Geology and hydrologic setting of springs and seeps on The Sevilleta National Wildlife Refuge

By

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I. INTRODUCTION

In this report I describe the geologic setting and hydrologic framework of the springs on the Sevilleta National Wildlife Refuge (hereafter referred to as "the refuge"). For each spring, this report includes paper copies and GIS coverages of the geologic maps and cross sections, photographs in digital form, a description of the geology, an interpretation of the hydrologic setting and water source, and an assessment of the possible threats and/or potential enhancements. I also describe the seeps on the refuge and provide a bibliography of relevant hydrogeologic studies and reports covering the refuge area.

The body of the report consists of an overview of the geology and hydrology of the refuge, an outline of the methods used, a discussion of springs vs. seeps, descriptions and interpretations of the springs and selected seeps, a list of references cited and a bibliography of previous hydrogeologic studies of the refuge area.

II. OVERVIEW OF THE GEOLOGY AND HYDROLOGY OF THE REFUGE

Concise overviews of the geology and hydrology of the refuge and surrounding area can be found in Roybal (1991) and Spiegel (1955). More detailed information about the Rio Grande rift can be found in Keller and Cather (1994) and the New Mexico Geological Society's geology guidebooks that cover the region.

Geology of the refuge

The dominant geologic structure of the refuge area is the Rio Grande rift. The present-day Rio Grande River flows down the center of rift, which has formed by extensional tectonic activity since the middle Tertiary period (~30 million years ago). The rift extends from central Colorado to Mexico and consists of a series of deep sedimentary basins filled with relatively young sedimentary rocks deposited by the Rio Grande and its predecessor rivers. The refuge encompasses the southern end of the Albuquerque basin, one of the largest in the rift. Along its whole length, the basins of the rift are flanked by mountain blocks uplifted along faults at the edge of the basins. The Los Piños Mountains and Ladron Peak are classic examples of these uplifted mountain blocks.

The refuge can be divided into sections with distinct geologic structures, ages, and types of rocks. The area bounded on the north by the border of the refuge, on the west by the foothills of Ladron Peak and the Lemitar Mountains, on the east by the steep face of the Los Piños Mountains, and on the south by the Joyita Hills and the general vicinity of San Acacia is the southern terminus of the Albuquerque basin. This area is underlain by mostly flat-lying Tertiary and Quaternary sedimentary rocks of the Santa Fe Group. These include sandstones, mudstones, conglomerates, local layers of volcanic rock and ash, and unconsolidated surficial deposits such as arroyo alluvium, gravels on eroded bedrock surfaces, and windblown sand. The topography is generally subdued and flat except for the escarpment at the edge of the inner valley of the Rio Grande River.

Ladron Peak and the Los Piños Mountains are both uplifted blocks of Precambrian granite and metamorphic rocks such as schist, quartzite and amphibolite, overlain by thick beds of Paleozoic limestone. The Los Piños Mountains were uplifted along the steeply dipping Los Piños fault on their west side, resulting in the dramatic escarpment. The mountain block is tilted to the east, and the limestone beds on top form a shallow slope that dips to the east. The opposite is true of Ladron Peak – the limestone beds there dip to the west because the range was uplifted along the Jeter fault along the east side of the range. However, the geology on the east side of Ladron peak is considerably more complex than that its “mirror image” in the Los Piños Mountains, partly because the Jeter fault has a shallow dip. There are exposures of early Tertiary rocks that predate the Rio Grande rift on the east side of Ladron Peak.

The Lemitar mountains extend south from Ladron Peak to the southern edge of the refuge at San Lorenzo Canyon and beyond, and east to where the topography becomes subdued. This small range is composed of west-dipping rocks from Precambrian granite to lower Tertiary volcanic rocks such as basalt, andesite, and rhyolite tuff. It is also an uplifted mountain block bordering the Rio Grande rift, but the geology is more complicated than that of Ladron Peak or the Los Piños Mountains because of multiple episodes of faulting and volcanism.

From the Lemitar mountains west to the west edge of the refuge and beyond to the Magdalena Mountains is the La Jencia Basin. This is another sedimentary basin of the Rio Grande rift. It too is filled with flat-lying tertiary and Quaternary sedimentary rocks

The modern valley of the Rio Grande east from the Lemitar Mountains is narrow. This area is termed the “Socorro constriction”, and is the boundary between the Albuquerque basin to the north and the Socorro basin to the south. The geology here consists of Tertiary sedimentary and volcanic rocks of the Santa Fe Group. Some of the basalts crop out prominently as the black mesa at San Acacia.

The final distinct geologic section of the refuge is the area from San Acacia east to the refuge boundary and north to the Los Piños Mountains, which is dominated by folded and faulted Paleozoic sedimentary rocks. Just east of the river are the rugged Joyita Hills, composed of Precambrian granite overlain by generally west-dipping Pennsylvanian, Permian, and Triassic sedimentary rocks. These are in turn overlain by Tertiary volcanic and sedimentary rocks. The older rocks in the Joyita Hills were folded and faulted during the Laramide mountain building episode that preceded the formation of the Rio Grande rift. Younger faults related to the rift cut all of the rocks.

East of the Joyita Hills is a wide valley which is filled with Quaternary alluvium and underlain by Mesozoic sedimentary and lower Tertiary sedimentary and volcanic rocks. Beyond the valley, to the east border of the refuge, is the rugged terrain of the northern Quebradas. This area is underlain by shallowly dipping Paleozoic sandstones, mudstones, limestones, and gypsum beds that are moderately folded and cut by both near-horizontal Laramide (?) detachment faults and steeply dipping faults related to the formation of the rift.

Hydrology of the refuge

The most important groundwater-bearing geologic units in the refuge area are Quaternary alluvial deposits; Quaternary and Tertiary sedimentary rocks of the Santa Fe Group; Tertiary volcanic rocks such as the Datil Group; and the Permain Abo and Yeso

Formations (Roybal, 1991). All of these rocks are developed as aquifers for human and livestock use to varying degrees in Socorro County.

Wells developed in the Quaternary deposits and the Santa Fe group are the most important and usually have large yields (50 gallons per minute or more) and good quality water. The Permian rocks form an important aquifer in eastern Socorro County as there are no younger deposits. However, they have significantly smaller yields than the Quaternary and Tertiary aquifers (usually 20 gallons per minute or less) and the water is often of poor quality, with high levels of dissolved solids and toxic compounds such as nitrate, lead, and selenium (Roybal, 1991).

Water table surface maps presented by Roybal (1991) and Spiegel (1955) that cover the refuge area show contours that close to the north and decrease in elevation to the south, or downstream on the Rio Grande. The water table resembles a subdued version of the land surface topography. Regional groundwater flow is in the downslope direction of the water table, converging on the Rio Grande from the Albuquerque basin to the north and mountains to the east and west. The gradient is steepest on the east side of Ladron Peak. The data indicate that on a large scale water discharges from the groundwater system to the river. There are many smaller scale complexities. In addition, evapotranspiration from native, cultivated, and exotic vegetation and evaporation from waterlogged lands outweighs the contribution to the river from groundwater discharge, and the reach is therefore losing water.

Although data are sparse, the water table surface map in Roybal (1991) for wells completed in the Quaternary and Tertiary deposits of the La Jencia basin shows contours trending slightly west of north and decreasing in elevation to the northeast. This indicates that groundwater is flowing from the Magdalena mountains towards the Rio Salado, along the general trend of La Jencia Creek. The water table contours in the Rio Salado area indicates that the groundwater in the La Jencia basin eventually reaches the Rio Grande valley (Spiegel, 1955).

These water table data are consistent with the fact that most of the recharge in Socorro County comes from mountain front areas and ephemeral streamflow. Much of the rainfall and snowmelt in the basin-flanking mountains and infiltrates near the mountain front into arroyos floored by Quaternary and Tertiary sedimentary rocks. Similarly, most ephemeral stream flows in the Rio Puerco, Rio Salado La Jencia Creek, and other large arroyos infiltrate into the ground before reaching the Rio Grande.

III. METHODS

I examined the aerial photograph collection at the refuge headquarters and marked 59 possible spring sites on 7.5 - minute quadrangle maps, based on vegetation and topography. I also examined the lists of springs in Roybal (1991) and Spiegel (1955). Ken Wolf of the refuge provided a map with the locations of several springs. All of these sites were visited in the field. Most were not springs or seeps. For all springs and several seeps in the Ladron Peak area, I mapped the local geology, took photographs, recorded the location of the spring with a handheld GPS unit, and later constructed geologic cross sections. In all cases, this was sufficient for understanding the basic hydrologic setting and delineating the likely source area for the water discharging at each spring.

IV. SPRINGS

I differentiated springs and seeps using one or more of the following criteria. Springs are those points of groundwater discharge which are marked on the USGS 7.5 – minute quadrangle map, have extensive phreatophyte vegetation, evidence of having been developed for human or livestock use, or were flowing at the time of first observation in June or July 2002. Springs flowing at this time are likely to be reliable water sources as early summer 20002 was preceded by months of drought and a very dry winter.

V. SEEPS

Seeps on the refuge are more abundant than springs and are very common in outcrop areas of Proterozoic granite and metamorphic rocks, less common in Tertiary volcanic rocks and the Popatosa formation, and rare in other rock types. Seeps are places where small amounts of water have discharged from joints or fractures. I observed very few with active flow, and those only later in the summer after monsoon rains had begun; thus they are in general ephemeral and not perennial water sources. Field evidence for seeps includes salt and organic stains, and occasionally mosses. Some seeps are associated with cottonwood trees, willows, and tamarisk. Map 2, covering the Ladron Peak area, includes many seeps, and cross sections and descriptions are included for these seeps. This is not an exhaustive survey, but the seeps described are illustrative of the general character of seeps on the refuge. I did not attempt to locate all of the seeps in other areas of the refuge as it is extremely time consuming to find them. However, photos of some seeps outside the Ladron Peak area are included.

VI. INVENTORY OF SPRINGS

The following table lists all of the springs and seeps discussed in this report. They are listed in the table in the order of their estimated importance, based on amount and reliability of discharge.

Number	Map	Cross section	Spring name	7.5-min quadrangle	UTM E	UTM N
SC1	1	1	“Rio Salado Spring”	Silver Creek	307354	3800272
SC2	1	1	“Rio Salado Spring”	Silver Creek	307152	3800292
LP1	2	2		Ladron Peak	309254	3806949
LP2	2	3		Ladron Peak	309261	3807186
SLS1	3	4	San Lorenzo Spring	San Lorenzo Spring	314071	3790309
SdC1	4	5	Cibola Spring	Sierra de la Cruz	345376	3788897
SC3	5	6	Tortola Spring	Silver Creek	314304	3795816
SA1	6	7	"Canyon del Ojito Spring"	San Acacia	318221	3792605
SdC2	7	8	"Milagro Spring"	Sierra de la Cruz	339295	3786795
LP3	2	9		Ladron Peak	309708	3805700
LP4	2	9		Ladron Peak	309313	3805646
LP5	2	10		Ladron Peak	309463	3808073
LJ1	8	11	Los Alamos Spring	La Joya	~335500	~3797900
SdC3	7	8		Sierra de la Cruz	340017	3786683
LP6	2	10		Ladron Peak	310596	3808529
LP7	2	10		Ladron Peak	311012	3808640
LP8	2	12		Ladron Peak	311093	3810238
LP11	2	3		Ladron Peak	310701	3806498
LP9	2	13		Ladron Peak	312404	3808486
LP10	2	14		Ladron Peak	311633	3809481
SC4	2	15		Silver Creek	309737	3803159
SLS3	3	4		San Lorenzo Spring	313920	3790213
SLS2	3	4		San Lorenzo Spring	315441	3790571
LP13	2	3		Ladron Peak	308923	3807434
SLS4	3	4		San Lorenzo Spring	313564	3790206
LP12	2	14		Ladron Peak	310959	3809492

<u>Springs SC1 and SC2 (“Rio Salado Springs”)</u>

Locations: Silver Creek 7.5 - minute quadrangle, SC1 UTM coordinates: 307354E, 3800272N; SC2 UTM coordinates: 307152E, 3800292N.

Description: These two springs are not marked on the Silver Creek quadrangle. They are 3.5 km west of the Sevilleta refuge on a quarter section of land owned by Ross Ligon.

They are both located along the Rio Salado where it cuts through the limestone ridge on the west flank of Ladron Peak. SC1 discharges from joints in bedrock on the south bank, just east of the Salado Box. It has tremendous flow, enough to make a small "fountain" 30 cm high, and bubbles audibly. SC2 is within the Salado Box and discharges in the sand and gravel bed of the river. It is an area of 10's of square meters where water can be seen and heard bubbling up through the sand. The bubbling and hissing is loud enough to suggest that the water is exsolving gas, probably CO_2 (Andrew Campbell, personal communication). The discharge from both springs flows east down the Rio Salado and onto the refuge. Both springs were flowing on August 20, 2002.

Geologic Setting: The geology surrounding this spring is shown on map 1 and cross-section 1. The Rio Salado cuts through a ridge of west dipping Pennsylvanian Madera limestone, forming the narrow canyon of the Salado Box. To the east and west of the ridge are subhorizontal sandstones and conglomerates of the Tertiary Santa Fe Group. Several small displacement (<10 m) east-side down normal faults cross the canyon at the location of SC2 and ~50 m west of SC1.

Hydrologic Setting and Water Source: Both springs discharge from joints and fractures in Pennsylvanian Madera limestone that dips west underneath Tertiary rocks. The evidence of degassing suggests that the water has abundant dissolved CO_2 and has traveled a long distance through the limestone, perhaps all the way from the Colorado Plateau to the west. The large discharge suggests a flow system of highly transmissive fractures within the limestone, probably enlarged by solution, and a deep source and/or large recharge area. The ultimate source is to the west, down the dip of the strata.

Potential Threats: The greatest potential threat is that extensive groundwater pumping in the Colorado Plateau area to the northwest and, possibly, the La Jencia Basin to the west, may alter the regional water table configuration in terms of the magnitude and direction of the gradient. This could ultimately result in a decrease or complete cessation of spring discharge. However, given the likelihood that the springs are discharging deep-sourced and far-traveled water, this threat may not be as great as for other springs discharging water from the La Jencia basin.

There are tamarisk thickets along the banks of the Salado, but none within the channel itself that could directly intercept the stream flow. The landowner, Ross Ligon, has worked with the BLM for several years on maintaining the riparian zones in this area (Mark Matthews, BLM Socorro office, personal communication).

Potential Enhancements: Continued maintenance of the local riparian zone.

Spring LP1

Location: Ladron Peak 7.5 – minute quadrangle, UTM coordinates: 309254E, 3806949N.

Description: This spring is marked on the Ladron Peak quadrangle. It was developed as a water source for the DeGeer homestead. There is a water-filled pit surrounded by grasses at the outlet, and an old trough dug down the slope to the homestead. Water flows out of the pit and across the ground ~5 m. The spring was flowing on June 28, 2002.

Geologic Setting: The geology surrounding this spring is shown on map 2 and cross-section 2. The spring is at the toe of a ridge of isoclinally folded Proterozoic quartzite, on the contact of this quartzite with red Capirote granite. This contact is approximately on the strike of the Ladron fault as mapped by Condie (1976), but there is no evidence in the vicinity of the spring that this contact is a fault contact. However, the exposures are rather poor. The spring is above the main drainage in the canyon just to the west, and above the floor of Mule Canyon to the east. Foliations in the quartzite, adjacent schist, and granite dip 40-50 degrees east. The foliations and joints developed along foliations and bedding create a strong north-south structural grain.

Hydrologic Setting and Water Source: This spring, along with springs LP2 and LP13, likely derives its water from Ladron Peak to the north. Its location suggests the water is moving to the spring from the northwest, down the ridge from the main mass of Ladron Peak. Springs LP1, 2, and 13 are thus part of the same flow system in the quartzite. The local structural grain is the dominant control on the groundwater flow system and rules out a significant water source to the west.

The abundant flow indicates that the water is moving through fractures or a joint set in the quartzite with relatively wide aperture and very good connectivity, resulting in very high transmissivity. The flow path to the springs must be localized to avoid discharging at the surface in the upper reaches of Mule Canyon directly to the north of the ridge. Truncation of these features at the contact with the granite, or poor continuity across the contact, may result in the migration of water to the surface along the contact.

Potential Threats: None.

Potential Enhancements: The pit dug at the spring could be enlarged into a stock tank with an overflow pipe and lined to prevent leakage.

<u>Spring LP2</u>

Location: Ladron Peak 7.5 – minute quadrangle, UTM coordinates: 309261E, 3807186N.

Description: This spring is marked on the Ladron Peak quadrangle. It is about 60 m higher and slightly to the west on the same ridge as LP1. It is directly on the boundary of the refuge; the fence runs right over it. A pipe runs from the spring to a small stock tank off of the refuge. There is a patch of muddy ground with abundant grasses and shrubs and the spring flow is audible. The spring was flowing on June 28, 2002.

Geologic Setting: The geology surrounding this spring is shown on map 2 and cross-section 3. It is on the same ridge of isoclinally folded quartzite as spring LP1, near the contact with a schist layer that dips to the east. The geologic contacts, foliations, and joints developed along foliations and bedding create a strong north-south structural grain.

Hydrologic Setting and Water Source: This spring, along with springs LP1 and LP13, most likely derives its water from Ladron Peak to the north. Its location ~25 m below the crest of the ridge, far above the drainages on either side, makes it very unlikely that the water is derived from anywhere other than down the ridge from the main mass of Ladron Peak. The abundant flow indicates that the water is moving through fractures or a joint set in the quartzite with relatively wide aperture and/or very good connectivity, resulting in very high transmissivity. The flow path to this spring must be very localized to avoid discharging at the surface in the upper reaches of Mule Canyon directly to the north of the ridge, as well as anywhere along the flanks of the ridge. The location of the spring is probably determined by the intersection of a prominent fracture or joint with the ground surface. The abundant flow of this spring after months of drought and a dry winter indicates that this spring is a reliable water source.

Potential Threats: There are no tamarisk around the spring. The pipe obviously takes some water that could potentially discharge onto the refuge and diverts it to the stock tank.

