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CHEMISTRY OF WATER OF A SECTION OF THE EASTERN FLANK OF THE SACRAMENTO MOUNTAINS, LINCOLN AND OTERO COUNTIES, NEW MEXICO

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INTRODUCTION

The area described in this report is in Lincoln and Otero Counties, New Mexico, and lies between Tps. 8 and 12 S. and Rs. 11 and 19 E. (fig. 1). Approximately 1,400 square miles are included within these boundaries and they roughly coincide with the topographic boundary of the western part of the Rio Hondo drainage basin.

The part of the eastern flank of the Sacramento Mountains chosen for this study is of interest because ground water occurs in several major rock types where the chemistry of water has not been too affected by human activities, and because the area is a source of a substantial amount of recharge to the Roswell artesian basin.

This paper is based on work performed as part of a research project on chemistry of water of the Roswell basin at the New Mexico Institute of Mining and Technology. Particular thanks are due to those colleagues and graduate students with whom various aspects of the study were discussed. The author is deeply indebted to members of the U.S. Geological Survey at Albuquerque and Roswell for supplying chemical analyses not available in publications and for participating in many discussions of the problems involved in the study. Walter A. Mourant of the Geological Survey, who has worked extensively in the area, was especially helpful to the author.

TOPOGRAPHY AND DRAINAGE

The major topographic features of the area are the Sacramento Mountains, on the west, dominated by the Sierra Blanca, the Capitan Mountains along the northern boundary, and a broad upland area gently sloping to the east and incised by streams. The range in elevation above mean sea level is from about 10,000 feet in the mountains to about 4,700 feet at the eastern boundary.

Rio Hondo, the master stream draining the area, is formed by the junction of the Rio Bonito and Rio Ruidoso which have headwaters in the Sacramento Mountains (fig. 1). Relatively minor amounts of water are contributed by the Capitan Mountains. The stream beds are generally lower than the water table, and the streams have nearly perennial flow except toward the east where the Rio Hondo begins to lose water downstream from Picacho (Mourant, 1963, p. 10). The general flow distribution is modified, however, by diversions for irrigation and water-supply pipelines and locally where the water table is below the stream bed. The flow data in the following description of the major streams are from the records of the U.S. Geological Survey (Mourant, 1963, p. 7-12; Reiland and Haynes, 1963).

Rio Bonito

The source of the Rio Bonito is high in the Sacramento Mountains on the northern slope of the Sierra Blanca. The stream flows into Bonito Lake (sec. 12, T. 10 S., R. 12 E.), an artificial impoundment, where water is diverted to the Bonito Creek pipeline. Below the dam, the Rio Bonito gains some water but has no major tributaries. Salado and Magado Creeks contribute only minor amounts of water. The Rio Bonito at the gage just above the junction with the Rio Ruidoso (fig. 1) has an average annual flow of about 10 cfs (cubic feet per second) after having lost water to diversions at Bonito Lake and for irrigation of about 1,700 acres. The contributing area is 306 square miles. Selected flow-duration data show the following pattern:

Percent of time	Flow is equal to or greater than, cfs
51.2	0.1 (Approximate median flow)
39.1	1.0
33.4	2.0
15.8	10.4 (Approximate mean flow)

Rio Ruidoso

The Rio Ruidoso has headwaters in the Sacramento Mountains on the eastern and southern flanks of Sierra Blanca. The major tributaries are Carrizo and Eagle Creek. Most of Eagle Creek is diverted to the Eagle Creek pipeline. The Rio Ruidoso at the gage just above the junction with the Rio Bonito has an average annual flow of about 19 cfs after diversions to Eagle Creek pipeline and to irrigate about 1,700 acres. The contributing area is 307 square miles. Selected flow-duration data show the following pattern:

Percent of time	Flow is equal to or greater than, cfs
62.9	3.0
49.2	7.0 (Approximate median flow)
22.4	20.0 (Approximate mean flow)

*At the University of New Hampshire, Durham, New Hampshire since July 1, 1964.

