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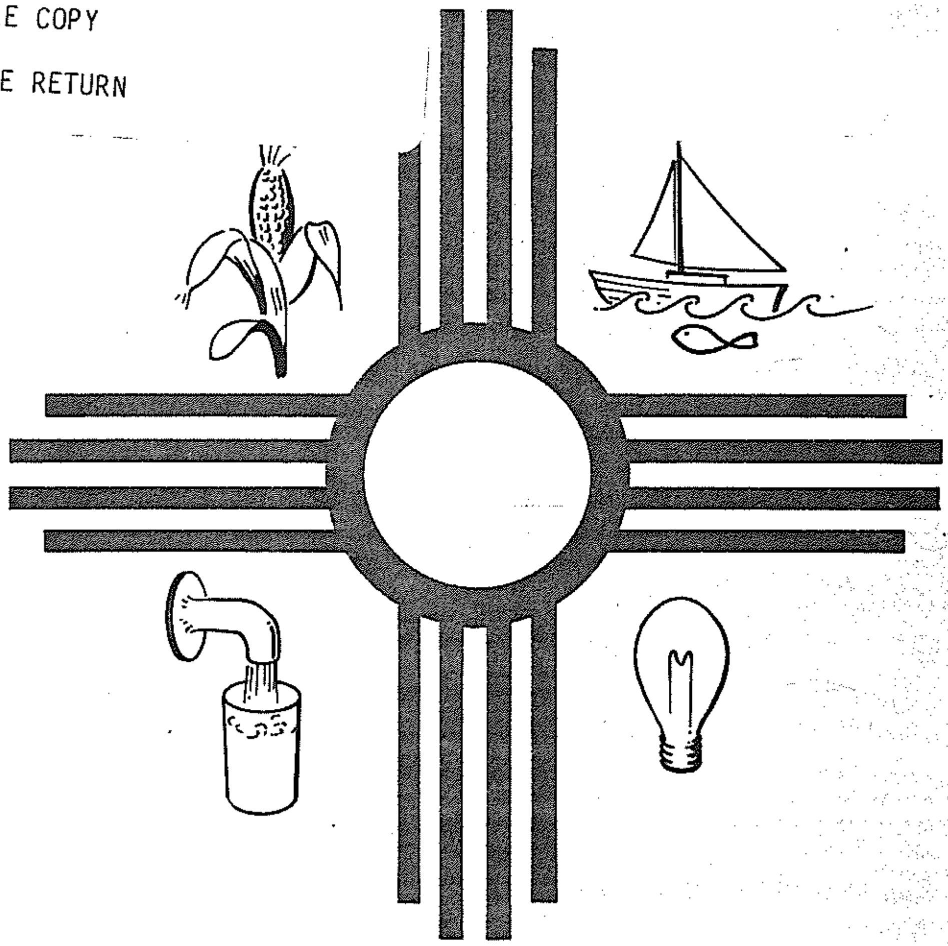
SPRING CHARACTERISTICS OF THE WESTERN ROSWELL ARTESIAN BASIN

Partial Technical Completion Report

Project No. A-055-NMEX



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SPRING CHARACTERISTICS OF THE WESTERN ROSWELL ARTESIAN BASIN

by

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ABSTRACT

Recharge transmitted underground from the western rim of the Roswell artesian basin, the Sacramento Mountains, substantially contributes to the ground water supply of the basin. This recharge occurs by either ground water flow eastward along the Yeso-San Andres Formation contact or by springs discharging into the main drainage "routes" which subsequently lose their flow in the Principal Intake Area to the east. The major geologic controls of spring occurrence are silts and clays within the Yeso Formation which act as aquitards under the spring ground water systems, and collapse features within the Yeso Formation which generally act as high permeability zones.

Chemistry of the spring water is more variable in the north than in the southern part of the basin. This is due to the different geologic settings for the two areas.

Springs issue from three types of hydrologic systems: perched springs issuing well above the canyon floors, valley underflow springs issuing from alluvium in the canyon floors, and, possibly, springs which issue from a regional ground water system. Tritium analyses indicate that valley underflow and regional springs discharge relatively older water than perched springs.

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Acknowledgements

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Ian Davis typed the original manuscript and designed various tables.

Jody Hinz prepared and typed the manuscript in its final form.

INTRODUCTION

Area and Physiography

The springs included in this study are located along the western flank of the Roswell artesian basin in Lincoln and Otero counties of southeastern New Mexico. The covered area encompasses approximately 4,600 square miles between latitudes 32°30' and 34° north and from the crest of the Sacramento Mountains to longitude 105° west (Figure 1). The area lies on the Pecos slope (Kelley, 1971) which rises from altitudes of 2,800 feet at the Pecos River to almost 9,700 feet in the Sacramento Mountains, 12,000 feet at Sierra Blanca and 10,200 feet in the Capitan Mountains.

The major drainage basins which are considered in this study are the Rio Peñasco, the Rio Ruidoso and the Rio Bonito. Although there are numerous other drainages on the Pecos slope, these three are most closely associated with the springs studied in this work. The major drainage direction is from west to east, with the exception of the Capitan Mountains. This mountain range trends east-west and has a radial drainage pattern.

Purpose and Previous Investigations

The purpose of this study was to define the characteristics of springs, their relationship to each other, and the role they play in

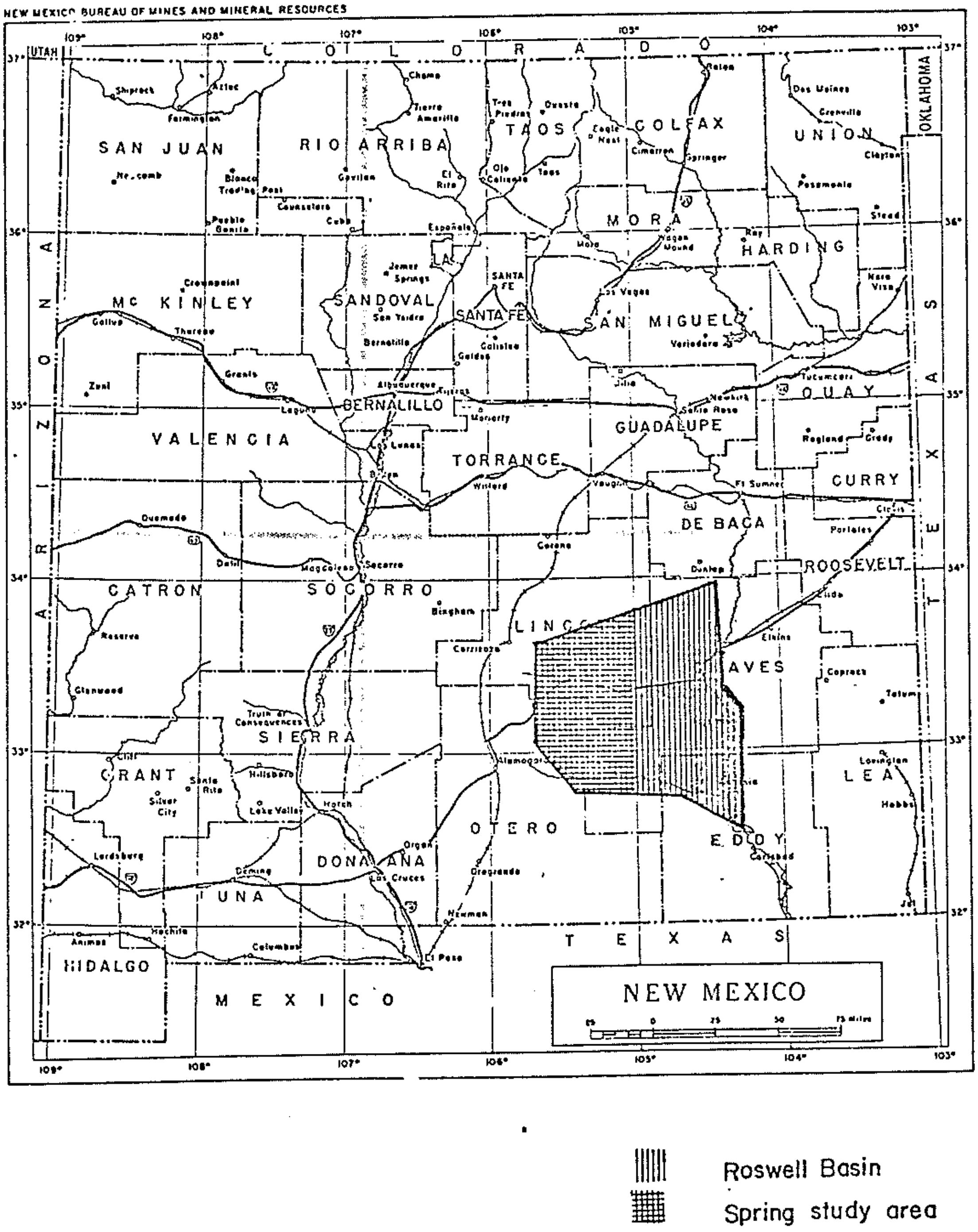

Figure 1. Orientation Map

ground water recharge. Although spring flow of this area is mentioned in several publications (e.g.: Neel, 1932; Fiedler and Nye, 1933; Mourant, 1963; and Hall, 1964), no publication was found that deals specifically with these relationships.

Procedure and Data

The study was conducted during the summer of 1977. Because of time limitations, only geologic features which appeared to be of hydrologic importance were described. In this report, the geology of some springs is given by a geologic cross section and a short description, others have a local map view of the geology or a short description of the geology. The cross sections, map views, and descriptions are given in Appendix A.

A summary of field data is given in Appendix B. The pH and conductivity measurements for the northern region were taken after returning from the field because the equipment was unavailable during the time of the field trip. The longest time between sampling and measurement was five days.

The term valley underflow spring is used to describe springs issuing from valley bottoms; they appear to be part of larger ground water systems than the more localized perched aquifers, which also feed a large number of springs. Valley underflow, in turn, is believed to be perched hundreds of feet above the regional water table sensu stricto by semipermeable zones in the alluvium or in the Yeso Formation below the alluvium. The present study indicates that springs from perched and underflow systems, respectively, exhibit different hydrologic characteristics. A very few springs could possibly be connected with the regional water table.

Chemical analyses and tritium measurements (Appendix C) were made of samples from springs which were thought to be of hydrologic importance.

The system for numbering springs in this study is the same as the well numbering system used in New Mexico (Figure 2).

Limitations

The most serious limitation was the accessibility of a number of springs. The Mescalero Indians own a major portion of the Sacramento Mountains, and due to their involvement in water rights disputes they would not allow us to visit the springs on their land. This effectively split our coverage into the areas north and south of their land.

The time available for this study severely limited the number of springs in the higher altitudes of the Sacramento and Capitan Mountains that could be visited. Only a few of the springs were revisited and, therefore, the knowledge of how they change with time is very incomplete.

Major Springs

It was not possible to have chemical and tritium analyses per-

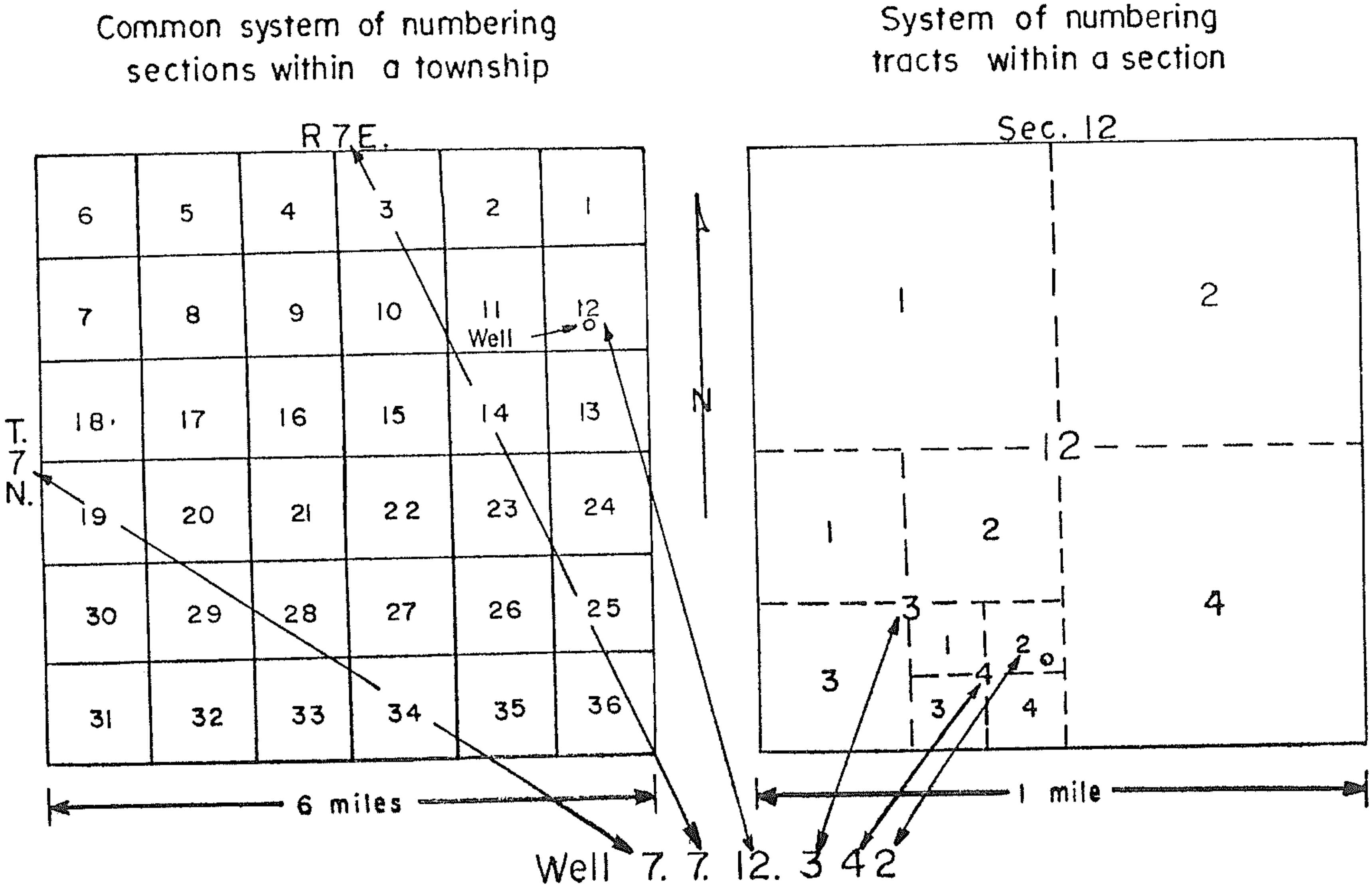

Figure 2. Well-numbering system.

formed on all of the springs of this study area, nor should it be necessary. To get a general idea of these characteristics, springs were selected which had either hydrogeologic features of peculiar interest or features common to a large number of springs in the region. They are designated as "major" springs. Table I lists these major springs, their location, and the reason why each spring was selected as a major spring. In order to facilitate the discussion, each spring is referred to by a reference number, as listed in Table I. The locations are shown in Figure 3.

TABLE I. MAJOR SPRINGS

Reference Number	Spring Location	Reason for Designation as a Major Spring. (Local Name).
1	17.12.16.43130	High altitude small spring issuing from the San Andres Formation.
2	17.12.17.14 & 23	Large spring which is currently depositing tufa. (Bluff Springs).
3	17.11.11.23	Headwater spring of the Rio Penasco.
4	17.13.25.441	Similar geologic setting as many other springs.
5	18.12.1.331	Large spring issuing from the Yeso Formation. (Boy Scout Camp Spring).
6a	18.12.26.411	Large spring issuing from the Glorieta Sandstone. (Barrel Springs).
6b	18.12.26.423	" " " " " " " . (Sand Springs).
7	16.16.2.323	Low altitude spring with geologic setting similar to many other springs. (Cleve's Spring).
8	16.14.31.113	Middle altitude spring with geologic setting similar to many other springs. (Mickison Spring).
9	16.14.26.343	Very large alluvial spring in the Rio Penasco valley bottom. (Posey Spring).
10	16.12.3.144	High altitude small spring issuing from alluvium.
11	10.12.24.431	High altitude spring issuing from igneous rocks. (Little Creek Spring).
12	10.12.12.144	Spring issues from Bonito Lake stock.
13	9.13.32.223	Spring issues from alluvium underlain by Cretaceous rocks. (Lamay Spring).

(continued)

TABLE I. CONTINUED

Reference Number	Spring Location	Reason for Designation as a Major Spring. (Local Name)
14	7.16.7.434	Spring issues from the Four Mile Draw member of the San Andres Formation. (Macho Springs).
15	7.16.7.431	Spring issues from the Four Mile Draw member of the San Andres Formation. (Macho Springs).
16	7.16.22.443	Spring issues from the San Andres Formation near the Capitan stock. (Kyle Harrison Spring).
17	10.16.26.441	Large spring issuing from the Yeso Formation. (Peter Hurd Spring).
18	11.14.14.2 1 & 3	Large alluvial spring in the Rio Ruidoso valley bottom. (Seeping Springs)
19	11.14.28.312	Large spring issuing from the Yeso Formation. (Agua Fria Spring).
20	11.13.14.312	Spring isues from alluvium underlain by Cretaceous rocks. (Bogg Spring).
21	16.16.11.342	Spring flow recorded with a V-notch weir. (Paul Spring).

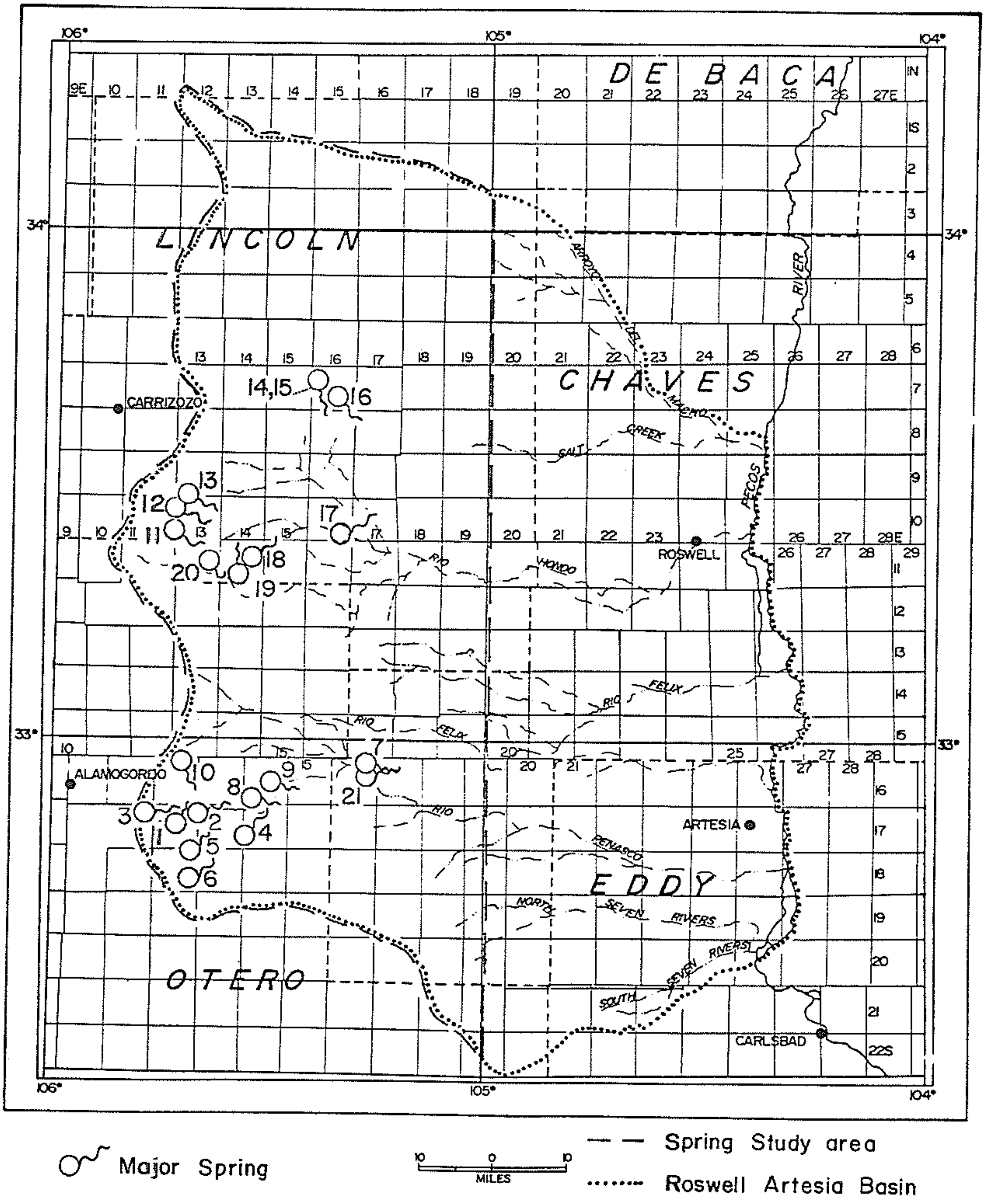

Figure 3. Major springs. Reference numbers are keyed to Table I.

GEOLOGY

A geologic sketch map of the Roswell Basin is presented in Figure 4, and the stratigraphic column in Table II.

In the southern study area, Permian strata are the only rocks exposed. The Leonardian Yeso Formation lies unconformably upon the Precambrian basement. Yeso rocks line the walls of the canyons which dissect this upland area. The San Andres Limestone conformably overlies the Yeso here and generally caps the hills which separate the canyons. This area lies upon the eastern flank of the Sacramento Uplift (Kelley, 1971), which is a fault block, gently tilted eastward.

In the northern area, Triassic, Cretaceous, and Tertiary rocks crop out along with the above mentioned Permian rocks. This area is much more varied than the southern area. The rocks have been faulted, folded, and intruded to a high degree. This area lies upon the eastern and northern dip slopes of the Three Rivers and Rio Bonito stocks, in the inner mountain region between these two stocks, on the Capitan laccolith, and on the north and south dip slopes of the Capitan laccolith.

