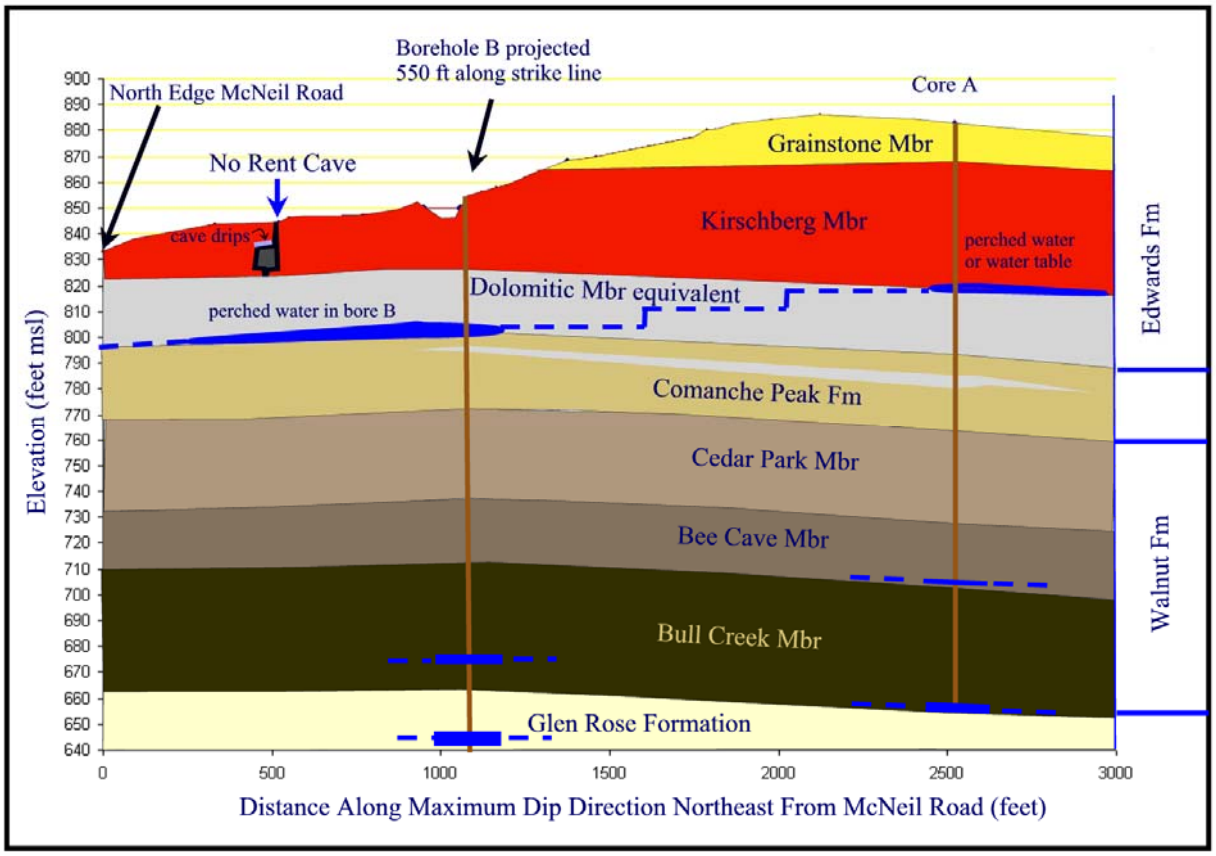
Hydrogeologic Study of
Fossil Garden, No Rent, Weldon, and McNeil Bat Caves

City of Austin Watershed Protection Department
December 16, 2010



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December 16, 2010

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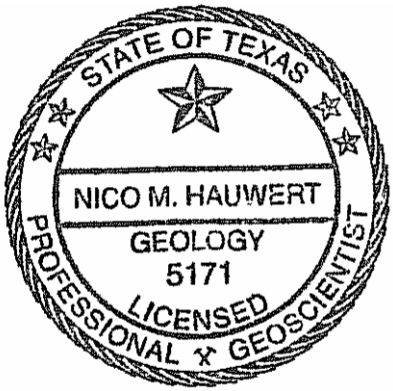