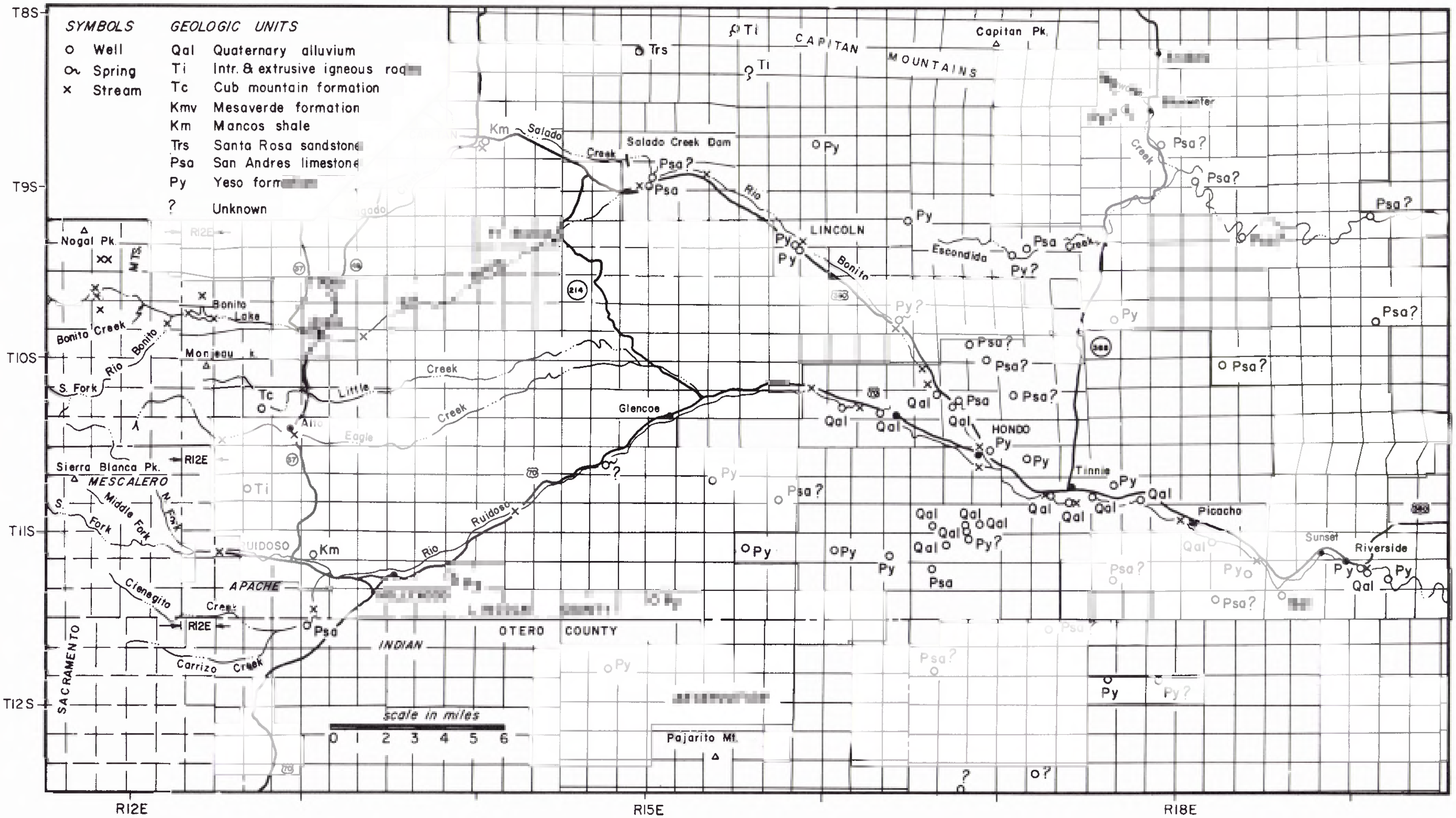

Figure 1. — Well, spring, and stream location map for a section of the eastern flank of the Sacramento Mountains, Lincoln and Otero Counties, New Mexico.

Rio Hondo

The Rio Hondo has no major tributaries between the confluence of its principal tributaries, Rio Bonito and Rio Ruidoso, and the eastern boundary of the area. The average annual flow at Picacho is about 40 to 50 cfs based on flow records at the Diamond A Ranch east of the area and on estimates of seepage loss below Riverside. Diversions for irrigation along the Rio Hondo are for about 3,000 acres. The contributing area below the confluence of Rio Bonito and Rio Ruidoso is 700 to 800 square miles.

GEOLOGY

The Sacramento and Capitan mountains consist of Tertiary intrusive and extrusive rocks. The remainder of the area has a sequence of sedimentary rocks abutting against the mountains and dipping gently eastward with some irregularities in dip due to faulting and folding. The sedimentary sequence includes Tertiary, Mesozoic, and Permian rocks close to the Sacramento Mountains; they in turn overlie older Permian rocks in most of the area east of the mountains. The uplands are mainly on the San Andres Limestone of Permian age, with the underlying Yeso Formation of Permian age exposed in the stream valleys. Downstream from Riverside, the Yeso is in the subsurface. Quaternary is found along the stream valleys. Table 1 taken from Mourant (1963, p. 15) summarizes the geologic section; in the present report the Glorieta Sandstone is included in the San Andres Limestone.

CHEMISTRY OF WATER

Most of the chemical analyses used in this study are published in reports of the U.S. Geological Survey (Mourant, 1963; Dinwiddie, 1963). Other analyses came from the files of the Geological Survey at Roswell and Albuquerque. Analyses of a few surface-water samples were made at the New Mexico Institute of Mining and Technology. The ranges of chemical constituents by source are summarized in table 2 and the sampling locations are shown in figure 1.

