Geology and hydrologic setting of selected springs on The San Andres National Wildlife Refuge

By

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I. INTRODUCTION

In this report I describe the geologic setting and hydrologic framework of the important springs on the San Andres 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, 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. The reference list encompasses most of the significant geologic and hydrologic studies of the area.

The body of the report consists of an overview of the geology and hydrology of the refuge, an outline of the methods used, descriptions and interpretations of the springs, discussion and summary , suggestions for future work, and a list of references.

II. OVERVIEW OF THE GEOLOGY AND HYDROLOGY OF THE REFUGE

General overviews of the geology of the refuge and surrounding area can be found in Bachman and Myers (1969), Kottlowski and LeMone (1994), and Raatz (2002). More detailed information about the Rio Grande rift can be found in Hawley (1978), Keller and Cather (1994), and the New Mexico Geological Society's Field Conference Guidebooks that cover the region.

Very little quantitative data has been published on the hydrogeology of the refuge area because of its remoteness, low population, paucity of wells, and restricted access. Regional groundwater studies are available (e.g., Herrick and Davis, 1965; King et al., 1971; Brady et al., 1984a; Brady et al., 1984b; Thompson et al., 1984) but all are largely focussed on the rift basins and have limited or no data from the San Andres mountains, especially water table elevations. An exception is Stone and Brown (1975), who present a study of the area around Ropes Spring.

Geology of the refuge

The dominant geologic structures of the refuge area are the San Andres Mountains and the adjacent Tularosa and Jornada basins of the Rio Grande rift. The Tularosa and Jornada basins are east and west of the San Andres mountains, respectively. The rift has formed by extensional tectonic activity since the middle Tertiary period (~30 million years ago). It extends from central Colorado to Mexico and consists of a series of deep sedimentary basins filled with relatively young sediments and sedimentary rocks deposited by the Rio Grande and its predecessor rivers. Along its whole length, the basins of the rift are flanked by mountain blocks uplifted along faults at the edge of the basins.

The San Andres Mountains are a spectacular example of one these uplifted mountain blocks. The range has risen along faults on its east side, which separate the mountain mass from the Tularosa basin. The Paleozoic sedimentary strata of the range dip west under the poorly consolidated Quaternary and Tertiary sediments of the Jornada basin.

The refuge itself is entirely within the San Andres mountains. The mountains consist of Precambrian igneous and metamorphic rocks overlain by Cambrian through early Tertiary sedimentary rocks inclusive of all of the Paleozoic and Mesozoic time periods. The sedimentary section exposed within the refuge is composed dominantly of the carbonate rocks limestone and dolomite. The exceptions are the Cambrian Bliss sandstone, the Devonian shales, and the upper Pennsylvanian Panther Seep Formation, which is a mix of ~75% shale and sandstone and ~25% limestone (Kues, 2001), with two thick gypsum beds. See section XII for detailed descriptions of the rock types within the refuge.

The range is essentially a single massive block tilted to the west. The dominant bedding dip is ~30º west and there are two regional, intersecting joint sets (systematic fractures), which are steeply dipping, and strike roughly northwest and southeast (Figure 1). The joints are likely an important control on groundwater flow.

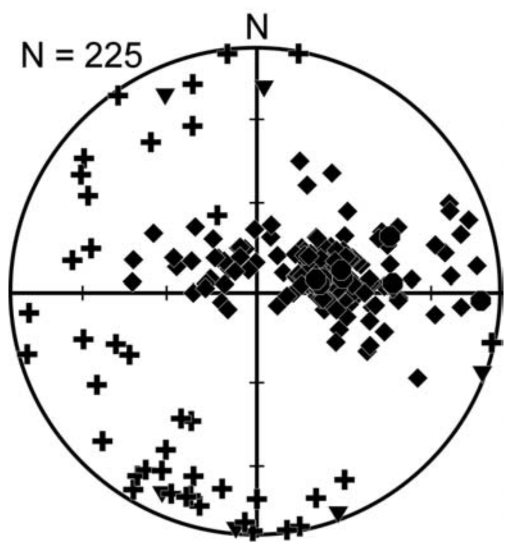

Figure 1. Equal area, lower hemisphere stereographic projection of poles to bedding (diamonds) and joints (crosses) in Paleozoic rocks and foliations (triangles) in Precambrian rocks.

A north-south zone of faulting and folding extends from between Ropes Spring and Lead Camp Canyon to Mayberry Canyon and beyond. These structures exhibit normal-sense motion, down to the west, but several subsidiary faults show reverse motion. An asymmetric anticline at the south end of this zone, outside of the mapped areas, has east vergence (the eastern limb of the fold is steeper than the western side) if the range block is rotated back to horizontal. The minor faults and fold vergence suggest that the zone was originally formed in compression, probably during the Late Cretaceous-Early Tertiary Laramide tectonic event. The main fault was originally a reverse fault and then reactivated as a normal fault as the range was uplifted during the formation of the Rio Grande rift. The details of these structures are discussed in more detail in the descriptions of individual springs.

The geomorphology of the range is strongly controlled by the geology. The carbonate rocks are largely cliff-formers and make up the dramatic escarpment on the east face of the range. There is a break in slope at the base of this escarpment at the contact with the underlying Cambrian and Precambrian rocks. The Precambrian rocks form a broad, generally shallowly sloping, concave upward surface. It is largely covered by colluvium from the cliffs above, but exposures are good in arroyos and along small ridges. I did not subdivide the Precambrian rocks in this study.

The north-south valley along the axis of the range, where the two refuge cabins are located, is eroded in the less resistant shales of the Panther Seep formation. There are low, east-west cross-ridges in this valley that form the drainage divides between the major east-west canyons. The eastern range crest formed by the lower Pennsylvanian

Lead Camp limestone is higher than the western crest formed by the Permian Hueco limestone.

Hydrology of the refuge

The San Andres mountains are a recharge area for the adjacent Jornada and Tularosa basins, where the Tertiary Santa Fe group and Quaternary sediments are the most important aquifers. However, the crystalline rocks, well cemented sandstones, massive carbonates, shales, and evaporites exposed in the refuge are not likely to be good aquifers. They all have low primary porosity, and therefore permeability and storage are provided largely by faults, fractures, and the two dominant joint sets, although cavernous porosity is possible in the carbonates. These geologic constraints suggest that conduit flow in faults and fractures and joints should be dominant over diffuse matrix flow in the groundwater flow systems underlying the refuge.

Stone and Brown (1975) present a water table map for the vicinity of Ropes Spring based on available well records. The water table slopes to the southwest at ~170 feet per mile within the range (Stone and Brown, 1975) and ~125 feet per mile across the Jornada basin to the west (Brady et al., 1984b). The break in slope is fairly sharp. However, because conduit flow in fractures and joints is likely dominant in the range, the water table is probably very irregular, perhaps perched locally, and may change in elevation significantly over short distances. This is suggested by the variations in depth to water in wells along the mountain front, from 20 to 113 feet (Stone and Brown, 1975). Similar conditions probably prevail throughout the refuge. The central portions of the San Andres mountains are classified as having an average depth to groundwater of greater than 500 feet by Brady et al. (1984b). It is probable that the average depth to water increases as elevation increases.

The carbonates, shales, and gypsum ($CaSO_4 \bullet 2H_2O$) may affect regional water chemistry by contributing large amounts of dissolved solids (Hem, 1985). Sulfate-type waters (wherein sulfate, SO_4^{2-} is the dominant anion) are dominant in the basins east and west of the range (Thompson et al., 1984). Dissolved solid concentrations in these waters range from < 5000 mg/l up to 10000 mg/l. This may be due to waters percolating through the gypsum beds in the Pennsylvanian Panther Seep formation and younger formations not exposed in the refuge.

III. METHODS

The springs to be studied in detail were chosen in discussions with the refuge staff and USFWS Water Resources Division. The main criteria was the importance of the spring as a water source to the wildlife on the refuge. Preliminary geologic mapping around the springs was based on aerial photo interpretation from the refuge photo collection and digital rectified aerial photos and orthophotos provided by the Environmental Stewardship Division of White Sands Missile Range. Field work was conducted in February and March 2003 and thus all descriptions of the springs are for as they appeared during this period. For all of the springs studied, I recorded the location of the spring with a handheld GPS unit, tested the water in the field for specific conductivity and temperature, mapped the local geology at 1:12000 scale, 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. INVENTORY OF SPRINGS

Table 1 lists all of the springs discussed in this report. Adjacent springs are grouped together, and the groupings are listed in the table from south to north by canyon. Spring names are primarily from USGS topographic maps. Where unnamed or not marked on the maps, names are from the spring compilation of Boykin et al. (1996). In some cases the choice of names was ambiguous because the GPS coordinates were not exactly the same, and the most likely match was chosen from the list of Boykin et al. (1996). Regardless of the name, the GPS coordinates in Table 1 should be the definitive identification for each spring. All coordinates are UTM, using the NAD27 datum.

Table 1. Inventory of springs

					upstream discharge point		end of surface water	
#	**spring name**	**map**	**cross section**	**7.5-min quad**	**UTM E**	**UTM N**	**UTM E**	**UTM N**
1a	Little San Nicholas	1	1	Bennett Mountain	359719	3605866		
1b	San Nicholas Canyon unnamed	1	1	Bear Peak	358767	3604534		
1c	Joe Taylor	1	1	Bear Peak	358408	3604209		
2a	Ash Spring Complex	2	2	San Andres Peak	355108	3611473		
2b	Ash Spring South	2	3	Bear Peak	355910	3610296		
3	Ropes Spring	3	4	San Andres Peak	353990	3616381	353795	3616326
4a	San Andres	4	5	San Andres Peak	353689	3623004	353783	3623032
4b	Stone Trough	4	5	San Andres Peak	352201	3622699		
5a	Mayberry 1	5	6	Gardner Peak	351591	3628130	351980	3628494
5b	Mayberry 2	5	6	Gardner Peak	352057	3628536	352066	3628508

V. SPRING WATER AND PRECIPITATION DATA

Tables 2 and 3 list water chemistry, temperature, and flow data from this study and previous work. Figures 2 and 3 show the conductivity, total dissolved solids, and temperature data. Figure 4 shows yearly precipitation data from the rain gauge at Ropes Spring.

VI. DESCRIPTIONS OF SPRINGS

Spring 1a - Little San Nicholas Spring

Location: Bennett Mountain 7.5 - minute quadrangle, UTM coordinates: 359719E, 3605866N.

Description: This spring is located in Little San Nicholas Canyon where it begins to open up east of the range front. It is marked on the Bennett Mountain quadrangle map. The spring discharges from bedrock fractures in the arroyo bottom with a trickling flow though several pools of standing water. There are abundant grasses, willows, and ash trees around the spring. North of the arroyo is a dilapidated building and just to the east is a rock-walled corral.

Geologic Setting: The geology around this spring is shown on map 1 and cross section 1. The line of the cross section does not pass through the spring, but the geology is very similar to that shown. The host rock is Precambrian granite gneiss. This rock generally has a well developed, steeply dipping, east-west striking foliation, but locally it is an unfoliated granite. It also contains scattered inclusions of schist, amphibolite, and diorite.

