acter of the rock enclosing the plugs and the depth necessary to withstand the pull of more than 2½ million pounds developed with a maximum load of 200 tons.

188. Geology of the Nevada Anchorage Site.—The sequence is comparatively simple on the Nevada side. Latite flow-breccia composing the upper portion of the canyon walls is free of serious defects. No question arose regarding its ability to support the high control tower. The sharp ravine immediately upstream, at right angles to the river, apparently is insequent rather than determined by any recognizable weakness. At the head of this defile is an intrusive sill of massive latite in which the anchorage was placed.

189. Geology of the Arizona Anchorage Site.—As shown in figure 102, the condition is somewhat more complicated on the Arizona side. A prominent fault, called the "anchorage fault" traverses the area in such a way that its influence could hardly be avoided because of the limitations imposed by the location of the powerhouse wing and outlet works to be serviced by the cable. The crustal block ultimately selected downstream from the fracture contains latite flow-breccia capped in succession by poorly consolidated Spillway Breccia overlaid by massive flows of basic latite. On account of the desired height of the control tower in Nevada and the fixed curvature of the cable, it was necessary to locate the anchorage tunnel portal in Spillway Breccia. The drift was carried an inclined distance of 60 feet from the surface. The aggregate weight of the incumbent rock under modest assumption of frictional resistance is sufficient at the completed stage to maintain the plug in position without cohesive union of blocks bounded by joints diverging from the fault.

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CHAPTER XI—MINERAL DEPOSITS IN THE RESERVOIR SITE

190. **Introduction.**—An important phase of any water-storage investigation is to make sure that the reservoir site contains no salt or other soluble mineral deposits that might make the stored water unfit for use. It was well known that there were several rather extensive salt deposits in that part of the Virgin River Valley which would be submerged by the proposed reservoir. Some of these deposits had been partially developed and commercially operated. To many of those who were not familiar with the origin of the deposits, it seemed logical to assume that the visible deposits were the outcrops of extensive salt beds underlying the entire reservoir site. Thus it was quite generally feared that such quantities of salt would be carried into solution as to make the stored water wholly unfit for irrigation or domestic use. Many of those who opposed the project urged this as one of the alleged insurmountable objections to its construction.

As a result of his preliminary examination of the mineral deposits within the reservoir site, Ransome[87] concluded that, although extensive deposits both of salt and of gypsum would be submerged by the water of the reservoir, the quantity of these minerals taken into solution would not be sufficient to appreciably affect the quality of the water.

A final detailed investigation—including extensive field examinations and surveys, and laboratory studies—as described in the following paragraphs, was made by Ransome[88] in 1929.

SALT DEPOSITS

191. **General Description.**—The visible salt deposits of Virgin Valley occur at rather widely separated localities on both sides of the Virgin River and within about 20 miles of its confluence with the Colorado River. All of them are in the lower part of the Muddy Creek formation, at a horizon that is estimated to be about 300 feet below an intercalated flow of basalt which

[87] Ransome, F. L., Geology of the Boulder Canyon and Black Canyon Dam Sites and Reservoir Sites of the Colorado River (unpublished), U. S. Bureau of Reclamation files, April 1923, p. 132.
[88] Ransome, F. L., Salt Deposits of the Virgin Valley, Nevada (unpublished), U. S. Bureau of Reclamation files, January 1930.

in some places lies below the floor of the valley, while in other places it is continuously exposed for miles, or exists only as detached remnants capping some of the higher hills. The Muddy Creek formation is composed of fine, lacustrine silts and sandy clays, and is considered to be of the Pliocene age. The character and distribution of the sediments and their association with layers of gypsum, common salt, and sodium sulfate indicate deposition under arid conditions in a closed basin.

192. **Relative Areas of Salt Exposures.**—Although some of the salt deposits seem large and actually contain relatively large quantities of salt, it will be seen that they are relatively insignificant as compared with the area of the reservoir.

Based on actual survey of the three large deposits, namely, the Salvation or Big Salt Cliff, 6.8 acres; the Calico, 5.5 acres; the Fairview, 8.8 acres; and an estimate of the remaining small outcrops, Ransome concluded that 22 acres is a generous estimate of the area of salt now actually exposed within the reservoir area. The area of the reservoir, with water surface at elevation 1222, is 142,700 acres. Comparing these areas, it is found that the area of the salt exposure is 0.000154, or less than 1/6,500 of the area of the reservoir.

In mapping the salt deposits an attempt was made to outline as generously as possible the salt masses actually exposed, as well as those so thinly or so locally covered by loose detritus that the presence of salt near the surface is practically certain. Areas where the salt is covered by a considerable depth of alluvial or other material were not included, as such covered or blanketed salt is regarded as practically protected against effective solution.

