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The Natural Salinity of the Colorado River

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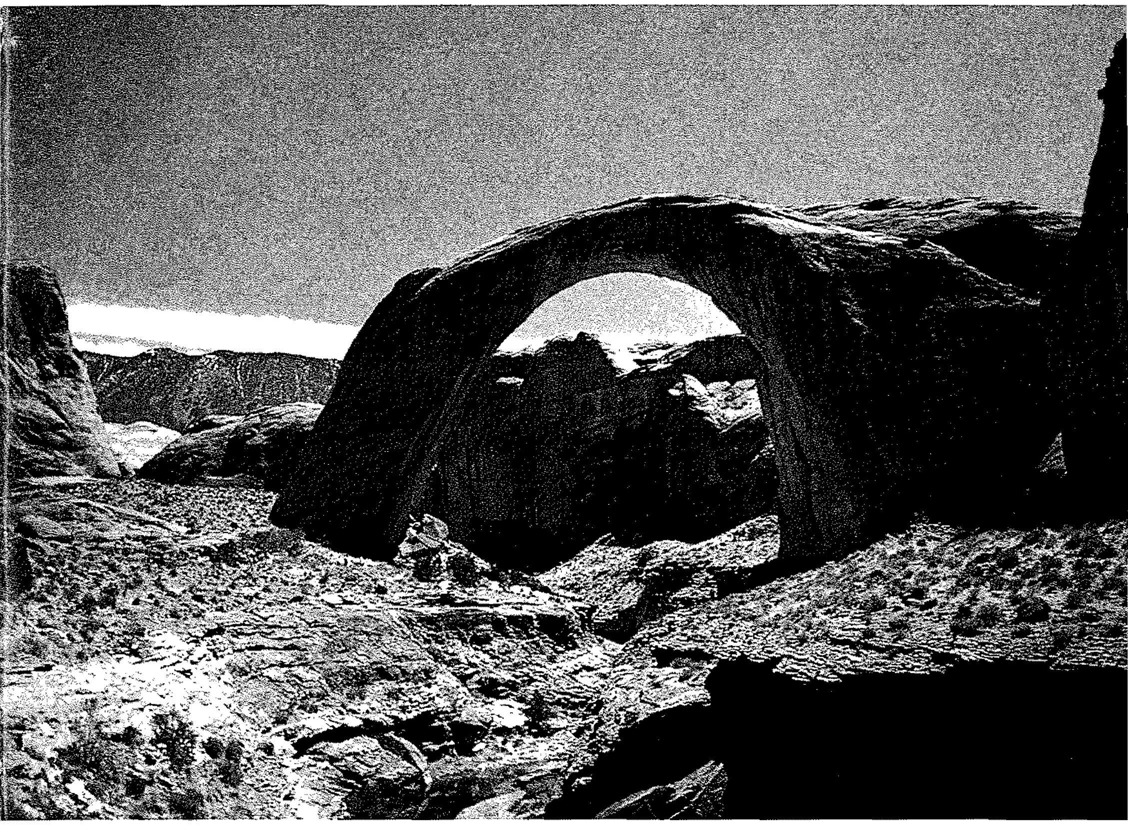
THE NATURAL SALINITY OF THE COLORADO RIVER

J. Stewart Williams



Occasional Paper 7

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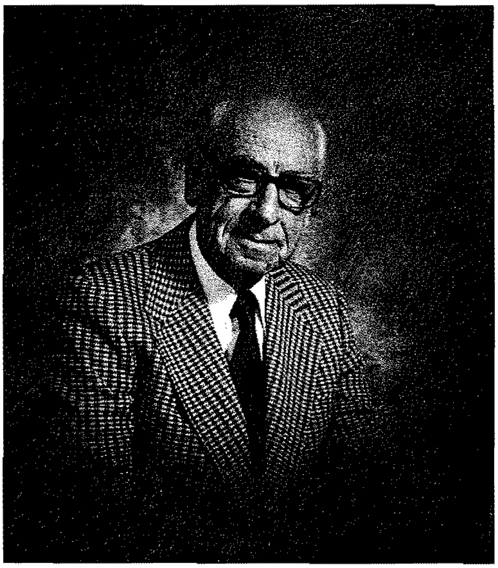

J.STEWART WILLIAMS

J. Stewart Williams is a native of Provo, Utah, and a graduate of Brigham Young, Columbia, and George Washington universities. In 1934-35 he did a year of postdoctoral work at Yale University. From 1935 to 1967 he was Professor of Geology and Head of the Department of Geology at Utah State University, and from 1950 to 1967 Dean of Graduate Studies at USU. As a Professor Emeritus he is now a consultant to the Utah Water Research Laboratory and the USU Foundation, and others, specializing in hydrogeology and environmental geology.

While Dr. Williams' principal contributions have been in stratigraphy, long teaching assignments in hydrogeology and surficial geology for students in soils, forestry, range management and engineering, have created a second peak of interest and expertise in these subjects. In the problem of the natural salinity of the Colorado River, all three interests are merged.

