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# GEOHYDROLOGIC AND ENVIRONMENTAL INDICATORS OF A DEWATERED WETLAND: OJO DEL GALLO, SAN RAFAEL, NEW MEXICO

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**Abstract**—A fault-controlled spring, the Ojo del Gallo, issues from the Permian San Andres Limestone on the eastern toe of the Zuni Mountains, immediately north of the village of San Rafael, New Mexico. The spring is a surface expression of the ground-water flow system that provides the water supply for the communities of Bluewater, Milan and Grants and supported the uranium industry during its heyday. As a result of agricultural development in the thirties and forties, and the uranium industry in the fifties, sixties and seventies, the spring's discharge declined from a virgin flow condition of approximately 7 cubic feet per second to zero discharge in 1953. A resurgence of the spring occurred in the winter of 1980–81 with the bust of the agricultural and uranium booms. The 27-year period of no discharge allowed eolian deflation to alter the surface expression of the related spring deposits so much that the historical connection of the Ojo del Gallo to the Rio San Jose was questioned. A combination of geohydrologic and environmental indicators were evaluated and found to support conclusively the continuity of the spring deposits from the Ojo del Gallo to the Rio San Jose.

## INTRODUCTION

Ground-water development, originally for agricultural purposes followed by the uranium industry, reduced the pressure head on the San Andres Limestone to a point below the ground surface elevation of Ojo del Gallo (1966 m) by the year 1953. The spring had historically provided water for local agricultural efforts, and had sustained a wetland environment. The collapse of the uranium industry in the seventies resulted in a rapid decline in the ground-water production from the carbonate aquifer, allowing the spring to reissue in the winter of 1980–81. The coincidence of a new period of water right transfers, preparations to quantify Indian water right claims and the resurgence of ground-water dischage at Ojo del Gallo after 27 years of no flow, raised the question of a hydrologic connection between the spring and the Rio San Jose. This paper presents the physical and environmental information gathered which confirms a connection between the two.

## LOCATION

Ojo del Gallo is located approximately 5.6 km south of Grants, New Mexico in sec. 3, T10N, R10W (Fig. 1). Related spring deposits occur in secs. 2, 3, 10, 11 and 12, T10N, R10W. A shallow channel passing through secs. 7 and 8, T10N, R9W joins the spring deposits and the Rio San Jose.