It seems apparent that the salt occurs as a series of lenses. Insofar as its effect on the reservoir water is concerned, however, it is of minor importance whether the salt occurs as lenses or as a continuous bed underlying Virgin Valley. Likewise, speculation as to possible extensive beds of salt beneath the valley floor or within the hills bordering the alluvial plain need cause no concern, since it will be readily apparent that salt in such positions can have no appreciable effect on the water of the reservoir.

193. **The Big Salt Cliff Deposit.**—This deposit, also known as the St. Thomas, or Salvation deposit, is on the west side of the flat alluvial valley of the Virgin River, 3 miles south of St. Thomas, Utah. According to a description by Gale,[89] the Big Salt Cliff, see figure 103, is a notable feature of the Virgin River Valley. The salt is exposed for nearly 2,000 feet along the cliffs of a small side ravine, locally known as the Salt Ravine; and is also exposed in places along the bluffs bordering the valley both north and south of the mouth of the ravine, for a total distance of about ½ mile. Along these cliffs, which have a maximum height of about 250 feet, there is a talus slope of loose chaotic material representing portions of the original

[89] Gale, H. S. (U. S. Geol. Survey), Mineral Resources of the United States in 1915, Part II, 1916, p. 109.

cliffs that have slumped down in consequence of the solution of the salt that formerly supported them. It seems probable that when the cliffs bordering the valley were originally formed, by cutting action of the river during a westerly swing at this locality, there was a continuous exposure of salt along the cliff for the entire distance of ½ mile. In the cliffs bordering the valley and north of the ravine, the top of the salt exposure appears above the debris slope at a height of about 150 feet above the valley, or approximately at elevation 1,250. The Big Salt Cliff is south of the Salt Ravine. The top of the deposit is here about 100 feet above the valley floor. From these high points the upper surface of the salt and the overlying beds bend sharply

FIGURE 103.—THE BIG SALT CLIFF DEPOSIT.
Typical Virgin Valley salt bed overlain by silt of the Muddy Creek formation.
(U. S. Geol. Survey, negative, Ransome 1329).

down to the north and south, and the salt passes below the floor of the valley. If all the debris, fallen rock, and earth were removed from the front of the cliff there would be exposed a crescent-shaped section of salt about ½ mile long and about 150 feet in maximum height above the base of the cliff.

Within the ravine, where the salt was originally exploited for local consumption, the top of the exposure rises to a height of 75 feet above the alluvial wash. The upper surface of the salt, as well as the overlying beds, dips away to the northwest and southwest. The deposit as a whole represents the northwesterly end of a small anticlinal fold which, to the northwest, plunges down under the overlying gypsiferous silts of the Muddy Creek formation, and to the southeast has been truncated by the lateral erosion of the Virgin River. A part of the salt mass is probably buried beneath the alluvium of the Virgin Valley.

That the salt beds of the Big Cliff or Salvation deposit have considerably greater extent that is indicated merely by its surface exposure is clearly shown by the evidence of local ground-surface collapse, sinkholes, and underground drainage, extending to distances up to ½ mile from the nearest visible salt. As herein explained, however, there need be no concern about deeply buried salt.

The nature of the rock upon which the Salvation salt mass rests is not known, as it is nowhere exposed. The overlying rock is the characteristic red-brown, fine-grained, silty material of the Muddy Creek formation. For 10 or 12 feet above the salt, this silty formation is highly gypsiferous and may be termed an impure gypsum.

The Salvation deposit is composed of coarsely crystalline, massive rock salt. In places it is practically pure; but much of it contains more or less very fine, brown, silty material which colors the mass and remains as a fluffy residue when the salt is dissolved.

At the time of Ransome's first examination of this deposit, which was in 1922, mining operations were in progress in a small way, chiefly to supply local demand. At the time of his last visit in December 1929, no work was in progress, but a tunnel had been driven which penetrates the principal salt cliff for about 400 feet, connecting with some fairly large stopes, and a small mill had been built for crushing and screening the salt. Although considerable salt has been extracted by various lessees, who usually worked on a royalty of about 50 cents a ton, the market for the product is apparently limited. The salt as a whole is too impure to make a high-grade product without solution and recrystallization.

Assuming from his examination that the Salvation deposit has an average thickness of 50 feet and an aggregate area of 80 acres, Ransome estimates the quantity at approximately 12 million tons. Samples tested for potash showed 94 to 99 percent of soluble material carrying from 0.08 to 0.29 percent of KCl.

