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April 13, 1956

Mr. Robert D. Nininger, Assistant Director
Division of Raw Materials
U. S. Atomic Energy Commission
Washington 25, D. C.

Dear Bob:

Transmitted herewith are three copies of TEI-320, "Occurrence and chemical character of ground water in the Morrison formation in southwestern Colorado and southeastern Utah," by David A. Phoenix, September 1955.

We are asking Mr. Hosted to approve our plan to publish this report as a chapter of a Geological Survey bulletin on mineralogy and geochemistry of the ores of the Colorado Plateau. Acknowledgment of AEC sponsorship will be made in the introductory chapter.

Sincerely yours,

John H. Eric

for W. H. Bradley
Chief Geologist

Geology and Mineralogy

This document consists of 23 pages,
plus 1 table.
Series A

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

OCCURRENCE AND CHEMICAL CHARACTER OF GROUND WATER IN THE MORRISON FORMATION IN SOUTHWESTERN COLORADO AND SOUTHEASTERN UTAH*

By

David A. Phoenix

January 1956

Trace Elements Investigations Report 320

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*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

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OCCURRENCE AND CHEMICAL CHARACTER OF GROUND WATER IN THE MORRISON FORMATION IN SOUTHWESTERN COLORADO AND SOUTHEASTERN UTAH

By David A. Phoenix

ABSTRACT

Ground water in the Morrison formation is in juxtaposition with deposits of uranium-vanadium ore minerals. This water is under water-table conditions in most of the region, but locally it is confined by impermeable clay strata. It is mostly derived from the infiltration of precipitation and surface runoff. Some water is contained in pore spaces in sandstone but most is in joints. Movement of this water is, at first, downward from the land surface; but, bedding planes, mudstone seams, and other places where the rocks have a low permeability act as barriers and divert its path usually toward the direction of regional dip. Under water-table conditions the permeable sediments are usually saturated for a few inches to a few feet above each extensive barrier; under artesian conditions the ore-bearing sandstone is entirely saturated. The amount of water contained in the rocks is not great and its movement is slow. Evaporation from the land surface and transpiration by plants are sufficiently high to dispose of most of the discharge, but discharge is great enough to form springs and seeps locally.

Samples of ground water from the Salt Wash and Brushy Basin members of the Morrison formation have been analyzed to determine their chemical character and metal content. The Salt Wash ground water is largely a bicarbonate solution with variable amounts of calcium and magnesium ions;

the Brushy Basin ground water is either a sulfate or bicarbonate solution with sodium. The ground water from the Salt Wash and Brushy Basin members is generally weakly alkaline. In most samples, uranium, vanadium, copper, lead and selenium are present in amounts less than 1 ppm (parts per million).

It is concluded that if ground water was responsible for introduction of the uranium and vanadium metals into the Salt Wash and if it was comparable to present ground water, it contained very small concentrations of the metal ions.

INTRODUCTION

Ground-water studies were undertaken in southwestern Colorado and southeastern Utah (fig. 1) to determine the influence recent ground water has had upon the uranium-vanadium deposits. This paper, therefore, is concerned mainly with the occurrence and chemical composition of ground water in the uranium-vanadium bearing Morrison formation. Water-level measurements in numerous bore holes have been used to determine the mode of occurrence of ground water in ore-bearing sandstone of the Morrison formation. Chemical analyses of ground water from 23 sample points in the Morrison formation establish its chemical characteristics and metal ion content.

The number assigned to a well or spring in this report is both an identification and a location number. It is based on the base and meridian system of the General Land Office. A typical number consists of three units. The first unit is the number of the township north or south of the base line. The second unit, separated from the first by a slant, is the number of the range east or west of the meridian. The third