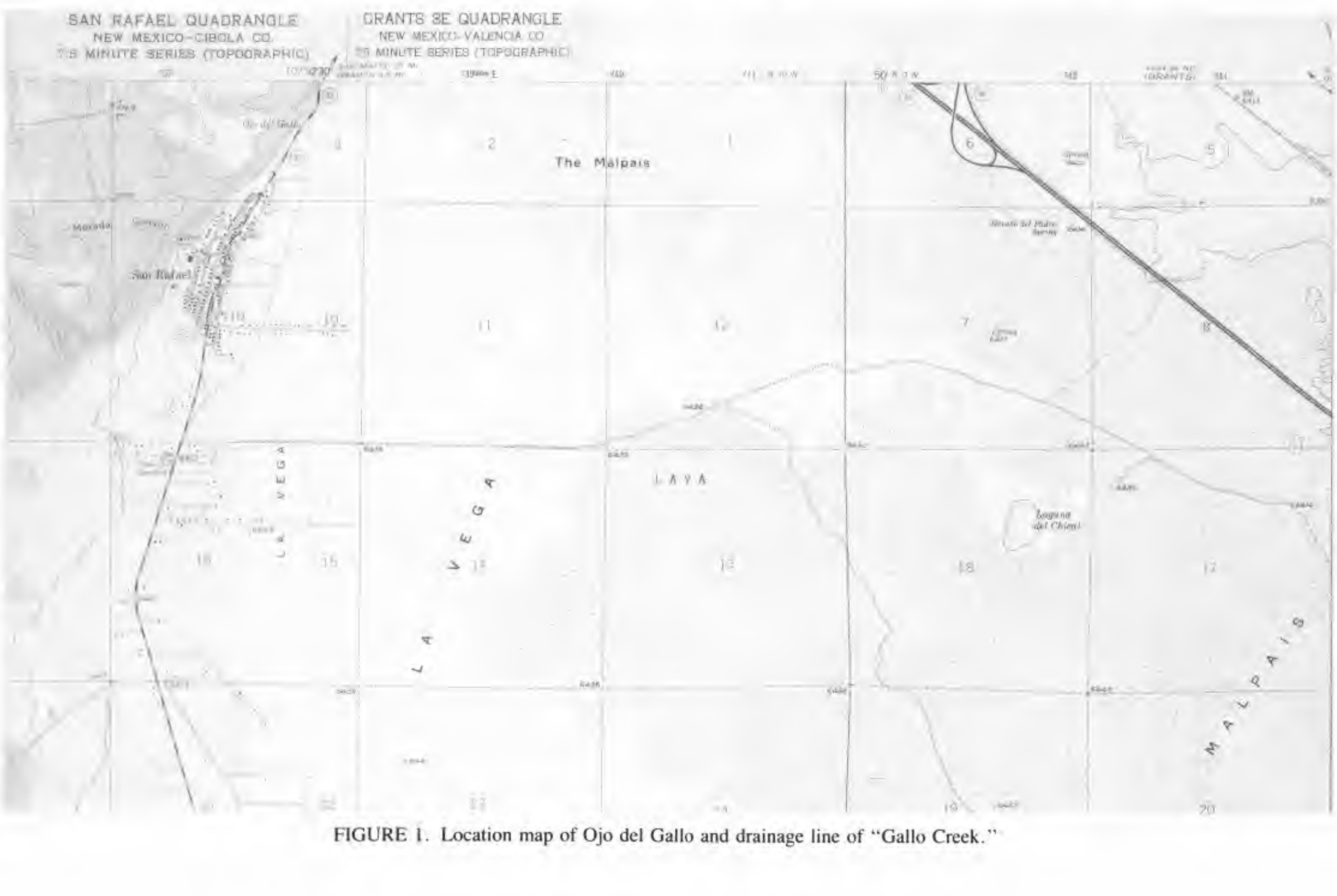


FIGURE 1. Location map of Ojo del Gallo and drainage line of "Gallo Creek."

## PHYSIOGRAPHIC AND GEOLOGIC SETTING

Ojo del Gallo issues at the lowest topographic elevation of the outcrop of the Permian San Andres Limestone which forms the dip-slope of the Zuni Mountains. Under natural conditions, the discharge of the spring flowed southeastward across a shallow gradient alluvial plain (La Vega, Fig. 1), thence eastward between two basalt flows of the Malpais (Zuni Mountain flow on the north, El Calderon flow on the south: Maxwell, 1982), thence east-northeastward across a lobe of an earlier El Calderon flow and finally across the Rio San Jose floodplain (Fig. 2). The total length of overland flow is approximately 9 km; 4 km of shallow channel is well defined in aerial photography as it crosses the El Calderon flow (Fig. 4). The 6.4 $km^2$ of spring deposits upgradient of this channel experienced eolian deflation and yardang development (wind carved ridges of soft sediment) during the 27-year period of no discharge.

## PREVIOUS WORK

P. V. Hodges conducted an exhaustive survey of irrigation and water supplies of Indian communities of the Rio Grande basin (P. V. Hodges, unpubl. report for Department of Interior Indian Irrigation Service, 1938). He reported the flow of Ojo del Gallo to be 7 $feet^3$ per second (cfs) in August and November of 1937, and a flow of as much as 4 cfs in the channel leading from Ojo del Gallo to the Rio San Jose in 1938. A later U.S. Geological Survey (USGS) study, the field work of which was done during the period of no flow from the spring, cited Hodges work as documentation that the discharge from Ojo del Gallo had contributed to the surface flow of the Rio San Jose. "The statements [Hodges'] suggesting that, aside from evapotranspiration losses in the swamp, most of the flow from Ojo del Gallo reached the Rio San Jose at Horace Springs are supported by measurements made by Hodges (1938, p. 341)" (Risser, 1982, p. 28).

The Bureau of Indian Affairs (BIA) tabulated the measured and estimated spring-flow values reported by past investigators in an in-house report concerning the Bluewater basin (W. P. Balleau and W. D. White, unpubl. report, 1984). The report documents the general decline in reported discharge of Ojo del Gallo from the 1930's through 1953 when the spring pool dried up. The spring returned to the surface in the winter of 1980–81. USGS flume measurements from June and July 1985,