194. The Calico Deposit.—This deposit, in the western part of Sec. 32, T. 18 S., R. 68 E., is near the road from Boulder Canyon to St. Thomas, and about 1 mile west of the Virgin River bottom lands.

The salt mass occurs in a small structural dome from which the central part has been removed by erosion, as illustrated in figure 104. The floor of this erosional depression, which is about 250 feet long and 100 feet wide, shows indications of subsidence and partial underground drainage. Apparently, therefore, it is underlaid by salt. The actual salt exposures are around the sides of the depression, and the top of the salt rises to a maximum height of about 50 feet above the floor at the west end of the depression,

where the overlying beds are uptilted to a nearly vertical attitude. The overburden, which is here about 125 feet thick, consists of tilted beds of volcanic ash; soft, brown sandstone and silty clay; but no gypsum. Elsewhere, the overburden is less, but as an average is about 50 feet in thickness.

The salt of the Calico deposit contains considerable fine silt which gives it a distinctly brown color. In general, it is much less pure than the salt of the Salvation deposit. At the time of Ransome's first visit in 1922, he noted that a few short tunnels or cuts had been made, apparently many years before. No further work had been done at the time of his last visit in 1929.

There are two outcrops of salt adjacent to the main exposure. One of these, about 2,000 feet southwest of the main deposit, shows a maximum

FIGURE 104.—THE CALICO SALT DEPOSIT.
(U. S. Geol. Survey negative, Ransome 1331).

visible thickness of about 12 feet of salt for a distance of about 1,000 feet. Another outcrop, about 20 feet thick and 90 feet long, is just south of the main exposure and near the road. These two outcrops are apparently parts of the same salt bed, the salt in the interval between them being blanketed by a deposit of terrace gravel. A small exposure of very impure salt, or more properly, saline sandstone, outcrops about 1,000 feet northwest of the main Calico deposit.

Because of the complexity of the structure at the Calico deposit, the relation of the central salt mass to these outlying exposures is far from clear. All four exposures may be parts of the same bed. It seems more probable, however, that the three outlying exposures belong to a lenticular bed of salt that is a little higher in the stratigraphic sequence than the main body of the deposit. The data relative to the Calico and adjacent deposits are too meager to justify an estimate of the probable quantity of salt.

195. Fairview Deposit.—This deposit is 1 mile southeast of the Calico deposit and about 2,000 feet west of the Virgin River bottom lands. Like the Calico deposit, it occupies the central part of a small stratigraphic dome of which the structure is complex in detail and in which a central depression has been formed by erosion. The beds forming the dome show dips up to 70 degrees. The depression is traversed by a ravine, and in addition to this surface drainage there are a number of sinkholes into which surface water flows during showers.

The Fairview outcrop is approximately circular in outline, with a diameter of about 500 feet. Within this area a part of the salt is covered by residual silt and alluvium and by remnants of the same flow which is exposed north of the Calico deposit; and north, west, and south of the Salvation deposit. Between this hill and the main body of salt, and approximately 50 feet higher stratigraphically than the salt, is a zone of thin-bedded, silty, brown sandstone which weathers with a thin white "bloom" of salt. This may be described as a fine-grained sandstone in which the cementing material is chiefly salt. The occurrence of this saliferous sandstone, which apparently is present elsewhere in the region, is suggestive of the probability that the actual salt deposits are lenticular and grade laterally into sandstone. The overlying material exposed in the bluffs and slopes that enclose the Fairview deposit is the prevalent brown silt of the Muddy Creek formation, with considerable gypsum in thin irregular seams and veinlets. The average thickness of the overburden immediately adjacent to the exposed salt masses is about 25 feet.

The salt of this deposit is generally brown and impure, containing a large proportion of included silt. Although a few pits and trenches have been made in the silt immediately above the salt, apparently as assessment work, there was no evidence at the time of Ransome's visit in 1922 and again in 1929 that any mining had been done.

196. The Black Deposit.—This exposure is near the east bank of the Virgin River, in the SE¼ of Sec. 16, T. 19 S., R. 68 E. The salt appears along the base of a westward-facing bluff for a distance of about 500 feet. The top of the salt bed rises about 75 feet above the river flat near the center of the exposure and descends to the level of the flat at both ends. The bed has a general dip to the east. The structure is that of a dome, of which the western part has been cut away by the Virgin River. The salt is overlain by impure gypsum which grades upward into red-brown silt, the aggregate thickness of gypsum and silt being approximately 40 feet. Overlying the silt is about 50 feet of gravel which apparently was deposited at an older and higher stage of the Virgin River. In at least one place there is associated with the salt a small mass of greenish, basic rock which probably is a basalt. This

has the appearance of being intrusive into the salt but may possibly be a remnant of a formerly overlying flow that has fallen into a solution cavity.

