Leakage from Solar Evaporation Ponds Associated with Sediment-Brine Interactions

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ABSTRACT

Leakage from solar evaporation ponds constructed in playa sediments may be increased dramatically by normal sediment-brine interactions. Certain fine-grained sediments, originally deposited in an environment less saline than the concentrated brine introduced into the evaporation ponds, are susceptible to subaqueous shrinkage, which creates vertical fissures in the fine-grained sediments. This phenomenon has been documented on the Bonneville Salt Flats and on the bottom of Great Salt Lake, and probably occurs at other similar localities.

Subaqueous shrinkage appears to occur during osmotic transfer of the fresher water from the sediments to the more saline brines in the pond, although syneresis may be an alternate mechanism for the dewatering.

Development of such fissures in a solid which is expected to remain impermeable could create serious problems in other engineering works, for example (1) clay liners in sanitary landfills producing saline leachate; (2) clay liners in brine-disposal or storage pits; or (3) earth-fill dams built to block saline springs (such as those proposed for tributaries to the upper Brazos River in Texas).

INTRODUCTION

Leakage of concentrated brines from solar evaporation ponds can have a serious deliterious effect on the economics of salt production. Reducing the leakage rate of these ponds is especially important in the ponds where brines are undergoing their final stages of evaporation, particularly where the very soluble salts of potassium, magnesium, and lithium may be lost. One gallon of brine saved in the latter stages of evaporation may eliminate the processing of several gallons of raw, low-grade brine to replace the lost concentrated brine.

Many brine evaporation operations are located in playas or similar hydrologic environments where fine-grained sediments form the floor of the evaporation ponds. An understanding of the interactions between the sediment and the brine in such geological environments may help to eliminate expensive errors in the design and construction of evaporation ponds. Data collected from the solar evaporation system at the Bonneville Salt Flats, Utah (Fig. 1) provide important insight into the mechanics of a potential leakage problem, although leakage at Bonneville has not been excessive.

DISTRIBUTION OF SALINE WATERS IN PLAYAS

The salinity of ground waters in playas varies within extremely wide limits. Most playas display a systematic change in salinity similar to that found at Bonneville—an increase of salinity toward the center of the playa. Motts (1965) referred to this kind of hydrochemical relationship as "water-quality facies."

According to Motts, the salinity of Estancia Playa, New Mexico, increases from a few hundred parts per million (ppm) total dissolved solids (TDS) at its edges to 5,000 ppm near its center. At South Panamint Playa in California salinity ranges from 200 to 200,000 ppm with the maximum in the center. Hunt and others (1966), in describing the distribution of salinity in Death Valley, California, made a statement that applies to almost all saline playas:

> . . . in general, salinity of the brines increases panward, is greatest in dry seasons, is greater in ground water than in surface water, and is greater in standing water than in flowing water . . .

The Bonneville brines follow this generalization.

