. 65, no. 1, p. 77–78.

Sands and clays, probably lacustrine, are exposed at arch of gentle anticline a few miles east of Auburn, Wash. Beds are bluish gray when damp, light gray when dry. Age is post-Miocene.

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[1] The Bonneville Beds of Gilbert were redefined (Hunt, Varnes, and Thomas, 1953) as the Lake Bonneville Group.

Glover, S. L.

1941. Clays and shales of Washington: Washington Div. Mines and Geology Bull. 24, 368 p.

Shales in the Swauk Formation of Eocene age are valuable in Chelan and Douglas Counties as high-alumina ceramic materials. These are most valuable where relatively monolithologic source rocks contributed debris to isolated lake basins.

Other clays and shales are of Pleistocene age and are used as ceramic materials; they occur in Ellensburg Formation, Ringold Formation, and others unnamed, as in Chelan Valley.

In Spokane, Stevens, and Whitman Counties, Latah Formation of Miocene age furnishes refractory clays [called Spokane-Clayton], china, and terra cotta clays. Resources are valuable and widely used.

Grabau, A. W.

1913. Principles of stratigraphy: New York, A. G. Seiler and Co., 1185 p.

Limestone strata, with or without fossils, composed of polygons of dendritic tufa, signify desert environment, or a closed basin lake (p. 340). Lake-deposited clastics are from two sources, erosion of shorelines and river contributions (p. 606). No real criteria are proposed to distinguish lacustrine clastic sediments.

Lake-formed deltas characteristically show steeply dipping (to 35°) lower beds, which are rather coarse and overlain by finer grained progressively flatter lying beds (p. 610). The ideal "delta"—topset, foreset, and bottomset—is virtually restricted to lakes. "Superimposition of obliquely bedded strata is, however, eminently characteristic of torrential deposits [p. 702]."

Where mud cracks extend 10 ft or so, as in upper part of Shinarump of Utah, "it is difficult to believe that they could be formed under other conditions than those permitting prolonged exposure such as is found only in the playas of the desert * * * [p. 709].

"Fresh water and terrestrial organisms when exclusively found in a formation, indicate a continental origin. But such remains may be as characteristic of fluviatile as of lacustrine deposits and often more so * * * Abundant remains of fresh-water mollusks, Crustacea, etc., of Chara and other fresh water plants, indicate a lacustrine or paludal origin of the formation containing them [p. 717]."

Gregory, H. E.

1938. The San Juan Country, a geographic and geologic reconnaissance of southeastern Utah: U.S. Geol. Survey Prof. Paper 188, 123 p.

Lacustrine deposits of Quaternary age are widely distributed but occur mostly as patches. In Lake Canyon (near lat 37°20′ N., long 110°40′ W.) at its junction with "East Branch," lacustrine sediments 80 ft thick are exposed. They are "arranged in strata less than one-tenth of an inch thick" and contain many small shells. The Quaternary lake deposits were not mapped separately.

1945. Post-Wasatch Tertiary formations in southwestern Utah: Jour. Geology, v. 53, no. 2, p. 105–115.

Gregory named and briefly describes Brian Head (Miocene?), Parunuweap (Pliocene?), and Sevier River (Late Pliocene or early Pleistocene) Formations; the first two include lacustrine strata. They overlie limestone of Eocene age in southwestern Utah. Lacustrine strata in the Brian Head consist largely of limestone or highly calcareous clastic sediments; both groups contain a sparse

fresh-water molluscan fauna. In the Parunuweap, the lacustrine facies consists of "thin layers of quartz sand and closely foliated sheets of calcareous and gypsiferous silts."

1949. Geologic and geographic reconnaissance of eastern Markagunt Plateau, Utah: Geol. Soc. America Bull., v. 60, no. 6, p. 969–997.

Brian Head Formation of Miocene(?) age shows abundance of lacustrine limestone in some sections, notably on Birch Mountain. Rock types include much tuffaceous limestone and locally very pure vitric tuff. No evidences of lacustrine deposition are cited.

1950. Geology and geography of the Zion Park region, Utah and Arizona: U.S. Geol. Survey Prof. Paper 220, 200 p.

Petrified Forest Member of Chinle Formation of Late Triassic age is, in part, lacustrine (p. 69). Kayenta Formation of Jurassic(?) age in area includes numerous, but not extensive, lenses of lacustrine limestone (p. 81). Pink Cliffs are composed of rocks of Wasatch Formation of Eocene age (p. 111) and include fluviatile and lacustrine sediments "placed laterally, overlapping, or superposed." Evidence cited for a lake environment includes extensive sheets of limestone—some only 1 inch thick, beds containing remains of fishes, and abundance, shape, and distribution of strata deposited as limy ooze and silt.

Grim, R. E.

1958. Concept of diagenesis in argillaceous sediments: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 2, p. 246–253.

As soil debris or fluvial sediment passes into a lake, changes in mineralogy will depend on chemical character of the lake waters. In fresh water, few changes are expected. Saline lakes should change clay particles to montmorillomite, illite, or both or to chlorite, sepiolite-attapulgite, and zeolites, depending on character and concentration of the water. In highly saline waters, two-layer clay minerals would disappear.

Whether any particular composition of clay minerals is characteristic of the lacustrine fresh-water environment cannot be determined on the basis of available data (p. 250).

Hail, W. J., Jr.

1956. (and Kinney, D. M., and Zapp, A. D.). Latest Cretaceous and earliest Tertiary rocks between Castlegate and Green River, Utah [abs.]: Geol. Soc. America Bull., v. 67, no. 12, pt. 2, p. 1794–1795.

Persistent lacustrine limestone beds not previously recorded permit comparison of stratigraphic nomenclature of other authors in area between Castlegate and Tuscher Canyon. Limestone occurs probably partly in the Price River Formation of Late Cretaceous age but mostly in the North Horn Formation of Late Cretaceous and Paleocene age.

Hance, J. H.

1914. Potash in western saline deposits: U.S. Geol. Survey Bull. 540, p. 457–469.

In Railroad Valley, Nev., about 100 miles northeast of Tonopah, shorelines show occupation by Pleistocene lake correlative with Lahontan. Hance (and H. S. Gale) attributes 100–200 ft thickness of sediments to the lake. A well drilled to 1,204 ft depth showed evidence of lake deposition intermittently to

depths of 1,175 ft; this evidence suggests lake occupation of the basin in earlier Pleistocene (or Pliocene?) time. Lake deposition is inferred by E. E. Free (cited by Hance) from chemical and microscopic study of well cuttings, some of which contained gaylussite and material resembling lake-shore tufas of Lahontan basin.

Harshbarger, J. W.

1957. (and Repenning, C. A., and Irwin, J. H.). Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo Country: U.S. Geol. Survey Prof. Paper 291, 74 p.

Glen Canyon Group is continental in origin. Most units in group contain some lacustrine deposits, ranging from ox-bow lake to broad fresh-water lagoon types. Rock Point Member of Wingate Sandstone of Triassic age was deposited in broad fresh-water "lagoon." Dinosaur Canyon Sandstone Member of Moenave Formation of Triassic(?) age is partly paludal and lacustrine (fig. 19), as is Jurassic(?) Kayenta Formation. Ancient local lakes are represented by limestone lenses in Navajo Sandstone. In San Rafael Group of Jurassic age, Todilto Limestone remains a puzzle as to origin, with authors tending to assign it to marine-lagoon origin but not ruling out lacustrine. Brushy Basin Member of Morrison Formation includes some lake deposits in Navajo Country. No criteria of lacustrine deposition are cited.

Hayden, F. V.

1871. U.S. Geol. Survey Terr., 2d Ann. Rept.: p. 29.

Hayden describes Sweetwater Valley in central Wyoming as site of a Tertiary fresh-water lake in which sediments were deposited unconformably over older rocks. Granitic mountains formed much of the lake basin and some stood as islands. Much of the Sweetwater Group of Oligocene age was eroded prior to deposition of sedimentary rocks of Pliocene age.

Heindl, L. A.

1952. Gila Conglomerate *in* Arizona Geol. Soc. Guidebook for field trip excursions in southern Arizona: p. 113–116.

The term Gila Conglomerate has been applied variously by many authors to fluvial, lacustrine, and playa deposits in areas throughout more than 30,000 sq mi in southern Arizona. Locally, the "Gila Conglomerate" demonstrably grades from fanglomerate along valley margins through fluvial sand and gravel to lake deposits basinward. Lake deposits occupy axial areas of many intermontane basins in the region and in some have been dated by vertebrate remains as Pliocene and early Pleistocene in age.

Herrick, C. L.

1904. Lake Otero, an ancient salt lake basin in southeastern New Mexico: Am. Geologist, v. 34, p. 174–189.

More than 200 ft of marl, saline beds, and gypsum of Pleistocene(?) age, which overlies Cretaceous sandstone and shale and which is sharply separated from the ovelying Tularosa Formation, was deposited apparently in ancient Lake Otero, lying between Sacramento and San Andres Mountains. Deposits contain shells of fresh-water mollusks.

Hershey, O. H.

1912. Some Tertiary and Quaternary geology of western Montana, northern Idaho, and eastern Washington [abs.]: Geol. Soc. American Bull., v. 23, p. 517–536.

In middle Miocene time Coeur d'Alene Valley, already in existence much as today, was dammed by masses of basalt which flooded against western slopes of Idaho mountains. The resulting Lake Latour, deposited about 500 ft of fine gravel, sand, and silt—the latter white and variegated—that make up the Latour Formation. Silts were deposited in an area more or less coextensive with present Coeur d'Alene basin and extend upriver at least as far as Kellogg, Idaho.

Hewett, D. F.

1928. A manganese deposit of Pleistocene age in Bannock County, Idaho: U.S. Geol. Survey Bull. 795–H, p. 211–218.

Lacustrine-beach sand at about 5,400 ft altitude has been cemented with manganese minerals in Gentile Valley, Idaho. Shorelines as much as 5,800 ft in altitude are interpreted as indicating the precursor of Lake Bonneville, although Lake Bonneville did not flood Gentile Valley. Elephant teeth in the sands indicate Pleistocene age.

1956. Geology and mineral resources of the Ivanpah quadrangle, California and Nevada: U.S. Geol. Survey Prof. Paper 275, 172 p.

Lake deposits of Pleistocene age, about 25 ft thick, are exposed near Valley Wells, Calif. Mollusks found in the predominantly calcareous beds are characteristic of lake environment. Similar beds about 250 ft thick and of lacustrine origin are exposed in Lanfair Valley which is almost on the California-Nevada State line.

1936. (and others). Mineral resources of the region around Boulder Dam: U.S. Geol. Survey Bull. 871, 197 p.

Six authors discuss reconnaissance studies of deposits of economic minerals in parts of four States near Lake Mead. Lake deposits of Tertiary age contain significant occurrences of manganese, common salines, borates, magnesite, strontium minerals, gypsum, clays, and diatomite.

Hill, M. L.

1958. (and Carlson, S. A., and Dibblee, T. W., Jr.). Stratigraphy of Cuyama Valley, Caliente Range area, California: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 12, p. 2973–3000.

Authors redefine Morales Formation (Pliocene), which is as much as 5,000 ft thick and composed, in part, of clay of lacustrine origin; upper Miocene Quatal Formation, as much as 2,700 ft thick, includes clay and gypsum of lacustrine origin. Map shows distribution of formations. Petroleum (Clayton Pool) occurs near base of Morales Formation. No specific evidence of lacustrine origin is given.

Hobbs, W. H.

1945. Scabland and Okanogan lobes of the Cordilleran glaciation, and their lake histories [abs.]: Geol. Soc. America Bull., v. 56, no. 12, p. 1167.

Lake Spokane occupied the Upper Spokane Valley during part of Pleistocene time, receiving meltwater of Scabland lobe and water spilling from glacial Lake Missoula via Clark Fork outlet. Lake Leverett extended from Bridgeport for 300 miles up the Columbia Canyon. Glacial Lake Okanogan occupied Okanogan Valley, which was blocked by moraines across valley at Chelan.

Hodge, E. T.

1933. Age of Columbia River and lower canyon [abs.]: Geol. Soc. America Bull., v. 44, pt. 1, p. 156–157.

Pyroclastics dammed "a small progenitor of the Columbia River * * *" and thus caused Condon Lake to form. Later, but still in Pleistocene time Condon Lake was expanded by another volcanic dam across a (then) larger Columbia River.

Howard, A. D.

1937. History of the Grand Canyon of the Yellowstone: Geol. Soc. America Spec. Papers 6, xii, 159 p.

Extent and deposits of Pleistocene Yellowstone Lake, Lake Hayden, and other lakes ponded for longer and shorter periods of time by glacial ice are discussed. Occurrences of lacustrine silt in Hayden Valley, Alden Valley, and elsewhere, are described. General criteria for recognition of lake deposits, especially varving and fine laminae, are cited.

Hubbs, C. L.

1948. (and Miller, R. R.). The zoological evidence; Correlation between fish distribution and hydrographic history in the desert basins of western United States, *in* The Great Basin: Utah Univ. Bull., v. 38, no. 20, p. 18–166.

Paper offers an exceptionally stimulating example of the use of biological and geomorphic data in reconstructing lacustrine history of the Quarternary in parts of California, all of Nevada, and some other western areas. Map shows authors' reconstruction of lake basins in Basin and Range province. Present and fossil fish distribution is basis for reconstructing ancient drainage relations—some notably different from those of today. The paper contains an extensive bibliography.

Hubert, J. E.

1958. Petrology of the Fountain formation along the foothills of the Colorado Front Range [abs.]: Geol. Soc. America Bull., v. 69, p. 1590.

About 3 percent of the Fountain Formation (Permo-Pennsylvanian), between Eldorado and Colorado Springs, is interpreted to be partly lacustrine and partly deltaic.

Huey, A. S.

1948. Geology of the Tesla quadrangle California: California Div. Mines Bull. 140, 75 p.

The Livermore Gravels (of Clark) are of probable Pliocene age, reach a maximum thickness of about 4,000 ft in the Livermore Valley, and are primarily fluviatile in origin but may include lacustrine sediments under the alluvium of the valley.

Hunt, C. B.

1956. Cenozoic geology of the Colorado Plateau: U.S. Geol. Survey Prof. Paper 279, 99 p.

Paper deals largely with reconstruction of Cenozoic history of the Colorado Plateau. Lakes of Tertiary time are mentioned, some inferentially mapped; Paleocene-Eocene paleogeography is especially useful. Paper contains a good bibliography for the region.

Hunt, C. B.

1942. (and McKelvey, V. E., and Wise, J. H.). The Three Kids manganese district, Clark County, Nevada: U.S. Geol. Survey Bull. 936–L, p. 297–319.

Fifteen miles southeast of Las Vegas sedimentary manganese is interbedded with lake and playa sediments of the Muddy Creek Formation of Pliocene(?) age. Paper-thin lamination and association of gypsum are mentioned.

1953. (and Varnes, H. D., and Thomas H. E.). Lake Bonneville: Geology of northern Utah Valley, Utah: U.S. Geol. Survey Prof. Paper 257–A, p. 1–99.

The sediments laid down in Lake Bonneville are called the Lake Bonneville Group (Pleistocene), consisting of the Alpine (at base), Bonneville, and Provo Formations. The stratigraphy, geochemistry, engineering geology, and occurrence of ground water in these and underlying sediments in northern Utah Valley are discussed.

Hutchinson, G. E.

1937. A contribution to the limnology of arid regions, primarily founded on observations made in the Lahontan Basin [Nevada]: Connecticut Acad. Arts Sci. Trans., v. 33, p. 47–132.

This is a limnological study with no direct discussion of lake deposits. It contributes to understanding of lacustrine environments of deposition and discusses microfloras and faunas. Author cites (p. 54) survival of the indigenous fishes, *Chamisites cujus* Cope and *Salmo sinaragdus* Snyder, to show that Pyramid Lake was not desiccated since high Lahontan stages.

1943. (and Wollack, Anne, and Setlow, J. K.). The chemistry of lake sediments from Indian Tibet: Am. Jour. Sci., v. 241, no. 9, p. 533–542.

The ratio Ca:SiO_2 is much larger in sediments of closed-basin lakes in arid regions than in sediments of open lakes in arid regions. Calcium content increases notably in sediments of closed-basin lakes. This criterion is useful only where surrounding rocks are not dominantly calcareous. Magnesium concentration increases materially only in sediments from concentrated, undrained lakes. Variations in strontium seem related mostly to lithology of the basins. No significant variations were found for phosphorous or nitrogen.

1956. (and Patrick, R. M., and Deevey, E. S., Jr.). Sediments of Lake Patzcuaro, Michoacan, Mex.: Geol. Soc. America Bull., v. 67, no. 11, p. 1491–1504.

Paper restates (p. 1492) Hutchinson's (1943) conclusion, drawn from Tibetan closed-basin lakes, that CaO is more abundant in sediments of undrained lakes than in those of lakes having outlets. It also gives large lists of diatom flora (chiefly modern) of known lacustrine habit.

Jahns, R. H.

1940. Stratigraphy of the easternmost Ventura basin California, with a description of a new lower Miocene mammalian fauna from the Tick Canyon formation: Carnegie Inst. Washington Pub. 514, p. 145–194.

The Tick Canyon Formation (Late Early Miocene) and Mint Canyon Formation (Middle to Upper Miocene) both include lacustrine facies near Saugus, Calif. The Mint Canyon Formation shows noteworthy lateral gradations from coarse fluviatile sediments to "evenly bedded lacustrine counterparts," some of which are complete, even including littoral sandstone zones, in distances of half a mile.

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Jenkins, O. P.

1923. Verde River lake beds near Clarkdale, Ariz.: Am. Jour. Sci., 5th ser., v. 5, no. 25, p. 65–81.

The name Verde Formation was proposed for Pliocene or Pleistocene sediments deposited when Verde River was dammed by lava flows. Formation rests on eroded Paleozoic and older sedimentary rocks and basic lavas. The area of the old lake exceeded 300 sq mi, and lacustrine deposits are about 2,000 ft thick. Lake environment is inferred from reconstruction of a basaltic dam at downstream end of the basin, from the thick deposits of limestone in which were found a few "gastropods having the appearance of some freshwater types," and from the presence in part of the basin of large deposits of salts consisting mostly of sodium sulfate but including some halite and gypsum. The basinal form of the deposit was determined by mapping.

Johnson, J. H.

1954. An introduction to the study of rock building algae and algal limestones: Colorado School of Mines Quart., v. 49, no. 2, 117 p.

With respect to the Charophyceae—typified by species of *Chara*, the author states that since Paleozoic time, when some apparently lived in shallow marine waters, the plants "grow submerged in fresh standing water * * *. They frequently form extensive meadows on the bottoms of lakes or ponds * * *. In some place the Chara remains * * * form a limestone." One deposit in the Morrison formation, seen in Perry Park, Colo., was more than 40 ft thick, exposed over a length of 800 ft, and "composed primarily of fragments of calcified stems and numerous fruits scattered throughout the mass."

Johnson, M. S.

1957. (and Hibbard, D. E.), Geology of the Atomic Energy Commission Nevada Proving Grounds area, Nevada: U.S. Geol. Survey Bull. 1021–K, p. 333–384.

The Oak Springs Formation of probable Miocene age, although largely volcanic in origin, includes cream-colored to light-gray marly limestone containing freshwater gastropods in areas along the south margin of Frenchman Flat. Higher in the formation are thick beds of water-laid tuff which "indicate deposition in water, probably large lakes or basins which existed at the time of volcanism." The Oak Springs is 2,000 ft thick, but the thickness of the lacustrine component is not stated.

Jones, D. J.

1953. Gypsum-oolite dunes, Great Salt Lake Desert, Utah: Am. Assoc. Petroleum Geologists Bull., v. 37, no. 11, p. 2530–2538.

The oolites are calcareous, and the "gypsum" of the title refers to the clastic sand fraction of the dune deposits near Knolls, Utah. Fossils found in dunes include fragments of snails and three genera of lacustrine Ostracoda, *Candona*, *Limnicythere* sp.(?), and *Ilyocypris* sp.(?).[2] These forms suggest that the Pleistocene lake to the west, which was the source of the sand, was less saline than the Great Salt Lake today.