Acknowledgements

This study was made possible with access permission provided by Austin White Lime and Round Rock Independent School District. Robin Skruhak and John Tyler of Austin White Lime generously escorted City of Austin geologists through active quarries and portions of Robinson Ranch. Albert Albers of Round Rock ISD provided access to the McNeil High School site. The Austin Water Utility, through project manager Janet Atkinson, PE, funded the three geological borings, downhole geophysical logging, surface geophysical surveys, and downhole karst species assessments that were vital for completing this report. Austin Water Utility surveyor Phillip Craft, arranged for surveying of the cave entrance locations. CoA Watershed Protection Department geologists Scott Hiers, PG and Sylvia Pope, PG, assisted in geological mapping of the project area and mapping measured sections at type locations. Sylvia Pope arranged access, co-logged Core A, and oversaw the drilling and plugging of the three geotechnical holes. Scott Hiers invested considerable effort to better understand the characteristics of the Comanche Peak and Walnut Formations through outcrop examination, measured sections, and literature research. Geological assistant Justin Camp helped log and describe the Core A, collect cutting samples from Boreholes B and C, and map McNeil Bat Cave. Mark Sanders, a USFW permitted karst biologist of CoA Balcones Canyonland Preserve Program of the Austin Water Utility, provided valuable observations of the caves and their drips, assisted in mapping the caves, and advised us in minimizing any impacts to the cave ecosystem during our visits. Erin Gundersen of Alan Plummer Associates, Inc. provided survey data for the north side of McNeil Road. Roger Glick, PE., Ph.D., and Richard Robinson of CoA Watershed Protection Department provided precipitation data used in this report. This report was reviewed by technical editor Mary-Love Bigony, CoA WP Environmental Resources Management supervising engineer Ed Peacock, PE, Groundwater Team leader David Johns, MS, PG., geologist Sylvia Pope, PG, Austin Water Utility Wildlands Conservation manager William Conrad, and Balcones Canyonland Preserve biologist Mark Sanders.

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Abstract

This study delineates the surface and subsurface drainage areas to Fossil Garden, Weldon, No Rent, and McNeil Bat Caves as required in USFWS permit PRT-788841. All four caves originated as collapsed sinkholes and have relatively small surface catchment areas, except for Fossil Garden Cave, which has matured to have a 5-acre internal drainage basin. Fossil Garden, Weldon, and McNeil Bat Cave have primarily developed within the uppermost pulverulitic beds of the Kirschberg Member, with entrances collapsing through the ceiling of the competent and less-soluble Grainstone Member. The caves were examined within a week of approximately 2 inches of rainfall to delineate drip horizons in each of the four caves. The drips were observed to characterize them as either short-duration or diffuse, suggesting source areas near the cave footprint, or persistent discrete drips that suggest convergence of flow paths from a farther source. The land-surface elevation higher than the combined cave drips horizons extended indefinitely to the west and north. In order to delineate contributing areas, this hydrogeologic assessment also included using geological mapping to identify perching or conveyance beds, measuring stratigraphic dip, using elevation gradients between surface and cave drips measured in the same hydrostratigraphic units on other sites, evaluating the subsurface catchments a minimum of 150 feet radius from cave footprints, and eliminating areas with unlikely shallow groundwater flow paths making sharp turns around drainages or along narrow ridges. The subsurface catchment area for each cave was conservatively overestimated based on analysis of these criteria to provide greater certainty of including the entire area contributing to the cave drips. In addition, surface geophysical surveys conducted as a separate study were considered in interpreting local geology and potential subsurface flow paths. A local stratigraphic dip or discontinuity offset to the northeast may direct subsurface flow toward the cave drips along bedding planes in that direction. In order to comply with USFWS permit requirements, the City is obligated to take measures “adequate to preserve the environmental integrity” of the cave when designing and constructing infrastructure near this site.