Table 2. Spring data collected in this study

Number	spring name	conductivity (mS/cm)[1]	water T (C)[2]	air T (C)
1a	Little San Nicholas	0.9	15.1	7.5
1b	Little San Nicholas Canyon unnamed	0.9	12.4	7
1c	Joe Taylor	0.7	15	6
2a	Upper Ash Spring Complex 1	0.7	10.4	10
2a	Upper Ash Spring Complex 2[3]	0.7	10	10.5
2a	Lower Ash Spring Complex[4]	0.7	6.6	8
2b	Ash Spring South	0.8	12	7.5
3a	Ropes Spring upstream	0.5	11.1	9.5
3a	Ropes Spring downstream[4]	0.7	10.9	9.5
4a	San Andres	0.6	18.8	22
4b	Stone Trough	1.9	17.7	17
5a	Mayberry 1 upstream	1.6	9.6	11.5
5a	Mayberry 1 downstream[4]	1.4	6.9	7
5b	Mayberry 2	1.5	11.6	11.5

Table 3. Spring data from previous work[5]

number	Spring name	water T (C)	conductivity (mS/cm)	DO (mg/l)[6]	pH	Salinity (g/l)[7]	1938 flow (gpm)[8]	TDS (mg/l)[9]
1a	Little San Nicholas						4	625
1b	Little San Nicholas Canyon unnamed						4	686
1c	Joe Taylor	15.4	1.0	10.7	9	0.67		687
2a	Upper Ash	12.3	0.77	7.3	8.7	0.49	3	1126
2b	Ash Spring South						1	706
3a	Ropes Spring Upstream						5	454
3b	Ropes Spring Downstream							
4a	San Andres	19.8	0.85	3.5	8	0.54	11	492
4b	Stone Trough							
5a	Mayberry 1 Upstream	22.5	1.4	5	7.9	2.2	3.5	1299
5a	Mayberry 1 Downstream							1182

[1] milliSiemens per centimeter
[2] temperature in degrees Celsius
[3] repeat measurement at same point on a different day
[4] measured at lowest pool of surface water
[5] data from Tashjian (1998), except as noted
[6] dissolved oxygen in milligrams per liter
[7] salinity in grams per liter
[8] spring discharge in gallons per minute, as reported in Anonymous (1958)
[9] total dissolved solids in milligrams per liter, from Boykin et al. (1996)

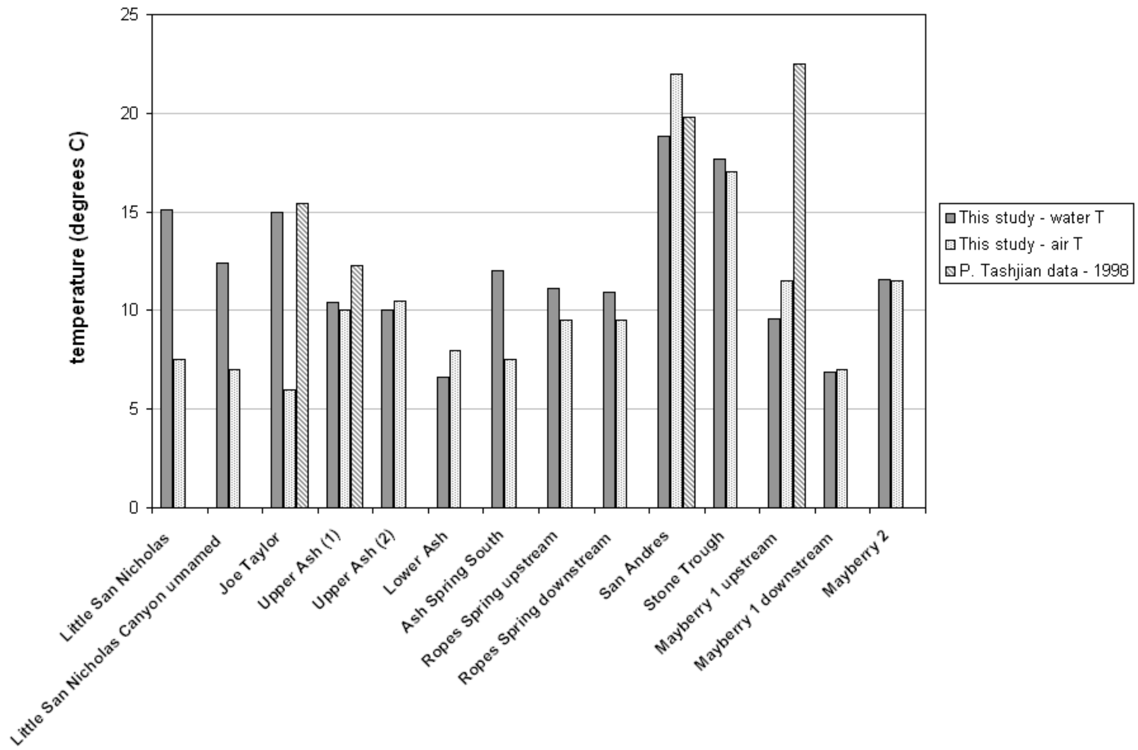

Figure 2. Temperature data for springs on the refuge.

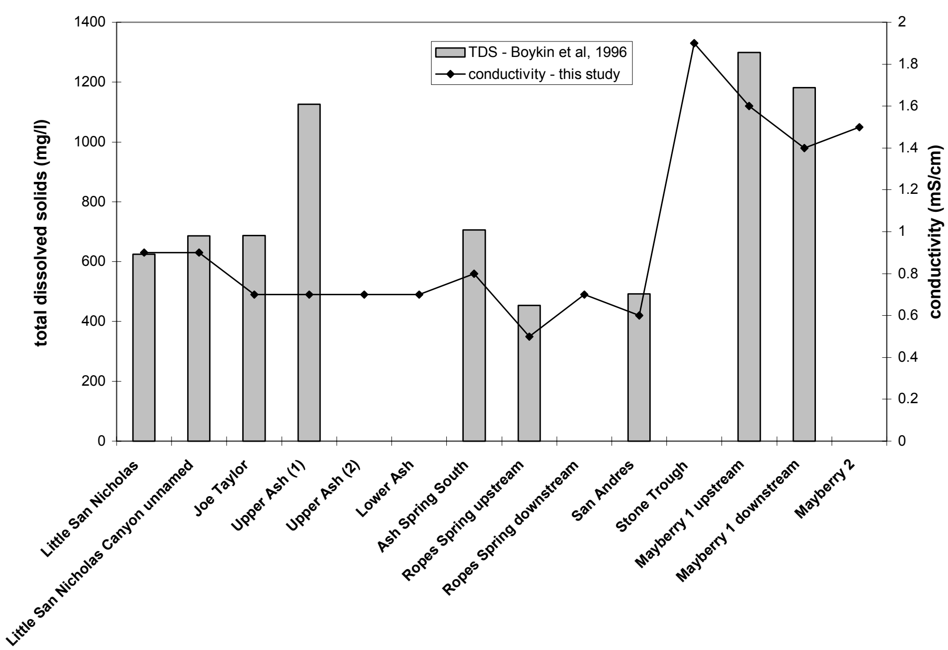

Figure 3. Conductivity and total dissolved solids data for springs on the refuge.

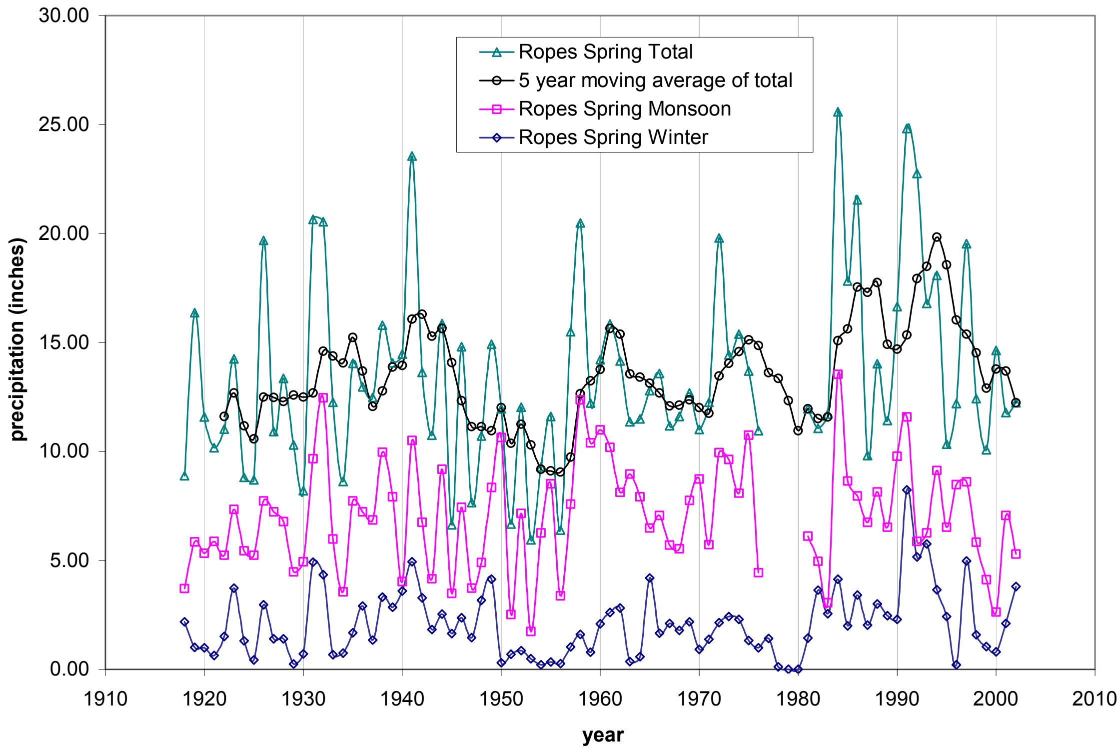

Figure 4. Yearly precipitation data from the Ropes Spring rain gauge. Monsoon is the sum of July, August, and September. Winter is the sum of December, January, and February. Data are from Mara Weisenberger, SANWR.

The canyon is eroded along the trace of a fault zone oriented at a high angle to the range front. The fault has normal movement with the southeast side down, and juxtaposes Ordovician El Paso group carbonates against Precambrian crystalline rocks. However, as can be seen from the map, the fault zone is complex, with several interconnecting strands which enclose slivers of Cambrian-Ordovician Bliss sandstone. Displacement on the fault decreases to the southwest, and the fault dies out where the canyon turns from northeast-southwest to north-south. The fault zone is thus a “scissors fault”, uplifting the range front to the north and dropping it to the south. This scissors movement can be seen by comparing the elevation of the base of the Ordovician Montoya Group on the northwest and southeast walls of the canyon.

The spring is not on the main trace of this fault zone, but there are several exposures of small faults along the canyon bottom, and the rock is pervasively jointed. It is likely that these subsidiary faults and jointing are related to the larger fault and are the major control on local groundwater flow.

Hydrologic Setting and Water Source: The spring discharges from joints in the Precambrian bedrock. The water temperature, conductivity, and total dissolved solids data are similar to the other springs in Little San Nicholas Canyon (1a and 1b). Together with their geologic setting, this suggests that these springs are discharging from the same flow system (see description below for Joe Taylor Spring, spring 1c).

Potential Threats: As there is little development in the postulated recharge area, the mains threats to the spring are encroachment of invasive phreatophytes such as tamarisk.

Potential Enhancements: Continued monitoring of the local riparian zone.

<u>Spring 1b – Little San Nicholas Canyon unnamed</u>

Location: Bear Peak 7.5 - minute quadrangle, UTM coordinates: 358767E, 3604534N.

Description: This spring is located in Little San Nicholas Canyon about 500 m northeast of where the canyon bottom starts to widen. It is marked on the Bear Peak quadrangle. The spring discharges from bedrock fractures in the arroyo bottom with a trickling flow though several pools of standing water with much algae. There are abundant grasses, willows, and ash trees around the spring.

Geologic Setting: The geology around this spring is shown on map 1 and cross section 1. The line of the cross section does not cut through the spring, but the geology is essentially the same as shown, and is similar to that of spring 1a. A mapped fault trace with a good outcrop exposure of the fault plane is just east of the spring.

Hydrologic Setting and Water Source: The spring discharges from joints in the Precambrian bedrock. The water temperature, conductivity, and total dissolved solids data are similar to the other springs in Little San Nicholas Canyon (1a and 1c). Together with their geologic setting, this suggests that these springs are discharging form the same flow system (see description for Joe Taylor Spring).

Potential Threats: As there is little development in the postulated recharge area, the mains threats to the spring are encroachment of invasive phreatophytes such as tamarisk.

Potential Enhancements: Continued monitoring of the local riparian zone.

Spring 1c – Joe Taylor Spring

Location: Bear Peak 7.5 - minute quadrangle, UTM coordinates: 358408E, 3604209N.

Description: This spring is located in Little San Nicholas Canyon where the canyon turns from north-south to northeast-southwest and begins to widen. It is not marked on the Bear Peak quadrangle. The spring discharges from bedrock fractures in the canyon bottom with audible flow though several pools of standing water with much algae. There are abundant grasses, willows, and ash trees around the spring, and a crumbling rock cabin.

San Nicholas Spring is marked at approximately the same spot on the Bear Peak quadrangle. It was ~ 50 m up the canyon from Joe Taylor Spring where several ledges of Bliss Sandstone cross the canyon bottom, and there used to be a large pool. The spring and the pool have both dried up since the mid 1990's (Mara Weisenberger, personal communication).

Geologic Setting: The geology around this spring is shown on map 1 and cross section 1. The spring is located at the unconformity between Precambrian granite gneiss and Cambrian-Ordovician Bliss sandstone, within a very deep canyon. In this area the unconformity is a plane, with little relief. To the southeast on a small ridge are several faults of the previously described "scissors" fault zone that runs down the canyon

Hydrologic Setting and Water Source: The spring discharges from the plane of the unconformity and joints in the Precambrian bedrock immediately below it. The water temperature, conductivity, and total dissolved solids data are similar to the other springs in Little San Nicholas Canyon (1a and 1b). Together with their geologic setting, this suggests that these springs are discharging form the same flow system. The water source is likely the main mass of the range front to the north and south. The water migrates through fractures in the Precambrian bedrock and along the Precambrian – Cambrian unconformity, and discharges at the canyon, which is a local low point.