The Permian System

Yeso Formation

Outcrops are commonly disturbed by collapse, folding, and landsliding. Beds consist of yellow and red sandstone, siltstone, and clays. Gypsum occurs in these beds in the upper 200 feet of the formation, but rarely crops out. Limestome and thin-bedded dolomite also occur in this formation.

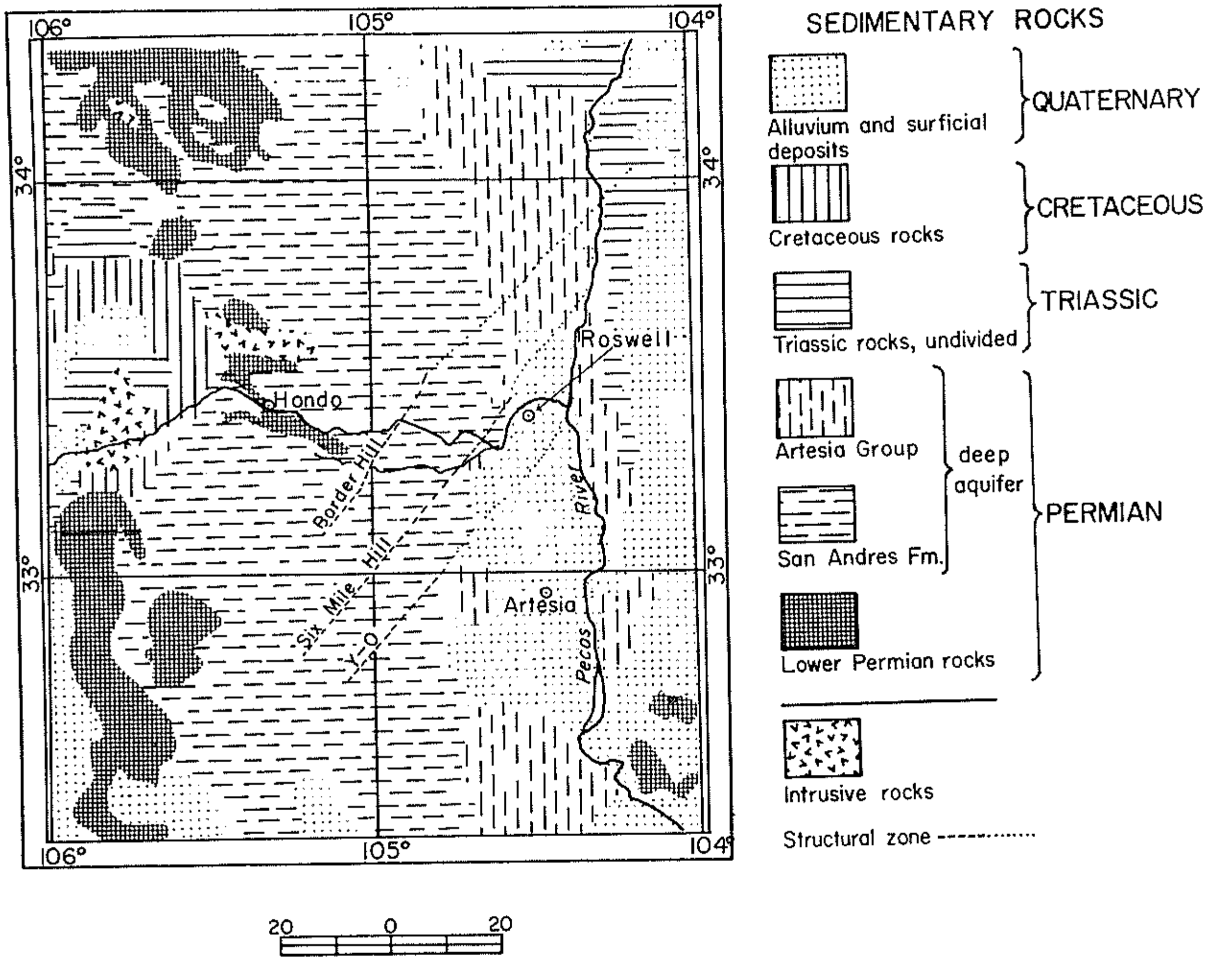

Figure 4. Geologic sketch map.

San Andres Formation

This formation consists of three members. They are from the bottom upward : Rio Bonito, Bonney Canyon, and Fourmile Draw. In addition, a basal sandstone, the Glorieta Sandstone, has special hydrologic significance. It occurs as tongues or lenses at or near the base of the San Andres Formation. It reaches a thickness of 60 feet in the area and consists of massively bedded, well sorted, medium to fine-grained sandstone.

In the Rio Bonito Member, beds of 2 to 6 feet predominate, but some are up to 30 feet thick. Grainstone and packstone are the dominant fabrics, with dolomite and limestone being the major lithologies.

The middle Bonney Canyon Member is dominantly dolomite with local limestones. It is grey to light-grey, locally black, and thin bedded. It is 0 to 300 feet thick.

The upper Fourmile Draw Member is more evaporitic in nature than the other two. It consists mainly of dolomite, gypsum, and anhydrite. It is 0 to 700 feet thick.

The Triassic System

Santa Rosa Sandstone

This formation consists of sandstone, conglomerate, and mudstone which is brown, buff, or lavender in color. It is 0 to 300 feet thick.

Table II. Geologic Column of Study Area (After Kelley, 1971)

Formation & Members		Thick	Description
Holocene & Pleistocene	Assorted surficial deposits	0- 300	Valley alluvium, terrace and pediment gravel, caliche soils, aeolian sand, travertine
Oligocene	Sierra Blanca Volcanics	700- 4,000	Andesite breccia and tuff; some flows
Paleocene	Cub Mountain Formation	500- 2,000	Sandstone, mudstone, conglomerate, arkose; white, buff, lavender, purple, maroon
Cretaceous	Mesaverde Formation	500- 1,500	Sandstone, shale, coal, conglomerate; buff, gray, black
	Mancos Shale	400- 700	Shale, siltstone, with local thin sandstone and limestone; black grayish-black
	Dakota Sandstone	100- 150	Sandstone, conglomerate, black shale, gray to tan
Upper Triassic	Chinle Shale	0- 300	Mudstone with some claystone and thin sandstone; reddish brown
	Santa Rosa Sandstone	0- 300	Sandstone, conglomerate, mudstone; brown, buff, lavender
Permian	San Andres Formation: Fourmile Draw Member	0- 700	Dolomite, gypsum, reddish mudstone; sandstone locally at top; thin-bedded
	Bonney Canyon Member	0- 300	Dolomite, local limestone; gray, light-gray, local black; thin-bedded
Leonardian Series	Rio Bonito Member	250- 350	Dolomite, limestone, sandstone (Glorieta); gray, brownish gray; thick-bedded
	Yeso Formation	0- 1,400	Sandstone, siltstone, dolomite, gypsum; tan, red-yellow, gray, white
Precambrian	Syenite, gneiss, and diabase		

Chinle Shale

This formation consists of reddish brown mudstone with some claystone, and a thin sandstone. It is 0 to 300 feet thick.

The Cretaceous System

Dakota Sandstone

This formation consists of grey to tan sandstone which weathers to a light brown. It is massively bedded except in the top 50 feet where it is thin-bedded and intercalated with the overlying Mancos Shale. It is 100 to 150 feet thick.

Mancos Shale

This formation consists mainly of black shale. It is often interbedded with greyish siltstone, or it may contain thin limestone beds or lenses. It ranges in thickness from about 400 to 700 feet.

Mesaverde Formation

Near Capitan, this formation consists of three units: a lower sandstone unit about 150 feet thick, a middle shale and coal section about 150-200 feet thick, and an upper sandstone unit about 100-150 feet thick. South of Capitan the upper sandstone unit thins rapidly. Northwest of Capitan both sandstone units thicken at the expense of the middle shale and coal unit. The formation ranges from 300-600 feet in this area.

The Tertiary System

Cub Mountain Formation

It consists of purplish mudstone, and buff, coarse-grained, arkosic sandstone. The sandstone is generally friable. There are also several conglomeratic sandstone beds which are friable. This formation is 0 to 600 feet thick in the study area. It is commonly intruded by dikes and sills.

Sierra Blanca Volcanics

These volcanics crop out in a 200 square mile area in and around the Sierra Blanca Mountains. They consist of massively bedded, purplish-brown, andesitic breccias, flows and tuffs which are overlain by trachyte breccias. The volcanics range in thickness from 700 to 4000 feet.

The Quaternary System

Colluvium

On most of the canyon slopes, drift from bedrock has been deposited and thin soil profiles have developed.

Alluvium

Many of the springs issue directly from the alluvium in the canyon floors. It is generally black in color, and mostly silt with some clays. There is drift from the canyon walls in the alluvium also.

Calcareous Tufa

Many of the springs are depositing tufa near their issuing points. The deposits are generally thin and spotty. The tufa is also very impure containing much moss and other plant parts.

Intrusive Rocks

There are three major intrusive bodies in the northern study area. The largest is the Capitan Laccolith or Stock. It is a porphyritic granite to quartz monzonite. The Bonito and Three Rivers stocks are the other two. They are both porphyritic syenites. Dikes and sills also occur in this northern area. Most are diabasic.

Geologic Controls of Springs

For the vast majority of the springs surveyed, stratigraphic controls are much more important than are structural controls. The major stratigraphic controls of spring occurence are the aquitards within the Yeso Formation. Where there are good outcrops around the spring issuing points, red and yellow clays and siltstones of the Yeso Formation are almost always underlying the spring. This is the case for springs issuing from limestones in the Yeso Formation, the Glorieta Sandstone, and from the Rio Bonito Member of the San Andres Formation. Where springs issued from colluvium, adjacent outcrops were examined to determine the spring source rocks. This also led to the conclusion that impermeable beds within the Yeso Formation are primarily responsible for the location of springs.

The limestone beds from which many springs issue are generally located on canyon slopes. These limestone beds are in some places horizontal, but commonly dip back into the hill at angles between 7 and 60 degrees. A few springs issue from collapse breccias in the Yeso Formation. Higher permeabilities within these collapse features have channeled the groundwater flow and created a spring where the collapse is exposed.

Nearly vertical joints are an important control upon the location of springs, especially in limestones.

One of the most notable exceptions to the above controls is Lamay Spring (No. 13, Appendix A). The aquitard is a thin mafic sill underlying the issuing point of this spring.

Owing to the cursory nature of the geologic investigation, the stratigraphic position of most springs could not be determined precisely. Terms such as upper Yeso Formation, Rio Bonito Member of the San Andres Formation or, in some cases, just a formation name are used to describe the approximate stratigraphic position of the springs. There are, however, two locations in the study area where much better stratigraphic correlation of springs could be obtained without further geologic investigation.

The first location is in the southern half of the study area in Agua Chiquita Canyon. There are two springs in this canyon: Sand Spring (No. 6a) and about 3/8 of a mile up the canyon, Barrel Spring (No. 6b, Appendix A). Both springs issue along the southern wall of the canyon at the base of the slope. These two springs have the same stratigraphic position. They both issue from near the base of the Glorieta Sandstone and are probably controlled by clays and siltstones of the underlying Yeso Formation.

The second location is in the valley of the Rio Bonito between Hondo and Lincoln, New Mexico. Along the northern side of this valley there is a distinctive group of folds, the "Lincoln Fold System" (Craddock, 1964), which is in the Yeso Formation. Kelley (1971) refers to these folds as incompetent folds and attributes them to solution collapse. Above this fold system are the undisturbed beds of the San Andres Formation. Hulbert Spring (9.16.34.1411; see Appendix A), and Emil Fritz Spring (10.16.12.411) both appear to issue at the contact between the fold system, and the undisturbed beds. Emil Fritz Spring is about 3 miles southeast of Hulbert Spring. About 4 miles southeast of Emil Fritz Spring, Colonel Fritz Spring (10.17.29.4143; see Appendix A), issues from a fault, but it is possible that the fold system is a control for this spring also. It may seem unusual that the large-scale collapses act as aquitards here, since collapse breccias appear to be highly permeable zones in other areas. One possible reason why these collapses act as aquitards is that the small collapses seem to be mostly confined to beds of limestone with small amounts of clays, while the large-scale collapses involve all the beds in the upper part of the Yeso Formation. This means that much more clay and silt would be associated with the large-scale collapse features.

There is a general lack of obvious stratigraphic and structural control associated with the few springs sampled which issue from igneous rock. The major control on these springs would seem to be joint systems.

CHEMISTRY

General Chemistry

The results of the chemical analyses of the major springs are shown in Appendix C. These results indicate that the spring water of the region is generally of good quality, suitable for domestic use. This is in fact the main use of this water. The high quality of the rest of the springs is indicated by the specific conductances given in Appendix B. The average conductance is 628 μmhos/cm $(25^{\circ}C)$ with a range from 180 to 2100 and a standard deviation of 353. Hem (1970) gives a range of conversion factors for multiplying the specific conductance and obtaining the total dissolved solids. Using the limiting values of these conversion factors, 0.55 and 0.75, one obtains an average total dissolved solids content of 345 and 471 ppm, respectively, and a range from 99 ppm to 1575 ppm. Generally, this water is of much higher quality than the water from the rest of the basin (Fiedler and Nye, 1933).

pH and Bicarbonate Measurements: Field vs Laboratory

Equipment was not available to measure bicarbonate in the field. Therefore, the change in bicarbonate measurements between time of sample collection and laboratory measurement could not be evaluated in this study. (Roberson et al. 1963) state that the change in bicarbonate content is smaller than the change in pH, and for their study the bicarbonate change averaged only 3 ppm.

The change in pH readings from field to laboratory was evident in this study. Of the eight samples for which pH measurements were made, both in the field and in the laboratory, seven show decreases in pH and one shows a slight increase. The average change is a decrease of 0.54 pH units with a standard deviation of 0.32 pH units. The range of changes go from an increase of 0.1 to a decrease of 0.9 pH units. Although care was taken to have every sample bottle filled to capacity, there was still a small amount of air at the top of the bottles; it is also possible that the sample bottles were left open in the laboratory prior to pH measurement.

Relationship of Water Chemistry to Source Rock Type

Table III shows the range of chemical composition for the springs in equivalents per million according to rock type. In examining this chart it is important to note that there are a relatively small number of analyses. In considering the relationship of water chemistry to rock type one must take into account the fact that water issuing from one formation could have spent a great deal of time in the overlying formations. This is especially important in considering water which issues from the Yeso Formation which is overlain by the San Andres Formation and/or alluvium in many places.

Igneous Rocks, and Alluvium Underlain by Igneous Rocks

These rock types appear to produce the water of highest quality observed in this study. This is probably due to the fact that these were small springs and therefore small systems in which the water did not reside long enough to pick up large amounts of dissolved solids. The higher quality could also be due to the non-reactive nature of the igneous rocks.

Table III RANGE OF CHEMICAL COMPOSITION OF SPRING WATER IN EPM

Aquifer	No. of Analyses	Ca^{++} plus Mg^{++}	Mg^{++}/Ca^{++}	$Na^{+} + K^{+}$	HCO_3^-	$SO_4^=$	Cl^-	Anion Total	Total Dissolved Solids	Conductivity
Alluvium Ti	1	2.03	.22	.25	1.12	.97	.29	4.08	135	280
Alluvium Kd, Km, Kmv	2	19.63-21.03	.37-.44	2.49-2.91	3.84-5.56	14.81-15.4	3.95-4.31	22.96-24.91	1391-1491	2200-2250
Alluvium Py	5	3.82-14.92	.23-.45	.37-1.66	3.04-3.75	.94-12.41	.14-1.94	4.32-17.39	227-1121	420-2100
Ti	1	3.79	.75	.36	1.4	2.4	.28	8.23	241	370
Psf	2	9.53-10.39	.47-.50	.73-.74	2.08-2.24	7.61-8.55	.80-.85	10.49-10.64	642-714	1020-1140
Psr	3	2.78-4.65	.39-.52	.39-1.37	2.0-2.91	1.06-2.8	.17-.47	3.23-6.18	177-338	320-640
Psg	1	2.94	.41	.16	2.57	.5	.17	3.24	165	310
Py	5	2.65-18.05	.36-.56	.17-1.22	2.56-3.56	.5-14.53	.11-1.96	3.68-20.05	189-1218	270-1800

Py = Yeso Formation
Psg = Glorieta Sandstone
Psr = Rio Bonito Member
Psf = Fourmile Draw Member

Kd = Dakota Sandstone
Km = Mancos Shale
Kmv = Mesaverde Formation
Ti = Tertiary Intrusives

Alluvium Underlain by Cretaceous Rocks

This water is of the poorest quality encountered in this study, probably due to the abundance of shale units within the Cretaceous formations.

Yeso Formation and Alluvium Underlain by the Yeso

The water from these units is characterized by a large range in chemical composition probably reflecting the varied rock types within the Yeso, as previously discussed. The gypsum contained within the Yeso Formation generally causes these waters to have a higher sulfate content than waters from the San Andres Formation. The chloride content of these waters is also higher than that of waters from the San Andres Formation. Several of the springs issuing from the Yeso Formation are supersaturated with respect to calcium carbonate as evidenced by the fact that they are presently depositing calc-tufa.

San Andres Formation

The water from this formation varies according to the different members of the formation. The Glorieta Sandstone has the least amount of dissolved solids, which would be expected for water from a clean sandstone. The water from the Four Mile Draw Member contains more calcium, magnesium, sulfate, and chloride than water from the Rio Bonito Member. This is due to evaporites which are present only in the Four Mile Draw Member.

The Northern vs the Southern Area

The two areas north and south of the Mescalero Apache Indian Reservation are somewhat dissimilar in chemical characteristics. Fig. 5 shows histograms of specific conductance for the regions north and south of the Mescalero tribal lands. The southern region shows much less variation in chemical content than does the northern region. This is a direct result of geologic control. The southern area is basically a uniform dip slope underlain by the Yeso and the San Andres Formations. In the northern area this same dip slope has been intruded by igneous rocks; water issuing from these igneous rocks as a rule has low conductivity. The northern area is also highly faulted and exposes Cretaceous rocks. Water from these rocks has high conductivity. To obtain a clearer idea of the differences in chemical composition between the northern and southern regions the chemical analyses of the major springs are plotted on trilinear diagrams (Piper, 1944) for each area (Figs. 6, /). The trilinear diagrams have an anion field in the lower right, a cation field in the lower left, and a combined field in the center diamond. Analyses are plotted on the graphs as percentages of equivalents per million. The major difference between the two areas lies in the anion composition. The southern area is characterized by $CO_3^=$ and HCO_3^- making up about 60 to 80 per cent of the anions, $SO_4^=$ from 10 to 35 per cent, and Cl^- from 1 to 10 percent. The northern area shows a much larger percentage of sulfate, from about 40 to 75 per cent, a smaller amount of $CO_3^=$ and HCO_3^-, from 25 to 60 percent, and a slightly larger percentage of chloride, from about 5 to 20 percent.

These differences could be due to the geologic factors already

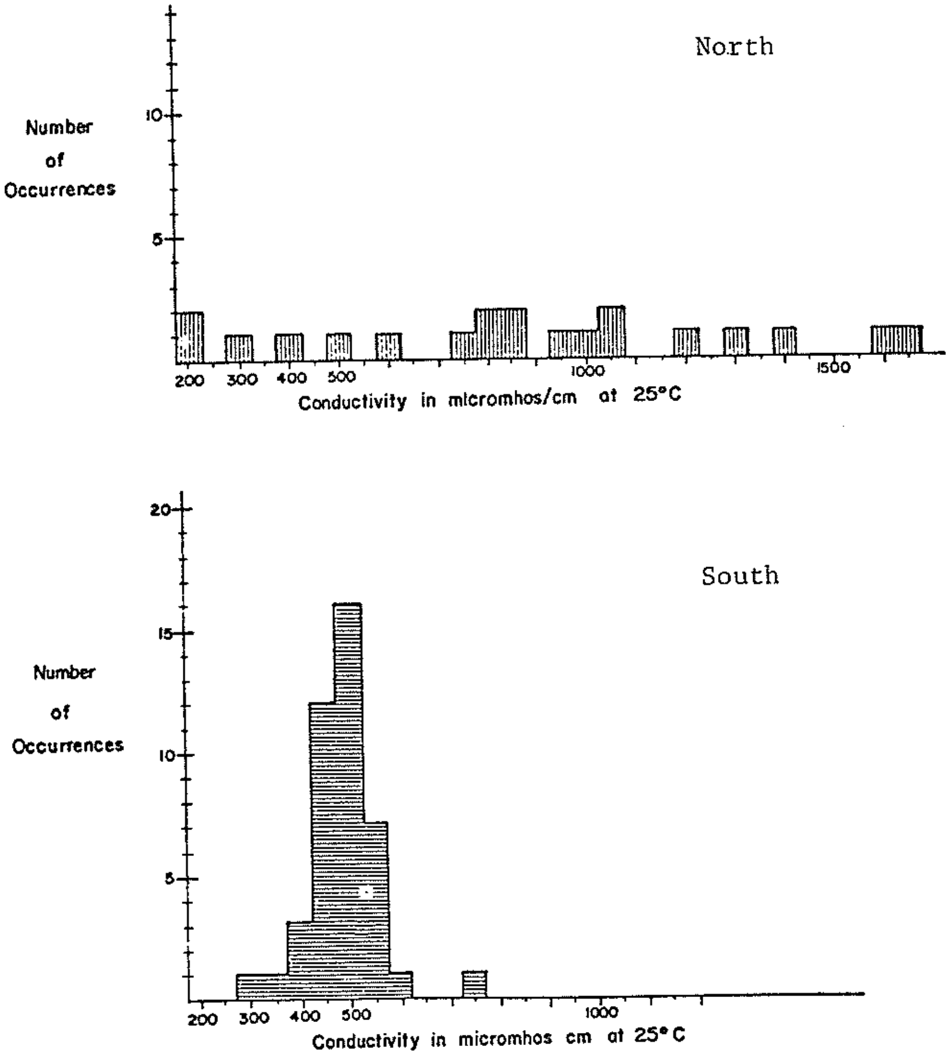

Figure 5. Histograms of electrical conductivity of spring water north (top) and south (bottom) of the Mescalero tribal lands.