Potential Enhancements: The spring currently discharges into a muddy area with abundant vegetation and water flowing over the ground surface. A tank could be built on the refuge to create a permanent water supply rather than having most of it be lost into the soil.

<u>Spring SLS1 – San Lorenzo Spring</u>

Location: San Lorenzo Spring 7.5 – minute quadrangle, UTM coordinates: 314071E, 3790309N.

Description: This spring is marked on the San Lorenzo Spring quadrangle. It is located at a small narrows or slot in San Lorenzo Canyon and flows out of fractured rock over and down a polished bedrock chute. From there the water quickly infiltrates into the sand and gravel of the canyon bottom. The sand and gravel around the spring above the chute are wet and there is abundant algae. Several willows and a Russian olive are growing around the spring. The spring was flowing on July 19, 2002.

Geologic Setting: The geology surrounding this spring is shown on map 3 and cross-section 4. This spring is located in an area of Tertiary andesite and basaltic andesite lava flows with interbedded conglomerates, overlain to the west by younger, west-dipping, Tertiary conglomerates of the Popatosa formation. In this area, the rocks are west dipping and are cut by numerous north- or south-striking normal faults with motion down to the east or west. Displacement on some of these fault varies laterally, and some of the faults end within the map area.

The spring is located where the canyon cuts a basaltic andesite lava flow that is several tens of meters thick. It arises from fractures in the lava flow. To the west of the spring is a fault with unknown, but probably small (< 20m) displacement, that juxtaposes the flow against an andesite flow. Both flows dip to the west under Tertiary conglomerate.

Hydrologic Setting and Water Source: The water source for this spring is the La Jencia Basin to the west. The water flows east through the relatively permeable Popatosa formation conglomerates along (and across?) the dip of the strata and rises to the surface when it encounters the relatively impermeable lava flows. As these flows strike north-south and are quite extensive, San Lorenzo Spring may collect groundwater from a large area if it migrates north and south along the flows to reach the spring, which is a topographic low. The small fault west of the spring may facilitate lateral movement of the water and/or its rise to the surface.

Potential Threats: The greatest potential threat is that extensive groundwater pumping in the La Jencia Basin to the west may alter the regional water table configuration in terms of the magnitude and direction of the gradient. This could ultimately result in a decrease or complete cessation of spring discharge.

There are no tamarisk around the spring, but tamarisk growth was extensive upstream. These trees were cut in the summer of 2002. The invasive plant Russian olive was growing near the spring and should be removed.

Potential Enhancements: Tamarisk should be removed as it grows back.

<u>Spring SdC1 – Cibola Spring</u>

Location: Sierra de la Cruz 7.5 – minute quadrangle, UTM coordinates: 345376E, 3788897N.

Description: This spring is marked on the Sierra de la Cruz quadrangle. It is located in Cibola Canyon at the eastern end of a short (~ 400 m) slot canyon. The spring flows out of gravel in the canyon bottom. The water then flows over exposed limestone bedrock with many water pockets. Bubbles can be seen rising from the arroyo bed into pools of clear standing water. There are abundant grasses and tamarisk along the arroyo banks, but the bottom is free of vegetation. At the west end of the slot canyon is a plunge pool ~10 m in diameter and several meters deep. This pool was full on

August 27, 2002. The spring was flowing on July 17, 2002, and the flow had increased significantly by August 27, 2002 after a month of monsoon rains.

Geologic Setting: The geology surrounding this spring is shown on map 4 and cross-section 5. The spring is located on a north-striking, east-side down normal fault. It juxtaposes Permian Abo formation sandstones and mudstones on the east against Pennsylvanian Madera formation limestone on the west. All of the rocks are shallowly dipping to the west. The Madera formation is more resistant to erosion and forms a ridge through which the slot canyon has been eroded.

Hydrologic Setting and Water Source: The large change in flow of this spring after a month of monsoon rains indicates a shallow hydrologic system that responds rapidly to precipitation. This response is typical of fractured Madera limestone aquifers and is similar to spring behavior in the Placitas area north of Albuquerque (Peggy Johnson, NMBGMR, personal communication). A local source of recharge is the large expanse of Madera outcrop to the north of the spring. The Madera is widespread in this area and potentially forms a large, fractured aquifer that can discharge at the spring. Highly transmissive fracture networks and joint sets deliver the water to the fault, where it moves laterally to the spring.

It is unlikely that much of the flow comes from the Abo formation in the hanging wall of the fault, as it consists of fluvial channel sandstones surrounded by relatively impermeable mudstones. However, some water may enter the fault where it intersects the more permeable channel sandstones.

Potential Threats: There are tamarisk growing on the arroyo banks, but none immediately near the spring. Between July and August a flash flood had significantly rearranged the arroyo bottom and moved many large boulders, so it is unlikely that any significant invasive vegetation can persist around the spring.

Potential Enhancements: None.

<u>Spring SC3 – Tortola Spring</u>

Location: Silver Creek 7.5 – minute quadrangle, UTM coordinates: 314304E, 3795816N.

Description: This spring is marked on the Silver Creek quadrangle. It is located a few meters from the head of a small slot canyon in Cañada de la Tortola. The spring outlet is beneath the gravel bottom of the canyon; there are small pools of standing water with abundant algae and trickling surface flow. Damp sand extends for ~10 m downstream of the spring to an old concrete dam built across the mouth of the slot canyon. A pipe from this dam probably once led to a stock tank. There are tamarisk, willows, grapes, and jimsonweed growing near the spring and more willows downstream near the concrete dam. The spring was flowing on July 11, 2002.

Geologic Setting: The geology surrounding this spring is shown on map 5 and cross-section 6. The spring is within an area of dark red volcaniclastic boulder conglomerates of the Tertiary Popatosa formation (Unit Tscd). These conglomerates were shed from Tertiary andesite lava flows (Unit Ta3 on Map 4) that form the summit of the high ridge that extends directly to the south of the spring. The conglomerates appear to be a fan that formed at the depositional or erosional edge of these flows.

The spring is located on one of several small displacement (probably <10 m) normal faults synthetic to the large-displacement, northwest-striking Silver Creek fault to the east. All of the small faults strike north-south and are east-side down. The old concrete dam was built where the east-side down Silver Creek fault crosses the canyon. To the east of the Silver Creek fault are pinkish-tan to red conglomerates, sandstones, and mudstones of the Popatosa formation (Unit Tpfp). Similar rocks interfinger with the red volcaniclastic conglomerates to the west of the spring.

The small slot canyon where the spring is located ends in a headwall several meters high just west of the spring. Just upstream from there the drainage turns ~ 90° to the south and forms a small valley between two roughly parallel, north-south ridges. The east ridge is formed of unit Ta3 and was mentioned above; the west is ridge is also topped by west-dipping andesite lava flows (Units Ta2 and Ta1). These flows are truncated by the Silver Creek fault to the north of the mapped area. The drainage is eroded in sandstones and conglomerates of the Popatosa formation between the lava flows. The western ridge becomes subdued to the south and is broken by several crossing drainages that empty west into the north-flowing Silver Creek. Both ridges rise several hundred feet above the terrain to the east and west and plunge down to the north towards the Rio Salado.

Hydrologic Setting and Water Source: The only extensive topography higher than the spring that could provide a local recharge area is the twin ridge to the south of the spring. However, this is only a few square kilometers in area. The spring is discharging at an elevation of 5480 feet from a conglomerate layer that is overlain to the west by west-dipping, relatively impermeable andesite lava flows (see Map 4 and cross-section 5) that could act a confining layers. West of these ridge-forming lava flows is the steep canyon of Silver Creek whose floor is about 200 feet lower than the spring. Approximately eight km to the north is the Rio Salado at an elevation of 5000 feet. The landscape to the east drops in elevation to Valle Frutosa and the Rio Salado.

Because the spring was flowing during July 2002 after several months of drought and a dry winter, it is likely that the water source is a regional scale groundwater system less susceptible to annual precipitation variations. The spring is located below the surface outcrop of a potential confining layer (Units Ta1 and 2), at the northern outcrop extent of another potential confining layer (Unit Ta3). This suggests that the spring is discharging from an aquifer (the Popatosa conglomerates) between these two confining layers. The spring is also just to the west of the Silver Creek fault, which could be a barrier or conduit for groundwater flow.

Given these topographic and hydrogeologic constraints, a likely source for the water of Tortola Spring is from the west and/or southwest, rising up the dip of the strata, ultimately from the La Jencia basin. In addition, groundwater flow from the west or northwest could be diverted southeastward by the Silver Creek fault to vicinity of the spring. In either case, the spring location is controlled by where the relatively permeable conglomerate intersects the surface along the Silver Creek fault, and by the northern end of Unit Ta3.

Potential Threats: The greatest potential threat is that extensive groundwater pumping in the La Jencia Basin to the west may alter the regional water table configuration in terms of the magnitude and direction of the gradient. This could ultimately result in a decrease or complete cessation of spring discharge. The tamarisk growing in the canyon bottom near the spring are also a threat.

Potential Enhancements: The old concrete dam could be improved or replaced to create a tank with permanent water.

<u>Spring SA1 ("Canyon del Ojito Spring")</u>

Location: San Acacia 7.5 – minute quadrangle, UTM coordinates: 318221E, 3792605N.

Description: This spring is marked on the San Acacia quadrangle, but the marked location is incorrect. The spring is ~300 m upstream from the marked location in Canyon del Ojito. The spring is located at a 3 m high bedrock chute where the canyon narrows to a slot. The spring issues from fractured bedrock and flows as a sheet over the surface of the chute. There is wet sand in the canyon above the mouth of the chute and the canyon bottom is wet for several meters downstream of the spring. There are several small seeps in the immediately adjacent canyon walls. There are several tamarisk and Russian olive trees upstream and downstream of the spring. The spring was flowing on July 19, 2002.

Geologic Setting: The geology surrounding this spring is shown on map 6 and cross-section 7. It is located within an area of interbedded andesite and basaltic andesite lava flows and dark red to brown volcaniclastic conglomerates. These rocks comprise an eroded Tertiary volcanic center. They are surrounded by pinkish-tan to dark brown conglomerates, sandstones and mudstones of the Tertiary Popatosa formation. These rocks are faulted against and likely interfinger to some degree with the rocks of the volcanic center. They have been bevelled to a pediment surface with a thin gravel veneer.

The spring is located just upstream of an east-side down normal fault with displacement on the order of 80 meters. It places interbedded lavas, conglomerates and sandstones, against a thick (10s to 100s of meters) lava flow that forms the footwall of the fault. The footwall andesite is subhorizontal and strongly fractured adjacent to the fault. The water discharges from these fractures, which bound lozenge-shaped fragments of rock. Downstream of the spring on the south side of the canyon are several smaller displacement faults which bound steeply dipping interbedded lavas, sandstones and conglomerates. These fault do not appear to cross the canyon, as the north wall is dark brown volcaniclastic conglomerate overlying the same basaltic andesite lava that hosts the spring.

Hydrologic Setting and Water Source: The spring is discharging from a fractured zone in normally impermeable basaltic andesite lava adjacent to a fault. It is likely the water has risen some distance along the fault, probably from more permeable sedimentary rocks similar to the nearby conglomerates and sandstones. That the water is issuing from fractures adjacent to the fault suggests that the fault itself is a barrier to lateral flow and is forcing water to the surface in the adjacent fractures. The ultimate source is from the west, up and across the regional dip of the Popatosa formation sedimentary rocks that surround the volcanic center, as the regional topography drops steadily to the east to the Rio Grande and north to the Rio Salado.

Potential Threats: The greatest potential threat is that extensive groundwater pumping in the La Jencia Basin to the west may alter the regional water table configuration in terms of the magnitude and direction of the gradient. If this is the main source of water for the spring, this could ultimately result in a decrease or complete cessation of spring discharge.

The tamarisk and Russian olive trees growing in the canyon bottom near the spring both upstream and downstream of the spring are also threats.

Potential Enhancements: Removal of said trees.

Spring SdC2 ("Milagro Spring")

Location: Sierra de la Cruz 7.5 – minute quadrangle, UTM coordinates: 339295E, 3786795N.

Description: This spring is not marked on the quadrangle. The spring is discharging form beneath a small overhanging rock ledge 200 m north of Arroyo Milagro. Below the spring is a small draw heavily vegetated with grasses willows and one tamarisk. The flow trickles over the rock surface into a small pool within a marshy area below the ledge. This spring was developed for livestock use in the past, as there is a decrepit rock wall around the draw and a crumbling cabin just uphill form the spring. There is also an old windmill in the arroyo (Milagro Wells). The spring was flowing on July 17, 2002, and the flow had not changed when observed again on August 26, 2002.

Geologic Setting: The geology surrounding this spring is shown on map 7 and cross-section 8. The spring is within the Meseta Blanca member of the Yeso formation, which consists of sandstone and siltstone, with subordinate shale. It discharges from beneath an overhanging ledge of medium-grained sandstone which overlies reddish brown shale. To the south of the spring, the Meseta Blanca member plunges beneath and is juxtaposed against the overlying Torres member along a normal fault. The Torres member consists of sandstone, limestone and gypsum. In places the gypsum horizons are dissolved, creating breccias, chaotic bedding, and local faulting. They also commonly host shallowly dipping to subhorizontal detachment (normal) faults.

East of the spring, the lower Permian Abo formation outcrops beneath the Meseta Blanca member. It consists of mudstones, rhythmically bedded sandstones and mudstones, and siltstones and subordinate limestones. The outcrop pattern of the Meseta Blanca member and the Abo formation extends to the northeast towards higher ground outside of the map area.

The rocks in the vicinity of the spring are generally shallowly west-dipping. They and are folded into open anticlines and synclines and are cut by shallowly dipping detachment faults that remove portions of the geologic section. One of these faults is poorly exposed at the base of the buttes south of Arroyo Milagro. This fault places Upper Permian Glorieta sandstone and overlying San Andres limestone on top of the Torres member of the Lower Permian Yeso formation. The intervening Cañas gypsum and Joyita sandstone members of the Yeso formation have been faulted out. There is another detachment fault within the Torres member of the Yeso formation in the southwest portion of the mapped area. Numerous normal faults with east- or southeast-side down senses of movement and offsets of meters to tens of meters are present throughout the map area. Bed drag adjacent to a fault in the southwest portion of the map area suggests left-lateral strike-slip motion. Strike-slip motion may be present on some of the other faults in the area as well. Additionally, within the gypsum-bearing members of the Yeso formation (Torres and Canas) there are areas of breccia, chaotic bedding, and local faulting due to dissolution of gypsum.

Hydrologic Setting and Water Source: The spring is discharging from a depositional contact with sandstone above and shale below. The sandstone is likely more permeable than the shale. The overhang at the spring suggests that sapping has occurred, causing recession of the outcrop and perhaps forming the small draw below the spring.

As a hydrostratigraphic unit, the Meseta Blanca member of the Yeso formation which hosts the spring is likely to be more permeable than the overlying Torres member or the underlying Abo formation. Because of the many potential confining layers in the local stratigraphy, as well as the occurrence of subhorizontal detachment faults, the groundwater may have migrated along the sedimentary contact for some distance, probably along strike from the hills to the northeast. However, this does not provide a very large recharge area; thus it is likely that the water may have a deeper source and reached the level of the sedimentary contact by vertical movement along a normal fault. Note that Milagro Well in the arroyo south of the spring is located along the trace of a normal fault – this suggests that such faults in this area may be fairly permeable. A deeper and/or more distant source is consistent with the fact that the spring was flowing, albeit not tremendously, during an extended drought, and that the flow did not increase after the monsoon rains began. This is in contrast with the significant increase in flow observed at Cibola Spring in August, which indicates a shallower and/or more aquifer than that feeding Milagro Spring.

Chupadera Mesa to the east and the Los Piños Mountains to the northeast both are possible ultimate source areas for the spring water. However the water table in the area east of the refuge is complex, with a drainage divide east of the Los Piños Mountains that trends northeast across the north end of Chupadera Mesa. The water table also is strongly offset by the Montosa fault east of the Los Piños Mountains (Spiegel, 1955).

Potential Threats: The likelihood of a deep and/or distant source suggests that regional water table changes due to extensive groundwater pumping could negatively affect this spring. The most likely area where extensive pumping could have a negative effect is east of the Los Piños Mountains. The tamarisk trees growing near the spring in the draw are also a threat.

Potential Enhancements: Removal of said trees and perhaps development of a tank at the overhang. However, care should be taken not to disturb the marshy area as it provides beneficial wildlife habitat.

Springs LP3 and LP4

Locations: Ladron Peak 7.5 – minute quadrangle, LP3 UTM coordinates: 309708E, 3805700N; LP4 UTM coordinates: 309313E, 3805646N.

Description: Both of these springs are marked on the Ladron Peak quadrangle. They are between Ladron Peak and Cerro Colorado. LP3 is located at a 3 m high polished bedrock chute where Mule Canyon narrows considerably. There is a plunge pool below the chute that is 2 m in diameter and 0.5m deep. Around the chute and plunge pool are extensive salt stains, algae growth, and black organic stains. Upstream of the chute is a dense thicket with abundant willows and tamarisk. The spring was not flowing on July 1, 2002, but the plunge pool was filled with water, and there was no stream flow upstream in Mule Canyon.

LP4 is located 400 m west of LP3 in a tributary canyon to Mule Canyon. Although marked on the quadrangle as a single spring, it is actually an area about 100 m in length of multiple small springs in the canyon floor, all of which were dry on July 1 2002. Throughout this length there is abundant vegetation, in places forming impenetrable thickets. The vegetation includes cottonwood trees, grapevines, willows, tamarisk and grasses. The bedrock floor of the canyon has abundant salt and organic stains, and numerous small pools, some of which had standing water.

Geologic Setting: The geology surrounding these springs is shown on map 2 and cross-section 9. They are in a small basin bordered by Ladron Peak to the north, Cerro Colorado to the south, and a south-plunging ridge to the west capped by west-dipping Pennsylvanian limestones.