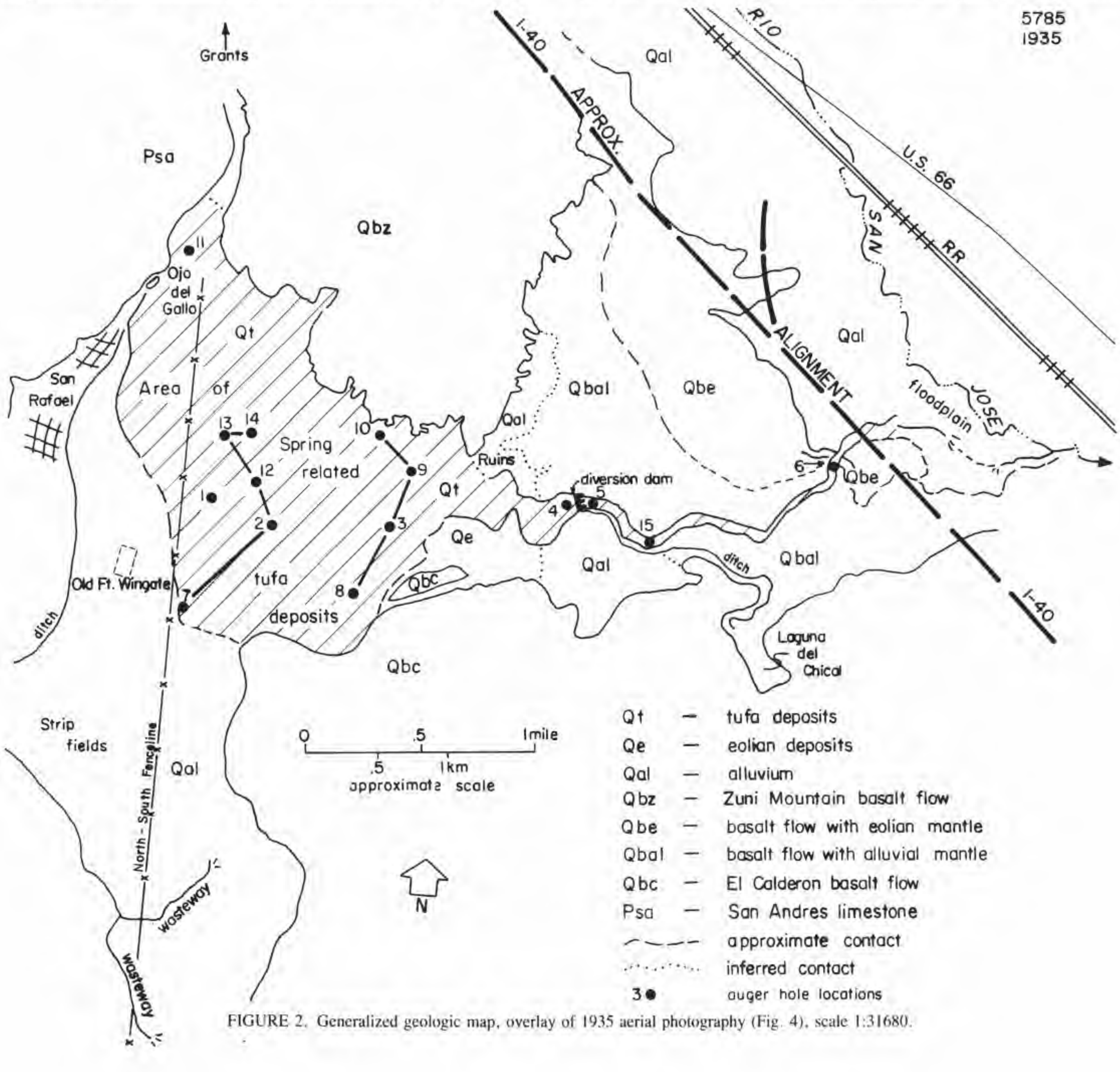


FIGURE 2. Generalized geologic map, overlay of 1935 aerial photography (Fig. 4), scale 1:31680.

indicate a fairly constant discharge of 1 cfs from a spring pool.

Dr. Dwight Taylor, Professor of Geology, University of Oregon, has investigated the Ojo del Gallo area in his search for sites reported to have living mollusks during the 1890's. He confirmed and identified at least three mollusk species as having been present in the marsh deposits associated with Ojo del Gallo near San Rafael, New Mexico (D. Taylor, oral commun., 1985).

## TECHNIQUES OF INVESTIGATION

### Auger holes

The spring deposits were hand-augered to depths of 2 to 3 m at 15 locations during the summers of 1984 and 1985 (Fig. 2). The augered material was inspected at 0.3-m depth intervals, and lithology, texture, color and shell content of the excavated deposits were recorded. The information was used to construct cross sections of the spring deposits.

### Elevation survey

Two elevation surveys were performed using a Lietz-Sokkisha B1 Automatic Level and Philadelphia Rod. Darker, organic-rich horizons within the deflated spring deposits were traced laterally and surveyed to obtain gradient information (Fig. 3).

### Aerial and ground-level photography

Aerial photography, flown in 1935, 1952, 1981 and 1986, at respective scales of 1:31680, 1:20000, 1:15840 and 1:15840, was used


FIGURE 3. Locations of gradient surveys, 1981 aerial photography, scale 1:15840.

to aid in tracing the lateral extent of the spring deposits. Resulting maps showing the extent of the deposits and other geomorphic information are presented in Figures 4 and 5.

Ground photography was used to document the ground surface expression, vegetation conditions, eolian activity, cultural remains, spring deposit textural detail and resurgent marsh conditions. This photography was done at various times during this investigation, mainly during August 1984, May 1985 and November 1988.

### Artifact, vegetation and mollusk-shell collections

Potsherds and lithic scatters were noted at various locations within the spring deposits. The Albuquerque Area Office Archeologist, Dr. Bruce Harrill, visited the field and provided his findings in an in-house report (B. Harrill, unpubl. report for the Bureau of Indian Affairs, 1985). Vegetal remains were observed to occupy specific zones in the field. Selected vegetation samples were collected for identification by Dr. Martin, Professor of Biology, UNM. The denuded ground surface yields an abundance of mollusk shell remains within the area of the spring deposits. Dr. Dwight Taylor investigated the same area in the 1960's and '70's and identified the shell remains.