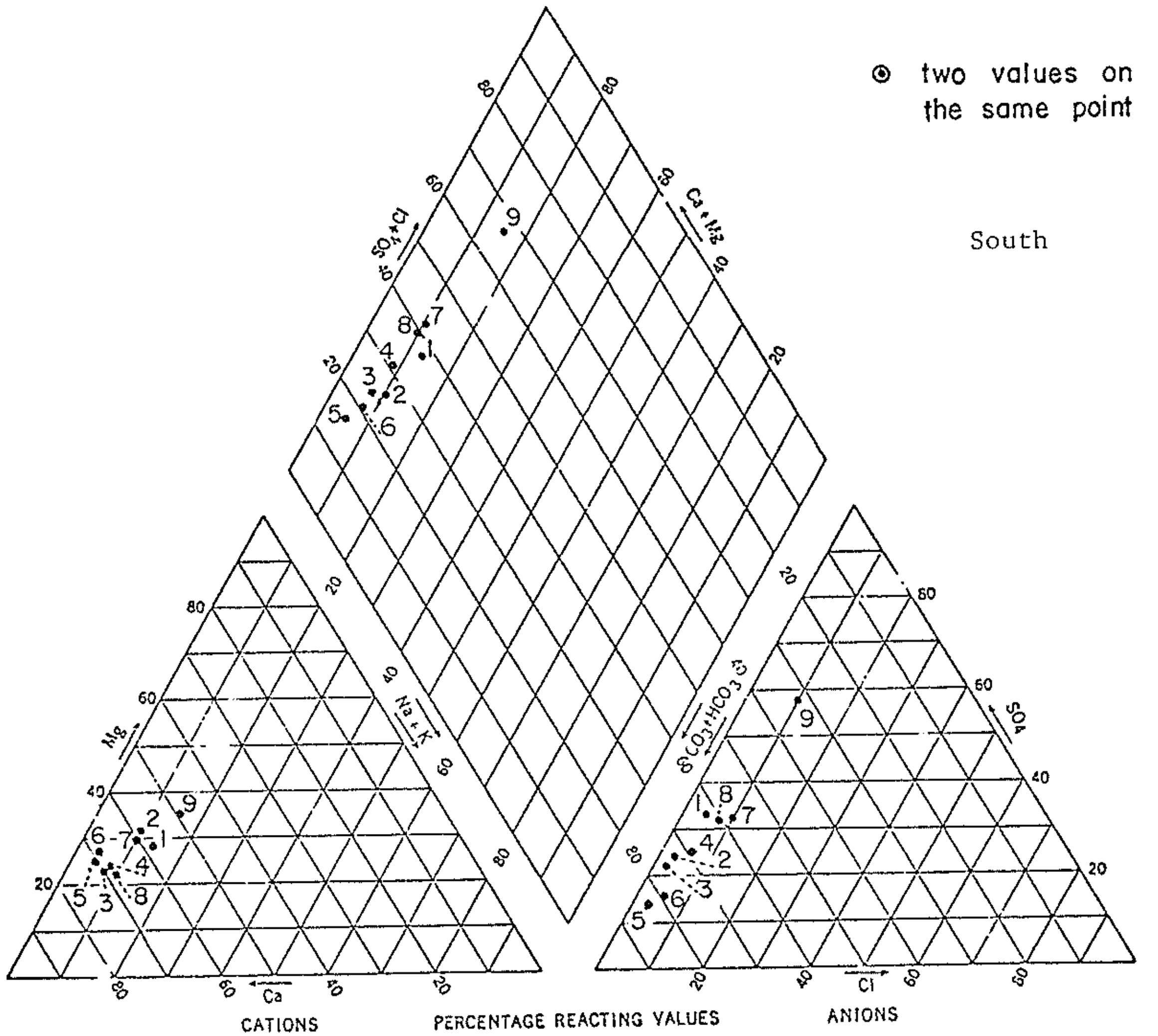

Figure 6. Trilinear diagram of the southern springs.

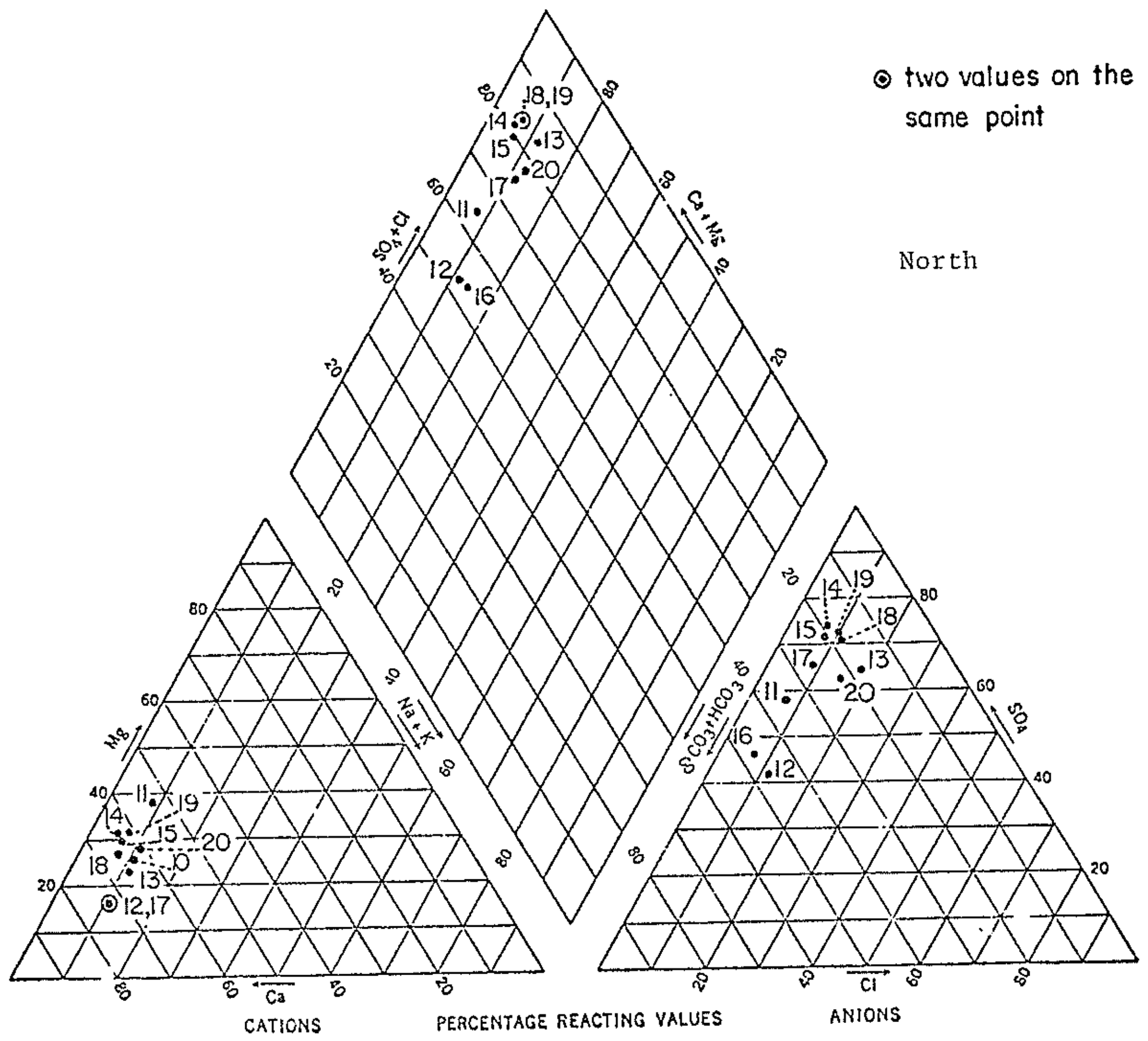

Figure 7. Trilinear diagram of the northern springs.

mentioned, and also to facies changes within the primary units, the Yeso and San Andres Formations. An increase in evaporitic facies of both the Yeso Formation and the Four Mile Draw Member of the San Andres Formation from south to north is noted by Kelley (1971). This could help account for the difference in anion composition between the northern and southern areas. It should be noted, however, that there is not a corresponding change in the cations, sodium and calcium.

Water Temperature

The temperature of the spring water is a function of several factors including the temperature of the infiltrating water and its residence time in the ground, and therefore, the size of the system.

The spring temperatures, measured in late May and early June 1977 for springs above 8000 feet elevation in the southern area, are remarkably similar. They range from 0° to 6°C. These consistently low temperatures seem to indicate that the major factor involved is the temperature of the infiltrating water, and that the infiltrating water is probably snow melt.

Assuming that the size of the systems is nearly constant over the varying altitudes, and that the temperature of the infiltrating water is related to the altitude of the system, it should be possible to define a relationship between temperature of the springs and the altitude of the spring outlet. Figure 8 shows a possible linear relationship between altitude and temperature for the southern area, for both underflow and perched systems. The relationships seem to indicate that the major factor influencing spring temperature is the temperature of the infiltrating water.

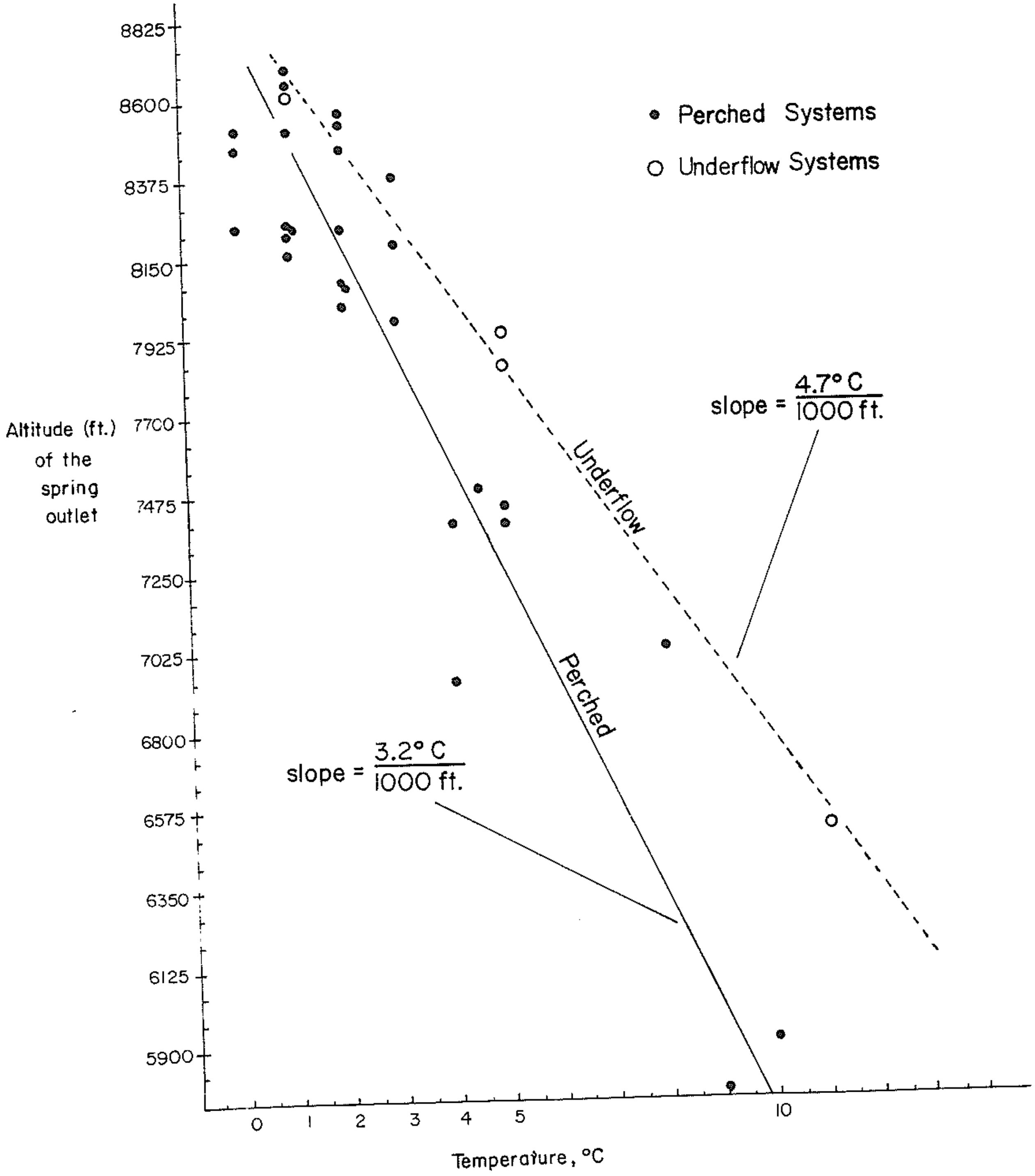

Figure 8. Temperature vs. altitude for the southern springs.

The same relationships described above were not evident in the northern area. This is probably due to a wider range in the size of the systems, which is a result of the more complex geology of the northern area.

Changes in Chemistry with Time

Several springs were revisited and sampled at the end of the summer of 1977, but it was not possible to have complete chemical analyses run on these samples. Therefore, the data on changes in chemical composition with time is limited to a few measurements of the pH and conductivity, and information obtained from other sources. Table IV shows this information. It is not known if the pH and conductivity data given in the other sources are field or laboratory measurements. Also, the exact date of sampling was not given by Garcia (1974) which eliminates the possibility of using Garcia's data to find seasonal changes.

The data given in Table IV do not show clear changes or fluctuations in the chemical makeup of the springs. It appears that most changes are small and show no clearcut trends. One exception is the abnormally low sulfate content for spring number 19 given by Garcia (1974). Since all the other meausrements given for this spring appear to agree fairly well, it is possible that this difference is due to an error in measurement.

The scarcity of data could be the main reason why no changes in chemical composition with time could be delineated, that is, of course, assuming that these changes exist.

Table IV CHANGES IN CHEMICAL COMPOSITION OF SPRING WATER WITH TIME

Location	Sample Date	Conductivity	T.D.S.	pH	HCO_3^-	Cl^-	$SO_4^=$	Na^+	K^+	Mg^{++}	Ca^{++}	$Mg^{++}Ca^{++}$
#6a 18.12.26.4111	5-27-77	550		6.9								
	8-18-77	480		6.5*								
#2 17.12.12.3,4	5-24-77	490		7.2								
	8-18-77	495		6.8*								
#10 16.12.3.1441	3-29-56**	622		7.7	341	11	52					
	1973***	621		8.0	312	10	63					
	6-3-77	500		7.7								
#19 11.14.28.31231	4-27-55**	1570		7.1	266	52	649				240	
	9-12-61**	1560		7.6	257	55	665					
	1973***	1165.5		7.5	297.4	74.6	302	55.6	1.56	52.3	149.2	
	8-12-77	1800	1218	7.7	217	69.5	698	26.4	2.6	75.0	238	
#17 10.16.26.441	8-23-55**	1820		7.2	274	67	776					1080
	5-16-77	2100		7.7	229	51.2	482					254.6

* Lab measurement; ** Dinwiddle (1963); *** Garcia (1974).

Conductivity in μmhos/cm at 25°C.; all chemical species in parts per million

HYDROLOGY

Figure 9 shows the three types of hydrologic systems in the study area: obviously perched systems, valley underflow systems, and a regional system. The regional water table was possibly encountered in one area in this study; its existence is suggested by previous investigations (Fiedler and Nye, 1933). Springs 14, 15, and 16, located to the north of the Capitan Mountains, appear to discharge from this regional system, as evidenced by their artesian nature, i.e. they all percolate upward at their discharge points. The perched systems shown in the figure are held up by the clay and siltstone of the Yeso Formation. This leaves out the perched systems within igneous rocks. These are probably held up by other igneous rock which is less fractured and thus less permeable. Perched systems within igneous rock produce only small amounts of spring flow.

For some springs the distinction between perched and underflow systems is difficult to make. Good examples of this are Sand and Barrell Springs (#6). They seem to issue from a perched system, but they are very close to the lowest part of the valley. The water table is right at the surface, evidenced by the marshy nature of the valley. It could be said, then, that the valley underflow and the perched systems in this valley are one system, at least where these springs issue.

Figures 10 and 11 show the distribution of flow in underflow and perched systems. The average flow for perched springs is 41.6 gpm, and the average flow for underflow springs is 135.3 gpm. This difference is not surprising since some flow from the perched springs eventually will

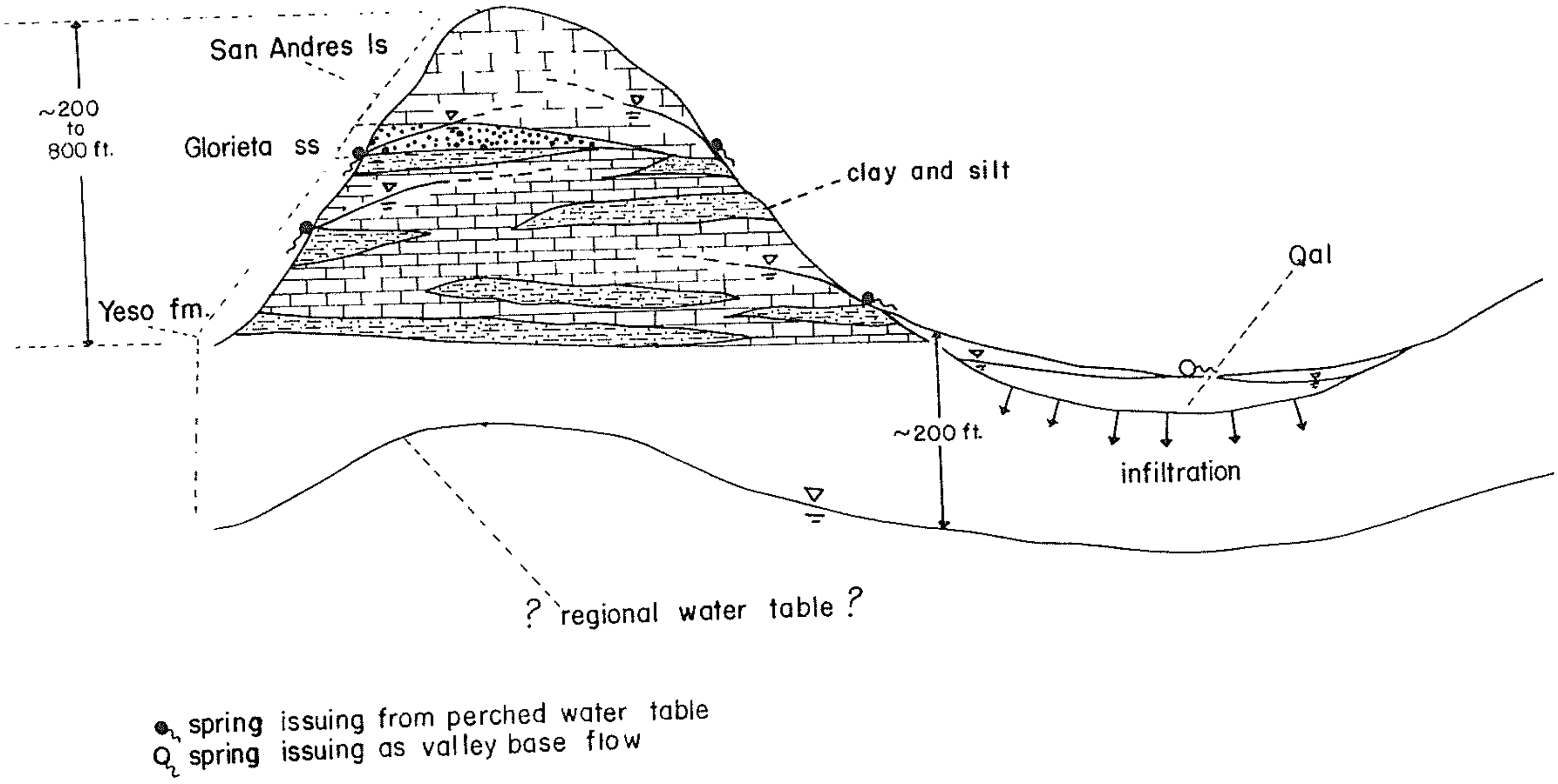

Figure 9. Three types of hydrogeologic systems encountered in this study.

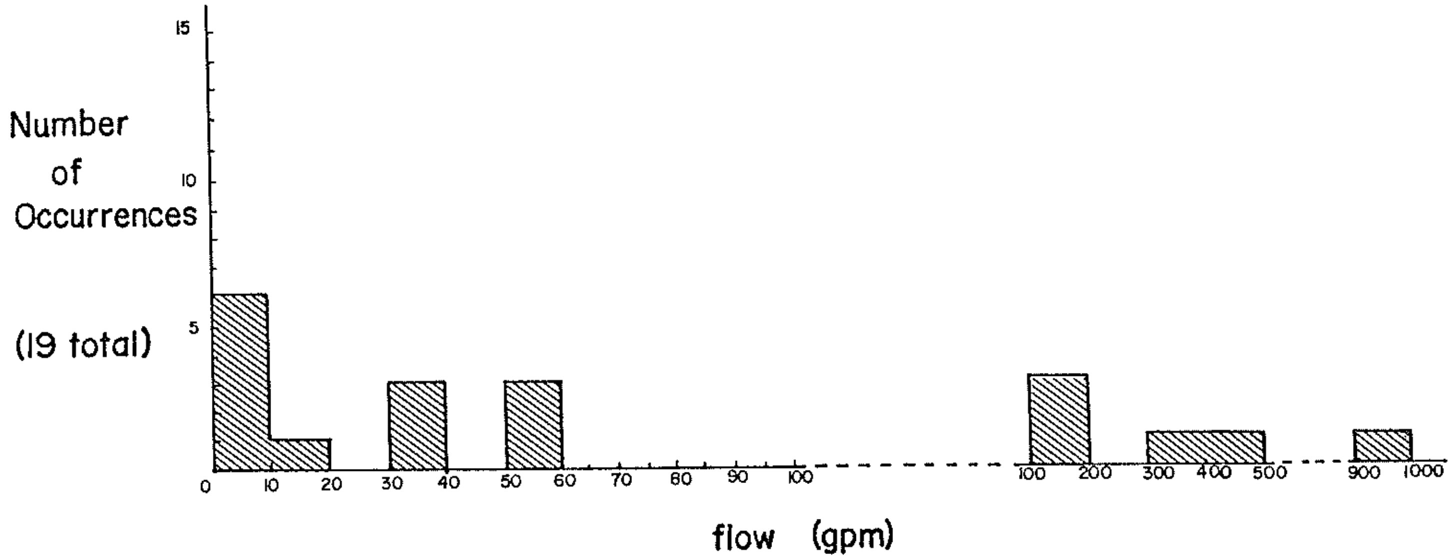

Figure 10. Discharge histogram of valley underflow springs.