1955. Quarternary sedimentation in the Great Salt Lake Basin [Utah; abs.]: Jour. Sed. Petrology, v. 25, p. 138–139. [Quoted from rept.]

Quarternary sediments in the Great Salt Lake basin are primarily those of Pleistocene Lake Bonneville and its relict, Great Salt Lake. * * * The lacus-

[2] Later work by I. G. Sohn has shown this to be *Cytherissa* cf *C. lacustris*.

trine facies of each stratigraphic unit has two subfacies: (a) nearshore or subaerial gravels or both and (b) offshore silts and clays * * *. The following formational units are recognized, in ascending order above the volcanic sand and lake beds of the Tertiary Salt Lake group:

1. *Green clay series:* 800–1,000 ft in thickness, consisting of alluvial fans and mudflows grading basinward into a series of well-indurated gray-green siltstones and claystones.

—Unconformity—

2. *Alpine Formation:* 300–400 ft in thickness, composed of nearshore gravels, * * * grading basinward into thinbedded silts and clays. Deposits by turbidity currents are common in the Alpine.

—Unconformity—

3. *Provo and younger Pleistocene sediments:* 40–80 ft in thickness, * * * include offshore clays and silts, algal reefs, fringes of tufa and tufa-cemented talus cones. Fluvial sediments consist of terrace gravels and stream channels prograded into the retreating lake.

—Unconformity—

4. *Postglacial and Recent deposits:* 20–60 ft in thickness, include playa deposits of the Great Salt Lake Desert, marginal dunes of gypsum and oolites, lacustrine deposits of Great Salt Lake, and fluvial facies.

Quaternary lake sediments in the Great Salt Lake basin closely resemble marine sedimentary units in shallow relict seas, with similar units such as gravel beaches, spits, hooks, bars, sea cliffs, and turbidity-current deposits. Further similarities include fringing and barrier reefs of algal limestones, thin-bedded evaporites, and organic sediments.

Judson, S. S., Jr.

1950. Depressions of the northern part of the southern High Plains of eastern New Mexico: Geol. Soc. America Bull., v. 61, no. 3, p. 253–274.

Part or all "Pliocene cap rock" of the area may be lacustrine in origin. Algal platy structure and great purity of upper few feet of limestone are mentioned as evidence. Lines of depressions occur in area, and lake clays have accumulated in them. Age is Pliocene or Pleistocene or both.

Kay, J. L.

1949. The Tertiary of Utah, *in* Hansen, G. H., and Bell, M. M., The oil and gas possibilities of Utah: Salt Lake City, Utah Geol. Mineralog. Survey, p. 102–108.

The Uinta Formation of Eocene age in the central part of the Uinta basin consists of "lacustrine marls, siltstones, and thin beds of sandy limestone." No evidence is given.

Keller, W. D.

1956. Clay minerals as influenced by environments of their formation: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 11, p. 2689–2710.

Microclimate of fresh-water lakes grades into sea-water equivalent with increasing salinity. Illite is considered characteristic of marine shales; therefore, an illite-rich shale presumably is not lacustrine.

Kew, W. S. W.

1924. Geology and oil resources of a part of Los Angeles and Ventura Counties, California: U.S. Geol. Survey Bull. 753, 202 p.

Kew names and briefly describes the partly lacustrine Mint Canyon Formation of Miocene age. Thickness is several thousand feet. The formation is stratigraphically important because it forms a link between Tertiary marine strata containing characteristic assemblages of fossils and the Mojave Desert Tertiary continental beds containing vertebrate fossil. Fine grains and fresh-water fossils are given as evidence of local lacustrine conditions.

Kindle, E. M.

1917a. Some factors affecting the development of mud cracks: Jour. Geology, v. 25, no. 2, p. 135–144.

Polygons with flat or convex upper surfaces imply salt-water environment; concave surfaces are related to fresh-water environment. (Compare W. H. Bradley, 1933.)

1917b. Recent and fossil ripplemark: Canada Geol. Survey Mus. Bull. 25, Geo. ser. 34, 56 p.

"The asymmetrical or current ripplemark is characteristic of marine and fluvial deposits but is seldom met with in lacustrine sediments [p. 12]." Symmetrical ripple mark is characteristic of ponds and lakes but is "seldom seen on the seashore [p. 23–24]." Symmetrical ripple mark is "The prevailing type in lake sediment * * *; however, asymmetric ripples are occasionally developed on lake bottoms by currents set up by storms or other causes [p. 26, p. 48–53]. On the shores of lakes where ripplemark is due entirely to wave action it always runs parallel with the coast [p. 27]." On the other hand, "current-made ripplemarks * * * trend at right angles to the coastline [p. 28]." (Compare McKee. 1954.)

Kirkham, V. R. D.

1929. (and Johnson, M. M.). The Latah formation in Idaho: Jour. Geology, v. 37, no. 5, p. 483–504.

The Latah Formation of Miocene age consists of strata formed largely in a series of "temporary lakes of varying sizes, depths, and durations, separated by mountain ranges or low hills." Maximum observed thickness in Idaho is about 350 ft. Strata occur interbedded with Columbia River basalt in an area at least 175 miles long by 75 miles wide. Forty outcrops are listed in Idaho, and a location map is given. Fossils, largely leaf imprints, are listed from 13 localities. Lacustrine deposition for parts of the total thickness is inferred from reconstruction of geologic conditions which included repeated disruption of drainage by lava flows with resultant ponding and from agreement of these authors with earlier workers.

1931. Revision of the Payette and Idaho formations: Jour. Geology, v. 39, no. 3, p. 193–239.

Paper reviews the extensive and complex literature on the Payette and Idaho Formations of Miocene and Pliocene age, respectively. The Payette Formation is "a lake-bed and terrestrial series several hundred feet thick which generally occurs interbedded with the Columbia River Basalt," and is exposed only in intermontane basins. The Idaho Formation "includes all lake beds overlying the Columbia River Basalt and Owyhee Rhyolite but excludes the Pleistocene * * * formations. It is several thousand feet thick and occurs chiefly in "the Snake River downwarp * * *."

Klepper, M. R.

1957. (and Weeks, R. A., and Ruppel, E. T.). Geology of the southern Elkhorn Mountains, Jefferson and Broadwater Counties, Montana: U.S. Geol. Survey Prof. Paper 292, 82 p.

The Kootenai Formation of Cretaceous age includes 10–30 ft of intercolated fresh-water gastropod-bearing limestone lenses near the top of a section of claystone, siltstone, and sandstone; total measured thickness is 455 ft.

Elkhorn Mountain Volcanics (Cretaceous), include water-laid tuffs and marly layers that contain fresh-water mollusks, fish teeth, ostracodes, and algae—an assortment inferred to represent "a shore deposit of a sizeable body of water (p. 37)." Oligocene and Miocene(?) tuffaceous sediments are of fluviatile and lacustrine origin and are preserved in the principal valleys and basins.

Knappen, R. S.

1930. (and Moulton, G. F.). Geology and mineral resources of parts of Carbon, Big Horn, Yellowstone, and Stillwater Counties, Montana: U.S. Geol. Survey Bull. 822–A, p. 1–70.

Authors cite absence of marine fossils and presence of petrified wood, bone fragments, and gastroliths as evidence of continental environment. They suggest that plane contacts between beds, fine grain and scarcity and shallowness of channels indicate sluggish streams or standing water. Absence of wave ripples, absence of or poorly defined lamination and presence of current ripples and current crossbedding are characteristic of alluvial deposits.

Knechtel, M. M.

1938. Geology and ground-water resources of the valley of Gila River and San Simon Creek, Grahan County, Arizona: U.S. Geol. Survey Water-Supply Paper 796–F, p. 181–222.

Author considers lacustrine deposits of the area to be equivalent to the Gila Conglomerate and to be of Pliocene age. Reported lake beds are covered on the average by 100 ft of fluviatile sand and gravel. Water occurs in lake beds which interfinger toward margins of basin with fanglomerate. Evidence of lacustrine environment is largely provided by collections of diatoms suggesting deposition in "warm, somewhat saline lake water," and supported by gradation of fanglomerate along basin margins to progressively finer and better bedded materials toward axis of the valley. Maximum thickness is reported to be about 1,600 ft.

Knopf, Adolph

1917. Strontianite deposits near Barstow, Calif.: U.S. Geol. Survey Bull. 660–I, p. 257–270.

Ten miles north of Barstow, lake and terrestrial deposits, which are part of the Barstow Formation of Miocene age, contain large amounts of strontianite. This mineral occurs in layers parallel to bedding throughout an interval of several hundred feet; it is also found as resinous fibers and as gray aphanitic masses resembling limestone. Grade runs to as much as 88 percent $SrCO_3$.

In western part of district calcium carbonate exactly resembling even the resinous fibers occurs in place of much of the $SrCO_3$ and can be distinguished only by chemical tests. Author considers strontianite a replacement by cold meteoric waters of calcite in lakebed limestones.

Knopf, Adolph

1918. A geologic reconnaissance of the Inyo Range and the eastern slope of the southern Sierra Nevada, California, with a section on the stratigraphy of the Inyo Range, by Edwin Kirk: U.S. Geol. Survey Prof. Paper 110, 130 p.

In the foothills of the Inyo Range, east of Zurich, Owens Valley, Calif., lake deposits "consist mainly of shales with associated sandstones, conglomerates, thin limestones, and arkosic grits. They are evenly and persistently stratified in thin beds * * *," and are at least 150 ft thick. Locally, even the conglomerates are "crowded with fresh-water fossils. They were therefore laid down in a lake." Diatomite of fresh-water origin crops out south of Big Pine. Other outcrops in the valley are also inferred to be lacustrine, but evidence is less conclusive.

East and southeast of Lone Pine, the Owens River channel exposes beds deposited in a fresh-water predecessor of saline Owens Lake where strata of Pleistocene age consist of horizontally bedded clay, silt, and fine sand aggregating at least 300 ft in thickness. Fresh-water mollusks were found. Shore features were recognized in some places.

Koenig, K. J.

1960. Bridger Formation in the Bridger Basin, Wyoming, in Wyoming Geol. Assoc. 15th Ann. Field Conf. Guidebook: p. 163–168.

In the Bridger Basin, the Bridger Formation (Eocene) is 1,750 to nearly 2,000 ft thick. The bulk of the formation is of flood plain origin. Throughout, however, are thin beds of tuffaceous limestone, marl, and clay containing abundant fresh-water ostracodes and mollusks. Also abundant are wedge-shaped deltaic and lacustrine sandstones and siltstones associated with lacustrine limestone, mudstone, and shale. The lithology and contained fossils indicate lacustrine deposition.

Kottlowski, F. E.

1958. Lake Otero—second phase in formation of New Mexico's gypsum dunes [abs.]: Geol. Soc. America Bull., v. 69, no. 12, p. 1733–1734.

Five billion tons of gypsum sand, a four-century supply for the United States, occurs in Tularosa basin. Originally formed in Permian seas, the redissolved gypsum from mountains bordering the basin was concentrated in 280 sq mi of Pleistocene salinas composing Lake Otero. The lake was probably always saline and undrained. Shore features were not recognized; reported benches are fault-line scarps.

Krumbein, W. C.

1951. (and Sloss, L. L.). Stratigraphy and sedimentation: San Francisco, Calif., W. H. Freeman and Co., 497 p.

Authors describe nonmarine limestone as lacustrine in origin, typically a product of chemical changes resulting from photosynthesis. Marl is considered lacustrine in origin.

Kuellmer, F. J.

1956. Geology of the southern Black Range area, Grant, Luna, and Sierra Counties, New Mexico [abs.]: Geol. Soc. America Bull., v. 67, no. 12, p. 1798.

In the Black Range south of lat. 33°00′ N. is a series of Tertiary-Quaternary rocks that are largely of volcanic and sedimentary-volcanic origin but that include the following: "Fluviatile and lacustrine sediments dated within limits as early Miocene to early Pliocene * * * [author's unit 6]."

Kunkel, Fred

1960. (and Upson, J. E.), Geology and ground water in Napa and Sonoma Valleys, Napa and Sonoma Counties, California: U.S. Geol. Survey Water-Supply Paper 1495, 252 p.

The middle of three members of the Sonoma Volcanics consists of sand, volcanic ash and gravel, pumice, clay, silt and diatomite. Diatoms identified indicate a Pliocene age and deposition in a shallow lake of moderate temperature. Thickness of the lacustrine section is not stated.

The diagnostic diatoms (identified by Lohman) include species of: *Amphora, Caloneis, Cocconeis, Cymbella, Diatoma, Diploneis, Epithemia, Eunotia, Fragilaria, Gomphoneis, Gomphonema, Gyrosigma, Melosira, Navicula, Nitzchia, Pinnularia, Rhoicosphenia, Rhopalodia, Stauroneis, Stephanodiscus, Surirella, Tabellaria,* and *Tetracyclus.*

Lahee, F. H.

1941. Field geology, 4th ed.: New York, McGraw-Hill Book Co., 853 p. [Quoted from rept.]

A vertical section through a choked lake exhibits coarser sediments over finer sediments. This is often called the normal lake succession [p. 72–73].

LaMotte, R. S.

1936. The upper Cedarville flora of northwestern Nevada and adjacent California *with a section on* Diatoms from 49 Camp, by K. E. Lohman: Carnegie Inst. Washington Pub. 455, p. 57–142.

Deposits of lacustrine diatomite and white volcanic ash of Miocene age aggregating at least 70 ft in thickness crop out: near 49 Camp, Nevada; on Rattlesnake Butte, Modoc County, Calif.; and at Pit River Ranger Station, Modoc National Forest, Calif. Lohman considers diatoms indicative of a fresh-water lake environment. Overlying Alturas Formation of Pliocene age may include thin lake beds.

Lance, J. F.

1958. Pleistocene capybara from Arizona [abs.]: Geol. Soc. America Bull., v. 69, no. 12, p. 1693–1694.

Pleistocene vertebrate fossils, including capybara and horse, were found in lake beds in the Gila River valley.

1958. (and Wood, P. O.). New Miocene fossil locality from southwestern Arizona [abs.]: Geol. Soc. America Bull., v. 69, no. 12, p. 1694.

Camel and rodent remains found 6 miles northeast of Wellton, Ariz., and scanty geologic information suggests that the 4,000 ft. thickness of Miocene strata are lake and flood-plain sediments.

Larsen, E. S., Jr.

1956. (and Cross, C. W.). Geology and petrology of the San Juan region, southwestern Colorado: U.S. Geol. Survey Prof. Paper 258, 303 p.

The Creede Formation of Miocene age, which occurs in the Rio Grande Valley adjacent to Creede, Colo., was deposited when the basin was deeper than at present. It laps up on the sides and is overlain at the axis of the valley by younger alluvium. The upper member, more than 1,000 ft thick, includes lake deposits, stream wash into lake, and fluviatile beds. The lower member, more than 500 ft thick east of Creede, was deposited mostly in quiet water in a local intervolcanic lake. Strata of the lower member are fine grained, well bedded, creamy or light gray and are characteristically composed of shaly-bedded tuff

containing fossil plants and insects. Local coarse deposits probably represent talus. Much interbedded travertine is probably of hot-spring origin. The lake environment is inferred from great thicknesses of very fine shaly clastic sediments and from the form of the basin of deposition.

Lasky, S. G.

1949. (and Webber, B. N.). Manganese resources of the Artillery Mountains region, Mohave County, Arizona: U.S. Geol. Survey Bull. 961, 86 p.

The Artillery Formation of early Eocene age is at least 1,500 ft thick and contains limestone as much as 50 ft thick. This evidence suggests "that lakes or playas existed from time to time." Palm roots, *Chara*, and gastropods are the only fossils found but are reasonably diagnostic of Eocene age.

The Chapin Wash Formation of Pliocene(?) age is a closed-basin deposit containing finely laminated tuff, sedimentary manganese ore—in part as "layers of essentially pure sooty pyrolusite," and beds of limestone as much as 5 ft thick. Data suggest, both internally and by analogy with the Muddy Creek Formation manganese deposit (Three Kids, near Las Vegas, Nev.), alternating intermittent lakes, playas, and subaerial conditions. The formation was observed to be 582 ft thick but may be 1,350 ft or more. Fossils include canid jawbone and palm roots. A Pliocene(?) age is assigned, however, on the basis of stratigraphic relations.

Lawson, A. C.

1914. Description of the San Francisco district, Tamalpais, San Francisco, Concord, San Mateo, and Hayward quadrangles: U.S. Geol. Survey Geol. Atlas, Folio 193, 24 p.

Near south border of the Concord quadrangle, Lawson identifies 6,000 ft of strata as Orinda Formation of Pliocene age and notes the presence of lignite seams at a few places. The Orinda includes limestone beds that contain fresh-water gastropods; others are made up wholly of shells of ostracodes.

The Siesta Formation also of Pliocene age, consists of 200 ft of fresh-water conglomerate, sandstone, and shale with lesser amounts of lignite, clay, limestone, chert, and tuff deposited in "an extensive lake basin" which was formed when volcanic rocks of Moraga Formation disrupted drainage patterns. Limestone in the Siesta Formation contains fresh-water gastropods.

Lehner, R. E.

1958. Geology of the Clarkdale quadrangle, Arizona: U.S. Geol. Survey Bull. 1021–N, p. 511–592.

The Verde Formation is interpreted on the basis of indirect evidence to be of Pleistocene age, possibly in part late Pliocene. It is probably correlative with adjoining Hickey Formation consisting of fanglomerates and fluviatile deposits containing abundant volcanic rocks. The lacustrine Verde Formation is more than 2,000 ft thick, fine grained, and mostly calcareous. It contains two basalt flows near top of section and has an areal extent of 300 sq mi. The Verde consists mostly of fine-grained limestone, calcareous sandstone and siltstone, and marl; some beds contain fresh-water gastropods. Near Camp Verde, beds of sodium sulfate and sodium chloride have accumulated.

Lindgren, Waldemar

1898a. The mining district of the Idaho Basin and the Boise Ridge, Idaho: U.S. Geol. Survey 18th Ann. Rept., pt. 3, p. 632–634.

More than 1,000 ft of strata are assigned to the Payette Formation of Miocene age. The strata consist mostly of light-colored granitic sands, locally cemented by hot-spring deposits into hard sandstones. Clay was deposited in sheltered areas of the ancient Lake Payette, and a few coal seams are intercalated in basal part of the formation in some areas. The Payette rests unconformably on granite. It is partly coextensive with Idaho Formation but is older.

1898b. Truckee, California: U.S. Geol. Survey, Geol. Atlas, Folio 39.

At the close of a pre-Pleistocene period of volcanic activity, the Truckee Valley was occupied by a lake into which sand and clay were washed from the surrounding hills. Near Truckee, these deposits were largely covered by Pleistocene lake beds. In Little Truckee Valley, the older lake beds are better preserved and consist of yellowish sands and clays and a "brilliantly white substance which is probably a volcanic ash and which contains diatoms."

In Pleistocene time, the Squaw Valley meadows were occupied by a lake dammed by morainal deposits. There was also a lake in the lower part of Blackwood Creek Valley. Along Five Lakes Creek, level sandy flats suggest former existence of a series of Pleistocene lakes.

During Neocene (Pliocene?) and earlier Pleistocene time, waters of Lake Tahoe were dammed by andesitic lavas to levels 700–1,000 ft higher than present water stage, but distinct beaches are found to levels only 100 ft above 6,225 ft. Other stands were 20, 40, and 80 ft above the 6,225 ft level.

In Truckee Valley, beach gravels of Pleistocene age are found all around the basin margins to elevations of 6,000 ft, reflecting damming of the outlet by basalt eruptions. Northeast of Boca, the shores have been elevated to about 6,300 ft. The Truckee Lake was drained during the later stages of the glacial epoch.

More than 100 lakes, both large and small, occur in the summit areas of the region. Nearly all are of glacial origin and occupy over-deepened basins or are dammed by moraines. Many other lakes have been filled or drained, their bottoms now forming swamps or meadows.

1900. The gold and silver veins of Silver City, DeLamar, and other mining districts in Idaho: U.S. Geol. Survey 20th Ann. Rept., pt. 3, p. 65–256.