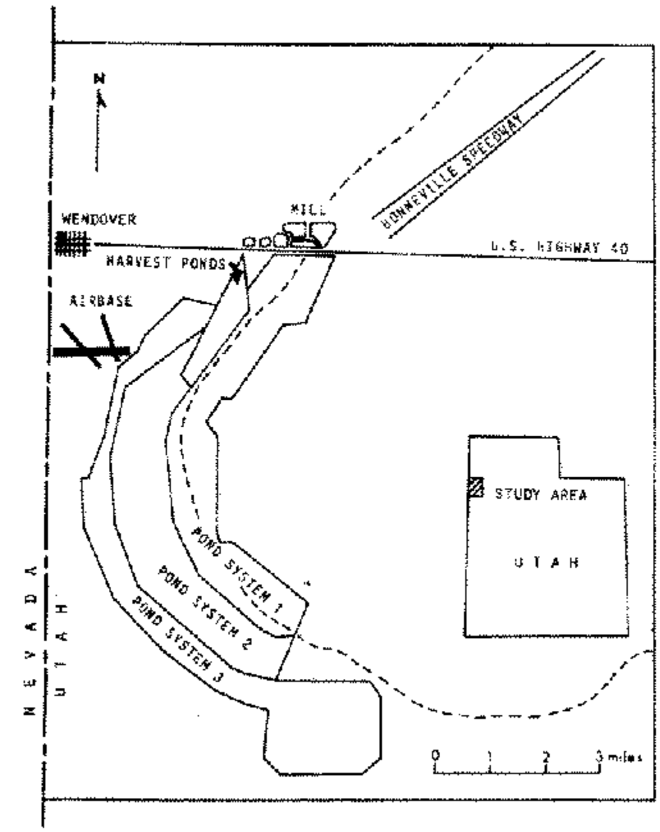

Figure 1. Index map of the Bonneville Salt Flats potash recovery system in 1967. The three pond systems shown have been abandoned in favor of a new pond system. U.S. Highway 40 has been replaced by Interstate Highway 80. The deposit is owned and operated by Kaiser Aluminum and Chemical Corporation. Dashed line is approximate edge of salt crust mapped by Nolan (1927). (Modified slightly from Turk, 1970.)

Vertical variations in salinity are also widespread among saline playas. Some of the changes are due to upward movement of ground waters and the subsequent evaporation of water, which concentrates the salts at or near the ground surface. Sharp vertical changes of salinity occur in the Death Valley playa. At one locality salinity declines from 4.3% three to four inches below the surface to 2.5% three and one-half feet below the surface (Hunt and others, 1966).

Salinity of the Bonneville brines decreases markedly with depth, although sampling control is not sufficient to allow calculation of a meaningful depth-salinity relationship. Nevertheless, brine from 1,000 feet deep wells contains less than half the TDS of the near-surface brine, and water below a depth of 1,900 feet in an old oil test contains only 5% to 10% as much TDS as the near-surface brines. At least part of the vertical salinity variation at Bonneville is a result of the increasing salinity of Lake Bonneville as the sediments were deposited—perhaps all the variation below a depth of a few feet can be explained by a changing environment of deposition. Lake Torrens, Australia, exhibits a closely similar case of salinity variation with depth. Johns (1968) found a progressive decline in total dissolved solids from 257,000 to 342,000 ppm at the surface to about 34,000 ppm at a depth of 600 feet. The salinity variation at Lake Torrens also may be due to a changing environment of deposition

The generalization that salinity decreases with depth does not apply near the surface in areas where there is water standing on the playa. Jones and others (1968) stated that interstitial solutions within shallow, fine-grained playa sediments are invariably more concentrated than associated surface waters, except in peripheral zones of ground water inflow. In a talk at the symposium on the geochemistry of brines held in 1968 at Lawrence, Kansas, Jones compared wet and dry playas in the vicinity of Albert Lake, Oregon. He concluded that salinity within the dry-surface playas declines steadily, while salinity within the wet-surface playas rises in the first few feet below the surface, then declines at greater depths.

DESIGN OF EVAPORATION PONDS

Evaporation ponds may be designed in several different ways. A common method is merely to build a low dike around a large area to impound the brines. Small ponds

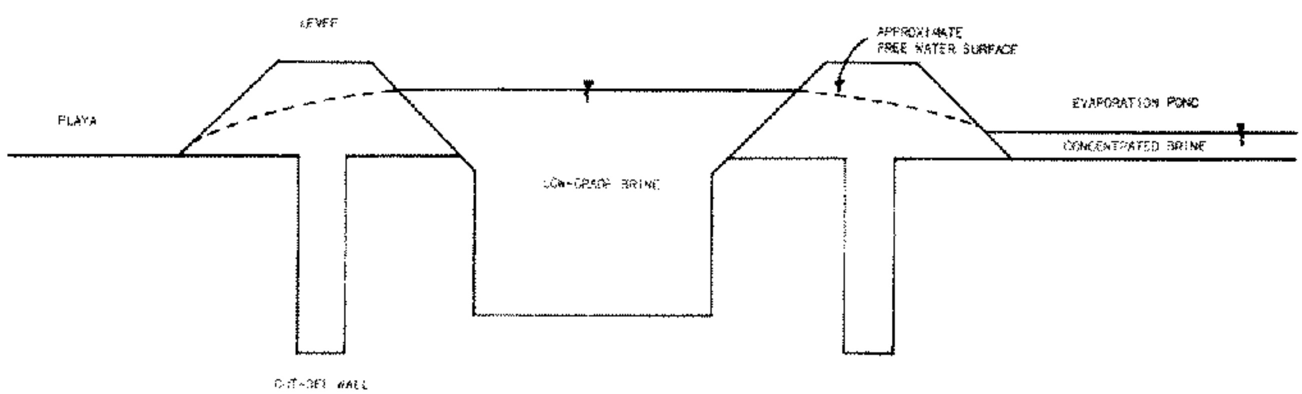

Figure 2. Schematic cross section of seal ditch designed to hold concentrated brine in evaporation pond.