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I. Introduction

This study includes a hydrogeologic study of four caves, Fossil Garden, No Rent, Weldon, and McNeil Bat Caves that form the McNeil Cluster (BCP, 2007). These four caves are included on the federal Balcones Canyonland Conservation Plan 10a-1B permit (PRT-788841) held by the City of Austin and Travis County for the purpose of preserving endangered karst arthropod invertebrates within the Balcones Canyonland Preserve (BCP) including the Tooth Cave ground beetle (*Rhadine persephone*), Tooth Cave pseudoscorpion (*Tatarocreagris texana*), Tooth Cave spider (*Neoleptoneta myopica*), Kretchmarr Cave mold beetle (*Texamaurops reddelli*), Bone Cave harvestman (*Texella reyesii*), and Bee Creek Cave harvestman (*Texella reddelli*), as well as 27 karst invertebrate species of concern, and listed endangered birds. The Bone Cave harvestman (*Texella reyesii*) has been collected from all four caves on the site (USFW, 1996; BCCP annual 2008 report). The study area is located within the Karst Zone 1 and the North Austin karst geologic areas mapped by Veni (1992). It is also included in the Edwards Aquifer Recharge Zone on official maps by the Texas Natural Resource Conservation Commission. Since karst species require water, the amount and quality of surface and subsurface flow is important to sustain cave ecology. Elliott (1997) recommended that a hydrogeologic study be prepared for the four caves.

The surface and subsurface catchment areas for the four caves are delineated. Surface morphology and topography around the cave entrance is used to measure the surface catchment area that contributes runoff to the cave entrance. This assessment examines the geologic influences on shallow groundwater and cave development of this area that are utilized in order to conservatively overestimate the subsurface catchment areas of these four caves. This evaluation is limited to the known extent of these caves as shown on cave maps presented by Elliott (1997) and new maps prepared in this study. Three deep (230 feet) borings were conducted in the area to measure stratigraphic dip, which can influence the direction of groundwater flow to cave drips in the unsaturated zone, provide subsurface geology data not obtainable from local quarries and outcrops, and identify beds that may serve to convey or perch water flow. Subsurface catchment areas were then delineated using a combination of methods, including the land area above the elevation of the cave drip horizon, delineating hydraulic gradient of surface to cave drip horizon, and mapping of hydrostratigraphic framework focusing on units that convey or perch groundwater.

This hydrogeologic study is intended for City of Austin, Travis County, U.S. Fish and Wildlife staff, their consultants, and property owners who participate in the protection of Balcones Canyonland Preserve federal permit caves. Cave locations are necessarily shown in this report for the intention of protecting these features. Public release of these locations can create a hazard for untrained persons who might use these maps to locate them, threaten the caves through excessive traffic impacts and vandalism, threaten water supplies, and potentially create problems for the land owner. Therefore, this report is not intended for public release.

At this time, the tracts containing the four caves are primarily on undeveloped ranch land. No Rent and Weldon Caves are located on undeveloped portions of McNeil High School site, which is part of the Round Rock Independent School District. Fossil Garden and McNeil Bat Caves are located on private ranch land near the school. The City of Austin Water Utility has a Capital Improvement Project to construct a 54-inch water line from Martin Hill roughly following McNeil Drive west to Hwy 183. This report does not evaluate the effects of a specific projects or land use on the caves. Additional recommended management practices are discussed in the BCP Karst Species Land Management Plan, such as maintaining a 164-ft radius from the cave footprints as preserve for cave cricket foraging area that is treated for imported red fire ant (*Solenopsis invicta*) treatment (using boiled water), public education, and monitoring/research (BCP, 2007).