Paper briefly describes the Payette (Miocene) and Idaho (Pliocene) Formations in Idaho and in adjacent southeastern Oregon and their contained flora (identified by F. H. Knowlton) and invertebrate (mollusk) and vertebrate fossils. Shore gravels of the Payette Formation are reported at altitudes ranging from 3,000 to 4,600 ft; gravels of the shore facies of the Idaho Formation, were identified at an altitude of about 2,800 ft in Payette valley. Elsewhere in area, shore features were recognized at different altitudes, implying that deformation occurred after the formation of the lakes. Locally the strata are fine grained and flat bedded and carry very well preserved leaf imprints.

Another lake, unnamed, was formed (in Miocene time) in Long Valley, northern Boise County, about 40 miles long and 5–10 miles wide when the Columbia Plateau basalt flows dammed the drainage. A few lake deposits are found; one occurs at Paddy Valley (p. 244).

Lofgren, B. E.

1955. Résumé of the Tertiary and Quaternary stratigraphy of Ogden Valley, Utah, *in* Utah Geol. Soc. Guidebook no. 10: p. 70–84.

Lake deposits known from Ogden Valley are reported from the top down as follows: (1) Pleistocene, 65 ft of brownish-tan sand and silt; cyclic bedding in lower part suggests varves; these are deposits of Lake Bonneville which, in higher stages, flooded Ogden Valley leaving recognizable shore features; (2) Pleistocene, 100 ft or more of pre-Lake Bonneville silt, which is dark bluish gray, variegated, and micaceous and is derived exclusively from drainage of the North Fork of the Ogden River; it forms a confining layer over artesian aquifers; its thin horizontal bedding implies deposition in a lake; (3) Pleistocene, 100 ft or more of gravel, fluviatile for the most part; (600 ft of gravel, sand, silt and of fanglomerate intervene); (4) early Oligocene, 800 ft or more of tuff, which is light colored to white and fluviolacustrine in origin and which contains lenses of volcanic conglomerate and ostracodes which are not described.

Longwell, C. R.

1928. Geology of the Muddy Mountains, Nevada, with a section through the Virgin Range to the Grand Wash Cliffs, Arizona: U.S. Geol. Survey Bull. 798, 152 p.

Paper defines the Horse Spring Formation, which is hundreds (locally thousands) of feet thick and probably lacustrine. It was deposited in a series of small basins and includes limestone, clay, colemanite, volcanic ash, magnesite, gypsum, and sandstone. Its age is questionable; Longwell (oral communication, 1959)[8] infers that it may be as old as Paleocene; hence it is included on the Paleocene-Eocene map (pl. 2) of this report. The Horse Spring is overlain unconformably by the Muddy Creek Formation (Miocene?). See Longwell (1936) for further discussion.

1936. Geology of the Boulder Reservoir floor: Geol. Soc. America Bull., v. 47, no. 9, p. 1393–1476.

Much of the Boulder Reservoir floor consists of Tertiary or probably Tertiary rocks. The descriptions of formations reflect the wide range of rock types and drastic changes in character, vertically and horizontally, that appear to be characteristic of lake deposits in areas adjacent to rapidly eroding highlands.

The Muddy Creek Formation (p. 1419–1440) of Miocene(?) age is a highly varied and thick group consisting of clastic rocks and lake or playa chemical precipitates, especially gypsum and halite. Fanglomerates commonly include fragments of rocks exposed in mountains surrounding basins, contain fragments up to tens of feet long near source, and grade basinward to silt in less than a mile in some places; siltstones interbedded with gypsum and with gypseous clays make up much of the total thickness.

In Callville Wash, 150 ft of pure white evaporite, having a theoretical composition (U.S. Geol. Survey analysis) of pure dolomite, is interbedded in the Muddy Creek.

In some valleys, the Muddy Creek Formation is overlain by the Hualpai Limestone. Total thickness of this limestone is measured in thousands of feet; however, no specific figure is given.

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[8] A potassium-argon age determination suggests a possible Miocene age. Biotite from near the base of the Horse Spring was dated at about 23 million years (C. R. Longwell, written communication, 1961).

The Hualpai Limestone is a spongy tufalike deposit of Pliocene(?) age. Individual beds are compact, nonvuggy, and hard; in other beds up to 50 percent of the volume is vugs. Color of the limestone grades from gray to pink to light brown.

The widespread and generally uniform character of the bedding and the thickness (more than 1,000 ft originally) of the Hualpai seem to rule out playa deposition or hot springs. The possibility exists that the Hualpai was formed in a lake or chain of lakes containing water of high lime concentration resulting from presence of limestone mountains nearby or from contributions by hot springs. A shallow-lake environment is probable, as stemlike tubes of plants are common in some beds.

The Chemehuevi Formation of Pleistocene age (W. T. Lee's "Chemehuevi gravel", p. 1443–1447) consists chiefly of sand, silt, and clay and minor gravel components, occupying a narrow strip along the Colorado River and some major tributaries. The rocks are only slightly consolidated and several hundreds of feet thick; they accumulated when the Colorado River had cut nearly to present grade. History of the Chemehuevi Formation indicates either damming or marked climatic changes.

1949. Structure of the northern Muddy Mountain area, Nevada: Geol. Soc. America Bull., v. 60, p. 923–968.

The Willow Tank Formation of Late Cretaceous age crops out in a belt several miles long on each of two fault blocks of northern Muddy Mountains. Fossils indicate ponded fresh-water deposition of clay and tuffaceous sandstone which overlie basal conglomerate. Total thickness is about 300 ft, of which all but 30 ft is lacustrine.

1954. Geologic setting of Lake Mead, *in* Smith, W. O., and others, Lake Mead Comprehensive Survey of 1948–49: Boulder City, Nev., U.S. Dept. Interior and others, v. 1, p. II–16 II–28.

Upper Cretaceous beds south of Las Vegas Wash include fresh-water limestone. The Horse Spring Formation suggests "a chain of lakes." The Muddy Creek Formation (Miocene?) shows evidence of "deposition in shallow lake waters * * *." The Hualpai Limestone was formed in a lake. The Chemehuevi Formation "* * * must have been deposited in a deep lake * * * the great Chemehuevi lake" [See Longwell (1936, 1949) for discussions of these formations].

Lorenz, H. W.

1956. (and McMurtrey, R. G.). Geology and occurrence of ground water in the Townsend Valley, Montana: U.S. Geol. Survey Water-Supply Paper 1360–C, p. 171–290.

Parts of the Chadron and Brule Formations of Oligocene age aggregate about 800 ft in thickness and contain light-colored fine-grained sediments, diatomaceous earth, and some tuff. Miocene strata, estimated to range from 3,000 to 5,000 ft in thickness, overlie Oligocene deposits. The Tertiary deposits are commonly referred to as "lake beds" and are mapped as a unit. No discussion of their origin is given.

Love, J. D.

1956a. Cretaceous and Tertiary stratigraphy of the Jackson Hole area, northwestern Wyoming, *in* Wyoming Geol. Assoc. 11th Ann. Field Conf. Guidebook: p. 76–94.

The Camp Davis Formation of probable Pliocene age is at least 5,600 ft thick in the Jackson Hole area. Of the total thickness, nearly 4,300 ft consists of conglomerate; a basal conglomerate 280 ft thick and an upper section 4,000-ft thick make up the rest. The interval from 280 ft above base to about 1,300 ft is occupied by limestone, claystone, tuff, pumicite, conglomerate, and diatomite. Some of the nonconglomeratic part is lacustrine according to Love (1956b).

In the area the Teewinot Formation, also Pliocene in age, is more than 5,000 ft thick. A basal conglomerate is 1,400 ft thick. Two other members consist of limestone and pumicite and of claystone and pumicite, respectively. Individual limestone beds range from 25 to 75 ft in thickness and most are white, nodular, and porous. Some of the claystones are laminated and interbedded with carbonaceous paper shales, others are almost coquinas of small fragile mollusks and ostracodes. Mollusks identified include species of *Pisidium*, *Valvata*, *Scalez*, *Lymnaea*, *Vorticifex*, and *Promenetus*, all of fresh-water habitat. Land snails also occur in some beds, as do caddis fly larval cases and ostracodes, which have been identified as species of "*Candona*", *Cyprinotus*, *Illyocypris?*, and *Limnocythere*. According to Love (1956b), a playa-lake environment of deposition is indicated.

1956b. Summary of the geologic history of Teton County, Wyoming, during Late Cretaceous, Tertiary, and Quaternary times, *in* Wyoming Geol. Assoc. 11th Ann. Field Conf. Guidebook: p. 140–150.

During Pliocene time, part of the Camp Davis Formation was deposited in a lake near the southern margin of Teton County. Rhyolitic ash, pumice, and obsidian fragments were deposited in the lake waters as well as diatomites.

Later, largely quiescent conditions prevailed during deposition of the Teewinot Formation of middle Pliocene age. The formation is 5,000 ft thick and contains at least 1,000 ft of white fresh-water limestone, 500 ft of pumicite, and 400 ft of very fine grained claystone and diatomite. Fine lamination and varvelike appearance are characteristics; one bed half an inch thick was traced for a distance of 2 miles; abundant mollusks and ostracodes suggest a playa-lake environment. Similar environments prevailed in the Alpine area southwest of Teton County.

Lovering, T. S.

1932. (and Behre, C. H., Jr.) Battle Mountain (Red Cliff-Gilman) mining district [Colorado], *in* Henderson, C. W., Colorado Internat. Geol. Congress Guidebook 19: p. 69–77.

Twelve miles from Red Cliff, en route to Leadville, the south lateral moraine of the Pleistocene Homestake Glacier ponded waters in the valley of Homestake Creek, southward, so that deltaic lacustrine sediments were deposited. At Pando, another moraine crossed a broad valley tributary to Homestake Creek. Eagle River once flowed in that valley but was ponded by the moraine and diverted eastward, cutting a new outlet gorge.

Ludlum, J. C.

1942. Pre-Cambrian formations at Pocatello, Idaho: Jour. Geology, v. 50, no. 1, p. 85–95.

The Pocatello Formation of Ludlum includes 350 ft of varved slates. Laminae range from less than 1 mm to several centimeters in thickness. Coarser grains are more abundant in light-colored layers. Characteristics are interpreted to indicate "glacial origin," especially as varved sediments occur in close association with tillite of same formation.

Occurrences of varved slates are cited in the Bannock Range just east of Pocatello, Idaho, and at Little Mountain, 14 miles west of Ogden, Utah.

MacGinitie, H. D.

1937. The flora of the Weaverville beds of Trinity County, California; with descriptions of the plant-bearing beds, *in* Eocene flora of western America: Carnegie Inst. Washington Pub. 465, p. 83–151.

Sedimentary rocks 2,000 ft thick are considered to be of Oligocene age and include flood plain, swamp, and lake deposits and coal, water-laid tuff, and paper shale. They occur in the Weaverville-Minersville valley, where they are mostly fluviatile, and in areas from Hayfork upstream and around Hyampon, where lacustrine facies are abundant. Diatom floras show lake ecology (p. 103).

State geologic map (Jenkins, 1951) shows areas as marine Upper Eocene, which appears to be unreasonable on the basis of MacGinite's statement (citing determinations by G. D. Hanna), that the diatoms submitted are fresh-water species, of which several are lacustrine, and occur with spicules of fresh-water sponges.

1953. Fossil plants of the Florissant beds, Colorado: Carnegie Inst. Washington Pub. 599, 198 p.

The Florissant Lake Beds, of Oligocene age, are 50 ft thick and interbedded with andesitic tuffaceous shales, sands, and gravels. The basin of deposition was once larger; the fact that the remaining strata extend in full thickness to fault contacts against which they are dragged indicates preservation in a graben. The lake beds are a complex series showing frequent alternations of fine-grained paper shales, bedded tuffs, and a few thin layers of gypsum. Many beds carry extensive and well-known flora, remains of insects, and—in some places—well-preserved fishes. Local layers are "covered with enormous numbers of ostracod shells and * * * egg cases of water fleas (Cladocera)."

The inferred environment of deposition included a rich forest along streams and lake shores. The basin of deposition was a region of moderate relief, having high volcanoes to the west that were vigorously producing ash and pumice during the periods of deposition. The climate was moderately warm, and the rainfall was insufficient to support forests except in river valleys and adjacent to the lakes.

McKee, E. D.

1954. Stratigraphy and history of the Moenkopi formation of Triassic age: Geol. Soc. America Mem. 61, 133 p.

Shallow, marginal ponds and lakes of the Moenkopi basin are recognized, in part, by the relative abundance of a characteristic limestone-gravel conglomerate, especially in Little Colorado River area.

Where gypsum occurs without aphanitic limestone immediately underlying it, one of two conditions should have prevailed: (1) sea water deposited calcium carbonate in a different basin, and carbonate-deficient water then flooded the area of gypsum deposition; or (2) gypsum was formed in lakes fed by streams

deficient in calcium carbonate (The gypsum of the Moenkopi is considered of marine origin, see p. 51).

Kindle's (1917b, p. 48) suggestion that symmetrical ripple mark is largely confined to lake environment because current action is rare in lakes does not seem to be valid. Moenkopi strata show current and wave-type ripple marks in the same series of beds and, rarely, even superimposed on one another on the same surface.

Fossil amphibians in the Moenkopi include numerous fish-eating types (crocodilians) that imply perennial lakes or rivers. Lacustrine environment cited (p. 78) as present in some places during Moenkopi deposition.

1956. (and others). Paleotectonic maps of the Jurassic system: U.S. Geol. Survey Misc. Geol. Inv. Map I–175, 6 p.

Interval D (of the authors, representing later Jurassic time) includes "ponded-water" deposition in the Morrison Formation, which extends northward from Four Corners area. Two lake, or playa, areas are shown on R. W. Imlay's paleographic map of the Colorado Plateau, but the map does not include the top of the Morrison (Brushy Basin Member), which has been cited by other authors as more predominantly lacustrine in origin than other members.

Malde, H. E.

1960. Evidence in the Snake River Plain, Idaho, of a catastrophic flood from Pleistocene Lake Bonneville: U.S. Geol. Survey Prof. Paper 400–B, p. 295–297.

Overflow from Lake Bonneville was ponded by a lava dam near the present American Falls, Idaho, causing a shallow lake to form. From a point a few miles downstream from American Falls, the lake extended up the valley of the Snake River to, and presumably past, Pocatello. The sediments deposited in the lake are in some respects comparable to the catastrophic-flood lacustrine deposits characteristic of the scabland areas in Washington.

1958. (and Powers, H. A.). Flood-plain origin of the Hagerman lake beds, Snake River Plain, Idaho [abs.]: Geol. Soc. America Bull., v. 69, no. 12, p. 1608.

The paleoecology and sedimentary features of the Hagerman "lake beds" of Pliocene age, as interpreted, suggest that sediments are of flood-plain, not lacustrine, origin. Marks of plant roots on clay layers, the presence of intercalated layers of sand that rest on scoured surfaces showing a few inches (rarely a few feet) of relief, and the presence of open vesicles and columnar joints in a basalt flow that formed some pillows at the base are taken as evidence of flood-plain environment. Fossil mollusks and diatoms suggest a landscape of ox-bow ponds, sloughs, and marshy stream borders, moist soil, and puddles.

Mansfield, G. R.

1920. The Wasatch and Salt Lake formations of southeastern Idaho: Am. Jour. Sci., 4th ser., v. 49, no. 294, p. 399–406.

The Salt Lake Formation of Pliocene(?) age is recognized as fluviatile and lacustrine from Idaho Falls to the Wyoming-Utah line south of Evanston, Wyo. It is at least 1,000 ft thick and contains deposits of white marl and calcareous clay, some fresh-water mollusks, and abundant ostracodes. Separation of fluviatile and lacustrine phases is not made, nor are criteria for recognition of the environments discussed.

Mansfield, G. R.

1927. Geography, geology, and mineral resources of part of southeastern Idaho: U.S. Geol. Survey Prof. Paper 152, 453 p.

The Gannett Group of probable Cretaceous age includes the Draney Limestone as the uppermost formation. The Draney is 200 ft thick and consists of limestone in beds mostly about 1½ ft thick in which fresh-water mollusks were found.

Stratigraphically below the Draney is the Bechler Conglomerate, and below the conglomerate lies the Peterson Limestone, much resembling the Draney except in stratigraphic position. The Peterson is also about 200 ft thick, consists of fresh-water limestone, and contains fresh-water mollusks.

The strata overlying the Gannett Group are referred to the Wayan Formation, which is 11,800 ft thick and of Cretaceous age. The lower 2,800 ft of the Wayan includes limestone carrying fresh-water mollusks, occurring in thick beds and series of beds and in thin lentils and lenses. Total thickness of the fresh-water limestones is not stated.

The occurrences of thick sections of fresh-water limestone suggests lacustrine deposition.

1952. Geography, geology, and mineral resources of the Ammon and Paradise Valley quadrangles, Idaho: U.S. Geol. Survey Prof. Paper 238, 92 p.

The Peterson Limestone (of Gannett Group, Upper Jurassic and Lower Cretaceous) is a persistent fresh-water limestone, 200± ft thick, that is characteristically dead-white in float, but slate gray to light gray, with reddish and purplish material in outcrop. Fresh-water gastropods, ostracodes, and charophytes suggest an Early Cretaceous age (see Peck, 1941).

Wayan Formation, 1,500–2,000 ft thick, is of Early(?) and Late Cretaceous age; lower unit contains fresh-water limestone beds, sandstones, and shales, some of which are carbonaceous.

Salt Lake Formation (Pliocene?) crops out over about half the area of each of the two quadrangles. Conglomerate predominates, but marl and limestone, calcareous clay, sandstone, grit, and tuff occur. Areas mapped as Salt Lake Formation doubtless include younger materials, according to Mansfield.

Marsell, R. E.

1955. (and Jones, D. J.). Pleistocene history of lower Jordan Valley, Utah, *in* Utah Geol. Soc. Guidebook no. 10: p. 113–120.

The problem of Pleistocene formational boundaries involves length of duration of lakes in the Bonneville basin. Tertiary (Salt Lake Formation) beds seem to be marked by pumiceous deposits, abundance of marls, and presence of moderately steep dips. The Bonneville and Stansbury shorelines (of Gilbert, 1890) of Lake Bonneville may be relics of a lake or lakes older than Lake Bonneville proper. The boundary between the Pleistocene Lake Bonneville Group and Recent sediments is commonly obscured by absence of well-marked erosional unconformity, absence of angular unconformity, and similarity in sedimentary types.

Matthes, F. E.

1930. Geologic history of the Yosemite Valley: U.S. Geol. Survey Prof. Paper 160, 137 p.

Paper cites a morainal lake that occupied the valley floor during part of Pleistocene time. The lake was 5½ miles long and extended full width of the valley from its head to El Capitan. The lake water is estimated to have been from 100 to 300 ft deep. The thickness of lake deposits is not known.

A smaller lake, 1½ by 2½ miles in extent, occupied Little Yosemite Valley; the water is estimated to have been from perhaps 25 to more than 50 feet deep. Deposits formed in this lake were negligible.

1960. Reconnaissance of the geomorphology and glacial geology of the San Joaquin Basin, Sierra Nevada, California: U.S. Geological Survey Prof. Paper 329, 62 p.

The text makes no reference to occurrence of Pleistocene lakes in the area of study. It is reasonable, however, to suppose that lakes must have been present behind moraines where the debris blocked drainage from various valleys. The map (pl. 1) shows ancient glaciers and glacial features of the area and a number of meadows lying immediately upgradient from moraines that extend completely across the valleys. In a few of the larger of these valleys, the present writer (Feth) infers that lakes existed and has transferred the areas large enough to show on the scale used to the map showing Pleistocene lakes of the west (pl. 4, this paper). No doubt other meadows in the High Sierra were occupied by lakes in Pleistocene time. Several such areas have been reported by Axelrod (written communication, 1961) from areas south of that reported in Prof. Paper 329.

Matthew, G. F.

