Owens Lake, an ionic soap opera staged on a natric playa

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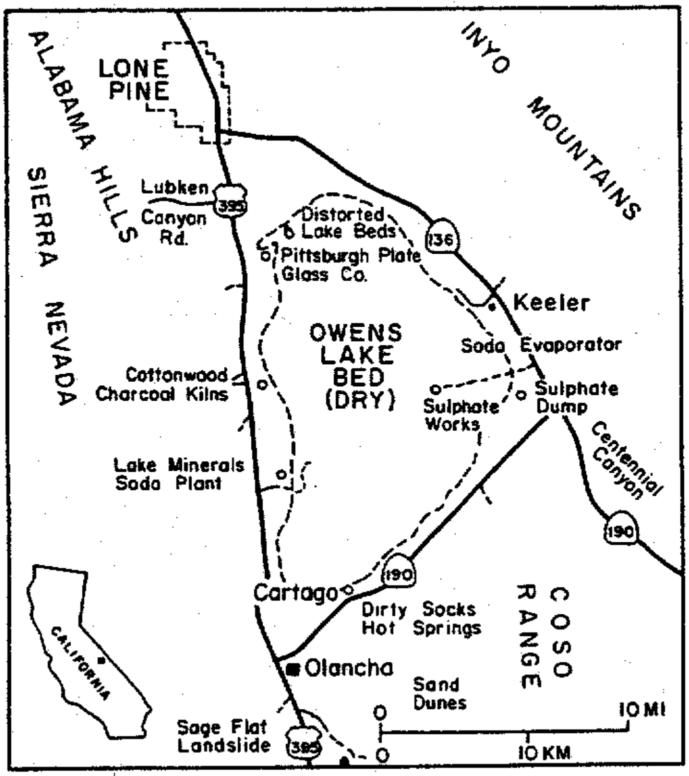

Figure 1. Map showing features mentioned in the text.

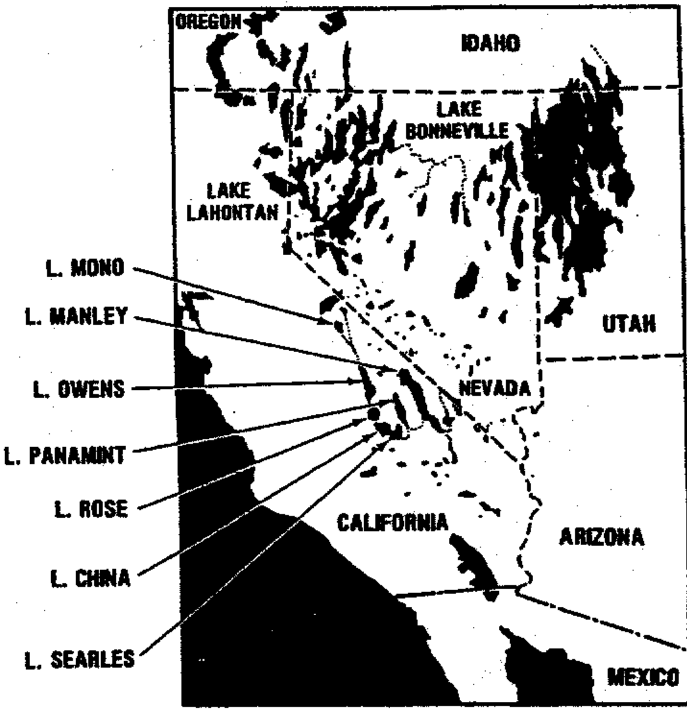

Figure 2. Pleistocene Lakes. Owens Lake was a part of a chain of lakes that stretched from Mono Lake to Death Valley. All the lakes except Mono Lake are now dry, and the streams no longer run.

LOCATION AND SIGNIFICANCE

Owens Lake, 17 mi (27 km) south of Lone Pine in Inyo County, California, is reached via U.S. 395, (Fig. 1). This 110-mi^2 (285-km^2) lake bed, once part of a chain of Pleistocene lakes, was full of saline water until the 1920s. Now dry, it shows the processes at work in a wet, natric playa and tells of climatic change and of the effect of man on the desert.