Both springs discharge from fractures and joints in bedrock on the contact between homogenous Proterozoic Capirote granite that forms the peak of Cerro Colorado, and a complex zone of several types of metasedimentary and metavolcanic rocks pervasively intruded by Capirote granite. Condie, (1976) mapped this zone as a "transition zone" between the Capirote granite and metamorphic rocks to the north. It is a border facies or zone of inclusions within the granite pluton. The metamorphic rocks in this zone are similar to those further north and include schist, phyllite, metarhyolite and amphibolite. In general it was not practical to map out all of the inclusions, but several of the larger ones are delineated on the map. There are two large masses of amphibolite between the transition zone rocks and the main mass of the granite. All of the rocks are foliated. The foliations are continuous between rock types, and define a southward plunging syncline or basin in the vicinity of the springs. The granite extends west an unknown distance west beneath the limestone ridge on the south flank Ladron Peak.

Hydrologic Setting and Water Source: The source of water for these springs is the mass of Capirote granite and transition zone rock that surrounds the springs and form the high topography to the south and west. The groundwater flow system is likely separate from that in the Proterozoic quartzite that feeds springs LP1 and LP2 to the north, as they had abundant flow in July 2002, whereas LP3 and 4 were dry. The multiple seeps and springs that comprise LP4 imply a less localized flow system than that discharging at springs LP1 and LP2.

If LP3 and LP4 only discharge water collected from the adjacent basin and high topography, it is not surprising that they were dry after an extended period of drought. However, the water in the plunge pool below LP3 was certainly derived from the spring, as there had been no precipitation for months when I observed it. This suggests that LP3 normally has more discharge than the many ephemeral seeps in the Ladron Peak area (described below). This in turn implies that the water is derived from a larger flow system in the Capirote granite, which may extend a considerable distance to the west.

Potential Threats: The greatest potential threat is that extensive groundwater pumping in the area west of Ladron Peak and Cerro Colorado may alter the regional water table configuration in terms of the magnitude and direction of the gradient. However, this does not appear likely because any producing wells would have to be very deep and drilled though hard limestone. The water table was more than 268 feet below the surface in the only well Spiegel (1955) reported in the area. Both springs have extensive thickets of tamarisk trees.

Potential Enhancements: The tamarisk trees at both springs should be removed. LP3 has a plunge pool that acts a natural tank. It is probably not practical to enhance LP4 with a tank, as there appears to be minimal flow and it is located in a narrow bedrock canyon.

Spring LP5

Location: Ladron Peak 7.5 – minute quadrangle, UTM coordinates: 309463E, 3808073N.

Description: This spring is not marked on the Ladron Peak quadrangle. It is located in a steep, narrow segment of Mule Canyon on the south flank of Ladron Peak. To the west of the spring the canyon steepens considerably, forming several overhangs and dropoffs. Small amounts of water discharge from joints in bedrock. The flow forms sheets across the bedrock surface an collects in several small pools. Along the canyon bottom are several large cottonwood trees, willow thickets, grapevines, and grasses. The spring had trickling flow on June 28, 2002.

Geologic Setting: The geology surrounding these springs is shown on map 2 and cross-section 10. The spring discharges at several sets of joints around the contact between moderately east-dipping amphibolite and schist where these units cross the narrow canyon. Immediately to the west is the isoclinally folded Proterozoic quartzite unit which hosts springs LP1 and 2. The amphibolite and schist are likewise probably isoclinally folded, but this is harder to discern in the field because these units lack the cross bedding of the quartzite. All of the rocks strike roughly north-south, as do the foliations in the area, creating a strong north-south structural grain. The quartzite unit forms a subsidiary peak on the south flank of Ladron Peak.

Hydrologic Setting and Water Source: The source of water is most likely the high ground of Ladron Peak to the north. The north-south structural grain probably is the dominant control on the groundwater flow system, and rules out a significant water source to the west. The flow system must be highly localized along developed joints that are not hydrologically connected to the flow system discharging at springs LP1 and 2, because of the great difference in discharge between the springs. This difference in discharge may also indicate smaller recharge area and/or a less transmissive flow system.

Potential Threats: None.

Potential Enhancements: None.

<u>Spring LJ1 - Los Alamos Spring</u>

Location: La Joya 7.5 – minute quadrangle, UTM coordinates: ~335500E, ~3797900N.

Description: This spring is marked on the La Joya quadrangle, but there is no evidence of a spring on the ground. The marked location is within Arroyo los Alamos west of

El Valle de la Joya and north of the Joyita Hills. Here the arroyo is in a broad valley with cottonwood trees lining the main channel and a very large, dense thicket of tamarisk covering many acres. To the north of the arroyo is a decrepit stone wall against the canyon wall that was possibly a corral. This suggests that there may have been a flowing spring in the vicinity in the past.

Geologic Setting: The geology surrounding this spring is shown on map 8 and cross-section 11. It is located in an alluvium-filled valley in an area of northwest-dipping Paleozoic and Mesozoic sedimentary rocks overlain by middle Tertiary volcanic and volcaniclastic rocks. These are faulted into a series of northeast-striking half-grabens bounded by east-side down normal faults. The rocks are bevelled and overlain by unfaulted, gently west-dipping sandstones and conglomerates of the upper Tertiary Santa Fe Group.

Hydrologic Setting and Water Source: The spring is in the middle of a large area of Quaternary alluvium; however it is roughly on strike with the trace of a normal fault to the north which could provide a conduit for deep groundwater, or water from beneath the high-level pediment to the north of the valley. Conversely, if the spring has been dried up by the large tamarisk thicket, it may be more likely that the groundwater flow system feeding it was a shallow system in the alluvium. In this case, the most likely source area for the spring is El Valle de la Joya to the east. Spiegel (1955) reported shallow alkaline groundwater and several seeps and expanses of salt crust along the east side of this valley. He also reported small flows from Los Alamos Spring and a seep upstream in the winter of 1949 that stopped by March

1950. It is likely that the continued growth of tamarisk and since then and the recent years of drought have lowered the water table enough to dry up the spring.

Potential Threats: It is possible the spring has been dried up by the tamarisk trees – these should be removed.

Potential Enhancements: See above.

Spring SdC3

Location: Sierra de la Cruz 7.5 – minute quadrangle, UTM coordinates: 340017E, 3786683N.

Description: This spring is not marked on the Sierra de la Cruz quadrangle. It is located 800 m east of SdC2, "Milagro Spring". It is adjacent to Arroyo Milagro, and is in a small grass-filled depression surrounded by juniper trees and an old barbed wire fence. It was not flowing on August 26, 2002.

Geologic Setting: The geology surrounding this spring is shown on map 7 and cross-section 8. It is in an area of complex folding, faulting, abundant dissolution breccia within the Torres member of the Yeso formation. It is approximately on the axis of an east-trending syncline. To the north is an east-side down normal fault, and to the west are several small displacement thrust faults. This folding and fault may be related to the dissolution of gypsum.

Hydrologic Setting and Water Source: Although this spring is close to "Milagro Spring", the local geology is quite different. The spring probably discharges along a small fault or zone of fractures related to the syncline. The water source is difficult to determine given the complex geology – it may have been a relatively deep source rising along the above-mentioned structures; or it may have been draining a cavernous area related to gypsum dissolution, a source potentially more susceptible to drought conditions. In any event, it is probably moving along a different flow path than the water discharging at “Milagro Spring”, as there is no phreatophyte vegetation or any other evidence that it has flowed in the recent past. The ultimate source may be the same as that for “Milagro Spring” however; Chupadera Mesa to the east and the Los Piños Mountains to the northeast.

Potential Threats: The likelihood of a deep and/or distant source suggests that regional water table changes due to extensive groundwater pumping could negatively affect this spring. The most likely area where extensive pumping could have a negative effect is east of the Los Piños Mountains.

Potential Enhancements: None.

VII. EXAMPLES OF SEEPS IN THE LADRON PEAK AREA

<u>Seeps LP6 and LP7</u>

Locations: Ladron Peak 7.5 – minute quadrangle, LP6 UTM coordinates: 310596E, 3808529N; LP7 UTM coordinates: 311012E, 3808640N.

Description: These seeps are not marked on the Ladron Peak quadrangle. They are in the bedrock floor of La Cueva Canyon. The water discharges from joints. Both seeps have salt and organic stains around the joints and in adjacent small depressions.

Cottonwood trees and willow thickets are present, but no tamarisk. Neither were flowing on June 27, 2002

Geologic Setting: The geology around these seeps is shown on map 2 and cross section 10. They are located in an area of strongly jointed Proterozoic Capirote granite in an east-trending canyon. The joints largely strike north-south. There are hills to the north and south, and the drainage opens to the west into a broad valley filled with alluvium and colluvium. This valley is underlain by Proterozoic schist, metarhyolite and amphibolite that dip steeply to the east.

Hydrologic Setting and Water Source: There are at least two possibilities for the water source for these seeps. The hills to the north and south of the drainage could provide a local, but small, recharge area and the dominant north-south joint set provides a pathway to the seeps. In this case, it is not surprising that the seeps were dry after months of drought. Another possibility is that the seeps discharge water from a deeper or more distant source, perhaps the main mass of Ladron Peak to the west, and are at the periphery of a larger groundwater flow system. In this case these seeps may only flow during times of regionally high groundwater levels, such as during spring snowmelt. The available data are not sufficient to choose between these two scenarios.

Potential Threats: None.

Potential Enhancements: None.

Seep LP8

Locations: Ladron Peak 7.5 – minute quadrangle, UTM coordinates: 311093E, 3810238N.

Description: This seep is in the bedrock floor of an unnamed canyon near the north boundary of the refuge. It is located at a small knickpoint or bedrock ledge; upstream and downstream the canyon is floored with sand and gravel. There are abundant salt and organic stains on the rocks and in small depressions. Cottonwood trees, willows, and tamarisk shoots grow around the seep. It was not flowing on July 3, 2002, but was trickling water on August 2, 2002, after the monsoon rains.

Geologic Setting: The geology around this seep is shown on map 2 and cross section 12. It is located near the contact between two Proterozoic granitic plutons, the Capirote granite and the Ladron quartz monzonite. All of the rock is pervasively jointed. To the west are steeply east-dipping, northeast-striking layers of amphibolite, metarhyolite and schist. The terrain to the east is dominated by broad valleys eroded in granite with shallow drainages and isolated high hills, some of which are capped by Quaternary (?) or Tertiary (?) gravels. Immediately to the west, the terrain rises rapidly to the summit of Ladron Peak, has greater local relief and is far more rugged.

Hydrologic Setting and Water Source: The probable water source for these springs is the main mass of Ladron Peak to the west. There are no obvious geologic factors influencing the seep's location. It is possible that the local topographic change causes a shallow flow system to discharge at the surface here. The trickling of water observed later in the summer suggests a shallow flow system, or that the seep may be fed by saturated colluvium upstream in the drainage (see description of LP12 below).

Potential Threats: The tamarisk shoots growing around the seep.

Potential Enhancements: Removal of the tamarisk.

<u>Seeps LP9 and LP10</u>

Locations: Ladron Peak 7.5 – minute quadrangle, LP9 UTM coordinates: 312404E, 3808486N; LP10 UTM coordinates: 311633E, 3809481N.

Description: These seeps are not marked on the Ladron Peak quadrangle. Both are in bedrock within drainages on the east flank of Ladron Peak. Both have abundant salt and organic stains on the rocks and associated cottonwood trees and willows, but no tamarisk. Neither seep was flowing on June 27, 2002.

Geologic Setting: The geology around these seeps is shown on map 2 and cross sections 13 and 14. LP9 is within an area of altered, foliated Proterozoic Capirote granite with abundant amphibolite inclusions. It discharges from east-striking joints in a bedrock high in the drainage. LP10 is within an area of jointed, Proterozoic Ladron quartz monzonite. Similar to LP8, the terrain to the east is dominated by broad valleys eroded in granite with shallow drainages and isolated high hills, some of which are capped by Quaternary (?) or Tertiary (?) gravels. To the west, the terrain rises to the summit of Ladron Peak and has greater local relief. However, the topographic change here is not as drastic as that near LP8.

Hydrologic Setting and Water Source: The probable water source for these springs is the main mass of Ladron Peak to the west. There are no obvious geologic factors influencing either seep's location. Again, it is possible that the local topographic change causes a shallow flow system to discharge at the surface here.

Potential Threats: None.

Potential Enhancements: None.

<u>Seep LP11</u>

Location: Ladron Peak 7.5 – minute quadrangle, UTM coordinates: 310701E, 3806498N.

Description: This seep is not marked on the Ladron Peak quad. It is located in a bedrock-floored drainage on the southeast flank of Ladron Peak in an area of rounded hills between Mule and La Cueva Canyons. There are salt and organic stains surrounding fractures, and thickets of tamarisk, Russian olive, and willow, and three cottonwood trees. The seep was not flowing on July 1 or August 19, 2002.

Geologic Setting: The geology around this seep is shown on map 2 and cross section 3. It is located within a large expanse of foliated Proterozoic Capirote granite, on a broad, hilly interfluve between two south flowing drainages. The rock is heavily jointed, with a northwest-southeast strike being most common.

Hydrologic Setting and Water Source: The water source for these springs is not obvious. There are hills to the north and west that could provide a local recharge area. The water could also be derived from a deeper flow system, ultimately from the main mass of Ladron Peak to the north and west. There are no obvious geologic factors influencing the seep's location.

Potential Threats: None.

Potential Enhancements: None.

Seep SC4

Location: Silver Creek 7.5 – minute quadrangle, UTM coordinates: 309737E, 3803159N.

Description: This seep is not marked on the Silver Creek quad. It is located in a gravel-floored arroyo on the southeast side of Cerro Colorado. There is no sign of a discharge point, but it may be obscured by the thick vegetation. There are several cottonwoods and a thicket of willows, reeds, tamarisk and grasses. The seep was not flowing on July 1 or August 13, 2002.

Geologic Setting: The geology around this seep is shown on map 2 and cross section 15. It is located in an area of strongly foliated Proterozoic Capirote granite with numerous irregular bodies and dikes of pegmatite. The hills on either side of the drainage are capped with Quaternary (?) or Tertiary (?) gravels. The thicket of vegetation is on the trace of a northeast striking, oblique-slip fault. Slickensides on the fault indicate east-side down, right lateral movement. 500 m to the east of the seep is an east-side down normal fault that places greyish-tan conglomerates and sandstones of the Tertiary Popatosa formation against the granite. The first fault may be a splay of this larger fault.

Hydrologic setting and water source: Because the seep is on the trace of a fault, it may be discharging water with a deep or distant source. Another possibility is that Cerro

Colorado to the west provides a recharge area for a shallow flow system which is diverted to the surface by the fault. The available data are not sufficient to choose between these two scenarios.

Potential Threats: The tamarisk growing around the seep.

Potential Enhancements: Removal of the tamarisk.

<u>Seep LP12</u>

Location: Ladron Peak 7.5 – minute quadrangle, UTM coordinates: 310959E, 3809492N.

Description: This seep is not marked on the Ladron Peak quadrangle. It is located at a bedrock constriction which forms a ledge just downstream of where two steep drainages come together. The seep is marked by salt and organic stains around fractures. It was dry on June 27 2002, but had a trickling flow on August 2, 2002, after the monsoon rains had begun.

Geologic Setting: The geology around this seep is shown on map 2 and cross section 14. It is in an area of jointed Proterozoic Capirote granite. Upslope from the seep is an area of colluvium where the two steep drainages come together.

Hydrologic Setting and Water Source: The water source for this seep is the colluvium upslope in the drainage. The several rainstorms between the two observations of the seep saturated the colluvium. The water slowly drains downslope into shallow subsurface joints and then discharges at the seep at the bedrock ledge. This is a common geometry for seeps on the refuge. Water pockets upslope from seeps also can provide water sources.

Potential Threats: None.

Potential Enhancements: None.

VIII. SPRINGS OFF OF THE REFUGE

Spring SLS2

Location: San Lorenzo Spring 7.5 – minute quadrangle, UTM coordinates: 315441E, 3790571N.

Description: This spring is marked on the San Lorenzo Spring quadrangle. It a few meters south of the refuge fence on the north side of San Lorenzo Arroyo, 1.5 km east of SLS1. It has been developed; there is a buried steel box filled with water. There is a marshy area around the spring with grasses, willows, cattails, and cottonwood trees. The spring was flowing on July 19, 2002.

Geologic Setting: The geology around this spring is shown on map 3 and cross section 4. It is located at the east side of a rugged outcrop belt of Tertiary lava flows and shallow intrusive rocks that extends north to the Rio Salado and south towards Socorro. The geology is complex; the rocks are strongly faulted, and the strikes and dips of strata and faults are variable. The spring is at the toe of a small promontory of basaltic andesite lava overlain by rhyolite ash-flow tuff. It is approximately on the contact of the basaltic andesite lava with mudstones, sandstones and conglomerates of the Popatosa formation which extend to the east and form the slot canyons of San

Lorenzo Arroyo. These sedimentary rocks appear to lap onto or interfinger with the volcanic rocks.

Hydrologic Setting and Water Source: The contact between the sedimentary and volcanic rocks controls the location of this spring. The sedimentary rocks are more permeable than the lava flows and tuff, although the volcanic rocks may have locally enhanced permeability from fractures and faults. The abundant flow suggests a reliable, deep-seated water source, likely the La Jencia Basin to the west. The water flows east through the relatively permeable Popatosa formation conglomerates in the basin and/or the underlying volcanic rocks along (and across?) the dip of the strata and rises to the surface where it encounters the relatively impermeable lava flows. The flow path to this spring through the volcanic rocks is along flow contacts, joint networks and faults.

Potential Threats: : The greatest potential threat is that extensive groundwater pumping in the La Jencia Basin to the west may alter the regional water table configuration in terms of the magnitude and direction of the gradient. This could ultimately result in a decrease or complete cessation of spring discharge.

Potential Enhancements: None.

<u>Springs SLS3 and 4</u>

Locations: San Lorenzo Spring 7.5 – minute quadrangle, SLS3 UTM coordinates: 313920E, 3790213N; SLS4 UTM coordinates 313564E, 3790206N.

Description: SLS4 is marked on the San Lorenzo Spring quadrangle; SLS3 is not. They are located just west of the refuge boundary and SLS1 in bedrock outcroppings in San Lorenzo Canyon. The sand and gravel around both springs are wet and there are abundant algae and salt stains at both springs. Several willows are growing near SLS3. Around SLS4 are grasses, reeds, cattails, willows and several pruned tamarisk. Both springs were flowing on July 19, 2002, with a trickle coming from SLS3 and several pools of standing water around SLS4.