The actual exposure of salt at the Black deposit is small, and, as suggested by Ransome, could easily be covered should it be necessary by blasting down the overlying bluff. The salt is brown and impure and resembles that of the Fairview deposit. Development work consists of five tunnels and a few small trenches, none over 30 feet in length, and these were in the same condition when examined by Ransome in 1929 as when first visited by him in 1922, showing that nothing had been done during the interim. Apparently no shipments were ever made.

197. The Bonelli Deposit.—The Bonelli salt deposit is in the NW¼ of

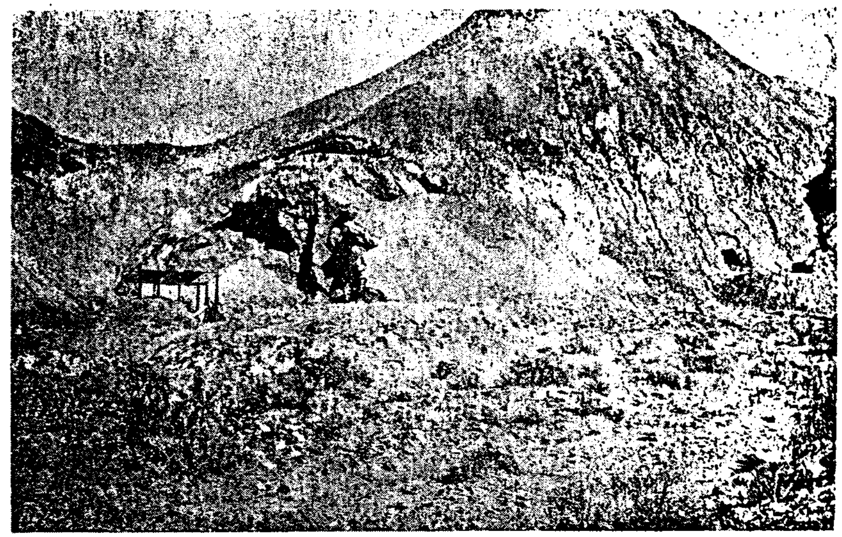

FIGURE 105.—THE BONELLI SALT DEPOSIT.
(U. S. Geol. Survey negative, Ransome 1323).

Sec. 4., T. 20 S., R. 68E., and near the east bank of the Virgin River.

The salt exposure, as illustrated in figure 104, is confined to the western extremity of a minor spur where it appears as the crest of a small, sharp, anticlinal fold of which the axis strikes about 50 degrees east. The salt mass, as seen in section in the open cut shown in the illustration, is about 20 feet high and 40 feet wide. It is directly overlain by about 70 feet of brown silt containing lenses of very impure gypsum. Overlying this brown silt is about 10 feet of impure gypsum which forms the summit of the spur. In a small ravine immediately north of the salt deposit, crystalline rocks, presumably of pre-Cambrian age, are exposed. The salt-bearing beds were either deposited against a steep slope of these rocks or have been faulted down against them.

In either case the salt bed is definitely limited in that direction. To the east and south the salt mass dips steeply under the overlying silts of the Muddy Creek formation. On the west, the salt bed has been cut away by the Virgin River. Some of the higher hills north of the deposit are capped with basalt, indicating that the salt probably lies in the same general stratigraphic zone as the other deposits, namely, a few hundred feet below the basalt flow of the former lacustrine period.

A tunnel, shown in figure 105, to the right of the open cut, has been driven into the fill for about 100 feet, penetrating brown silt. Between the tunnel and the open pit there is exposed a little very impure salt, apparently the result of the impregnation of the silt by salt carried in solution from the main salt mass. It is reported that some salt was secured from this deposit about 1895 to 1900, but apparently no mining has been done since that time.

198. **The Salt Well.**—This interesting feature, illustrated by figure 106, is about 2½ miles west of Bonelli Ferry on the north side of the Colorado River. It is a nearly circular pit with a diameter at the top of approximately 250 feet, and with steep walls. In this pit there is a pool of clear brine with its surface about 40 feet below the ground surface at the edge of the pit. The light-colored, fine-grained metal appearing in the lower part of the walls in the picture is a soft, silty clay. Overlying this are gravels.