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This paper was prepared for presentation at a seminar on "Salinity Management Within the Colorado River Basin" which was held at Utah State University (USU) on May 4, 1973. The author expresses his appreciation to the USU Salinity Committee for the opportunity to participate in this seminar. Particular thanks are extended to Mr. John T. Maletic, Chief, Water Quality Office, Engineering and Research Center, U.S. Bureau of Reclamation, Denver, Colorado, for his very significant role in the publication of this paper. Mr. Maletic encouraged the publication, reviewed the manuscript, and provided the necessary funding. As part of the review, Mr. Maletic and his staff provided several helpful and constructive suggestions relating to the format and the content of the manuscript.

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THE NATURAL SALINITY OF THE COLORADO RIVER

Standing by the muddy waters of the Colorado River (Fig. 1) as they swirl and glide through canyons of the plateau province, one realizes, of course, that these waters, including their dissolved, suspended, and traction loads, are as much a part of the geologic scene as the beautiful canyon walls, towering above them. The river, like the canyons it has eroded, has grown out of the geologic past. The quality of its water is basically a geologic feature, now modified by man's activities. At this time, one of the most highly developed and controlled rivers in the world, its pristine quality will not be restored. Perhaps it can be approximated if the degradation caused by irrigation use is decreased by better water management in the irrigated areas, and offset by control or elimination of some natural point sources. In any case, its basic quality, a geologic fact of life, is the starting point for any consideration of future modification that may be made either by better management or the

Figure 1. Colorado River near Moab, Utah.

application of various technologies. Figure 2 shows the location of salinity improvement projects in the Colorado River basin. The annual salt load of the Colorado River at Imperial Dam, California is estimated to be near 10,000,000 tons.

The quality of the river's waters, being determined by the nature of the rocks the river drains, relates to the stratigraphy of the Colorado

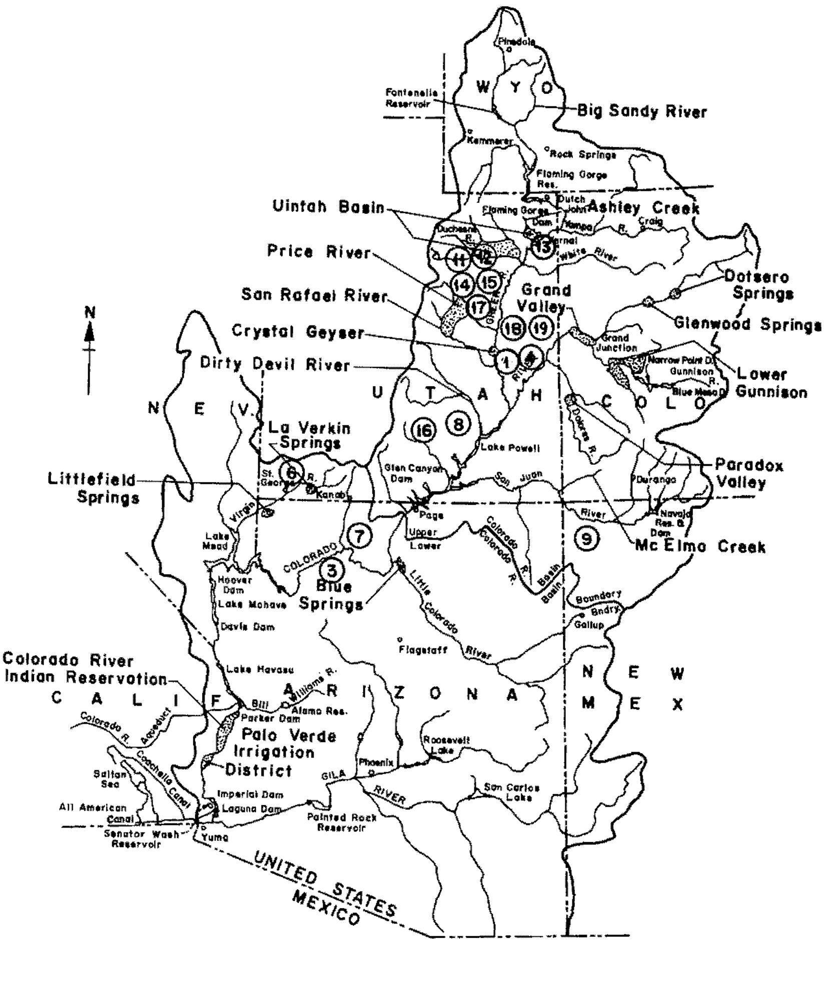

Figure 2. Index map showing location of salinity improvement projects in the Colorado River Basin and location of photos in this paper.

Plateaus. These plateaus are carved from a thick succession of strata of mostly sandstones and shales, deeply dissected by the river and its tributaries (Fig. 3). The surrounding highlands, exporters of water, are the primary source of the river but the water's quality downstream is largely determined by its travel across the plateaus. If the thick sandstones in the succession are the makers of great canyons, cliffs, and bridges (Fig. 4), the shales are the spoilers of the water quality. Add a few faults across the stream that bring deeply circulating saline water to the river and salt domes (Fig. 5) that lie in the path of some tributaries, and the major natural villians are named in the degradation of the high-quality water from the highlands as it loses its quality in passing toward the sea.