A rather arbitrary procedure was used in determining the ranges of constituents tabulated in table 2. When an analysis deviated greatly from the normal range from its source, it was not included in table 2. In all instances, the deviant analyses fitted the range of another source. The deleted analyses included one from Tertiary igneous rocks that closely resembled Mesaverde Formation or similar water, four analyses from the San Andres that resemble Yeso water, and four analyses from the Yeso that resemble San Andres water.

An expanded version of the trilinear graph (Piper, 1944) is used to display the chemical data. Figure 2 is for water from wells and springs, and figure 3 is for water from streams. A trilinear graph has a cation field in the lower left, an anion field in the lower right, and a combined field in the central diamond. Analyses are plotted on the graphs in percentage of equivalents per million (epm) in terms of 100 percent cations and 100 percent anions. The location in the central diamond can be indicated by a decimal number where the first part is percent calcium plus magnesium and the second part is percent carbonate plus bicarbonate. The decimal number is also useful for descriptive purposes. Some analyses used in this study do not plot in the anion field or central diamond, and these will be discussed in the text.

Chemical concentrations, ratios, and percentages are given in equivalents per million (epm). In the analyses given in this paper total dissolved solids in parts per

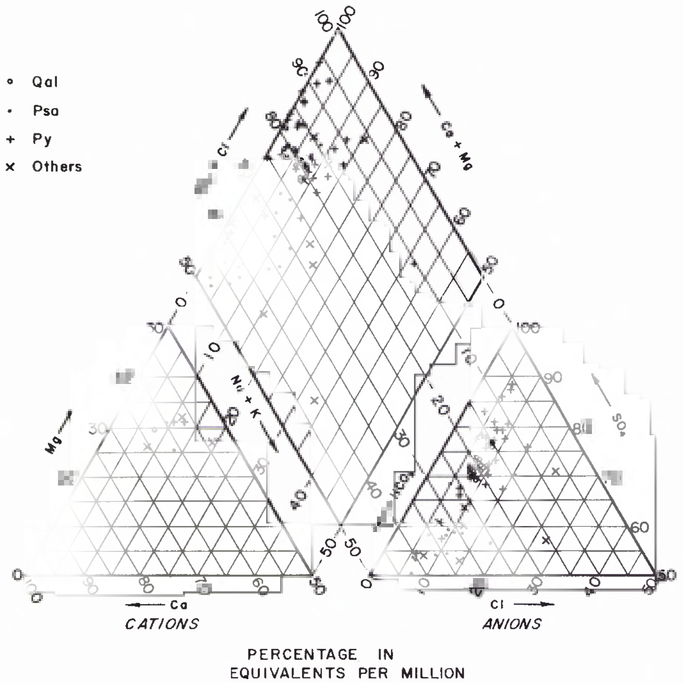

Figure 2. — Expanded Trilinear graph for well and spring samples

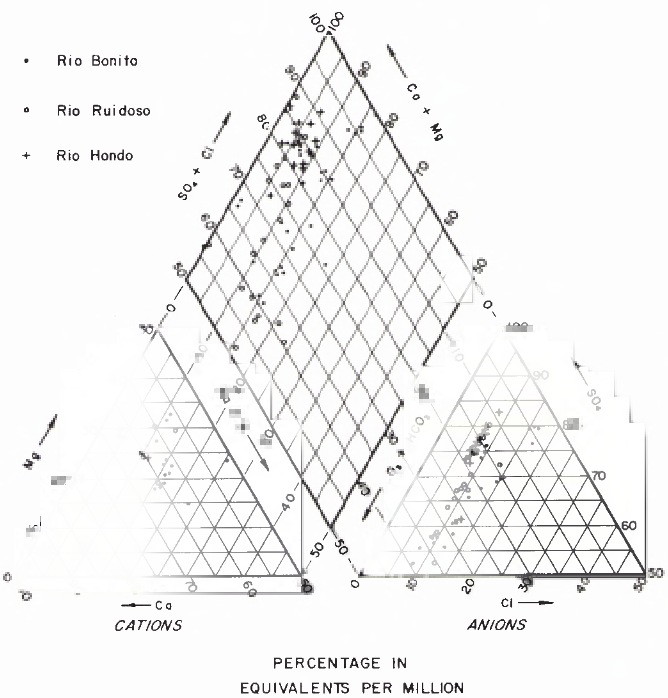

Figure 3. — Expanded Trilinear graph for stream samples

TABLE 1

GENERALIZED SECTION OF GEOLOGIC FORMATIONS IN THE RIO HONDO DRAINAGE BASIN, CHAVES, LINCOLN, AND OTERO COUNTIES, NEW MEXICO
(From Mourânt, 1963, p. 15)