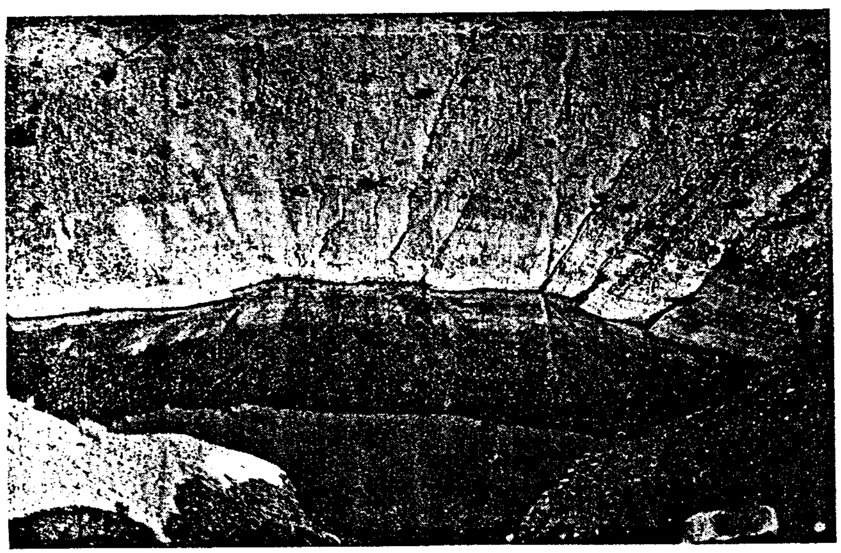

FIGURE 106.—THE SALT WELL.
(U. S. Geol. Survey negative, Ransome 1332).

Apparently the pit was formed by the solution of an underlying salt deposit and resultant sinking of overlying silt and gravel into the solution

cavity. This occurrence suggests that any attempt to estimate the quantity of buried salt in the Virgin Valley is complicated by the possible removal, by solution, of part of the salt originally present.

Tests by the United States Geological Survey show that the brine of the salt well contains 30.77 percent of dissolved salts. These contain 2.39 percent of KCl, and the remainder is probably NaCl.

199. **The Brine Spring.**—About 3 miles below the mouth of the Virgin River is a brine spring which at low water can be seen boiling up through the muddy water of the river. This spring clearly marks the point where some of the underground drainage from the Virgin Valley, or other salt deposits under the visible Muddy Creek beds, comes to the surface. It is one manifestation of a subterranean circulation of saline water which will cease when the reservoir is filled with water and the hydrostatic head which now makes such circulation possible no longer exists.

SOLUTION OF SALT IN RESERVOIR

200. **Rate of Solution.**—In experiments conducted by Ransome,[90] rectangular cleavage blocks of salt from the Salvation deposit were embedded in paraffin so as to leave exposed one cleavage surface ½ inch square in each block. Two of these blocks at a time were then immersed, face upward, in a 2-liter beaker of fresh water, at room temperature. After 6 hours the first two blocks had been dissolved to an average depth of 3 millimeters below the exposed surfaces, or at the rate of 0.5 of a millimeter per hour, or 4.38 meters (14.37 feet) per year.

Two other blocks, immersed in 2 liters of fresh water for 28 hours, were dissolved to an average depth of 7 millimeters below the exposed surfaces, or at the rate of 0.25 of a millimeter per hour, or 2.19 meters (7.19 feet) per year. Another pair of blocks, immersed in 2 liters of fresh water for 48 hours, were dissolved to an average depth of 8 millimeters below the exposed surfaces, or at the rate of 0.167 of a millimeter per hour, or 1.46 meters (4.79 feet) per year.

These experiments indicate that the longer the salt is immersed in standing water, the more concentrated becomes the solution immediately above the exposed surface and the slower becomes the rate of solution, a result that was to be expected. It was observed that particles of silt included in the blocks of salt protected the underlying salt, so that at the conclusion of the experiments these silt particles rested upon little pinnacles of salt. These pinnacles were not considered in measuring the average depth of recession.

As stated by Ransome, on the assumptions (1) that there is sufficient circulation in the water of the reservoir to prevent the accumulation of a concenrated solution in contact with the submerged salt, (2) that solution is not retarded by any covering of silt, and (3) that the rate of solution is not

[90] Ransome, F. L., op. cit., 1930, p. 33.

increased by porosity of the salt bodies, the experiments show that the recession of any particular salt deposit as the result of solution will be less rather than more than 15 feet annually. Since, however, none of these assumptions is in agreement with fact, namely, (1) the water of the reservoir will not be in rapid circulation, and there will be increasing concentration of salt solution next to the salt deposits as solution proceeds; (2) the accumulation of a silt covering will soon become increasingly effective in retarding the rate of solution; and (3) the salt deposits are traversed by solution channels so that solution will occur, at least for a time (until prevented by concentration of solution), on other than the exposed surfaces of the salt deposits, it is apparent that solution will be increasingly retarded and after a time practically cease.