Potential Threats: As there is little development in the postulated recharge area, the main threats to the spring are encroachment of invasive phreatophytes such as tamarisk.

Potential Enhancements: Continued monitoring of the local riparian zone.

Spring 2a – Ash Spring Complex

Location: San Andres Peak 7.5 - minute quadrangle, upper discharge point UTM coordinates: 355108E, 3611473N; lowest pool UTM coordinates: 355406E, 3611193N

Description: This spring is located in Ash Canyon in its broad upper reach that trends approximately north-south. It is marked on the San Andres Peak quadrangle. Water discharges from bedrock fractures in the floor of the arroyo and along the west wall. A flowing stream and several deep pools are present for several hundred meters down the canyon, past the point where it narrows and turns east. Along this length, the drainage has thick vegetation including grasses, willows, ash trees, and two Arizona cypress trees. There are abundant small hanging gardens of thick vegetation along the canyon wall in its upper reaches, which are damp and commonly trickle water.

The distinctive feature of this spring complex is the abundant deposits of calcareous flowstone and tufa encrustations. Many of the ledges in the canyon bottom have smooth flowstone chutes, and locally the mud and decomposed vegetation in the canyon bottom is cemented by flowstone. The encrustations are common on vegetation such as the overhanging gardens and mosses on the canyon floor.

The extent of the spring complex has diminished since the mid 1990's, and the upstream discharge point has migrated down the canyon a few hundred meters (SANWR staff, personal communication). This can be seen by the abundant flowstone and tufa deposits upstream from the current discharge point.

Geologic Setting: The geology around this spring is shown on map 2 and cross section 2. Note that the position of the spring on the cross section is projected from north of the section line. The spring is in the canyon bottom. The upper discharge point is located at the contact between the Lower Pennsylvanian Lead Camp Limestone and the overlying Upper Pennsylvanian Panther Seep Formation. Both formations are uniformly west-dipping. It is also just downstream from the end of a thick alluvial-colluvial fill in the canyon. The lower end of the complex is slightly downsection within the Lead Camp Limestone. The upper portion of the spring complex is within the strike valley in the that runs along much of the range in the Panther Seep formation. The high ridge of the range is to the east, a dip slope on the Lead Camp Limestone. To the west is another, lower ridge capped by the Permian Hueco limestone. Downstream of the lower end of the complex is a small normal fault. Displacement dies out abruptly along this fault to the east and west, forming a small monocline on the western end that is well exposed in the canyon wall.

Hydrologic Setting and Water Source: The spring discharges from the contact between a dominantly carbonate section below and a mixed carbonate-shale-sandstone-gypsum section above. This lithologic contact appears to be a flow conduit. The source area for the water is probably from the western ridge of the range and/or from the north end of the Ash Canyon drainage. The water from this spring has a high total dissolved solids value (1126 mg/l), but a low conductivity (0.7 mS/cm). To the north, Mayberry Spring Complex and Stone Trough Spring have similar geologic settings and both high dissolved solids and/or conductivity. Ash Spring South is nearby, but discharges from a different lithologic horizon and has different water temperature and chemistry. The flow systems discharging at these two springs are not connected, probably because their recharge areas are in opposite directions, they are at different stratigraphic levels, and are separated by the fault and associated monocline.

Potential Threats: As there is little development in the postulated recharge area, the mains threats to the spring are encroachment of invasive phreatophytes such as tamarisk.

Potential Enhancements: Continued monitoring of the local riparian zone.

Spring 2b – Ash Spring South

Location: Bear Peak 7.5 - minute quadrangle, UTM coordinates: 355910E, 3610296N;

Description: This spring is located in a small tributary canyon to Ash Canyon, near the base of a large cliff. It is marked on the Bear Peak quadrangle. It discharges from bedrock fractures in the floor of the canyon. A trickle of water and several small pools are present. The drainage is choked with vegetation. There are ash trees, grasses, and moss around the spring and salt stains on the rocks, but none of the calcareous deposits typical of Ash Spring. Several lengths of broken, rusty pipe lead away from the spring and down the canyon, indicating it was once developed.

Geologic Setting: The geology around this spring is shown on map 2 and cross section 3. It is located at the unconformity between the Silurian Fusselman Dolomite and the overlying Devonian shale. The rocks dip to the west similarly to those at Ash Spring. The Fusslman Dolomite holds up a spur to the east of the spring, and the exposed upper surface of the Fusselman extends up the hill from the spring. The spring is about 150 feet above the floor of Ash Canyon. There is a small normal fault to the north that places the Upper Ordovician Montoya Group against the Lower Ordovician El Paso Group. Displacement dies out abruptly along the fault to the east and west, forming a small monocline on the western end that is well exposed in the canyon wall.

Hydrologic Setting and Water Source: The lithologic contact where the spring discharges appears to be a flow conduit. The chemistry and temperature of the water is markedly different from that of Ash Spring, suggesting that the two springs discharge from distinct flow systems. This contact crops out to the north in Ash Canyon at a lower elevation than at Ash Spring South, but this is north of the small monocline. If flow is focussed along this contact, then the monocline may act as a barrier to divert flow to Ash Spring South. It also may be important in separating the flow system from that feeding Ash Spring. The ultimate source is likely to the southwest.

Potential Threats: As there is no development in the postulated recharge area, the main threats to the spring are encroachment of invasive phreatophytes such as tamarisk.

Potential Enhancements: Continued monitoring of the local riparian zone.

<u>Spring 3 – Ropes Spring</u>

Location: San Andres Peak 7.5 - minute quadrangle, UTM coordinates: 353990E, 3616381N;

Description: This spring is located in Ropes Draw, a broad drainage on the west slope of the San Andres mountains. It is marked on the San Andres Peak quadrangle. It is a series of springs and pools in the main drainage, with abundant riparian vegetation. The spring has been developed with water piped to storage tanks.

Geologic Setting: The geology around this spring is shown on map 3 and cross section 4. It is located within the Upper Pennsylvanian Panther Seep Formation, near its lower contact with the Lower Pennsylvanian Lead Camp Limestone. Up slope from the spring, the Lead Camp forms a spectacular dip slope to the summit of San Andres Peak. Downslope is the western ridge of the range underlain by the Permian Hueco limestone. It is more subdued here than to the north and south, and the surface drainage of Ropes Draw is to the west through a small gap in the western ridge, rather than north-south. All of the rocks dip 20-30º to the west. Low drainage divides separate Ropes Draw from Ash Canyon to the south and Lead Camp Canyon to the north.

Hydrologic Setting and Water Source: The spring discharges from fractures in the bottom of Ropes Draw. The probable recharge area is the main mass of San Andres Peak directly to the east. This spring may be the discharge point of a topographic flow system recharged high on the mountains and discharging on the lower slopes. There is no obvious topographic control on the location of this spring, but it may be geologically controlled by its proximity to the Lead Camp - Panther Seep contact.

Potential Threats: As there is no development in the postulated recharge area, the main threats to the spring are encroachment of invasive phreatophytes such as tamarisk.

Potential Enhancements: Continued monitoring of the local riparian zone.

Spring 4a – San Andres Spring

Location: San Andres Peak 7.5 - minute quadrangle, upper discharge point UTM coordinates: 353689E, 3623004N; lowest pool UTM coordinates: 353783E, 3623032N;

Description: This spring is located in Lead Camp Canyon, downstream of the old lead mine workings, where the canyon broadens at the range front. It is marked on the San Andres Peak quadrangle. Trickling flow and pools extend about 100 m east from the discharge point. There is a lush riparian area with abundant cottonwood trees, willows, grasses, moss, and algae in the pools.

Geologic Setting: The geology around this spring is shown on map 4 and cross section 5. The spring is located at the unconformity between Precambrian granite gneiss and Cambrian-Ordovician Bliss sandstone. The unconformity is essentially a plane, with little relief.

To the west, the old mine workings are developed along a north-south fault that dies out upsection within the Devonian and Mississippian rocks. Movement on this fault is west side down. On the north canyon wall the Lower Pennsylvanian Lead Camp Limestone is folded over the tip of the fault. A southeast-trending splay of this fault slightly offsets the Montoya-Fusselman contact. On the south canyon wall, a small subsidiary reverse fault within the Mississippian limestone has thickened the section. This suggests that the main fault originally had reverse movement, probably during the Late Cretaceous-Early Tertiary Laramide tectonic event, and was reactivated as a normal fault during the uplift of the San Andres mountains.

Hydrologic Setting and Water Source: The spring discharges from alluvium on the canyon floor. The water is probably coming from the unconformity and fractures in the Precambrian bedrock, similar to Joe Taylor Spring. The water source is likely the main mass of the eastern ridge of the range to the north and south. The water flows through fractures in Precambrian bedrock and along the Cambrian-Precambrian unconformity and discharges at the canyon, which is a low point. The water has lower total dissolved solids than the springs at higher elevations in the range which discharge from the Pennsylvanian rocks.

Potential Threats: As there is no development in the postulated recharge area, the main threats to the spring are encroachment of invasive phreatophytes such as tamarisk.

Potential Enhancements: Continued monitoring of the local riparian zone.

Spring 4b – Stone Trough Spring

Location: San Andres Peak 7.5 - minute quadrangle, UTM coordinates: 352201E, 3622699N

Description: This spring is located in Lead Camp Canyon in a tributary drainage north of the main drainage. It is marked on the San Andres Peak quadrangle, but not named. It has a trickling flow and several small pools. The spring discharges from fractured bedrock and has abundant salt staining.

Geologic Setting: The geology around this spring is shown on map 4 and cross section 5. It is located within the Upper Pennsylvanian Panther Seep Formation in the broad valley between the east and west ridges of the range. It discharges from fractured black shale. The bedrock dips west about 23º. A small displacement fault with calcite mineralization is a few meters north of the spring.

Hydrologic Setting and Water Source: A probable recharge area for this spring is the local section of the broad central valley of the range, extending to drainage divides a few kilometers to the north and south. Two named springs within a half kilometer of this one, Lead Camp Spring and Horse Spring, are marked on the San Andres Peak quadrangle, but are currently dry, and were dry at the time of the Boykin et al. (1996) study in the early 1990s. They are a few tens of feet higher in elevation than Stone Trough Spring. Lead Camp spring has been developed with a pipe leading to a concrete trough, so at one time it had considerable flow. It is possible that a small lowering of the water table has cut off the two now dry springs but has not yet affected Stone Trough. The spring water has very high conductivity. This is probably due to its source within shales of the Panther Seep Formation.

Potential Threats: As there is no development in the postulated recharge area, the main threats to the spring are encroachment of invasive phreatophytes such as tamarisk.

Potential Enhancements: Continued monitoring of the local riparian zone.

Spring 5a – Mayberry Spring 1

Location: Gardner Peak 7.5 - minute quadrangle, upper discharge point UTM coordinates: 351591E, 3628130N; lowest pool UTM coordinates: 351980E, 3628494N

Description: This spring complex is several hundred meters long and consists of several discharge points and pools within the reach bounded by the UTM coordinates above. It is marked on the Gardner Peak quadrangle. There are many seeps and, both wet and dry, at low elevations along the bedrock walls of the canyon. Some of these seeps have minor flowstone sheets associated with them. There is abundant riparian vegetation such as willows, grasses, mosses, and cottonwood trees.

Geologic Setting: The geology around this spring is shown on map 5 and cross section 6. It is discharges from the upper portion of the Lower Pennsylvanian Lead Camp Limestone, probably from fractures, although in many places the water discharges from alluvium in the canyon bottom. The upstream discharge point is a few hundred meters from the contact with the overlying Panther Seep Formation. The bedding in the Lead Camp Limestone dips west 15º to 20º along this reach but to the east the dips steepen sharply up to 75º as the bedding is folded up adjacent to a west-side down normal fault. This fault and the associated folding are the continuation of similar structures exposed in Lead Camp Canyon. Here the fault cuts the Lead Camp Limestone, and has approximately 500 feet of subvertical movement. Subsidiary faults in the Mississippian limestone exposed in the south wall of the canyon have reverse displacement. As at Lead Camp Canyon, this suggests that the structural zone may have originally had reverse displacement and was reactivated as a normal fault during Rio Grande rift-related extension and uplift of the San Andres mountains.