1883. On a method of distinguishing lacustrine from marine deposits: Canada Royal Soc. Trans., v. 1, p. 147–149.

Matthew determined that lacustrine clays, including marl, are of lower specific gravity than marine strata of similar appearance underlying the fresh-water beds. Only one occurence was considered. This difference is probably due to finely disseminated organic particles in lacustrine strata. All samples were air dried before determining specific gravity.

Maxey, G. B.

1948. (and Hameson, C. H.). Geology and water resources of Las Vegas, Pahrump, and Indian Spring Valleys, Clark and Nye Counties, Nevada: Nevada State Engineer's Office, Water Res. Bull. 5, 121 p.

Plate 1 shows Quaternary lake deposits in all three areas named in title. These deposits are defined as Pleistocene in age and are not more than 50 ft thick. Mollusks reportedly indicate permanent fresh-water bodies.

Mayo, E. B.

1934. The Pleistocene Long Valley Lake in eastern California: Science new ser., v. 80, no. 2065, p. 95–96.

Shore features were found at 7,100-ft altitude. Lacustrine beds are at least 100 ft thick. Large thermal springs built deltas cemented with opaline silica into Long Valley Lake, which was 17 miles long, 8 miles wide, and 250 ft deep. Tufa domes are present locally.

Meinzer, O. E.

1911. Geology and water resources of Estancia Valley, New Mexico: U.S. Geol. Survey Water-Supply Paper 275, 89 p.

Shore features and lake deposits of Pleistocene age in Estancia Valley are described, as are lake deposits in nearby Encino basin. At its maximum, Estancia Lake had a shoreline near the 6,200-ft altitude and an area of about 450 sq mi and was 150 ft deep. It had no known outlet.

Meinzer, O. E.

1917. Geology and water resources of Big Smoky, Clayton, and Alkali Spring Valleys, Nevada: U.S. Geol. Survey Water-Supply Paper 423, 167 p.

Paper describes shore features, beach gravel, and lake-bottom deposits of Pleistocene Lakes Toyabe and Tonapah but gives no thicknesses for these lake sediments. Paper repeats Spurr's (1905) description of the Esmeralda Formation (Miocene), including its lake deposits.

1922. Map of the Pleistocene lakes of the Basin-and-Range Province and its significance: Geol. Soc. America Bull., v. 33, no. 3, p. 541–552.

At least 125 closed drainage basins occur in the Basin and Range province (p. 541). Map (p. 543, fig. 1) shows 68 Pleistocene lake basins; Utah and Nevada have the most, California next, then Oregon. Controls of size of the Pleistocene lakes were complex. They include size of drainage basin, permeability of bedrock, altitude, relief, latitude, and climatic belt in which basin lies.

Meinzer suggests that the range of humidity between basins in Pleistocene time was comparable to the difference in humidity between the Pleistocene and the present in a given basin. Climate in New Mexico and southeastern Arizona in the Pleistocene was probably comparable to modern climate in southern Oregon. The Pleistocene in southeastern California and trans-Pecos Texas was comparable (too dry for lakes to exist) to southern Nevada today.

1913. (and Kelton, F. C.) Geology and water resources of Sulphur Spring Valley, Arizona: U.S. Geol. Survey Water-Supply Paper 320, 231 p.

The northern part of the Sulphur Spring Valley contained Pleistocene lakes of two or more times. The shores of a more recent lake outline an area of about 120 sq mi at its maximum stand of 4,180 ft. Occurrence of an older lake is inferred from well logs; its size is unknown. Water occurs in lake deposits under artesian pressure.

Merrill, G. P.

1908. The Meteor Crater of Canyon Diablo, Arizonia, its history, origin, and associated meteoric irons: Smithsonian Inst. Washington Misc. Coll. no. 50, p. 461–498.

Lake deposits of Pleistocene age occur in Meteor Crater.

Merritt, Z. S.

1956. Upper Tertiary rocks of the Alpine, Idaho-Wyoming area, *in* Wyoming Geol. Assoc. 11th Ann. Field Conf. Guidebook: p. 117–119.

Star Valley, Wyo., and Grand Valley, Idaho, form a continuous trough that crosses the State line. In this basin, the Teewinot Formation of Pliocene age is more than 5,000 ft thick and has characteristics resembling those displayed in Teton County, Wyo., where as Love (1956b) indicates 1,000–2,000 ft is of lacustrine origin. In addition to vertebrate remains, the Teewinot in the Alpine area yielded fresh-water mollusks identified as species of *Pisidium*, *Sphaerium*, *Lymnaea*, *Planorbidae*, and *Promenetus*, as well as abundant ostracodes not identified generically, and sparse oogonia of *Chara*.

713–182—64——6

Metzger, D. G.

1952. Ranegras Plain area, Yuma County, *in* Halpenny, L. C., and others, Ground water in the Gila River Basin and adjacent areas, Arizona—a summary: U.S. Geol. Survey open-file report (duplicated), p. 171–176.

Older alluvium of Tertiary(?) age consists of clay containing small amounts of interbedded sand and gravel. The upper part of the sequence may be of Pleistocene age. By analogy with other localities a lake environment of deposition is inferred, but occurrence of a marine estuary is considered possible. Thickness of the clay is not stated.

Miller, R. R.

1946. Correlation between fish distribution and Pleistocene hydrography in eastern California and southwestern Nevada, with map of the Pleistocene waters: Jour. Geology, v. 54, no. 1, p. 43–53.

Miller presents icthyologist's interpretation of Pleistocene drainage and lakes in the area cited by means of a useful review and map. Map shows areas occupied by lakes, as Miller interprets data, pointing out that these areas are not all contemporaneous.

Miller, W. J.

1928. Geology of Deep Spring Valley, California: Jour. Geology, v. 36, no. 6, p. 510–525.

Map shows exposures of soft white limy Pleistocene lake beds, which record a lake that was 12½ by 4½ miles in its maximum extent and 400–500 ft deep and that overflowed to Eureka Valley. Near-shore deposits were found at four localities consisting, in part, of soft marly stratified material and containing small fossil mollusks.

Montagne, John de la

1957. (and Barnes, W. C.), Stratigraphy of the North Park Formation, in the North Park area, Colorado; in Rocky Mountain Assoc. Geologists Guidebook to the geology of North and Middle Parks Basin, Colorado: p. 55–60.

The North Park Formation of Miocene age consists of three facies in the Saratoga Valley which continues the trend of North Park northward for 75 miles. The channel and flank facies are made up of alluvium and colluvium, respectively. The overbank facies consists of fine tuffaceous siltstone and marl, algal limestone, claystone, and laminated shale, which were deposited in "backwaters and lakes along flat reaches of the ancestral North Platte floodplain." This facies is notably calcareous. Vertebrate fossils have established the age of the formation.

Moore, B. N.

1941. (and Tolman, C. F., Jr., Butler, B. S., and Hernon, R. M.). Geology of the Tucson quadrangle, Arizona: U.S. Geol. Survey open-file report.

The Pantano Formation of Tertiary age includes a strip along the trace of a thrust fault at the southwest base of the Catalina Mountains and part of a remnant of an overthrust block near Bellota Ranch. It is "very probable" that Pantano sediments underlie the bolson between the Catalina and Tucson Mountains.

In Rincon Valley, the Pantano Formation is red; patches of tufa along west base of Tanque Verde Mountains record lakes or ponds. Beds of gypsum suggest playa conditions.

Morrison, R. B.

1940. Ground-water resources of the Big Sandy Valley, Mohave County, Arizona: Tucson, Arizona State Water Commissioner, 6 p. (mimeographed).

The older fill of uncertain age in this intermontane basin grades laterally from fanglomerate along the margins to lake deposits that are mainly silty sandstone, silt, and clay but include some limestone, volcanic ash, diatomite, analcite sandstone, bentonite, and gypsum. Thickness is not stated, but structure sections drawn to scale imply at least 500 ft.

1952a. Late Quaternary climatic history of the northern Great Basin [abs.]: Geol. Soc. America Bull., v. 63, no. 12, p. 1367.

The deposits of Lakes Bonneville and Lahontan record similar sequences of lake cycles and interlake-cycle soil development which show that the same succession of climatic changes affected both areas.

The record of fluctuating lake levels indicates changes in balance between precipitation and evaporation. Comparatively small increases in precipitation or decreases in evaporation from present rates could have resulted in the formation of the highest lakes within relatively short intervals of time. Comparison of volumes of Lahontan lakes and of tributary Sierra Nevada glaciers shows that inflow came mainly from normal runoff within the drainage basin; only negligible amounts came from melting glaciers.

1952b. Stratigraphy of Lake Lahontan and associated Quaternary deposits in the Carson Desert area, near Fallon, Nevada [abs.]: Geol. Soc. America Bull., v. 63, no. 12, pt. 2, p. 1367–1368. [Abstract quoted in full.]

Detailed mapping in the southern Carson Desert area shows the following stratigraphic section of Quaternary deposits:

1. At base, thick fan gravel grading to shallow-lake sediments; very strong Brown Soil profile in the gravel.
2. Sediments of several high-lake cycles (substages), which Russell defined collectively as Lake Lahontan:
   a. First lake substage: gravel, ranging to 4,382 ft altitude, highest Lake Lahontan shoreline; mainly boulder gravel, locally with lithoid tufa; offshore sand and clay rarely exposed, but encountered in wells.
   b. In highlands, eolian sand and alluvium with strong Brown Soil profile; in lowlands, shallow-lake sediments with local eolian sand and alluvium down to 3,930 ft and swamp muck down to 3,850 ft, indicating intermittent complete desiccation.
   c. Second lake substage; gravel, sand, and tufa on hill shores to 4,370 ft altitude (contrary to Russell's interpretation that the second lake substage rose higher than the first); clay offshore.
   d. Local eolian sand and alluvium on hill shores, demonstrating lake recession to about 4,050 ft altitude.
   e. Third lake substage: gravel, sand, and tufa to about 4,200 ft on hill shores; clay offshore conformable on second lake substage clay.
3. Deposits of seven post-lake Lahontan low lakes separated by subaerial deposits and disconformities recording intervals of complete desiccation. High shore of first lake was 3,975 ft; those of later lakes successively a few feet lower. Before first lake and between first and second lakes extensive deflation and eolian deposition took place in lowlands, followed by weak Gray Desert Soil profile development. Subsequent disconformities are less marked.

Morrison, R. B.

1959. Stratigraphic sections, well logs, and soil-profile sections in the southern Carson Desert near Fallon, Nevada: U.S. Geol. Survey open-file report, 294 p. (duplicated).

In the area named, the Lahontan Valley Group of Pleistocene age is more than 330 ft thick. Of this total, two units are entirely lacustrine, having been formed in the waters of Lake Lahontan. These are the Sehoo Formation, 96 ft thick, and the Eetza Formation, 90 ft thick. The Lahontan Valley Group is overlain in places by the Fallon Formation of Recent age in which 20 ft of the total 35-ft thickness is lacustrine. One outcrop of lacustrine silt (locality not stated in discussion) suggests that there was a lake older than Lake Lahontan. The lacustrine and subaerial sediments, shore features, and three major and a number of minor soil horizons suggest a complex history of repeated flooding and partial to complete desiccation in Pleistocene and Recent time. The body of the report consists of well logs, stratigraphic sections, and auger-hole profiles.

Moulder, E. A.

1958. (and Kohout, F. A.). Ground-water factors affecting drainage in the First Division, Buffalo Rapids Irrigation Project, Prairie and Dawson Counties, Montana: U.S. Geol. Survey Water-Supply Paper 1424, 198 p.

A short-lived Pleistocene lake was formed when Yellowstone River Valley was dammed by glacial ice. The lake extended at least 90 miles upstream from a point near Sidney, Mont. Other authors have suggested glacial-ice dam near Intake, Mont.

Muessig, Siegfried

1957. (and White, G. N., and Byers, Jr., F. M.), Core logs from Soda Lake, San Bernardino County, California: U. S. Geol. Survey Bull. 1045–C, p. 81–96.

Five core holes, ranging in depth from 78 to 1,070 ft, were drilled in the basin of Soda Lake. The site was occupied in Pleistocene time by Lake Mohave, one of the members of the Mojave River Pleistocene-lake system. One stratum of clay containing ostracodes was found in every hole at depths ranging from 30 to 120 ft and is considered to be a deposit of Lake Mohave. The absence of appreciable amounts of salts in the strata cored indicates that the lake(s) that occupied the basin had exterior drainage. The character of lacustrine sediments of the basin is given by the core logs.

Mullineaux, D. R.

1959. (and Gard, L. M., and Crandell, D. R.). Continental sediments of Miocene age in Puget Sound lowland, Washington: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 3, p. 688–696.

Fluvial and lacustrine sediments of Miocene age occur at three places east of Tacoma, Wash. As much as 20 ft of lake-deposited strata are exposed. Evidence for environments of deposition is not specified.

Mulryan, Henry

1939. Fresh-water diatomite in the Pacific Coast region: Am. Inst. Mining Metall. Engineers Tech. Pub. 1057, 8 p.

Paper lists 11 common fresh-water diatom species found in the Pacific Coast diatomites. Diatomite deposits in California, Nevada, Utah, Oregon, Idaho, and Washington are characteristically circular in plan, thickest toward middle, and commonly occur beneath vesicular basalt flows. All the described deposits are

lacustrine. Their individual geologic age is not specified, but their overall range is from Miocene to Recent. Lacustrine deposition is inferred from circular shapes of deposits and habitats of the diatoms.

Nace, R. L.

1939. Geology of the northwest part of the Red Desert, Sweetwater and Fremont Counties, Wyoming: Wyoming Geol. Survey Bull. 27, 51 p.

In the mapped area several formations contain lacustrine deposits. The Tipton Tongue of the Green River Group is 167 ft thick and sandy and is inferred to represent a shore facies of the Tipton. In the Morrow Creek Tongue of the Green River Group, a thickness of 32 ft of limestone, calcareous shale, and well-consolidated clay and shale is inferred to be lacustrine in origin. It contains silicified algal balls, abundant ostracodes, and a thin silicified algal reef. Both units are of Eocene age.

The Bridger Formation (Eocene) is separated into upper and lower sections. Both sections contain sandstones, siltstones, clays, shales, and limestones and have yielded fresh-water mollusks, algae, gar-pike scales, and other fossil remains of fishes. The presence of limestone and fresh-water gastropods and fishes suggest that the Bridger is, in part, lacustrine.

Newcomb, R. C.

1952. Ground-water resources of Snohomish County, Washington: U.S. Geol. Survey Water-Supply Paper 1135, 133 p.

The Admiralty Clay of Pleistocene(?) age is locally exposed in Snohomish County from sea level to an altitude of 200 or 209 ft. Well logs show comparable strata to about 1,500 ft below sea level. The Admirality Clay consists of thin horizontally bedded clay and silt and, locally, of intercalated sand and gravel. It was named "Admirality Fill" by Bailey Willis and G. O. Smith (1899, Tacoma, Washington, U.S. Geol. Survey Geol. Atlas, Folio 54). Newcomb considers the clay-silt beds to be lacustrine, stating (p. 34) that "The Puget Basin, in which the Admirality clay was deposited, was a large rather shallow lake." Definitive reasons for this conclusion are not given.

1958. Ringold formation of Pleistocene age in type locality, the White Bluffs, Washington: Am. Jour. Sci., v. 256, no. 5, p. 328–340.

Measured sections total 620 ft of exposed Ringold Formation, of which 505 ft is interpreted as lacustrine. On the basis of well data, this formation is projected into the subsurface of the Pasco basin to include 50 ft of conglomerate and 100–290 ft of lacustrine silt, clay, and sand resting on basalt. (The latter interval makes up what drillers commonly call "blue clay".)

1958. (and Hart, D. H.). Preliminary report on the ground-water resources of the Klamath River basin, Oregon: U.S. Geol. Survey open-file report, 248 p.

The Yonna Formation of Middle Pliocene(?) age, is 2,000 ft in maximum thickness. Its lower part is largely sedimentary and includes diatomite, laminated siltstone, and water-laid volcanic ash. It is inferred that deposition was in lakes and on volcanic plains. The lamination and the widespread diatomite imply the lake environment.

Nightingale, W. T.

1930. Geology of Vermilion Creek gas area in southwest Wyoming and northwest Colorado: Am. Assoc. Petroleum Geologists Bull., v. 14, no. 8, p. 1013–1040.

In the Vermilion Creek area, the Hiawatha member of the Wasatch Formation (Eocene) lies below the Tipton tongue (of Green River age). Gray shale makes up most of member, which also contains green to pink shale, carbonaceous shale, lignite, and some local sandstone lenses. The sandstone lenses are important known and possible gas-producing zones. The member is about 4,100 ft thick. The formation is partly fluviatile, partly lacustrine in origin.

Noble, L. F.

1954. (and Wright, L. A.). Geology of the central and southern Death Valley region, California: California Div. Mines Bull. 170, chap. 2, no. 10, p. 143–160.

Various rocks of Tertiary age are exposed in the region. The sedimentary deposits consist of clay shales, siltstones, sandstones, and conglomerates and appear to occupy areas that were troughs and basins of deposition in Tertiary time. The Furnace Creek Formation (Pliocene) is about 2,500 ft thick and contains playa deposits that include gypsum and borates, rock salt, and celestite in various areas of exposure.

At the southern end of Amargosa Valley, a series of apparently unnamed "conglomeratic lake beds of Pleistocene age" overlie the China Ranch Beds (Pliocene?). Overlying all older rocks with unconformity are alluvial fans, playa and lake deposits, sand dunes, and—locally—basaltic cinders and cinder cones, all of Quaternary age. Salt, interlayered with clay, underlies at least 125 sq mi of the floor of Death Valley. Test holes have penetrated 600–1,000 ft of salt and clay without penetrating the base.

Nolan, T. B.

1928. Potash brines in the Great Salt Lake Desert, Utah: U.S. Geol. Survey Bull. 795–B, p. 25–44.

Analyses of clays and silts from the Great Salt Lake Desert show 11–15 percent soluble salts, inferred to be residual, deposited with the clastic materials and not flushed out by percolating waters.

Brines in surface salt crust are the direct result of evaporation of the residual lake; the last arms to be flooded were those away from Gilbert's hypothetical axis of uplift. Occurrence of brines at various horizons below the surface and their restriction to thin layers within predominantly salt-free clay layers probably result from deposition of thin crusts of salt as proto-Lake Bonneville lakes were desiccated; then crusts were covered rapidly with land-derived waste.

1935. The Gold Hill mining district, Utah: U.S. Geol. Survey Prof. Paper 177, 172 p.

The White Sage Formation of Eocene(?) age includes fresh-water limestone containing fresh-water gastropods. It is locally exposed in the northwestern part of the Gold Hill quadrangle, and at one place is 600 ft thick. Original thickness of the White Sage is not known.

Nolan, T. B.

1956. (and Merriam, C. W., and Williams, J. S.). The stratigraphic section in the vicinity of Eureka, Nevada: U.S. Geol. Survey Prof. Paper 276, 77 p.

The Newark Formation of Early Cretaceous age occurs in two areas in Eureka, Nev., is 1,800 ft thick, and contains fresh-water limestone, fresh-water fishes and mollusks, and plant remains.

Oakeshott, G. B.

1951. Mineral fuels of the San Francisco Bay Counties: California Div. Mines Bull. 154, p. 223–230.

All California coals were deposited in lagoons, swamps, and shallow lakes in Paleocene, Eocene, and Miocene time.

Pack, R. W.

1920. The Sunset-Midway oil field, California, Pt. 1, Geology and oil resources: U.S. Geol. Survey Prof. Paper 116, 179 p.

The Paso Robles Formation (now called Tulare Formation) is Pleistocene(?) and Pliocene in age and is partly lacustrine. It is 2,000–4,000 ft thick in the area northwest of main Temblor Range and 2,300–3,400 ft thick elsewhere in the area. Lenticularity is a prime characteristic; some lenses are large, some small. Knife-sharp contacts may occur. In Midway field, the Paso Robles is oil bearing. Quiet-water deposition of part of the formation is inferred from presence of compact very fine-grained clay.

Palmer, A. R.

1957. (and others). Miocene arthropods from the Mojave Desert, California: U.S. Geol. Survey Prof. Paper 294–G, p. 237–280.