## RESULTS

### Mollusk identification

Dr. Dwight Taylor, Professor of Geology, University of Oregon, has identified the remains of three mollusks in the Ojo del Gallo area: *Physa*

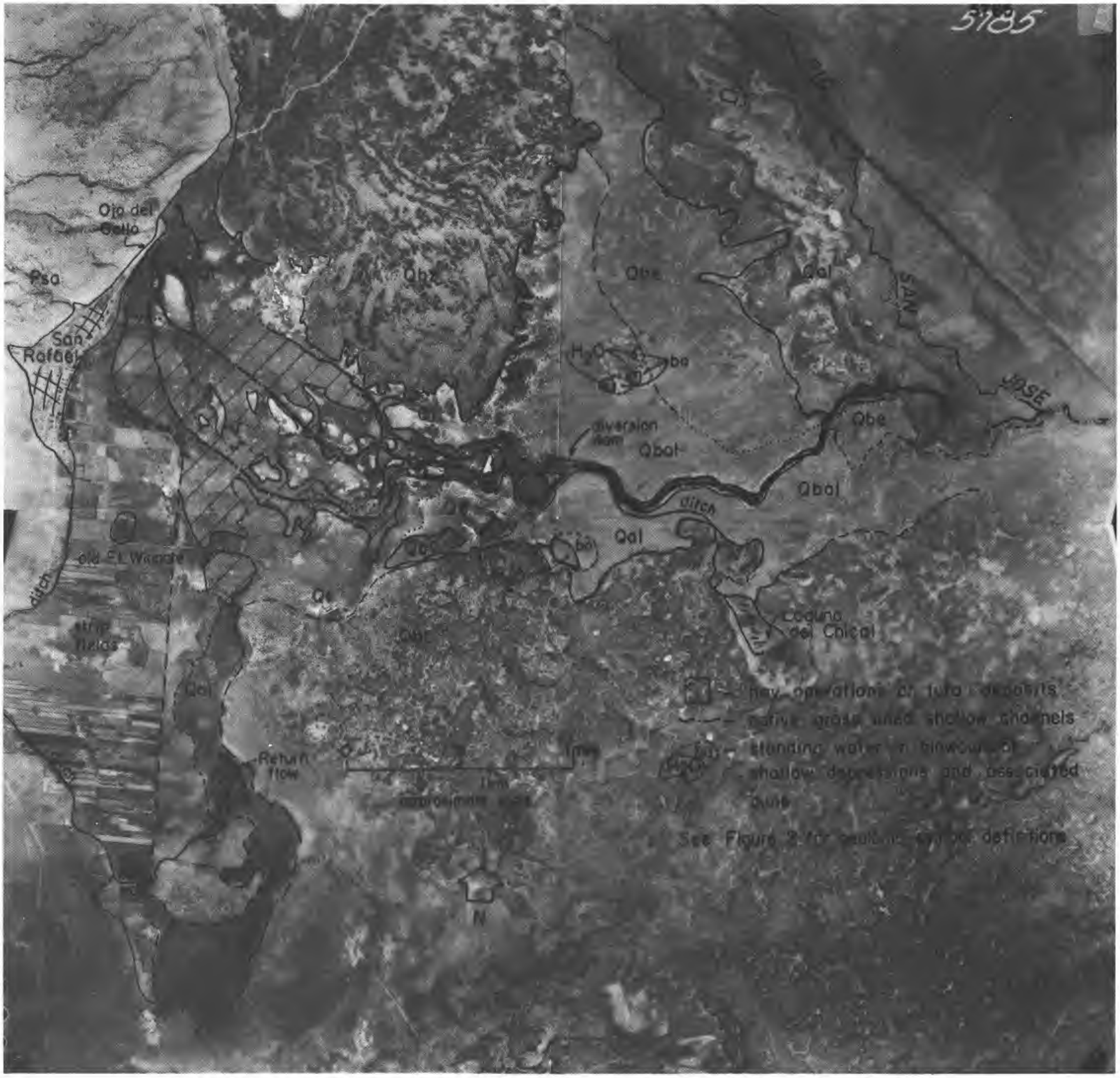


FIGURE 4. Geomorphic map overlay of Ojo del Gallo spring deposits, 1935 aerial photography, scale 1:31680.

sp., *Promenetus exacuous* and *Pisidium* (*Cyclocalyx*) *pauperculum*, the last two having been identified as specimens identical to mollusks that had been collected alive in the 1890's by Rev. E. H. Ashman, Superintendent of Indian Schools (D. Taylor, oral commun., 1985). The habitat of these mollusks is one of slow-moving creeks to marshes that are spring-fed with stable flow. Shells of *Physa* sp. were found to be the most abundant of the mollusk remains in the spring deposits.

### Vegetation identification

The uppermost horizon of the spring deposits is marked by a desiccated, densely packed vegetal root mat (Fig. 6). The root mat has been undercut by eolian activity resulting in pedestals and yardangs of spring deposits capped by tufts of the root mat. Dr. Martin, UNM, identified the root mat, from a sample brought in from the field, as *Sporobalus wrightii*, a native grass that furnishes hay. The 1935 aerial photography, when viewed in stereo, clearly shows hay stacks present in the area of the spring deposits (secs. 2, 3, 10, 11 and 12, T10N, R10W: Fig. 4). Accordingly, a 1935 date can be assigned to the root-mat horizon in present-day photography.

Present-day dunes of reworked spring deposits are colonized by *Phragmites communis* (Dr. Martin, oral commun., 1985), commonly known as reed grass (Fig. 7). The habitat of the reed grass is well-drained soils and indicates a 1.2 to 3 m depth to ground water.

Portions of the present-day ground surface are marked by accumulations of dense masses of precipitate, some in bulbous concretion form (the size of cow droppings), some in the form of irregular cylindrical


FIGURE 5. Geomorphic map overlay of Ojo del Gallo spring deposits, 1952 aerial photography, scale 1:20000.