The shales of the Colorado Plateaus were deposited mostly in shallow seas that were often restricted and very saline and deposited much calcium sulphate, if not sodium chloride, and even potassium salts. The oldest shales that have a significant affect on the quality of the Colorado are those of the Pennsylvanian Paradox Formation. Deposited in a restricted sea centered near the Four Corners area, and adjacent to a rapidly rising Uncompahgre Highland to the northeast, the black shales grade into anhydrite and sodium chloride. These easily deformed lenses of shale and salt, pressured by the weight of overlying Permian

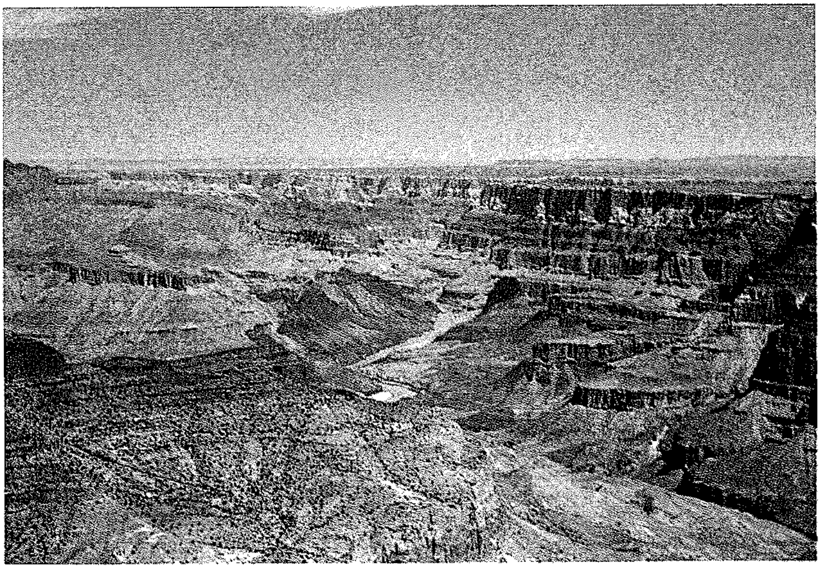

Figure 3. The Grand Canyon from the south rim, Arizona.

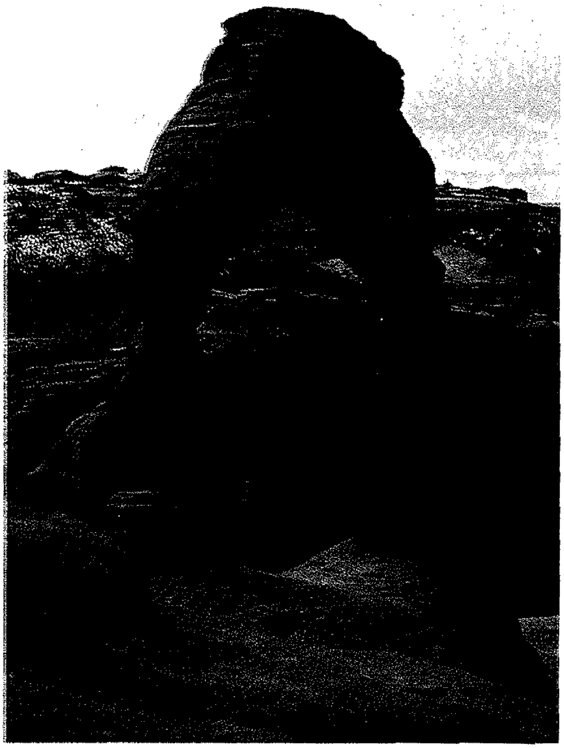

Figure 4. Delicate Arch and Salt Valley, Utah.

sediments, began squeeze-ups as early as Triassic time, rising in areas of less resistance, to form salt islands or shallows in the subsequent Jurassic and Cretaceous seas. The squeezing up has continued to the present, but with the deep erosion of the province, the shale and salt plugs now appear as jumbled masses of clay, gypsum, and salt in elongated valleys, surrounded by hogbacks or cliffs of younger sandstone. Figure 5 shows the location of the salt-dome valleys and the outcrops of Paradox Formation. In Figure 4 one can glimpse a part of Salt Valley through Delicate Arch.

The prime example of Colorado River waters contaminated by Paradox salt is that of the Dolores River crossing Paradox Valley, but other tributaries perform the same function, such as Courthouse Wash draining the Salt Valley area of Arches National Park, and the runoff of small streams that drain the badlands of gypsiferous shale along the margins of Moab Valley.

Another point source of poor quality water, in which the Paradox Formation probably plays a major role, is the Glenwood-Dotsero area, Colorado, where deeply circulating groundwaters, probably move along fault zones and also probably gain much of their salt load from the Paradox Formation which in this area contains hundreds of feet of gypsum. The outcrops belt of the Paradox Formation crosses the Colorado River valley at Dotsero.