The Calico Mountains contain outcrops of the Barstow Formation (Miocene), especially in area east of Odessa Canyon. The Barstow includes about 2,000 ft of lacustrine and fluviatile sediments, beds—locally—having gypsum and associated borate minerals and petroliferous limestone nodules. Nodules carry remarkably preserved arthropod fauna and occur in thin beds of brown shale underlying a prominent 5-ft ledge of white gypsum in lake-bed sequence. The aquatic species of the fauna are strikingly similar to living assemblages found in Soap Lake in Central Washington and, with the lithology, imply deposition in a Miocene lake that may have been highly alkaline.

Pardee, J. T.

1910. The glacial Lake Missoula: Jour. Geology, v. 18, no. 4, p. 376–386.

Notable shorelines at the 3,700- and 4,200-ft altitudes and the presence of erratics at 4,100 ft in a nonglaciated valley indicate that Bitterroot Valley was occupied by a lake in Pleistocene time. Site of the city of Missoula was 1,000 ft under water at maximum stage. A dam of glacial ice is visualized as the control.

1913. Coal in the Tertiary lake beds of southwestern Montana: U.S. Geol. Survey Bull. 531–G, p. 229–244.

Various northwest-alined basins contain tuffaceous lake strata having fresh-water mollusks and ostracodes as well as vertebrate fossils. The coal-bearing strata are Oligocene(?), perhaps equivalent to Wind River Formation, and the non-coal-bearing sequence is Miocene.

Pardee, J. T.

1925. Geology and ground-water resources of Townsend Valley, Montana: U.S. Geol. Survey Water-Supply Paper 539, 61 p.

Paper reviews literature pertaining to the description and occurrence of lacustrine deposits—mostly Oligocene, some Miocene, which together are referred to as "Tertiary lake beds" in valleys of western and southern Montana. A map of Townsend Valley is included. The regional literature cited includes repeated mention of fresh-water mollusks, fossil fishes and turtles, beds of diatomite, and gradation from coarse-grained sediments along basin margins to flat-bedded laminated strata of clay- and silt-size particles near the basin axes, which in their entirety are apparently interpreted as indicating a lacustrine environment.

1926. (and Bryan, Kirk). Geology of the Latah formation in relation to the lavas of the Columbia Plateau near Spokane, Washington: U.S. Geol. Survey Prof. Paper 140–A, p. 1–16.

The Latah Formation consists chiefly of clay and shale but includes beds of sand and gravel and a few of impure diatomite. In its type area near Spokane, it is at least 250 ft thick, but near Coeur d'Alene, Idaho, its thickness may be 1,500 ft. Plant fossils indicate a Miocene age. Still-water deposition is indicated by fine grain and delicate lamination. Where leaves were preserved as perfect imprints parallel to lamination of the shale, the occurrence would "seem to indicate the presence of lakes." Where vegetable remains are macerated, a swamp environment is inferred.

Peale, A. C.

1893. The Paleozoic section in the vicinity of Three Forks, Montana: U.S. Geol. Survey Bull. 110, 56 p.

Peale mapped but did not describe the "Bozeman Lake Beds (Neocene)" in a large area near Three Forks, Mont.

Pease, M. H., Jr.

1957. (and Hoover, Linn). Geology of the Doty-Minot Peak area, Washington: U.S. Geol. Survey Oil and Gas Inv. Map OM 188.

Map extends outcrop of Robert's (1958) Wilkes Formation of Miocene and Pliocene(?) age, which includes some lake deposits, from Chehalis area westward to points of disappearance as it interfingers with marine strata of equivalent age.

Peck, R. E.

1941. Lower Cretaceous Rocky Mountain nonmarine microfossils: Jour. Paleontology, v. 15, no. 3, p. 285–304.

Ostracodes and charophyte oogonia are described from the Gannett Group, Bannock County, Idaho, Lincoln County, Wyo., and northward across Snake River. The Peterson and Draney Limestones yielded the fossils.

The Kootenai and Bear River Formations yielded microfossils which suggest marked similarities between the Gannett Group, Kootenai Formation and lower Bear River Formation (of Peck). Peck assigns an Early Cretaceous age to all which are younger than the Morrison Formation (Jurassic) and with which he contrasts the microfossils found.

Peck, R. E.

1957. North American Mesozoic Charophyta: U.S. Geol. Survey Prof. Paper 294–A, p. 1–44

Paper describes charophyte species from Jurassic and Cretaceous strata of six Rocky Mountain and Plateau States and assigns them to nonmarine habitat of shallow slow-moving or static water. Distinction of forms specifically diagnostic of lakes is not yet made. Fossils are found most frequently in fresh-water limestone or in adjacent clay above or below limestone.

Pettijohn, J. J.

1957. Sedimentary rocks, 2d ed.: New York, Harper and Bros., 718 p.

Pettijohn's description of fresh-water limestone is cited in full in the present report (p. 28).

Phalen, W. C.

1914. Celestite deposits in California and Arizona: U.S. Geol. Survey Bull. 540–T, p. 521–533.

Deposits of celestite occur north of Barstow near the south end of Death Valley in a belt 9 miles long by 1.5 miles wide. Celestite is interbedded with salt, gypsum, clay, sand, and gravel; the whole sequence is interpreted as lacustrine.

Picard, M. D.

1956a. Tertiary oil and gas fields in Utah and Colorado [abs.]: Geol. Soc. America Bull., v. 67, no. 12, p. 1800.

Nonmarine hydrocarbons were produced as of Jan. 1, 1956, in Utah and in Colorado from 161 wells distributed in 19 fields. Of these, 71 produced oil, 85 gas, and 5 both. Formations are of Paleocene or Eocene age, or both; primary environments of deposition were lacustrine and fluvial with minor deltaic and paludal phases. Source rocks are probably mostly lacustrine.

1956b. Summary of Tertiary oil and gas fields in Utah and Colorado: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 12, p. 2956–2960.

In 1955 nonmarine Tertiary strata produced 1,484,951 bbl of oil in the intermontane region, cumulative total through 1955 was 7,646,402 bbl. Gas is also produced from zones that occur in the Fort Union, Wasatch, Green River, and Uinta Formations of Paleocene and Eocene age. It is further stated that "these various oils originated from several Tertiary stratigraphic units deposited in a lacustrine environment * * * [p. 2960]."

1957a. Criteria used for distinguishing lacustrine and fluvial sediments in Tertiary beds of Uinta Basin, Utah: Jour. Sed. Petrology, v. 27, no. 4, p. 373–377.

Preliminary conclusions are given from the study of lacustrine and fluvial units of Paleocene and Eocene age in the Uinta Basin (they may not apply elsewhere).

Lacustrine sandstones, generally acted upon longer by water than fluvial sandstones, tend to be more uniform in appearance than the fluvial and contain less clay, feldspar, mica, and rock fragments. Red sandstones are scarce in lacustrine sequences, rather common in fluvial. Ostracodes and oolites are common in lacustrine, scarce in fluvial strata. Sandstones of both environments are similar, but the lacustrine sandstones appear more uniform. The lacustrine shales are denser, harder, better bedded, more continuous, somewhat thicker, and contain more limestone and dolomite than the fluvial. The lacustrine units com-

monly have limestone, dolomite, and—locally—coquinoid, algal, or detrital limestone, but the fluvial units have only sparse thin beds of limestone.

Lacustrine and fluvial shales and sandstones

Character	Lacustrine shales	Fluvial shales
Color	Various shades of brown or gray, less commonly of green.	Generally reddish or greenish. At places tan, ocher, maroon or gray.
Hardness	Moderately hard to very hard.	Soft to moderately hard.
Luster	Subwaxy to resinous, locally earthy.	Earthy.
Accessory materials.	Pyrite, marcasite, chert, silica and—rarely—saline minerals.	Rock fragments.
Cement	Calcite, dolomite, or silica	Calcite.
Bedding	Thin bedded to varved	Generally indistinct.
Lateral continuity.	Usually much greater than fluvial units.	
Bed thickness	Overall somewhat thicker than fluvial units.	

Character	Lacustrine sandstones	Fluvial sandstones
Mineralogy	Low orthoquartzite, high subgraywacke, arkose.	Same.
Roundness	Subrounded (most common) to rounded.	Subangular to subrounded.
Size	Usually fine to very fine sand; Siltstones common.	Fine to medium sand, generally coarser than lacustrine.
Cement	Calcite, dolomite, or silica	Calcite; at places clay or clay and calcite, rarely any others.
Color	Mostly white to light gray	White to light and medium gray, red, green, greenish gray.
Bedding	Graded bedding locally present.	Current bedded.
Lateral continuity.	Generally more continuous than the fluvial units.	

1957b. Red Wash-Walker Hollow Field, stratigraphic trap, eastern Uinta Basin, Utah: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 5, p. 923–936.

Red Wash-Walker Hollow Field is an example of a stratigraphic trap, 44 sq mi in area. It produced 800,000 bbl oil in 1955 and is probably the largest lacustrine oil field in the world.

The Douglas Creek Member of Green River Formation (Eocene) is the producing formation. It is 440 ft thick and consists of sandstone, siltstone, shale, limestone, and minor amounts of dolomite.

Piper, A. M.

1932. Geology and ground-water resources of The Dalles region, Oregon: U.S. Geol. Survey Water-Supply Paper 659–B, p. 108–190.

The Dalles Formation (of Miocene or Pliocene age) is mostly fluviatile but contains thin elements near the base, consisting of laminated (varved?) clay and laminated sandy clay that are interpreted as lacustrine. It is considered generally contemporaneous with the Mascall and Ellensburg Formations.

1939. (and Robinson, T. W., and Park, C. F., Jr.). Geology and ground-water resources of the Harney Basin, Oregon: U.S. Geol. Survey Water-Supply Paper 841, 189 p.

The Danforth Formation of Pliocene age is more than 700 ft thick. The upper part is about 400 ft thick and consists of conglomerate, sandstone, silt, and beds of pumice and pumiceous silt and tuff. Rhyolite and volcanic breccia and ash are abundant especially near the top of the section. About 100 ft of the total thickness is or may be lake-deposited sediments.

Unamed deposits of Pleistocene and Recent age include lake and playa sediments. The presence of ancient lakes is inferred from geologic evidence indicating that the basin was closed at times by eruptions of basalt and, separately, of volcanic ash and by analogy with other Oregon basins where lacustrine environments are more clearly defined.

Powell, W. J.

1958. Ground-water resources of the San Luis Valley, Colorado, with a section on an inflow-outflow study of the area by P. B. Mutz: U.S. Geol. Survey Water-Supply Paper 1379, 284 p.

Powell states (p. 21) that the Alamosa Formation of Pliocene or Pleistocene age is probably fluviatile in origin, thus differing from Siebenthal (1910) who considered the formation to be lacustrine. Neither paper discusses the origin in any detail.

Powers, H. A.

1932. The lavas of the Modoc Lava Bed quadrangle, California: Am. Mineralogist, 1. 17, no. 7 p. 253–294.

The author mentions "a great thickness of lake beds and basalts." The beds consist of gravel, diatomite, silt, and ash and overlie a "Massive lava group" (Pliocene?) and underlie Warner Basalt (Pliocene and early Pleistocene). A map on page 1 shows the distribution, but the stratigraphy of the lake deposits was not studied.

Powers, W. E.

1933. The extinct Lake San Augustin, New Mexico: Science new ser., v. 77, p. 51–52.

At its highest stages, an ancient lake, Lake San Augustin, was about 32 by 11 miles and about 165 ft deep. The shorelines are clearly marked. This lake connected with an unstudied basin to the east and is considered late Wisconsin in age. The shore features are cut on alluvial fans.

Putnam, W. C.

1949. Quaternary geology of the June Lake district, California: Geol. Soc. America Bull., v. 60, no. 8, p. 1281–1302.

Putnam suggests the name "Lake Russell" for the Pleistocene equivalent of Mono Lake. The author found that Lake Russell had an outlet at Tahoe stage into the Owens Valley-Death Valley sequence. He describes 160 ft of Lake

Russell sediments exposed near Leevining and mapped Tahoe- and Tioga-stage shorelines on the west side of Mono Lake. The lacustrine sediments "deposited near the mouth of a large glacial stream" include five beds of gravel. Some beds of sand show contorted bedding, the folds overturned lakeward. Putnam infers that the contortions resulted from slippage off the edge of a delta as the delta lip became overloaded.

Regnier, J. P. M.

1956. Tertiary geology of Pine Valley, north-central Nevada [abs.]: Geol. Soc. America Bull., v. 67, no. 12, pt. 2, p. 1822–1823.

Horizontal Pleistocene lake beds in Pine Valley overlie 2,700 ft of Miocene sediments that consist largely of volcanic debris with intercalated diatomite. Pleistocene beds consist of clay, limestone, and vitric ash. Eastward they grade into fanglomerates.

Reiche, Parry

1950. Geology of part of the Delta-Mendota Canal near Tracy, California: California Div. Mines Spec. Rept. 2, 12 p. [Quoted from rept.]

A characteristic feature of the Tulare Formation [Pliocene and Pleistocene(?)] is its small-scale variation; in very short distances, rapid lensing and channeling and less readily noted rapid graduation in the proportion of the various grade fractions are the rule. One can seldom match a given bed or lens across the [Delta-Mendota] canal cut, a distance of only 48–102 ft. * * * The uppermost 30 to 35 ft of the local Tulare, however, is a single nearly homogeneous bed of marked continuity. [This diatomaceous siltstone is interpreted as having been deposited] either in a river floodway or in a shallow lake subject to flood overflow.

Repinning, C. A.

1954. (and Irwin, J. H.). Bidahochi formation of Arizona and New Mexico: Am. Assoc. Petroleum Geologist Bull., v. 38, no. 8, p. 1821–1826.

The Bidahochi (Pliocene) Formation consists of three members: an upper, which is fluviatile; a middle, which consists of a basalt flow and associated volcanic sediments; and a lower, which is lacustrine (C. A. Repenning, oral communication, 1959). The lower member is found only in Arizona, where it is 213 ft thick. It occurs mainly in the headwater areas of the Little Colorado River on the Navajo Indian Reservation. The paper includes maps and a measured section.

Rezak, Richard

1957. Stromatolites of the Belt series in Glacier National Park and vicinity, Montana: U.S. Geol. Survey Prof. Paper 294–D, p. 127–154.

Stromatolites and their use in zoning and correlating outcrops of the Belt Series are described. Environments of formation of various algal structures are summarized in a table (p. 145–146), and the principle items are as follows:

Marine environment

Depth 1–6 ft: unattached spheroidal bodies.

Near sea level but above low watermark: sediment-binding algae may produce stromatolites like those of Belt Series.

Deeper water: calcareous algae exist but do not form stromatolitelike structures.

Continental environments

Fresh-water lakes: arborescent algal structures or concretionary (water biscuit) forms; not stromatilites.

Fresh-water streams: concretionary structures.

Shallow lakes, saline and warm, whose salinity varys with time, such as Lakes Bonneville and Lahontan and their present remnants: tufa that is porous, laminated, and lithoid and that resembles stromatolites of Belt Series forms in nearshore environment; on shallow-lake bottoms, tufa is compact, laminated, irregularly shaped, lithoid, and only roughly like stromatolite of Belt Series.

Deeper, colder lakes with fluctuating lake levels and wave action: beach-zone tufa as in shallow saline lakes; on lake bottoms, arborescent forms occur in mildly saline lakes as well as fresh-water lakes (above).

Richmond, G. M.

1952. (and Morrison, R. B., and Bissell, H. J.). Correlations of the late Quaternary deposits of the La Sal Mountains, Utah, and of Lakes Bonneville and Lahontan by means of interstadial soils [abs.]: Geol. Soc. America Bull., v. 63, no. 12, pt. 2, p. 1369. [Abstract quoted in full]

Late Quaternary sediments in the La Sal Mountains and in the basins of extinct Lakes Bonneville and Lahontan contain four to six buried soil profiles. Although a given soil profile may change facies laterally as it passes from one soil-forming environment to another, it maintains about the same degree of development relative to the other soils. This coincidence in the degree of development and stratigraphic position is found not only within each area but also among the three areas. The authors suggest, therefore, that the soil profiles are markers and provide a means of regional correlation of the late Quaternary deposits. The relative development of soil profiles is the basis for the following correlation:

Standard sequence	La Sal Mountains	Lake Bonneville	Lake Lahontan
Late Recent moraines.	6th glacial substage.	------	5th and younger lake substages.
	Very weak soil	Younger lake substages.	Weak soil.
Cochrane(?) substage.	5th glacial substage.	------	4th lake substage.
Moderate soil	Moderate soil	Moderate soil	Very weak soil.
Mankato substage.	4th glacial substage.	4th lake substage	3d lake substage.
Weak (Two Creeks) soil.	Weak soil	Weak soil	(Disconformity.)
Cary substage	3d glacial substage.	3d lake substage "Prove'.	2d lake substage.
Strong (Brady) soil.	Strong soil	Strong soil	Strong soil.
Tazewell substage.	2d glacial substage.	2d lake substage "Bonneville."	1st lake substage (double?).
Weak soil	Weak soil	Weak soil	
Iowan substage	1st glacial substage.	1st lake substage "Alpine."	
"Gumbo" soil	Very strong soil	Very strong soil	Very strong soil.
Pre-Wisconsin tills.	Two glacial stages	Early fan-gravel	Early fan gravel.

Roberts, A. E.

1958. Geology and coal resources of the Toledo-Castle Rock district, Cowlitz and Lewis Counties, Washington: U.S. Geol. Survey Bull. 1062, 71 p.

The name Wilkes Formation is proposed for 760 ft of claystone, siltstone, sandstone, and conglomerate, all typically tuffaceous. The strata were deposited in Miocene time, extending perhaps to Pliocene in the area of the Napavine syncline in western Washington, and include lacustrine facies. The age was determined by plant fossils. Delicate lamination and well-preserved leaves imply ponded water.

Roberts, R. J.

1951. Geology of the Antler Peak quadrangle, Nevada: U.S. Geol. Survey Geol. Quad. Map GQ-10.

Buffalo Valley, west of Battle Mountain, was occupied by a lake in Pleistocene time, probably Lake Lahontan time. Shorelines are cut to a maximum altitude of 4,640 ft on the alluvial-fan materials in the valley.

Rosenqvist, I. Th.

1959. Physico-chemical properties of soils—soil-water systems: Am. Soc. Civil Engineers Proc., v. 85, Paper 2000, SM 2, pt. 1, p. 31–53.

One sample of fresh-water clay and two samples of marine clay are shown in electron photomicrostereographs. As illustrated, there are material structural differences between the fresh-water and the marine samples. The fresh-water sample is denser, having better organized and more closely compacted components. The sampling shown is small, and the specific applicability of the method to recognition of lacustrine clay is untested.

Russell, I. C.

1885. Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: U.S. Geol. Survey Mon. 11, 288 p.

At its maximum extent, Lake Lahontan occupied an area of 8,422 sq mi and had a maximum depth of 886 ft. The lake had no outlet at any time. The resulting concentration of its waters by evaporation contributed to the formation of the lithoid, thinolitic, and dendritic forms of tufa for which the basin is famous. The clastic sediments were interpreted as representing three lake stages as follows: Lower lacustral marls, an early high-water stage; medial gravels, an intervening low-water stage; and upper lacustral marls, a later high-water stage. The clastic and chemical sediments are described in detail and illustrated. Measured sections and cross-section illustrations are numerous and show many smaller sedimentary structures, as well as gross relations. Shore features such as bars, spits, embankments, and sea cliffs are described and illustrated.

Fossils recovered include bones of mammals and fishes, mollusks, and—locally—abundant tests of ostracodes; the ostracodes make up entire beds in some areas. All assemblages imply a Quaternary age.

1889. Quaternary history of Mono Valley, California: U.S. Geol. Survey 8th Ann. Rept., p. 261–394.

The Mono Valley, at the east base of the Sierra Nevada, was occupied by an extensive lake in Quaternary time. Sediments accumulated to known thicknesses of 200–300 ft and may be thicker. Many of the lacustrine strata consist of silt and clay so finely laminated that they resemble the grain in wood. Diatomite is at least 20 ft thick. Ostracode shells are locally abundant, but other fossils were not found. The sequence of sediments—fine toward base of exposed sections, coarser near the middle, and again fine toward the top—suggests two periods of high water separated by an interval of near, or complete, desiccation analogous to the sequences recognized for Lakes Bonneville and Lahontan.