may be lined with low permeability material. Figure 2 shows schematically the dike design used at Bonneville, which utilizes seal ditches to place a hydraulic head against brine within the evaporation pond and to form a subsurface barrier to prevent leakage through the highly permeable sediment of the playa. The sediment is dredged out, then replaced in the trench. Reworking the sediment destroys its extensive fracture system and greatly reduces the overall permeability. The seal ditches are effective during the first few years following their construction, but with time the cut-off walls apparently deteriorate and leakage becomes a problem.

HYDROLOGIC CHARACTERISTICS OF SEDIMENTS

In conjunction with a comprehensive hydrogeologic study of the Bonneville Salt Flats (Turk, 1970; Turk and others, 1973) numerous pumping tests were conducted to determine the hydrologic characteristics of the sediments. More than 90 shallow wells were augered by hand and cased with plastic pipe, and more than 70 pumping tests were conducted. One well would be pumped at a constant rate while drawdown of the water table was measured in adjacent boreholes. The data were used to calculate the permeability of the brine-saturated sediments. The distribution of permeability within the sediments correlated closely with the distribution of salinity within the brines (Turk and others, 1973). There one sees that the axis of highest transmissivity (an index of the permeability) corresponds with the axis of high original salinity.

The extremely high permeability is due to an extensive fracture system developed in the fine-grained sediments. We interpreted the increase of permeability toward the center of the playa to be a result of differential subaqueous shrinkage of the fine-grained sediments. Open fractures within the sediments can be seen clearly on the walls of collection ditches.

Several pumping tests were run near the evaporation ponds next to the seal ditches. One of the tests near a relatively new seal ditch indicated that an impermeable boundary was present along the ditch and cut-off wall. However, two tests near older portions of the system indicated that the seal ditch was actually a recharge boundary of exceedingly high permeability, rather than an impermeable boundary as expected. It appears, therefore, that the same mechanism which naturally increased the permeability of the playa sediments has acted on the artificial barrier as well.

SHRINKAGE MODEL

The shrinkage within the natural playa sediments was ascribed to osmotic desiccation due to a salinity gradient set up between the less saline brines in the sediments toward the more saline brines of ancient Lake Bonneville, which caused a partial dewatering of the material and the consequent shrinkage. Figure 3 is a conceptual model of the osmotic process. When two fluids of different ionic strength are separated by a semipermeable membrane, water molecules pass back and forth across the membrane, but the larger salt molecules cannot pass through the barrier. However, the salt molecules take up space and interfere with the movement of the water molecules. Therefore, a greater number of water molecules hit the membrane, and pass through it, on the side of lower salinity, and hence, there is a net flux of water toward the more saline brine.

Figure 4 demonstrates the occurrence of this process in a playa environment. At first, the near-surface clay-rich deposits act as a semipermeable membrane separating the brines of contrasting salinity (Fig. 4a). As the sediment dewaters shrinkage cracks open, allowing the denser brine to enter (Fig. 4b). Finally, an osmotic gradient obtains from the interstitial brines to the denser brine within the cracks (Fig. 4c). Eardley (1966) described subaqueous cracks of a similar nature in the bottom sediments of Great Salt Lake. I believe that they are formed by a process similar to that at Bonneville.

If this shrinkage mechanism *is* an effective process by which permeability can be increased, why do remolded sediments in the cut-off walls shrink again when placed in contact with concentrated brine in the evaporation ponds? The answer appears to be that the evaporation ponds were constructed outside the area of high natural salinity in the playa. In fact the ponds *are* outside the original salt crust shown on Figure 1. As the concentrated brine is introduced into the fine-grained sediments near the edge of the playa the sediments shrink because of the new osmotic gradient established between the lower salinity waters in