Hydrologic Setting and Water Source: There appear to be several discharge points along the spring complex. Some may be underflow in the alluvium reaching the surface at bedrock ledges, whereas others are true discharge points from fractured bedrock. Immediately to the west is San Andrecito Spring, which is currently dry, but had a large pool of water in the early 1990s (Mara Weisenberger, personal communication). The geologic setting of both springs is similar. It is possible that a small lowering of the water table has cut off San Andrecito spring but has not yet affected Mayberry 1. Similar to Stone Trough Spring, a probable recharge area for this spring is the local section of the broad central valley of the range, extending to drainage divides a few kilometers to the north and south. However, the seeps in the canyon wall adjacent to the spring complex suggest that some water is coming from the large ridge of Lead Camp Limestone to the south. The high conductivity and total dissolved solids values for this spring suggest the bulk of the water has passed through the overlying Panther Seep Formation shales. The water may be moving near or along the Lead Camp – Panther Seep contact, and thus discharging at the low point of this contact in Mayberrry Canyon

Potential Threats: As there is no development in the postulated recharge area, the main threats to the spring are encroachment of invasive phreatophytes such as tamarisk.

Potential Enhancements: Continued monitoring of the local riparian zone.

<u>Spring 5b – Mayberry Spring 2</u>

Location: Gardner Peak 7.5 - minute quadrangle, upper discharge point UTM coordinates: 352057E, 3628536N; lowest pool UTM coordinates: 352066E, 3628508N

Description: This spring complex is about a hundred meters long and may have multiple discharge points, but the riparian vegetation and alluvium are too thick to be sure. It is marked on the Gardner Peak quadrangle. There is an obvious upstream discharge point and several pools with thick algae.

Geologic Setting: The geology around this spring is shown on map 5 and cross section 6. Note that the spring is projected into the cross-section; it is actually in the canyon bottom. It discharges from the lower portion of the Lead Camp Limestone, probably from fractures, where the bedding dips begin to steepen to form the fold adjacent to the west-side down normal fault. The local geology is otherwise the same as that described for Mayberry Spring 1.

Hydrologic Setting and Water Source: This spring probably discharges from a fracture network related to the fold adjacent to the normal fault. The conductivity, total dissolved solids data, and proximity to the other springs suggest the water is from the same flow system as that discharging at Mayberry Spring 1. Thus, the recharge area for this spring is the same as Mayberry 1, the local section of the broad central valley of the range extending to drainage divides a few kilometers to the north and south. However, it is likely that there may be a greater contribution from the ridge of Lead Camp Limestone north and south of the spring.

Potential Threats: As there is no development in the postulated recharge area, the main threats to the spring are encroachment of invasive phreatophytes such as tamarisk.

Potential Enhancements: Continued monitoring of the local riparian zone.

VII. DISCUSSION

Spring types and source areas

The springs on the refuge examined in this study can be divided into two main types based on their geologic setting and water chemistry. The first type are those in Little San Nicholas Canyon and San Andres Spring. They discharge from fractured Precambrian bedrock and/or the Cambrian - Precambrian unconformity. The spring waters have low conductivity and total dissolved solids values, typical for waters in crystalline rocks (Hem, 1985). The source for these springs is likely the eastern ridge of the range, and the water moves north and south to the springs and discharges in the canyon bottoms. Each spring therefore represents the approximate center and low point of separate but similar groundwater flow systems, The high points of the systems probably roughly coincide with the summits of the ridge between the canyons (cf., (Hubbert, 1940; Toth, 1963). Crawford Spring, downstream of Mayberry Spring also was probably of this type, as it has the same geologic setting. It is now dry.

Ash Spring, Stone Trough Spring, and Mayberry Spring represent the second type of spring. They discharge from the Lead Camp Limestone – Panther Seep Formation contact, or slightly downsection within the Lead Camp Limestone. The waters of these springs have high dissolved solids and/or conductivity values. The differences in water chemistry indicate that these springs discharge from a separate flow system from the type one springs. The source of the dissolved solids in the waters is likely the Panther Seep Formation, with its abundance of fine-grained calcareous clastic rocks and argillaceous limestones. The fine-scale fracturing of these rocks and their small grain size would promote both slow travel and thus relatively long residence times of the water, and enhance the likelihood of dissolution of soluble minerals. The water sources are most likely the individual drainage basins surrounding each spring within the central valley of the range. Burro Spring, Salinas Spring, and Salt Canyon Spring are all probably of this type, as they are in similar topographic and geologic settings (within the Panther Seep Formation). Stinking Spring, and Rock House Spring also are probably type two springs, although they are located near faults (Bachman and Myers, 1969), which may be important structural controls.

Ash Spring South and Ropes Spring do not fit neatly into either of these two spring types. Ropes Spring is similar to the type two springs in its geologic setting, but it has low conductivity and total dissolved solids values. Thus, rather than flowing extensively through the Panther Seep Formation, the water has probably moved downslope from the eastern ridge of the range through the Lead Camp Limestone, and is diverted to the surface when it reaches the Panther Seep Formation. Flow through this unit is through fractures and joints, probably dissolution-enlarged over geologic time, and present-day flow has faster travel and shorter residence times than flow in the Panther Seep Formation. Combined with the generally massive, thick-bedded nature of the Lead Camp Limestone, this would decrease the ability of the water to dissolve soluble minerals as compared to flow through the Panther Seep Formation. Goldenburg and Chinch Bug

Springs have analogous geologic settings on the west flank of the western ridge of the range capped by the Hueco Limestone, and thus may be similar to Ropes Spring.

Ash Spring South discharges from the Devonian shale – Silurian Fusselman Dolomite contact, and has water chemistry similar to the type one springs. The overlying Devonian shale may be an aquitard that separates the flow system of the type one springs from that of the type two springs. However, if this were the case, then it is not likely that the recharge area for the type one springs is the eastern ridge of the range, as the Devonian rocks everywhere underlie the thick carbonates that make up the summit, and they would divert groundwater flow to the west. The fault and monocline to the north of the spring probably prevent mixing of the waters that discharge at Ash Spring South with those of Ash Spring. If Ash Spring South is the discharge point of a type one flow system, it is not clear why it discharges upsection from the Cambrian - Precambrian unconformity and at a higher elevation than the other type one springs.

Ash Spring

Ash Spring is of particular interest for its abundant tufa and flowstone deposits. It is also interesting in that it has high total dissolved solids values but low conductivity. There are several possible explanations for this.

The total dissolved solids data of Boykin et al. (1996) were collected in the early 1990's. The spring water chemistry may be different now, and thus the conductivity data of this study and the data of Boykin et al. (1996) are not comparable. It may be that the spring is not currently precipitating anything.

If the spring is currently precipitating the flowstone and tufa, this implies that the spring water is supersaturated with calcium carbonate. I tested the water in the pool furthest upstream in the spring complex. It was not clear where the actual discharge point was; it was probably beneath the abundant vegetation on the west wall of the drainage. It is possible that the water chemistry changed upon contact with the atmosphere, perhaps drastically, between the discharge point and the pool (Peggy Johnson, personal communication). The water may have already precipitated the calcium carbonate, or minute suspended crystals may have formed from the calcium and carbonate ions, and thus the conductivity would be low.

It is not clear why Ash Spring is the only spring with abundant tufa and flowstone deposits. The geologic setting and probable water source are similar to several of the other springs in the refuge. Some of these have minor flowstone deposits (e.g., Mayberry Spring), and it may simply be a matter of degree. The water discharging at Ash Spring may have had a longer residence time in contact with soluble minerals.

Spring flow and precipitation

Flow data for springs on the refuge and yearly precipitation data from the Ropes Spring rain gauge are shown in Table 3 and Figure 4, respectively. I did not collect flow data in this study, but refuge staff reported that several springs have decreased in flow or dried up altogether since the early 1990s. For example, San Andrecito Spring and San Nicholas Spring (just upstream from Joe Taylor Spring) both had enough flow to form large pools that are now gone. Anonymous (1958) includes flow data from 1938 for several springs that are now dry, including Stinking Spring, Burro Spring, Lead Camp Spring, Horse Spring, and Crawford Spring.

From Figure 4 it can be seen that the 5-year moving average of precipitation in the 1920's and 1930's was a steady upward trend. In the decade preceding this study, the 5-year moving average of precipitation has dropped precipitously from the highest values in the period of data collection. Because of the fracture dominated groundwater flow systems in the refuge, on the average, flow times can be expected to be fast, residence times short, and the amount of groundwater held in storage low, although this will vary between formations as described above.

It is apparent that decline in precipitation during the 1990's has already propagated through the groundwater system, with widespread effects on the refuge springs. The type two springs have been strongly affected, with the only type one springs drying up being Crawford Spring and San Nicholas Spring. This again suggests that there are two separate flow systems feeding the type one and type two springs, and that the type two system is shallower and has less storage. It will be interesting to see the effect a future year of high precipitation, similar to say, 1991, will have on spring flow.

There are several examples on the refuge of recently dry springs near to springs that are still flowing, e.g., San Nicholas near Joe Taylor, Horse and Lead Camp near Stone Trough, and San Andrecito near Mayberry. These groups of springs are of both types one and two. This phenomena again suggests that the flow systems are fracture dominated and water tables are extremely irregular, even on a scale of tens of meters. Individual fracture or joints may be feeding individual springs, and changes in flow and storage of the groundwater flow systems of the magnitude induced by the recent precipitation changes can dewater the fractures or joints feeding a given spring while not affecting those nearby.

Threats to the springs

The is little development in the refuge and none is expected in the immediate future. There is little in the immediate area as the refuge is surrounded by the White Sands Missile Range. Thus it seems unlikely that the water resources of the refuge will be negatively impacted by development in the near future, and there is no reason to believe that the recent drying up of springs is anything other than a natural phenomenon. The main threat to the springs appears to be the encroachment of nonnative phreatophyte vegetation. This does not appear to be serious problem at present, but the springs should be monitored to prevent it happening in the future.

VIII. SUMMARY

Most springs on San Andres National Wildlife Refuge can be classified into two types based on geologic setting and water chemistry. The two types appear to be discharging from separate groundwater flow systems. Type one springs discharge from fractured Precambrian bedrock and the Cambrian - Precambrian unconformity and have water chemistry characterized by low conductivity and total dissolved solids. Type two springs discharge from the vicinity of the Lead Camp Limestone - Panther Seep Formation contact and have high conductivity and total dissolved solids. Ash Spring South has water chemistry similar to type one springs but discharges from a stratigraphically higher horizon. Ropes Spring is similar to type two springs geologically, but has different water chemistry. Ash Spring is unique for its tufa and flowstone deposits. The rapid transit times and low storage of the fractured bedrock aquifers have resulted in several refuge springs drying up due to decreased precipitation in the past decade. The type two springs have been more strongly affected, probably because they discharge from a shallower flow system with less storage.

IX. SUGGESTIONS FOR FUTURE WORK

The data collected in this study strongly suggest the existence of two spring types discharging from two different groundwater flow systems. However, a more detailed water chemistry study could be performed to confirm this interpretation. Isotopic study of the water discharging from the springs is the best technique available to differentiate the two flow systems.

The lack of groundwater level data is a hindrance to the interpretation of the hydrology of the refuge. Collection of this data would be prohibitively expensive however, because so few wells are present in the area, and a drilling program would probably negatively affect the wildlife habitat.

Few of the springs have manmade structures to store water, and they do not seem to be necessary, as many of the springs have natural pools or available basins associated with them to store spring water for wildlife.

The unique geologic features and interesting water chemistry data for Ash Spring warrant further study. It would be of interest to know whether the spring is currently precipitating tufa and flowstone, and whether the spring water chemistry has changed significantly in the seven years between the study of (Boykin et al. 1996) and this study. If such changes occur, and can be perhaps related to changes in flow and/or precipitation in the refuge area, this spring could provide greater understanding of the hydrology of the refuge and the interrelation of precipitation, residence time of water in the aquifers, and spring flow.

X. ACKNOWLEDGEMENTS

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XII. STRATIGRAPHY AND UNIT DESCRIPTIONS FOR GEOLOGIC MAPS

Qa – Unconsolidated Recent alluvium: Mud, sand, cobbles, and boulders in active and ephemeral stream channels and arroyos.

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

Qe – Unconsolidated Recent eolian sand: Well rounded fine to coarse dominantly quartz sand. Forms sheets and small dunes.

Qc – Unconsolidated to poorly consolidated Recent colluvium: Sand, cobbles, and boulders on hillslopes.

Qc-rf - Unconsolidated to poorly consolidated Recent mixed colluvium and rockfall deposit: Sand, gravel, and boulders, with scattered angular boulders of Montoya Group carbonates up to 10 m in diameter.