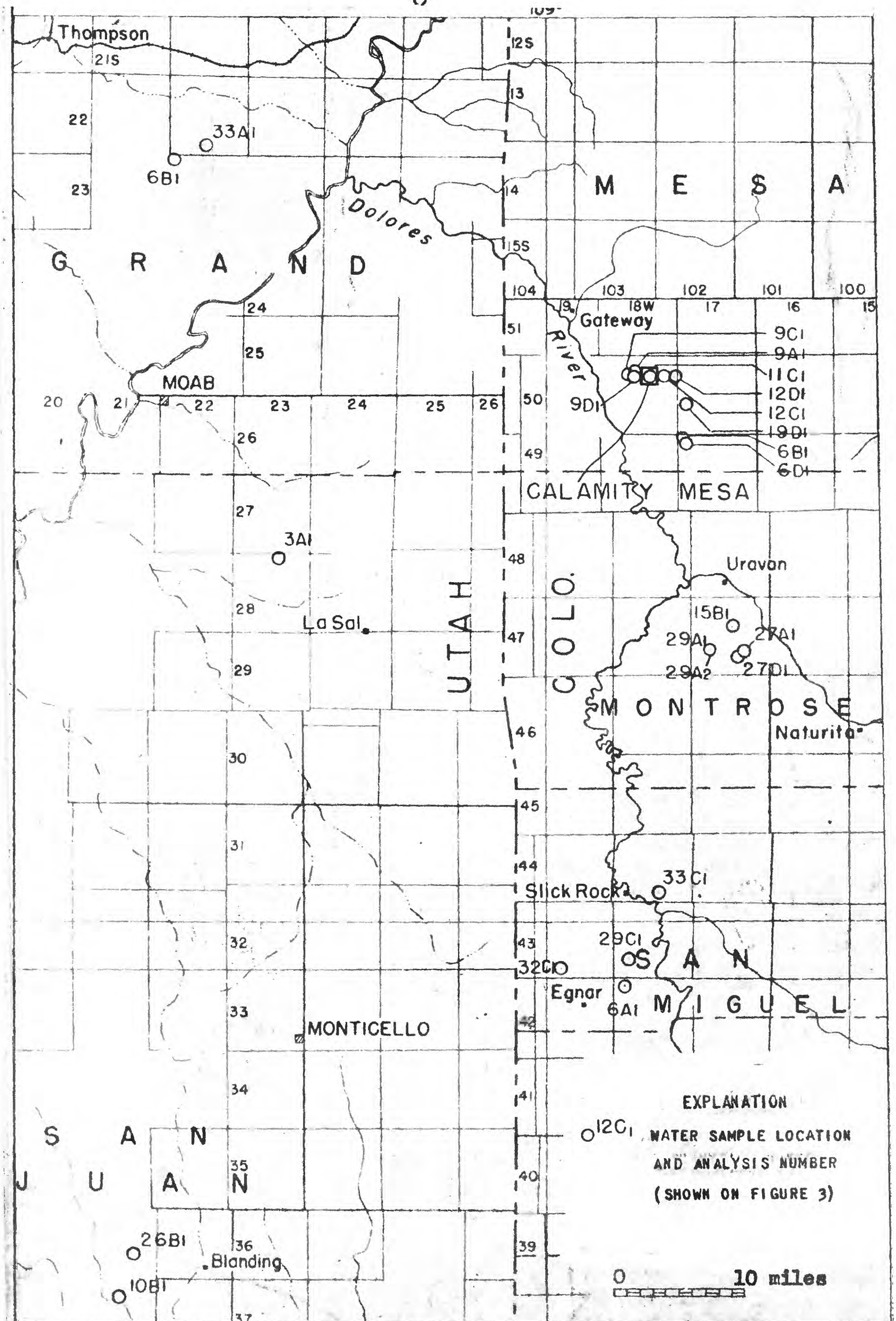

Figure 1. INDEX MAP OF SOUTHWESTERN COLORADO AND SOUTHEASTERN UTAH, SHOWING WATER SAMPLE LOCATIONS AND THE AREA OF GROUND WATER

unit, separated from the other two units by a dash, lists the number of the section and is followed by a letter designating the quarter section, and finally a number to show the order in which the well or spring was recorded within the subdivision. The letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quarters of the section. On figure 1, owing to space limitation, only that part of the number designating the subdivision of the section and the order in which the well or spring was recorded in that subdivision is shown.

CLIMATE

The climate of the region is semiarid, but the average annual precipitation differs from place to place. The average monthly and annual precipitation in different geographic and topographic localities is summarized in table 1. In Colorado, the Norwood and Northdale stations are on upland mesas; the Paradox and Gateway stations are in the bottoms of steep-walled canyons. The station at Monticello, Utah, is on the east flank of the Abajo Mountains, and precipitation here is probably duplicated on the upland mesas east of the La Sal Mountains. Thompson, Utah, is on the eastern edge of the Green River desert; this region receives less rainfall than most areas in southwestern Colorado and southeastern Utah. The average annual precipitation in the area of detailed ground-water study (fig. 1) is probably not as great as that at the Norwood or Northdale stations or as little as that at the Gateway station. The average precipitation in the area of detailed ground-water study is probably about 12 inches a year.

Table 1. Average monthly and annual precipitation, in inches, at eight climatological stations in southwestern Colorado and southeastern Utah.