I.1. Site Geology

The McNeil area was mapped in some detail by Outlaw (1947). Outlaw mapped the Buda formation to be over 13 feet thick at the top of Martin Hill (then called Pilot Knob North), underlain by 45 feet thick Del Rio Clay, underlain by 40 feet of Georgetown Formation. He noted that an erosional unconformity below the Georgetown Formation had removed over 100 feet of the Edwards limestone beneath it.

The Edwards is currently designated as a formation north of the Colorado River (Table 1) and as a group south of the Colorado River (Table 2). However, this arbitrary change from formation to group does not necessarily represent an abrupt change in geological units across the Colorado River. Since the 1990's, studies led by the USGS have mapped hydrostratigraphic units in finer detail and have correlated the extension of some of these units from the San Antonio area north to the Colorado River (Small, et al, 1996). The hydrostratigraphic units mapped from the San Antonio area to South Austin have not yet been correlated northward of the Colorado River, in part due to lack of mapping effort as well as a lack of sufficient vertical surface exposure of the rock units. The most detailed geologic map that is available prior to mapping conducted for this study is from the Bureau of Economic Geology (Proctor, 1974; Collins, 2005). The BEG map does not distinguish units of the Edwards Formation. The Edwards Group was originally named Barton Creek limestone because of its excellent exposure just south of the Colorado River along Barton Creek. However, north of the Colorado River the exposure of the Edwards section is limited.

I.2. Geological Influences on Groundwater Flow

Local geology can influence shallow vadose flows in a number of ways. Veni (1992) noted that

> "The distribution of cave fauna is fully dependent on the distribution of strata and fractures that are more susceptible to karstic dissolution, and hence cave development, and on the extent of connectivity between those caves and related conduits. Local geology thus dictates not only the distribution of cavernicole habitat but also determines the avenues for the influx of nutrients, contaminants, and competing species."