Ph - Permian Hueco Limestone: Massive grey bioclastic limestone. Forms prominent ridge on west side or range.

- unconformity -

IPps – Pennsylvanian Panther Seep Formation: Dominantly gray to black calcareous and carbonaceous shale (~60 %), with the remainder being subequal olive to dark gray clastic and argillaceous limestone and brownish sandstone and siltstone (percentages from Bachman and Myers, 1969). Two prominent gypsum beds near the top of the formation. Underlies the central valley of the range. Shales are generally poorly exposed; limestones and sandstones form ledges.

- unconformity -

IPps – Pennsylvanian Lead Camp Limestone: Massive gray clastic limestone with abundant chert nodules and layers, and minor sandstone, shale and conglomerate. Forms prominent cliffs and caps most of the eastern crest of the range.

- unconformity -

Mu – Mississippian undivided: Gray cherty limestone. The Mississippian system has been divided into several formations (e.g., see Kottlowski and LeMone 1994), but they are too thin to be mapped at 1:12000 scale. Generally forms cliffs continuous with overlying Lead Camp Limestone.

- unconformity -

Du – Devonian undivided: Shale, siltstone, limestone, and fine grained sandstone. The Devonian system has been divided into several formations (e.g., see Kottlowski and LeMone, 1994) but they are too thin to be mapped at 1:12000 scale. Very poorly exposed, forms a slope under overlying limestones.

- unconformity -

Sf – Silurian Fusselman Dolomite: Massive medium to dark grey cherty dolomite. Generally forms cliffs.

- unconformity -

Om – Ordovician Montoya Group: Basal dolomitic pebbly Cable Canyon Sandstone, locally absent, overlain by massive dark gray Upham Dolomite, medium to dark gray cherty Aleman Dolomite, and light to medium gray thin bedded Cutter Dolomite. Unit has been variously described as a group or formation, the subdivisions being formations or members respectively. Subdivisions are readily identifiable but I did not map them separately. Generally forms cliffs.

- unconformity -

Oep – Ordovician El Paso Group: Dark to light gray limestones. Generally forms cliffs.

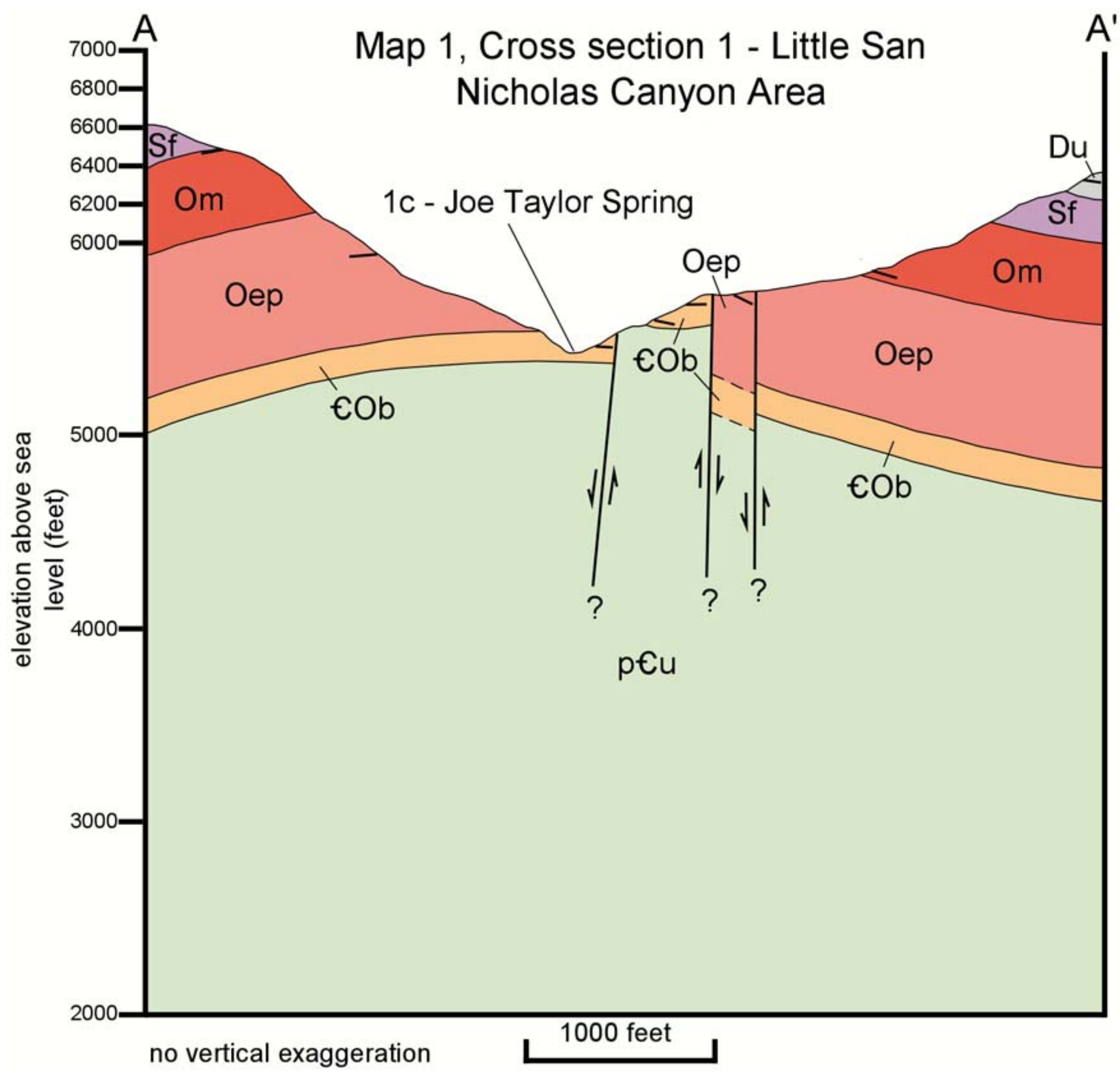
ЄOb – Cambrian-Ordovician Bliss Sandstone: Dark brown to dark red to black , glauconitic, locally calcareous sandstone. Locally has pebbles and oolitic hematite. Gradational contact with overlying El Paso Group limestone.

- unconformity -

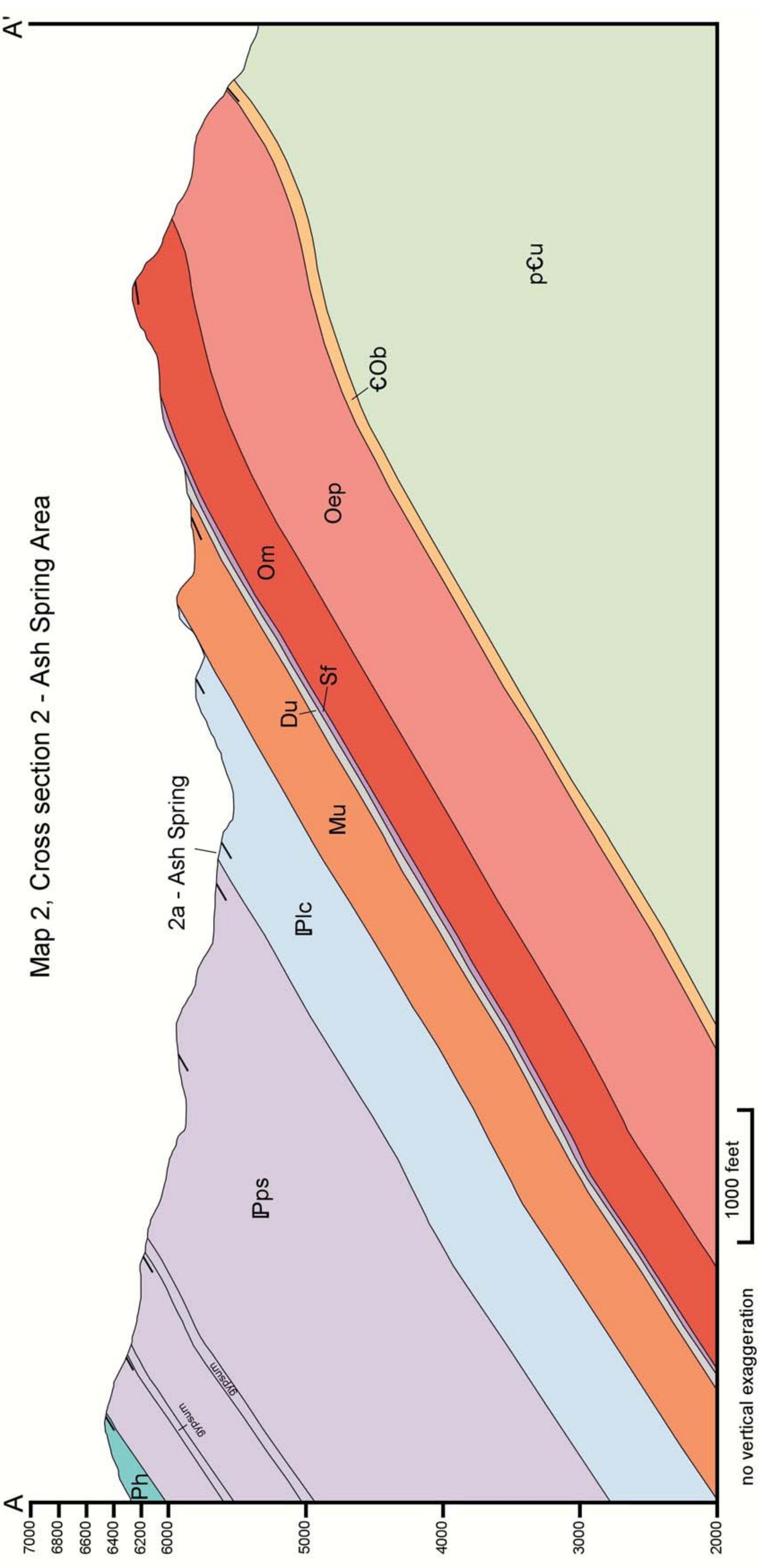
pЄu - Precambrian undivided: Dominantly pink to red granite gneiss with well developed, steeply dipping, east-west striking foliation. Locally grades into unfoliated granite. Contains scattered inclusions of schist, amphibolite, and diorite.