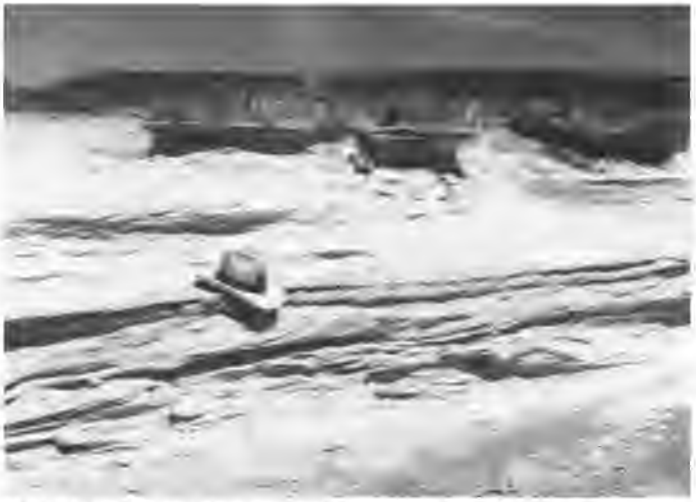

FIGURE 6. Desiccated root mat of *Sporobolus wrightii*, a native grass that marks the 1935 horizon of haying operations, capping wind-carved tufa deposits.

FIGURE 7. View to the northwest (City of Grants at base of mesa in background) of coppice dune colonized by *Phragmites communis*, center of photograph, within white field of bulbous precipitate interpreted to mark the bottom of an evaporation pan. The pan is surrounded by elevated banks of tufa deposits stabilized by a remnant root mat of native hay, the medium-toned horizon in middle ground of photograph. Also visible is a horizon of sedge casts draped across the shallow channel in the middle foregound of the photograph.

casts (straw shaped, 6 to 10 cm in length) and draped as a horizon across the land surface (Fig. 7). The casts, when broken in half and viewed in cross section, reveal a wedge-shaped tube in the center of the cast. The wedge shape is indicative of another reedy plant life, commonly known as sedges. The habitat of sedges is semi-aquatic, on intermittently flooded creek banks and marsh margins.

### Lithologic and soil identifications

A sample of the spring deposits was collected and brought into the soils lab at the Geology Department, UNM. Using the Chittick procedure (Dreimanis, 1962) to determine the percent carbonate content, analysis showed the sample to be nearly 100% carbonate. Accordingly, the soft but coherent spring deposits (the bulk of the deposits) are referred to as tufa, whereas dense masses of precipitate are referred to as travertine.

Certain horizons, markedly discolored gray to dark gray, may qualify as histosols, organic-rich soils that formed subaqueously, i.e., under reducing conditions in which the water table was at the land surface (the horizon the hat rests on in Figure 6). Light-colored tufa deposits (the bulk of the yardang in Figure 6) represent the subaerial accumulation of calcium carbonate precipitate. Recent observation of the accumulation of white precipitate on denuded flats, presumably by evaporation of capillary water from the resaturated tufa deposits, may represent the mechanism for precipitation of the older, light-colored deposits.

Av horizons were identified at various depths below the 1935 root-mat horizon. An Av horizon is one that displays a vesicular texture, resulting from the solar heating of a wetted surface with the subsequent expulsion of air which forms the vesicular texture (L. McFadden, oral commun., 1985). The vesicular texture is preserved as new accumulations of loosely compacted tufa occur over a given Av horizon.

### Historic and prehistoric associations

An article in the *Rio Abajo Weekly Press* from Albuquerque dated 23 June 1863, entitled "Letter from Fort Wingate," provides a description of the marshy area east of Ojo del Gallo:

> It is situated on a broad flat or valley at the foot of towering summits, near the head water of the Ojo del Gallo, surrounded by an Amphiteater [*sic*] of Mountains and Hills resembling something in the shape of an inverted hat. . . . The valley of the Ojo del Gallo is valuable for its exumberant [*sic*] pasturage. It spreads out in two directions below the Post, one branch leading in the direction of Zuni, and the other meandering due east in its course, in the direction of the Indian Villages of Acoma and Laguna. The water which flows from the spring is pure as crystal, and is of unfailing quality the whole year round.

During field inspections of the environs east of San Rafael, scattered and isolated pottery fragments were found. Dr. Harrill identified the potsherds as pottery types used by prehistoric Indian cultures during time periods spanning A.D. 900 to 1200. One site, however, yielded an abundance of lithic scatters and arrowheads, indicative of an Indian campsite of Archaic Tradition and probably resumed over a period of 3000 years, from about 2500 B.C. to A.D. 500 (B. Harrill, unpubl. report, 1985).