System	*Stratigraphic Unit*	*Thickness (feet)*	*Physical Character*
Quaternary	Alluvium	0-210±	Poorly sorted to well-sorted sand, gravel, and clay in lenses, stringers, and parallel beds.
	Alluvial fans	-	Mainly boulders and unsorted finer rock debris from intrusive igneous rocks.
Quaternary(?) and Tertiary(?)	Pediment gravel	0-50±	Unsorted angular to rounded fragments of igneous, sedimentary, and metamorphic rocks.
	Unconformity		
Tertiary(?)	Intrusive and extrusive igneous rocks	-	Andesite, diorite, microgranite, and rhyolite dikes, sills, and stocks.
	Cub Mountain Formation	0-500±	Red and white sandstone and chert pebble conglomerate; varicolored shale.
	Unconformity		
Cretaceous	Mesaverde Formation	0-540±	Gray, yellow, and buff quartzose sandstone; gray shale; coal; and carbonaceous shale.
	Mancos Shale	0-400±	Black fissile shale, thin-bedded limestone, and intercalated limestone and sandstone.
	Dakota Sandstone	0-130±	Ferruginous quartzose sandstone interbedded with gray shale and conglomerate.
	Unconformity		
Triassic	Chinle Formation	0-180±	Red and gray shale and white and gray dense limestone.
	Santa Rosa Sandstone	0-380±	Gray, yellow, and tan sandstone; thin-bedded limestone; red and gray shale; and chert pebble conglomerate.
Permian	Artesia Formation	0-450±	Gypsum, anhydrite, dolomite, impure limestone, siltstone, red shale and sandstone.
	Unconformity		
	San Andres Limestone	0-1,200	Mainly cherty limestone and dolomite; minor siltstone, sandstone, gypsum, anhydrite, and shale.
	Glorieta Sandstone	0-160	Mainly light-tan to dark-red, medium-grained quartz sandstone; minor silty limestone, siltstone, gypsum, and anhydrite.
	Yeso Formation	1,000± to 2,000±	Thin-bedded red and yellow siltstone; some limestone, sandstone, shale, gypsum, anhydrite, and salt.

TABLE 2

RANGE OF CHEMICAL COMPOSITION OF NATURAL WATERS IN EQUIVALENTS PER MILLION.

Aquifer or Stream	Number of Analyses	Ca^{++} plus Mg^{++}	Mg^{++}/Ca^{++}	Na^{+} plus K^{+}	HCO_3^{-}	SO_4^{--}	Cl^{-}	Anion Total
Alluvium	17	14.40-21.60	.47[a]	.12-2.79	2.69-4.92	10.63-16.56	1.04-1.89	14.83-23.09
Tertiary Igneous Rocks	2[b]	1.06[c]	-	.27-.52	.56-.67	.60-.73	.17-.18	1.33-1.58
Cub Mountain Formation	1	-	-	-	4.64	7.72	2.03	14.39
Mesaverde Formation	1	17.52	.50	4.13	6.10	13.12	2.06	21.64
Mancos Shale	2	33.00-39.01	.56[a]	5.26-5.87	2.69-6.74	25.38-27.66	8.52-12.07	38.87-44.24
Santa Rosa Sandstone	1	12.80	-	2.59	4.07	9.88	1.44	15.39
San Andres Limestone	18[d]	6.08-11.60	-	0-2.13	2.43-4.95	1.96-6.74	.39-1.66	6.06-11.54
Yeso Formation	20[d]	13.10-29.40	.53-.58[e]	0-3.75	2.10-4.67	11.06-24.75	.68-4.37	14.26-30.14
Yeso Formation (?)	3[f]	37.60-50.40	-	0-1.60	2.44-3.44	32.86-44.30	1.80-2.85	38.19-50.32
Rio Bonito above Bonito Lake	10	1.24-4.34	.24-.41[g]	.37-.70	.39-1.59	.94-3.04	.23-.56	1.61-4.98
Rio Bonito-anomalous	4[h]	6.16-17.70	.33-.47	.88-6.00	0-4.39	2.83-21.86	.56-1.75	7.33-23.70
Rio Bonito below Bonito Lake	18	6.12-22.00	.48-.58[i]	.10-2.88	2.10-3.54	3.58-16.37	.56-3.44	6.24-22.67
Magado Creek	4	38.60-43.20	-	6.00-7.88	2.02-2.82	34.74-39.94	6.91-8.97	45.40-50.93
Rio Ruidoso-upstream	4	1.46-1.88	.39[a]	.01-.55	.57-.92	.85-1.18	.18-.31	1.61-2.37
Rio Ruidoso-downstream	11	5.46-25.00	.43[a]	.25-2.30	2.59-4.80	3.16-20.28	.68-2.06	6.53-26.23
Eagle Creek-upstream	5	1.98-3.03	.29-.52[e]	0-.51	.87-1.39	.67-1.62	.17-.94	2.01-3.38
Eagle Creek-downstream	1	5.46	-	1.07	2.69	3.16	.68	6.53
Carrizo Creek	1	13.78	.50	1.48	4.92	8.98	1.35	15.28
Rio Hondo	15	9.99-23.23	.34-.45[e]	.17-2.30	2.26-4.54	7.03-20.07	.70-2.00	10.62-25.33

Footnotes

a—One value
b—One analysis deleted
c—Two values
d—Four analyses deleted
e—Three values
f—Not like other waters from the Yeso
g—Seven values. One additional value at .64
h—From geochemical prospecting (Griswold and Missaghi, 1964)
i—Four values

million can be very roughly approximated by multiplying the cation or anion total in epm by 70. Individual constituents can be converted to ppm by multiplying by the proper combining weights.