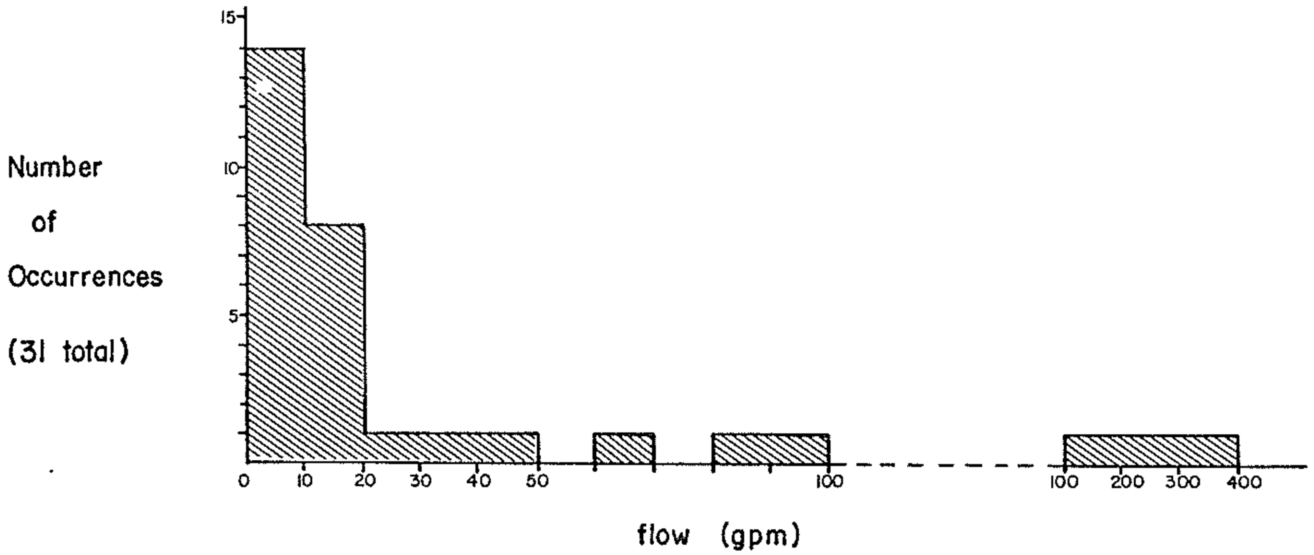

Figure 11. Discharge histogram of perched springs.

flow in the underflow systems, and the recharge area for an underflow spring is much larger than the recharge area for most of the perched springs.

The majority of the springs studied, 62%, are perched springs. Of these, 68% issue from the Yeso Formation, and 13% issue from the Rio Bonito Member of the San Andres Formation. The other 19% issue from slope colluvium, Tertiary igneous rocks, and the Glorieta Sandstone. Those springs which issue from slope colluvium actually issue from underlying rock, which probably means that the percentage of perched springs which issue from the Yeso is higher than 68%. This is so because Yeso beds occupy most of the valley slopes and colluvium is best developed on the easily erodible clays and siltstones of the Yeso Formation.

INTERPRETATION OF TRITIUM ACTIVITY

Tritium (H^3) is the unstable hydrogen isotope with a half-life of 12.36 years. It is produced naturally in the stratosphere by cosmic ray bombardment of atmospheric molecules (nitrogen). It combines with oxygen to form tritiated water vapor and falls to earth as precipitation. Between 1954 and 1963, large quantities of tritium were produced by atmospheric nuclear bomb tests. Much of this tritium also has entered the hydrologic cycle. Tritium activity measurements in precipitation, surface water, and ground water are valuable as a hydrometeorologic tracing and dating tool (Gross et al., 1976).

For this report, most springs could be analyzed only once (Table V). A single tritium analysis has limited usefulness. To estimate seepage velocity and residence time, periodic analysis of spring water and of precipitation falling in the spring recharge area must be made and correlated. There are, however, some qualitative generalizations which can be made with the data at hand. The variance of tritium concentrations from spring to spring, even within the same hydrogeologic system, is probably a reflection of the complexity and varying characteristics of the spring systems.

In the southern half of the study area tritium concentration averages 25.3 TU* in the perched springs and 13.2 TU in the underflow springs. This implies that the water flowing from the perched springs is younger than that flowing from the underflow springs. The average

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* 1 tritium unit (TU) = 1 tritium atom per 10^{18} hydrogen atoms and is equivalent to 3.24×10^{-15} Curies per milliliter or 7.2×10^{-3} dpm/ml.

Table V. Natural Tritium Activity in Major Springs

Spring Number	Type of System	Date Sample Collected	Tritium Concentration (TU)
1	Perched	24 May 77	15.1 ± 0.4
2	Perched	24 May 77	27.4 ± 0.4
3	Underflow	25 May 77	19.2 ± 0.5
4	Perched	25 May 77	17.2 ± 0.6
5	Perched	27 May 77	34.1 ± 0.6
6	Perched ?	27 May 77	55.9 ± 0.5
7	Perched	27 May 77	5.7 ± 0.6
8	Perched	3 June 77	21.6 ± 0.4
9	Underflow	3 June 77	7.2 ± 0.5
10		---	---
11	Perched	9 Aug 77	63.3 ± 0.5
12	Perched	9 Aug 77	54.0 ± 0.5
13	Underflow	9 Aug 77	7.8 ± 0.6
14	Regional ?	10 Aug 77	9.3 ± 0.6
15	Regional ?	10 Aug 77	7.4 ± 0.5
16	Regional ?	10 Aug 77	5.1 ± 0.5
17		---	---
18	Underflow	12 Aug 77	39.4 ± 0.5
19	Perched	12 Aug 77	4.9 ± 0.5
20	Underflow	12 Aug 77	54.8 ± 0.5

value of 13.2 TU for the underflow springs was calculated using only 2 springs. Spring #6 (Barrel Spring) is considered a perched spring here for reasons described in the hydrology section.

Springs #14, 15, and 16 are all located north of the Capitan Mountains. The latter spring is located 2.7 miles north of the base of the Capitan Mountain slopes. The other two springs are located approximately 5.2 miles northwest of this point. We assume that these three artesian springs are all part of a single system which receives recharge along the break in slope of the Capitan Mountains. The tritium values of 9.3, 7.4, and 5.1 TU, respectively, for the springs suggest that they are all discharging relatively "old" water, and they all could be part of one ground water system.

Spring #9 is an underflow spring, and its flow, 1,000 gpm, is the largest encountered in the study. This spring is apparently part of a rather large system because of its location and its large flow. The tritium activity, 7.2 TU, for this spring indicates that the residence time is long for this system, when compared with most of the perched systems.

A plot of elevation vs the logarithm of tritium activity of spring waters issuing from the Yeso Formation is shown in Figure 12. The linear relationship depicted could be explained by several factors. Increased precipitation in the higher elevations could create more solution features in the higher aquifers. This in turn would cause faster ground water velocities and therefore higher tritium values. Another possible explanation is that the systems of the higher regions are smaller and therefore have shorter travel times.

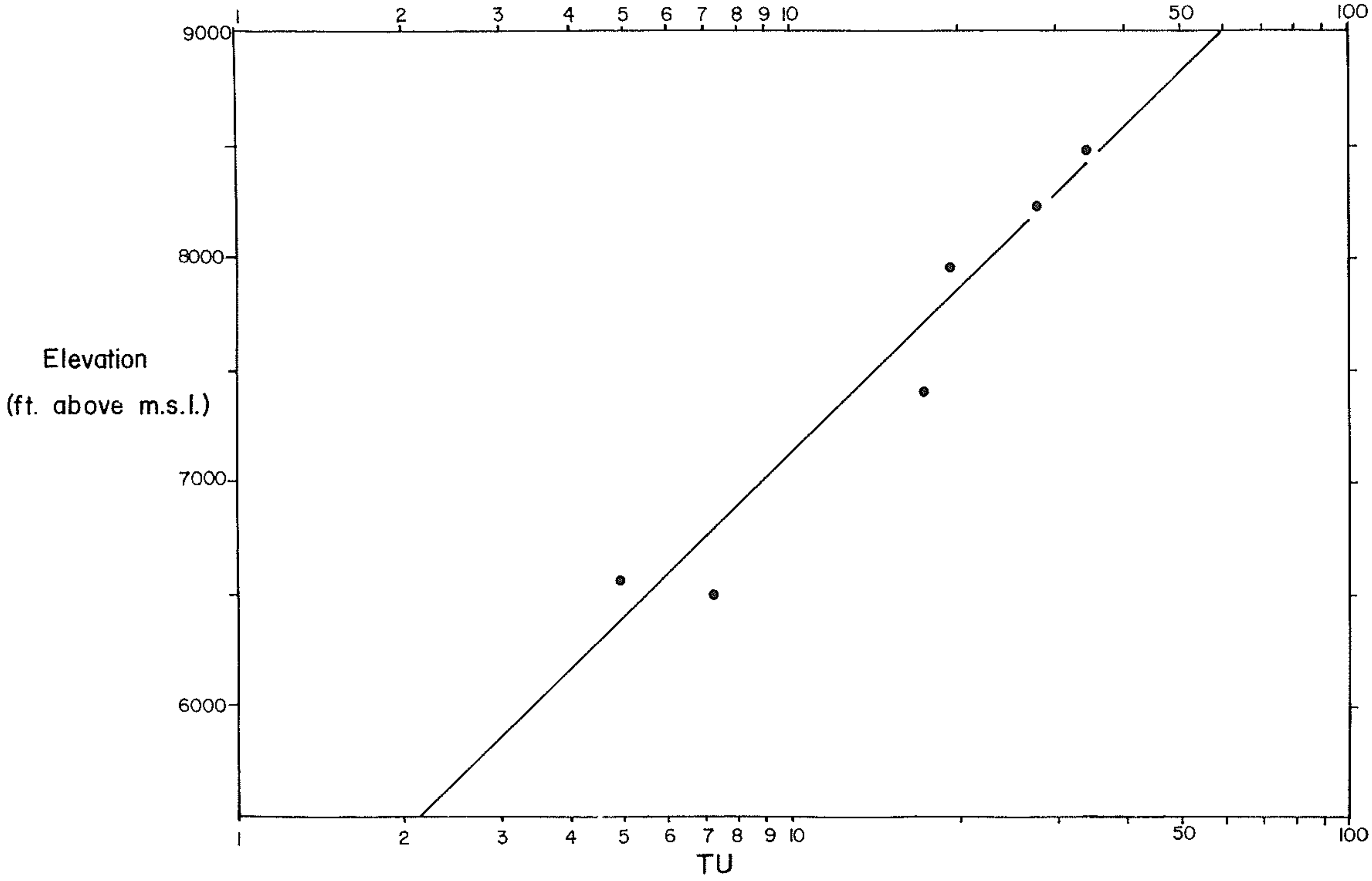

Figure 12. Elevation vs tritium activity for springs discharging from the Yeso Formation.

SPRING WATER AS RECHARGE WATER

The water feeding the springs of the western Roswell artesian basin contributes to the recharge of the main aquifer, the San Andres Formation, in one of two ways. It may percolate directly down into the main aquifer of the western region, the Yeso Formation, and then flow eastward across the Yeso-San Andres contact into the San Andres Formation. It may also discharge as springs or as underflow into streams which eventually lose their flow directly to the San Andres Formation in the Principal Intake Area (Fiedler and Nye, 1933).

Chemical Evidence

The chemistry of the water in the main aquifer should be basically similar to that of the spring water. Table VI shows the average chemical composition of the southern springs and the average chemical composition of the wells on the Flying H Ranch taken from DeWilde (1961). The Flying H Ranch is located on the east central edge of the southern region and the wells produce water from the upper portion of the Yeso Formation. The wells contain nearly twice the amount of each chemical constituent as the springs do. This is expected since the water from the main aquifer should have a much longer residency than the water from the springs. The fact that the water of the springs and of the wells flows through basically the same type of rocks is reflected by the amount of the chemical constituents in the springs being consistently less than the amounts in the well waters by nearly the same percentage for each constituent.

Water from 18 wells producing from the main aquifer in the San Andres Formation (Bunte, 1960) in the artesian area of the basin is compared to

Table VI. Average Chemical Composition of the Major Springs of the Southern Region and of the Wells of the Flying H Ranch.

	Major Springs of the Southern Area	Wells of the Flying H Ranch*
Total Dissolved Solids	254	530
HCO_3^-	179	248
Cl^-	10	26
Na^+	10	14.52
Mg^{++}	19	32.6
Ca^{++}	52	111.4

*From De Wilde, 1961.

Table VII. Average Chemistry of the Major Springs vs Average Chemistry of Water from the San Andres Formation

	Major Springs	Artesian Wells of the Main Basin*
Total Dissolved Solids	544	1856
HCO_3^-	203	217
Cl^-	36	542
$SO_4^=$	295	534
Na^+	20	381
K^+	1.8	5.5
Mg^{++}	34	61.3
Ca^{++}	117	198.3

*From Bunte, 1960.

the water of all the major springs in Table VII. Most constituents show a systematic increase, which would be expected of water traveling from the western region to the eastern region. HCO_3^-, Cl^-, and Na^+ need to be considered separately. A large percentage of the bicarbonate content is assumed to be derived from the atmosphere and from the water percolating through the soil zone (Hem, 1970). Therefore, a substantial increase of bicarbonate with distance traveled would not be expected. It is unlikely, however, that the very large increase in the amount of sodium and chloride can be accounted for solely on the basis of the distance traveled. A more evaporitic lithology in the eastern part of the basin could account for these large increases. These increases could also be due to mixing of ground water recharged in the western part of the basin with the highly saline ground water known to exist along the northeastern margin of the basin.

Geologic Evidence

It is not known percisely how the spring flow enters the main artesian aquifer of the basin. Probably both of the mechanisms mentioned at the beginning of this section are important. For an understanding of the recharge mechanisms, spring stratigraphic locations are significant because these locations lend evidence as to how the ground water which does not issue as spring flow may recharge the main artesian aquifer.

The upper Yeso Formation contains considerable amounts of water, even in the western part of the basin, as shown by the numerous springs which issue from it. It also contains many impermeable beds which hold up the water to create the springs. How do these impermeable beds affect the ground water flowing within the formation? Do they prevent lateral movement of the ground water across the Yeso/San Andres Formation contact?

Fiedler and Nye (1933) suggested that the percolation down the dip of the Yeso Formation is not large because the Yeso Formation is relatively impervious. This is not necessarily true, much of the limestone within the Yeso is permeable, and most of the impervious beds are lenses (Fiedler and Nye, 1933) rather than continuous beds, which would restrict flow more. Also, the beds of low permeability within the Yeso Formation are mostly silt. The existence of a number of springs that issue directly from these silts indicates that they are capable of transmitting substantial amounts of water. Large springs issue from the Glorieta sandstone and many springs issue near the Yeso/San Andres Formation contact. This would seem to indicate that near this contact ground water flow is significant, and flow along this contact may be a large component of recharge to the main artesian aquifer of the basin.

SUMMARY OF CONCLUSIONS

The upper portion of the Yeso Formation is the main aquitard which slows downward-percolation of groundwater and causes the perched systems in this study area.

The main structural control of spring occurrence is bedding which dips toward the hills containing the perched water bodies. These dips are caused by collapse features in the upper Yeso Formation.

Fracturing is a major control on the local point of issuance of some springs. In most cases, it is more important than bedding planes in determining exactly where a spring will issue.

The Lincoln fold system appears to act as an aquitard holding up several perched systems.

The difference in the geology of the northern and southern regions causes a significant difference in the chemistry of the spring waters of the two regions.

Spring water temperatures indicate that snow melt is a major component of recharge to the higher altitude springs.

Three types of systems were encountered: obviously perched systems, perched valley underflow or base flow, and possibly the true regional system.

Spring water forms a component of recharge by flowing into the major streams of the region which then loose their flow to the main artesian aquifer in the Principal Intake Area.

Tritium analyses indicate that the valley underflow contains relatively older water than the perched systems.

The existence of springs and their stratigraphic location indicate recharge which flows along the San Andres-Yeso contact eastward into the main artesian aquifer of the basin (the San Andres Formation).

RECOMMENDATIONS FOR FURTHER STUDY

A survey should be attempted of the springs on the Mescalero Indian Tribal Lands, and springs at the higher elevations in the study area, which have not been visited. This would provide a more complete overview of the spring characteristics of the western Roswell-Artesia basin.

Major springs of the study area should be revisited periodically to define time dependent characteristics, such as quantity of flow, tritium concentrations, and changes in water chemistry.

Detailed studies of the major springs could be useful in obtaining hydrologic parameters and recharge characteristics.

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APPENDIX A

Summary of Geologic Information for Individual Springs

GEOLOGICAL NOTES FOR MISCELLANEOUS SPRINGS

7.16.22.443 (#16)

This artesian spring issues through a soil cover which is underlain by the Rio Bonito Member of the San Andres Limestone.

9.13.33.21

This spring issues from the valley floor covered by a thin sheet of alluvium. Scattered outcrops of Mesa Verde or Cub Mountain sandstone lie in the channel bed and along the walls about 1/8 mile upstream from the spring. These sandstone beds are highly faulted and folded.

10.13.8.241

This spring issues from a small outcrop of porphyritic andesite which is surrounded by alluvium.

10.16.26.441 (#17)

This spring on the south side of the Rio Ruidoso valley, issues about 5 feet above the channel, from alluvium. The alluvium is directly adjacent to a hillside which is composed of Yeso rock. This spring could be from the Yeso Formation (Perched) or from the valley alluvium (Underflow).

11.13.14.312 (#20)

This spring issues from alluvium in a broad flat area. There are outcrops of Santa Rosa Sandstone, Dakota Sandstone, and Mancos Shale on the hills adjacent to this flat area.

11.14.32.233

Yeso beds of red siltstone and massive limestone line the east canyon wall about 200 feet down the canyon from the spring. The spring issues from the west canyon wall about 15 feet above the canyon floor. It issues from alluvium or from the upper part of the Yeso Formation.

17.11.24

Yeso outcroppings can be found in road cuts all the way up this canyon. They are typically thin bedded limestone, and red and yellow siltstones and clays. In many places there are collapse features.

17.12.26.(3 & 4)

All the springs issue from alluvium in the valley floor which is underlain by the Yeso Formation.

17.13.11.3(3 & 4)

The springs all issue from alluvium in the floor, and on the adjacent slopes of Bear Canyon. The alluvium is probably underlain by the Yeso Formation which crops out in the adjacent slopes also.

17.13.31.122

The spring issues from alluvium about 20 feet above the valley floor. The Yeso Formation underlies the alluvium.

17.13.32.144

The spring issues from alluvium in the valley floor. The Yeso Formation underlies the alluvium.

18.13.21.221

The spring issues from a talus slope just below a thin bed of flat lying limestone. The limestone is in the Yeso Formation.

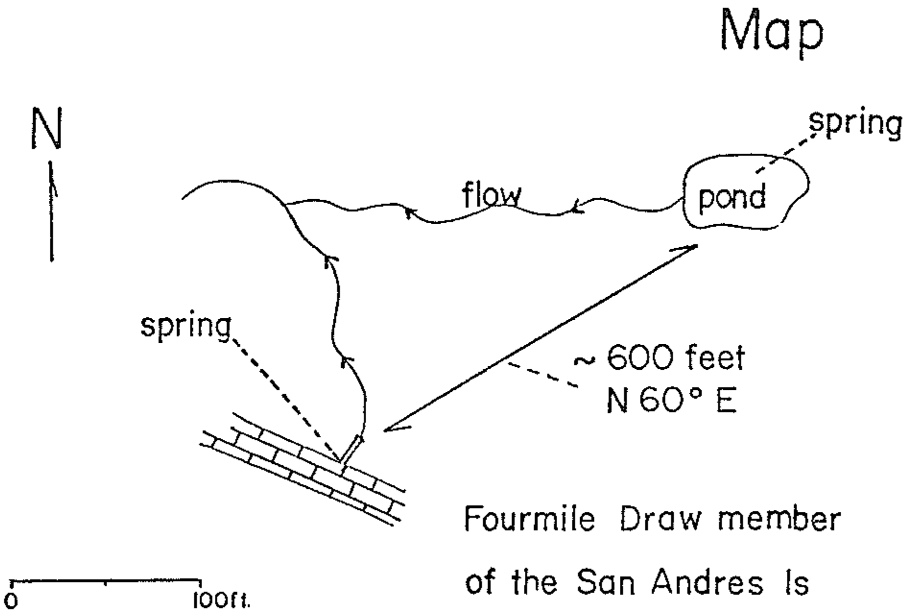


Figure A1: Map view of springs 7.16.7.434 and 7.16.7.431 (Ref. #14, 15. Macho Springs). Spring #14 issues from alluvium underlain by the Fourmile Draw Member of the San Andres Formation. It flows up at the bottom of a pond which is about 5-7 feet deep. Spring #15 issues directly from limestone beds of the Fourmile Draw Member. These beds are 3-5 feet thick and have attitude N73°E, vertical. Scale is approximate.