### Geologic cross sections and air photo maps

The information collected from 15 auger holes (Fig. 2) is displayed in Figure 8. The tufa deposit ranges in thickness from 0.6 to 2.4 m, and occupies approximately 6.4 $km^2$ between Ojo del Gallo and the low relief, basalt-boulder diversion dam at the head of the channel ("Gallo creek"; Fig. 3) crossing an earlier El Calderon flow. The Zuni Mountain basalt flow forms the northern limit of the tufa deposit. Alluvial sands and clays form the western and southern limits, while eolian sands and the El Calderon basalt flow form the southeastern limit of the tufa deposit (Fig. 2). The alluvial deposits extend below the tufa deposit as shown by arkosic sand and gravels, and heavy black clays found in auger holes 3 and 12, respectively. The top of the tufa deposit is bounded by the 1935 root mat of *Sporobalis wrightii* (Figs. 6 and 7). This root mat has been dissected, and underlying deposits have been extensively deflated by wind activity, which results in yardangs (Fig. 9) and coppice dunes of tufa sand on top of the 1935 horizon and along fence lines (Fig. 10).

Small islands of older dune deposits, reddish sands with carbonate concentrations of up to a foot in diameter, occur within the tufa deposits and apparently were covered very late in the depositional sequence of the tufa. Location 14 (Figs. 2 and 8) is an Indian site of Archaic Tradition occupying such an island of older dune deposits within the tufa. The older deposit correlates to the "old dune sand" of Bryan and McCann (1943), a reddish colored, compact dune sand with calcium carbonate concretions and Archaic Indian artifact associations in the Grants area (Bryan and Toulouse, 1943). Artifacts of the San Jose culture were also found at this location (B. Harrill, unpubl. report, 1985).

### Gradient of selected spring-deposit horizons

Using an automatic level and rod, selected dark-colored, organic-rich horizons were traced around the margins of deflated areas and from blowout to blowout between coppice dunes to determine the gradient of the horizon. Concentrated effort was spent on the area between the basalt flows, an irregular ground surface of shallow blowouts and coppice dunes (Fig. 3). In the flats between the toes of the basalt flows, gradients were determined to range from 0.0008 to 0.0015 toward the

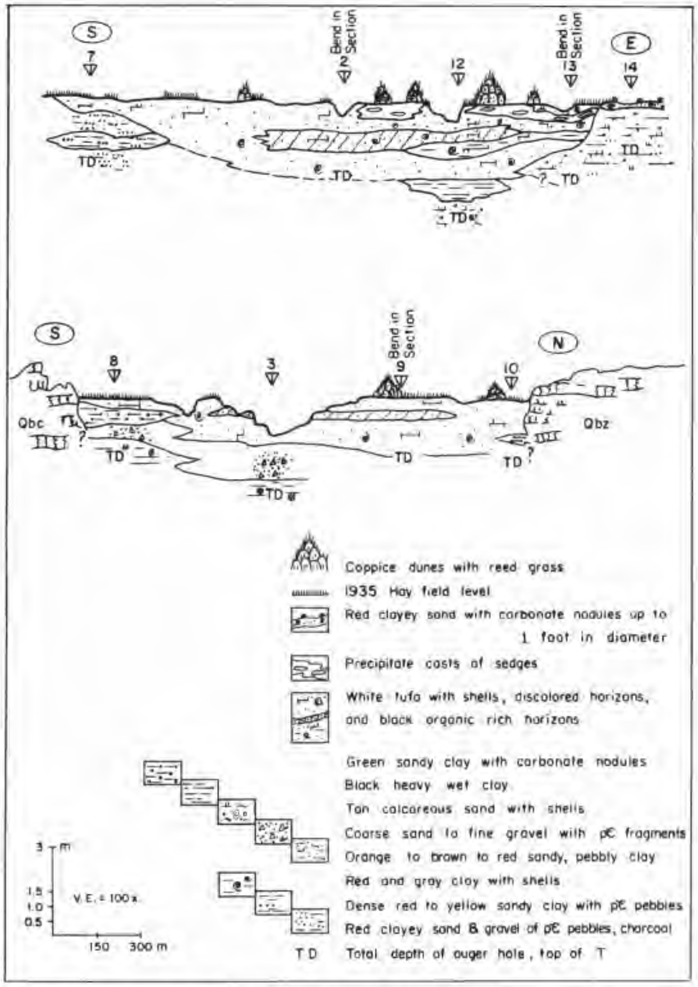


FIGURE 8. Generalized geologic cross sections of spring deposits; auger hole locations shown on Figure 2.

FIGURE 9. Yardang field, wind-carved tufa deposits, August 1984; view to the northeast. The root-mat-capped yardang behind the person in the center of the photograph is the yardang of Figures 6 and 12. Field located on Figures 3 and 13.

east, for horizons below the 1935 horizon. In the east half of this area, gradients were determined to range from 0.0009 to 0.0012 toward the east for horizons less than 0.3 m below the 1935 horizon.

The channel alignment leading eastward from the diversion dam in Figure 3 appears on the USGS Grants SE topographic quadrangle (Fig. 1). Using a map measure to determine the length of the channel between

FIGURE 10. Modern dune trapped along fence line, before resaturation of spring deposits, August 1984; view to the south. View and fence intersection, southeast corner of yardang field, shown on Figure 3.

the 6400- and 6420-foot contours, a gradient of 0.0039 toward the east is calculated. This is the steepest portion of the channel where it crosses from older portions of the El Calderon basalt flow to the floodplain of the Rio San Jose. Extending the channel symbol to the 6440 contour, a gradient of 0.0013 toward the east is determined, a value that agrees very well with the gradients of specific horizons determined by level and rod surveys during May 1985.