Shales in the Permian Cutler Formation, such as the Halgaito and Organ Rock probably have minor effects on the quality of the Colorado as do the Supai Formation and Hermit shale of the Grand Canyon area (except perhaps their affect on Blue Spring). Blue Spring has the distinction of being the largest point source of salt for the Colorado. Issuing from the Mississippian Redwall Limestone, it apparently gathers

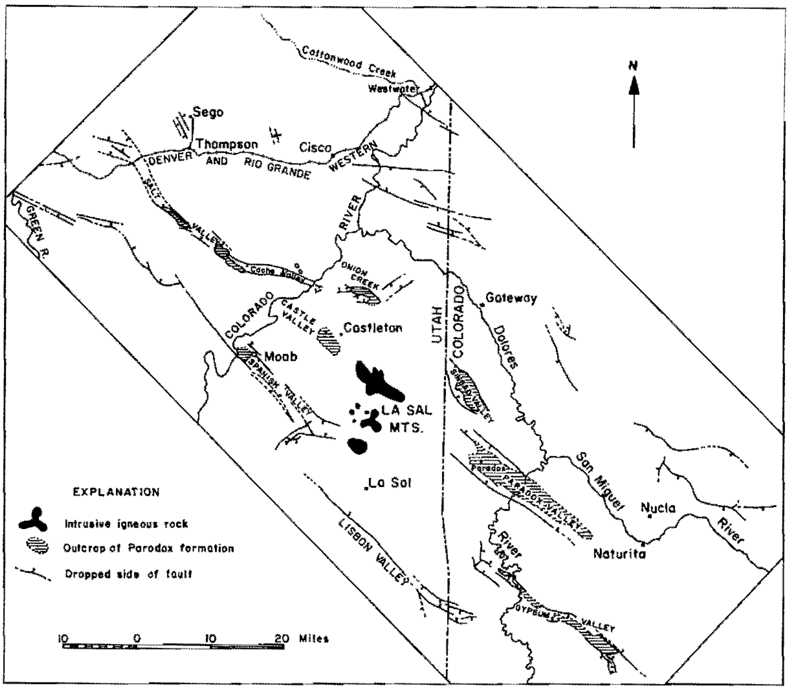

Figure 5. Location of salt-dome valleys and outcrops of the Paradox Formation (after Dane, 1935).

water from a very large drainage area, that has percolated through a geologic section some 3,000 feet thick. All this contact with the rocks provides the salt load of the water, but there is little doubt that the 1300 or so feet of Supai and Hermit provide a considerable share. Triassic shales, particularly the Moenkopi, are a different matter.

In Triassic time the sea entered the Colorado Plateaus area from the west, and the Moenkopi Formation along the Virgin River in southern Utah (Fig 6), contains prominent beds of gypsum (as seen in Hurricane

Figure 6. Moenkopi Formation and gypsum beds, Hurricane Mesa, Utah.

Mesa, Utah). These must be responsible, in part, for the poor quality of the Virgin, apart from the salt added by La Verkin Springs. At Flaming Gorge, the white Moenkopi is silt, not gypsum. The highly colored Chinle shale, maker of spectacular badlands in many areas, particularly the Painted Desert (Fig. 7), must have considerable affect on the quality of the Little Colorado above Blue Spring, and on the flow from Chinle Wash into the San Juan, but its affects of water quality are probably less per unit area of exposure than that of the less colorful, but more gypsiferous Mancos shale, higher in the section. However, it also makes colorful landscapes at Clay Crossing in San Juan County.

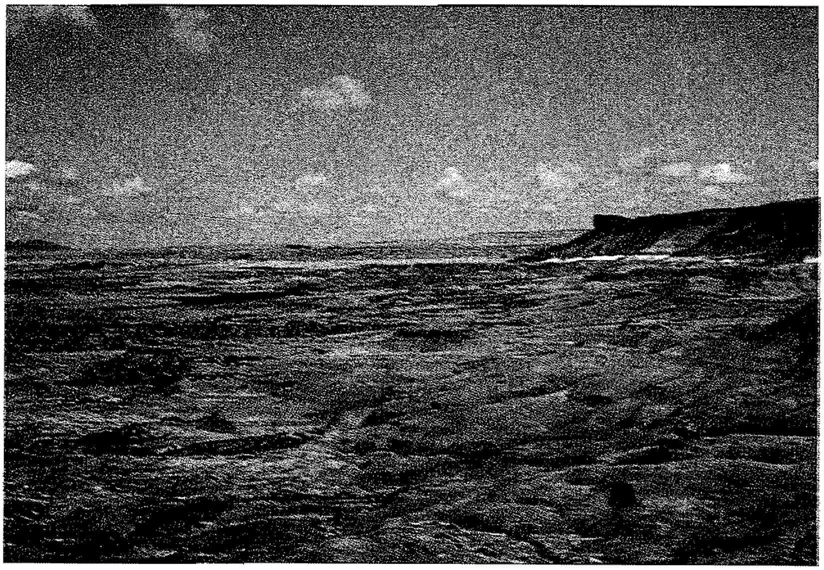

Figure 7. Chinle shale, Painted Desert, Arizona.