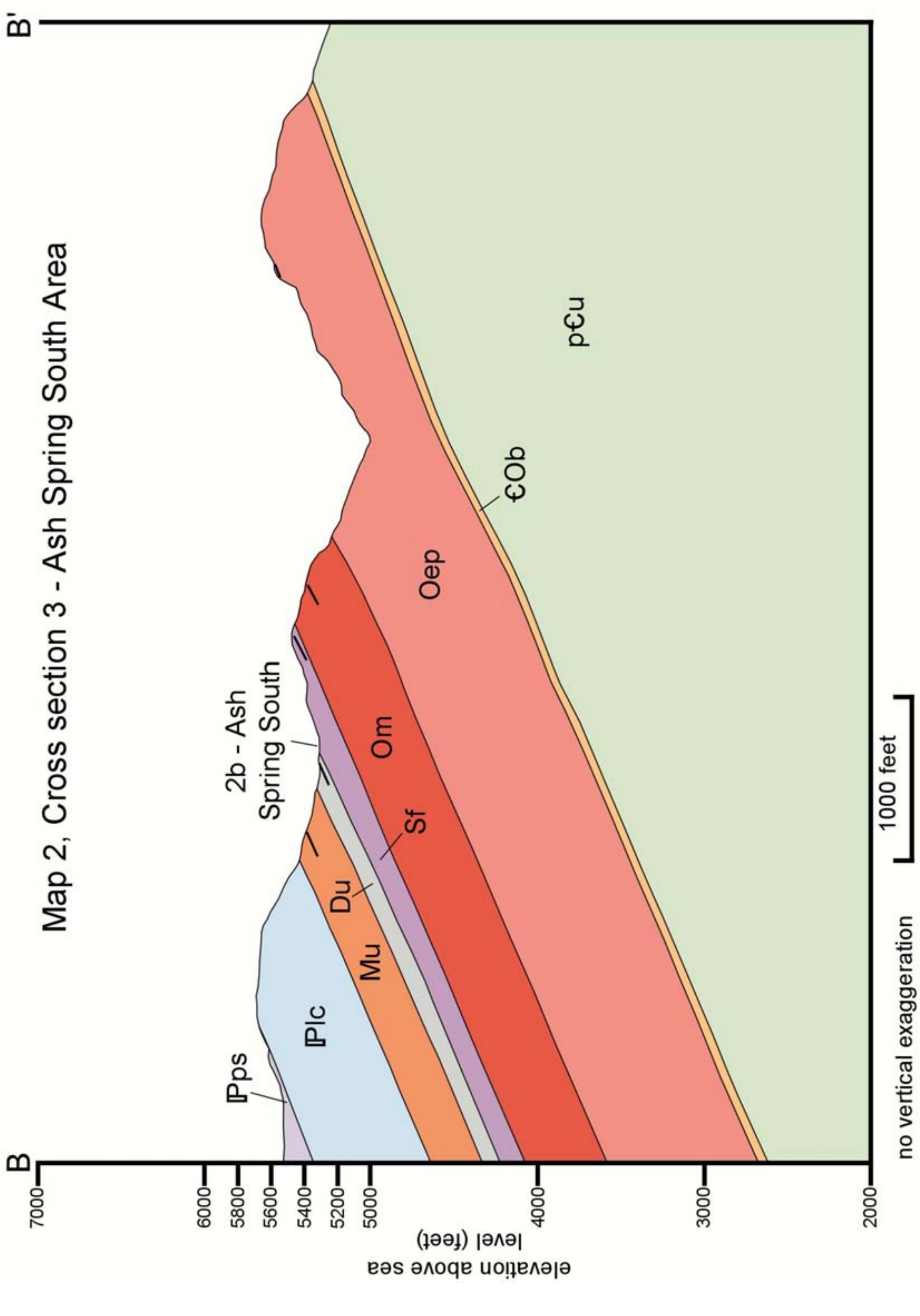
XIII. CROSS SECTIONS

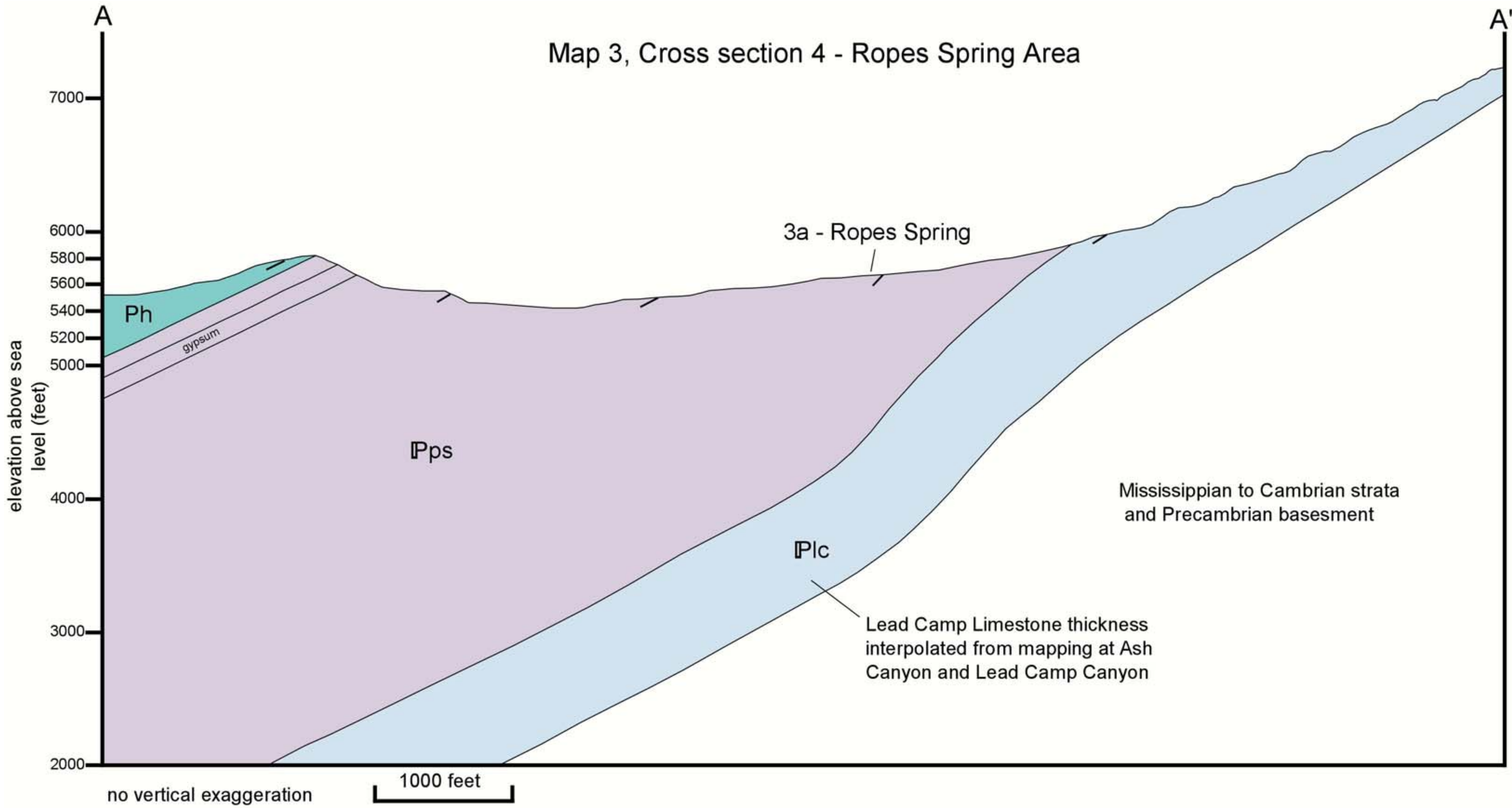
The geologic cross sections are on the following pages in the order presented in table 1.



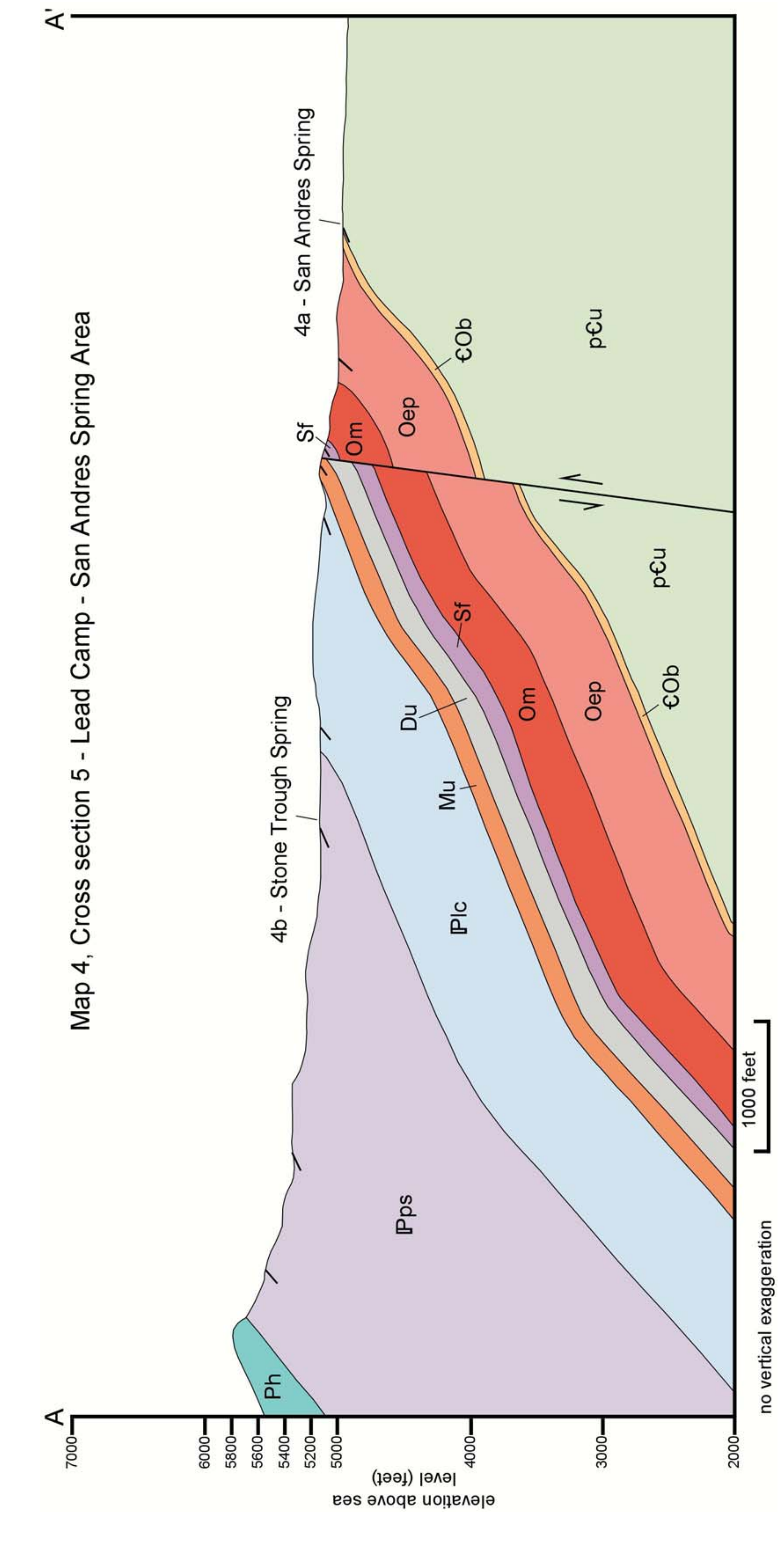
A
A'
Map 1, Cross section 1 - Little San Nicholas Canyon Area
7000
6800
6600
6400
6200
6000
5000
4000
3000
2000
elevation above sea level (feet)
Sf
Om
Oep
€Ob
1c - Joe Taylor Spring
Oep
€Ob
Du
Sf
Om
Oep
€Ob
?
?
?
p€u
no vertical exaggeration
1000 feet

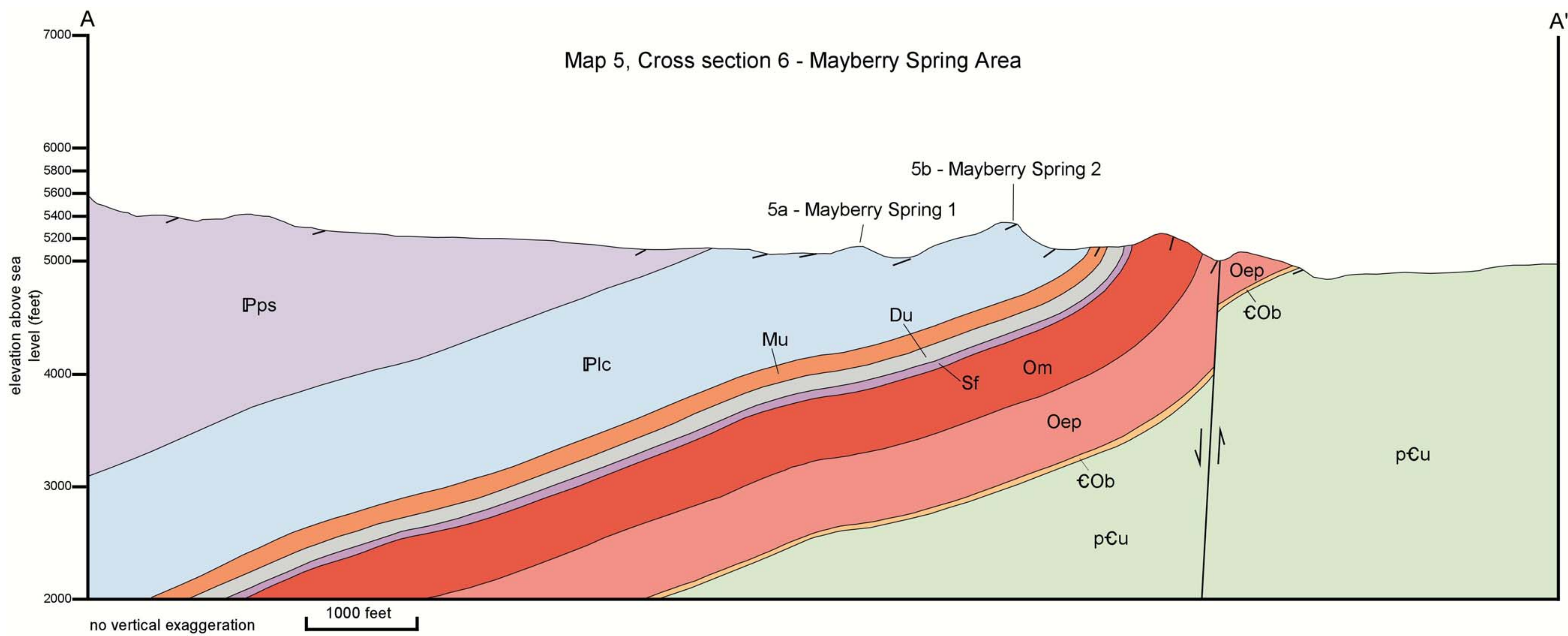

Map 2, Cross section 2 - Ash Spring Area
A
A'
7000
6800
6600
6400
6200
6000
5000
4000
3000
2000
elevation above sea level (feet)
Ph
gypsum
gypsum
ℙps
ℙlc
2a - Ash Spring
Mu
Du
Sf
Om
Oep
€Ob
p€u
1000 feet
no vertical exaggeration