Glacial moraines at four canyon mouths are marked by shoreline features. This evidence indicates that one high stand of the lake, at least, was postglacial. The fact that abundant volcanic lapilli and pumice from adjacent Mono Craters occur throughout the lake sediments at various horizons suggests that volcanic activity was intermittent before, during, and after the Quaternary lake occupied the basin.

Numerous springs discharged into the ancient lake, their orifices being marked by cones of calcareous tufa, some at least 40 ft high. The Lahontan types of tufa—lithoid, thinolite, dendritic—are recognized, but the order of deposition is not identical with that inferred for the Lahontan basin. Some of the springs are still active and are observed to discharge around the present Mono Lake and beneath its waters as well.

1900. A preliminary paper on the geology of the Cascade Mountains in northern Washington: U.S. Geol. Survey 20th Ann. Rept., pt. 2, p. 83–210.

The name Swauk Sandstone [Formation] was applied to 6,000–8,000 ft of thick-bedded nearly white impure sands containing shale intercalations. The formation occurs variously east of Wenache [Wenatchee] Mountains, in the Valley of Wenache, and in drainages of the Middle and North Forks of the Teanaway River and Swauk Creek. The Swauk was deposited in a single Eocene lake or estuary. The Roslyn Sandstone [Formation] is also named; it occurs in the same general area and is of Eocene age, but younger than the Swauk. The Ellensburg Formation (Miocene) is described as lacustrine in origin. Quiet-water deposition for parts of the Swauk and Roslyn Formations is inferred from the excellent preservation of leaf imprints—some in laminated clay, some in thin beds of sandstone.

Russell, R. J.

1928. Basin Range structure and stratigraphy of the Warner Range, northeastern California: California Univ., Dept. Geol. Sci. Bull., v. 17, no. 11, p. 387–496.

The Cedarville Series (of Russell) consists of three members, the lowest including at least 300 ft of sediments consisting in large part of dark fine carbonaceous shale carrying seams of lignite most of which are less than an inch thick. The upper member includes "5 percent of non-volcanic sediments" which is not described. Plant fossils found in the sediments indicate Miocene age. LaMotte (1936) reports lacustrine diatoms recovered from the upper Cedarville.

Surprise Valley contains lake sediments of Quaternary age having a known thickness (well data) of 835 ft. Shallow-water deposition is inferred from the abundance of organic debris found throughout most of the depth of the well. Quaternary lakes also occupied other valleys in the region, as follows: Present Goose Lake near Alturas, where lacustrine sediments are nearly 100 ft thick; Jess Valley where lacustrine sediments are 60 ft thick; Long Valley, where there is a thin veneer of lake sediments; Pine Creek Basin, where sediments indicate a succession of several landslide lakes; and parts of Benton Meadows, Halls Meadow, meadows along Davis Creek, and Fandango Valley, where thin layers of dark sediments suggest the presence of short-lived lakes.

Schwennesen, A. T.

1917. Ground water in San Simon Valley, Arizona, and New Mexico: U.S. Geol. Survey Water-Supply Paper 425–A, p. 1–36.

Lake strata of Pliocene(?) and Pleistocene age are known from wells in the valley and crop out extensively in the lower (northern) part of the valley. A geologic cross section shows 150 ft of stream deposits at the surface, 350 ft blue clay (lake beds), and at least 750 ft clay, sand, gravel, sandstone, and conglomerate; part of the 750 ft probably is lacustrine and part older stream deposits. During the investigation, maximum penetration by wells was 1,230 ft, at which depth basement was not reached.

1918. Ground water in the Animas, Playas, Hachita, and San Luis basins, New Mexico: U.S. Geol. Survey Water-Supply Paper 422, 152 p.

Pleistocene lakes once occupied lower Animas, San Luis, Lower Playas Valley and probably Hachita Valley but almost entirely south of the Mexican border. Shore features are identifiable. Thickness of lake deposits may not be greater than 20 ft.

1919. Geology and water resources of the Gila and San Carlos valleys in the San Carlos Indian Reservation, Arizona: U.S. Geol. Water-Supply Paper 450–A, p. 1–27.

The unnamed lake deposits of Quaternary age consist of sandstone, tuff, limestone, and marly clay intercalated with basalt flows. The total thickness is inferred to be about 700–800 ft by projection of "Gila conglomerate" dip-slope surfaces. The lake deposits are inferred to overlie a surface of erosion cut on the "Gila conglomerate."[4]

1918. (and Meinzer, O. E.). Ground water in Quincy Valley, Washington: U.S. Geol. Survey Water-Supply Paper 425–E, p. 131–158.

Clay and sand with local beds of gravel and boulders occur but are not exposed except locally on faces of terraces and where deflation has removed the overburden. These beds, which are of Pleistocene age, rest unconformably on Yakima Basalt and are unconformably overlain by glacial outwash and wind-blown silt and sand. Colors are light gray, greenish gray, blue, and black. The beds contain petrified wood, bones, and fossil shells. Finer grained strata are probably lacustrine.

Sears, P. B.

1955. (and Foreman, Fred, and Clisby, K. H.). Palynology in southern North America: Geol. Soc. America Bull., v. 66, no. 5, p. 471–530.

This noteworthy study of materials from the Mexico City Basin shows the possibilities that lie largely untapped in correlating several disciplines into a unified set of data and is included in the bibliography for that reason, although Mexico is not otherwise considered. Sears (p. 472) cites "collaboration of engineer, geologist, sedimentologist, pollen analyst, ecologist, and archeologist. In turn," he continues, "information of intrinsic interest to each group, as well as to the climatologist and plant geographer, has been obtained."

Foreman recognizes seven zones based on changes in water content, relation between fresh volcanic ash and weathered ash, chemical considerations, and fossil content. From those considerations he infers conditions that existed in the lake during deposition and tectonic and volcanic activity. Results are presented

[4] Others (see Heindl, 1952) believe the lake deposits in these and other basins in the region are facies of the group of sediments that have the general designation "Gila conglomerate" and in which the coarser (fanglomerate) and finer (lake and playa deposits) sediments interfinger.

in a table. The exceptionally high content of volcanic materials make the criteria used applicable only to unusual conditions such as prevailed in the Basin of Mexico during the time of deposition of the sediments studied.

A useful tabular presentation compares deposits on the margin of the basin with lake and marsh deposits believed to be time-equivalents of the marginal deposits.

The section that correlates pollen profiles with the sedimentary profiles (Clisby and Sears, p. 511–520) makes several points worthy of note. "High pollen density is associated with slow sedimentation and high water content of the sediments, whereas stages of rapid sedimentation and low water content are marked by sparseness or absence of pollen." Composition of upland forest pollens reflects climate and, hence, also reflects major tectonic events or periods of pronounced volcanism. Ruderal pollens (such as composites and grasses) in high concentration reflect fresh ash falls and tectonic activity.

The final section (Sears and Clisby, p. 521–530) discusses the Pleistocene climate extending probably as far back as early Wisconsin time. Correlations are made with the North American midcontinent glacial advances and retreats. For tropical Mexico, it is concluded that moist periods of glacial nourishment were relatively warm.

Sharp, R. P.

1939. The Miocene Humboldt formation in northeastern Nevada: Jour. Geology, v. 47, no. 2, p. 133–160.

Miocene basin deposits of fluviatile and lacustrine origin that are 5,800 ft thick and that once covered about 40,000 sq mi, of which 2,000 sq mi centers about Elko, Nev., were studied. Three members are listed:

Upper, consisting of conglomerate, sandstone, mudstone, siltstone, and shale, is dominantly fluviatile. Mudstone and shale predominate in upper member, which reaches a maximum thickness of 3,600 ft.

Middle, characterized by rhyolitic tuff and ash. Middle member cannot be identified in a single outcrop, but a hundred feet or so of associated tuff and ash is distinctive. Maximum thickness is 1,300 ft.

Lower, consisting of shale, oil shale, fresh-water limestone, sandstone, and conglomerate. Oil shale and limestone containing numerous fresh-water mollusks identify this member and imply lacustrine deposition. Maximum thickness is 800–1,000 ft.

Siebenthal, C. E.

1910. Geology and water resources of the San Luis Valley, Colorado: U.S. Geol. Survey Water-Supply Paper 240, 128 p.

The Alamosa Formation of Pliocene or Pleistocene age consists of clay and interstratified water-bearing sands that form the artesian aquifers of San Luis Valley. Exposures are poor; the formation rests on the Santa Fe Formation at valley margins, and well records show more than 1,000 ft of lake deposits of Alamosa Formation. One log shows more than 80 changes in the character of materials in 400 ft—a fact which illustrates rapid vertical alternations characteristic of lake beds. The thickest unit reported is 14 ft. Siebenthal states (p. 46) that persistency and continuity of thin beds of sand and clay denote deposition in quiet water.[5]

[5] W. J. Powell (1958) implies fluviatile origin for the Alamosa Formation but does not discuss the problem of origin in any detail.

713-182—64——7

Silverman, S. R.

1958. (and Epstein, Samuel). Carbon isotopic compositions of petroleums and other sedimentary, organic materials: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 5, p. 998–1012.

The ratio C^{13}/C^{12} was studied in petroleum, modern plant constituents, and various other organic materials, such as marine invertebrates and natural gas. In marine organisms and in petroleum from marine sediments the ratio C^{13}/C^{12} is higher than in organisms and petroleum from nonmarine sediments. Nonmarine data were obtained largely from the Green River Formation.

Simpson, G. G.

1948. The Eocene of the San Juan Basin, New Mexico: Am. Jour. Sci., v. 246, no. 5, p. 257–282; no. 6, p. 363–385.

The author proposes the name San Jose Formation to replace the name Wasatch Formation in the San Juan Basin, principally in north-central and north-western New Mexico but extending northward into Colorado. The formation is at least 2,000 ft thick, contains an abundant vertebrate fauna, and was (p. 363) deposited, in part, in "small, shallow, temporary bodies of standing water." Elsewhere (p. 381) the author points to probable common occurrence of swampy terrane during deposition.[6]

Slentz, L. W.

1955. Salt Lake group in lower Jordan Valley, Utah, *in* Utah Geol. Soc. Guidebook no. 10: p. 23–36.

Jordan Narrows Unit (of Slentz) of the Salt Lake Group is considered to be entirely lacustrine. It consists of white marlstone (dominant), sandstone, clay, rhyolitic tuff, and oolitic, argillaceous, and cherty limestone. Its thickness exceeds 300 ft. Slentz considers its age to be uncertain but not younger than Miocene.

Smith, G. I.

1958. Late Quaternary stratigraphy and climatic significance of Searles Lake, California [abs.]: Geol. Soc. America Bull., v. 69, no. 12, pt. 2, p. 1706.

The author uses radiocarbon dates from organic muds to deduce history of Searles Lake including climatic fluctuations. As interpreted, the two main salt bodies resulted from desiccation of pluvial lakes formed during Tahoe and Tioga glacial stages of Blackwelder. The Tahoe stage is interpreted as having lasted from 60,000 to 150,000 years. The interval Tahoe to Tioga included six minor pluvials and seven periods of desiccation. Tioga stage began 25,000 years ago and ended 10,000 years ago.

1957. (and Pratt, W. P.). Core logs from Owens, China, Searles, and Panamint basins, California; U.S. Geol. Survey Bull. 1045–A, p. 1–62.

Report gives detailed lithology and mineralogy of six core holes, ranging in depth from 375 to 995 ft, drilled in modern playas. No discussion of the results is given. Diatoms and ostracodes are reported at many levels in cores from Owens and China lakes but are not identified. The strata are probably all of Pleistocene and Recent age.

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[6] C. A. Repenning (oral communication, 1959) believes that lakes existed in parts of the area during much of the period of deposition of the San Jose Formation.

Smith, H. I.

1942. Trona in Wyoming: Am. Inst. Mining Engineers Tech. Pub. 1489, Mining Technology, v. 6, no. 4, 3 p.

This report describes the mineralogy and occurrence of a massive deposit of trona within the Green River Formation of Eocene Age.

Smith, W. C.

1960. Borax and borates: Am. Inst. Mining and Metall. Engineers, Industrial minerals and rocks, 3d ed., p. 103–118.

Known borate deposits of Western United States occur in western Nevada, southern Oregon, and California and range in age from middle Miocene to Recent. The deposits are those characteristic of basins of interior drainage. Mineralogy, occurrence in lake deposits,[7] and methods of extraction and treatment of borate are discussed for major producers at Searles Lake and at Kramer. Other borate-mineral occurrences throughout the world are described briefly.

Snavely, P. D., Jr.

1958. (and Brown, R. D., Roberts, A. E., and Rau, W. W.). Geology and coal resources of the Centralia-Chehalis district, Washington: U.S. Geol. Survey Bull. 1053, 159 p.

Unnamed fluvial, lacustrine, and brackish-water deposits of siltstone, sandstone, conglomerate, and tuff, having a maximum thickness of 1,000 ft, overlie Columbia River(?) Basalt in area. Plant fossils imply Miocene age (Latah Formation equivalent) perhaps grading to Pliocene toward top of section.

Spieker, E. M.

1946. Late Mesozoic and early Cenozoic history of central Utah: U.S. Geol. Survey Prof. Paper 205–D, p. 117–161.

This paper defines the North Horn Formation (Cretaceous-Paleocene), raises the Flagstaff Limestone to formational rank, and states that fresh-water lakes existed in parts of the area from Late Cretaceous through Green River time.

The North Horn Formation at its type locality is 1,650 ft thick; of the total, 500 ft are considered to be lacustrine or mostly lacustrine because of the fine-grained, thin, regular beds, presence of limestone, and content of fresh-water mollusks. The Flagstaff Limestone (Paleocene and Eocene?) is 200–1,500 ft thick and consists dominantly of limestone; some beds are charged with fresh-water molluscan fossils. It contains interbedded gray shale and minor amounts of sandstone, gypsum, oil shale, and volcanic ash.

Spurr, J. E.

1905. Geology of the Tonopah mining district, Nevada: U.S. Geol. Survey Prof. Paper 42, 295 p.

White lake-deposited tuffs, uniformly bedded, are conspicuous near Tonopah, Nev. Conglomerate beds of well rounded pebbles are intercalated. Thickness was not determined because of faulting but exceeds 600 ft. Regularity of occurrence through hundreds of feet of the Siebert Tuff indicates long-enduring quiet water. (These strata are now included in the Esmeralda Formation of Miocene age.) Occurrence of a lake is further indicated by regional geologic relations and by the presence of fresh-water diatoms.

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[7] Smith reports (oral communication, 1961) that all known borate-mineral accumulations of significant size in United States were formed in lakes or marshes.

Stanton, T. W.

1905. (and Hatcher, J. B.). Geology and paleontology of the Judith River beds, with a chapter on the fossil plants, by J. H. Knowlton: U.S. Geol. Survey Bull. 257, 174 p.

At and near the type area in Montana, the Judith River Formation (Cretaceous) is about 500 ft thick; light colors and fine textures predominate. Fresh- and brackish-water forms are common among the fossil invertebrates; saurians, fish, and birds were recovered. Plant fossils are well preserved and fairly abundant. The environment inferred (p. 123) is that of a low-lying coastal area containing fresh-water swamps and lagoons. At intervals, the sea flooded the area, but during accumulation of 300 to 400 ft of strata there was no connection with the sea.

Staplin, F. L.

1956. Freshwater ostracodes applied to Pleistocene paleoecology in Illinois [abs.]: Resumenes de los Trabajos Presentados, 20th Internat. Geol. Congress, p. 186–187.

In Illinois, calcified specimens of *Candona* and *Cytherissa lacustris* indicate cool alkaline water. *Cyclocypris*, *Cypris*, *Physocypria*, and punctate species of *Candona* indicate warmer neutral or faintly acid waters. *Darwinula aurea* and *Cytherisa lacustris* are restricted to lakes; temporary ponds do not provide proper temperatures nor sufficient duration of water to support these forms which have extended life cycles.

Stark, J. T.

1949. (and others). Geology and origin of South Park Colorado: Geol. Soc. America Mem. 33, 188 p.

Lacustrine sedimentation occurred in the South Park region several times. In Late Jurassic time, the Morrison Formation was laid down under estaurine, lacustrine, and fluviatile conditions. The Balfour Formation is probably of early Oligocene age and includes lake deposits in the upper part. The Antero Formation (Oligocene) includes shale, containing limestone lenses in the middle member and limestone and shale in the lower member. These are inferred to be at least partly lake deposited and include algal beds and reefs, paper shales containing ostracode shells, and a single bed of limestone 20 ft thick that extends almost around the whole periphery of the Lake Antero basin. The Antero is locally at least 2,000 ft thick. Geologic evidence implies that the Lake Antero basin was formed early in Oligocene time.

Stearns, H. T.

1936. Origin of the large springs and their alcoves along the Snake River in southern Idaho: Jour. Geology, v. 44, no. 4, p. 429–450.

The Burley Lake Beds of Pleistocene age are known only from wells. A city well at Burley, Idaho, penetrated 150 ft of sediments interpreted as lake beds older than the Minidoka Basalt and younger than the Sand Springs Basalt (p. 434–439). Neeley Lake Beds of Pliocene(?) age consist of more than 100 ft of sandy flesh- to brown-colored strata that are largely reworked tuff and that are exposed in bluffs of the Snake River near Neeley, 5 miles southwest of American Falls.

Stearns, H. T.

1952. Collapse versus explosive origin of Valles Caldera, Sandoval County, New Mexico [abs.]: Geol. Soc. America Bull., v. 63, no. 12, pt. 2, p. 1371–1372.

Sediments reaching as much as 500 ft in thickness, formed in local lakes in the Jemez and San Antonio valleys in Pleistocene time. Lava dams controlled the lakes.

1956a. Ancient Lake Payette in Idaho [abs.] Geol. Soc. America Bull., v. 67, no. 12, pt. 2, p. 1736.

The Payette Formation was deposited in a series of disconnected to weakly connected basins. Strata are conformably intercalated with the Columbia River Basalt at various levels and were deposited between eruptions of the Columbia River Basalt during the Miocene. They predate the Snake River downwarp and north-south block faulting. The formation includes tuff and flood-plain deposits, as well as lake sediments some of which are diatomaceous or contain abundant fossil fishes.

1956b. Lake Idaho problem [abs.]: Geol. Soc. America Bull., v. 67, no. 12, p. 1736.

The Lake Idaho Formation (of Stearns) was deposited with angular and erosional unconformity relative to Columbia River Basalt in Pliocene and Pleistocene time. Remnants of the formation carry cinnabar at Nutmeg Mountain. Stearns implies that these deposits are not necessarily lacustrine and states that the Hagerman Formation is fluviatile in origin.

1938. (and Crandall, Lynn, and Steward, W. G.). Geology and ground-water resources of the Snake River Plain in southeastern Idaho: U.S. Geol. Survey Water-Supply Paper 774, 268 p.

Paper describes Pliocene(?) Neeley Lake Beds, Raft Lake Beds, and Hagerman Lake Beds and Pleistocene American Falls Lake Beds, lake beds near Terreton and Market Lake, and Burley Lake Beds.[8]

Identification of some of the units named as lake beds is based on the fine grain size of the sediments and on their deposition in the canyon of the Snake River above various lava dams, whose former presence is inferred from geologic mapping.

Stewart, H. B., Jr.

1958. Sedimentary reflections of depositional environment in San Miguel Lagoon, Baja California, Mexico: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 11, p. 2567–2618.