During much of Jurassic time the region of the Colorado Plateaus was a back shore area covered with magnificent sand dunes. Much of the sand may have been moved southward from the shore of the sea, then encroaching on the area from the north. The sea finally advanced far to the south and carried the very gypsiferous sediments of the Carmel Formation over the massive sands of the Glen Canyon Group. The outcrop area of the Arepien shale, the Carmel equivalent to the west in central Utah, exposes much halite and gypsum, but fortunately this area drains to the Great Basin. The gypsiferous Carmel Formation probably has its greatest affect on the quality of the Colorado through the San Rafael River and the Dirty Devil River both of which have relatively large areas of Carmel outcrop adjacent to them.

The Summerville Formation, is a thin-bedded colorful silty formation well developed in central Utah in the vicinity of Hanksville. It is the shore deposit of a second pulse of the Jurassic sea from the north and it is highly gypsiferous. Its contributions go largely to the Dirty Devil. Figure 8 shows an outcrop of the Summerville Formation, laced with veinlets of gypsum, near Hanksville.

The Brushy Basin shale member of the Morrison Formation is like the Chinle, highly colored, but it is relatively thin and thus without extensive outcrops. It also is probably non-marine, and thus has much less soluble matter to furnish to the runoff, than the marine shales.

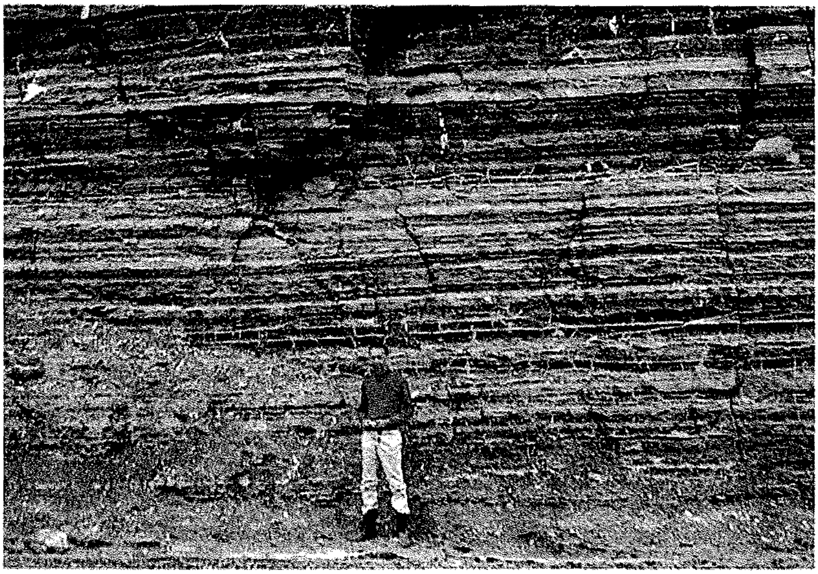

Figure 8. Gypsiferous Summerville Formation near Hanksville, Utah.

The thickest marine shale in the succession, and one of the great contributors to the degradation of Colorado River quality, is the Late Cretaceous Mancos shale and its equivalents, seen in Figure 9 near its type locality. There are Mancos badlands along the Paria and at many other places in the drainage basin.

From the area in western Colorado where the North Fork, the Gunnison, and the Uncompahgre join to make the Colorado, to the vicinity of Cisco in Utah, the course of the river is bordered on the north by a wide badlands eroded on the outcrop area of the Mancos shale (Fig. 10). The shale formation is about 5,000 feet thick, and the outcrop belt probably averages more than 10 miles in width. Numerous tributaries that rise in the Book Cliffs above the badlands, carry runoff across the gray clays to the Colorado. West of Crescent Junction where the drainage goes to the Green River, the Price River, and Saleratus Wash carry Mancos shale runoff to the main stream.

Further south and west, the Henrys Mountain syncline has preserved a wide outcrop of Mancos shale, drained to the north by Sweetwater Creek, and to the south by Bullfrog Creek. The former joins the Fremont, the latter goes directly to Lake Powell. Further downstream an outcrop belt of Mancos surrounds the Kaiparowitz Plateau.