(Data from U. S. Department of Commerce, Weather Bureau. Record from establishment of station to 1954 inclusive.)

Station	Altitude	No. of years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average annual
Blanding, Utah	6,036	46	1.05	1.20	1.08	0.94	0.76	0.58	0.99	1.24	1.47	1.29	0.82	1.35	12.77
Monticello, Utah	7,066	32	1.25	1.44	1.57	1.09	0.87	0.72	1.51	1.88	1.62	1.86	1.09	1.36	16.26
Moab, Utah	4,125	61	0.73	0.69	0.88	0.73	0.72	0.43	0.81	0.79	0.98	0.99	0.65	0.86	9.26
Thompson, Utah	5,150	30	0.59	0.56	0.73	0.67	0.51	0.51	0.85	0.90	0.97	1.10	0.49	0.72	8.60
Norwood, Colo.	7,017	26	1.00	1.27	1.45	1.56	1.10	0.96	1.78	1.97	1.52	1.32	0.82	1.11	15.86
Northdale, Colo.	6,842	24	1.10	1.16	1.31	1.18	0.82	0.63	1.15	1.45	1.91	1.52	1.35	1.19	14.20
Paradox, Colo. 1/ (2 mi. SE)	5,300	13	0.74	0.53	0.59	0.74	0.57	0.64	1.09	1.04	0.66	1.14	0.75	0.82	8.71
Gateway, Colo. 2/ (4 mi. NE)	4,903	7	0.93	0.61	0.67	0.87	0.82	0.48	0.90	1.29	0.89	1.33	0.59	0.54	9.57

1/ Averages based on incomplete record, 1942-54 inclusive.

2/ Averages based on incomplete record, 1947-54 inclusive.

MORRISON FORMATION

The Morrison formation of Jurassic age is divided into two members, an upper member, the Brushy Basin, and a lower member, the Salt Wash. The Brushy Basin member is varicolored bentonitic shale and mudstone interbedded with lenticular strata of sandstone and conglomeratic sandstone. Discrete strata of conglomeratic sandstone occur sporadically near the base of the member. The Salt Wash member is composed of lenticular strata of sandstone and mudstone. Near the top of this member the strata of sandstone give the appearance of a persistent layer because the strata overlap. In detail, however, they are separated by beds of mudstone or local disconformities. The uranium-vanadium ore deposits are largely confined to the uppermost sandstone strata of the Salt Wash member.

Erosion has dissected the Morrison formation so that it now forms the midslopes of many mesas in southwestern Colorado and southeastern Utah. Outcrops of the Brushy Basin member are sparse except in the most arid regions. The beds are usually covered by landslide debris or talus blocks of more resistant and younger formations. Outcrops of sandstone in the Salt Wash member are resistant and they usually form cliffs and broad benches. Because the Morrison formation has been dissected by erosion and also broadly folded, outcrops of the ore-bearing sandstone of the Salt Wash member differ in altitude from area to area so that the opportunity for ground-water recharge in the member depends upon local structural and topographic features as well as the average annual rainfall.

OCCURRENCE OF GROUND WATER

The main aquifer in the Morrison formation is composed of lenticular sandstone strata near the top of the Salt Wash member. This aquifer is locally called the "ore-bearing sandstone" because it contains most of the uranium-vanadium deposits in the Morrison formation. From a distance its appearance is often that of a continuous layer. Other strata of sandstone lower in the Salt Wash member as well as strata of conglomeratic sandstone at the base of the Brushy Basin member sometimes contain ground water, but generally they do not yield water to wells or springs.

Ground water in the ore-bearing sandstone is confined in some areas, but in most of the region it is unconfined. Unconfined ground water is common in the ore-bearing sandstone. It has been studied in the Calamity Mesa area, Mesa County, Colo. (fig. 1) in an area where the ore-bearing sandstone is exposed for about 2 square miles and where it has been explored by mine workings and cut by several hundred diamond-drill holes. Several months after drilling had stopped the depth to water was measured in 246 uncased diamond-drill holes. These drill holes are distributed throughout the Calamity Mesa area, and they penetrate the ore-bearing sandstone as well as several feet of mudstone below. Water was encountered in all but 20 of the diamond-drill holes. In drill holes near the central part of the mesa, water levels, in places, stand 20 or 30 feet above the base of the ore-bearing sandstone; in the drill holes nearer the edge of the mesa, water levels are only 2 or 3 feet above the base of the ore-bearing sandstone, and those that do not contain water are along the edge of Calamity Mesa where the ore-bearing sandstone is exposed as a cliff and where it is jointed.