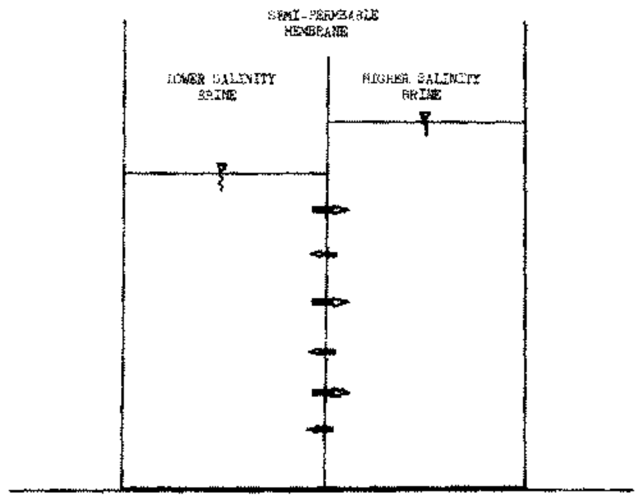

Figure 3. Conceptual model of osmotic transfer of water. Size of arrows represents relative amounts of fluid transfer. Net flux of water molecules is from lower to higher salinity.

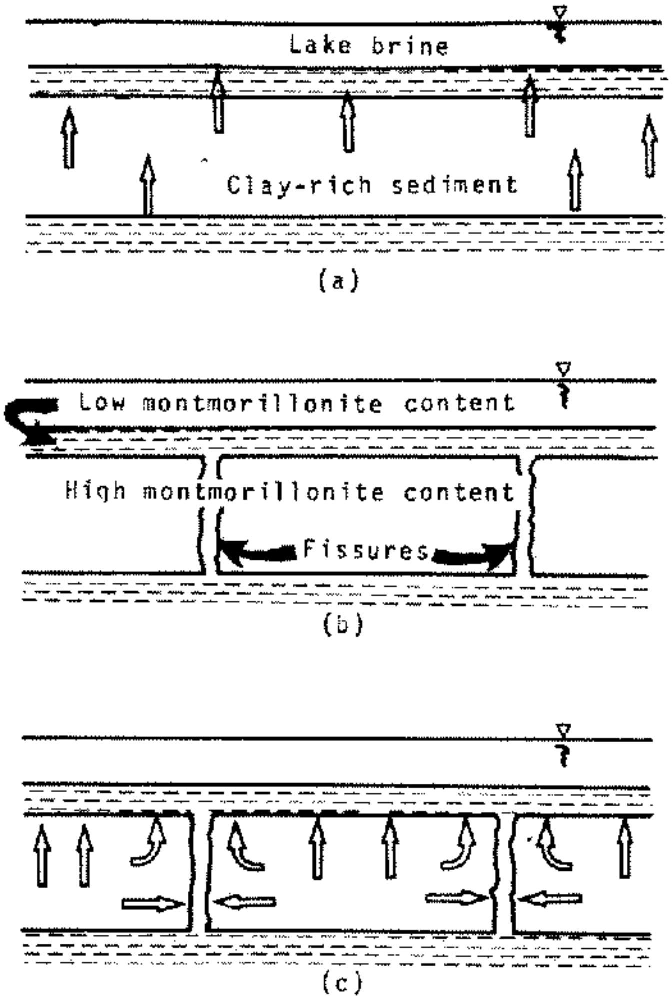

Figure 4. Proposed model for the development of fissures by osmotic desiccation. (From Turk and others, 1973).

the sediments and the concentrated pond brine. The process seems to be rather rapid, inasmuch as seal ditches only six to eight years old appear to be affected.

An alternate mechanism for the shrinkage phenomenon may be syneresis (Turk and others, 1973).

ENGINEERING IMPORTANCE OF SUBAQUEOUS SHRINKAGE

Subaqueous shrinkage may be important in many different types of engineered systems, for example:

1. Evaporation ponds may lose valuable brines when the brine encounters clays or other fine-grained sediments deposited under fresher water, as discussed in this paper.
2. Clay-lined evaporation ponds for the disposal of effluent from desalinization plants or geothermal brines may crack because of clay-brine interactions.
3. Clay liners placed in solid waste disposal sites to retain seepage may fail when the clay interacts with leachate produced within the landfill.
4. There could be severe effects on earth-fill dams, such as those proposed by a federal agency to dam up the saline springs which enter the tributaries of the upper Brazos River in Texas.

Before brines are placed in contact with fine-grained sediments laboratory studies should be conducted to determine their compatibility. If the brines cause shrinkage of the fine-grained material, it may be possible to preshrink the sediments by adding waste salt to the system before the construction is completed. In any case much better leakage controls can be designed and used if the shrinkage potential is determined *before* construction of the project, rather than after severe leakage begins.

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