HISTORICAL SYNOPSIS

The chain of Pleistocene lakes that extended from Mono Lake to Lake Manly in Death Valley (Fig. 2) was full during most of the Pleistocene; Gale (1914, p. 264) concluded that the flow to the south of Owens Lake ceased 3,500 to 4,000 years ago. A well 920 ft (280 m) deep in the central part of Owens Lake revealed a continuous series of clays and silts but no buried salines (Smith and Pratt, 1957). This led Smith and Street-Perrot (1983, p. 198) to conjecture that the lake had not desiccated for several hundred thousand years. However, some episodic drying must have taken place, because extensive layers of coarser sediments beneath the clays give rise to artesian wells. Studies of salt bodies in Searles Lake reveal fillings and dryings not easily seen in the other lakes in the series (Smith, 1979). The latest desiccation of Owens Lake was initiated by climatic change, accelerated by irrigation, and finished by export of water (Chalfant, 1933; Nadeau, 1974; Krahl, 1982).

In 1862, farmers began to move to Owens Valley because water was abundant. By 1917, 62,000 acres were in cultivation and 160,000 fruit trees had been planted (Newcomb, 1917); 450,000 acre ft (555 hm^3) of water were being used annually. Although the level of the lake dropped 16 ft (4.9 m) between 1894 and 1905, it later rose, due to above normal rainfall, and by 1911 had regained 18 ft (5.5 m), despite irrigation and export of water. The Department of Water and Power of Los Angeles (DWP) began to convey water from Owens Valley to San Fernando Valley in November 1913, and now exports 350,000 acre feet (430 hm^3) annually. The lake level began to fall in 1917. By 1926, the lake was dry, and most of the artesian wells and flowing springs within Owens Valley had dried up.

SITE DESCRIPTION

Start at Olancha, California (Fig. 1), and take California

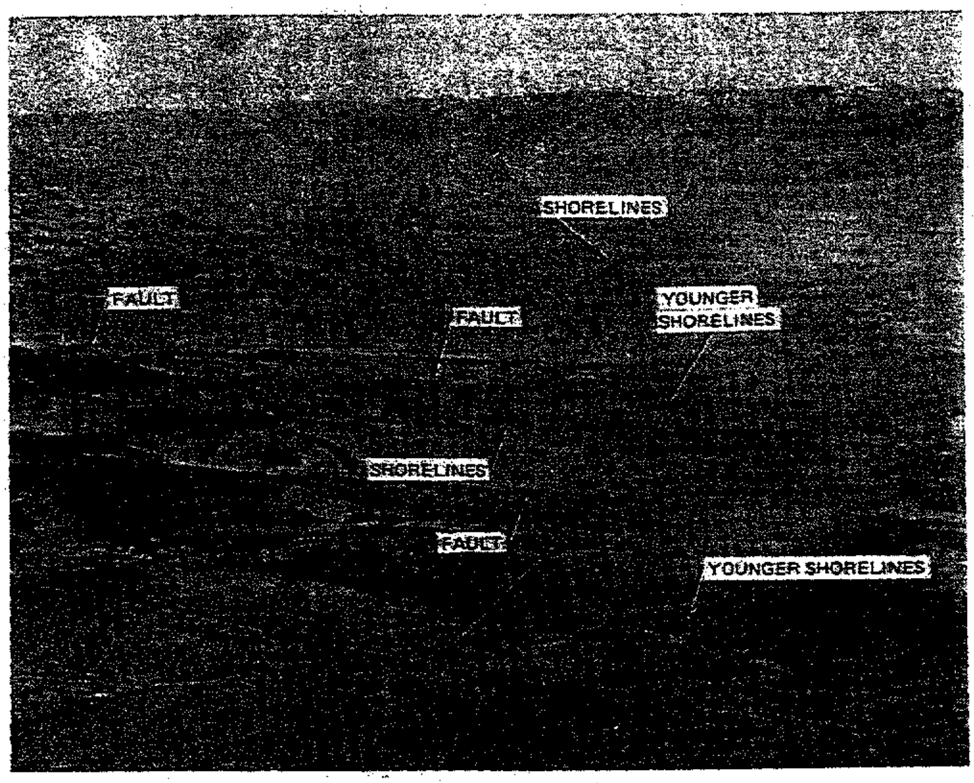

Figure 3. Shorelines around the south side of Owens Lake, looking southwest. A series of south-southeasterly trending faults offsets the Tioga Shoreline 1 mi (1.6 km) left laterally and 80 ft (24 m) vertically, up on the west side. A few younger shorelines can be seen between the Tioga lines and the 1913 shorelines at the extreme right of the photograph.