Particle-size analyses of sediments from four coastal lagoons and adjacent marshy areas suggest that distinctions can be made between fine sediments deposited in slack water and fine sediments deposited where river currents enter lagoons. The method involves plotting of median diameter of particles against the phi deviation measure ($\sigma\ \phi$). In all samples tested, slack-water deposits

[8] Recent re-examination (H. A. Powers, oral communication, 1959) shows that within the area of the Snake River plain the situation is, in brief, as follows: Idaho Formation (Pliocene and Pleistocene) contains one unit consisting of lake beds and four nonlacustrine units; the Payette Formation of Kirkham (Miocene and Pliocene(?)) contains lake deposits, but the formation is not as widespread as Kirkham (1931) showed it to be. Several other stratigraphic units south of the Snake River are of lacustrine origin and will be described and named in future publications.

and deposits from river currents yielded plots of points in nonoverlapping fields on the diagram.[9]

Stewart, J. H.

1958. (and Poole, F. G., and Wilson, R. F.). Stratigraphy and origin of major lithologic units of the Upper Triassic series on the Colorado Plateau [abs.]: Geol. Soc. America Bull., v. 69, no. 12, pt. 2, p. 1746.

The authors believe that the Colorado Plateau area in later Triassic time was a "vast alluvial plain" receiving sediments from south and east in large part. The Chinle Formation includes three units in order of decreasing age, as follows: (1) Shinarump, Monitor Butte, Moss Back, and Petrified Forest Members, deposited by streams and in lakes; (2) Owl Rock Member, dominantly lacustrine limestone and siltstone, and (3) Church Rock Member and lateral equivalents, deposited in lakes and by streams.

1959. (and Williams, G. A., Albee, H. F., and Raup, O. B.). Stratigraphy of Triassic and associated formations in part of the Colorado Plateau region: U.S. Geol. Survey Bull. 1046–Q, p. 487–576.

Discussion of the Chinle Formation of Triassic age includes suggestions for interpretation of continental environments of deposition as follows:

1. Stream and flood-plain deposits have associations of cross-stratified conglomeratic sandstone, channels, and fossil wood signifying streambed deposition; cresentic ripple-laminated sandstone lenses and structureless claystone are indicative of flood-plain deposition.
2. Lacustrine deposition is suggested by limestone beds, horizontal stratification, and nonmarine gastropods. Limestone-pebble conglomerates may have been formed during periods of slow deposition by wave action in a lake environment.

The Owl Rock and Church Rock Members of the Chinle Formation are largely lake or lagoonal deposits; the Petrified Forest Member may include some lacustrine limestone-pebble conglomerates; the Monitor Butte Member may include some swamp and lake deposits.

Stone, R. O'N.

1956. A geologic investigation of playa lakes: Univ. Southern California thesis (PhD.), unpublished, 302 p.

Playas occupy about 1 percent of the desert areas where they are common, as in the Mojave, Colorado, Sonoran, Arabian, Libyan, and Sahara Deserts. They range in size from a few hundreds of square feet through 10 by 16 miles, at Owens Lake, Calif., to 5 by 50 miles at Laguna Salada in Baja California. Fewer than 10 percent are 30 sq mi or larger in the area.

A classification of playas is suggested as follows: (1) Dry, having hard, smooth surfaces and a water table more than 10 ft below surface; (2) moist, having irregular puffy surfaces commonly of or containing abundant amounts of salts, a water table at less than 10 ft, and either salt-encrusted moist clay or crystal body surfaces; (3) compound, having a water table less than and more than 10 ft below surface in different areas of the same playa; and (4) artificial, areas, as Owens Lake, where man's activities have brought about playa conditions.

[9] The method might be used to distinguish fine lacustrine sediments from fine flood-plain sediments but apparently has not been tried. It would not be used to distinguish between current-deposited lake sediments and river deposits. The influence, if any, of transition from fresh water of the river to brackish water of the marsh or lagoon environments worked with by Stewart remains unevaluated.

Playa sediments are characteristically poorly sorted and generally do not show regular size gradations with distance from the margins or with depth; in areas having high relief adjacent to the playa, grain size of sediments is larger than in areas of surrounding low country. On dry playas, water-soluble salts make up less than 3½ percent of the sediments; on moist playas, 9–36 percent. Clays deposited in Pleistocene perennial lakes in (present) playa basins contain from 3 to 5 times as much organic carbon as do clays deposited during ephemeral stages of the lake.

Fossil snails, clams, fish and mammals all indicate, where found, an environment of fresh to brackish water and are of uncertain age within the range Pliocene to Recent. Evidence from varves, radiocarbon, and physiography indicates a Pleistocene age for most playas in the Western States and a Recent age for the rest. Sedimentation rates determined are on the order of 3–12 inches per thousand years; the lesser rate is probably more nearly correct.

The following criteria suggest playa sedimentation, where found in ancient sediments:

1. Thickness, a few to a few thousand feet.
2. Area, up to hundreds of square miles but usually less than 10.
3. Association with fanglomerate, arkose, sand and gravel; aeolian sands are commonly marginal to playa deposits.
4. Bedding, commonly poor to absent; no cross bedding, ripple mark, swash mark, or rain imprints.
5. Fossils, sparse to absent; fresh- to brackish-water types where found.
6. Diagnostic details of the sediments include:
   a. Clay 50–80 percent; sand 5–10 percent.
   b. Minerals of sand size mostly quartz, feldspar, and mica.
   c. Poor sorting; sorting coefficients typically 3–7.
   d. Organic content less than 0.3 percent.
   e. Color typically pale brown; darker colors seldom occur.

Swain, F. M.

1949. Early Tertiary Ostracoda from the Western Interior United States: Jour. Paleontology, v. 23, no. 2, p. 172–181.

The collections studied included three genera found in the Cannonball Formation of Paleocene age, which is considered to be marine. These genera are *Cythereis*, *Cytheridea*, and *Brachycythere.*

Species of the following genera are indicative of lacustrine environments where they occur in moderate or great abundance: *Candona*, *Cypridea*, *Cyprois*, *Darwinula*, *Erpetocypris?*, *Ilyocypris*, *Limnicythere*, and *Scottia*. On this basis, at least parts of the Fort Union and Flagstaff Formations of Paleocene age and of the Colton, Wasatch, Knight, and Green River Formations of Eocene age are inferred to be lacustrine.

Taliaferro, N. L.

1951. Geology of the San Francisco Bay counties, *in* Jenkins, O. P., ed., Geologic guidebook of the San Francisco Bay counties: California Div. Mines Bull. 154, p. 117–150.

During part of Paleocene time, western Alameda County stood above sea level; the country was low and swampy "and a fresh-water lake existed." In this lake, strata that contain fresh-water fossils were deposited. These beds are considered equivalent to part of the dominantly marine Martinez Formation.

The Green Valley Formation (Pliocene) is nonmarine, partly lacustrine, and 6,000 ft thick. In the Berkeley Hills, the Siesta Formation of Pliocene age is lacustrine and 50–700 ft thick. The Petaluma Formation (Pliocene) partly lacustrine, is as much as 4,500 ft thick, is probably time-equivalent to the Siesta Formation, and yields a little oil and gas. The Tehama Formation (Upper Pliocene) includes lake beds and is exposed in Berryessa Valley.

Thomas, H. D.

1952. Trona, *in* Osterwald, F. W., and Osterwald, D. B., Wyoming mineral resources: Wyoming Geol. Survey Bull. 45, p. 141–143.

Between Green River and Granger, Wyo., an exploratory oil test cored 11 ft of bedded trona, 1,500 ft below the surface in shale of the Green River Formation. Later drilling showed that about 30 sq mi is underlain by minable deposit, estimated to contain 250 million tons of trona, which has been mined by shaft and drift operations since 1947.

Thomas, H. E.

1948. (and Nelson, W. B.). Ground water in the East Shore area, Utah; Pt. 1, Bountiful district, Davis County: Utah State Engineer Tech. Pub. 5, p. 59–206.

The report deals with sediments of the Lake Bonneville Group and recognition of eroded and buried shorelines of earlier lake stages by remnants of beach shingle. Faulting has affected the lake deposits. Occurrence of ground water in several aquifers within the lake-bed sequence is described.

Thomasson, H. G., Jr.

1960. (and Olmsted, F. H., and LeRoux, E. F.), Geology, water resources and usable ground-water storage capacity of part of Solano County, California: U.S. Geol. Survey Water-Supply Paper 1464, 693 p.

The Central Valley, north of the Sacramento River delta, is underlain locally by diatomaceous clay, a few feet thick, assigned to the upper part of the Tehama Formation of Pliocene age. The diatoms are fresh-water species indicating that the clay is a probable northward extension of lacustrine clay in the Tulare Formation, which is widespread in the southern part of the Central Valley. *Coscinodiscus* cf. *C. lacustris* is the only diatom reported from the Tehama that is not also present in the Tulare (see Davis and others, 1959).

In the Putah area of the Sacramento Valley, rocks of probable Miocene or Pliocene age described as "volcanic sedimentary" strata crop out and are widely recognized in well cuttings. White ashy claystone, mudstone, or siltstone dominates the section which is about 400 ft thick. The writers infer from the lithology that "much of this fine grained sedimentary rock is of lacustrine origin and probably is diatomaceous." Microscopic examinations were not made.

Thompson, D. G.

1929. The Mohave Desert region, California, a geographic, geologic, and hydrologic reconnaissance: U.S. Geol. Survey Water-Supply Paper 578, 759 p.

Playa and lake deposits of the Owens-Searles-Panamint system and of Manix and Amargosa valleys are briefly discussed. Antelope Valley, Bristol Dry Lake, Cadiz Dry Lake, Fremont Valley, Harper Valley, Ward Lake, and Danby Dry Lake are mentioned as other probable Pleistocene lake areas. The writer dis-

cusses possible use of color of sediments as a criterion for determining the environment of deposition but concludes that color as a criterion is unreliable.

Thompson, G. A.

1956. Geology of the Virginia City quadrangle, Nevada: U.S. Geol. Survey Bull. 1042–C, p. 45–77.

Paper includes a recent discussion of Truckee Formation (Pliocene), a lake and stream unit laid down in tectonic basins near the east base of the Sierra Nevada. The formation is commonly glaringly white and contains much diatomite. The thickness is uncertain but may be as much as 3,000 ft.

Trauger, F. D.

1950. Basic ground-water data in Lake County, Oregon: U.S. Geol. Survey open-file report, 287 p.

Report includes reconnaissance geologic map showing areas of lake deposits of Pleistocene age and a few areas of Tertiary lake sediments. No descriptive text accompanies the maps and tables.

Trimble, D. E.

1957. Geology of the Portland quadrangle, Oregon-Washington: U.S. Geol. Survey Geologic Quadrangle Map 104.

The exceptional character of lacustrine deposits of Pleistocene age deposited by the Columbia River flood is described. The thickness of the lacustrine sediments is about 150 ft, of which—locally—100 ft consists of silt and clay. According to Trimble:

"The deposits were aggraded in a ponded valley system * * * The extent of the inundation is evident from the distribution of the deposits * * * and the erratics * * * A rapid loss in transporting energy * * * is evidenced by the zonate pattern of deposition, in deltaic bedding, and in a rapid decrease in size of boulders downstream from the mouth of the Columbia River gorge. These conditions are best explained by ponding. * * * The ponding was probably the result of the hydraulics of a system in which more water entered the region than could simultaneously escape * * * at the discharge end of the basin."

The lacustrine deposits include gravel, boulders as much as 7 or 8 ft in diameter, open-work pebble and cobble gravels, and gravelly sand, as well as finer grained facies.

Trowbridge, A. C.

1911. Terrestrial deposits of Owens Valley, California: Jour. Geology, v. 19, no. 8, p. 706–747.

Lake deposits of Pliocene or Pleistocene age in the "Waucobi embayment" and near Haiwee are discussed. Criteria by which to distinguish alluvial-fan deposits from standing-water deposits (lacustrine or marine) are suggested as follows:

1. In fan deposits, coarse material is widely distributed; in lake or marine it is confined to a narrow near-shore zone.
2. The textural range in a single exposure in fan deposits is large.
3. Fan material is poorly sorted.
4. Beds and surfaces on fans have depositional dips of 6°–18°; standing-water deposits as steep as 3°.
5. Fan materials have fewer and different fossils.
6. Fan materials display "lens and pocket" stratification.

7. Boulders are widely distributed vertically and horizontally in fans.
8. Still-water deposits are more likely to be cracked because of greater contraction during lithification; after cementation, they are more likely to carry veinlets [of secondary minerals?] than are fan deposits.

Tschanz, C. M.

1960. Regional significance of some lacustrine limestones in Lincoln County, Nevada, recently dated as Miocene: U.S. Geol. Survey Prof. Paper 400–B, p. 293–295.

Lacustrine limestone occurs in widely scattered localities in Lincoln and Clark Counties, Nev. On the basis of pollens and fossil fish, they have recently been dated as Miocene in age. These limestones are considered equivalent to part of the Horse Spring Formation of southern Nevada, earlier considered to be Cretaceous or Paleocene in age. Dating based on potassium-argon ratios found in biotite obtained from associated tuffs tends to support the younger age for the Horse Spring. In Nye County, Nev., limestone in the Oak Spring Formation is probably also equivalent in age. Other possible equivalents are lacustrine limestone in the Rencher and Grass Valley Formations of Cook in the Pine Valley Mountains, western Utah. Lacustrine limestone in the Claron Formation, where it occurs in the Pine Valley Mountains, is interpreted as being Oligocene or earliest Miocene on the basis of the new information. Borate deposits occur associated with some of the named lacustrine limestone, notably in extreme southern Nevada.

Turner, H. W.

1896. Further contributions to the geology of the Sierra Nevada: U.S. Geol. Survey 17th Ann. Rept., pt. 1–D, p. 521–762.

In the Mohawk Valley 40 to 50 miles southwest of Honey Lake, Pleistocene lake strata include terraced sand and gravel. Pebbles of andesite and rhyolite are abundant. The old lake area was 35 sq mi. Andesite eruptions formed a dam on ancestral Middle Fork of Feather River, causing a lake to form.

North of Mohawk Post Office, Tertiary lake deposits underlie the Pleistocene and consist chiefly of white shale containing some carbonaceous layers. These were partly eroded before Pleistocene beds were laid down.

1900. The Esmeralda formation, a fresh-water lake deposit: U.S. Geol. Survey 21st Ann. Rept., pt. 2–C, p. 191–208.

The Esmeralda Formation of Miocene age in southern Nevada consists of fresh-water-lake sandstone, shale, and marl; locally, breccia and conglomerate make up large parts of total thickness. Volcanic materials overlie lake sediments in some places and are interbedded with lake deposits in others. The thickness of the lacustrine parts of the formation aggregates 'hundreds of feet."

The map shows the distribution of the formation in the northern half of the Silver Peak quadrangle, Nevada. The text sets the boundaries as follows: South, Palmetto Mountains; east, Montezuma Mountains; west, Inyo Mountains; north, unknown. Coal is produced from Esmeralda strata at the north end of Silver Peak Range.

Twenhofel, W. H.

1932. Treatise on sedimentation [2d ed.]: Baltimore, The Williams & Wilkins Co., 926 p.

Treatise contains (p. 819–829) an extensive discussion of lacustrine sediments and criteria for their recognition.

Twenhofel, W. H.

1941. (and McKelvey, V. E.). Sediments of fresh-water lakes: Am. Assoc. Petroleum Geologists Bull., v. 25, no. 5, p. 826–849.

Although observations are reported from areas in the Middle West, the approach is useful in any area. No criteria are developed that, taken alone, suffice to distinguish lacustrine sediments from strata of other origins. Conclusions reached are believed to have 'somewhat general application * * * . Results * * * indicate that sediments of each lake are to some degree of individual character." Thirty-two variables are listed, each of which, singly or in combination with others, may affect the nature of sediments deposited.

The shape of lake deposits in plan is related to the type of lake as follows: Glacial, elongate, conforming to regional pattern; valley lakes, elongate, following regional drainage pattern; river, elongate or crescentic; structural, irregular; solution, eruption, and kettle—circular to elliptical.

Discussion of lake sediments includes a remark that "The coarsest sediments should be on the margin but it does not follow that marginal sediments are coarse." Sediments of lakes range in size from boulders to clay. The coarser sediments have restricted distribution and are found only where currents are strong. Organic sediments include marl, diatomite, iron hydroxide, manganese oxide, and various strictly organic material largely of plant origin. These plant materials include the following: Sapropel, high in bituminous constituents; dy, an organic sediment of colloidal origin found in humic waters; forna, little-altered plant and animal matter; afja, unstable protobituminous material which is the initial stage in forming gytta; and gytta, the result of extensive reworking of plant debris in digestive tracts of organisms.

In summary, an original lake deposit may lose its organic content, may lose or gain calcium carbonate, and ferric hydroxide may change to ferrous carbonate or to ferrous or ferric sulfide. A calcareous muck may become a limestone, diatomite, or mudstone. Where organic decomposition is inhibited, sediment may become black organic mudstone or peat.

Tweto, Ogden

1957. Geologic sketch of southern Middle Park, Colorado, *in* Rocky Mountain Assoc. Geologists Guidebook to the geology of North and Middle Parks Basin, Colorado; p. 18–31.

Large areas in Middle Park are underlain by an unnamed sequence of continental deposits which are all referred to "as 'lake beds', although many parts are doubtless stream deposits." The stratigraphy and occurrence remain imperfectly known. In various parts of the area, these deposits include tuffaceous clay or mudstone, tuff, tuffaceous conglomerate, dark shales, pastel-colored clays and sands, and white or bluish tuff. The thickness is about 200–500 ft but may originally have been greater. They probably range in age from Oligocene to Late Miocene or Pliocene. A map shows parts of the areas of outcrop.

Umpleby, J. B.

1917. Geology and ore deposits of the Mackay region, Idaho: U.S. Geol. Survey Prof. Paper 97, 129 p.

Lacustrine deposits of probable Miocene age underlie areas near Pass Creek summit and may be present, although covered by alluvium, in the valleys of Birch Creek, Little Lost River, and Big Lost River. The aggregate thickness is about 2,000 ft.

The lake beds are tuffaceous throughout and contain two layers consisting almost exclusively of tuff. They include limy shales, noncalcareous shales, carbonaceous layers—one prospected without success for coal—and coarser materials. No fossils were found, but the origin and age of the strata is inferred from their resemblance to lacustrine deposits in the Lemhi Valley which had been dated on the basis of fossil leaves.

Van Houten, F. B.

1944. Stratigraphy of the Willwood and Tatman formations in northwestern Wyoming: Geol. Soc. America Bull., v. 55, no. 2, p. 165–210.

The Tatam Formation (Early Eocene) is lacustrine and overlies the fluviatile Willwood Formation in part of the Bighorn Basin. Lacustrine deposition is inferred from the following: Prevalence of thin, flat bedding; scarcity or absence of current-formed sedimentary structures and of coarse sands; abundance of fresh-water ostracodes and mollusks; excellent preservation of leaf imprints on bedding surfaces; presence of oil shales and paper shales; and overall resemblance of Tatman to the shore facies of the Green River Formation.

1956. Reconnaissance of Cenozoic sedimentary rocks of Nevada: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 12, p. 2801–2825.

In Nevada and adjacent parts of Utah and California, a sequence of tuffaceous Upper Miocene to Middle Pliocene strata is widely distributed and is the most reliable stratigraphic marker in the nonmarine Cenozoic rocks of the region. The tuffaceous beds occur variously as parts of each of the following formations: Idaho, Humbolt, Salt Lake, Truckee(?), Esmeralda, Panaca(?), and Muddy Creek(?). Exact time equivalence, however, is not implied.

Important conclusions drawn by the author are as follows: Pre-middle Pliocene Cenozoic strata in Nevada were accumulated mostly under relatively quiet tectonic conditions including repeated episodes of lakes and swamps; carbonates in lake or swamp deposits are abundant in eastern Nevada and may reflect nearby sources in Paleozoic limestones; and aggradation was restricted during Oligocene epoch. Furthermore, extensive accumulation of vitric tuff, diatomite, and bentonitic mudstone has regional analogs in the following formations: The late Miocene-Middle Pliocene Cedarville and Alturas Formations in northeastern California; the Alvord Creek, Payette, and Idaho Formations in Oregon and Idaho; the Salt Lake Formation and Cache Valley Group (of Peale, 1879) in Idaho and Utah; and the Bidahochi Formation in Arizona. The present structural pattern of basins and ranges is at least locally different from the pattern of mid-Cenozoic.