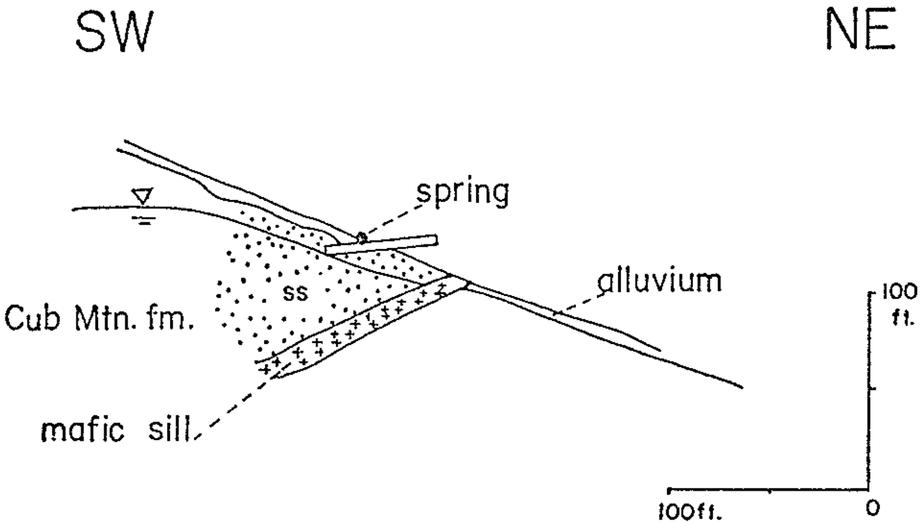


Figure A2: Cross section of spring 9.13.32.223 (Ref. #13. Lamay Spring). The spring issues from a pipe which has been set into alluvium and probably into a sandstone underneath it. The sandstone outcrops about 20 feet east of the spring. It has an attitude of N31°E, 16°SW. Under this sandstone there is a mafic, cryptocrystalline sill which is about 1 foot thick.
Scales are approximate.

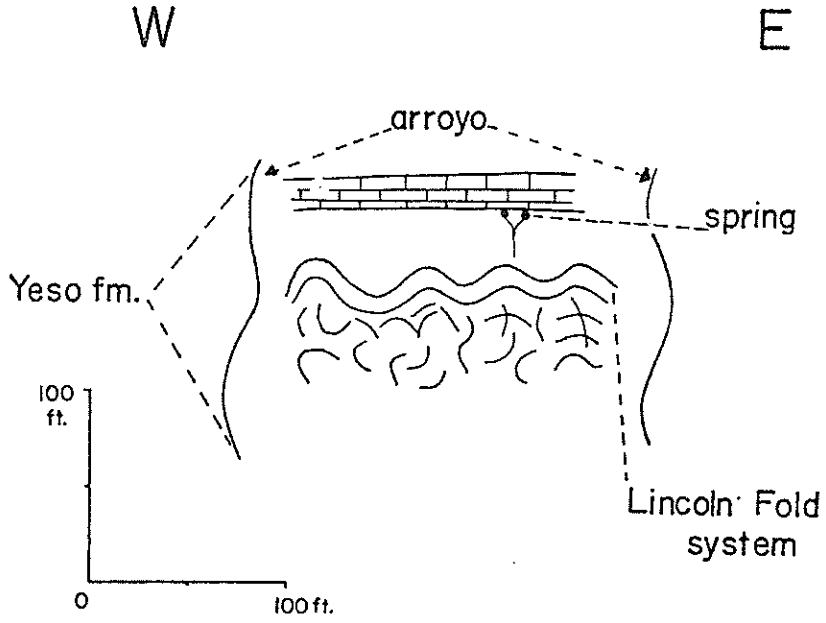


Figure A3: Front view of spring 9.16.34.141 (Hulbert Spring). The spring issues from two points on the same level, about 10 feet apart. They issue from the base of a 4 foot thick bed of limestone which strikes nearly east-west, and dips about 12°N, into the hill. Just below, there are large collapse features within the Yeso (Lincoln Fold system).
Scales are approximate.

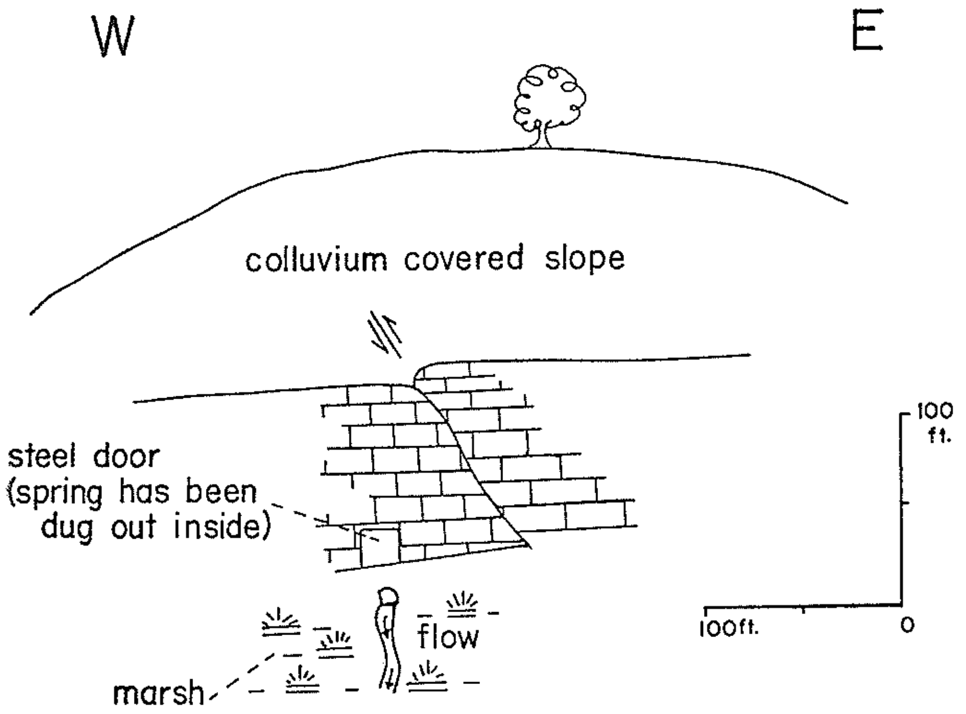


Figure A4: Front view of spring 10.17.29.414 (Colonel Fritz Spring; Spring Ranch Trout Farm). The spring issues from a small fault in the Rio Bonito member of the San Andres limestone. This limestone is massively bedded and flat lying. There is a distinctive bed of black chert about 4 feet above the spring. It is about 6 inches thick and has been squeezed into nodules in places. Scales are approximate.

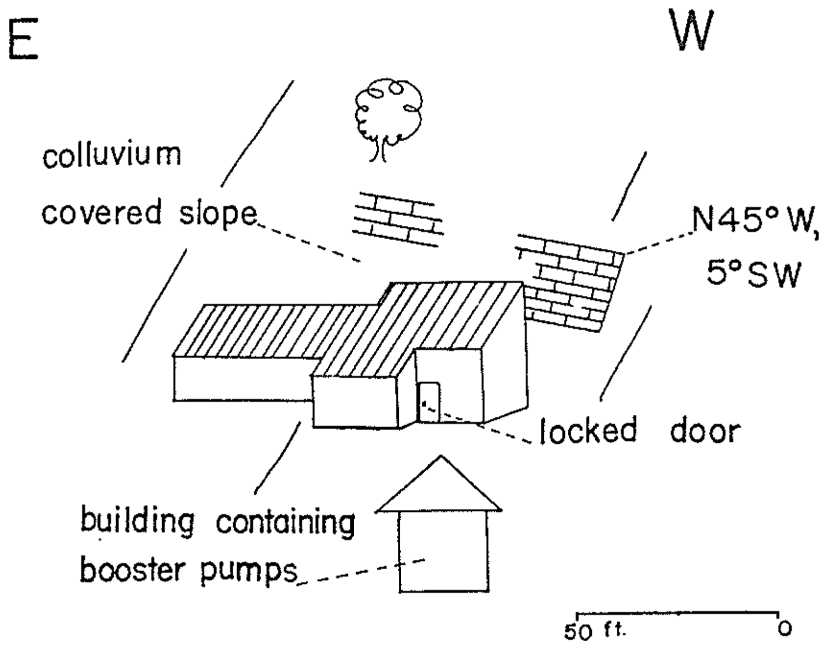


Figure A5: Front view of spring 11.14.28.312 (Ref. #19, Griffith Spring). The spring issues from a highly jointed, tilted, and probably collapsed limestone (Yeso Fm.).
Scale is approximate.

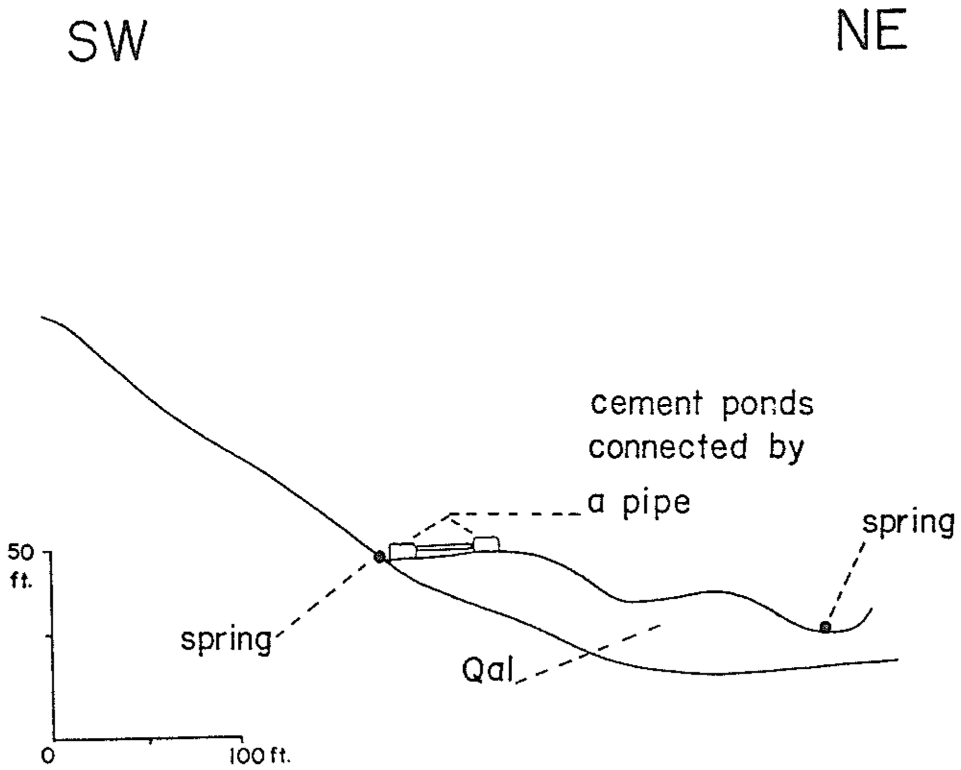


Figure A6: Cross section of springs 16.14.31.113 and 16.14.31.111. (Ref. #8, Mickison Springs). The upper spring issues from alluvium on what appears to be a stream terrace. It flows into a cement pond. This spring is depositing tufa. The other spring issues from alluvium in the valley floor. Scales are approximate.

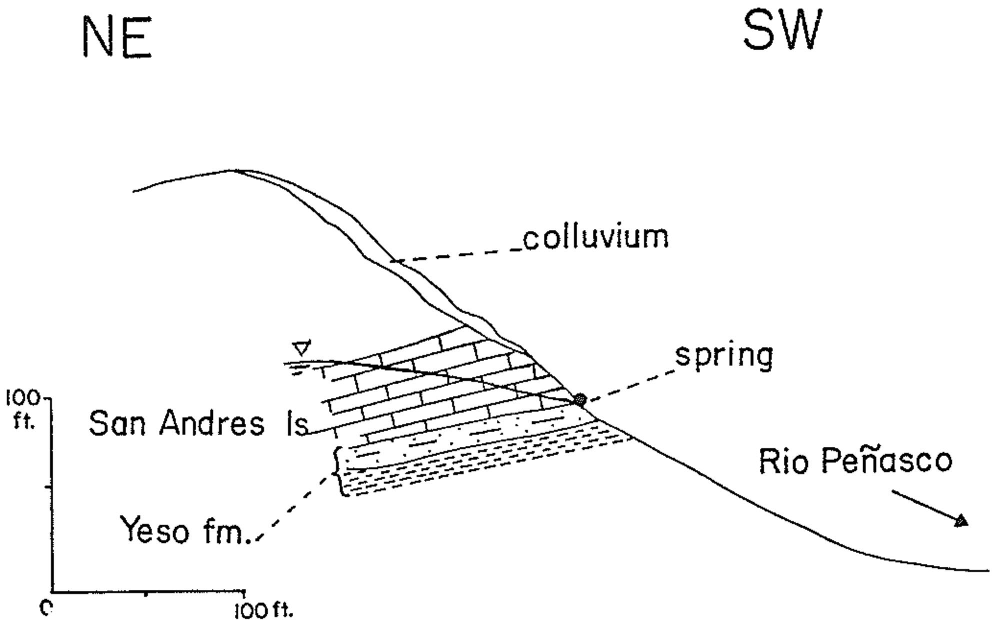


Figure A7: Cross section of spring 16.16.2.323 (Ref. #7, Cleve's Spring). The spring issues from a joint with attitude N12°W, 82°NE, and having about 2 inches of throw. The joint is in a flaggy to massively bedded limestone, Rio Bonito Member of San Andres Fm. It has an attitude of N27°W, 7°NE. Right below this limestone lies a siltstone, and a weathered clay lies below this.
Scales are approximate.

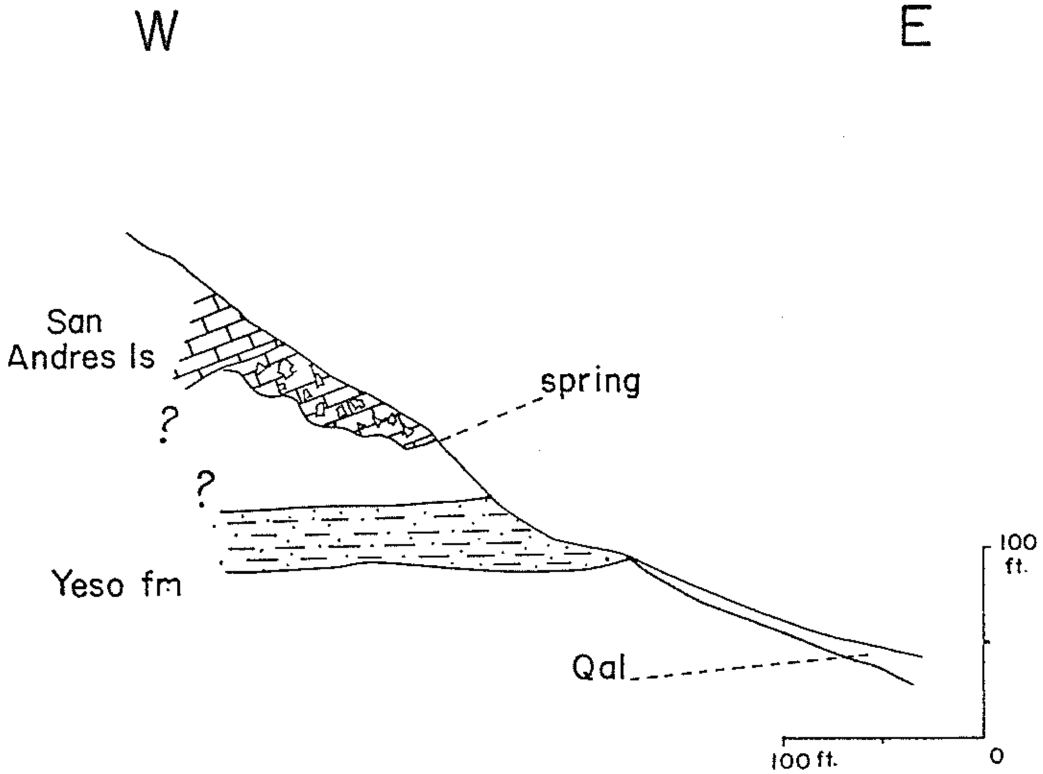


Figure A8: Cross section of spring 16.16.11.342 (Ref. #21, Paul Spring). The spring issues through a fracture in a highly brecciated limestone. Tufa and travertine are common within this brecciated zone. There is an unbrecciated limestone outcrop about 20 feet above the spring, with attitude N10°W, 15°SW. Red and yellow clays of the Yeso Fm. are found about 50 feet below the spring. Scales are approximate.

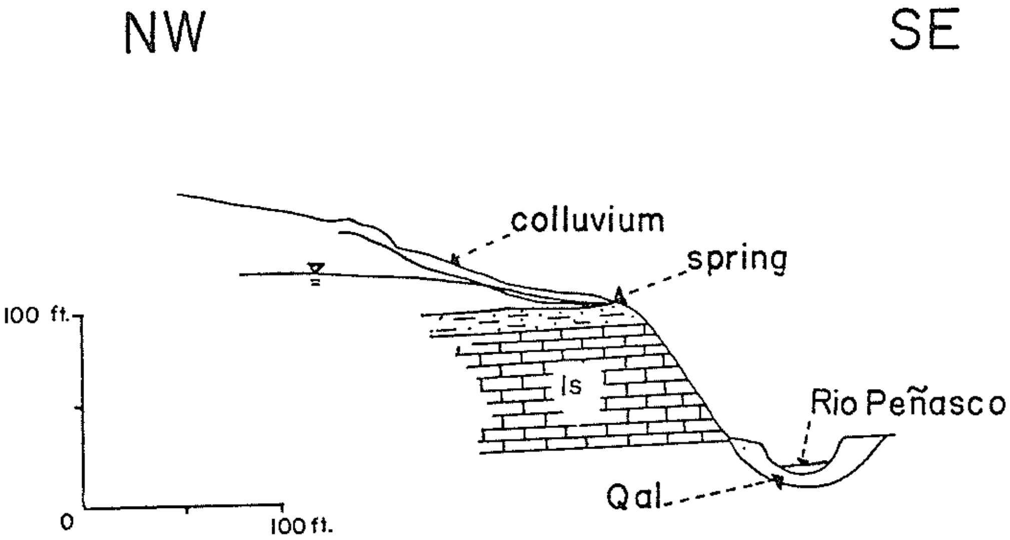


Figure A9: Cross section of spring 17.11.13.432. Gray clays of the Yeso Fm. directly underly the spring. About 1/8 mile north of the spring there is an outcrop of jumbled and collapsed Yeso rock.
Scales are approximate.

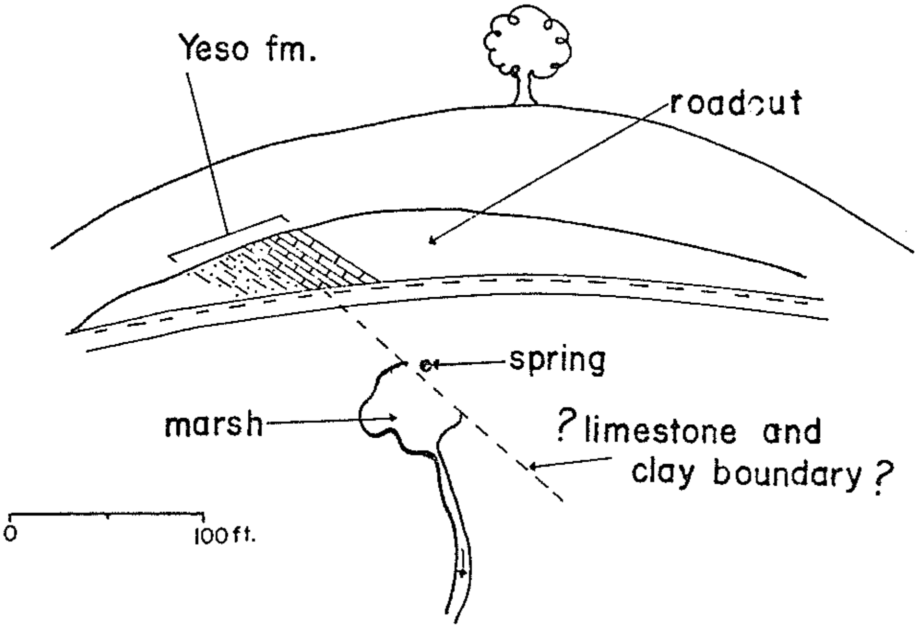


Figure A10: Aerial view of spring 17.12.8.443 looking northeast. The spring issues from colluvium; clays of the Yeso Fm. lie directly underneath the spring. The spring probably issues from the base of a limestone unit which can be seen across the road. The limestone has an attitude of N30°W, 15°SW.
Scale is approximate.

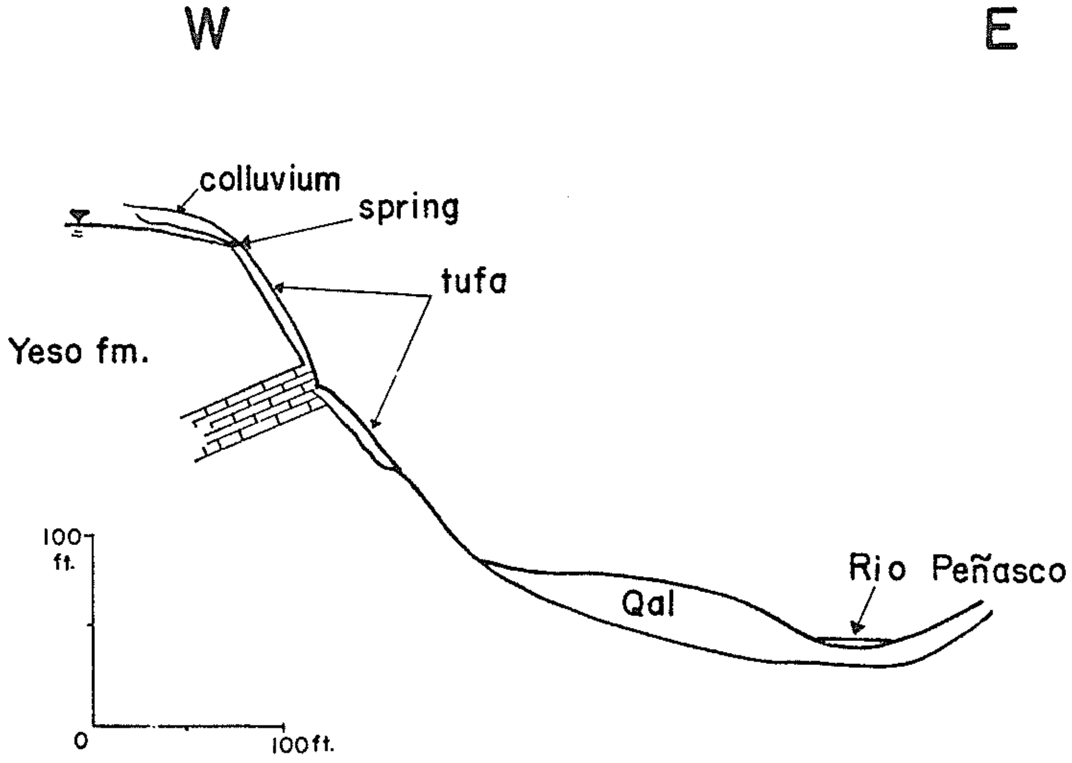


Figure A11: Cross section of spring 17.12.16.122. The spring issues from colluvium of pebble to cobble size. The spring has deposited much tufa upon the slope. There is a limestone outcrop about 80 feet below the spring with an attitude of N80°E, 15°NW. Scales are approximate.