Geologic Setting: The geology surrounding these springs is shown on map 3 and cross-section 4.They are located in an area of Tertiary andesite and basaltic andesite lava flows with interbedded conglomerates, overlain to the west by younger, west-dipping, Tertiary conglomerates of the Popatosa formation. The host rocks are west-dipping and are cut by numerous north- or south-striking normal faults with motion down to the east or west. Displacement on some of these fault varies laterally, and some of the faults end within the map area.

SLS3 is located approximately at the depositional contact between andesite lava to the east and Popatosa formation conglomerates to the west. It arises from fractures in the lava flow. SLS4 is located within the Popatosa conglomerates.

Hydrologic Setting and Water Source: As for SLS1, the water source for these springs is the La Jencia Basin to the west. The water flows east through the relatively permeable Popatosa formation conglomerates along (and across?) the dip of the strata and rises to the surface where it encounters the relatively impermeable lava flows. As these flows strike north-south and are quite extensive, the springs may collect groundwater from a large area if it migrates north and south along the flows to reach the spring which is a topographic low.

Potential Threats: : The greatest potential threat is that extensive groundwater pumping in the La Jencia Basin to the west may alter the regional water table configuration in terms of the magnitude and direction of the gradient. This could ultimately result in a decrease or complete cessation of spring discharge. Tamarisk growth in this area is extensive, but the trees were cut in the summer of 2002.

Potential Enhancements: Tamarisk should be removed as it grows back.

Spring LP13

Location: Ladron Peak 7.5 – minute quadrangle, UTM coordinates: 308923E, 3807434N.

Description: This spring is marked on the Ladron Peak quadrangle. It is on the same ridge as springs LP1 and 2, 250 m north of the refuge fence. The location is in a talus field with thick growth of piñon and juniper trees and grapevines. However, there is no sign of a spring on the ground or flowing water, marshy ground, etc. The spring was not flowing on June 28, 2002.

Geologic Setting: The geology surrounding this spring is shown on map 2 and cross-section 3. It is on the same ridge of isoclinally folded quartzite as springs LP1 and LP2. The foliations, and joints developed along foliations and bedding create a strong north-south structural grain.

Hydrologic Setting and Water Source: This spring, along with springs LP1 and LP2, most likely derives water from Ladron Peak to the north. Its location on the hillside, far above the drainages on either side, makes it very unlikely that the water is derived from anywhere other than down the ridge from the main mass of Ladron Peak. As with the adjacent springs, the flow path to this spring must be very localized as it was not flowing whereas the nearby springs were flowing abundantly. The location of the spring is probably determined by the intersection of a prominent fracture or joint with the ground surface.

Potential Threats: None.

Potential Enhancements: None.

IX. SUMMARY

With a few exceptions, the springs are at low places in the landscape, usually in drainages. Those that do not probably reflect highly channelized subsurface flow. Taken together, the springs on the refuge nicely illustrate the variety of geologic factors that can be involved in groundwater discharge, and the widely varying permeability of fault zones. For example: the large springs on the south flank of Ladron Peak discharge from localized flow systems in fractures and joints in quartzite; Cibola Spring discharges along a fault; the springs in western San Lorenzo Canyon discharge where a dipping, impermeable andesite bed intersects the surface; “Canyon del Ojito” spring discharges from fractures adjacent to an apparently impermeable fault in nominally low permeability andesite; and "Milagro Spring" discharges from a contact between sedimentary rocks of differing permeability.

The main threats to the springs, as noted in the individual descriptions, are regional groundwater pumping and the growth of tamarisk and other non-native phreatophyte vegetation. Los Alamos spring appears to have already been dried up by tamarisk growth. It is clear that the Rio Salado Springs, the springs in San Lorenzo Canyon, Tortola Spring, "Canyon del Ojito Spring", and probably springs LP3 and 4 are all discharging water from regional groundwater systems, and the source areas for these springs are reasonably well defined. "Milagro Spring" and spring SdC3 probably are discharging water from regional groundwater systems, but the source areas are less well known. These springs may be negatively affected by extensive groundwater pumping in the La Jencia Basin, the Colorado Plateau west and northwest of Ladron Peak, and perhaps on Chupadera Mesa and the area east of the Los Piños Mountains.

The main potential enhancement for most springs would be to build tanks to collect the spring discharge. However, as noted, for some of the springs this is probably not a good idea due to their very low flow, location in canyon bottoms, or because such construction may disturb the habitat around the spring.

The most common hydrologic settings and water sources for seeps are proximal upslope deposits of saturated alluvium or colluvium, or filled water pockets (e.g., LP12). Other seeps have no obvious local geologic cause (e.g., LP11), or appear to be controlled by local topography (e.g., LP9, LP10 and LP8). Seeps are potentially an important water source on the refuge, but are not perennial. Like the water pockets they are sometimes associated with, seeps can "store" precipitation after snow or rainfall events and release it over a time of hours (?) to weeks (?), thus increasing the availability of water that other wise would run off and not be available for wildlife.

X. SUGGESTIONS FOR FUTURE WORK

Some of the uncertainty about the sources of water for the springs could be resolved with a program of water chemistry testing. The spring waters could be sampled and analyzed for major and trace elements and the isotopic composition of the water. For example, high concentrations of dissolved gypsum in the waters from “Milagro Spring” would confirm the interpretation of a long flow path through the gypsiferous rocks. Differences in water chemistry from the springs on the south flank of Ladron Peak would confirm the interpretation of separate non-interconnected flow systems for these springs. High dissolved CO_2 levels in the waters of the springs in the Salado Box would be consistent with the interpretation of a long flow path through the Madera limestone for those waters. Such testing could also identify any high levels of dangerous compounds or elements, such as nitrate or selenium, or high levels of dissolved solids that would make the water unpalatable for wildlife.

Determining the ultimate source area for Milagro Spring and spring SdC3 requires more data on the water table contours in the eastern area of the refuge and beyond. This would require checking water levels in all wells in the area and/or installing piezometers. Removal of tamarisk around Los Alamos Spring and the valley to the east could raise the water table enough for the spring to begin flowing again.

Periodic or seasonal flow measurements of the more important springs could help determine whether spring discharges are being affected by regional groundwater pumping.

XI. UNIT DESCRIPTIONS FOR GEOLOGIC MAPS

Map 1 - Springs SC1 and SC2 ("Rio Salado Springs")

Qay – Unconsolidated Recent alluvium: Mud, sand and gravel in active and ephemeral stream channels and arroyos.

Qao – Unconsolidated to partly consolidated older alluvium: Mud, sand and gravel that forms terraces incised by modern stream and arroyos.

Tsfp – Tertiary Upper Santa Fe Group piedmont facies deposits: Pinkish-tan medium to coarse sandstone and conglomerate.

IPm – Pennsylvanian Madera Group limestone: Gray medium to thick-bedded limestone.

Map 2 – Springs and seeps in the Ladron Peak area

Qay – Unconsolidated Recent alluvium: Mud, sand and gravel in active and ephemeral stream channels and arroyos. Grades into colluvium west of springs LP6 and 7.

Qtp – Quaternary-Tertiary pediment deposits: Hill-capping gravels composed of cobble of granitic and metamorphic rocks.

Tpf – Conglomerate of Tertiary Popatosa formation : Greyish-tan conglomerate and sandstone deposited in alluvial fans.

p€q – Proterozoic quartzite: White to grey crossbedded quartzite.

p€am – Proterozoic amphibolite: Black fine- to coarse-grained amphibolite.

p€mv – Proterozoic metavolcanic rocks: Pink to orange, very fine-grained metarhyolite.

p€spq – undivided Proterozoic metamorphic rocks: Intimately interbedded and/or transposed schist, phyllite, "siltite" and feldspathic quartzite.

p€s – Proterozoic porphyroblastic schist: Mica schist with porphyroblasts of amphibole and chloritoid.

p€lap – late-stage components of the Proterozoic Ladron quartz monzonite: White quartz monzonite, aplite and pegmatite.

p€lg – Proterozoic Ladron quartz monzonite: Buff coarse-grained quartz monzonite.

p€cag – altered Proterozoic Capirote granite: Capirote granite altered to white chalky appearance.

p€ct – "Transition zone" of Proterozoic Capirote granite: Complexly intruded metasedimentary (schist and phyllite) and metavolcanic (metarhyolite and amphibolite) rocks.

p€cg – Proterozoic Capirote granite: Medium-grained red granite.

Map 3 - Springs SLS1 (San Lorenzo Spring), 2, 3, and 4

Qay – Unconsolidated Recent alluvium: Mud, sand and gravel in active and ephemeral stream channels and arroyos.

Tr – Tertiary rhyolite: Pinkish-red rhyolite ash-flow tuff with fiamme, 1% phenocrysts of quartz, and 1% phenocrysts of potassium feldspar. Lithic content increases upwards.

Ta1 – Tertiary andesite: Andesite lava flow with 8-10% phenocrysts of hornblende.

Ta2 – Tertiary andesite: Andesite lava flow with 1% phenocrysts of hornblende.

Tba – Tertiary basaltic andesite: Basaltic andesite lava flow with 3% phenocrysts of hornblende (needles and large crystals), 3% phenocrysts of olivine in clots, and 2% phenocrysts of plagioclase feldspar. Cu staining is abundant.

Ta3 – Tertiary andesite: Andesite lava flow with 5% phenocrysts of hornblende.

Tpf – Tertiary Popatosa formation conglomerate: Dark brown to red volcaniclastic conglomerate. Possible interfingering relationships with units Ta1 to Ta3.

Tpp – Undivided piedmont facies deposits of Tertiary Popatosa formation: Tan to pink coarse sandstone, sandstone and siltstone, with subordinate conglomerate and claystone. Gradational and interfingering relationship with Tpf.

Map 4 - Spring SDC1 (Cibola Spring)

Qay – Unconsolidated Recent alluvium: Mud, sand and gravel in active and ephemeral stream channels and arroyos.

Qao – Unconsolidated to partly consolidated older alluvium: Mud, sand and gravel that forms terraces incised by modern stream and arroyos.

Pa – Permian Abo formation: Interbedded red to brown sandstone, siltstone, mudstone and conglomerate.

ℙPb – Pennsylvanian-Permian Bursum formation: Light brownish gray, dark gray, and brownish black conglomerate, sandstone, shale and limestone.

ℙm - Pennsylvanian Madera Group limestone: Gray medium to thick-bedded limestone.

Map 5 - Spring SC3 (Tortola Spring)

Qay – Unconsolidated Recent alluvium: Mud, sand and gravel in active and ephemeral stream channels and arroyos.

Ta1 – Tertiary andesite: Andesite lava flow with 4% phenocrysts of hornblende.

Ta2 – Tertiary andesite: Andesite lava flow with 1% phenocrysts of hornblende and numerous zeolite-filled vesicles. Cu staining is abundant.

Tpfp – Conglomerate and undivided piedmont facies deposits of Tertiary Popatosa formation: Pinkish tan and red conglomerate, coarse sandstone, and sandstone, and red mudstone.

Tscd – Conglomerate, sandstone and debris flow deposits of Tertiary Popatosa formation: Dark red proximal volcaniclastic sedimentary rocks.

Ta3 – Tertiary andesite: Andesite lava flow with 4% phenocrysts of hornblende, 5% phenocrysts of plagioclase feldspar and abundant zeolite-filled vesicles.

Map 6 - Spring SA1 ("Canyon del Ojito Spring")

Qay – Unconsolidated Recent alluvium: Mud, sand and gravel in active and ephemeral stream channels and arroyos.

QTp – Quaternary-Tertiary pediment deposits: Cobbles on surface bevelled on dipping Santa Fe Group strata.

Tpp - Undivided piedmont facies deposits of Tertiary Popatosa formation: Tan to pink coarse sandstone, sandstone and siltstone, with subordinate claystone and conglomerate.

Tpf – Conglomerate of Tertiary Popatosa formation: White to gray conglomerate.

Tba1 – Tertiary basaltic andesite: Basaltic andesite lava flow with abundant hornblende phenocrysts.

Tba2 – Tertiary basaltic andesite: Basaltic andesite lava flow with olivine phenocrysts.

Ta – Tertiary andesite: Andesite lava flow with plagioclase phenocrysts.

Tba3 - Tertiary basaltic andesite: Basaltic andesite lava flow with olivine phenocrysts.

Tscb – Conglomerate, sandstone and breccia of Tertiary Popatosa formation: Dark brown to red volcaniclastic sedimentary rocks.

Tba4 - Tertiary basaltic andesite: Basaltic andesite lava flow with hornblende and olivine phenocrysts.

<u>Map 7 - Springs SdC2 ("Milagro Spring") and 3</u>

Qay – Unconsolidated Recent alluvium: Mud, sand and gravel in active and ephemeral stream channels and arroyos.

Qae – Recent aeolian sand: Sheets and small dunes of clean sand.

Psa – Permian San Andres Limestone: Medium-bedded gray limestone and dolomite.

Pg – Permian Glorieta Sandstone: Cross-bedded, white to cream, very well sorted quartz sandstone.

Pyt – Torres member of the Permian Yeso formation: Light reddish-brown sandstone, thin gray limestone, and light gray gypsum.

Pym – Meseta Blanca Sandstone member of the Permian Yeso formation: Orange and pink tabular sandstone with abundant salt casts and reddish brown siltstone.

Pa – Permian Abo formation: Grayish red, dark grayish red, and dark reddish brown, rhythmically bedded sandstone, siltstone, and mudstone. Fluvial sedimentary structures and channel bedforms common.

<u>Map 8 - Spring LJ1 (Los Alamos Spring)</u>

Qay – Unconsolidated Recent alluvium: Mud, sand and gravel in active and ephemeral stream channels and arroyos. Inset against Qao.

Qao – Unconsolidated to partly consolidated older alluvium: Mud, sand and gravel that forms terraces incised by modern stream and arroyos.

Tsfp – Tertiary Upper Santa Fe Group piedmont facies deposits: Pinkish-tan medium to coarse sandstone and conglomerate.

Tljba – Tertiary La Jara Peak (?) basaltic andesite: Aphanitic basaltic andesite.

Tvs – Tertiary volcaniclastic sandstone: Pink volcaniclastic sandstone.

Tljr – Tertiary La Jencia Tuff: Pink rhyolite ash-flow tuff with fiamme, 3% phenocrysts of quartz, 1% phenocrysts of sanidine, and 1% phenocrysts of hornblende and biotite.

Thmr – Tertiary Hells Mesa Tuff: Rhyolite ash-flow tuff. Base has 5% phenocrysts of biotite, 5% lithic fragments, and 1% phenocrysts of sanidine at base to 40% phenocrysts of quartz, 5% phenocrysts of sanidine, and 3% phenocrysts of biotite at top.

Tdaba – Andesite and basaltic andesite of Tertiary Datil Group: Multiple generations of basaltic andesite and andesite dikes, lava flows and/or sills.

Tdsc – Sandstone and conglomerate of Tertiary Datil Group: Red to tan volcaniclastic sandstone and conglomerate with cobbles and boulders of andesite.

Tdr – Rhyolite of Tertiary Datil Group: Rhyolite with 20% phenocrysts of quartz, 3% phenocrysts of biotite, and 2% phenocrysts of sanidine.

Tdrasc – Undivided volcanic and sedimentary rocks of Tertiary Datil Group: Interbedded rhyolite, andesite, and volcaniclastic sandstone and conglomerate.

Pa – Permian Abo formation: Interbedded red to brown sandstone, siltstone, and mudstone.

PIPb – Pennsylvanian-Permian Bursum formation: Dark brown sandstone and brownish gray limestone.

IPm - Pennsylvanian Madera Group limestone: Strongly brecciated gray massive limestone with dark brown chert.

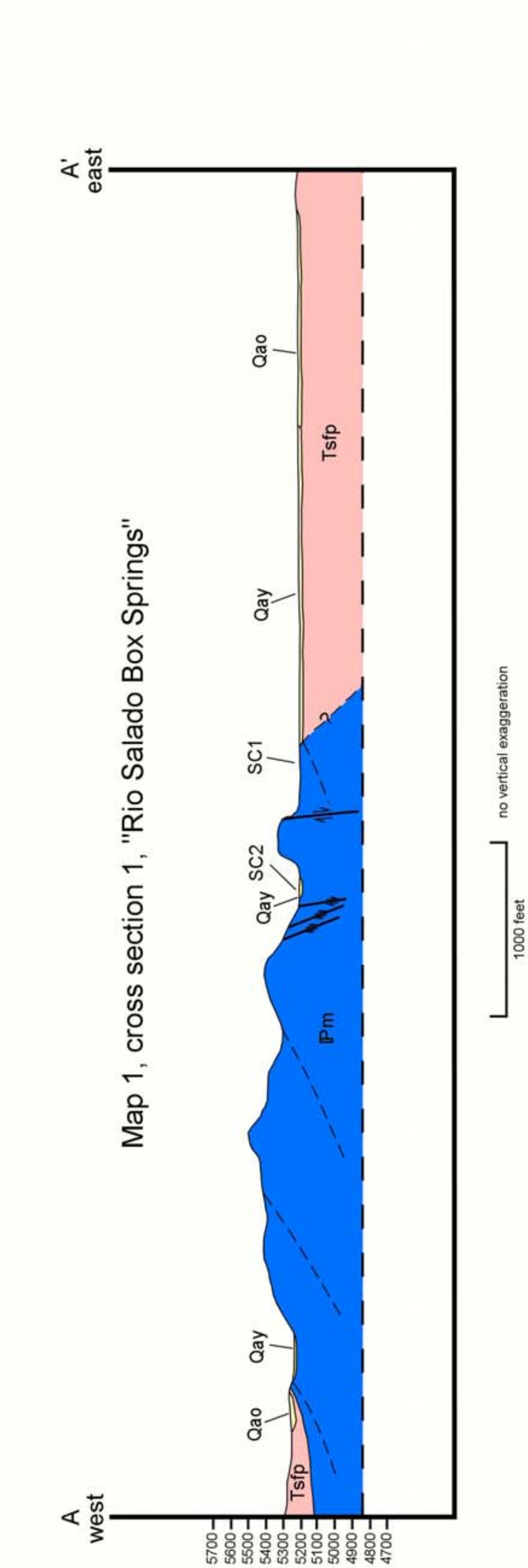
XII. PHOTO DESCRIPTIONS

The photos of the springs and seeps are in the "sev_field_pix" directory on the cd. They are also accessible by clicking on the spring marker on the maps in the .mxd or .pmf files with the hyperlink tool. This will open the .tif file in a graphics program such as Photoshop. They are labeled by spring number (see section V). The photos are either close-up shots or overviews of the immediate surroundings of the springs. There are no pictures for springs SC2, LP9, or LP10. Most photos have either a 30-cm rock hammer, a 6-cm lens cap, or vegetation such as piñon or juniper trees for scale. Three additional photos are included of seeps. Photo "pinos_seep_1.tif" shows a rain-filled water pocket in granite in the Los Pinos Mountains. Photo "pinos_seep_2.tif" shows a cliff face with black-stained seeps draining water pockets on the summit above. These are typical features in areas of Proterozoic bedrock. Photo SLC_seep.tif shows a seep emanating from a bedding contact in Tertiary Popatosa conglomerate in San Lorenzo Canyon.