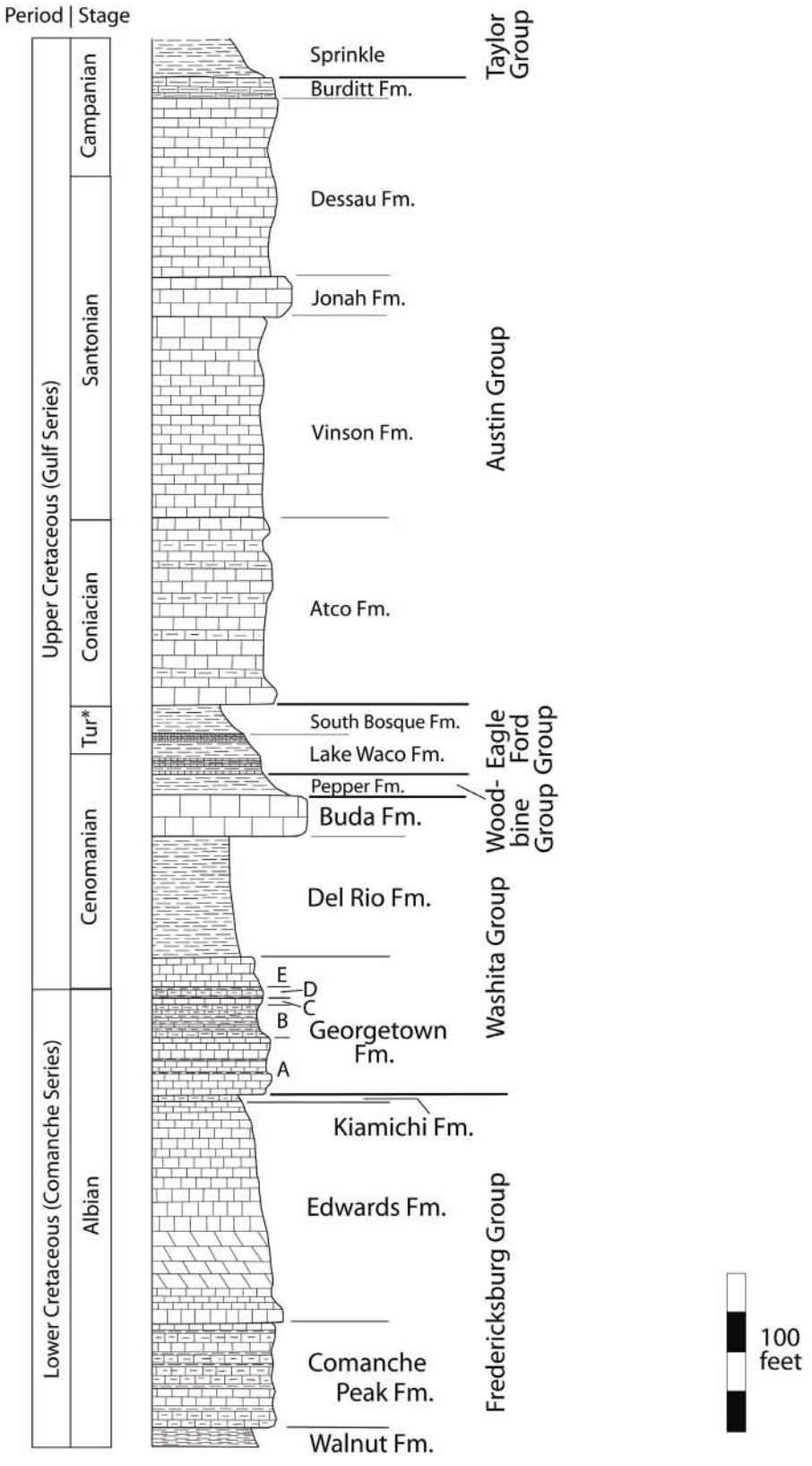
Veni (1992) summarized the effects of geology on cave development described by White (1988) and Ford and Williams (1989) including: vertical cave shafts generally develop above the water table and are associated with beds of lower permeability or lower solubility; horizontal cave passages develop in high permeability beds; caves typically become impassible at common lower permeable/lower solubility horizons or due to sediment fill; and springs discharge near horizons of permeability contrast and their discharge is proportional to the size of its catchment area. Based on the lowermost extent of 11 caves in the Georgetown-Round Rock area north of the McNeil Drive study area, Veni (1992) identified zones of cave development at intervals of 95-100 ft, 80-85 ft, 64-70 ft, 49-55 ft, and 25-40 ft above the base of the Edwards Limestone.

The hydrostratigraphic members of the Edwards Group in the Austin area vary in properties that influence whether the bed tends to convey or perch groundwater flows

(Small et al., 1996; Hauwert, 2009). In unconfined areas of karst aquifers, vadose flows tend to flow in a downdip direction where stratigraphic dip is present (Parmer, 1977; Ginsberg and Parmer, 2002; Veni, 1992; Hauwert, 2009). An analogy for the hydrogeologic effect of stratigraphic dip is pouring water on a ramp (such as a wooden wheel chair ramp): while some flow may penetrate through the ramp material and seams, the vast majority of flow is directed down the ramp and not to either side or up the ramp. Where stratigraphic dip is undetectable (such as less than about 10 feet per mile), vadose and groundwater flows may descend nearby down-dropped fault blocks or other discontinuities such as monoclines (Hauwert, 2009). An analogy for the hydrogeologic influence of down-dropped faults is pouring water at the top of a staircase bounded by walls on either side. Even though the steps themselves are level, the water is generally directed down the stairs. Rock-strata may also dip nearly parallel to fault directions because of ramp structures (Collins, 1993; Collins, 1995). Various reports have estimated a 1º eastward (Senger, Collins, and Kreitler, 1990) or 0.9º southeast dip (Outlaw, 1947) in this area. Outlaw (1947) reported a regional dip of 30 feet per mile with maximum dip direction of S30E (120º). He reported that the Edwards Limestone had a steeper dip of 80 feet per mile (or 0.9º vertical dip) than the overlying rocks but still in the S30E direction, and believed the difference in dip magnitude was possibly due to the unconformity that separated the Edwards Limestone from the overlying Georgetown Formation. How the bedding dip was measured and separated from down-dropping due to faulting was not discussed by Outlaw (1947).