Chemical Systems

A logical approach to the study of chemistry of natural waters is to consider the chemical processes that may occur in the rocks and to relate these to chemical systems and processes known from experimental work and theoretical calculations. If the chemical systems analogous to the rock types are known and solubility data are available, then theoretical compositions can be calculated for ideal conditions. Conversely, calculations can be made from analyses of natural waters to compare them with their theoretical compositions.

The main rock types present in the study area are intrusive and extrusive igneous rocks, limestone, dolomite, gypsum, anhydrite, and shale (table 1). The major process is chemical attack of rocks by water containing dissolved carbon dioxide and organic acids. The type and rate of reactions depend on length of time in contact, temperature, pressure, chemical composition, and surface area exposed to attack. Other processes such as oxidation - reduction and ion exchange may also take place. Before discussing equivalent chemical systems and theoretical compositions, however, three major problems affecting interpretation should be considered.

1. Rainfall, wind-blown dust, and human activities can provide extraneous sources of ions. Also, water may move from one rock type to another.
2. Bicarbonate content and pH are likely to change significantly between time of collection and time of analysis (Roberson and others, 1963). Therefore, good determinations of these characteristics can be obtained only in the field.
3. Most of the analyses are partials with concentrations only for calcium plus magnesium, sodium plus potassium, carbonate, bicarbonate, sulfate, and chloride. No analysis less complete than this was used in the study. About 25 percent of the analyses have individual determinations of calcium and magnesium, but with one exception they have no individual determinations for sodium and potassium. Some determinations are available for silica, nitrate, fluoride, iron, and boron but not enough for correlations with specific rock types.

Experimental data are available for calcium carbonate (calcite) and calcium sulfate (gypsum — $CaSO_4 \cdot 2H_2O$), both individually and in a combined system. Therefore, independent calculations can be made for the composition of water in a limestone and gypsum, a limestone, and a gypsum aquifer. If aragonite is present then the theoretical concentrations will be a little low as aragonite is more soluble than calcite. The solubility and phase relationships of gypsum and anhydrite are rather complex functions of temperature, pressure, and sodium chloride content. Anhydrite is more soluble at the pressures to be expected in the field and at temperatures lower than 40°C (Stewart, 1963). The calculations and discussions in this paper, however, are based on the simplifying but not necessarily correct assumptions that only calcite and gypsum are present in the aquifers. Calculations for dolomite are based on the assumption that dolomite solubility is the same as limestone solubility (Barnes and Back, 1964).

The approximate chemical compositions for the systems of limestone and gypsum and limestone alone are given in table 3 for three different partial, pressures of carbon dioxide (Pco_2). Gypsum solubility alone is unaffected by Pco_2. The values of Pco_2, in atmospheres, were selected on the following basis: 0.0003 is the average Pco_2 of the atmosphere and approximates that in rainfall; 0.02 is the average Pco_2 for many soils; and 0.1 is a reasonable maximum Pco_2 in soils.

The chemical compositions in table 3 allow some speculation as to the compositions of the more complex system of limestone and dolomite, dolomite and gypsum, and limestone, dolomite, and gypsum. Probably the best criterion for separating these is the magnesium/calcium (Mg^{++}/Ca^{++}) ratio which would range from zero in pure limestone and limestone and gypsum to one in dolomite. Ratios for the other systems would fall between zero and one. Waters from limestone rarely have a Mg^{++}/Ca^{++} ratio of zero but more commonly of 0.3 (White and others, 1963, table 6), indicating the presence of magnesium in the limestone. Waters from dolomite have a ratio of one in many instances with a range of from somewhat less than one to slightly greater than one (White and others, 1963, table 7).

The igneous rocks of the area are more or less highly silicic and in general range from diorite and andesite to granite and rhyolite. An analogous chemical system is water-carbon dioxide-silicates (mainly quartz and sodium-rich feldspars). Few calculations can be made for such a system at low temperatures and pressures. Waters from these rock types tend to have a low dissolved-solids content on the order of 150 to 300 ppm (about 2 to 4 epm); a sulfate-chloride ratio of about one with low concentrations; a sodium plus potassium content ranging from about 20 to 70 per cent of the cations; a Mg^{++}/Ca^{++} ratio on the order of 0.3 to 0.4; and bicarbonate making up about 70 percent of the anions (White and others, 1963, tables 1 and 2).