Confined ground water has been found in synclinal structures where erosion has not destroyed the nearly impermeable cover of the Brushy Basin member. Diamond-drill holes to the ore-bearing sandstone have encountered water under sufficient hydrostatic pressure to flow at the land surface near Uravan, Montrose County, Colo., near Slick Rock, Montrose County, Colo., near La Sal, San Juan County, Utah, and 6 miles west of Blanding, San Juan County, Utah. In these places the lenticular ore-bearing sandstone is probably saturated and the lenses are sufficiently connected hydraulically to be capable of transmitting ground water to drill holes for at least 2 or 3 miles from the nearest recharge area. Flows of 30 gallons per minute at the land surface and pressure sufficient to raise water levels 20 feet above the land surface have been recorded in the La Sal Creek and Uravan areas. However, the amount of ground water flowing from these drill holes and the hydrostatic pressure usually have decreased substantially within a few months after the hole was drilled. This indicates that the beds are not very permeable and hence, movement of water from the outcrop to the drill holes is slow.

Some of the characteristics of ground-water occurrence were determined from a contour map of the water table based on the measured water levels referred to a sea-level datum. The contour map indicates that ground water in the ore-bearing sandstone is perched on mudstone at the base of the ore-bearing sandstone and that the water table has a general slope of about 3° SW., approximately the same as the dip of the rocks. However, the contact between the ore-bearing sandstone and the mudstone below is an irregular surface with locally as much as 6 feet of relief. The water-table map is in places a subdued replica of a map of this surface. It is believed that the direction and rate of ground-water movement are controlled in part by irregularities in the contact. The "lows" in the contact may act as "channelways" along which the greater amount of the present day ground water moves.

The measurement of water levels was sometimes hindered by the presence of moisture on the walls of the diamond-drill holes. This moisture persisted throughout the 21 months of observation and it is believed to be ground water. In each case where it was detected, the upper level of moisture was above a lenticular stratum of mudstone or above some similar impermeable zone contained within the ore-bearing sandstone. It is difficult to evaluate the influence leakage from these local zones of saturated rocks may have had on water-level measurements in the diamond-drill holes for the rate of leakage could not be determined.

The movement of water into the rocks is at first downward from the surface. A large part of this water gains entry to the ore-bearing sandstone through joints, but some probably moves through the intergranular interstices in the more permeable places. The portion of this water that exceeds soil-moisture requirements is free to percolate to the water table and migrate laterally in the direction of the hydraulic gradient as ground water. The path of ground-water movement generally follows the direction of regional dip, but in detail it is devious for the ore-bearing sandstone contains numerous barriers in the form of lenticular clay strata, local disconformities, and bedding planes. The ore-bearing sandstone may thus be saturated above each impermeable zone for a few inches or even a few feet and in more than one place. It is believed that ground water may have "cascaded" from the extremity of each lenticular barrier eventually to reach the impermeable mudstone at the base of the ore-bearing sandstone.

The water levels in 22 of the holes were measured at monthly intervals from late 1949 through July 1951. The monthly measurements of 10 of these holes are plotted on figure 2 to show the water-level fluctuations. Although the water levels in some of the holes, notably CA-125, CA-501, CA-505, and CA-678, show fluctuations through the period of observation, water in other holes shows little or no fluctuation. These data suggest that the water in the sandstone strata is being recharged locally by the infiltration of surface water and precipitation, probably introduced into the sandstone through fractures that are open to the surface. The lack of response of the water level in other holes to seasonal variations in precipitation suggests that sandstone in the immediate vicinity of these holes is not fractured and has a relatively low permeability; in places pore spaces in the ore-bearing sandstone may be plugged with drill mud.

Discharge of ground water from the ore-bearing sandstone is by springs or seeps, by evaporation, and by plant transpiration. The fact that some drill holes in the ore-bearing sandstone are "breathing" air suggests that locally there is atmospheric circulation in the rocks; therefore, some ground water is probably lost by evaporation within the rocks. In places, the roots of juniper and pinon and probably the roots of other plants as well reach several tens of feet into the rocks, and these plants act as miniature pumps to discharge ground water. Along the