Geology also influences cave development: why caves are located in some areas and not others, as well as the genesis of sinkhole development. Because of the resistant and competent nature of the Grainstone Member, contrasted by the highly soluble and easily eroded underlying Kirschberg Member, collapsed sinkhole entrances to caves are extremely common near the contact of the Grainstone and Kirschberg Members (Hauwert, 2009). In the Austin area, cave volumes are highest in the Kirschberg and Leached/Collapsed Members (Small et al., 1996; Russell, 2007). Caves tend to trend either in the direction of local down dip or down dropped fault blocks, which is most commonly southeast in the Barton Springs Segment (Hauwert, 2009). Caves developed within the Leached/Collapsed, Dolomitic, and Basal Nodular/Walnut Members tend to be strongly fracture-influenced in the Barton Springs Segment and trend northeast-southwest. Cave development in the Georgetown Formation and Regional Dense Members, although less common, tend to be associated with vertical shafts and fissures in the Barton Springs Segment (Hauwert, 2009). Caves within the Dolomitic Member tend to be fissured and relatively tight, frequently resembling storm sewers connected by vertical shafts (Hauwert, 2009). The 4-foot-thick rhythmic beds near the top of the Dolomitic Member resembles the Regional Dense Member lithologically, and similarly serves to perch unsaturated vadose flows above it. Cave and stream passages such as the 200-foot-long culvert crawl passage in Flint Ridge Cave, passages in Cave X, and Bee Springs in Bee Creek are directly perched above the rhythmic beds (Hauwert, 2009). Just southeast of the study site and north of Parmer Lane, Veni (1998) attributed the lack of cave development and presence of flowing water in the creek to the presence of the Dolomitic Member at the ground surface. Veni (1998) noted at least 6 caves in the Cedar

Table 1. Generalized Stratigraphic Column of the Round Rock Area



Tur* - Turonian

From Housh, 2007

Table 2. Hydrostratigraphic Units of the Barton Springs Segment of the Edwards Aquifer