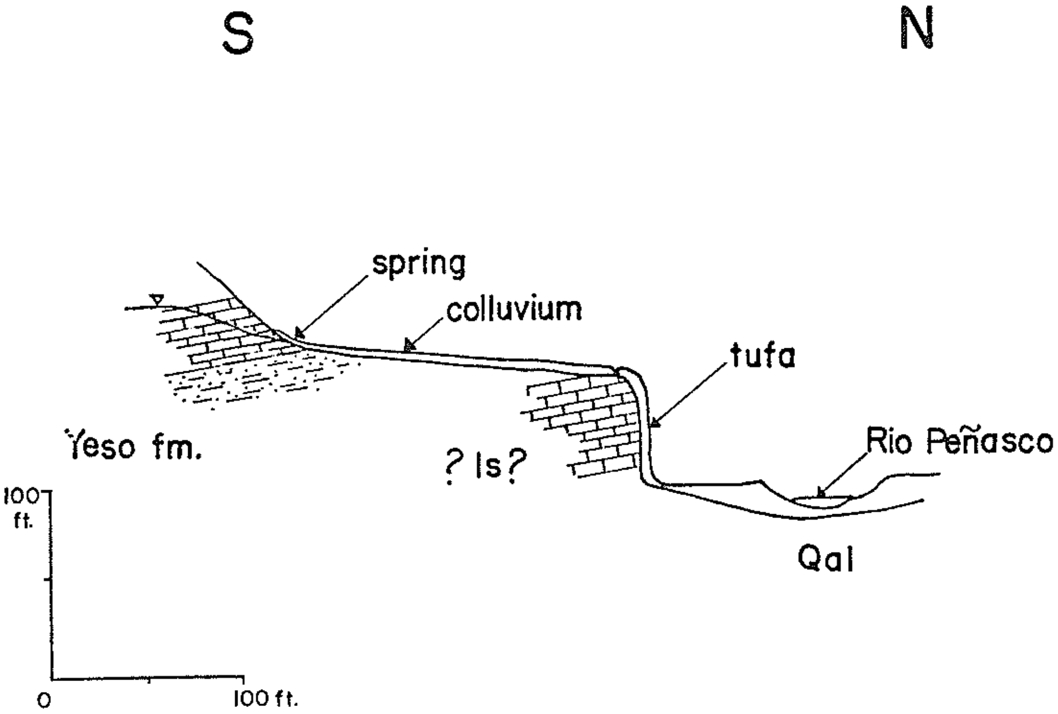


Figure A12: Cross section of spring 17.12.17.(14 and 23). (Ref. #2, Bluff Spring). The spring issues from colluvium. Some red and yellow clays and siltstones of the Yeso Fm. are locally exposed. This spring has deposited much tufa.
Scales are approximate.

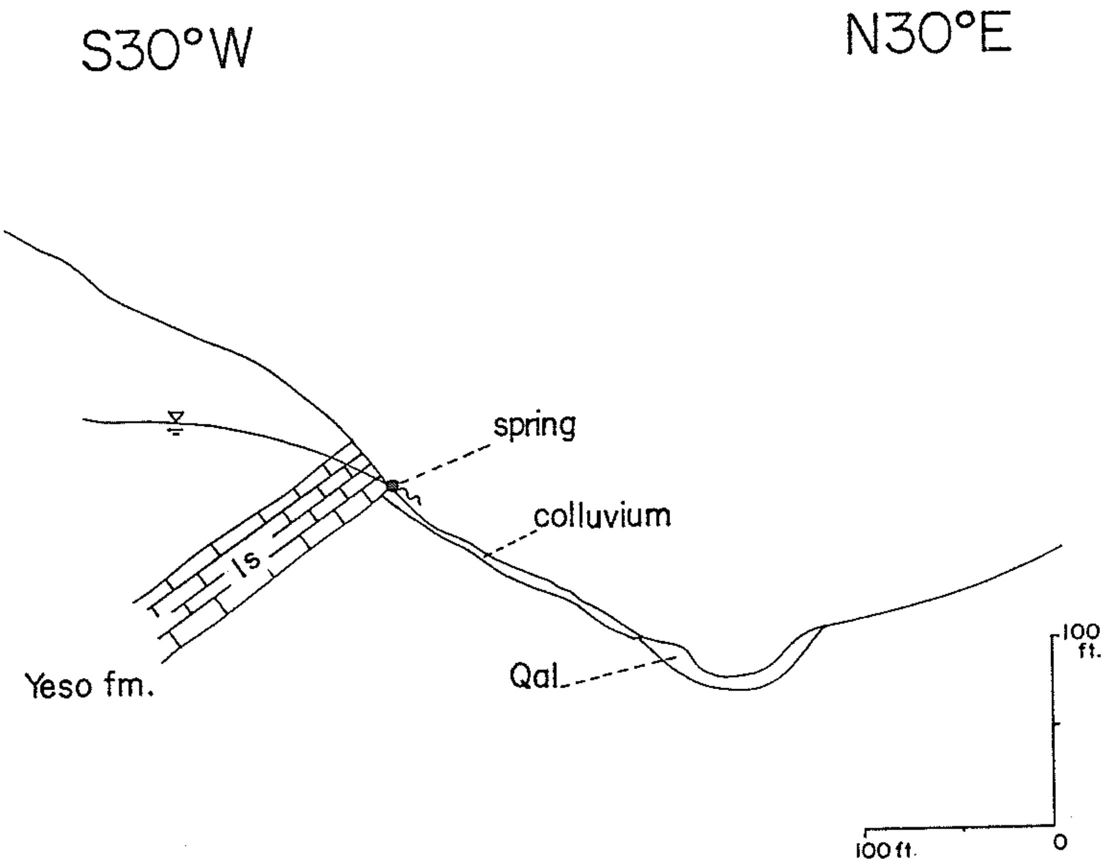


Figure A13: Cross section of spring 17.12.14.314. The spring issues from the base of a flaggy bedded limestone (5-15 cm). The attitude of this limestone is N60°W, 46°SW. This limestone unit is probably near the top of the Yeso Fm. Most of the slope below the spring is covered by colluvium.

Scales are approximate.

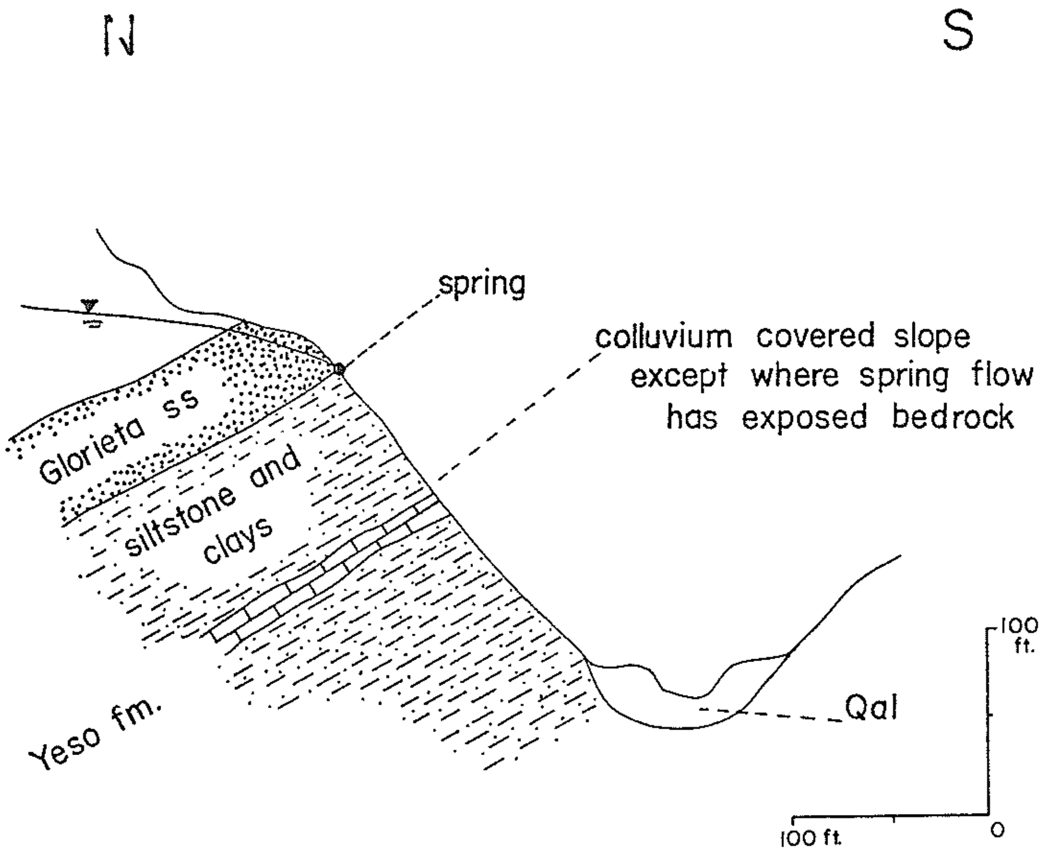


Figure A14: Cross section of spring 17.12.14.422. There are red and yellow clays of the Yeso Fm. cropping out for about the first 100 feet above the stream. There is a flaggy to massively bedded limestone above this, with attitude N86°E, 45°NE, and an apparent thickness of 6 feet. Above this, drift from the Glorieta sandstone can be found on the slope. The spring issues from a thin soil cover.

Scales are approximate.

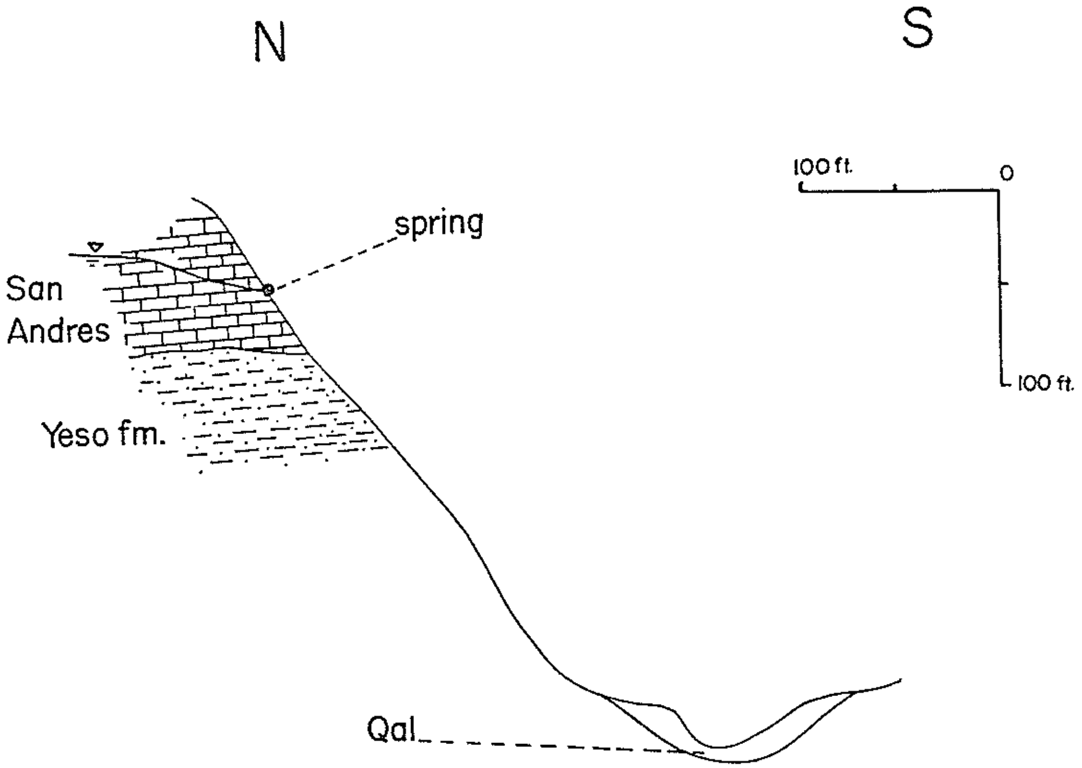


Figure A15: Cross section of spring 17.12.16.431. The spring issues about 30 feet above the base of the Rio Bonito Member of the San Andres Fm. The limestone is too massive and tufa covered to take its attitude. It appears to be flat lying.
Scales are approximate.

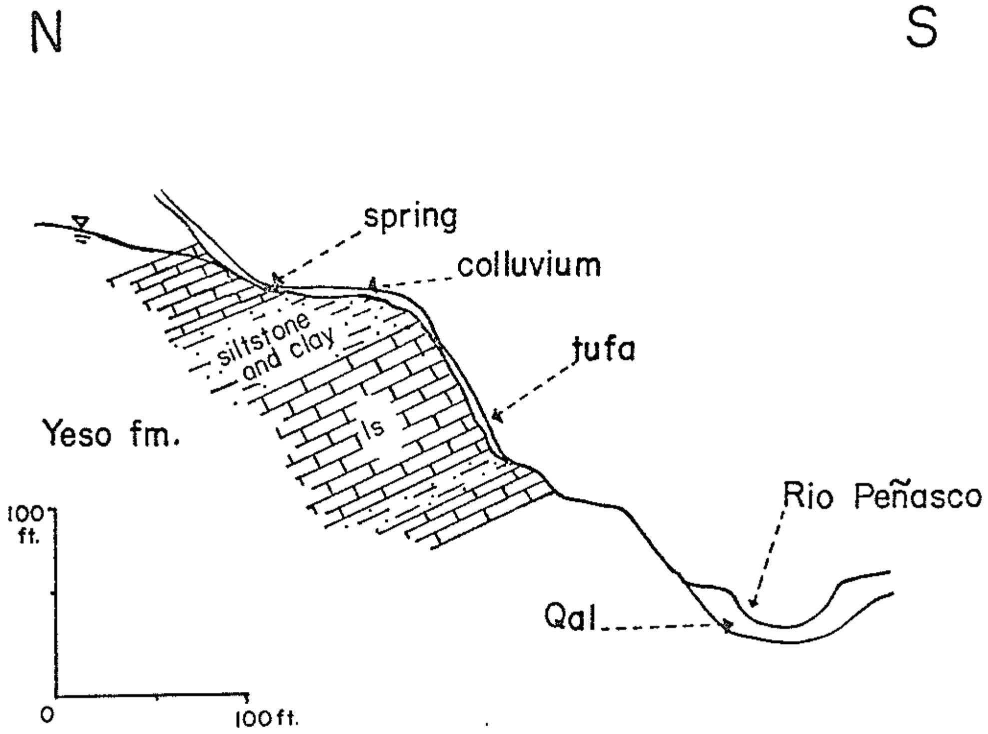
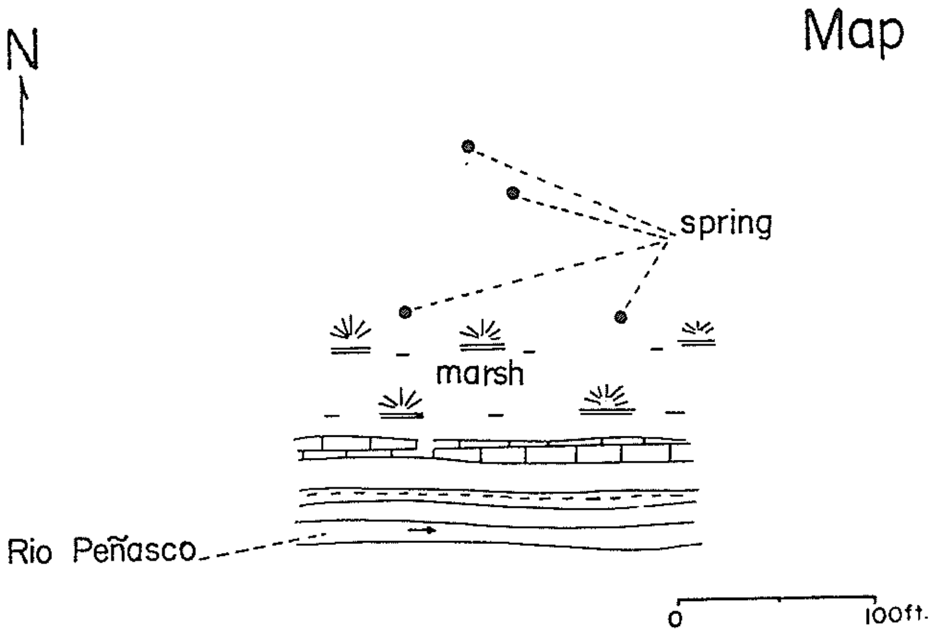


Figure A16: Cross section of spring 17.12.17.114. The spring issues from the top of a tufa-covered cliff. There are some limestone outcrops nearby which indicate the dips shown in the cross section. Scales are approximate.



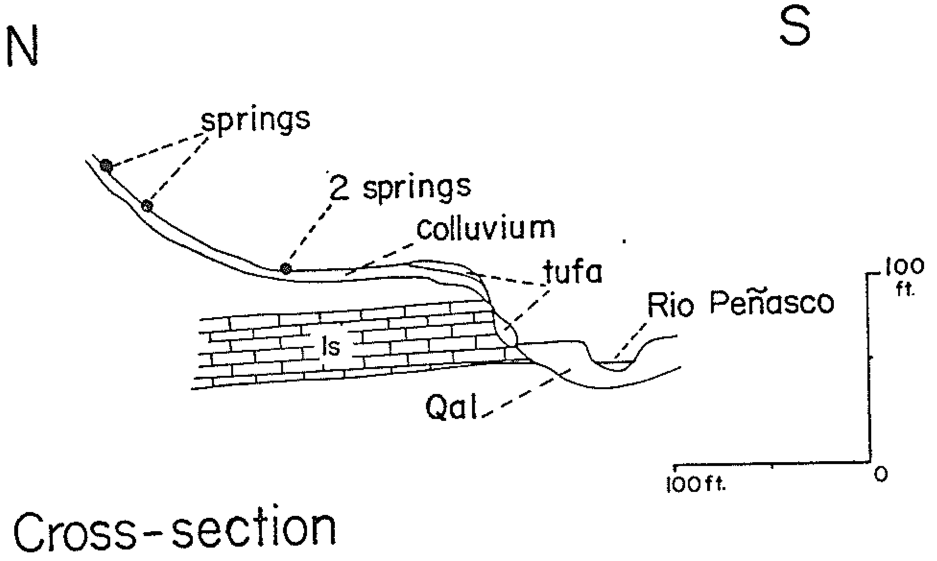


Figure A17: Cross section and map view of spring 17.12.17.121. North of the road there is an outcrop of tufa-coated flat-lying limestone. The two lower springs issue from colluvium, and flow up through 1-2 foot diameter holes. These upward flows, and the fact that there are so many issuing points of the spring would seem to indicate clays or other impervious material in the area. Scales are approximate.

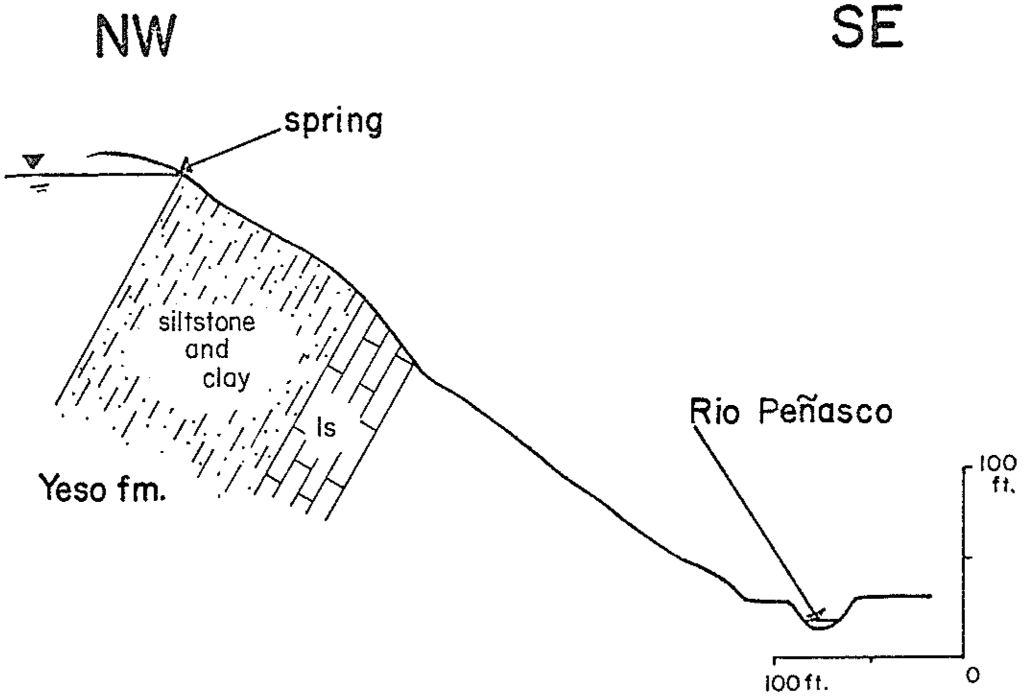


Figure A18: Cross section of spring 17.12.17.212. The spring issues from colluvium. There are some clays underneath the spring. About 100 feet down from the spring there are limestone outcrops on both sides of the rill created by the spring flow. They both have attitude N50°E, 60°NW.
Scales are approximate.