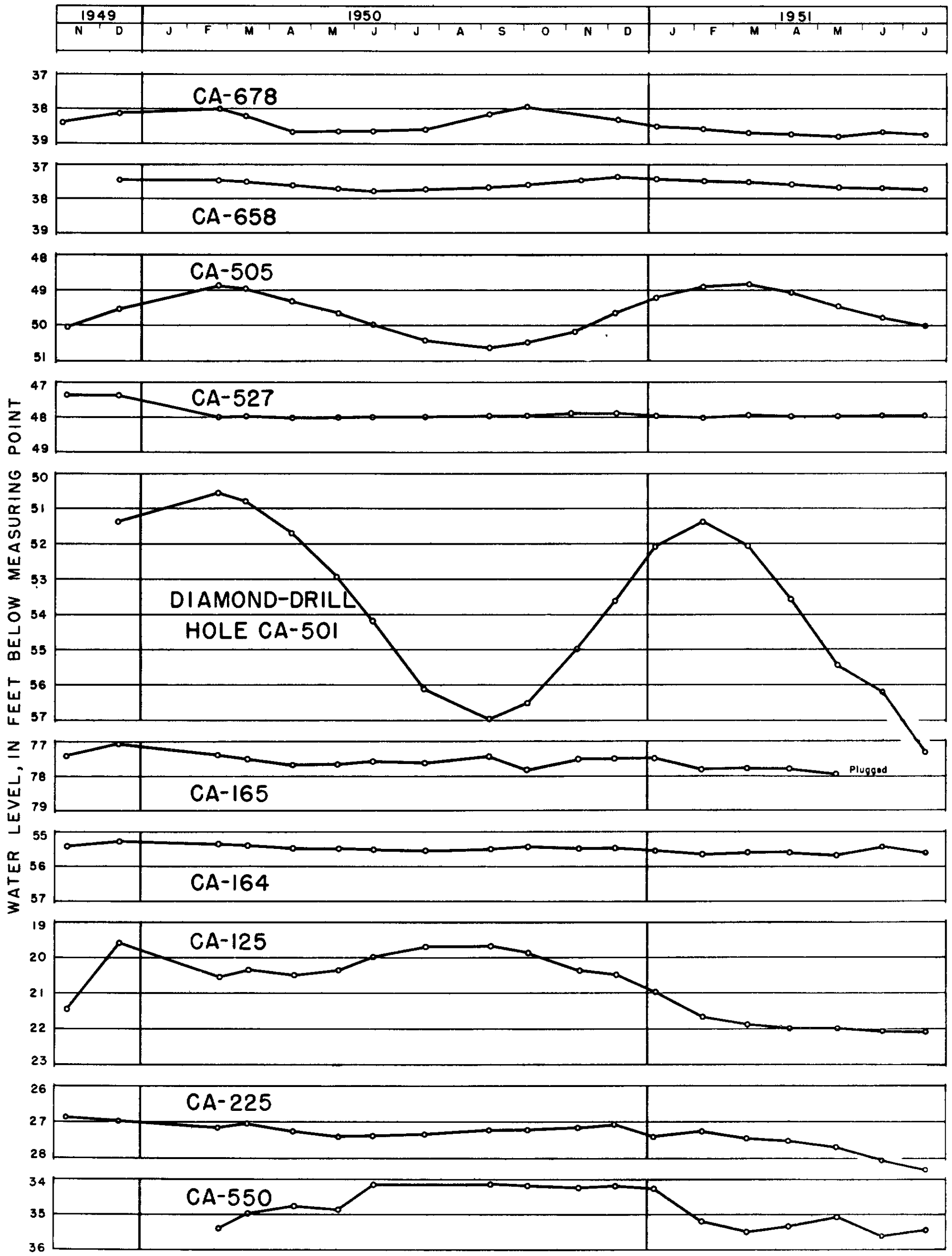

Figure 2. HYDROGRAPHS OF WATER-LEVEL MEASUREMENTS IN 10 DIAMOND-DRILL HOLES, CALAMITY MESA AREA, MESA COUNTY, COLORADO, NOVEMBER 1949 TO JULY 1951.

edge of Calamity Mesa plant roots penetrate joints to depths of about 20 feet below the top of the ore-bearing sandstone, but mine workings in the interior of the mesa have encountered roots along prominent joints to a depth of about 50 feet. The amount of ground water discharged from within the ore-bearing sandstone by plant transpiration is probably small, except near the outcrop or where the rocks are jointed and plant roots can easily penetrate to the zone of saturation or to its capillary fringe. Ground-water discharge is most active along the downdip or southwest edge of the mesa where the base of the ore-bearing sandstone is exposed. The total amount of ground water discharge from the Calamity Mesa area cannot be measured, but it is probably only a small fraction of the average annual rainfall.