Ver Planck, W. E., Jr.

1952. Gypsum in California: California Div. Mines Bull. 163, 151 p.

Pre-Tertiary gypsum is apparently marine in origin. Tertiary lakelaid gypsum deposits include the Quatal Canyon deposit in Ventura County, which occurs at the base of the nonmarine Quatal Red Clay Facies of the Santa Margarita Formation (Upper Miocene). In the Death Valley region are the China Ranch deposits of Pliocene(?) age and the Copper Canyon and Furnace Creek deposits, both occurring in the Furnace Creek Formation (Upper Pliocene) and Owl Hole Spring deposit, perhaps also of late Pliocene age. The Avawatz Mountains deposit in San Bernardino County consists of gypsum, salt, and celestite in later Tertiary lake deposits.

Quaternary playa-lake deposits having enough gypsum to be of commercial interest occur at Bristol Lake, San Bernardino County, and at Danby Lake, 35 miles southeast of Bristol. The Bristol Lake deposit of gypsum overlies clay that contains $CaCl_2$. Nodules of celestite occur in the mud of the playa margins in company with selenite.

Waagé, K. M.

1953. Refractory clay deposits of south-central Colorado: U.S. Geol. Survey Bull. 993, 104 p.

The Dry Creek Canyon Member of Dakota Sandstone (Early Cretaceous) was deposited in "relatively shallow fresh water, * * * swampy, * * * marshy, * * * or a single large shallow body." Remnants are found on the high plains south of Pueblo on the Huerfano River and thence northwest to Parkdale and Canon City. An area of at least 50 by 75 miles is involved. Deposits show sequence resembling cyclothems. Clays are mined for refractories. Depositional basin, flat beds, purity of flint clay, and alternating carbonaceous and flinty layers are taken to imply ponded water during parts of the period of deposition.

Walcott, C. D.

1897. The post-Pleistocene elevation of the Inyo Range, and the lake beds of Waucobi embayment, Inyo County, California: Jour. Geology, v. 5, no. 4, p. 340–348.

Large area of lacustrine deposition was recognized on both sides of Owens Valley near Big Pine, Calif. The beds of Quaternary age are nearly white, laminated, and calcareous. Some layers consist almost wholly of shells of fresh-water mollusks. The grain size decreases basinward in many of the beds which in general lithology are similar to those laid down in Lake Bonneville and in Lake Lahontan.

Wallace, R. E.

1949. Portion of the San Andreas rift in southern California: Geol. Soc. America Bull., v. 60, no. 4, p. 781–806.

An area about 20 by 5 miles, lying between Palmdale and Elizabeth Lake, is partly underlain by the Anaverde Formation (Pliocene), which is 2,000 ft thick. Of the total thickness, the upper 1,000 ft consists of highly gypsiferous brown to buff shales, which may represent playa-lake deposits.

1956. (and Calkins, J. A.). Reconnaissance geologic map of the Izee and Logdell quadrangles, Oregon: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–82.

Map shows terrace deposits of presumably Pleistocene age overlying the weakly consolidated lake-deposited Danforth Formation in Bear Valley along the Silvies River, Oreg.

Waring, G. A.

1918. Ground water in Reese River basin and adjacent parts of Humboldt River basin, Nevada: U.S. Geol. Survey Water-Supply Paper 425–D, p. 95–129.

Lacustrine strata of the Truckee Formation (Pliocene) are present beneath volcanic rocks in Antelope Valley and Reese River valley and consist mostly of sand and clay but include much volcanic ash.

Waring, G. A.

1921. Ground water in Pahrump, Mesquite, and Ivanpah valleys, Nevada and California: U.S. Geol. Survey Water-Supply Paper 450–C, p. 51–86.

Fifty ft or more of lacustrine or playa beds (Pleistocene) are exposed in Pahrump Valley. Well logs suggest alternating lacustrine and fluviatile or slope-wash deposition to a maximum reported peneration of 516 ft.

Weaver, Charles Edward

1958. Geologic interpretation of argillaceous sediments, pt. 1, origin and significance of clay minerals in sedimentary rocks: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 2, p. 254–271.

On the basis of present knowledge obtained from study of "thousands of X-ray analyses of clay minerals", it appears that any one of the clays can occur in abundance in any major depositional environment and no selective correlation is recognized. Weaver concludes that clay minerals reflect source materials more than influences present in environments of deposition. (See Grim, 1958.)

Weaver, C. E.

1937. Tertiary stratigraphy of western Washington and northwestern Oregon: Washington Univ. Pub. Geology, v. 4, 266 p.

The Swauk Formation of Eocene age is widely distributed in Washington east of the Cascade Mountains. It is at least 5,000 ft thick and the upper two thirds includes shale interbeds. The shales are commonly carbonaceous and, locally, contain abundant well-preserved leaf imprints. The formation was deposited on a topography of low relief where at times the river valleys contained fresh-water lakes.

The Chuckanut Formation of Eocene(?) age and more than 10,000 ft thick is entirely of continental origin in Whatcom and Skagit counties, where deposition was largely as alluvial fans. Local irregularly shaped lakes were temporarily formed. Stratified sandy clay containing remains of semitropical vegetation was deposited in them.

In later Eocene time areas east of the present Cascade Mountains held major westward-flowing streams "which at times became temporarily dammed, giving rise to extensive lakes within which there accumulated * * * alluvial valley deposits and fresh-water lake deposits now represented by the Roslyn and Manastash formations. [p. 202]"

The Clarno Formation in eastern Oregon is partly of valley alluvial origin and partly lacustrine and of Eocene age.

1945. Geology of Oregon and Washington and its relation to occurrence of oil and gas: Am. Assoc. Petroleum Geologists Bull., v. 29, no. 10, p. 1377–1415.

Weaver lists the following as wholly or in part lacustrine:

1. Miocene lacustrine and fluviatile sediments in local area north of Spokane; no name mentioned. (These are presumably Latah Formation or equivalent strata.)
2. Lacustrine and fluviatile sediments (unidentified by name) formed in Eocene, Oligocene, and Miocene time; found in the Blue Mountains between Columbia and Malheur plateaus.
3. Ellensburg Formation is partly lacustrine; age range is from Miocene to Pliocene.

4. Clarno Formation (Eocene) is "probably lacustrine." John Day Formation was deposited in part in "numerous small lakes" in Oligocene to Miocene time.
5. Mascall Formation "all * * * probably lacustrine in origin * * * and of Miocene age."
6. Roslyn and Guye Formations are lacustrine and fluviatile in origin and of Eocene age.
7. Swauk Formation is lacustrine and fluviatile in origin and of Eocene age.

1949. Geology of the Coast Ranges immediately north of the San Francisco Bay region, California: Geol. Soc. America Mem. 35, 242 p.

The Petaluma Formation of Pliocene age was deposited in a local fresh-water basin that was at times estuarine. It consists of more than 3,000 ft of sandstone, conglomerate, and clay shale containing fresh- and brackish-water mollusks. The fine-grained calcareous shales carrying fresh-water fossils and the accompanying limestone indicate lacustrine conditions. The outcrop areas are shown on a geologic map.

Webb, R. W.

1952. Upland meadows of the southern Sierra Nevada, California [abs.]: Geol. Soc. America Bull., v. 63, no. 12, pt. 2, p. 1309.

Upland meadows occur on the Boreal Plateau erosion surface south of the southern limit of Wisconsin (Tioga) glaciation and are clustered about the Great Western Divide. In 12 meadows, the sequence of meadow development is as follows: (1) lakes and swamps; (2) grasslands; (3) trenched grasslands; and (4) dissected basins of stream excavation. The trenches expose deposits of fresh-water lakes. The basins are probably glacial features formed in pre-Wisconsin time.

Westgate, L. G.

1932. (and Knopf, Adolph). Geology and ore deposits of the Pioche district, Nevada: U.S. Geol. Survey Prof. Paper 171, 79 p.

The authors used the name Panaca Formation (Pliocene(?)) for a series of water-laid tuffs, some cross bedded and some containing flinty concretions, ranging from white through cream and brown to terra cotta. The thickness is reported to be several hundred feet. It was originally (1921) named Panaca Beds by Chester Stock.

The texture is extremely fine. Locally, thin horizontal layers consisting of fragments of older limestone extend 100 to 150 ft outward from limestone cliffs against which the horizontally bedded tuff of the Panaca Formation was deposited. The tuff beds locally contain fresh-water diatoms.

Wheeler, H. E.

1954. (and Cook, E. F.). Structural and stratigraphic significance of the Snake River capture, Idaho-Oregon: Jour. Geology, v. 62, p. 525–536.

The Idaho Formation of Pliocene age is generally valid as described originally by Lindgren and invalid as redefined by Kirkham. The late Pliocene or early Pleistocene (or both) Idaho Lake was formed by the damming of the Snake River, probably by structural deformation or perhaps by volcanic eruption.

White, D. E.

1955a. Thermal springs and epithermal ore deposits, *in* pt. 1 *of* Bateman, A. M., ed., Economic geology: p. 99–154.

Many nonmarine manganese deposits are associated with lake sediments on shorelines of ancient lakes. Deposition probably occurred when thermal waters bearing manganese came in contact with alkaline-lake waters or migrated into recently deposited lake sediments (p. 137–138).

1955b. Violent mud-volcano eruption of Lake City hot springs, northeastern California: Geol. Soc. America Bull., v. 66, no. 9, p. 1109–1130.

Pleistocene lake deposits are more than 835 ft thick in Surprise Valley where hot springs are located (see Russel, 1928). In March 1951, an otherwise placid hot spring burst into violent mud-volcano eruptions of short duration. The water involved is chemically nearly neutral. High thermal gradients are deduced, and latent volcanic heat is probably the source of the energy.

Analogies are made with other mud-volcano areas of which the following involve the lakebed environment: (1) Gerlach Hot Springs, Washoe County, Nev., "probable deep-basin fill * * * fine-grained lacustrine mud and silt" and (2) Volcano Lake, Baja California, "underlain by very thick and probably fine clastic sediments—lake beds."

Wiese, J. H.

1950. Geology and mineral resources of the Neenach quadrangle, California: California Div. Mines Bull. 153, 50 p.

At the south base of the Tehachapi Mountains, a narrow band of fine-grained ostracode-bearing sediments crops out in Antelope Valley over a distance of 8 miles. Considered to be of Pliocene(?) age, the strata are characteristically finely laminated tuffaceous siltstone, clay, and marl and range in color from white through gray to orange or brick red. Chocolate-brown concretionary limestone layers are common. Faulting disrupts the sequence, but a total thickness of as much as 5,000 ft is inferred as is lacustrine deposition analogous to that of the much greater thickness of lacustrine strata in Ridge Basin (Eaton, 1939), which is 10 miles south.

Willden, C. R.

1958. Cretaceous and Tertiary orogeny in Jackson Mountains, Humboldt County, Nevada: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 10, p. 2378–2398.

The King Lear Formation of Early Cretaceous age is 200–300 ft thick and includes lacustrine-limestone lenses containing fresh-water mollusks. The formation is named and first identified as Cretaceous and occurs in the Jackson Mountains, northwestern Nevada, north of Jango and Sulfur.

Williams, J. S.

1958. Geologic atlas of Utah, Cache County: Utah Univ. Geol. and Mineralog. Survey Bull. 64, 98 p.

This report mentions three formations within the Salt Lake Group: (1) Cache Valley Formation, the youngest and largely lacustrine, which makes up most of the thickness of the group, (2) West Spring Formation, which is now considered invalid, and (3) the Collinston Conglomerate. The group may span time from Oligocene into Pliocene.

Wilson, R. F.

1958. Sedimentary facies of the Moenkopi formation of Triassic age on the Colorado Plateau [abs.]: Geol. Soc. America Bull., v. 69, no. 12, pt. 2, p. 1749.

The Moenkopi Formation includes three main lithologic types, interpreted as follows: (1) Cross-stratified sandstone and siltstone represents restricted currents, mainly stream channels; (2) ripple-laminated siltstone probably reflects "sheet-flow" currents on tidal flats or river flood plains; and (3) horizontally stratified siltstone, claystone, limestone, and gypsum implies quiet-water deposition as in lakes on tidal flats and river flood plains, in marginal lagoons, or in marine waters.

Winchester, D. E.

1923. Oil shale of the Rocky Mountain region: U.S. Geol. Survey Bull. 729, 204 p.

This report presents a comprehensive description of occurrences of oil shale in the West.

Winfrey, W. M., Jr.

1958. Stratigraphy, correlation, and oil potential of the Sheep Pass formation, east-central Nevada: Geol. Record (Am. Assoc. Petroleum Geologists, Denver, Colo.), p. 77–82.

Sheep Pass Formation consists of about 3,500 ft of lacustrine sedimentary rocks including limestone carrying fresh-water gastropods and ostracodes of Eocene age. This formation crops out on Pancake, Grant, and Egan ranges in the area south and southwest of Ely, Nev. Virtually the entire thickness is lake deposited. Several zones showed signs of oil when the formation was penetrated by drilling.

Wolcott, H. N.

1952. Salt River Valley area, Maricopa and Pinal Counties, *in* Halpenny, L. C., and others, Ground water in the Gila River Basin and adjacent areas, Arizona—a summary: U.S. Geol. Survey open-file report (duplicated), p. 171–176.

Massive clay (Pleistocene) is known from well logs between Phoenix and Litchfield Park, reaching a thickness of 700 ft. The thickness and extent suggest the lake environment of deposition. Top of the clay lies 300–700 ft below the land surface. A known lava dam occurs downstream.

Wood, H. E., 2d

1941. (and others). Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. America Bull., v. 52, no. 1, p. 1–48.

A correlation chart and useful bibliography is included. The chart is "a provincial time scale for the North American continental Tertiary * * *" as known to 1941 and shows tentative correlations with European scale.

Wood, P. R.

1960. Geology and ground-water features of the Butte Valley region, Siskiyou County, California: U.S. Geol. Survey Water-Supply Paper 1491, 150 p.

Diatomite of Pliocene age, containing fresh-water species, is widely exposed in the Butte Valley area. It is considered to be equivalent to diatomite exposed northward in Oregon and to have been formed in an ancient lake that occupied the Klamath basin. It is white and locally interbedded with volcanic ash, lapilli,

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pumice, and sand. It ranges in thickness from a few to more than 1,000 ft, including interbedded materials.

Butte Valley and Red Rock Valley are underlain by lake beds of Pleistocene to Recent age. Known largely from well logs, the deposits consist of clay interbedded with sand; the maximum thickness penetrated is 947 ft of alluvium and lake beds. Locally, a basalt flow overlies the lacustrine strata. Fossil mollusks and ostracodes suggest the lake environment.

Woodring, W. P.

1940. (and Stewart, Ralph, and Richards, R. W.). Geology of the Kettleman Hills oilfield, California, stratigraphy, paleontology, and structure; U.S. Geol, Survey Prof. Paper 195, 170 p.

Gradual freshening of waters in the Kettleman Hills area took place during late Etchegoin and during San Joaquin time. The Tulare Formation is of Pliocene and Pleistocene(?) age, and it is all of fresh-water origin except for brief brackish-water interludes. In the Tulare Formation, thin-bedded sediments in the lower part suggest lake deposits. Fossil mollusks and diatoms confirm this conclusion. Overlying sandstone and conglomerate are probably stream deposited.

1950. (and Bramlette, M. N.). Geology and paleontology of the Santa Maria district, California: U.S. Geol. Survey Prof. Paper 222, 185 p.

Paper cites the occurrence in the Paso Robles formation (Pliocene and Pleistocene(?)) of nonmarine clay, at many places acompanied by fresh-water limestone having nonmarine ostracodes and gastropods that suggest deposition in ponds and small lakes. Individual strata are a few inches to 30 ft thick within greater thicknesses of sand and gravel. The Paso Robles Formation is 2,000 ft thick.

Worts, G. F., Jr.

1951. Geology and ground-water resources of the Santa Maria Valley area, California: U.S. Geol. Survey Water-Supply Paper 1000, 169 p.

The Paso Robles Formation of Pliocene and Pleistocene(?) age is 200–2,000 ft thick and is probably the oldest nonmarine formation in the area. Boulders, gravel, sand, silt, and clay occur in quick alternations; locally, there is basal fresh-water limestone.

Wright, H. E., Jr.

1946. Tertiary and Quaternary geology of the lower Rio Puerco area, New Mexico: Geol. Soc. America Bull., v. 57, no. 5, p. 383–456.

The Santa Fe Formation (Pliocene) was deposited in a subsiding structural depression consisting of a number of basins separated end to end by structural constrictions. Playa deposits are found mostly in the Gabaldon Badlands, where at least 4,100 ft of tan, buff, and brown sand and brown and red gypsiferous silt and clay compose the lower and middle members of the Santa Fe Formation. Comparable strata are not known in other areas underlain by the Santa Fe Formation.

Yen, Teng-Chien

1946a. Late Tertiary fresh-water mollusks from southeastern Idaho: Jour. Paleontology, v. 20, no. 5, p. 485–494.

Collections from a coarse light-gray massive oolitic calcareous sandstone in the Salt Lake Formation are indicative of the shallow-water facies of a large lake

assigned to upper Miocene age. The collection includes species of the fresh-water clam *Pisidium* and of fresh-water snails in the genera *Valvata, Amnicola, Brannerillus, Lymnaea, Physa, Armiger, Vorticifex, Carinifex, Planorbifex,* and *Papyrotheca.* Ostracodes are reported as abundant but were not identified.

1946b. Eocene nonmarine gastropods from Hot Springs County, Wyoming: Jour. Paleontology, v. 20, no. 5, p. 495–500.

Assemblage is taken to indicate, as does the uniform lithology of the strata, that deposition was in a large but shallow body of water. Mollusks are now found in fine marly gray limestone at northeast end of Lysite Mountains. The following genera of fresh-water snails are reported: *Charydrobia, Lymnaea, Physa, Australorbis, Anisus, Menetys.* Two genera of land snails, *Glypterpes* and *Vertigo,* also occur and are considered to be accidental admixtures.

1951. Fossil fresh-water mollusks and ecological interpretations: Geol. Soc. America Bull., v. 62, no. 12, pt. 1, p. 1375–1380.

Paper sets up systematic method of collecting data on fossil fresh-water mollusks as part of a program for understanding of paleoecology.

Modern examples illustrate open, wave-washed beach and river environments. A table shows ranges (Triassic tc Recent) of common fresh-water molluscan families. Very few families are short ranged and three (Unionidae, Valvatidae, Amnicolidae) span the entire range cited.

Fossil assemblages discussed and molluscan population listed are as follows:

1. Truckee Formation (Pliocene) near Carson Sink, Nev. (lake).
2. Tulare Formation (early Pleistocene or late Pliocene), Kettleman Hills, Calif. (lake).
3. Kootenai Formation (Early Cretaceous), near Harlowtown, Mont. (river).
4. Fort Union Formation (Paleocene), southern Montana (river).

No single form is distinctive enough for an environmental determination; assemblages, however, may be.

A deposit having a "well-represented assemblage of Unionidae, Sphaeriidae, Viviparidae, and Pleuroceratidae, together with a smaller percentage of pulmonates * * * may be considered of fluviatile origin. On the other hand, if a deposit contains a large number of Sphaeriidae, Valvatidae, and Amnicolidae, in addition to a well-represented assemblage of aquatic pulmonates, it could probably be considered lacustrine.

"A fossil bed that yields an assemblage of a few varieties but with an abundance of individuals, including those of younger stages, may well be taken to represent an original habitat area. On the other hand, if it contains a large number of varieties and numerous individuals, it may indicate a drifted assemblage, actually an admixture of littoral and sublittoral forms in addition sometimes to terrestrial species [p. 1379]."

1954. Nonmarine mollusks of Late Cretaceous age from Wyoming, Utah, and Colorado: U.S. Geol. Survey Prof. Paper 254–B, p. 45–66.

The Bear River Formation in southwestern Wyoming was deposited, in part, in an estuary at the beginning of Late Cretaceous time. The mollusks indicate that later the area emerged from the sea and became a lowland dominated by woodlands, rivers, and small lakes.

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