201. **Effect of Covering.**—That a relatively thin covering of silt, sand, or mud will effectively protect salt deposits against solution by overlying bodies of fresh water is conclusively shown by the relation of such deposits to associated sedimentary beds in all parts of the world. An example is the great Strassfurt deposits in Germany. After the deposition of over 1,000 feet of common and other soluble salts the basin was invaded by water, unsaturated with respect to the sodium and potassium salts, and a layer of clay 15 to 30 feet thick was deposited on the salt beds. Above this clay a second series of soluble salts was subsequently deposited as the water became concentrated by evaporation. As another example, the well-known Paleozoic salt beds of New York State are interstratified with shallow-water detrital deposits, showing that the conditions of evaporation and concentration were repeatedly interrupted by incursions of fresh water. Despite this, the beds of salt previously deposited were covered by sediments and thus effectively protected from solution.

It is a fairly well established fact that deposits of buried salt would be exceedingly rare if solution of salt beds were not largely prevented by overlying sediments. The geological record shows that epochs of salt accumulation have been followed by the deposition of ordinary sediments in fresh or only moderately saline water. The salt deposits of the Virgin Valley exhibit such a sequence of events.

It has been shown by a number of investigators that when clay is deposited in salt water, a part of the sodium combines with the clay, resulting in a so-called sodium clay, which is flocculent and permeable. When this sodium clay is subjected to the action of fresh water, the excess of neutral sodium salt is washed out and the clay becomes impermeable both to water and gases. Taylor[91] describes experiments with a sand from Egypt which contains less than 5 percent of clay. The clay, however, is a sodium clay; and this sand, with only 5 percent of clay, is impermeable to fresh water in the same manner as the heaviest clay.

[91] Taylor, E. McK., The Bearing of Base Exchange on the Genesis of Petroleum: Journal of the Institute of Petroleum Technologists, Vol. 14, 1928, p. 3.

It is apparent that if the salt deposits of the Virgin Valley receive a covering of fine clayey silt, as they undoubtedly will, a sodium clay will be formed immediately above the salt, and the fresh water of the reservoir will make this clay practically impermeable. Even without the sodium clay and the process just outlined, a blanket of fine-grained silt, by checking convection currents and keeping a saturated solution in contact with the solid salt, will undoubtedly soon reduce the rate of solution to such an extent as to make it practically negligible.

202. **Probable Salt Content of Reservoir Water.**—Although it is readily apparent from the foregoing discussion that it is impossible to compute the quantity of salt that will be carried into solution when the reservoir is filled, it will be of interest to consider the probable results on the basis of certain assumptions.

If, as an extreme case, it be assumed that the whole of the 22 acres of exposed salt is dissolved to an average depth of 15 feet during the first year the reservoir is filled, which is the maximum rate found by experiment, and making no allowance for retardation by increasing concentration of solution in contact with the exposed surface, then the quantity dissolved during the first year would be 15 times 22 or 330 acre-feet, approximately equivalent to 532,000 cubic yards or 987,000 tons. Although this seems like an appalling quantity of salt, it appears small when compared with the quantity of water in which it is dissolved. The reservoir, when filled to the 1,222-foot contour, will contain about 29.5 million acre-feet of water weighing 40,100 million tons. Accordingly, the solution of 987,000 tons of salt will give a sodium chloride content of 24.6 parts per million, by weight, or a chloride radical content of 15.0 parts per million.

The foregoing assumption does not recognize any lateral solution of salt beyond the boundaries of the 22 acres; but, on the other hand, it disregards the fact that as solution proceeds, much of the solid salt will soon be covered by silt and by debris from overhanging cliffs, and thus protected. The topography of the salt deposits and adjacent areas clearly shows that the solution of 15 feet of salt along the outcrops would result in extensive slumping of the overlying material. This would provide a cover that would effectively protect a considerable part of the total area, and thus greatly reduce the general rate of solution. The assumption of a recession of 15 feet annually is believed to be far in excess of that which will actually occur.

As pointed out by Ransome[92] in his report of January 30, 1930, on which the foregoing computations are based, no allowance is made in this method for change in the water due to inflow and outflow. It is assumed there has been no water added to the reservoir after its initial filling and none drawn off. Obviously, the result of inflow and outflow will be to reduce the salt content. Assuming that 30 million acre-feet will be stored within a period of

[92] Ransome, F. L., op. cit., 1930.