Hydrogeologic subdivision		Group	Formation	Member	Full Thickness (m)	Lithology	Field Identification	General Hydrogeologic Properties
Quaternary		Alluvium			<10	gravel	loosely or unconsolidated limestone or shale	high permeability
		Colorado River Terrace Deposits			<10	gravel	loosely or poorly consolidated with quartz cobbles	high permeability
Upper Cretaceous	Overlying Confining Units	Taylor	Sprinkle		120	calcareous clay	dark clay	low permeability
		Austin			119	chalk	*Inoceramus subquadratus* , *Inoceramus undulatoplicatus, Exogyra ponderosa, Phyrygia aucella* and occasional igneous deposits	gen. low permeabilty, conduits possible where faulted or weathered on surface
		Eagle Ford		South Bosque Shale Bouldin Flags Cloice Shale Pepper Shale	12 - 14	calcareous sandy shale	*Fish fossils,Acanthoceras sp .,Eucalycoceras bentonianum ,Neocardioceras ,Romaniceras ,Coilopoceras ,Prionotropia ,Alectryonia lugubris*	general low permeability
		Washita	Buda		11 - 18	nodular to massive porcelaneous limestone	Orange pelloids in massive beds, *Budaiceras* , ammonites, *Exogyra clarki* , *Pecten roemeri* , *Codiopsis texana* Whitney, and *Mantelliceras*	commonly feeds shallow wells and small springs
			Del Rio		15 - 18	clay	*Ilymatogyra arietina,* pyrite, gypsum seams	low permeability clay
Lower Cretaceous	Edwards Aquifer		Georgetown		12 - 18	nodular to massive fossilferous limestone	*Waconella wacoensis, Arctostrea carinata* , *Texigryphaea washitaensis* , *Neithea texana* , echinoids, and ammonites.	vertical fissure development
		Edwards	Person	Cyclic and Marine undiv.	0 - 21	massive limestone	chert and caprinids	cavernous
				Leached and Collapsed undivided	21 - < 7	wackestone, mudstone, and grainstone with well-sorted matrix	*Toucasia* , *Chondrodonta* , and sparse miliolid foraminifera	horizontal and vertical extensive cave deveopment
				Regional Dense	4.5 - 10	well-sorted lt tan fissile mudstone	*Pleuromya knowltoni* , rarely *Ceratostreon texanum,* iron-oxide stains	local aquitard frequently breached with vertical fissures
			Kainer	Grainstone	14 - 18	lt gray-white massive grainstone	Miliolid foramnifera, *Chondrodonta* , caprinids, turitella, mudcracks, and bedded chert	small corkscrew passages and rooms. Serves as competent roof over Kirschberg Mbr
				Kirschberg	12 - 23	crystalline limestone and dolomite pulverulite	Terra rosa. *Cladophyllia, toucasia, caprinid-bearing siliceous remnants*	extensive cave development esp. in pulverulitic beds
				Dolomitic	~ 43	Highly bedded gen. with poorly-sorted matrix	*Toucasia, Caprinid, Dictyoconus walnutensis.* Nodular chert	significant cave development primarily along fissures
				Basal Nodular	16 - 18	fossilferous, nodular limestone	*Texigryphaea* packestone intermediate miliolid grainstones and burrowed mudstone, echinoids, lower *Ceratostreon Texanum* packstone	vertical pits and fissures. Produces many minor springs.
	Underlying units	Trinity	Glen Rose		150 - 250	Alternating massive limestone/dolomite and marl layers	dinosaur tracks, plant fossils, celestite nodules, *Trigonia* , *Pecten* , *Alectryonia carinata* , *Orbitolina texana* foraminifera, various echinoids	little cave development documented here although supports abundant springs/wells.

From Hauwert, 2007

Park area to the west developed horizontally in the lowermost Edwards strata just above the lower permeability Comanche Peak Formation.

Whether flow is directed horizontally along a cave passage may depend on whether the vertical drains are water-saturated by a water table, perched upon less permeable beds, or flooded with excessive flow. While horizontal cave development is observed to be extensive within the Kirschberg Member, particularly along a pulverulitic bed at its top (Russell, 2007; Hauwert, 2009), long-term observation in caves such as Whirlpool, Dunvegan, and Flint Ridge Caves suggest that *small* flows do not extend horizontally for long distances but descend subvertically to lower, often inaccessible sections of the cave. In these Kirschberg Member caves the passage floor is irregular in many places and contains solution cavities that serve to drain the passage. A solution cavity floor drain in the passage of Whirlpool Cave completely infiltrated 300 gallons per minute and more than 10,000 gallons total during a dye-trace injection (Hauwert et al., 2004). Whirlpool and Flint Ridge Caves do show signs, through observation of wood debris, that under rare conditions, *flood* waters will flow considerable distances roughly horizontally along the cave passage. The observation that Kirschberg Member caves have a strong vertical flow component is expected for hydrostratigraphic units with high overall permeability. There has been no documentation that horizontal flows continue for long distances in any caves developed within the Kirschberg Member, unless the cave is water saturated by a water table or flooding.