190 east to the junction with California 136. Shorelines of Tioga age ring the basin 300 ft (100 m) above the lake bottom (Carver, 1967), and are incised by small quebradas that have built subaerial fans onto the sloping surface beneath, but are otherwise uneroded. Thirteen mi (21 km) east of Olancha, faults multiply offset the Tioga shorelines 1 mi (1.6 km) left laterally (Fig. 3). Turn north on California 136 and continue for 4 mi (6 km). Turn west 1.4 mi (2 km) south of Keeler to the center of Owens Lake playa. In winter, the playa surface is covered with mirabilite; in summer, mirabilite melts, leaving thenardite.

A large pile of sodium sulphate lies to the south of the road, which leads to the ruins of a loading ramp. An artesian well, surrounded by grass, waters the surface. Ponds near artesian wells are saturated with sodium sulphate. The soda has disintegrated ties from an abandoned railway; the soft parts of the wood have been destroyed and only the hard, lignitic, winter rings remain. The poles of a tripod standing in a pool of water have an expanded section for 2 ft (0.6 m) above the maximum reach of the brine (Fig. 4).

The clay playa. The playa surface is hard in summer but soft in winter, when vehicles sink several inches into an efflorescent crust, and it cannot be traversed after rain or snow. When the surface temperature of the playa first reaches 95°F in the spring, polyhydrates lose water of hydration and wet the playa surface; this process cycles diurnally.

The playa is covered with a thin layer of windblown sand mixed with clay, and an alkali crust. The clay beneath is free of sand. When the surface is dry, the first few centimeters are a loose, fluffy layer of aggregated clay particles. The crust when dry arches above the clays, but when wet it collapses and the fluffy material reverts to a reconstituted plastic clay. The clays are illite and montmorillinite, with some chlorite. The clay beneath contains 40 to 50 percent water in about a 3 percent brine.

In summer, the upper clays dry. Desiccation polygons, tens of feet (10+ m) across, form on the surface. The edges of the polygons are covered with salts. Open cracks appear in the edges (Fig. 5). The clay, to a depth of 2 or 3 ft (~1 m), breaks into blocks a foot or less (<30 cm) in size, with lesser cracks an inch or so (2–3 cm) wide throughout the polygons. The cracks at the edges of the polygons fill with sand and form clastic dikes. The clay near the top is khaki to greenish gray in color. At depth, it is a bluish black, solonetz containing carbonized leaves and twigs. Near the clastic dikes the color is bleached to that of the surface (Fig. 6).

Efflorescent crust. Alkali crusts form on playas where the water table is less than 10 ft (3 m) below the surface. Crusts on

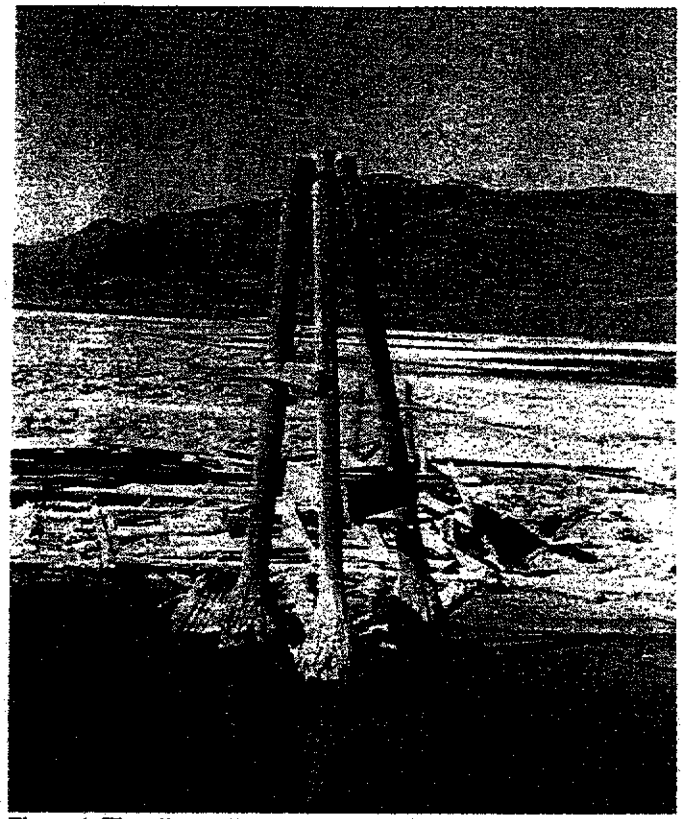

Figure 4. The effects of crystallizing salts are seen where the legs of the tripod are greatly expanded, just above the water. The town of Keeler is in the background; the dark areas are springs, where grasses grow in the fresher water. The surface is covered with a winter crust of halite, mirabilite, and natron.