3 years, during which the inflow will be 15 million acre-feet annually and the outflow 5.0 million acre-feet annually, the quantity of water available for solution of salt will be 45 million acre-feet or 61.2 billion tons. In this, the solution of 987,000 tons of salt will give a sodium chloride content of 16.1 parts per million.

It is believed that the assumed depth of solution, 15 feet, used in the foregoing calculations is excessive and improbable. In the opinion of Ransome, it would be well within the limits of safety to assume a rate of 7 feet annually. Using this rate in the foregoing computations, we find a sodium chloride salinity of 11.5 parts per million in 29.5 million acre-feet of water, and 7.5 parts per million in 45 million acre-feet.

203. **Salt Tolerance—Permissible Salt Content of Drinking Water.**— According to Whipple,[93] experiments show that water must contain about 200 parts per million of sodium chloride before the presence of salt can be

TABLE 9.—CHLORINE IN WATERS OF VARIOUS LAKES AND RIVERS

(In parts per million)

Lake Michigan at St. Ignace	2.31
Lake Erie, at Buffalo	6.58
St. Lawrence River, opposite Montreal	2.41
Hudson River, at Hudson	3.96
Raritan River, at Bound Brook	5.52
Potomac River, above Great Falls	3.27
Mississippi River, at Memphis	4.10
Tennessee River, near Gilbertsville, Ky.	2.93
Laramie River, 50 miles below Laramie	6.32
Yellowstone Lake	7.96
Rio Grande, at Mesilla, N. Mex.	13.55
Pecos River, New Mexico	22.56
Colorado River, at Yuma	19.92
Salt River, at Mesa, Ariz.	41.56
Sacramento River, above Sacramento, Calif.	5.79
San Gabriel River, near Rivera, Calif.	3.22
Snake River, near Weiser, Idaho	7.99
Umpqua River, near Elkton, Oreg.	4.85

detected by taste. W. D. Collins of the United States Geological Survey states[94] that few people can detect the taste of salt in water containing less than 600 or 800 parts per million. He also classes[95] as "good" water one

[93] Whipple, G. C., The Value of Pure Water, Wiley and Sons, New York, 1907, p. 66.

[94] Collins, W. D., The Industrial Utility of Public Water Supplies in the United States: U. S. Geol. Survey, Water-Supply Paper 496, 1923, p. 24.

[95] Bryan, Kirk, Geology and Ground-Water Resources of Sacramento Valley, California (section on Quality of Water, by W. D. Collins): U. S. Geol. Survey, Water-Supply Paper 495, 1923, p. 97.

that, among other requirements, contains less than 250 parts per million of the chloride radical, equivalent to 412 parts of sodium chloride.

The United States Public Health Service specifies in Reprint 1029, Public Health Reports, April 10, 1926, that an acceptable water supply should not contain over 250 parts of chloride per million.

It is generally assumed that the chlorine given in a water analysis is combined with enough of the available sodium to form sodium chloride. Such analyses usually give the chlorine ion, or chloride radical, in parts per million. Accordingly, it will facilitate comparison with such analyses to determine the quantity of the chlorine ion that corresponds to a salt content of 7.5 parts per million. Taking the atomic weight of chlorine as 35.3, and that of sodium as 23, this equivalent is found to be 4.6.

204. **Chlorine in Waters of Lakes and Rivers.**—Table 9 is taken from Ransome's report of January 1930, and is a compilation of data from U. S. Geological Survey Bulletin 770 (1924), "Data on Geochemistry," by F. W. Clarke.

According to Clarke, on page 119 of his report, the average chlorine content of the waters of lakes and rivers of North America is 7.44 parts per million. In general, the chlorine content of rivers of the arid regions is higher than the average, and that of rivers of humid regions is less.

On the basis of the preceding calculations and comparisons, it is obvious that the salinity produced in Boulder Canyon reservoir by the solution of all salt outcrops to a depth of 7 feet, amounting to 7.5 parts of sodium chloride per million, or 4.6 parts of chloride radical, will be far too slight to make the water objectionable for irrigation or domestic purposes. Even though we consider the first and improbable assumption that the salt exposures will be dissolved to a depth of 15 feet, with no inflow of fresh water after the initial filling, which gives a salt content of 24.6 parts per million or a chloride radical content of 15.0 parts per million, the quality of the water would be superior to that in use on several long-established and successful irrigation projects in the southwest and obviously would improve after the first year of operation.