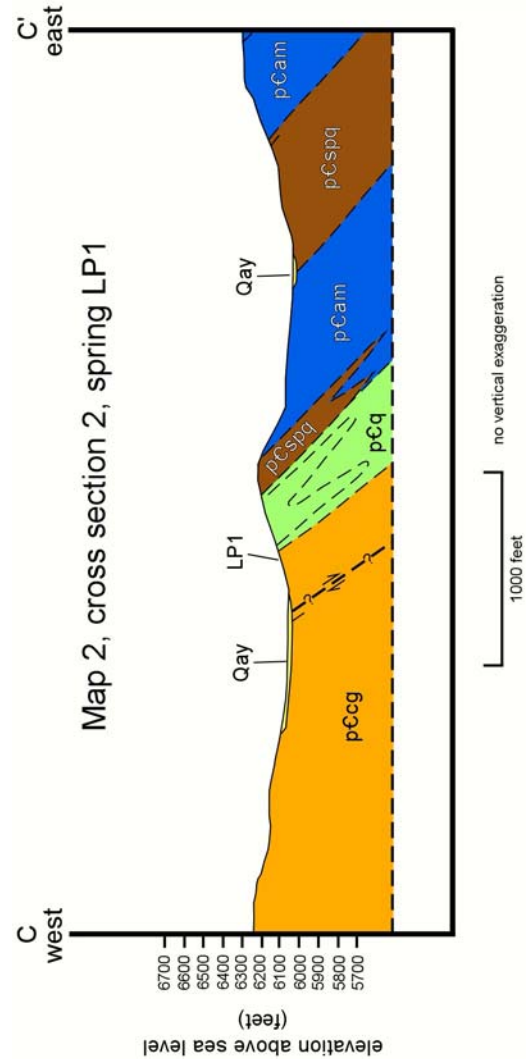
XIII. CROSS SECTIONS

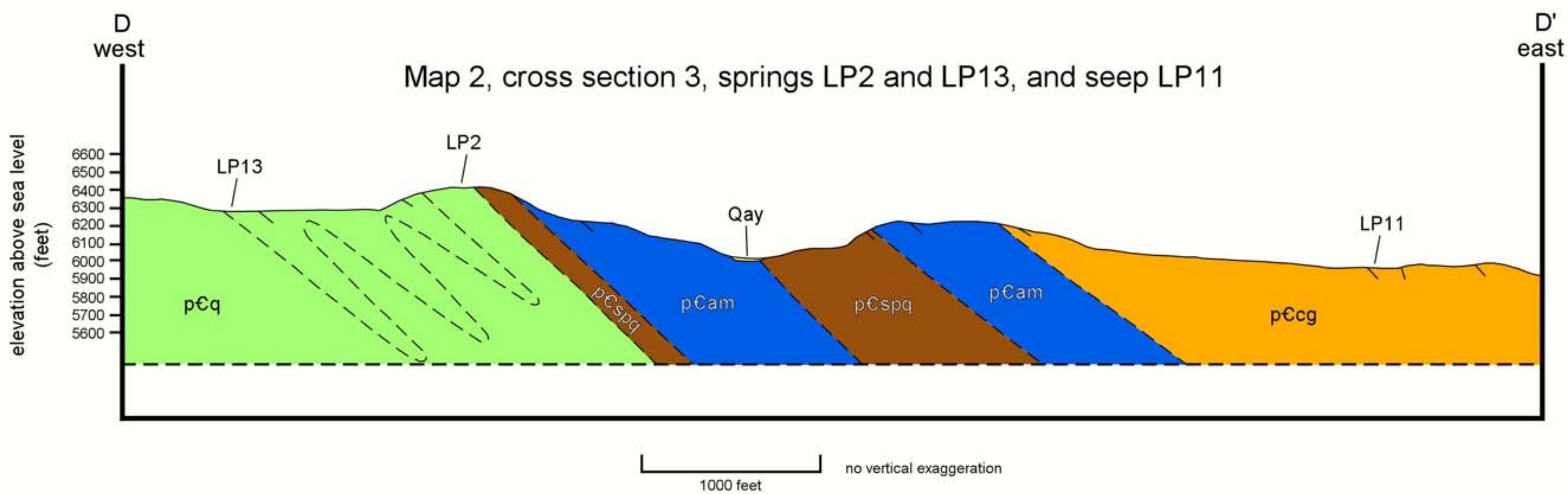
The cross sections are included on the following pages in the order given in sections V, VI, and VII. See the geologic maps and section X for the unit descriptions.

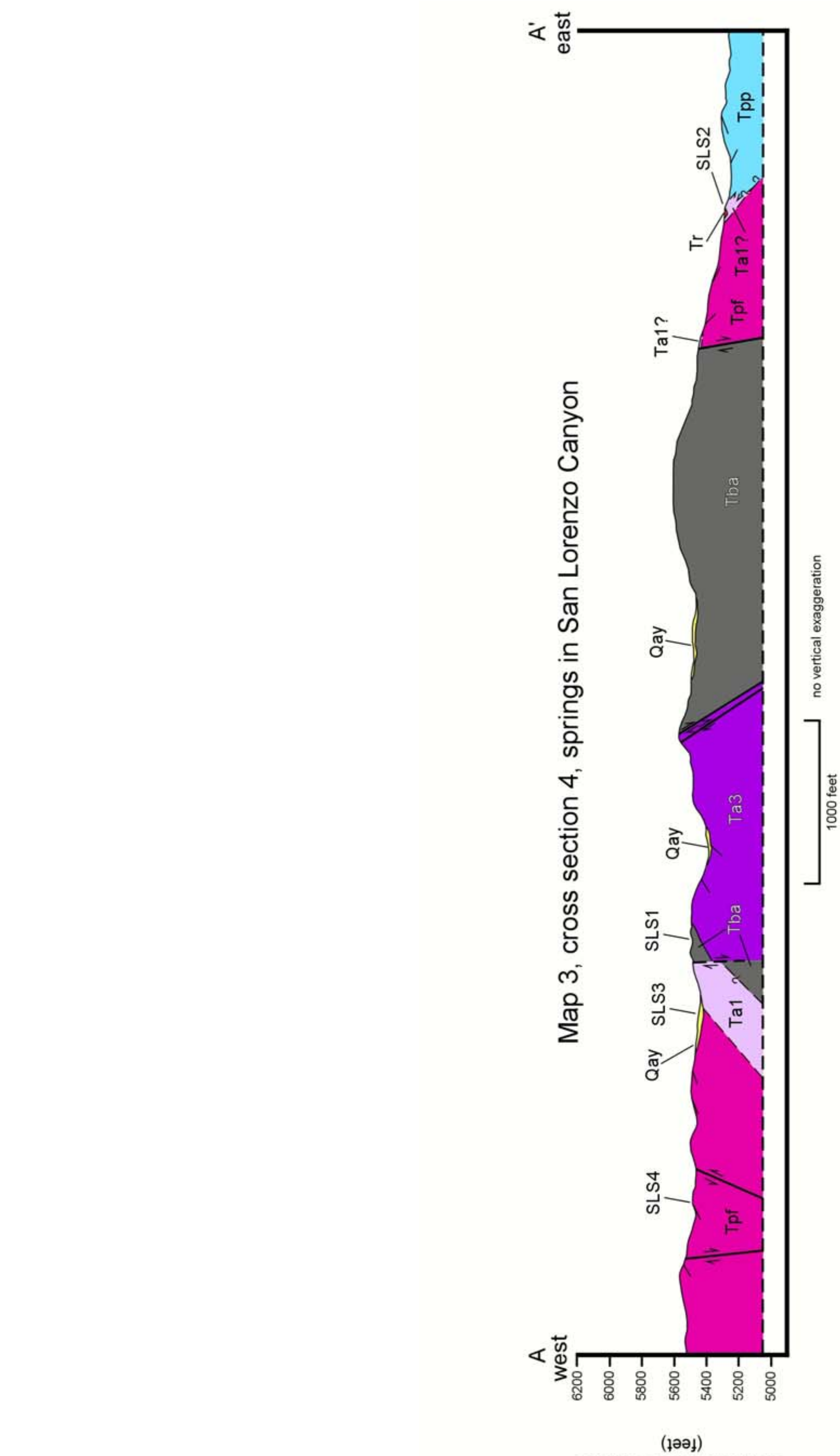
Note that cross sections 1 and 7 are slightly smaller than true scale (~95% true scale) so as to fit on a single page.



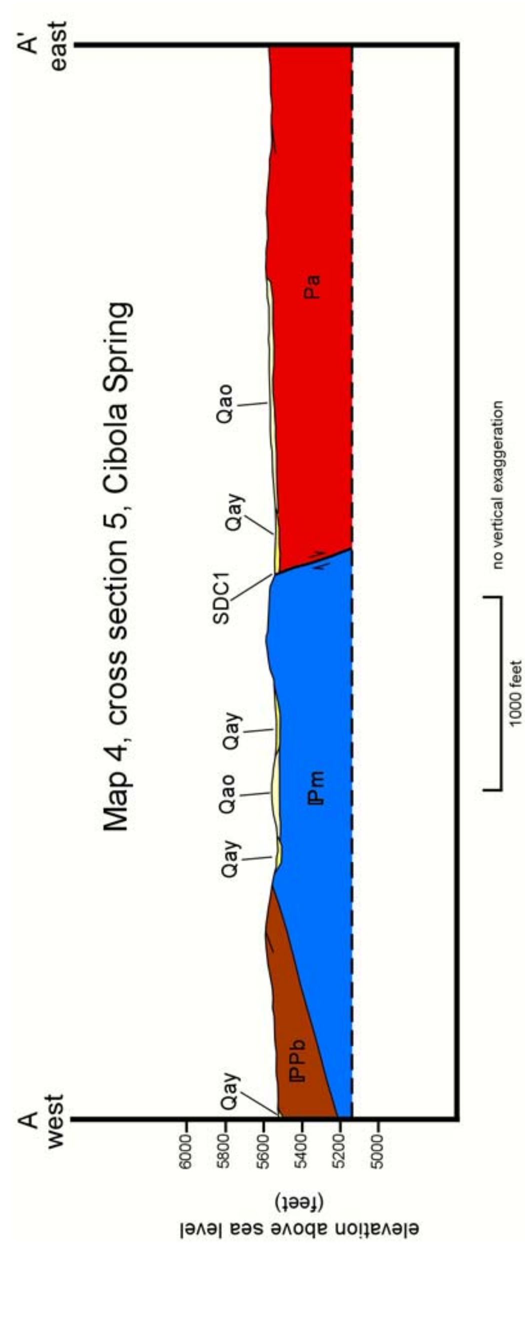
Map 1, cross section 1, "Rio Salado Box Springs"
A
west
A'
east
elevation above sea level
(feet)
5700
5600
5500
5400
5300
5200
5100
5000
4900
4800
4700
Tsfp
Qao
Qay
IPm
Qay
SC2
SC1
Qay
Tsfp
Qao
1000 feet
no vertical exaggeration


Map 2, cross section 2, spring LP1
C
west
C'
east
elevation above sea level
(feet)
6700
6600
6500
6400
6300
6200
6100
6000
5900
5800
5700
Qay
LP1
Qay
p€cg
p€q
p€spq
p€am
p€spq
p€am
1000 feet
no vertical exaggeration

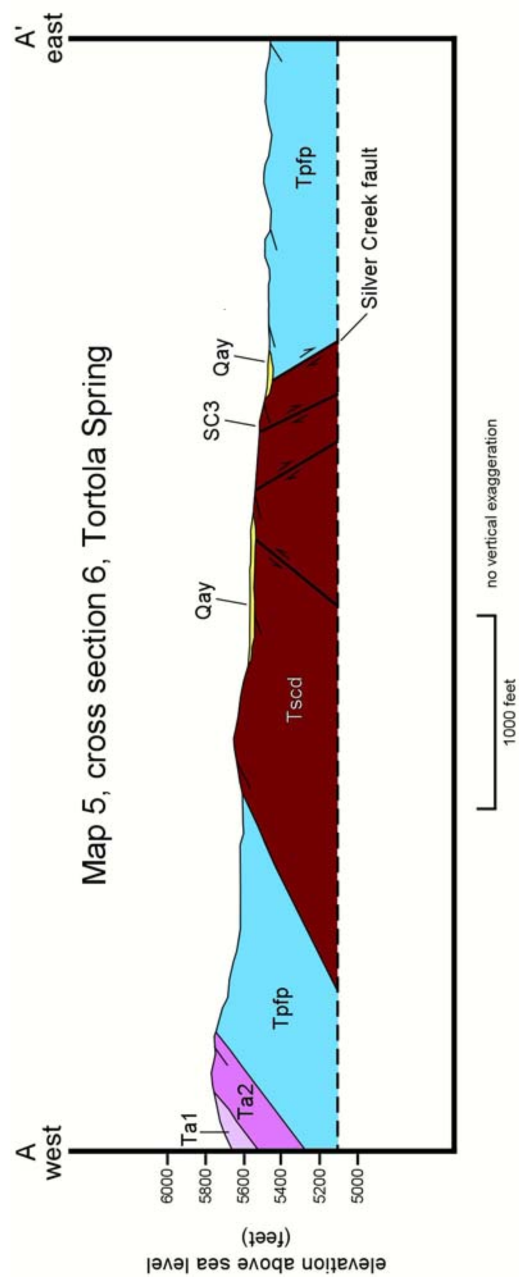

D
west
D'
east
Map 2, cross section 3, springs LP2 and LP13, and seep LP11
elevation above sea level
(feet)
6600
6500
6400
6300
6200
6100
6000
5900
5800
5700
5600
LP13
LP2
Qay
LP11
p€q
p€spq
p€am
p€spq
p€am
p€cg
1000 feet
no vertical exaggeration

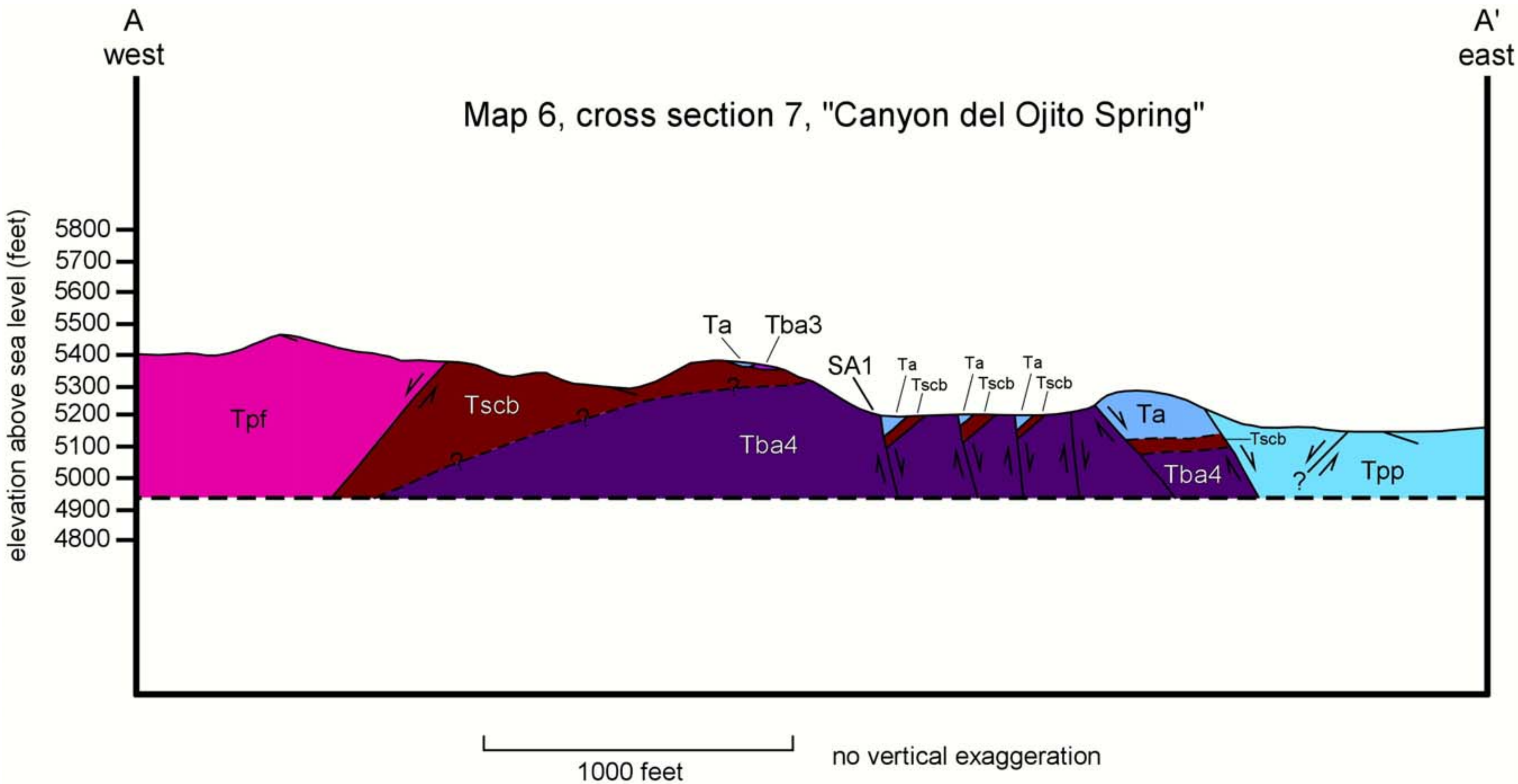


Map 3, cross section 4, springs in San Lorenzo Canyon
A
west
A'
east
elevation above sea level
(feet)
6200
6000
5800
5600
5400
5200
5000
Tpf
SLS4
Qay
SLS3
Ta1
SLS1
Tba
Qay
Ta3
Qay
Tba
Ta1?
Tpf
Ta1?
Tr
SLS2
Tpp
1000 feet
no vertical exaggeration