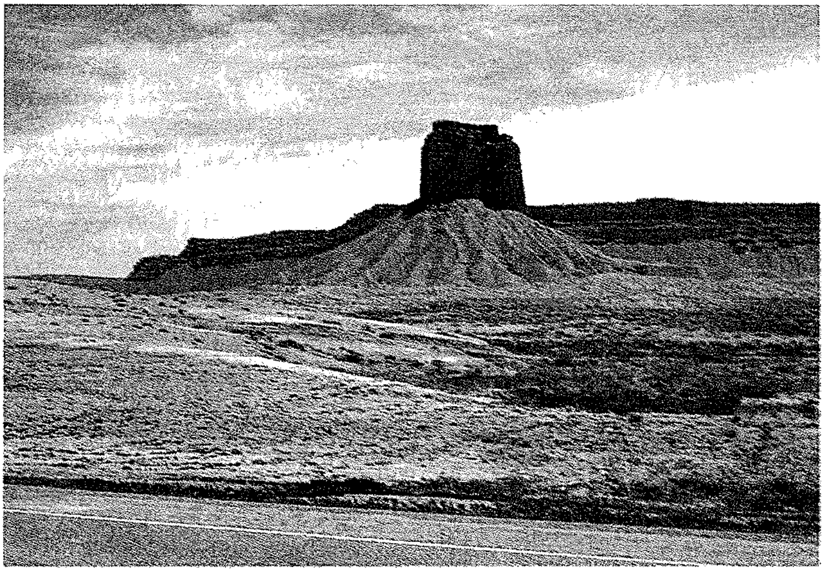

Figure 9. Mancos shale at Chimney Rock, New Mexico.

Tertiary formations in the Green River Basin, particularly the shale tongues of the Green River Formation, not only impart the pale greenish-gray color to the river that first bore the name, but they are probably primarily responsible for the salt load that marks Big Sandy Creek particularly, a major degrader of river water quality. Big Sandy Creek travels some 30 miles across these shales after collecting its waters on the Wind River Mountains. The salt seeps identified as the major sources of contamination could be localized by small faults that guide concentrations of groundwater through the shales. Green River from the junction of Big Sandy Creek continues to the Flaming Gorge Reservoir largely in Laney shale tongue of the Green River Formation. Along the Big Sandy, tuff beds in the Bridger Formation probably contribute significant amounts of salt to the stream.

The Price River is now thought to be the third largest contributor of salt to the Colorado. It begins in the Roan Cliffs of Green River shale near Soldiers Summit, and its upper course follows the outcrop belt of the red shaley Colton Formation across Emmas Park until it drops down through the Book Cliffs to Castle Gate. Here it begins its passage across the Mancos shale to the Green River.

Although most of the salt load of the Price River is undoubtedly a diffuse load picked up by overland runoff from rains and melting snows

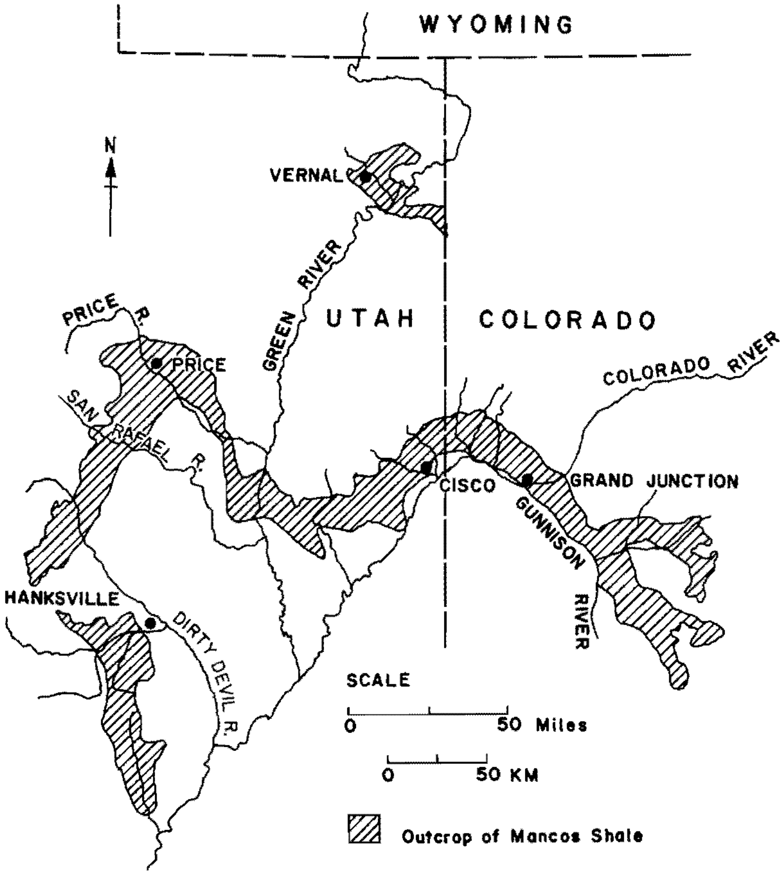

Figure 10. Outcrop of the Mancos shale along part of the Colorado River.

on the Mancos badlands of Castle Valley, several other sources may contribute.

At Castle Gate the stream crosses the outcrop of the Blackhawk (Fig. 11), the coalbearing formation at the base of the Book Cliffs. Large spoil piles lie close to the river for some distance, and may contribute a leachate of very low quality to the river.