Map 2, Cross section 3 - Ash Spring South Area
B
B'
7000
6000
5800
5600
5400
5200
5000
4000
3000
2000
elevation above sea level (feet)
ℙps
ℙlc
Mu
Du
Sf
Om
Oep
€Ob
p€u
2b - Ash Spring South
1000 feet
no vertical exaggeration

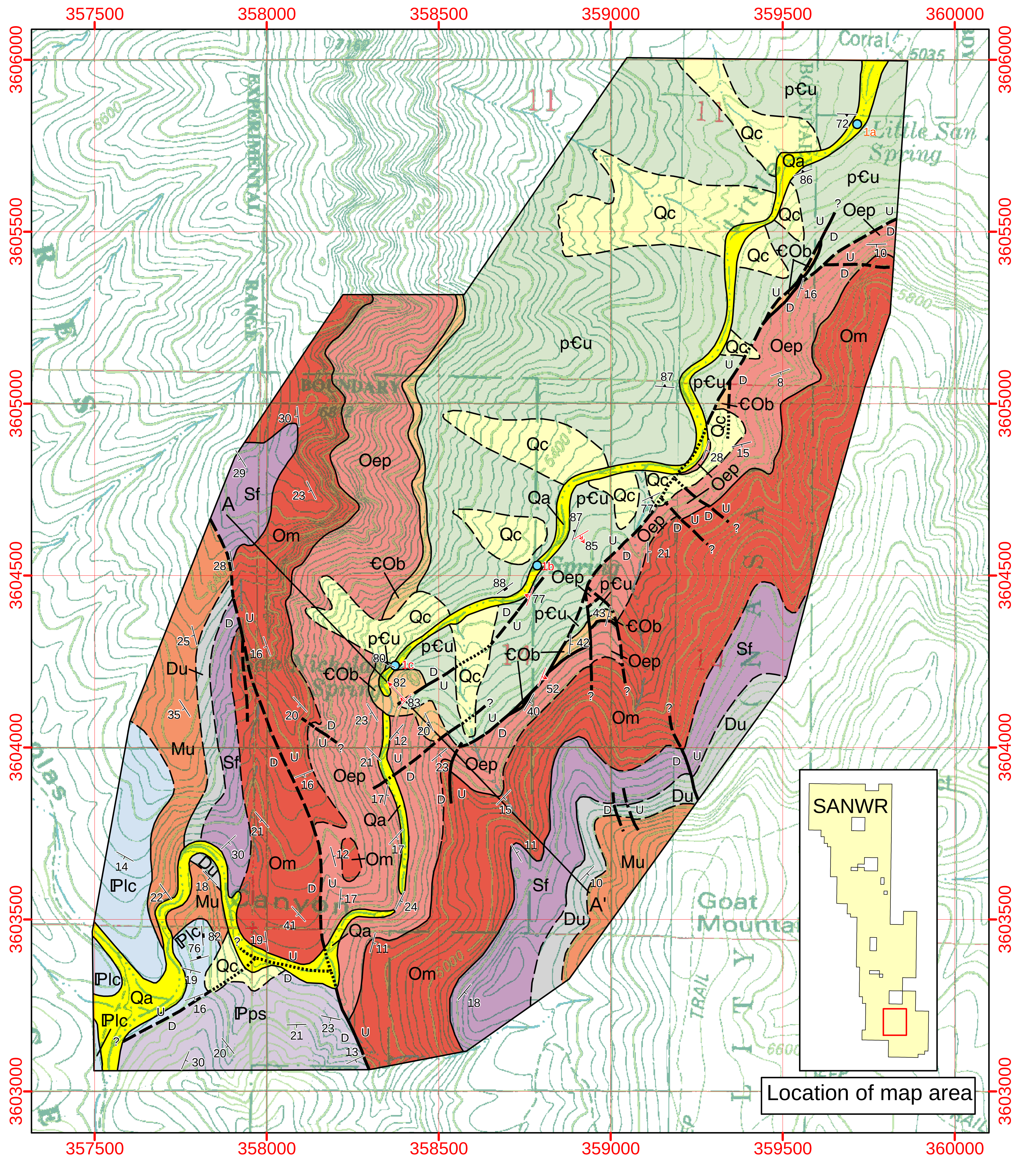


A
A'
Map 3, Cross section 4 - Ropes Spring Area
7000
6000
5800
5600
5400
5200
5000
4000
3000
2000
elevation above sea level (feet)
Ph
gypsum
ℙps
3a - Ropes Spring
ℙlc
Mississippian to Cambrian strata and Precambrian basement
Lead Camp Limestone thickness interpolated from mapping at Ash Canyon and Lead Camp Canyon
no vertical exaggeration
1000 feet


Map 4, Cross section 5 - Lead Camp - San Andres Spring Area
A
A'
4b - Stone Trough Spring
4a - San Andres Spring
Ph
IPps
IPlc
Mu
Du
Sf
Om
Oep
€Ob
p€u
Sf
Om
Oep
€Ob
p€u
1000 feet
no vertical exaggeration
elevation above sea level (feet)
7000
6000
5800
5600
5400
5200
5000
4000
3000
2000


A
A'
Map 5, Cross section 6 - Mayberry Spring Area
7000
6000
5800
5600
5400
5200
5000
4000
3000
2000
elevation above sea level (feet)
5a - Mayberry Spring 1
5b - Mayberry Spring 2
ℙps
ℙlc
Mu
Du
Sf
Om
Oep
€Ob
p€u
no vertical exaggeration
1000 feet

Map 1 - Geology of the Little San Nicholas Canyon area, Bennett Mountain and Bear Peak 7.5 - minute quadrangles, San Andres National Wildlife Refuge



Explanation of symbols

by Geoffrey Rawling

- bedding
- foliation
- fault plane
- small fault
- lineation
- joint
- spring

- geologic contact - certain
- geologic contact - approximate
- faults: ? = uncertain, U = up, D = down
- fault - certain
- fault - approximate
- fault - covered
- cross section

- Qa
- Qc
- IPps
- IPlc
- Mu
- Du
- Sf
- Om
- Oep
- €Ob
- p€u

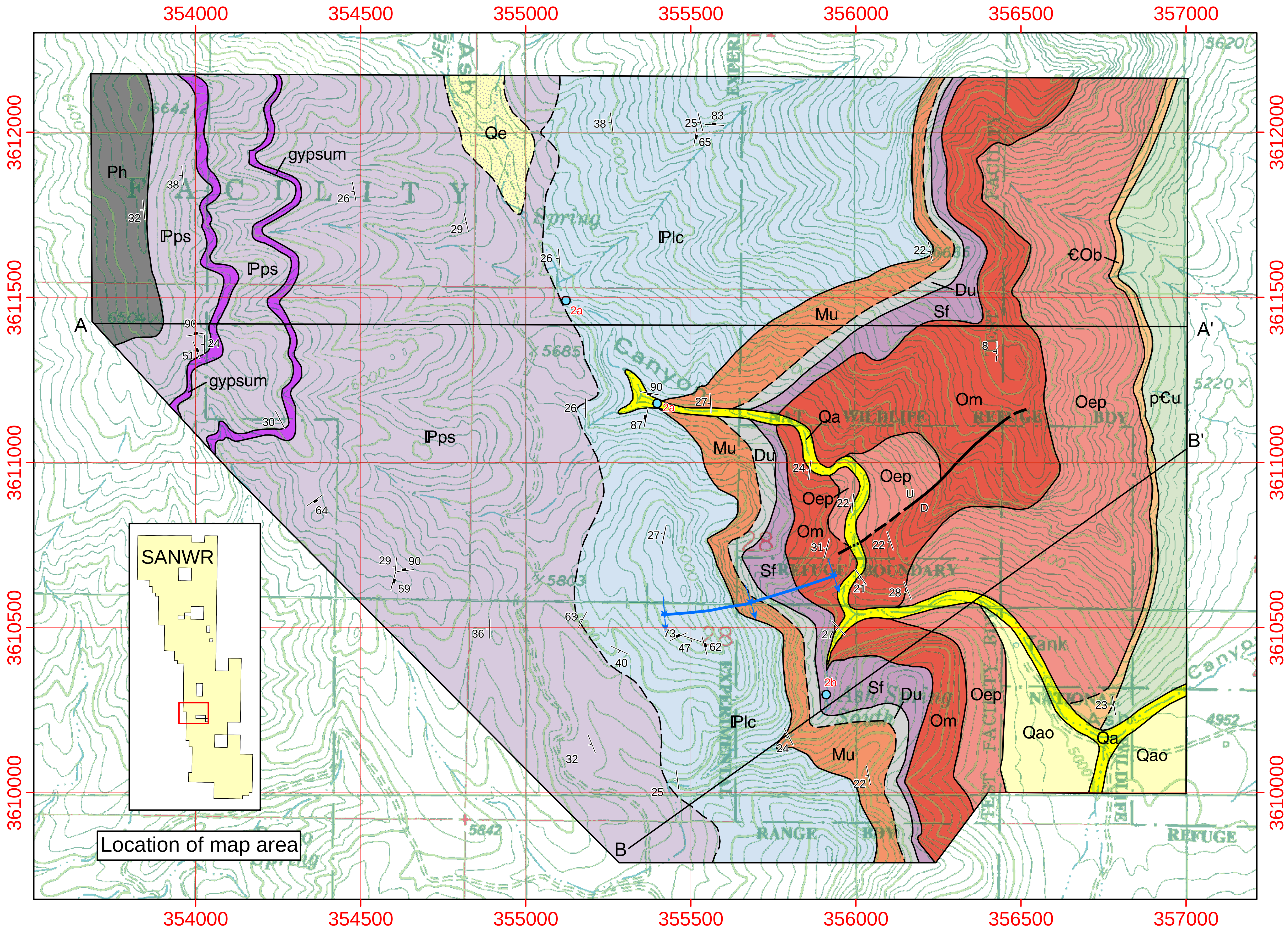
1:12,000

Meters

0 100 200 300 400 500

500 meter UTM grid, zone 13, NAD27, shown in red

Map 2 - Geology of the Ash Canyon area, San Andres Peak and Bear Peak 7.5 - minute quadrangles, San Andres National Wildlife Refuge



Explanation of symbols

- bedding
- photo-interpreted bedding
- joint
- spring
- geologic contact - certain
- geologic contact - approximate

faults: U = up, D = down

- fault - certain
- fault - approximate
- fault - covered
- monocline
- cross section