It is believed that all the assumptions are well on the side of safety, and that the quantity of salt actually carried into solution will be far less than that used in the foregoing calculations. However, even though we double the area of the salt exposures, and assume that they are dissolved to a depth of 15 feet during the initial filling of the reservoir, with no change in water due to inflow and outflow, giving a sodium chloride salinity of 49.2 parts per million, or a chloride radical content of 30.0 parts per million, the water would still be usable and the presence of salt could not be detected by taste.

The foregoing discussion leads to the conclusion that the salt deposits within the reservoir area will have no appreciable effect upon the quality of the stored water.

OTHER SOLUBLE SALTS

205. **Sodium Sulfate.**—The reservoir area is known to include at least one deposit of sodium sulfate. This is ½ mile south of the Salvation salt deposit and occurs as a series of lenticular beds interstratified with silts of the Muddy Creek formation. The outcrop is in a steep bluff on the west side of the Virgin River flat and is marked by a white efflorescence which might be mistaken for salt. No chemical analysis was made, but the deposit is probably hydrous sulfate, the efflorescence resulting from the loss of water on exposure to dry air. The material is far from pure.

When visited by Ransome in December 1929, a tunnel had been extended into the deposit for about 140 feet, and a winze was being sunk near the face with the hope of reaching a concentrated solution from which a pure product could be secured by evaporation and recrystallization.

206. **Gypsum.**—As the result of his examination, Ransome concluded that the reservoir area contains a larger quantity of gypsum than of salt, see figure 107. Practically none of the gypsum is pure, most of it being interstratified with silt. Some of it undoubtedly will go into solution, but the rate of solution is much slower than that of salt and obviously will become increasingly slower with the accumulation of a silt covering.

In view of the conclusions concerning the salt, it is exceedingly improbable

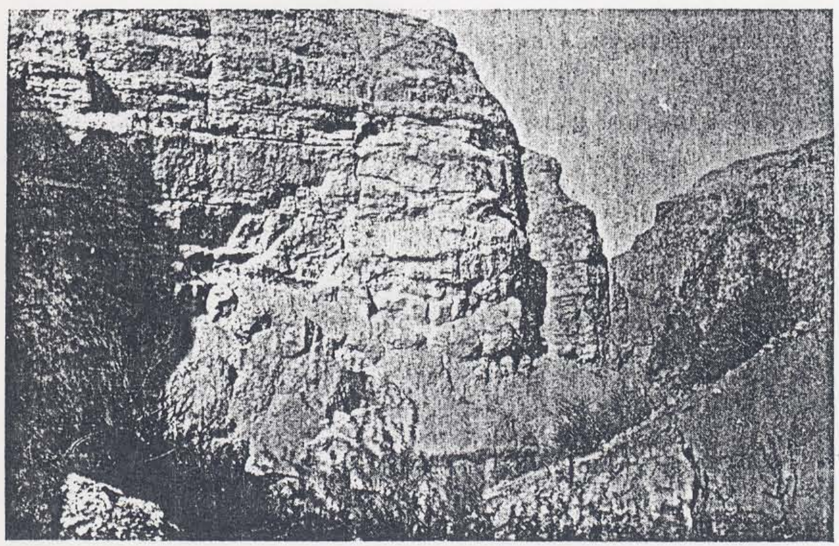

FIGURE 107.—MASSIVE GYPSUM DEPOSIT.
View of west side of Detrital Wash, 6 miles south of Colorado River. Entire cliff, which is about 500 feet high, is gypsum interstratified with silt.
(U. S. Geol. Survey negative, Ransome 1294).

that the gypsum can have any appreciable effect on the stored water. Chemical analyses of the reservoir water will undoubtedly show a decrease in calcium sulfate after the first year.

CONCLUSIONS

207. **Effect of Salt Deposits.**—As a result of studies outlined in this chapter, the following conclusions were made as to the probable effect of salt deposits in the Hoover Dam reservoir area:

1. Under the improbable assumption that the salt exposure will be dissolved to a depth of 15 feet during the first year of reservoir operation, resulting in the solution of 987,000 tons of salt, with no change of water in the reservoir, the salinity of the reservoir water will be increased by a chloride radical content of 15.0 parts per million. Adding this to the average content of 98 parts per million in the river water entering the reservoir, we have 113.6 parts per million chloride radical content, which is less than one-half of the 250 parts per million of chlorides that the United States Public Health Service specifies as permissible in an acceptable water supply.
2. The quality of salt that will actually go into solution the first year will probably be much less than one-half of that assumed in the preceding paragraph.
3. The quantity of salt going into solution will rapidly decrease after the initial filling of the reservoir.
4. The effect of the salt deposits on the quality of the stored water will be practically negligible.