The probable composition of waters from shales cannot be calculated with any confidence. Many shales were deposited in saline environments and will reflect this in their chemical compositions (White and others, 1963, p. 6-7, table 5). In the study area, the shales are associated with rocks consisting of limestone, gypsum, dolomite, and anhydrite; therefore, waters from the shales are likely to be similar to waters from these rock types. Waters from the shales may have a higher chloride content and may be subject to cation exchange.

RELATIONSHIP TO ROCK TYPE

The relationship of chemical content of water to rock type is considered in terms of the geologic unit from which the ground-water sample was obtained or over which the surface water was flowing. Analyses are not available for the Artesia Formation, Chinle Formation, Dakota Sandstone, pediment gravel, and alluvial fans. These rocks are of limited areal extent, except for the last two which are more widespread. Water from the Artesia will probably resemble water from the

TABLE 3

ESTIMATED AND CALCULATED CHEMICAL COMPOSITIONS OF WATER IN SELECTED ROCK TYPES

Rock type	P_{CO_2}	Calcium			Magnesium			Bicarbonate			Sulfate		
		ppm	epm	%	ppm	epm	%	ppm	epm	%	ppm	epm	%
Limestone[1]	0.0003	20	1.00	100	-	-	-	61	1.00	100	-	-	-
	0.02	80	4.00	100	-	-	-	244	4.00	100	-	-	-
	0.1	160	8.00	100	-	-	-	488	8.00	100	-	-	-
Dolomite[2]	0.0003	10	.50	50	6	.50	50	61	1.00	100	-	-	-
	0.02	40	2.00	50	24	2.00	50	244	4.00	100	-	-	-
	0.1	80	4.00	50	48	4.00	50	488	8.00	100	-	-	-
Gypsum[3]		610	30.60	100	-	-	-	-	-	-	1,470	30.60	100
Limestone	0.0003	749	37.40	100	-	-	-	30	.50	1	1,772	36.90	99
and	0.02	679	33.89	100	-	-	-	178	2.92	9	1,487	30.97	91
Gypsum[4]	0.1	697	34.78	100	-	-	-	353	5.78	17	1,393	29.00	83

[1]Frear and Johnston, 1929

[2]Assuming dolomite solubility equals limestone solubility

[3]Shternina and Frolova, 1945

[4]Hall, 1963. Calculation at 0.0003 is a rough approximation

Yeso Formation; water from the Chinle Formation may be similar to water from the San Andres Formation; and water from the Dakota is probably similar to water from the Santa Rosa Sandstone. The pediment gravel and alluvial fan deposits are usually above the water table. Only one analysis each is available for the Santa Rosa Sandstone, Mesaverde Formation, and Cub Mountain Formation. These formations are of restricted extent, and the chemistry of water will not be discussed except to note that the three analyses resemble water from the San Andres or Yeso Formations (table 2).

Yeso Formation

Ground water from the Yeso Formation is of a pronounced calcium-sulfate type in the general decimal range of 75-100.5-25 in figure 2. The range of chemical constituents shown in table 2 for the three analyses listed as Yeso (?) are appreciably higher in content of calcium plus magnesium, sulfate, and total dissolved solids than the rest of the samples from the Yeso; however, they are within the Yeso decimal range in figure 2.

The Yeso Formation is of a mixed lithological character with thin-bedded siltstone, limestone, sandstone, shale, gypsum, and anhydrite. Limestone and gypsum appear to be the major contributors of dissolved constituents. A source of magnesium either in the limestone or from dolomite is indicated by the Mg^{++}/Ca^{++} ratios in table 2. Apparently, only a minor source of chloride is present, possibly in the form of isolated halite crystals or from meteoric-water recharge.

A comparison of waters from the Yeso Formation in table 2 with the limestone and gypsum system in table 3 suggests near saturation with regard to limestone and undersaturation with regard to gypsum. The lack of attainment of equilibrium probably can be explained in one of the following ways: (1) The Yeso does not fit the proposed system of limestone and gypsum; (2) insufficient gypsum is present to meet equilibrium requirements; or (3) there is insufficient time in contact to reach equilibrium. The third possibility seems the most plausible, as explained below, but the other two cannot be completely disproved.

The three analyses listed as Yeso Formation(?) in table 2 are supersaturated with respect to gypsum. The analyses are not like the rest of the Yeso in concentrations, nor do they resemble samples from the other aquifers. The sample locations are NE¼NW¼ NW½ sec. 32, T. 11 S., R. 15 E. (two samples) and SE¼SE¼NW¼ sec. 19, T. 11 S., R. 16 E. The waters could have come only from the Yeso, or possibly the San Andres Limestone which is not likely. The supersaturation might be due to contact with anhydrite at lower than normal temperatures, but this would be hard to explain. A possible mechanism suggested by S. W. West, U.S. Geological Survey, (personal communication) is that these types of waters have been in a more highly saline environment and then migrated out of the environment with chloride being held behind by shale layers acting as selective membranes.