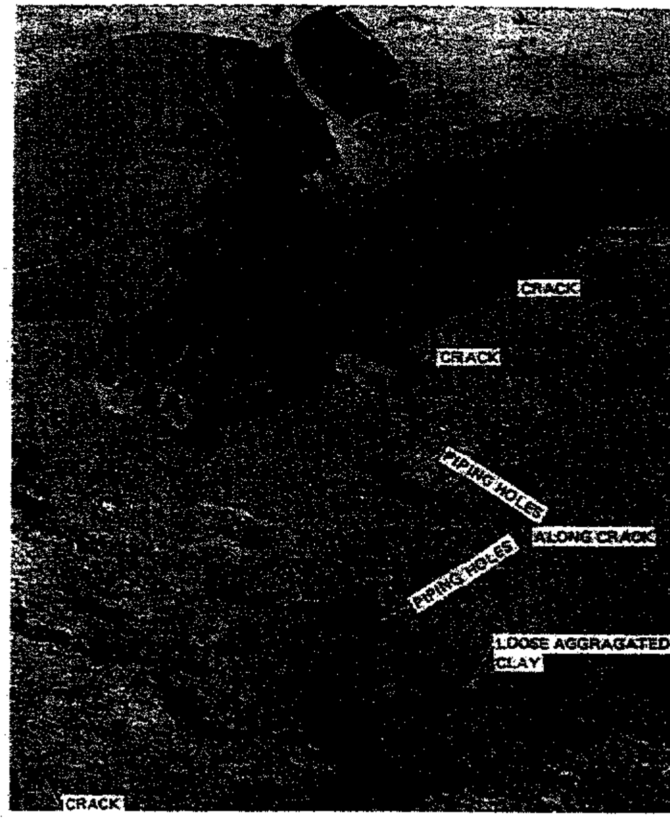

Figure 5. Cracks forming on the surface of the playa in November 1985. A melting snow has dissolved most of the early crust, leaving holes in the surface developed by piping. The soil beneath is a loose aggregation of clay particles.

playas containing only sodium chloride, or nonhydrated minerals are usually damp and hard. The crust on Owens Lake contains sodium chloride, carbonate, sulphate, and minor amounts of borates, nitrates, potassium, and lithium.

The chemistry of the crust varies with the seasons as shown in Figure 7. The left side of the diagram explains the winter, the right side the summer situation. Begin at the "start" block. The first question asks if the temperature is greater than 18°C. If so, follow the yes arrow to the right—trona, thenardite, and halite form. If enough rain falls, the precipitates dissolve and move below the surface by the Soret effect, the forces of osmosis opposing those of capillarity. If the temperature rises above 65°C, thenardite and halite remain, but trona converts to thermonatrite. The crust is hard and not easily dislodged by wind.

In winter, when the temperature is below 18°C, trona and halite form, and thenardite changes to mirabilite in the presence of water. A transient dihydrate phase may precede the formation of mirabilite (Bernasovskii, 1953); it is likely that a septahydrate also forms. The mirabilite occupies 4.1 times the volume of the thenardite. This breaks the crust and separates the clay grains. With enough rain, it all dissolves and starts over; with less rain, more mirabilite forms. Upon exposure to dry air, trona and halite are stable, but the uppermost mirabilite dehydrates to amorphous thenardite with a volume decrease. If the wind blows, a dust rich in sulphate-bicarbonate with particles of clay is ablated.

If the temperature drops below 10°C., mirabilite, amorphous sodium sulphate, and halite are stable but trona converts the natron with a 4.8 times volume increase. The hydrates grow on the bottom, encouraged by osmotic pressure operating in the same direction as the capillary forces, to bring water to the surface through the clay. They dehydrate as they grow, encouraged in part by an osmotic gradient of the water, to halite. Natron dehydrates to amorphous sodium carbonate, with a concomitant volume decrease. Anhydrous sodium carbonate and sodium sulphate are thus present in a thin farinaceous surface layer. Samples of the crust show no structure in X-ray crystallography, except for halite and silica, but chemical tests reveal the presence of carbonate and sulphate ions. A 15 knot wind will ablate a carbonate-sulphate–rich dust and particles of clay.