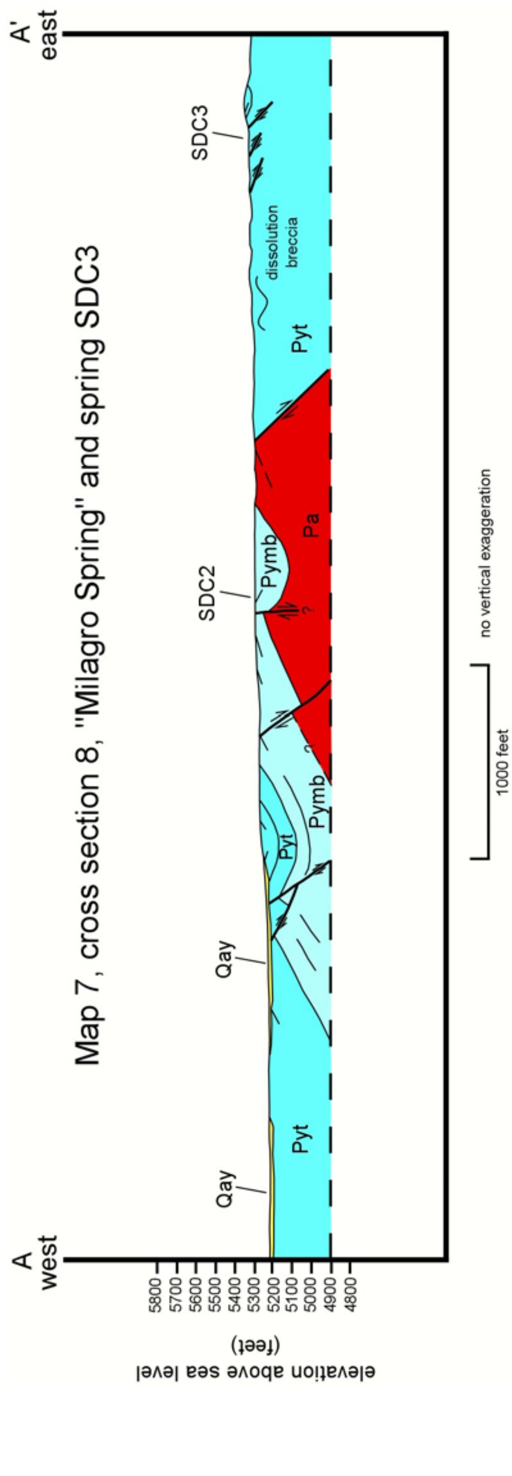


Map 4, cross section 5, Cibola Spring
A
west
A'
east
elevation above sea level
(feet)
6000
5800
5600
5400
5200
5000
Qay
IPPb
Qay
Qao
Qay
IPm
SDC1
Qay
Qao
Pa
1000 feet
no vertical exaggeration

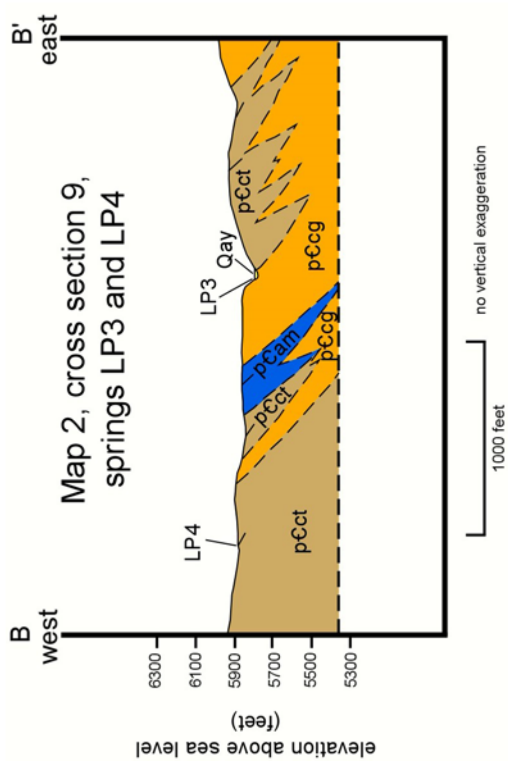

Map 5, cross section 6, Tortola Spring
A
west
A'
east
elevation above sea level
(feet)
6000
5800
5600
5400
5200
5000
Ta1
Ta2
Tpfp
Tscd
Qay
SC3
Qay
Silver Creek fault
Tpfp
1000 feet
no vertical exaggeration

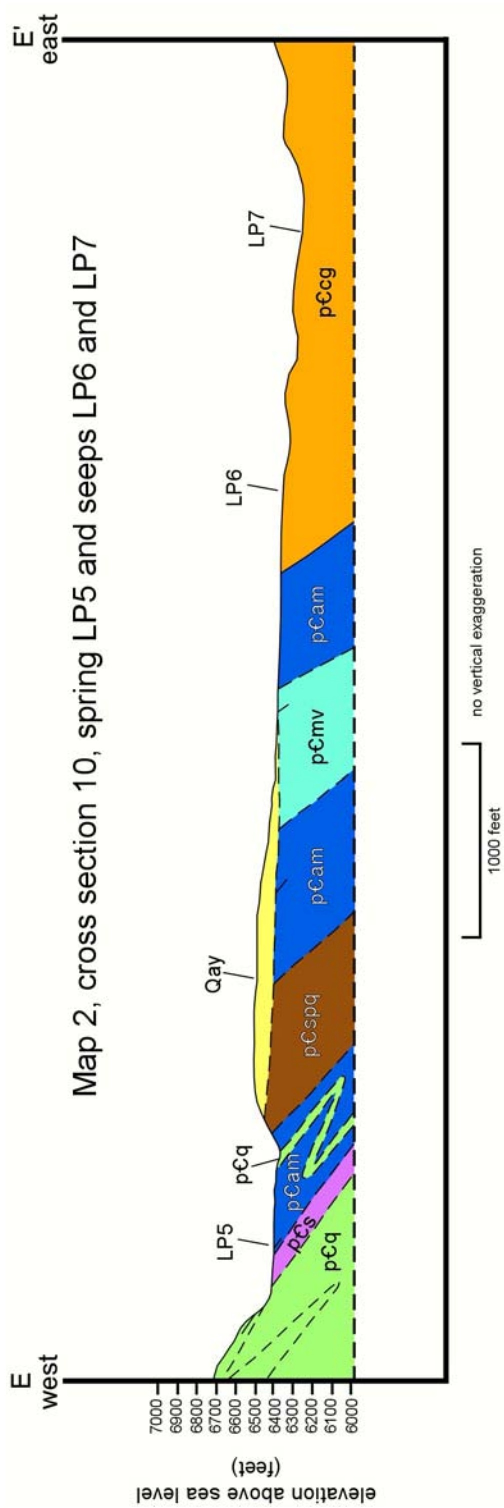


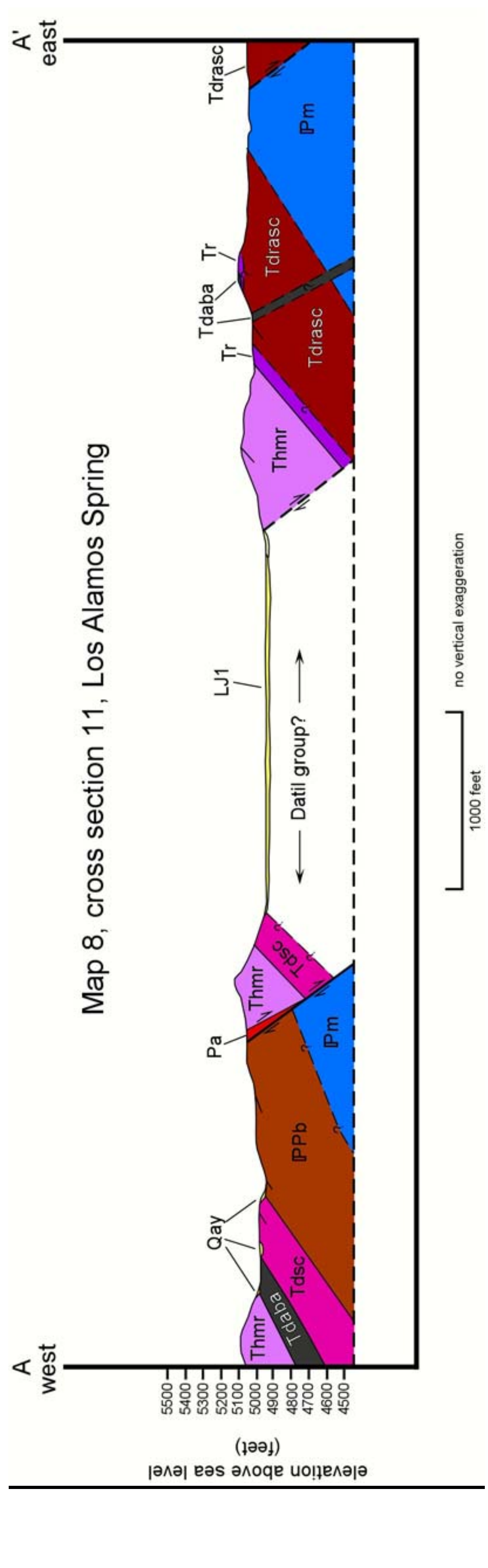
Map 6, cross section 7, "Canyon del Ojito Spring"
A
west
A'
east
elevation above sea level (feet)
5800
5700
5600
5500
5400
5300
5200
5100
5000
4900
4800
Tpf
Tscb
Tba4
Ta
Tba3
SA1
Ta
Tscb
Ta
Tscb
Ta
Tscb
Ta
Tscb
Tba4
Tpp
?
1000 feet
no vertical exaggeration

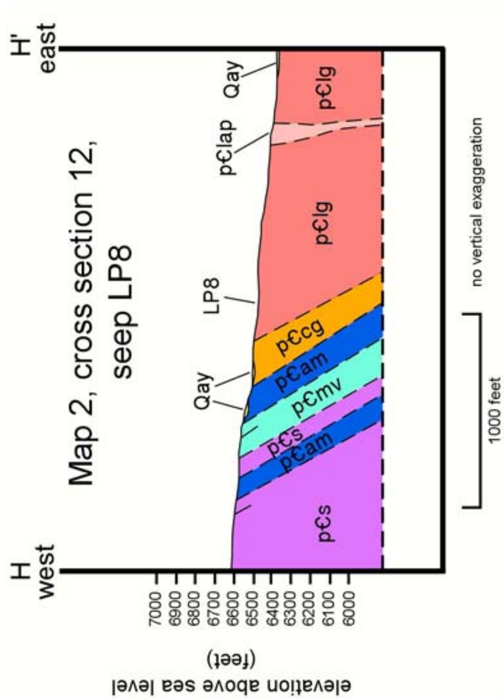


Map 7, cross section 8, "Milagro Spring" and spring SDC3
A
west
A'
east
elevation above sea level
(feet)
5800
5700
5600
5500
5400
5300
5200
5100
5000
4900
4800
Qay
Pyt
Qay
Pyt
Pymb
SDC2
Pymb
Pa
Pyt
dissolution
breccia
SDC3
1000 feet
no vertical exaggeration

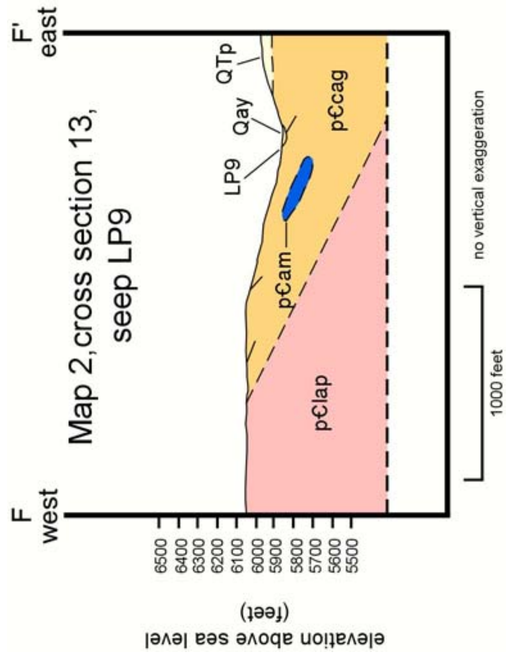

Map 2, cross section 9, springs LP3 and LP4
B west
B' east
elevation above sea level (feet)
6300
6100
5900
5700
5500
5300
LP4
LP3
Qay
p€ct
p€am
p€cg
1000 feet
no vertical exaggeration

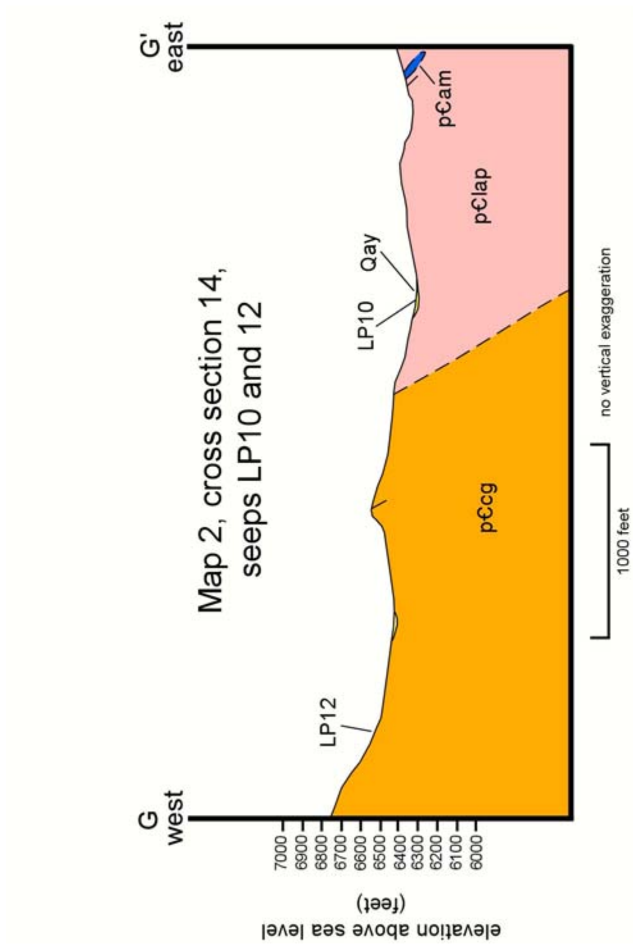

Map 2, cross section 10, spring LP5 and seeps LP6 and LP7
E
west
E'
east
elevation above sea level
(feet)
7000
6900
6800
6700
6600
6500
6400
6300
6200
6100
6000
LP5
p€q
p€s
p€am
p€q
Qay
p€spq
p€am
p€mv
p€am
LP6
p€cg
LP7
1000 feet
no vertical exaggeration


Map 8, cross section 11, Los Alamos Spring
A
west
A'
east
elevation above sea level
(feet)
5500
5400
5300
5200
5100
5000
4900
4800
4700
4600
4500
Thmr
Tdaba
Tdsc
Qay
PPb
Pa
Pm
Thmr
Tdsc
LJ1
Datil group?
Thmr
Tr
Tdaba
Tr
Tdrasc
Tdrasc
Pm
Tdrasc
1000 feet
no vertical exaggeration

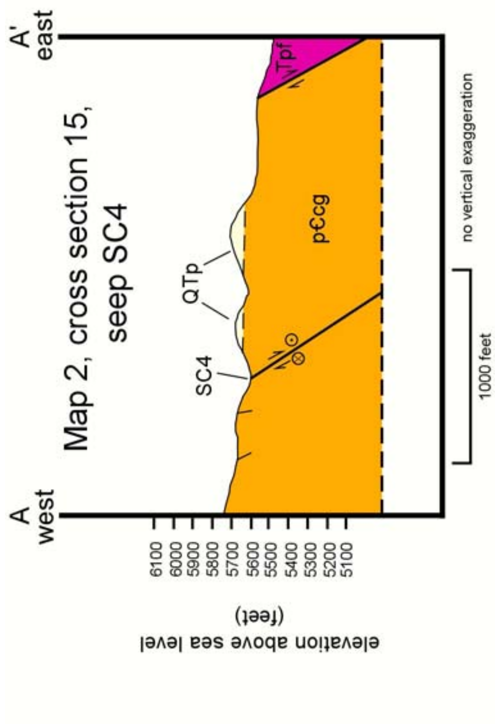


Map 2, cross section 12, seep LP8
H west
H' east
elevation above sea level (feet)
7000
6900
6800
6700
6600
6500
6400
6300
6200
6100
6000
p€s
p€am
p€s
p€mv
p€am
p€cg
p€lg
p€lap
p€lg
Qay
LP8
Qay
1000 feet
no vertical exaggeration


Map 2, cross section 13,
seep LP9
F
west
F'
east
QTp
Qay
LP9
p€am
p€cag
p€lap
elevation above sea level
(feet)
6500
6400
6300
6200
6100
6000
5900
5800
5700
5600
5500
1000 feet
no vertical exaggeration



Map 2, cross section 14,
seeps LP10 and 12
G
west
G'
east
elevation above sea level
(feet)
7000
6900
6800
6700
6600
6500
6400
6300
6200
6100
6000
LP12
LP10
Qay
p€cg
p€lap
p€am
1000 feet
no vertical exaggeration



Map 2, cross section 15, seep SC4
A west
A' east
SC4
QTp
p€cg
Tpf
elevation above sea level (feet)
6100
6000
5900
5800
5700
5600
5500
5400
5300
5200
5100
1000 feet
no vertical exaggeration

XIV. ACKNOWLEDGEMENTS

Paul Tashjian of the U.S. Fish and Wildlife Service and Paul Bauer of the New Mexico Bureau of Geology and Mineral Resources initiated this project and provided comments that greatly improved the report and maps. Peggy Johnson of the NMBGMR reviewed my conclusions on the hydrologic setting of the springs and suggested several improved interpretations. Terry Tadano, Ken Wolf, and Stan Culling of the refuge all were very helpful in answering my questions and solving logistical problems. Mark Matthews of the Socorro BLM office helped with access to the Salado Box area, and landowner Ross Ligon kindly granted me permission to map on his land. Adam Read, Mark Mansell, and Dave McCraw of the NMBGMR answered many questions and greatly facilitated the digital map production.