Qa	Mu
Qe	Du
Qao	Sf
Ph	Om
IPps	Oep
IPps - gypsum	€Ob
IPlc	p€u

by Geoffrey Rawling

N

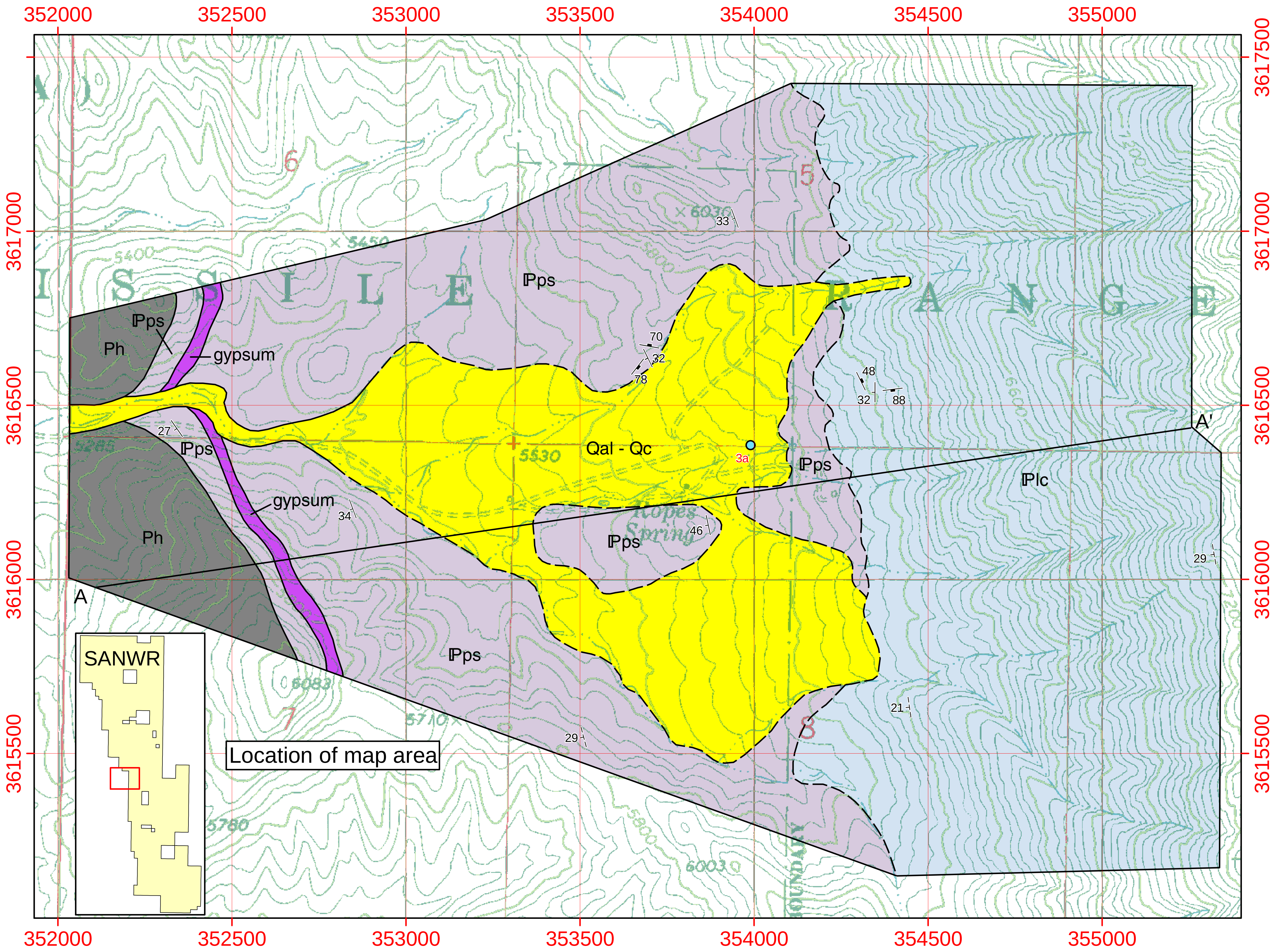
Meters

0 100 200 300 400 500

1:12,000

500 meter UTM grid, zone 13, NAD27, shown in red

Map 3 - Geology of the Ropes Draw area, San Andres Peak 7.5 - minute quadrangle, San Andres National Wildlife Refuge



Explanation of symbols

bedding

photo-interpreted bedding

joint

spring

geologic contact - certain

geologic contact - approximate

cross section

Qal - Qc

Ph

Pps

Pps - gypsum

Plc

by Geoffrey Rawling

N

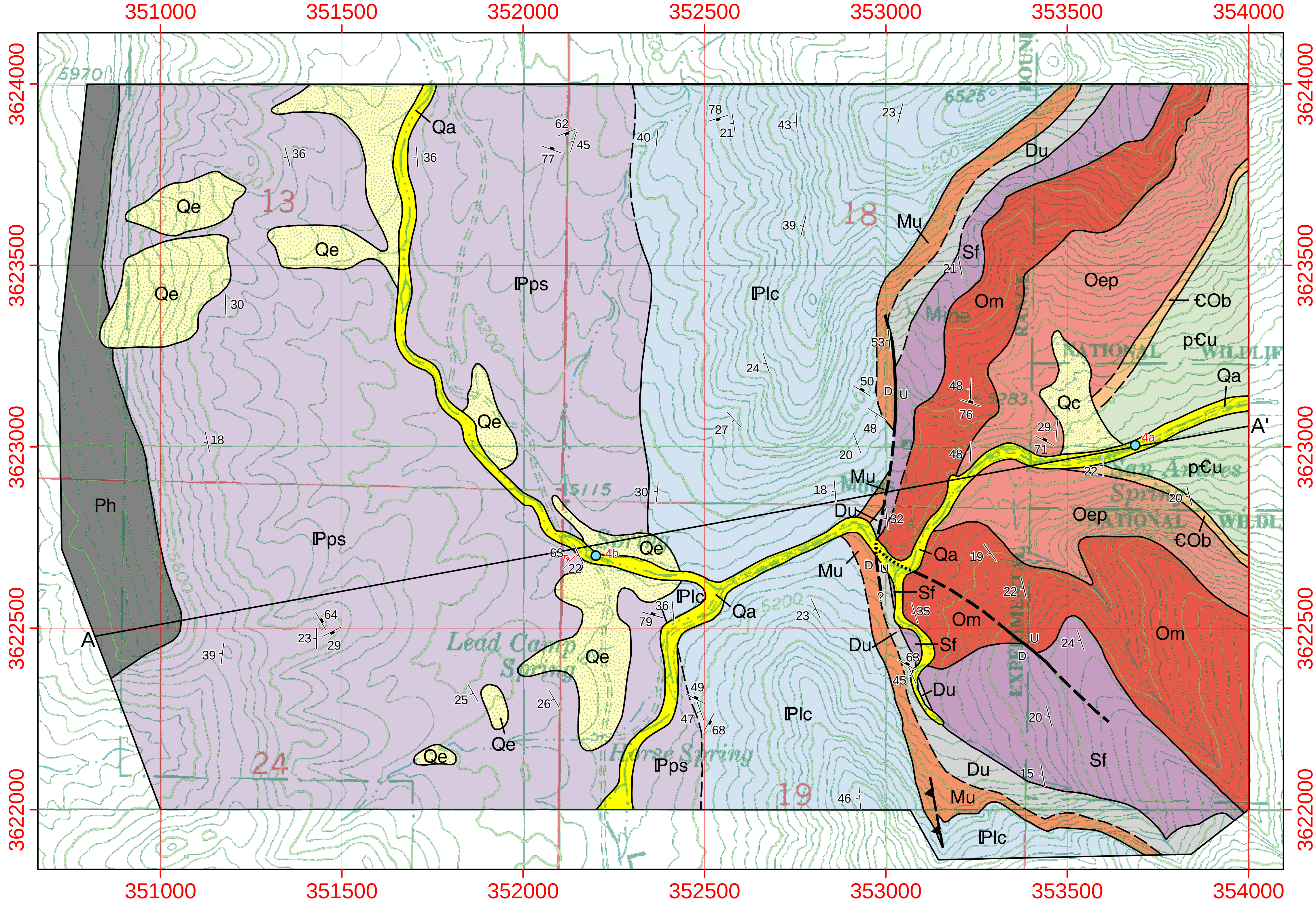
Meters

0 100 200 300 400 500

1:12,000

500 meter UTM grid, zone 13, NAD27, shown in red

Map 4 - Geology of the Lead Camp Canyon area, San Andres Peak 7.5 - minute quadrangle, San Andres National Wildlife Refuge



Explanation of symbols

- bedding
- photo-interpreted bedding
- small fault
- joint
- spring
- geologic contact - certain
- geologic contact - approximate

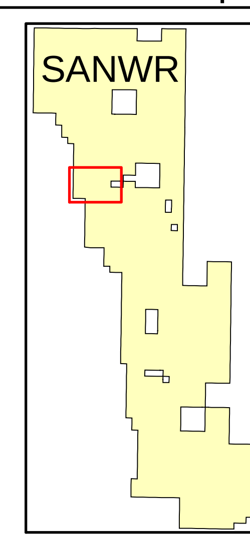
faults: ? = uncertain, U = up, D = down

- fault - certain
- fault - approximate
- fault - covered
- reverse fault - approximate
- cross section

Qa, Qe, Qc, Ph, IPps, IPlc

Mu, Du, Sf, Om, Oep, €Ob, p€u

Location of map area



N

Meters

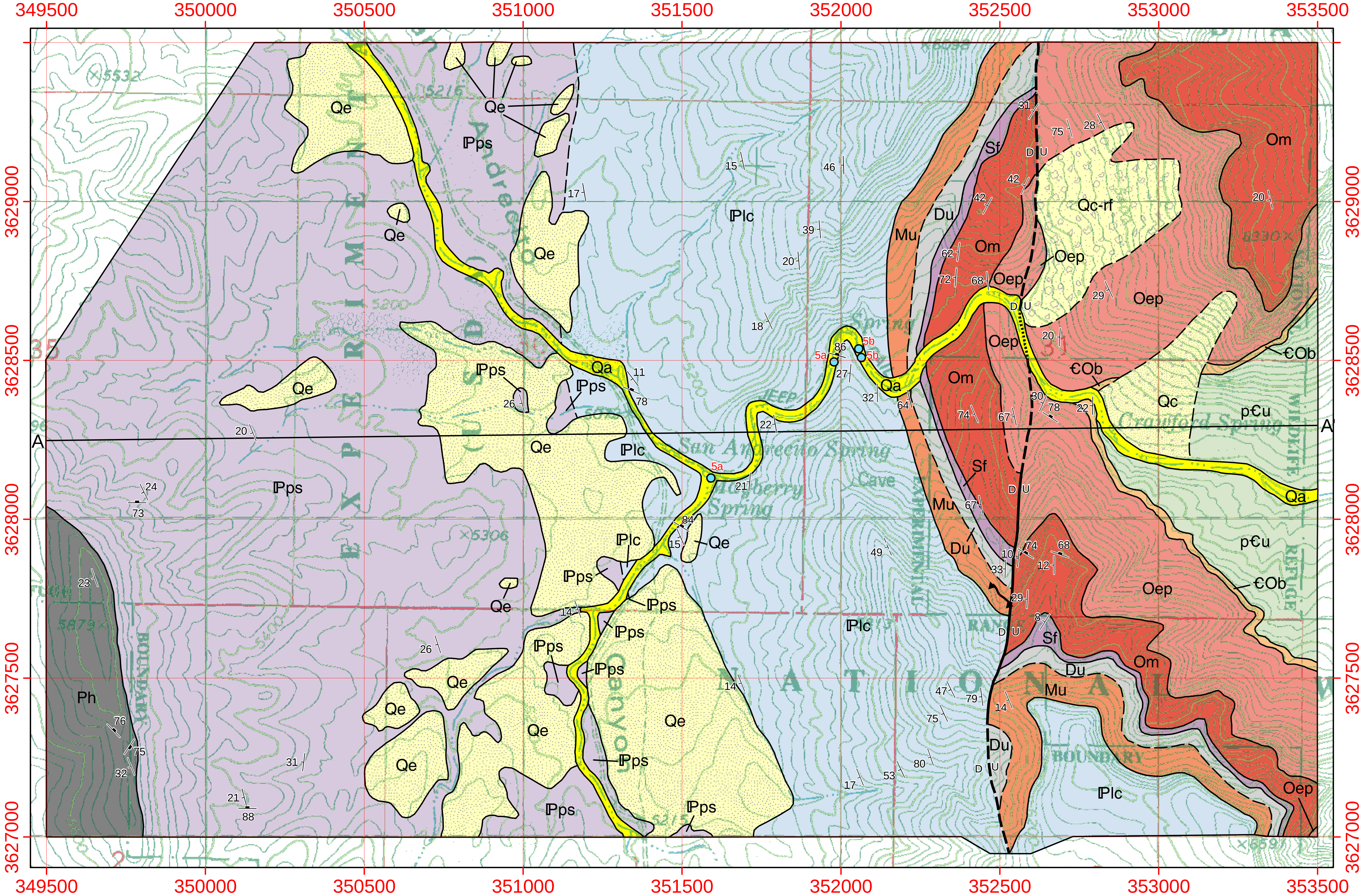
0 100 200 300 400 500

1:12,000

by Geoffrey Rawling

500 meter UTM grid, zone 13, NAD27, shown in red

Map 5 - Geology of the Mayberry Canyon area, Gardner Peak 7.5 - minute quadrangle, San Andres National Wildlife Refuge



Explanation of symbols

- bedding
- photo-interpreted bedding
- joint
- spring
- geologic contact - certain
- geologic contact - approximate

faults: U = up, D = down

- fault - certain
- fault - approximate
- fault - covered
- reverse fault - certain
- cross section

Qa	Mu
Qe	Du
Qc	Sf
Qc-rf	Om
Ph	Oep
Pps	€Ob
Plc	p€u

by Geoffrey Rawling

N

Meters

0 100 200 300 400 500

1:12,000

500 meter UTM grid, zone 13, NAD27, shown in red

Location of map area