These conditions lead to dust storms when the wind blows

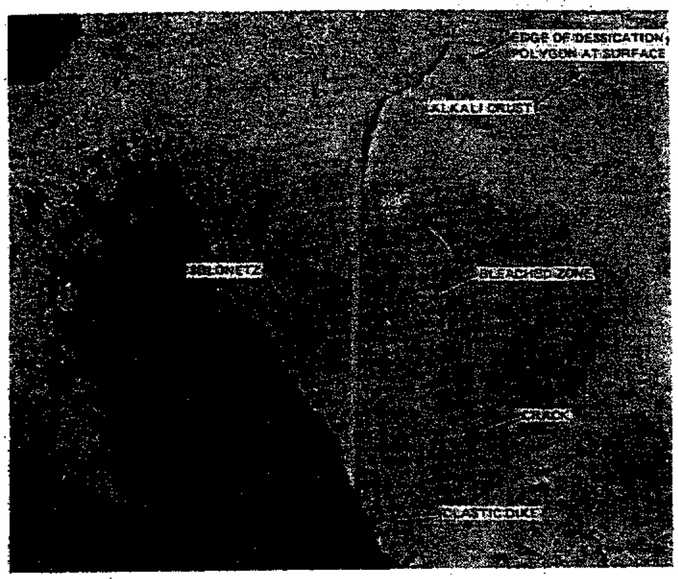

Figure 6. The crack with the piping in Figure 5 has been excavated. The thin, alkali crust on the surface is almost gone. The crack extends downward into the clays and fills with windblown sand, and with silts and clays washed in during the piping. These clastic dikes give the clays a vertical permeability. At about 1 ft (30 cm) depth, the clay is a deep blue-black solonetz. Numerous cracks develop from just above the vadose layer and extend upward into the clay.

in late fall, winter, and early spring. The storms interfere with air and surface transport and cause health problems (Saint-Amand and others, 1986). Dust from the Owens Lake playa has been tracked for 250 mi (400 km) south. Several tons of material are removed per second during large storms.

SODA PRODUCTION AT KEELER

This town of 100 souls had 5,000 people, schools, churches, two hotels, theatres, and other adult amusements in the early days. A soda extraction plant used the seasonal changes just described until 1904. Lake water was concentrated in shallow basins by solar evaporation. In hot weather, trona (summer soda) precipitated, was collected, dried, heated to drive off excess CO_2, and sold as sodium carbonate monohydrate. In winter, when the temperature fell below the stability field of trona, icelike crystals of natron (winter soda) formed in the pools, were collected, dehydrated, and sold as anhydrous sodium carbonate. Large amounts were used in China for making china. This operation was abandoned when the lake water became so concentrated that trona precipitated in the lake. In 1911, carbon dioxide from limestones and dolomites of the Inyo Mountains was used to precipitate trona. The operation continued until 1937 (Dub, 1947).

TECTONICS OF THE LAKE BASIN

In the northwestern "corner" of the lake, an area of distorted lake sediments has been uplifted, truncated, and dextrally offset by north-south faulting (Fig. 8). The site is accessible by foot starting about 1.2 mi (1.9 km) south of Lubken Canyon Road. This fault is dextral; the one on the other side of the lake is sinistral. They diverge slightly, hinting that the Coso Mountains are being displaced southward, leaving an area of low tectonic relief into which the main part of the lake is dropping, perhaps explaining the formation of this deep basin.

As the lake continued to dry, the brine became concentrated on the west side of the lake. The Pittsburg Plate Glass Company plant at Bartlett Point, one of the world's largest soda producers in its time, operated from 1929 to the 1950s. The brine was concentrated in evaporators; trona was precipitated by carbonation, calcined, and CO^2 recycled; and borax was recovered. Production ceased because of changes in the water level of the lake. A 6,920 ft (2,110 m) hole, drilled near the plant, passed through lake bed sediments and gravels but did not reach bedrock!

Lake Mineral Company controls the roads onto the playa and along the west bank of the lake. Responsible persons requesting access are welcomed. Trona is collected for use at Boron. Complex sodium minerals, including burkeite, and mirabilite are found in the area. Collectors should seal their samples in airtight containers and transport them in ice chests.