A comparison of sulfate content with distance from the western side of the area shows that the waters range from lowest in the west to highest in the east. Chloride content also shows the same trend, but bicarbonate is relatively unaffected by distance. The relationship of increasing sulfate content with distance toward the east is good reason for believing that the lack of equilibrium is due to inadequate contact time.

The courses of the Rio Bonito, Rio Ruidoso, and Rio Hondo east of the mountains are cut for a considerable distance into the Yeso Formation, and waters from these reaches have compositions very similar to waters from the Yeso (fig. 3). Figure 4 is a graph of river distance above the point at which the Rio Hondo leaves the area versus sulfate content based on spot samples and estimated flows (Mourant, 1963, table 4). Where possible, approximate lines are drawn for equal flow rates to put the gain in sulfate on a comparative basis. The trend of increase of sulfate in the streams is similar to that of the ground water in the Yeso. The rate of increase along the Rio Hondo is smaller than for the other streams. The reasons for this are not clear but might be due to the fact that toward the east, the top of the Yeso is dipping beneath the valley of the Rio Hondo.

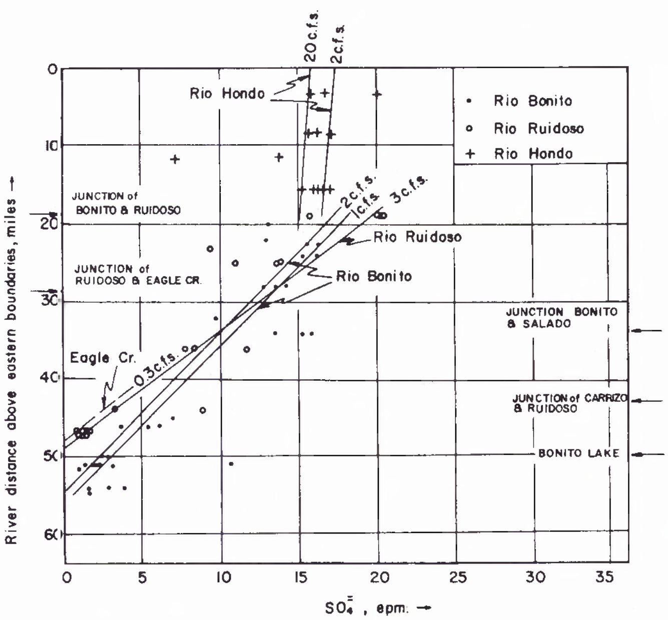

Figure 4. — Graph of sulfate content versus river distance for stream samples.

San Andres Limestone

Water from the San Andres Limestone is of a calcium sulfate to calcium bicarbonate-sulfate type with a general decimal range of 85-100.25-55 (fig. 2). A number of analyses do not plot in the anion field and a few do not plot in the central field of Figure 2. The reasons for this are a bicarbonate content of slightly greater than 50 per cent and a sulfate content slightly less than 50 per cent. The ranges of constituents in water from the San Andres are given in Table 2.

The San Andres Limestone consists mainly of cherty limestone and dolomite with some sandstone, gypsum, and anhydrite (table 1). No magnesium determinations are available, but the Mg^{++}/Ca^{++} ratio is probably on the order of 0.5. The sulfate range is much too low for equilibrium with gypsum, but too much calcium is present for equilibrium with limestone (table 3). Chloride content is lower than in the Yeso Formation. A comparison of sulfate and bicarbonate content with distance from the western side of the area shows little or no correlation between distance and content. The lack of equilibrium with gypsum probably is caused by a small gypsum content in the San Andres. Therefore, the San Andres Limestone can be considered nearly to fit the limestone system of Table 3 but with too much calcium from gypsum for equilibrium.

Mancos Shale

Analyses are available for two ground-water samples and four surface-water samples taken from Magado Creek in the outcrop area (samples from secs. 17 and 18, T. 9 S., R. 14 E.). The ground-water samples under the "others" category (fig. 2) are at 85.07 and 88.15, and the surface-water samples under the Rio Bonito category (fig. 3) cluster around 85.05. Magado Creek drains to the Rio Bonito by way of Salado Creek, but the volume of flow must be small as there is no perceptible effect on the Rio Bonito. The water is a calcium sulfate type with a high chloride and total dissolved-solids content.

The Mancos Shale consists of black shale, limestone, and sandstone (table 1). The ground-water samples are supersaturated in gypsum, and the surface-water samples are undersaturated in gypsum. The problems of gypsum-anhydrite phases and the suggested cause of supersaturated of the Yeso(?) Formation samples may apply to the Mancos as well, but the discrepancies are difficult to understand on the basis of such limited data. The high chloride content is very likely due to water entrapped during deposition or to salts precipitated by evaporation during deposition in a saline or brackish water environment. The surface-water analyses are at 42 and 43 miles above the eastern boundary of the area, but they are too high in sulfate to be in figure 4.