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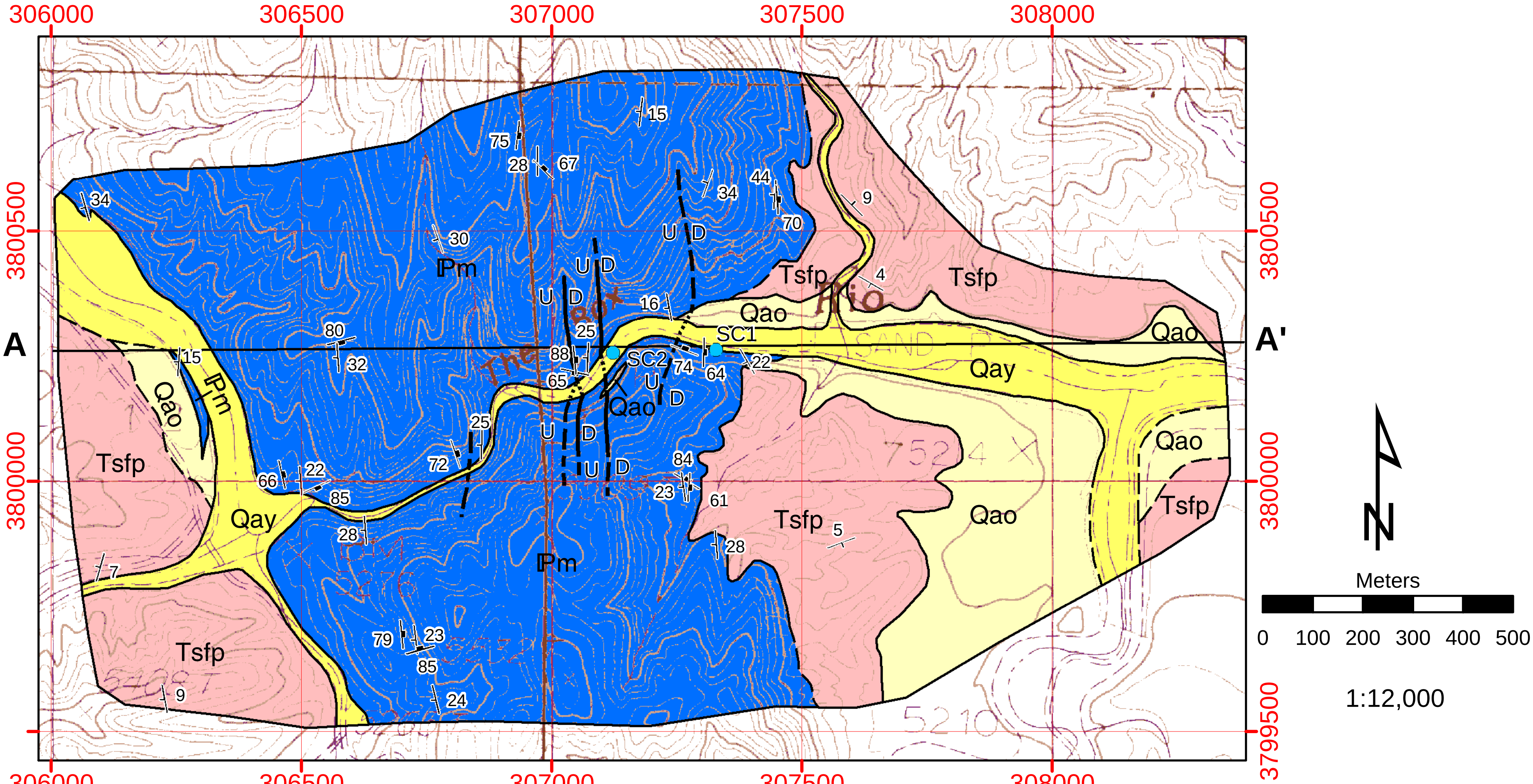
Map 1- Geology of the area around Rio Salado Box Springs, Silver Creek 7.5 - minute quadrangle, Sevilleta National Wildlife Refuge

by Geoffrey Rawling



Location of map area

Explanation of symbols

bedding

joint

spring

fault motion: U = upthrown side, D = downthrown side

fault - exposed

fault - approximately located

fault - concealed

cross section

geologic contact - exposed

geologic contact - approximately located

Qay

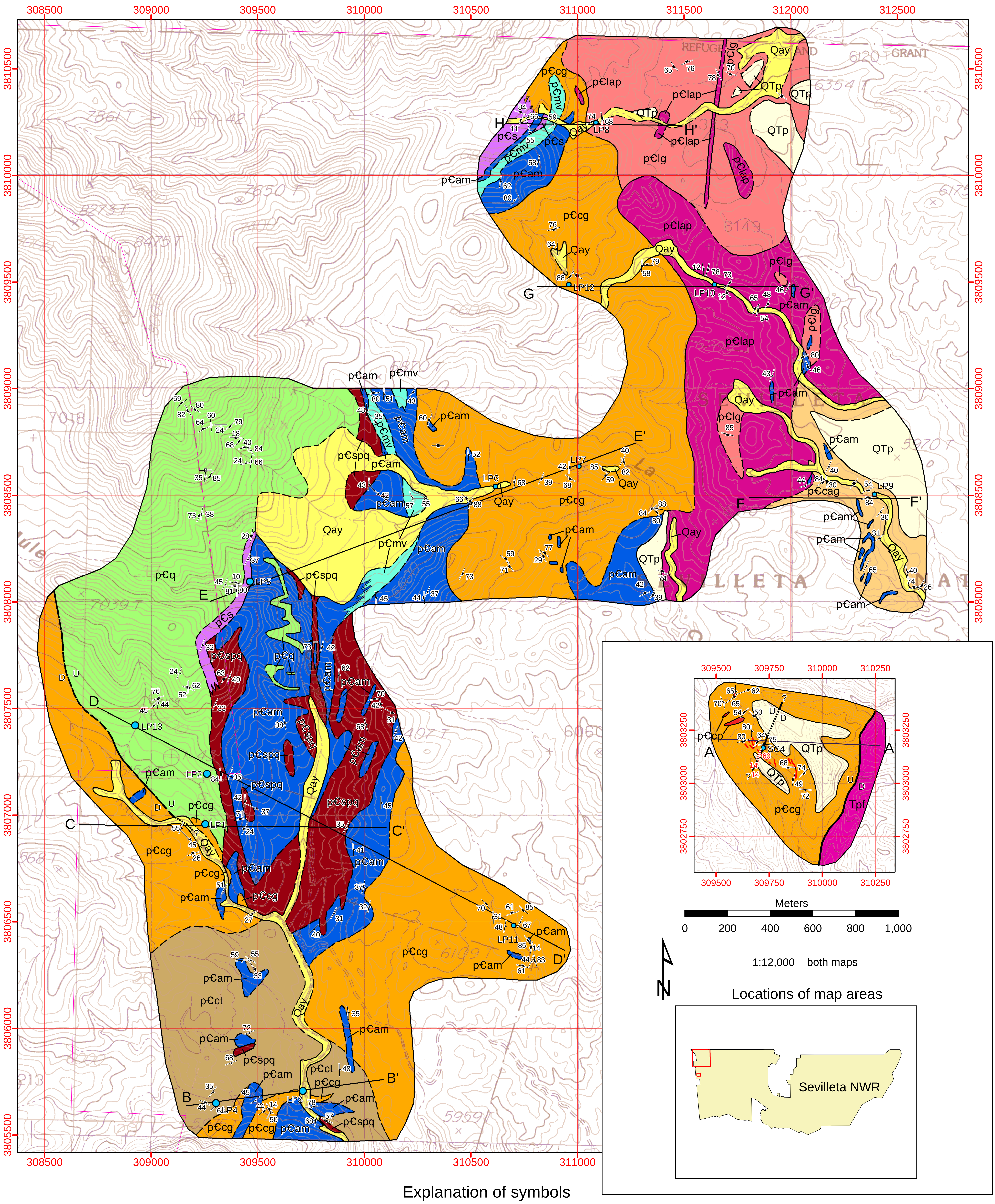
Qao

Tsfp

Pm

Map 2 - Geology of the area around springs and seeps on Ladron Peak, Ladron Peak and Silver Creek 7.5 - minute quadrangles, Sevilleta National Wildlife Refuge

by Geoffrey Rawling



Explanation of symbols

- refuge boundary
- strike and dip of bedding
- strike and dip of overturned bedding
- strike and dip of tectonic foliation
- trend and plunge of tectonic lineation
- strike and dip of joint
- strike of vertical joint
- strike and dip of exposed fault plane
- trend and plunge of fault striation
- seep
- spring

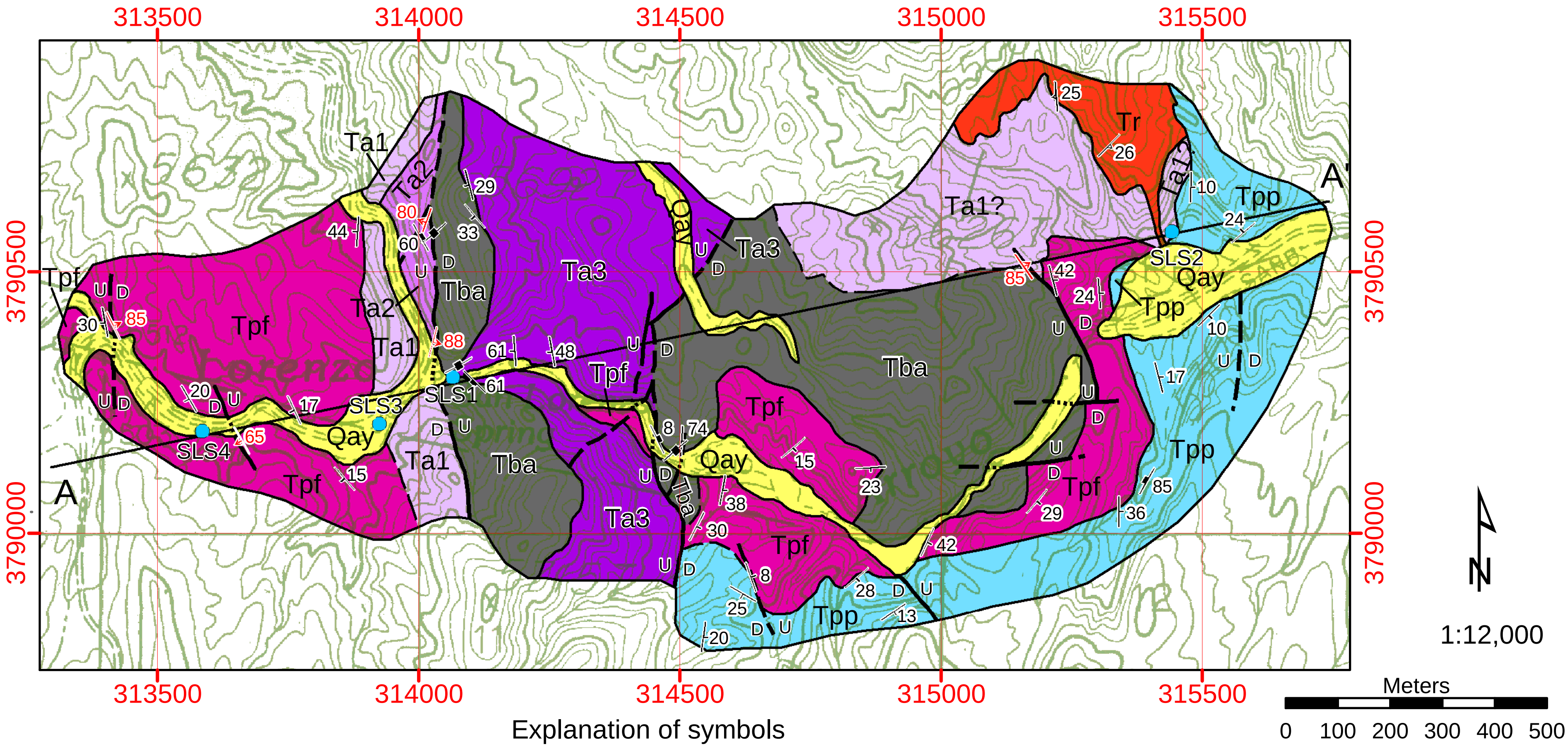
fault motion: U = upthrown side, D = downthrown side

- fault - exposed
- fault - approximately located
- fault - concealed
- pegmatite dike - approximately located
- geologic contact - exposed
- geologic contact - approximately located
- geologic contact - concealed
- geologic contact - gradational
- cross section

Qay	pЄmv
QTp	pЄspq
Tpf	pЄs
pЄlap	pЄcag
pЄlg	pЄcp
pЄq	pЄct
pЄam	pЄcg

Map 3 - Geology of the area around springs in San Lorenzo Canyon, San Lorenzo Spring 7.5 - minute quadrangle, Sevilleta National Wildlife Refuge

by Geoffrey Rawling



Explanation of symbols

strike and dip of bedding

strike and dip of eutaxitic foliation

strike and dip of exposed fault plane

strike and dip of joint

vertical joint

spring

cross section

fault motion: U = upthrown side, D = downthrown side

fault - exposed

fault - approximately located

fault - concealed

geologic contact - exposed

geologic contact - approximately located

Qay

Ta2

Tr

Tba

Ta1

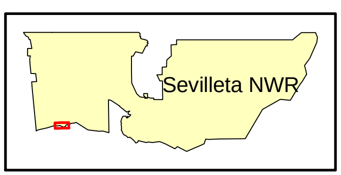
Ta3

Ta1?