A short drive (<2 mi; 3 km) along the shore to the north of the Lake Minerals Company staging area leads to outcrops of an older formation of unknown provenance. This well-sorted, cemented, and folded pebble conglomerate is found along the west side of the lake from here northward. The nearest similar outcrop is in Darwin Wash, 5 mi (8 km) to the south-southeast on top of the Coso Mountains. The formations may not be related, but both are anomalous in location and similar in appearance.

BRINE POOL

One can walk to the water body from the Lake Minerals Company operational area, from the Pittsburgh Glass Plant, from the charcoal kilns, or from Cottonwood Spring. In dry years, it is 1 or 2 ft (30 to 60 cm) deep, and extends for about 1 mi (1.6 km) north-south and a few hundred feet (meters) east-west. Salts form on the bottom, and float on the top, as the many possible compounds precipitate. When water has been dumped in the lake, or following rains, the pond is larger. The properties change as salines are redissolved (Smith, 1979; Friedman and others, 1976). Owens Lake contains 1.6×10^8 tons of anhydrous salts (Gale, 1914) of which 6.7×10^7 tons are sodium chloride, 6.3×10^7 tons are sodium carbonate, 2.3×10^7 tons are sodium sulphate, and 7.4×10^6 tons are potassium, boron, iron, aluminum, lithium, and other elements.

On the shore of the brine pool, the surface temperature at noon often exceeds 165°F. Just below the surface, a gelatinous material, probably sodium silicate, thickens the brine. At a depth of a few centimeters, the temperature is usually 75°F. Fresh spring water enters the playa, mixes with the brine and forms