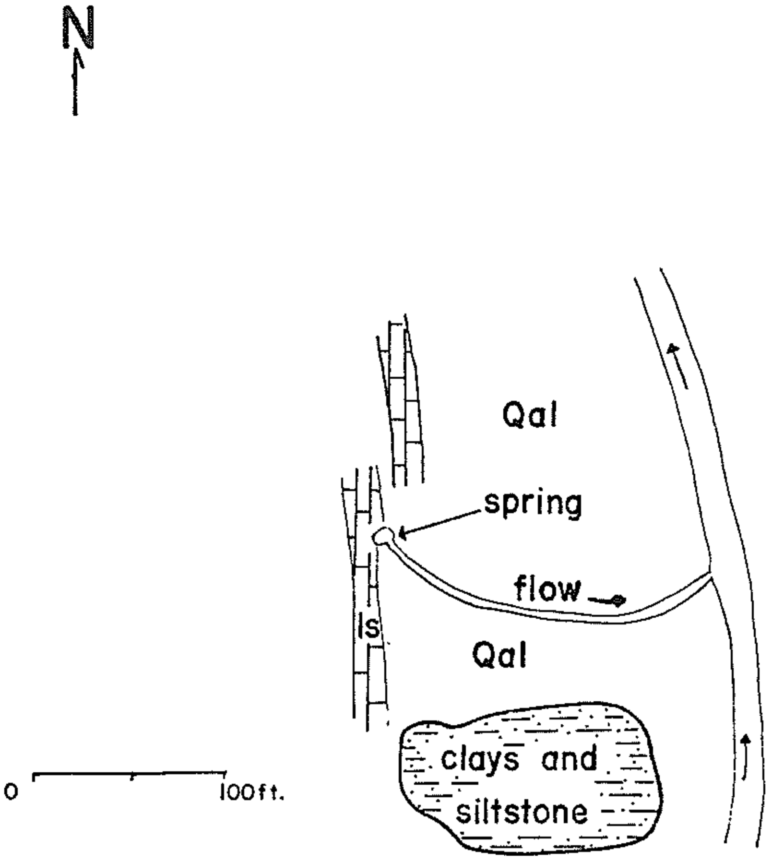


Figure A19: Map view of spring 17.12.20.444. Flat lying limestone beds crop out above the spring and to the north of the spring. Along the slope, south of the spring, red and yellow siltstone and clay of the Yeso Fm. crop out. The spring issues about 50 feet above the river bed. Scale is approximate.

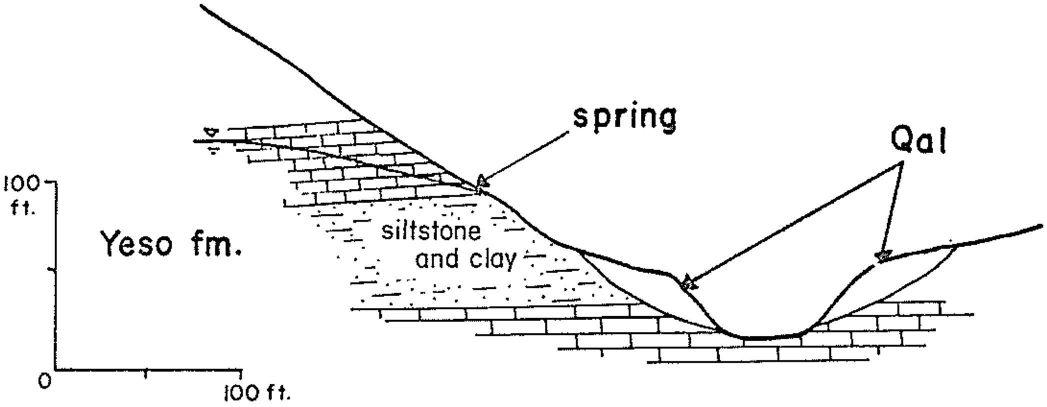


Figure A20: Cross section of spring 17.12.21.331. The spring issues through a joint in a flaggy bedded, flat lying limestone. There are silty clays underneath the spring's issuing point. The stream has incised itself through the alluvium here and limestone beds crop out at the base of the channel. These beds are also flat lying. Scales are approximate.

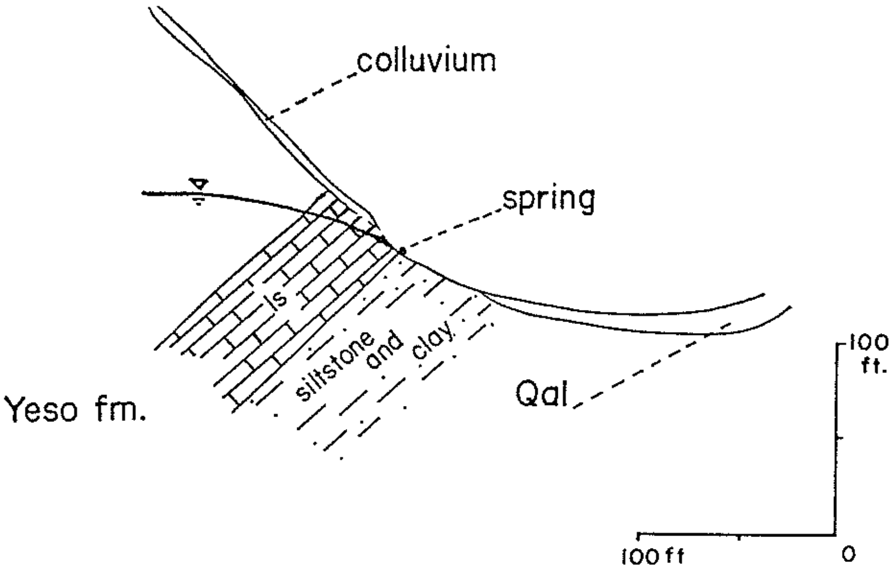
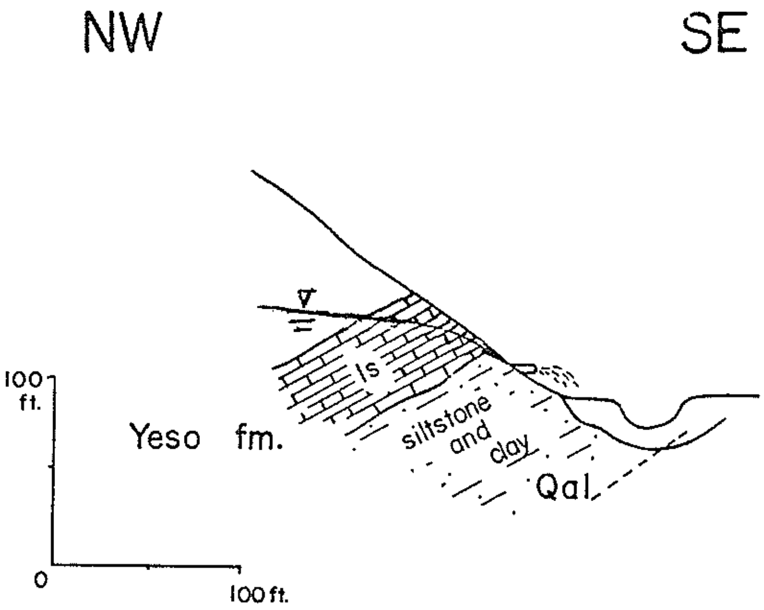


Figure A21: Cross section of spring 17.12.26.223. The spring issues from colluvium which is underlain by a limestone with attitude N85°E, 57°NW. Red clays of the Yeso Fm. underlie this limestone unit. Scales are approximate.



<u>Figure A22:</u> Cross section of spring 17.13.20.314. A 3 inch pvc pipe has been placed into a flaggy to massively bedded limestone, with attitude N26°E, 43°NW. Red clay and siltstone underlie this limestone unit.

Scales are approximate.

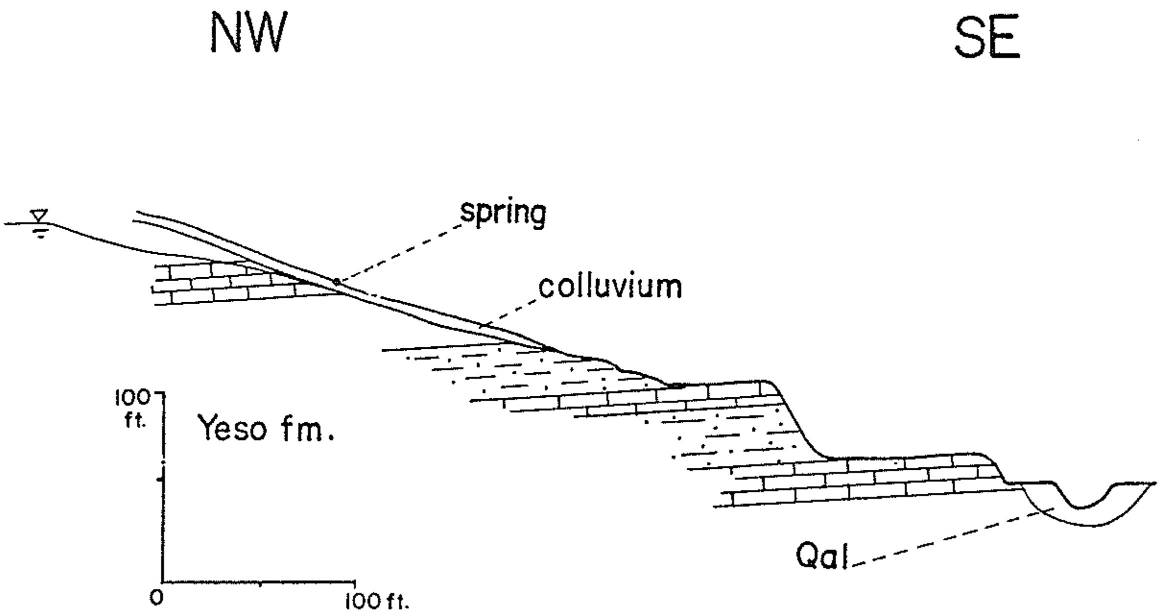


Figure A23: Cross section of spring 17.13.25.341. There is a limestone unit which is about 30 feet thick from the road up. It is flat-lying and fissile to flaggy bedded. This is overlain by a reddish brown siltstone. Over this an 8 foot section of resistant limestone forms a waterfall. There are more red and yellow clays above this. The spring issues from colluvium.

Scales are approximate.

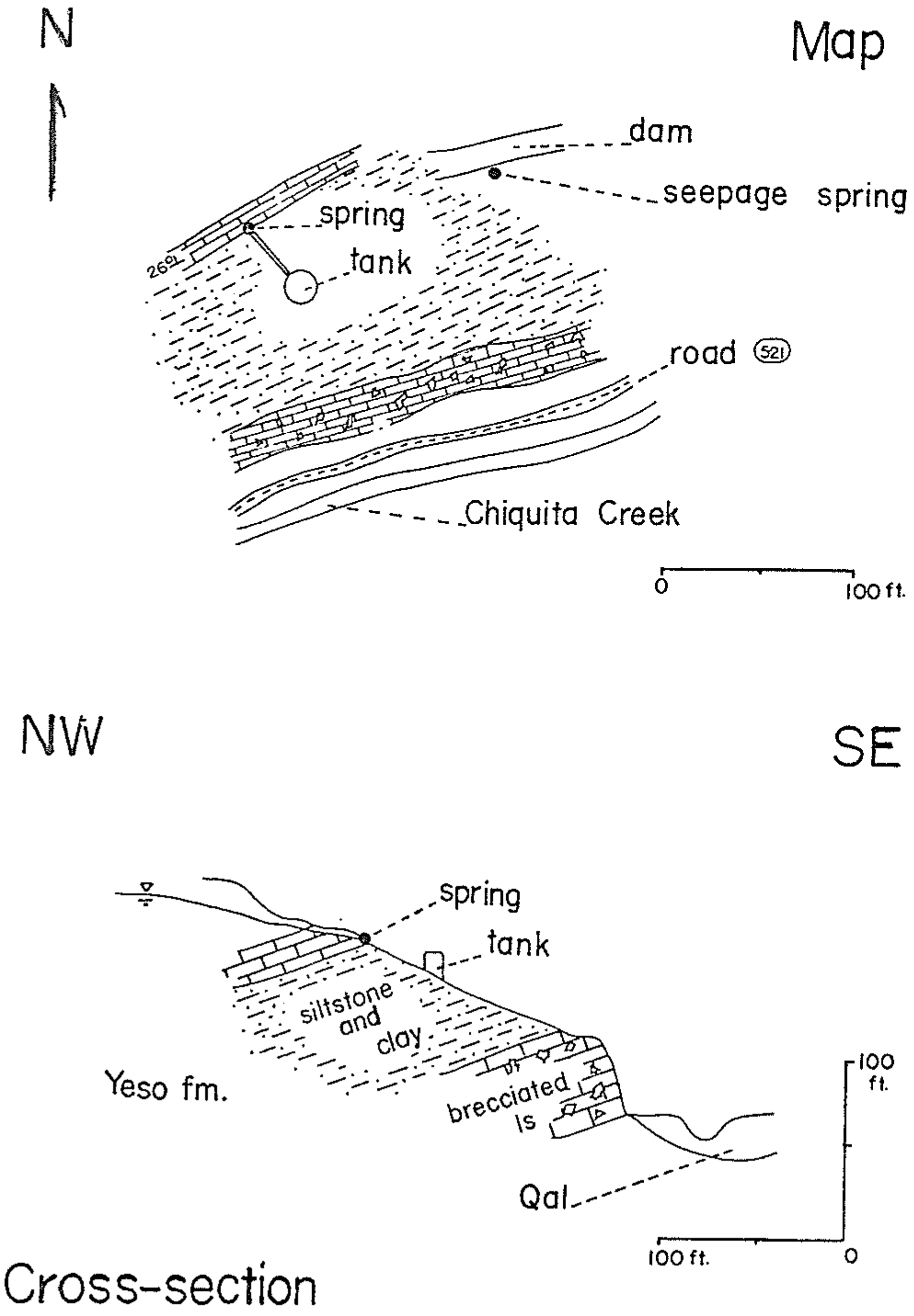


Figure A24: Cross section and map view of spring 17.13.25.441. (Ref. #4). There is an outcrop of brecciated limestone just above the road. It has an apparent thickness of about 50 feet, and has been brecciated due to collapse within the Yeso Fm. Red and yellow siltstone and clay overlies this unit. Above this, the spring issues from a joint in a limestone, with attitude N20°E, 26°NW. There is another spring here, but it is just seepage under a man-made dam.
Scales are approximate.

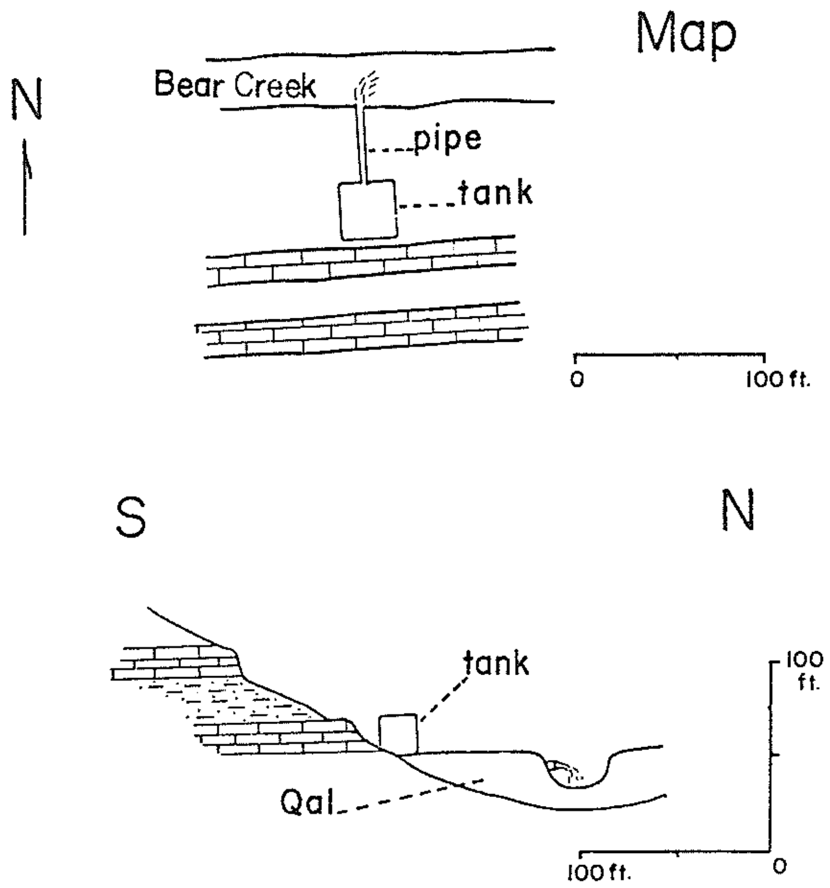


Figure A25: Cross section and map view of spring 17.14.7.243. (Weems Spring). There is an outcrop of limestone directly above the tank into which the spring issues, and a similar limestone outcrop about 50 feet above the tank. Both limestone units are flat-lying, and about 5-10 feet thick. Scales are approximate.

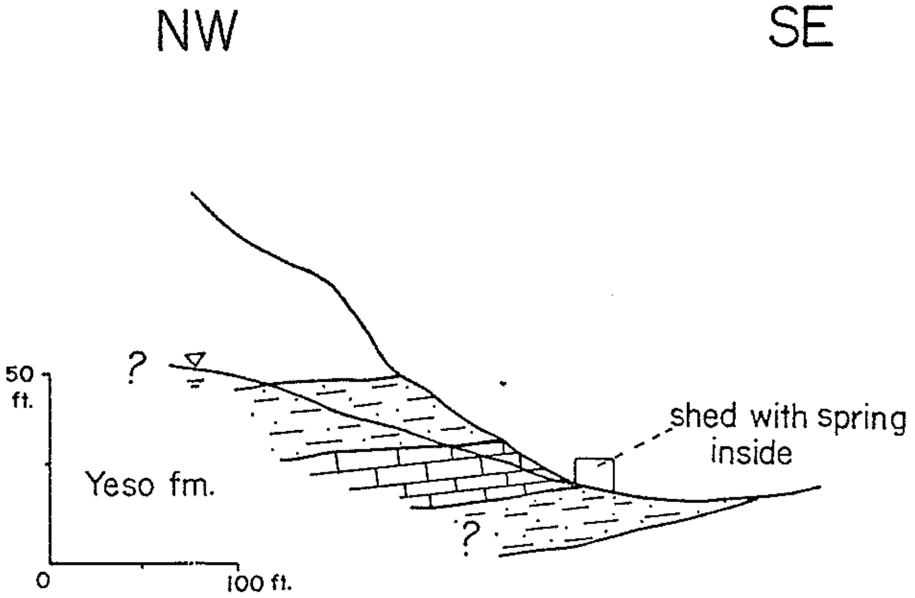


Figure A26: Cross section of spring 18.12.1.331. (Ref. #5, Boy Scout Camp Spring). The spring issues from a flat-lying flaggy to massively bedded limestone. The limestone unit is overlain by red siltstone.
Scales are approximate.

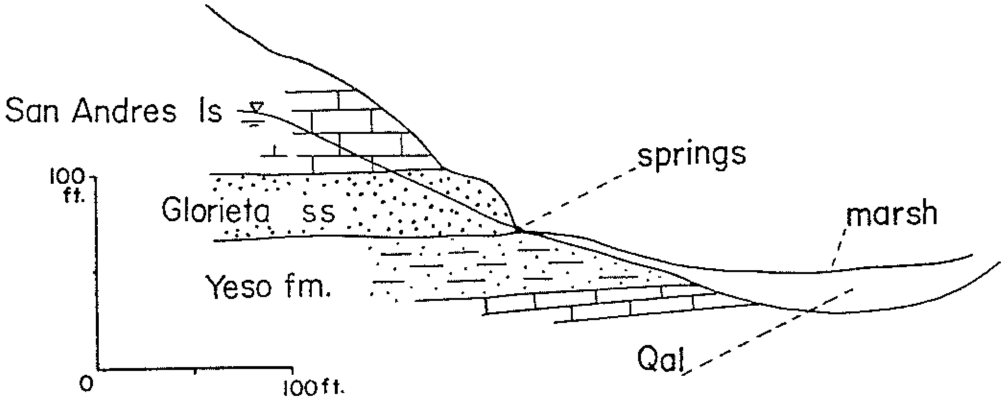


Figure A27: Cross section of spring 18.12.26.423 (Ref. #6b, Sand Springs). Also cross section of spring 18.12.26.4111 (Ref. #6a, Barrel Springs). Both of these spring groups issue from the base of a massive, well sorted, medium-grained, flat-lying sandstone (Glorieta Sandstone).

Scales are approximate.