Tertiary Igneous Rocks

Analyses are available for ony two ground-water samples from the Tertiary igneous rocks; however, the surface-water samples listed in table 2 as Rio Bonito above Bonito Lake, Rio Bonito-anomalous, Rio Ruidoso-upstream, and Eagle Creek-upstream were all collected within the outcrop area of the Tertiary igneous rocks. The waters are in the compositional range of calcium bicarbonate to calcium sulfate with a decimal range in figure 3 of 75-100.25-60 which is close to the decimal range of the San Andres Limestone. The two ground-water analyses fall within the same range. A few analyses do not plot in figure 3 because of high bicarbonate and low sulfate.

The tertiary igneous rocks are both intrusive and extrusive with complex relationships in many areas. The main rock types on the Rio Bonito are syenodiorite, diorite, and basaltic andesite (Griswold and Missaghi, 1964). The rocks on the Rio Ruidoso and Eagle Creek are not so well known, but they are similar to the Rio Bonito (table 1). The composition of the waters is more or less what might be expected from the igneous rocks except that the calcium and sulfate contents are quite high and the sodium content is low. The Mg^{++}/Ca^{++} ratio has a range of 0.24 to .58.

The samples listed in table 2 as Rio Bonito-anomalous were collected during a geochemical prospecting program (Griswold and Missaghi, 1964); most of them were collected near oxidizing sulfide mineral deposits. One sample (from NE¼SE¼ sec. 34, T. 9 S., R. 11 E.) has 21.86 epm sulfate, no bicarbonate, and a ph of 3.3. In figure 4 all of the values to the right of the Rio Bonito curves above 50 miles are from the geochemical program. Trace amounts were found of molybdenum, copper, and zinc in some of the samples. The waters in the main Rio Bonito do not appear to show much addition of sulfate from the oxidizing sulfides. Therefore, oxidizing sulfides probably are not a major source of sulfate.

The major source of the high calcium-sulfate content and possibly some calcium carbonate is probably wind-blown dust from the east. A point of interest in this regard is that waters from the Tertiary igneous rocks and the San Andres Limestone are quite similar in composition and fall within the same decimal range. The only major difference appears to be the higher dissolved-solids content of the San Andres.

Quaternary Alluvium

Waters from the alluvium are of a calcium sulfate type with a decimal range of 87-99.15-22 (fig. 2). The chemical composition and decimal range fall within those for the Yeso Formation. This indicates that the alluvium receives water from the Yeso in many reaches. The samples from the alluvium show the same trend of increasing content of sulfate toward the east. The waters from the alluvium also closely resemble waters from the streams east of the igneous rocks. The samples in the alluvium show the same pattern of undersaturation in gypsum as do waters from the Yeso Formation and from the streams. Insufficient time in contact seems to be the best explanation for this.

SUMMARY AND CONCLUSIONS

The ground and surface waters on the eastern flank of the Sacramento Mountains are predominantly calcium sulfate to calcium bicarbonate-sulfate types characterized by waters from the Tertiary igneous rocks, the San Andres Limestone, and the Yeso Formation. Sedimentary rocks of Mesozoic and Tertiary age are of rather limited extent, and waters from them more or less resemble one of the main types. The only exception is water from the Mancos Shale which is a calcium-sulfate water but with a fairly high chloride content. The waters can be summarized as follows:

1. *Tertiary igneous rocks.* Calcium sulfate to calcium bicarbonate waters with a low dissolved-solids content. The general composition is what might be expected from the igneous rocks except for the high content of sulfate and calcium. Some sulfate is derived from oxidizing sulfides, but wind-blown dust probably is the major source. Ground water and surface water is from

the area of the upstream reaches of the Rio Bonito, Rio Ruidoso, and Eagle Creek.

2. *San Andres Limestone.* Calcium sulfate to calcium bicarbonate-sulfate water of a moderate dissolved-solids content. The water is too high in calcium to be in equilibrium with limestone but is too low in sulfate to be in equilibrium with limestone and gypsum. The lack of equilibrium appears to be due to a small gypsum content in the San Andres. The chemical composition of water from the San Andres is similar to water from the Tertiary igneous rocks except for a higher dissolved-solids content.
3. *Yeso Formation.* Calcium-sulfate water of moderate to fairly high dissolved-solids content. With few exceptions, however, the samples are undersaturated with respect to gypsum. The undersaturation is probably due to insufficient time in contact to attain equilibrium. Waters from the Quaternary alluvium, the Rio Hondo, and the downstream parts of the Rio Bonito and Rio Ruidoso are all quite similar to water from the Yeso.

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