The community of Price is largely a coal-mining town, but there is a small farming area, made possible by a thin layer of alluvium spread over the Mancos shale by the Price River and its tributaries like Soldier

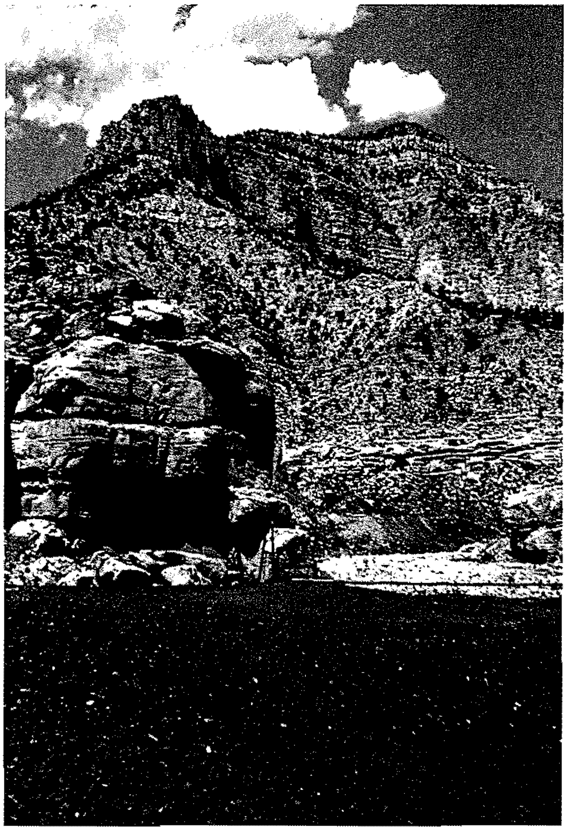

Figure 11. Castle Gate Formation and spoil pile, Castle Gate, Utah.

Creek (Fig. 12). Irrigation water, diverted on the thin alluvium quickly reaches the shale, and the return flow to the river is of very low quality. A similar situation exists, or course, in Ashley Valley near Vernal, Utah (Fig. 13), and in the Grand Valley area of Colorado, and the picture on Ashley Creek shows coarse alluvium on the Mancos, and the salty return flow to the stream.

Although the water used to wash coal at a plant below the city of Price is recycled, and stored in a reservoir nearby, some of it may reach the river by seepage, or in necessary drainage ditches (Fig. 14), lowering the water quality in the stream. (Figure 14 shows a drainage ditch that gets some water from the reservoir.)

Figure 12. Alkali ground below farmstead, near Price, Utah.

Water loss by transpiration from thick stands of salt cedar along the stream, as shown in Figure 15, adds further to the salt concentration.

A typical badlands area of Mancos shale is covered for long periods between storms by a fluffy layer of expanded shale. During a rain, or the melting of the snow cover, water penetrates a few inches into the shale, and swells it into a layer of mud, which dries into the fluff. The salts in the layer, temporarily in solution during the wetting, remain as a cement to the dried-out fluff, or even concentrate as a white efflorescence in the areas last to dry out, appearing as scattered patches of white on the early spring landscape (Fig. 16). Later in the season, they are less conspicuous, probably partly blown away by the wind, or partly covered by gray dust.

When a torrential summer rain strikes the badlands, the loose fluff is quickly swept into the small channels and on down to the river, supplying it immediately with a suspended load of clay and silt and a solution load, mostly of CA^{++} and SO_4^{--} ions, but also with considerable Na^+ and Cl^-. The water that penetrates a few inches into the shale prepares the next fluff.

Over much of the outcrop area of Mancos shale, where it is little disturbed, the shale at shallow depths is probably relatively tight, and penetration of water is limited to the few inches that produce the fluff. In

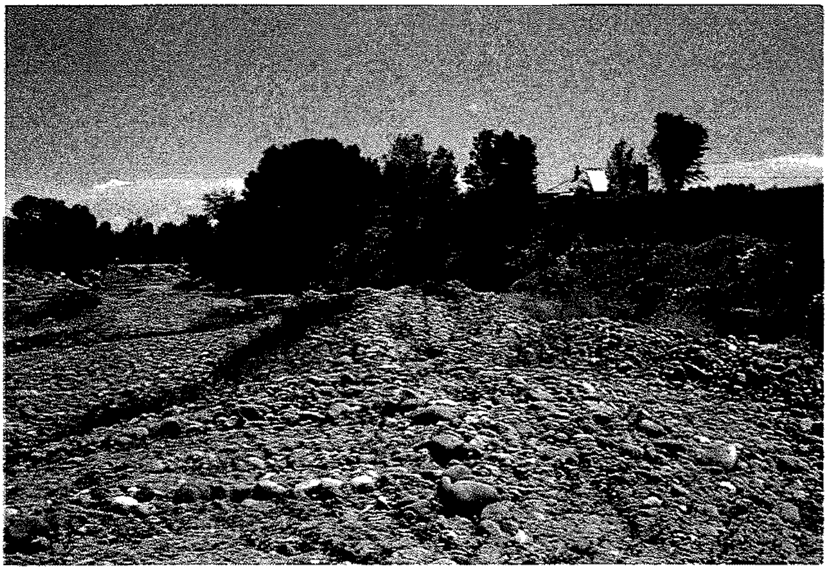

Figure 13. Water-bearing alluvium on Mancos shale, and return flow to Ashley Creek, Utah.