Chemical character of ground water

The chemical analyses of 23 samples of ground water from the Morrison formation are shown in table 2. These samples were collected from mines, springs, and wells in the Salt Wash and Brushy Basin members of the Morrison formation. All samples from the Salt Wash member were collected near ground known to contain uranium-bearing minerals. Samples from the overlying Brushy Basin member presumably had not percolated through or near rocks containing these minerals.

The milligram equivalents, or reacting values (Palmer, 1911, p. 5) (called equivalents per million in this report) of the soluble ions, have been computed for all the analyzed samples. The equivalents per million for 22 of the samples are shown graphically on figure 3 and

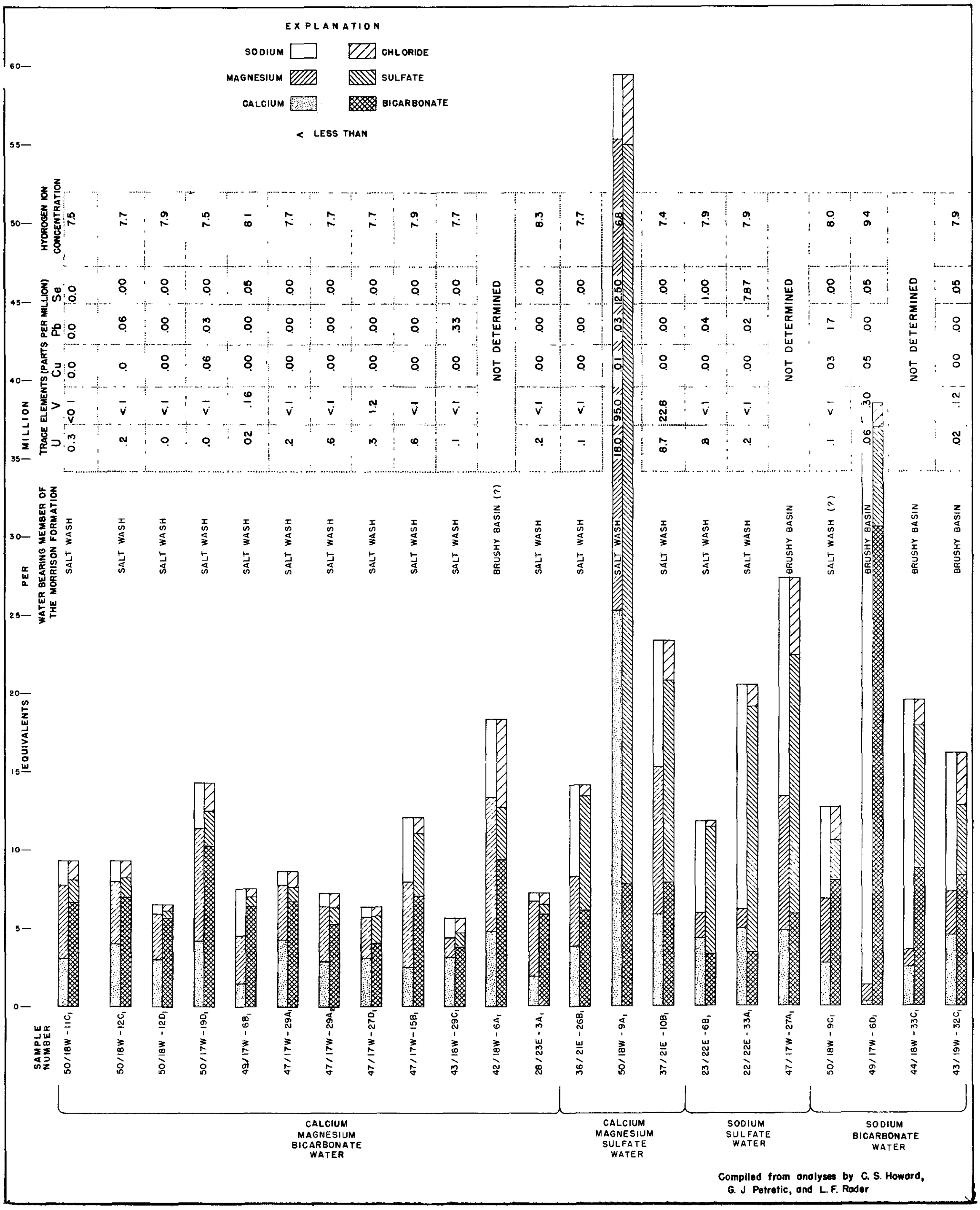

Figure 3. BAR GRAPH SHOWING ANALYSES OF GROUND WATER FROM THE MORRISON FORMATION IN EQUIVALENTS PER MILLION AND THE CONCENTRATION OF TRACE ELEMENTS IN PARTS PER MILLION. SAMPLE LOCATIONS SHOWN ON FIGURE 1.