Tpf

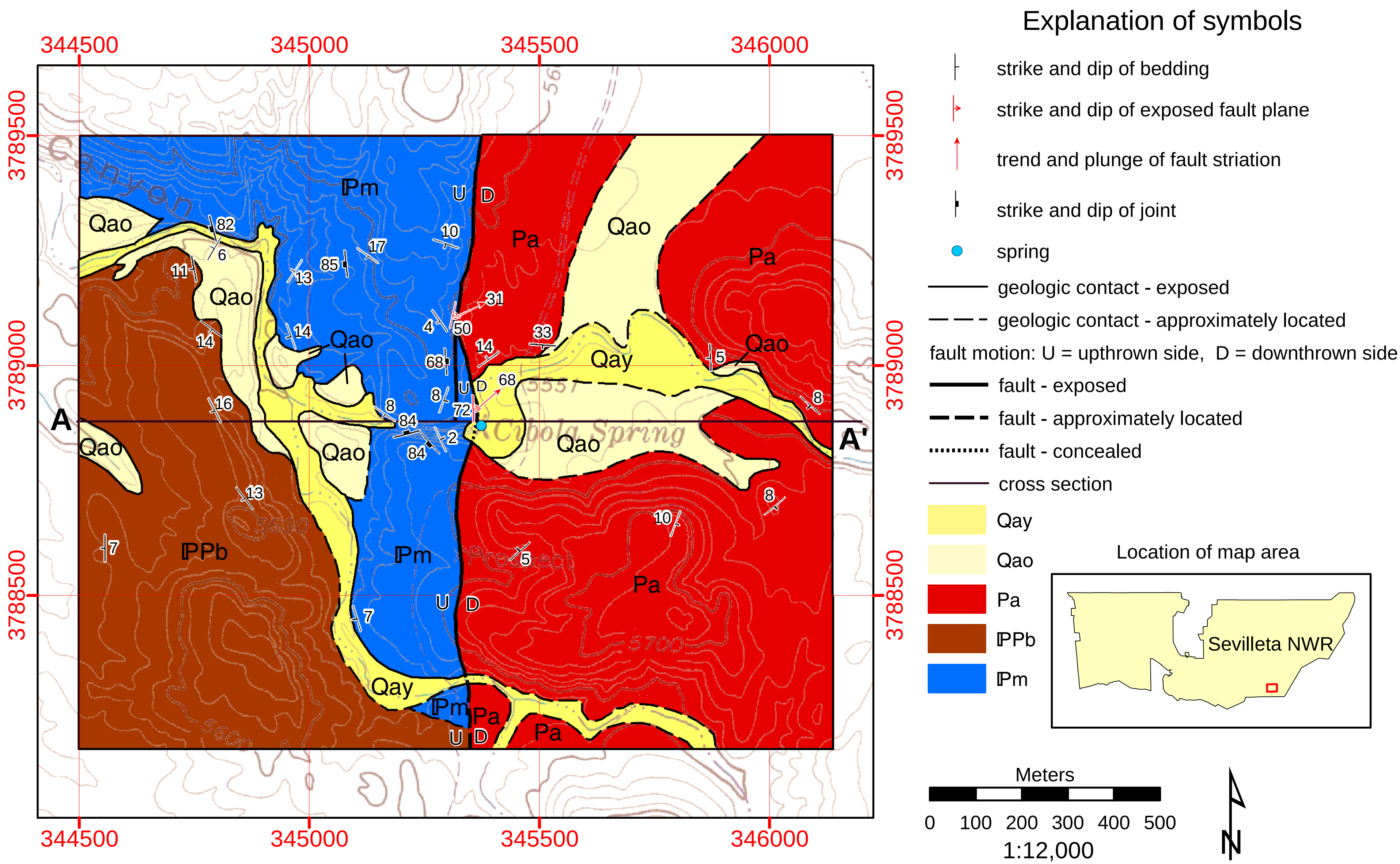
Tpp

Location of map area



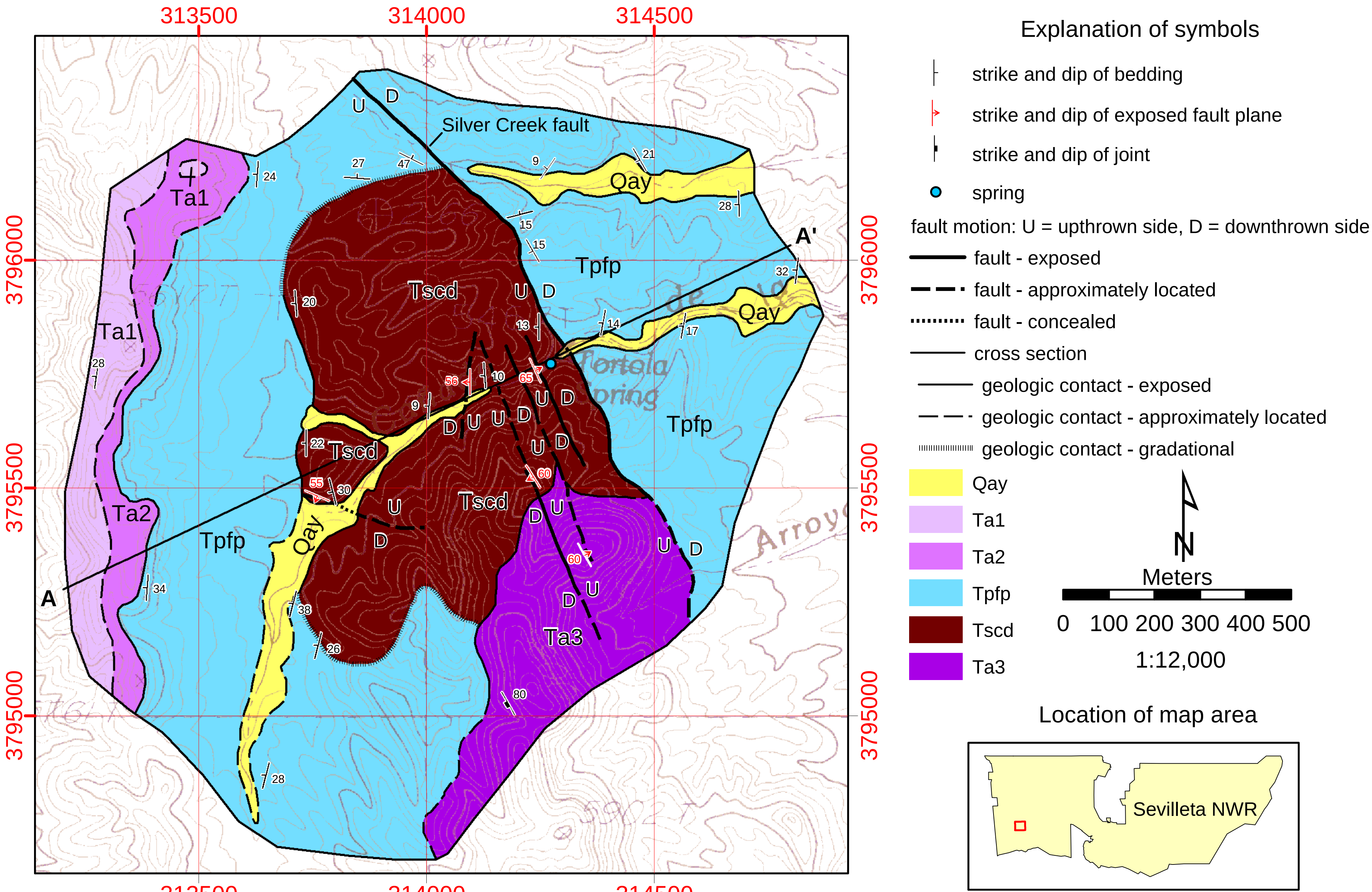
Map 4 - Geology of the area around Cibola Spring, Sierra de la Cruz 7.5 - minute quadrangle, Sevilleta National Wildlife Refuge

by Geoffrey Rawling



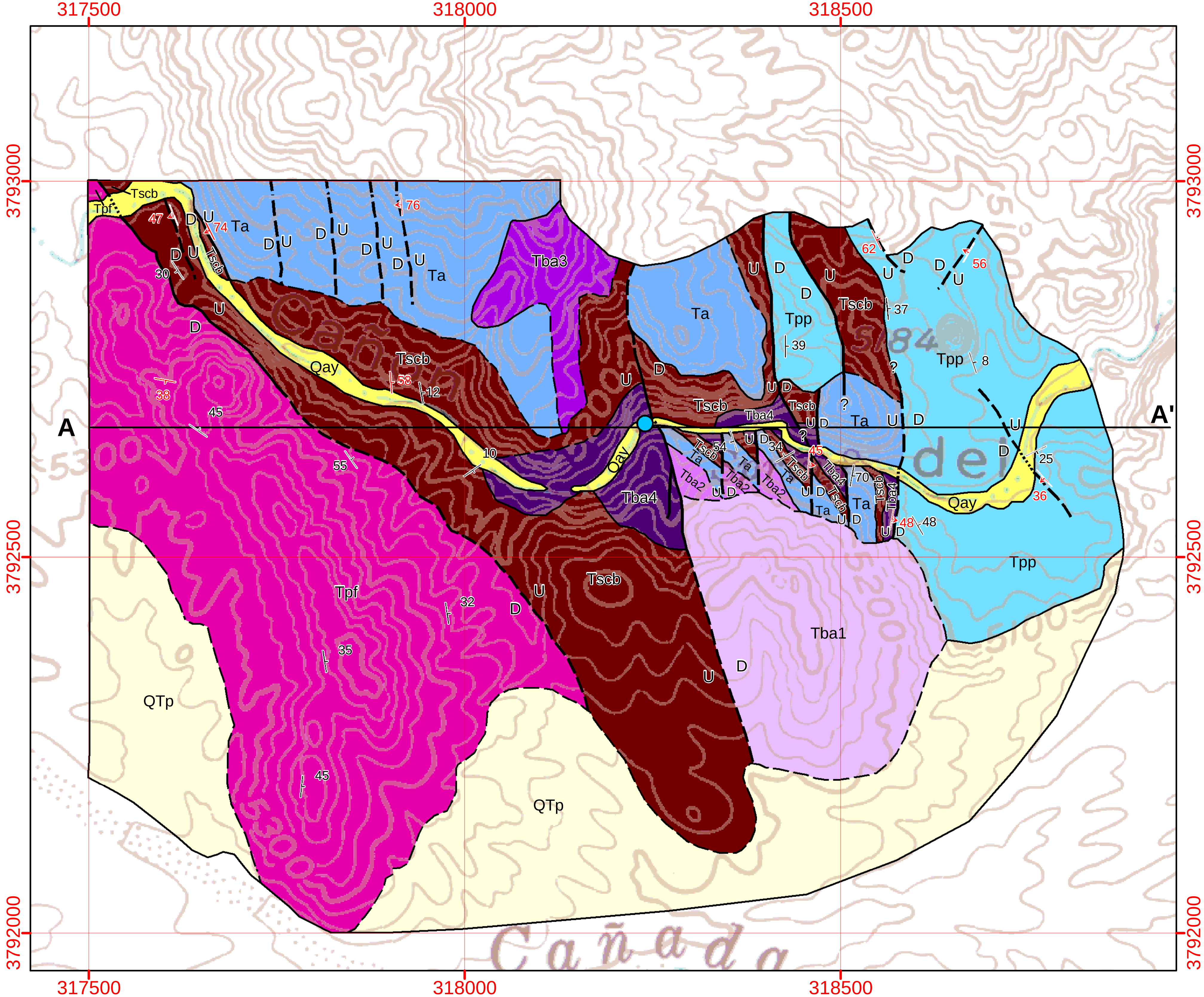
Map 5 - Geology of the area around Tortola Spring, Silver Creek 7.5 - minute quadrangle, Sevilleta National Wildlife Refuge

by Geoffrey Rawling



Map 6 - Geology of the area around "Canyon del Ojito" Spring, San Acacia 7.5 - minute quadrangle, Sevilleta National Wildlife Refuge

by Geoffrey Rawling
mapped at 1:12000 scale



Explanation of symbols

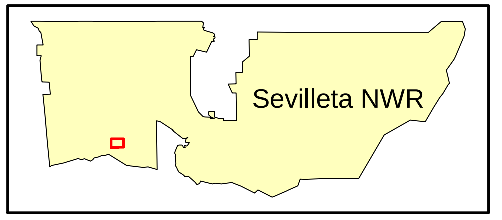
- strike and dip of bedding
- strike and dip of exposed fault plane
- strike and dip of small normal fault
- spring
- geologic contact - exposed
- geologic contact - approximately located

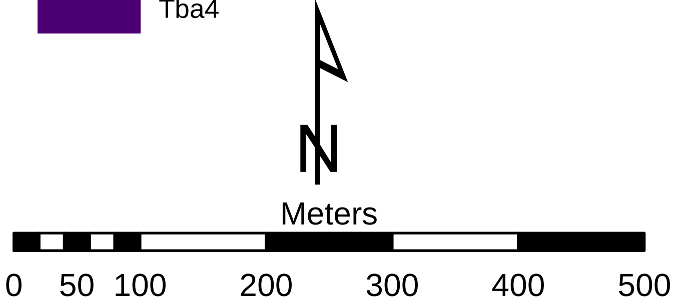
fault motion: U = upthrown side, D = downthrown side

- fault - exposed
- fault - approximately located
- fault - concealed
- cross section

- Qay
- QTp
- Tpp
- Tpf
- Tba1
- Tba2
- Ta
- Tba3
- Tscb
- Tba4

Location of map area





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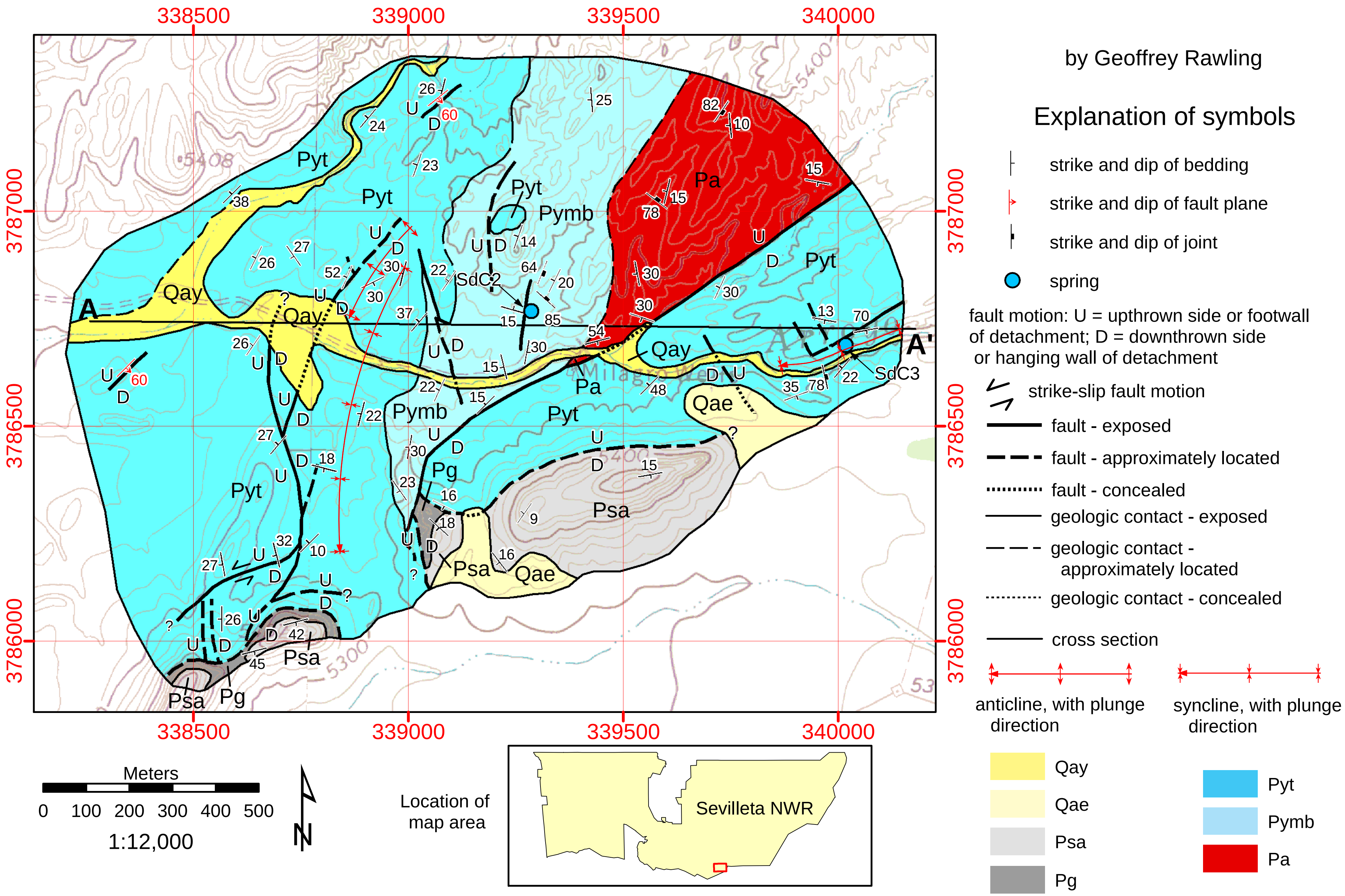
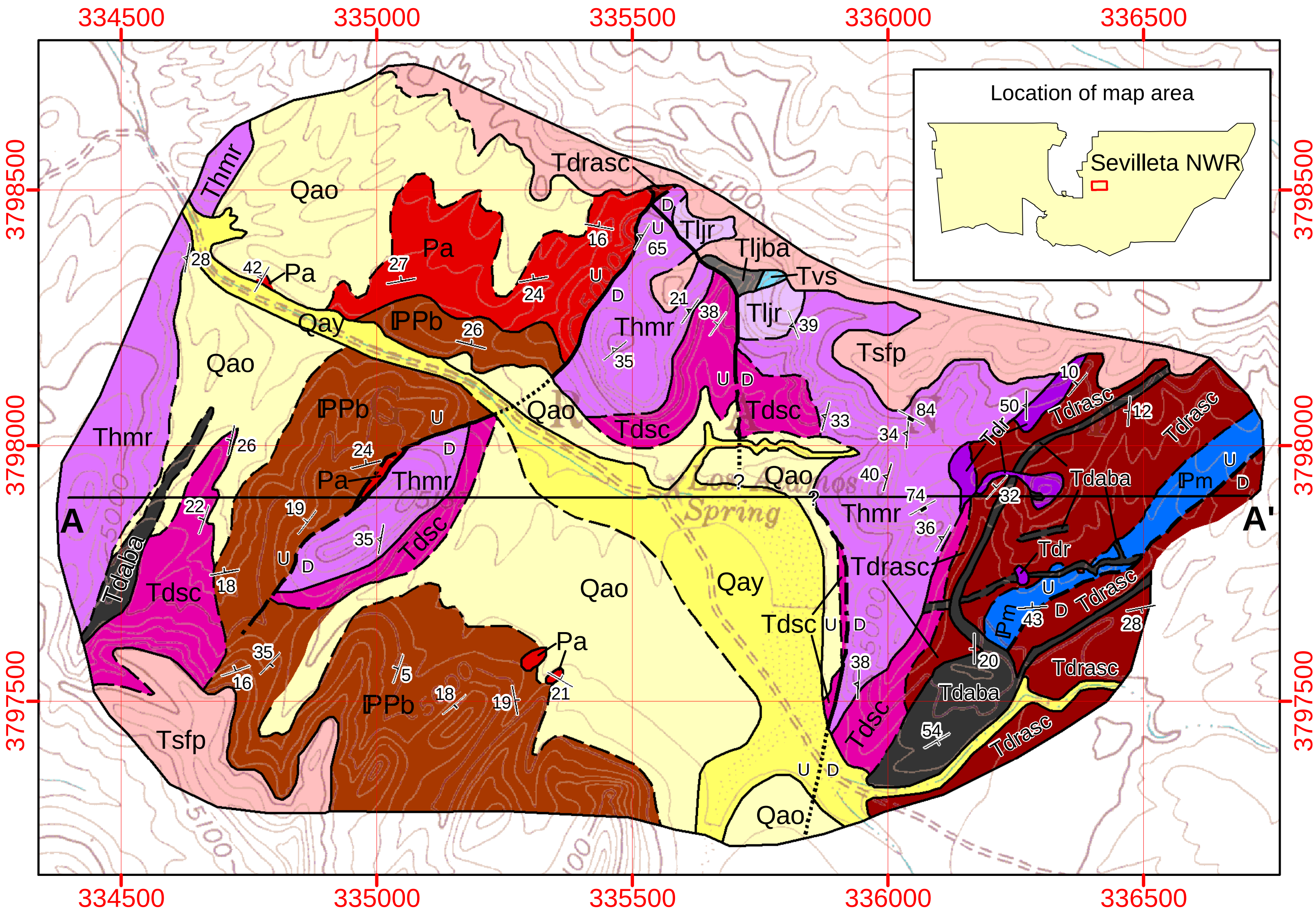
Map 7 - Geology of the area around "Milagro Spring", Mesa del Yeso and Sierra de la Cruz 7.5 - minute quadrangles, Sevilleta National Wildlife Refuge



Map 8 - Geology of the area around Los Alamos Spring, San Acacia 7.5 - minute quadrangle, Sevilleta National Wildlife Refuge

by Geoffrey Rawling



Qay
Qao
Tsfp
Tljba
Tvs
Tljr
Thmr
Tdaba
Tdsc
Tdr
Tdrasc
Pa
PPb
Pm

strike and dip of bedding

strike and dip of eutaxitic foliation

strike and dip of joint

fault motion: U = upthrown side, D = downthrown side

fault - exposed

fault - approximately located

fault - concealed

cross section

geologic contact - exposed

geologic contact - approximately located

Meters

0 100 200 300 400 500

1:12,000