Figure 14. Drainage ditch from coal-washing reservoir near Price, Utah.

Figure 15. Salt cedar stand, Price River near Price, Utah.

Figure 16. Efflorescence and shale fluff, Mancos shale near Hanksville, Utah.

other areas, however, where the shale has been broken by faulting, or where large masses have been loosened by mass movements, there may be enough permeability to produce a significant underflow, and the underflow, being in contact with the shale for a much longer time than the overland runoff, would carry to the river a much higher concentration of salt.

The Mancos shale and its enclosed sandstone tongues, dip gently in a northwesterly direction off the San Rafael Swell and beneath the Price area (Fig. 17). As a result the groundwater in these tongues is confined, and wells drilled into them should be artesian. More importantly for our interest the water should be of very poor quality. Some of this low grade artesian water may escape into the Price River where it crosses any fault or shear zone that would permit the confined water to rise to the surface.

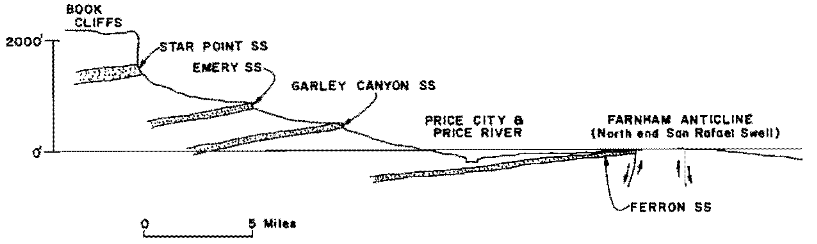

Figure 17. Diagram showing sandstone tongues in Mancos shale dipping WNW beneath and near Price, Utah.

Similarly, there is a gentle dip of the basal sandstone of the Upper Cretaceous Series, the Dakota Sandstone, or its equivalents, and any sandstone tongues in the Mancos shale, back toward the cliffs, throughout the area shown in Figure 10, and hence the conditions described for the Price area, and diagrammed in Figure 17, are essentially repeated from Grand Junction, Colorado, to the south end of Castle Valley, Utah.

The Mancos badlands have been lowered by the process of pedimentation, the shale being removed be small streams and sheet wash, originating on the sandstone cliffs above (Fig. 18). The traction load of sandstone pebbles and cobbles, picked up at or on the cliff face, and carried down across the shale, grade the pediment surfaces.

Lowering of base level at the major stream, or significant changes in the amount of runoff, dissect old pediment surfaces and create new ones

Figure 18. Pediment remnants and pediments draining to the Colorado River near Cisco, Utah.

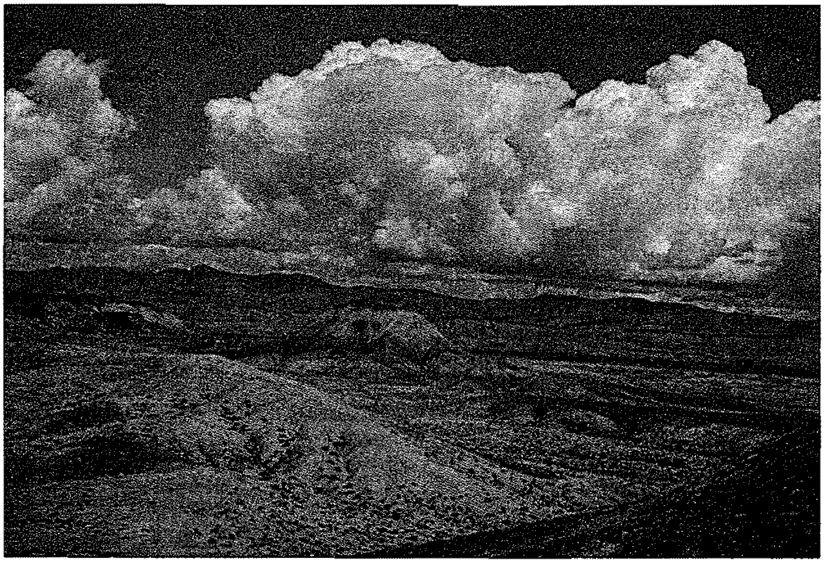

Figure 19. Pedimented terrain near Cisco, Utah.

at the expense of the old. In the Cisco area (Fig. 18) where Utah State University range students have studied the plant assemblages on at least three successive pediment surfaces, they have also gained insight, into the control of runoff. How this knowledge might be utilized for long-range control of water quality in the Colorado River has been discussed in other symposium papers.

Important as control of point sources of contamination along the river may be, and they are important, and as productive as better management of irrigated areas along the river may be in reducing the salt load, it seems well to bear in mind the basic geologic nature of the problem, which relates to one of the earths most interesting rivers draining an area of unusual geologic interest and unmatched scenic beauty.

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