indicate the chemical character of the water from each locality at the time the water was sampled for analysis. Of the 22 samples, 12 are classed as calcium, magnesium bicarbonate water, 3 as calcium, magnesium sulfate water, 3 as sodium sulfate water, and 4 as sodium bicarbonate water. These differences in character are probably determined in part by the duration of time the ground water has been in contact with the rocks, by the composition and physical properties of the rocks, by the presence or absence of soluble salts in the paths of ground-water movement, and by the degree to which the solution has been concentrated by evaporation and plant transpiration. For example 50/18W-9A (table 2), the total iron, sum of total dissolved solids, and tons per acre foot appear to be questionable determinations and their application should be used with reservation. The sample was turbid when collected and the iron probably includes that from ferruginous sediments. Although total iron should include both iron in solution and precipitated, it is based on the premise of a clear sample at the time of collection. This, however, does not disqualify it as a calcium, magnesium sulfate water.

Water from the Brushy Basin member has a high concentration of sodium ions, whereas, water from Salt Wash sandstone has a high calcium and magnesium ion concentration. It is believed that this difference in chemical quality is due largely to gross differences in mineralogy between the Salt Wash and Brushy Basin sediments.

The uranium, vanadium, copper, lead, and selenium content of 19 of the 22 water samples are also shown on figure 3. The concentration of uranium, vanadium, copper, and lead at the threshold of detection is about 0.01 ppm, whereas, the concentration of selenium at the threshold of detection is 0.05 ppm. Where 0.00 ppm is reported for selenium, it indicates less than 0.05 ppm; for the other metals 0.00 ppm indicates a concentration of less than 0.01 ppm. As a general rule, these metals were found in amounts of less than 1 ppm, and some are present in such small amounts that they are just above the threshold of detection as determined by quantitative methods used at the time these solutions were analyzed. Although the concentration of these metals differed within these limits, the amounts present do not seem to correspond to the variations of total dissolved solids in the ground waters.

Lead was detected in trace amounts in some of the samples collected from the ore-bearing sandstone. At the localities from which these waters were collected this metal is known to occur in minor amounts in the uranium-vanadium ore.

Selenium and copper, common in many ore deposits in the Salt Wash member, were detected in water from the Brushy Basin member, even though this member contains very few ore deposits.

Fluoride in ground water from ore-bearing sandstone in the Salt Wash member is usually present in amounts ranging from 0.20 ppm to 0.90 ppm. However, samples $49/17W\text{-}6D_1$ and $44/18W\text{-}33C_1$ collected from the Brushy Basin member have 2.60 and 1.00 ppm fluoride respectively. The significance of these differences cannot be determined from the few analyses available.

Detectable amounts of boron are present in most of the ground waters sampled for analysis. The average concentration of boron in all the samples analyzed is 0.05 ppm.

Uranium and vanadium were detected in all the water samples that were analyzed for these metals. The greatest amount of uranium and vanadium was detected in ground water from mine sumps (samples 50/18W-9A_1 and 37/21E-10B_1). Either the metals in these samples were present as colloids or else the ore minerals from these mines were more soluble in this ground water than elsewhere. It might be significant that these water samples have a higher magnesium ion and hydrogen ion concentration than those from any other locality. It is also suggested that the oxidation potential of these waters might differ from the ordinary ground-water solution from the Salt Wash member. In the remaining 17 samples, none contained uranium or vanadium in amounts greater than 1.20 ppm, and the median amount of uranium or vanadium in the normal ground water is about 0.10 ppm. As observed by Phoenix (1951) and reported by Judson and Osmond (1955), these amounts are appreciably higher than can be expected from nonmineralized areas.

Observed secondary uranium and vanadium minerals on fractures suggest that the concentration of the uranium and vanadium ions in the ground water might bear some spatial relationship to the ore deposits. To test this, sample 49/17W-6B_1 was collected at a spring issuing from ore-bearing sandstone of the Salt Wash at a point approximately 2,000 feet downdip from the nearest ore body, and sample 47/17W-29A_1 was collected from a mine stope in the immediate vicinity of sandstone that contained carnotite ore. The first sample contained 0.02 ppm uranium and 0.16 ppm vanadium, whereas, the second contained 0.20 ppm uranium and $<$0.10 ppm vanadium. The higher concentration of the uranium ions in the sample of ground water collected near an ore body suggests a difference that may be directly related to the proximity of the deposits.