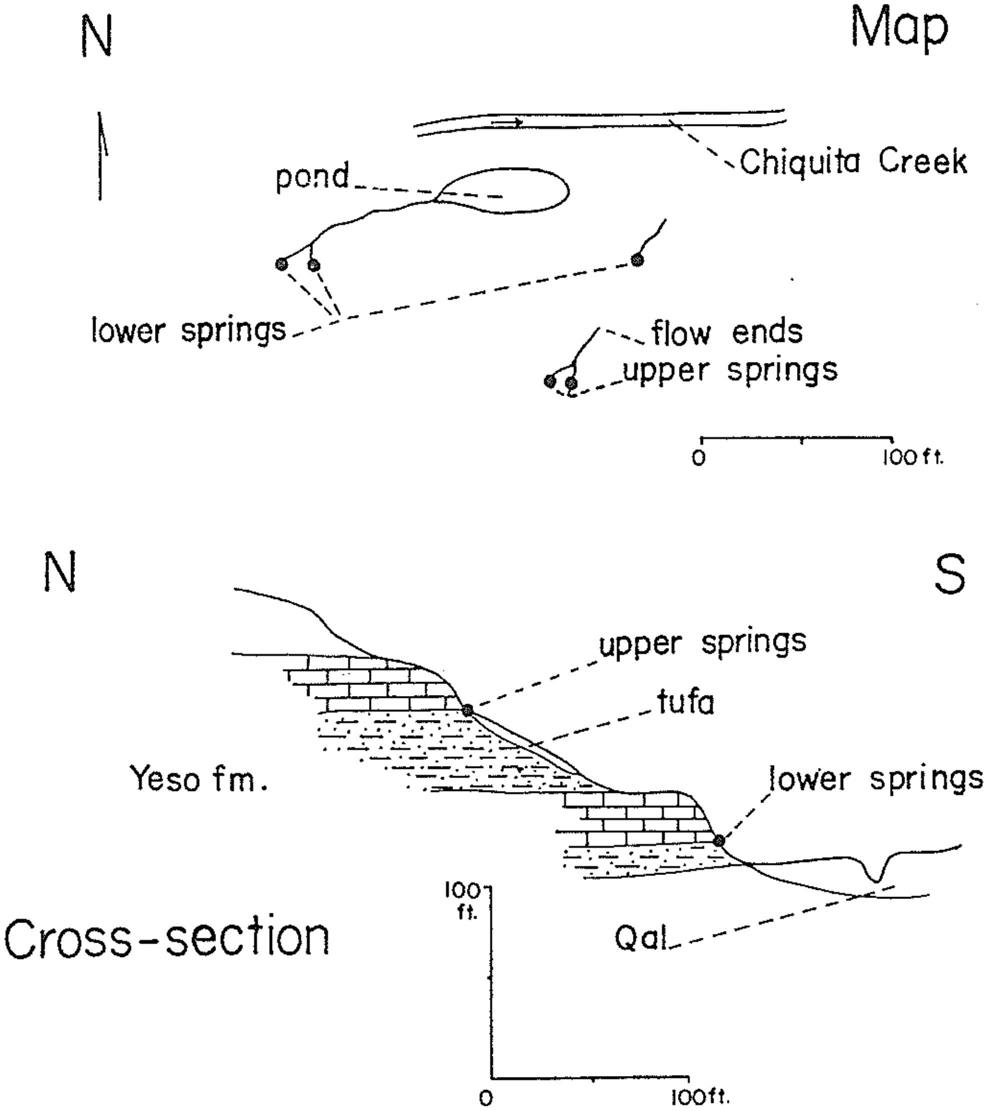


Figure A28: Cross section and map view of springs 18.13.6.422 and 18.13.6.434. The lower springs appear to issue from a flat-lying limestone. There is clay above this. The upper springs issue from a limestone unit above this clay. The lower springs could issue from colluvium and just be a reappearance of the flow from the upper springs.
Scales are approximate.

APPENDIX B

Summary of Spring Data

Explanation of Units, Abbreviations, and Symbols

Location: Refer to Figure 2. p - Section lines projected into unsurveyed area.

Altitude: Altitude in feet above mean sea level, determined by interpolation from topographic maps. The accuracy depends on the contour interval of the topographic map.

Major Drainage: The major drainage to which the spring flows is given only if at the time of measurement the spring was flowing into the major drainage directly or indirectly by way of a tributary stream.

Type of System: U = Underflow; P = Perched; R = Regional.

Flow: In gpm; ps-Parshal Flume (3"); gj-flow measured using a three gallon jug and a stop watch; est-estimate.

pH: Measured with an Orion Research Ionalyzer with a Fisher electrode.

Conductivity: Micromhos/cm at 25°C. Measured with a Hach field conductivity meter.

* : Measurement not taken in the field.

Geologic Formation: Py-Yeso Formation; Psg-Glorieta Sandstone, Psr-Rio Bonito Member, Psf-Fourmile Draw Member, all of the San Andres Formation; Tkc-Cub Mountain Formation; Ti-Tertiary igneous rocks; Qcl-Quarternary colluvium; Qal-Quarternary alluvium. When two formations are listed, the first is thought to be underlain by the second. A-additional geologic information in Appendix A. Also: A3 means Appendix A, Figure 3, etc.

Temp: Temperature in degrees centigrade.

Remarks: C-Chemical analysis is given in Appendix C; T-tritium analysis is given in Appendix D; Spring names appear in quotation marks.

SUMMARY OF SPRING DATA

Location	Sample Date	Altitude	Major Drainage	Type of System	Flow	pH	Conductivity	Geologic Formation	Temp	Remarks
7.16.7.434	8-10-77	5910	None	R ?	35 est	7.25*	800*	Qal,Psf,A l	21	This spring flows into a large pond from the bottom of the pond. Temperature is that of the pond. "Macho Spring #1", C,T.
7.16.7.431	8-10-77	5920	None	R ?	12 gj	7.2*	760*	Psf,A l	16	"Macho Spring #2". C,T.
7.16.22.443	8-10-77	6080	None	R ?	21 est	7.25*	500*	Qal,Psr, A	16	"Kyle Harrison Spring"; The flow bubbles up through the sand of a small pond. C,T.
9.11.34.41	8-9-77	8025	Bonito	U	10 est	6.6*	590*	Qal	13	
9.12.35.34	8-9-77	7840	None	U	54 gj	6.7*	1290*	Qal, Ti	28	Flow and temperature were measured about 1/2 mile from the spring outlet.
9.13.32.223	8-10-77	7230	None	U	3/4 gj	6.8*	1670*	Qal,A 2	17	C,T. "Lamay Spring".
9.13.33.21	8-10-77	7080	None	U	1 est	7.0*	1580*	Qal,A	15	
9.16.34.141	8-11-77	5760	Bonito	R	15-20 est	7.12	870	Py, A 3	18	"Hulbert Spring".
10.11.2.341	8-9-77	7650	Bonito	?	1 est	6.0*	1000*	Ti	12	This spring issues from a prospect pit in the Bonito Lake Stock. The water was a milky yellow color.
10.11.4.232 p	8-9-77		Bonito		29.2 ps	6.8*	395*		16	These measurements represent stream flow in Turkey Canyon.

(continued)

SUMMARY OF SPRING DATA (continued)

Location	Sample Date	Altitude	Major Drainage	Type of System	Flow	pH	Conductivity	Geologic Formation	Temp	Remarks
10.12.12.144	8-9-77	7500	Bonito	P	32 ps	6.92*	180*	Qcl, Ti	11	This spring flows into a large pond which is used for recreation. C,T.
10.12.24.431 p	8-9-77	7990	None	P	0.4 gj	6.3*	275*	Ti	14	C,T. "Little Creek Spring".
10.12.25.14 p	8-9-77	7990	Ruidoso	U	54 gj	6.1*	180*	Qal,T	15	This flow represents the head waters of Eagle Creek.
10.13.8.241	8-10-77	7200	None	U	4 est	6.75*	955*	Ti, A	14	
10.16.12.411	8-11-77	5550	Bonito	P		7.2	1060	Qcl,Py	18	"Emil Fritz Spring". This spring is used for the domestic supply of the Phillips house.
10.16.26.441	8-23-55 6-2-77	5360	Ruidoso	U?	100 200 est	7.7*	2100*	Qal, Py,A	15 9	(Mourant, 1963) "Peter Hurd Spring". This spring is used as the domestic supply for famous New Mexico artist Peter Hurd. C.
10.17.29.414	6-6-77 8-11-77	5360	Bonito	P	332	7.14*	735*	Psr,A 4	17 18	Unpublished data, U.S.G.S. "Colonel Fritz Spring". This spring is used for a trout farm and for a domestic supply for A.T. (Bert) Pfingsten. C,T.
11.13.8.411	8-2-77	7250	None	U	2 est	7.64*	780*	Qal,T	18	
11.13.14.312	8-2-77	6805	None	U		7.0*		Qal,A	12	"Bogg Spring"; C,T.

(continued)

SUMMARY OF SPRING DATA (continued)

Location	Sample Date	Altitude	Major Drainage	Type of System	Flow	pH	Conductivity	Geologic Formation	Temp	Remarks
11.14.14.2(1& 3)	8-12-77	6125	Ruidoso	U	415 est	7.1*	1215*	Qal, Py	15	"Seeping Springs". The seven springs lumped together for these measurements all flow upward into ponds which are used for recreation. C,T.
11.14.28.312	4-27-55 8-2-77	660	Ruidoso	P	246 220 est	7.0*	1395*	Py,A 5	12 14	(Mourant, 1963, Hale Spring). "Agua Fria Spring". Half of this spring provides the domestic supply for Ruidoso Downs and the other half is owned by Bruce Griffith. C,T.
11.14.32.233	8-2-77	6715	None	P	2 est	7.1*	1070*	Py,A	13	"Baston Spring"
16.12.3.144	6-3-77	8400	None	U	60 est	7.7	500	Qal	3	Two springs were combined for these measurements. C,T. Supply for village of Cloudcroft. Flow estimated by Dinwiddle (1963).
16.12.19.244	5-26-77	8825	None	U	7 est	8.0	425	Qal	6	This spring is the head water spring of Russia Canyon.
16.12.27.12	6-26-77		None		52.5ps	8.1	400	Qal	6	These measurements represent stream flow of Lucas Canyon at its intersection with Russia Canyon.
16.13.36.321	6-2-77	7450	None	P	15 gj	7.49	560	Qal	5	"Goat Springs".
16.14.31.113	6-3-77	7500	None	P	9 gj	7.3	470	Qal,A 6	4.5	"Mickison Spring". C,T.

(continued)

SUMMARY OF SPRING DATA (continued)

Location	Sample Date	Altitude	Major Drainage	Type of System	Flow	pH	Conductivity	Geologic Formation	Temp	Remarks
16.14.31.111	6-3-77	7450	None	U	4 est	7.75	510	Qal,A 6	12	"Mickison Spring #2".
16.14.32.444	6-3-77	7050	None	P	4 est	7.2	560	Qal,Psr	8	"Lighting Springs". Two springs combined for these measurements.
16.14.26.343	6-3-77	6520	Penasco	U	1000 est	7.12	760	Qal,Py	11	"Posey Spring". This spring forms a large pond in the Penasco Valley bottom. C,T.
16.16.2.323	6-2-77	5920	Penasco	P	15 gj	7.4	380	Psr,A 7	10	"Cleve's Spring". The flow from this spring used to issue out of a pipe which is about one foot higher and 12 feet to the south-west of the present spring location. At that time the water was used by a local school house which is now abandoned. It is possible that increased head at the pipe caused the spring to issue from the lower fracture which was filled with breccia. C,T.
16.16.11.342	6-2-77	7560	Penasco	P	50.35	7.5	380	Psr,A 8	9	"Paul Spring". The flow is being monitored with a 22° v-notch weir combined with a Stevens F-type recorder. The water from this spring is used as a domestic supply for the Charles Mulcock family. C,T.

(continued)

SUMMARY OF SPRING DATA (continued)

Location	Sample Date	Altitude	Major Drainage	Type of System	Flow	pH	Conductivity	Geologic Formation	Temp	Remarks
17.11.11.23	5-26-77 8-18-77	7950	Penasco	U	147.5 ps 167.1 ps	8.00	475	Qal,Py	5 11	This spring is the head water spring for the Rio Penasco. This spring issues throughout a large marshy area and the measurements were made at the intersection of forest roads 164 and 64. C,T.
17.11.13.432	5-25-77		Penasco	P	15.0 est	7.80	450	Py,A 9	0	These measurements represent two springs which are within 10 meters of each other.
17.11.24	5-26-77		Penasco		83.4 ps	8.10	360	Py,A	4	These measurements represent streamflow in Water Canyon 0.7 miles above the intersection of Penasco and Water Canyons
17.12.8.443	5-25-77	8250	Penasco	P	63.2 ps	7.50	500	Py,A 10	1	
17.12.16.122	5-24-77	8175	Penasco	P	5.0 est	7.70	470	Py,A 11	1	
17.12.17.14 & 23	5-24-77 8-18-77	8225	Penasco	P	175.0 ps 167.6 ps	7.20 6.80*	490 495*	Py,A 12	0 6.7	Two springs within 10 yards of each other were combined in these measurements. "Bluff Springs". C,T.
17.12.14.422	5-24-77	8175	Penasco	P	.5 est	7.15	490	Psg,A 14		
17.12.14.314	5-24-77	8200	Penasco	P	10.0 est	7.10	460	Py,A 13	3	
17.12.16.431	5-24-77	8700	Penasco	P	2.0 est	7.68	455	Psr,A 15	1	C,T.

(continued)

SUMMARY OF SPRING DATA (continued)

Location	Sample Date	Altitude	Major Drainage	Type of System	Flow	pH	Conductivity	Geologic Formation	Temp	Remarks
17.12.17.114	5-25-77	8250	Penasco	P	10.0 est	7.35	500	Py,A 16	1	
17.12.17.212	5-25-77	8225	Penasco	P	12.0 gj	7.30	520	Py,A 18	1	
17.12.17.121	5-25-77	8250	Penasco	P	25.0 est	7.30	470	Qcl,A 17	0	Four springs which issue into a marshy area were combined in these measurements. The lower western spring flows upward through a circular hole in the colluvium.
17.12.20.444	5-24-77	8475	Penasco	P	93.6 ps	7.12	470	Qal,A 19	0	
17.12.21.331	5-24-77	8525	Penasco	P	12.0 est	7.61	500	Py,A 20	0	
17.12.26.223	5-27-77	8525	None	P	9.5 gj	7.1	540	Qcl,A 21	1	There is a sign on the forest road adjacent to this spring, "Masterson Springs", but the U.S.G.S. topographic map shows "Masterson Springs" to be about 1/2 mile further up Hay Canyon.
17.12.26.3 & 4	5-27-77	8625	None	U	32.0 ps	7.8	380	Qal,A	1	"Masterson Springs". Eight springs were combined in these measurements.
17.12.29.223	5-24-77				147.5 ps	8.00	450		6	These measurements represent stream flow in Wills Canyon just above the junction of Wills and Hubbell Canyons.
17.12.29.223	5-24-77					8.05	320		9	Idem below the junction.

(continued)

SUMMARY OF SPRING DATA (continued)

Location	Sample Date	Altitude	Major Drainage	Type of System	Flow	pH	Conductivity	Geologic Formation	Temp	Remarks
17.13.11.3 & 4	5-26-77	7550	None	U	164.7 ps	7.8	440	Qal,A	10	All four springs of upper Bear Canyon were combined in these measurements which were taken approximately 1/4 mile east of the springs.
17.13.20.314	5-27-77	8025	None	P	16 gj	7.3	520	Py,A 22	2	At least two springs contribute to the flow.
17.13.25.441	5-26-77	7400	None	P	15 est	7.4	510	Py,A 24	5	Two springs were combined for these measurements. C,T.
17.13.25.341	5-27-77	7400	None	P	10 est	7.05	550	Py,A 23	4	Two springs contribute to the estimated flow.
17.13.31.122	5-27-77	8100	None	P	2-3 est	7.3	560	Qal,A	2	Two springs which feed a small stock and trout pond were combined for these measurements.
17.13.32.144	5-27-77	7850	None	U	3-4 est	7.5	480	Qal,A	5	"Cridebring Spring".
17.14.7.243	5-26-77 8-18-77	6950	None	P	1 gj 2.4 gj	7.0	525	Py,A 25	4 14.4	"Weems Spring".
18.12.1.331	5-27-77	8475	None	P?	90 gj	7.1	450	Py,A 26	2	This spring supplies water to a boy scout camp. "Boy Scout Camp Spring". C,T.
18.12.11.122	5-27-77	8650	None	P	2.6 gj	7.0	480	Qal	1	
18.12.26.423	5-27-77	8550	None	P	38 ps	7.0	530	Psg,A 27	2	Two "Sand Springs" combined in these measurements. The easternmost spring contributes about 9/10 of the flow.

(continued)

SUMMARY OF SPRING DATA (continued)

Location	Sample Date	Altitude	Major Drainage	Type of System	Flow	pH	Conductivity	Geologic Formation	Temp	Remarks
18.12.26.411	5-27-77 8-18-77	8570	None	P	295 ps ≈450 ps	6.9 6.5	550 480	Psg,A 27	2 6.7	"Barrel Springs". C,T. Flow was slightly higher than the capacity of the Parshall flume.
18.13.6.422	5-27-77	8100	None	P	5 est	7.0	505	Py,A 28	2	Three springs were combined in these measurements.
18.13.6.434	5-27-77	8250	None	P	9 est	7.3	510	Py,A 28	2	Two springs were combined in these measurements.
18.13.21.221	5-27-77	7977	None	P	33.4 ps	7.1	600	Qc1,A	3	"Jeffers Spring".

APPENDIX C

Chemical Analyses of Spring Water

CHEMICAL ANALYSES OF SPRING WATER

Location	Sample Date	pH	Conductivity	TDS Calc.	HCO_3^-		Cl^-		$SO_4^=$		Na^+		K^+		Mg^{++}		Ca^{++}		Cat./An. Balance % error
					ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	
7.16.7.431	8-10-77	7.6	1020	642	129	2.08	28.3	.80	366	7.61	15.8	.69	1.5	.04	37.0	3.04	130	6.49	2.2
7.16.7.434	8-10-77	7.9	1140	714	137	2.24	30.2	.85	411	8.55	15.9	.69	1.8	.05	42.0	3.45	139	6.94	3.6
7.16.22.443	8-10-77	7.9	640	338	173	2.91	16.6	.47	134	2.80	13.5	.59	2.3	.06	15.9	1.31	67.0	3.34	15.3
9.13.32.223	8-10-77	7.3	2200	1391	234	3.84	133	4.31	711	14.81	56.0	2.43	2.3	.06	64.0	5.26	288	14.37	3.9
10.12.12.144	8-9-77	7.6	280	135	68	1.12	10.2	.29	47	.97	5.1	.22	1.3	.03	4.5	.37	33.2	66	4.3
10.12.24.431	8-9-77	7.6	370	241	85	1.40	10.1	.28	116	2.40	7.8	.34	1.0	.02	19.7	1.62	43.4	2.17	1.7
10.16.26.441	8-23-55[5]	7.2	1820		274		67		776								1080[2]		
10.16.26.44	5-16-77	7.7	2100	1121	229	3.75	51.2	1.44	482	10.03	37.1	1.61	2.0	.05	30.6	2.54	224	11.17	.1
10.17.29.414	5-23-55[5]	8.2	861		253		24		235								450[2]		
11.13.14.312	8-12-77	7.6	2250	1491	339	5.56	140	3.95	740	15.40	61.3	2.68	9.2	.23	78.0	6.41	293	14.62	3.9
11.14.14.2 1 & 3	8-12-77	7.7	1650	1057	178	3.04	68.8	1.94	596	12.41	27.4	1.19	2.8	.07	59.0	4.85	214	10.70	3.4
11.14.28.312	4-27-55[4]	7.1	1570		266		52		649				11[3]		84		240		
DO.	9-12-61[4]	7.6	1560		257		55		665										
DO.	1973[6]	7.5	1165.5		297.4		74.5		302		55.6		1.56		52.3		149.2		
11.14.28.312	8-12-77	7.7	1800	1218	217	3.56	69.5	1.96	698	14.53	26.4	1.15	2.6	.07	75.0	6.17	238	11.88	4.0
16.12.3.144	1973[6]	8.0	621	375[1]	311.7		10.4		63.4		10		.48		48.1		38.3		
16.12.3.144	3-29-56[4]	7.7	622		341		11		52										

(continued)

CHEMICAL ANALYSES OF SPRING WATER (continued)

Location	Sample Date	pH	Conduc-tivity	TDS Calc.	HCO_3^- ppm	HCO_3^- epm	Cl^- ppm	Cl^- epm	$SO_4^=$ ppm	$SO_4^=$ epm	Na^+ ppm	Na^+ epm	K^+ ppm	K^+ epm	Mg^{++} ppm	Mg^{++} epm	Ca^{++} ppm	Ca^{++} epm	Cat./An. Balance % error
16.14.26.343	6- 3-77	7.8	570	501	157	2.60	30.0	.85	242	5.03	27.0	1.17	3.5	.09	36.5	3.00	83.9	4.19	.3
16.14.31.113	6- 3-77	7.7	420	285	190	3.12	13.0	.37	83	1.73	10.5	.46	.5	.01	14.3	1.18	68.5	3.42	2.9
16.16.2.323	6- 3-77	7.9	420	217	141	2.32	14.0	.39	62	1.29	8.6	.37	.7	.02	14.6	1.2	45.9	2.29	3.0
17.11.11.23	5- 6-77	7.9	420	227	198	3.24	5.0	.14	45	.94	8.0	.35	.7	.02	11.3	.93	57.9	2.89	3.1
17.12.17.14 & 23	5-24-77	8.0	350	200	168	2.76	4.0	.11	44	.92	8.3	.36	.5	.01	15.1	1.24	44.4	2.21	.8
17.12.16.431	5-24-77	8.3	320	177	122	2.0	6.0	.17	51	1.06	9.4	.41	.5	.01	12.0	.95	36.7	1.83	.9
17.13.25.441	5-26-77	7.8	330	202	156	2.56	7.0	.20	45	.94	7.6	.33	.7	.02	11.5	.94	52.1	2.6	5.0
18.12.1.331	5-26-77	7.8	270	189	185	3.04	5.0	.14	24	.50	3.5	.15	.7	.02	11.3	.93	52.0	2.59	.3
18.12.26.411	5-26-77	7.9	310	165	157	2.57	6.0	.17	24	.50	3.5	.15	.5	.01	10.4	.85	41.9	2.09	4.4

[1] Measured [2] $Ca^{++} + Mg^{++}$ [3] $Na^+ + K^+$ [4] Dinwiddie (1963) [5] Mourant (1963) [6] Garcia (1974)