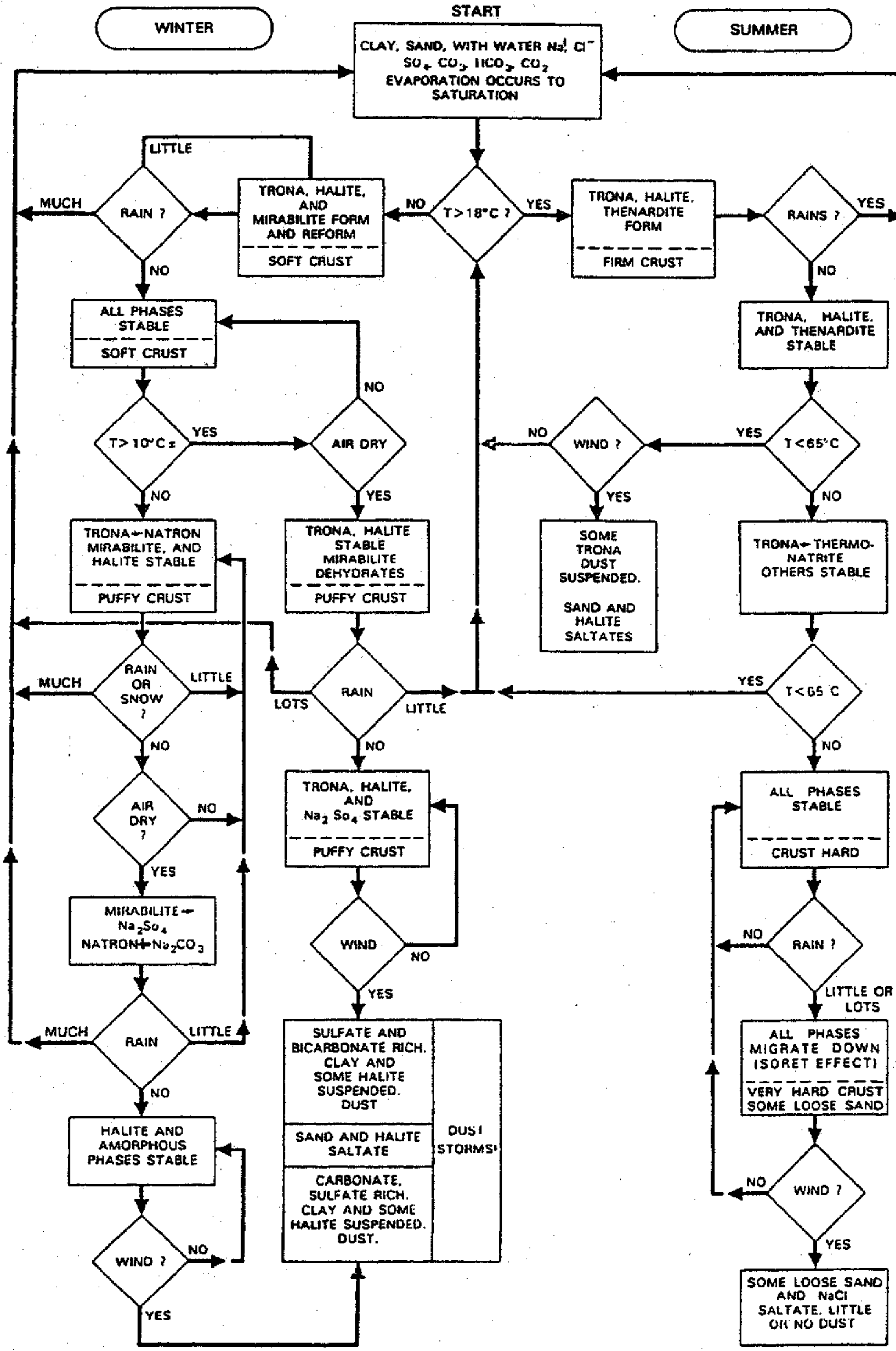

Figure 7. A logic diagram of the processes by which the alkali crust is formed on Owens Lake, and how the surface is conditioned to yield dust storms.

quicksand. It is unwise to wade in this area. Scratches produced by falling through the crust into the brine heal slowly because the carbonates saponify subcutaneous fats.

Hydrobiology. Algae such as *Dunaliela salina, D. viridis,* and halophilic bacteria such as *Halobacterium, Chromatium, Ectothiorhodospira,* and *Halococcus* (Larsen, 1980, p. 25 and 30), which have red carotenoids in their cells, color the water red. The microbiota metabolize sulphates and modify the carbonate dioxide content of the brine (Tew, 1980).

CLIMATES CHANGE

During the aluvial episodes, rainfall of at least 20 in (50 cm) per year prevailed over most of the desert. The rain probably came from the Pacific Ocean to the south, rather than from frontal storms of northern provenance that are now prevalent.

Under the influence of the present-day semipermanent high pressure area, a strong diurnal heating develops. Heated air rises at the sides of the valleys and descends in the central parts, being reheated by compression during descent. The heating produces a low-level, dry, thermal low that advects surface air from the desert to the south and east, further warming the region. If the Great Basin were damp enough to preclude the formation of a permanent high, the climate would become much more benign.

The drying trend exacerbates the desertification, which in turn reinforces the permanent high. Deserts are selfpropagating. The propagation is often accelerated by human activity, as has happened in the Sahara and the Sahel of Africa, the Caspian Basin, and India. The world has become much drier since biblical times. We are seeing this elsewhere in the arid west, but that is another story.

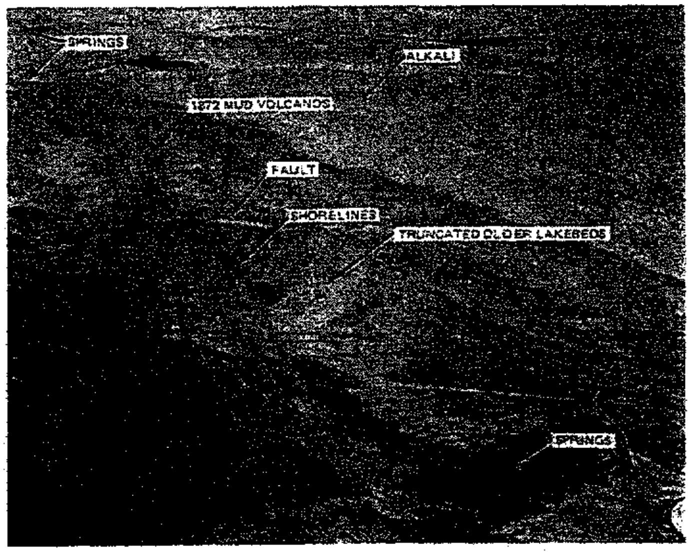

Figure 8. Looking northeasterly from the northwest corner of Owens Lake. The fault called out is a branch of the fault that produced the 1872 earthquake. Abandoned shorelines overlie a series of folded and faulted lake bed sediments truncated so that the edges are exposed. These lakebeds are repeatedly offset to the right by faulting. Thus, the Coso Mountains may move relatively southward between the two slightly divergent fractures.

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