## DISCUSSION

The tufa deposits found in secs. 2, 3, 10, 11 and 12, T10N, R10W are directly related to the natural discharge of calcium carbonate charged waters from Ojo del Gallo, a spring issuing from the San Andres Limestone between Grants and San Rafael, New Mexico. The naturally occurring discharge flowed eastward and spread across the shallow gradient alluvial valley, depositing calcium carbonate in the form of tufa (soft, powdery precipitate) or travertine (dense, solid precipitate) on stream and marsh banks, and on plant life as the water was partially evaporated and transpired. Evidence for a perennially wet environment includes an abundance of both: (1) travertine deposits forming casts of sedges, a semiaquatic plant life, and irregular clumps of precipitate forming sinuous mounds marking previously existing stream or marsh banks separated by lower elevation organic rich tufa horizons and preserved evaporation pan margins and bottoms, defined by a flat expanse of travertine aggregate bounded by raised banks stabilized by root-mat horizons (Fig. 7); and (2) mollusk shells of at least three different species: *Physa* sp., *Promenetus exacuous* and *Pisidium* (*Cyclocalyx*) *pauperculum*.

The mere presence of mollusk shells in the tufa is considered evidence for a surface-water connection between Ojo del Gallo and the Rio San Jose. Aerial photography clearly shows a vegetation change along a well-defined drainage line (Figs. 4 and 5). Auger holes along that line yield mollusk shells in both unconsolidated (tufa) and consolidated (travertine) deposits. Ant hills within the channel are found to show an abundane of *Physa* sp. shells, but none at all 3 to 5 m north or south of the low relief channel margins.

Bedded travertine was found only in the high gradient stream reach (0.0039) immediately upstream of Rancho del Padre Spring, which is fed by ground-water flow from the upgradient La Vega (Fig. 1). Traceable, organic-rich tufa horizons exposed by eolian deflation yield gradient information for the Ojo del Gallo paleochannel through the topographic constriction created by the basalt flows of the Malpais. The gradients correspond closely to gradient information from a USGS topographic map of the area (0.0008 to 0.0015, and 0.0013, respectively). The present-day lack of a defined surface-water channel is a result of eolian deflation of the loosely compacted, dewatered tufa deposits creating an irregular ground surface of blowouts with yardangs and coppice dunes.

The shallow gradient field conditions at Ojo del Gallo, its abundance

FIGURE 1 1. Similar view as Figure 10, after resaturation of spring deposits in November 1988. Light-toned area in center of photograph is new deposition of tufa by evaporation of capillary water.

FIGURE 12. View to the west of submerged yardang field. The ridge in the background is the San Andres Limestone, with the village of San Rafael at its base. The small island in the center of the photograph is the root-mat-capped yardang of Figure 6; view is depicted on Figure 3.


FIGURE 13. 1986 aerial photograph, scale 1:15840, indicating the extent of resurgent wetlands and resaturated spring deposits.

of tufa deposits, and the selective extent of travertine deposition, may be compared to the recent investigation by Lorah and Herman (1988) in Virginia. They concluded that travertine deposition from a stream supersaturated with carbonate was controlled inorganically by the rapid outgassing of carbon dioxide from the stream as it passed over a waterfall (gradient of 1). Their chemical data support their conclusion that biological processes were comparatively of no significance in controlling travertine deposition, as evident by the lack of travertine deposition along the vegetated stream banks. In this study, bedded travertine was found along the steepest gradient of the surface drainage line (0.0039), and an abundance of tufa with travertine forming irregular, bulbous masses and casts of grasses and sedges along a low gradient (0.0008) alluvial flat. At the Ojo del Gallo location, something other than inorganic outgassing allowed 8 ft of tufa and travertine to precipitate. I theorize that the wide expanse of shallow water conditions, an arid/semiarid climate and an abundance of marsh flora resulted in combined physical and biological controls on calcium carbonate precipitation.

Waters issuing from Ojo del Gallo were diverted southward for agricultural use in the San Rafael area before the mid-1800's; winter flows were allowed to flow eastward into the marsh area (P. V. Hodges, unpubl. report, 1938). Irrigation return flow and winter flows recharged the spring deposits east of San Rafael which supported haying operations that were active in the 1930's. Upon close inspection of Figure 5, the wasteways of the irrigation ditches can be seen. The water returned by these wasteways recharged the alluvial materials west of the El Calderon basalt flow. This recharge to the alluvial aquifer (dark-toned areas at the ends of the irrigation ditch lines in Figure 5) saturates deposits in a northward direction, toward the tufa deposits and the gap between the basalt flows.

Present-day (1988) discharge is turned out to La Vega during winter months, and wetlands are attracting water fowl once again (Fig. 11). The irregular land surface is under as much as 1.5 m of water in places (yardang field, Figs. 9 and 12), and ground-water flow through surface obstructions is evident by the disconnected surface pools. Surface flow between some pools in November 1988 was estimated to be 0.9 cfs (substituting visual estimates of wetted perimeter and channel roughness into the Manning equation, assuming a gradient of 0.0008 and flow cross section estimated to be 0.6 m $\times$ 0.1 m).