It was expected that there might be a major difference in the uranium and vanadium content between the waters collected from the Salt Wash member and those collected from the overlying Brushy Basin member, as the Salt Wash contains practically all the ore deposits found in the Morrison formation. Differences, however, are not too striking. Three water samples from the Brushy Basin average 0.04 ppm uranium and 0.17 ppm vanadium. Samples of ground water from the Salt Wash and from the Brush Basin together, excluding samples reported from ore or from mine sumps, and exclusive of those which a "less than" value is given, have the following average content: 0.24 ppm uranium in 5 samples ($50/18W\text{-}9C_1$, $50/18W\text{-}11C_1$, $50/18W\text{-}12C_1$, $49/17W\text{-}6B_1$, and $47/17W\text{-}27D_1$), and 0.45 ppm vanadium in 4 samples ($49/17W\text{-}6B_1$, $47/17W\text{-}27D_1$, $49/17W\text{-}6D_1$, and $43/19W\text{-}32C_1$).

The relation of metal concentration to the hydrogen ion concentration in the ground-water solutions cannot be determined with certainty from the few analyses available. Within the determined limits of hydrogen ion concentration, i.e., $10^{-6.8}$ to $10^{-9.4}$, uranium concentrations are between 18.95 ppm for the most acid solution to 0.06 ppm for those that are most alkaline, whereas, vanadium concentrations are between 95.00 ppm for the most acid solutions to 0.30 ppm for the most alkaline. These data would suggest a rather direct correlation with pH and the solubility of the uranium and vanadium. However, as Garrels (1953; 1955) has shown, the stability of uranium and vanadium in aqueous solutions is not only dependent upon the pH of the solution, but upon the Eh of the solution and upon the oxidation state of the uranium and vanadium compounds as well. Unfortunately, it has not been possible to measure Eh in natural solutions with consistent results, and thus no direct correlation between the amount of the uranium and vanadium in the groundwater solution and pH alone should be made until more data become available. The water samples that contain high concentrations of uranium and vanadium were collected from places where ores are undergoing active oxidation, thus giving maximum opportunity for solutions of unstable phases formed during the oxidation process.

The efflorescent coatings of bicarbonate and sulfate salts around the rims of springs or seep outlets distant from known ore deposits are not radioactive. There is thus no indication that carnotite, or some similar uranium mineral, is being precipitated from the normal ground water at these places. On the other hand, the carnotite observed coating many fracture surfaces in the ore-bearing sandstone near the ore deposits above the present water table, as well as the efflorescent coatings of uranium and vanadium salts on mine walls, shows that uranium and vanadium are migrating. Uranium minerals coating fractures may have formed from earlier ground water. It also seems likely that capillary water in the zone of aeration dissolves previously deposited minerals and carries uranium and vanadium only a short distance before precipitating them as salts on the mine walls.

CONCLUSIONS

Ground water is contained in sandstone strata of the Morrison formation that are ore bearing. This water is usually perched on mudstone and is free to fluctuate with seasonal variations in precipitation.

Locally, where structural conditions prevent drainage, ground water is confined and the sandstone strata are saturated. The occurrence and chemical character of ground water in the Morrison formation are thus dependent upon a number of factors including variation in climate, the geomorphic history of the region, and upon the structure and composition of the rocks.

The analyses of the samples of ground water collected from the Brushy Basin and Salt Wash members of the Morrison formation are believed to represent the chemical character of the ground water contained in these rocks. The Salt Wash ground water is a weakly alkaline bicarbonate solution with variable amounts of calcium and magnesium ions; the Brushy Basin ground water is likewise weakly alkaline, but is either a sulfate or bicarbonate solution with sodium.

The Salt Wash ground water, regardless of its chemical character, generally contains less than 1 ppm of the uranium, vanadium, copper, lead, and selenium ions. Uranium, vanadium, and selenium ions, in amounts of less than 1 ppm, are also believed to be typical constituents of Brushy Basin ground water. The significance of the amounts of these ions present in both Salt Wash and Brushy Basin ground water in regard to spatial relationships to the ore bodies cannot be determined with certainty from the number of samples analyzed, but significant differences may exist. If the fluid responsible for introduction of the uranium and vanadium metals into the Salt Wash was comparable to the recent ground water, it contained very small amounts of the metal ions.

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