Flow into the marsh area, in turn, contributed to the flow of the Rio San Jose, as surface flow up to the forties, and as ground-water flow through the channel deposit which still supports the Rancho del Padre spring on the downgradient side of the older El Calderon basalt flow. A 1986 aerial photograph (Fig. 13) shows wetlands being re-established and resaturated spring deposits following the same south and easterly courses evident in Figure 5.

## CONCLUSIONS

This paper has presented an evaluation of: (1) selected historical records (narrative site descriptions; scientific records and documents); (2) geohydrologic field conditions (lithology, texture and gradient of spring deposits); and (3) biologic remains (mollusk and vegetation identifications) which confirm the existence of a dewatered wetland associated with Ojo del Gallo, near San Rafael, New Mexico. A geohydrologic connection between the wetland deposits and the Rio San Jose has been established. The coincidence of wetland dewatering with ground-water developments upgradient of Ojo del Gallo, and the spring's resurgence after relaxation of the development stresses, strongly suggests an over-appropriation of water with unaccounted effects on rights.

## ACKNOWLEDGMENTS

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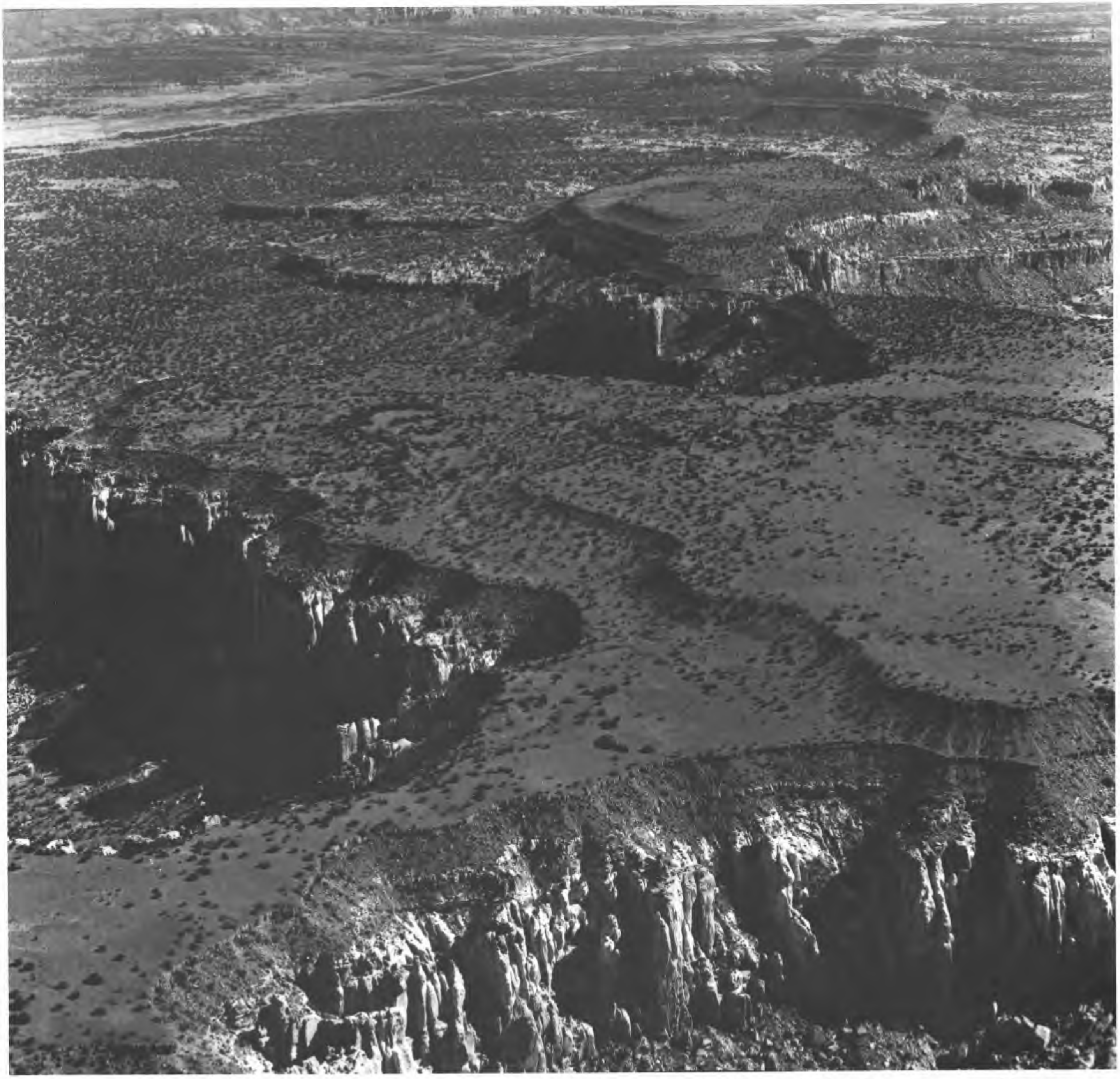

Aerial view of mesas east of Acoma Sky City show white cliffs of Jurassic Zuni Sandstone overlain by intertongued Dakota-Mancos sequence of Cretaceous age. Photograph taken 6 May 1989 by Paul L. Sealey.