Surface catchment areas are portions of the surface that can potentially drain directly into sinkholes. Sinkholes are skylight entrances to caves and can form by collapse of overlying rocks, dissolution and erosion of rock around a sinkhole, or both. Many local caves probably originated deep in the subsurface before denudation eroded the land surfaces to its current level. The subsurface caves may have originated near the water table by flowing groundwater, dissolved by vadose water flowing from surface sources to the water table, or possibly by deep hypogene flows from the underlying Trinity Aquifer. As land-surface erosion progresses, in some areas the roof of pre-existing caves becomes too thin to sustain, and a collapsed sinkhole forms into the cave. Collapsed sinkholes typically have overhanging or vertical entrances and small, poorly-developed catchment areas. Collapsed sinkholes and other karst features with well-developed subsurface connections may pirate surface flow, initiating modification of an immature collapsed sinkhole into a solution sinkhole. Solution sinkholes have concave bowls whose volume is proportional to the catchment area that has been pirated (Hauwert, 2009).

A subsurface catchment area for a cave is the land area that contributes water to drips or cave streams in the cave. The subsurface catchment cannot simply be determined from cave maps, although it can be assumed without direct testing that the mapped cave extent is at least as large as the cave map footprint area but it is likely larger. A large focused (discrete) drip or flowing cave stream indicates a relatively large source of water, typically a larger subsurface catchment area although high infiltration focused in a smaller area is also possible. Diffuse drips occur randomly or can be spaced across a drip horizon and more likely reflect drainage of the soil and bedrock surface pools in areas

closely overlying the cave footprint. Such drips may become active during rain events and sustain a slow or barely perceptible drip rate weeks or months afterward. Water observed in a cave originates by gravity flows from a higher elevation. The source of that water may generally be assumed to be natural infiltration of rain water but in some cases may originate from leaking urban infrastructure or a leaking water well. Generally, a very small portion of areas higher in elevation than the cave drip actually contribute to the cave drip; other criteria are necessary to more precisely limit the subsurface catchment area with high certainty. A high vertical gradient (vertical height of potential water source over horizontal distance to cave drip horizon) suggests a greater likelihood of a source area than a low gradient.

Points within and outside the subsurface catchment area to a cave drip can be directly determined by injection of a suitable tracer and monitoring the cave drip for breakthrough. In the Austin area, direct subsurface catchment area delineation was conducted at Barker Ranch #1 on the Tabor Water Quality Protection Land (Cowan et al., 2007).

Barker Ranch #1 cave in South Austin has three clusters of focused (discrete) drip areas and smaller, more diffuse drips in between. Differences in water quality and injected tracer concentration between the drips suggest that the drips within the same cave room actually originate from different sources. The potential subsurface area to Barker Ranch #1 drips were delineated in multiple ways. Although it is relatively high on a hill side, an area higher in elevation that the cave drip horizon extends more than 20,000 feet northwest. To refine the subsurface catchment for Barker Ranch #1 drips, multiple tracers were injected at 6 sites and monitored in the cave drips using autosamplers and grab water samples (Cowan et al., 2007; Cowan et al., 2010 in preparation). Injected tracers as far as 200 feet away have been recovered in the main drip of Barker Ranch #1. A gradient of 12% (25 feet vertical height over 200 feet distance) exists between the farthest traced points and the cave drip horizon. From one tracer injected 100 feet from the cave entrance, the bromide tracer discharged from the drip within 3 to 7 hours. One tracer injected 300 feet away (with an estimated vertical height of 26 feet above the cave drip horizon or 9% gradient) was not recovered at the drip. Although it is possible that with further tracing a narrow drip source could conceivably extend to 300 feet or farther along a narrow flow path, from the 6 injection sites used so far it appears that a gradient of about 10% may represent the limit of the subsurface catchment area to the discrete drips in Barker Ranch #1. In this direct trace to a discrete cave drip, the subsurface catchment area extends more than 150 feet beyond the 50-foot diameter mapped cave footprint. The drip flows appear to be perched by the Grainstone Member of the Edwards Group, but appear to descend vertically into lower inaccessible areas within the observable Kirschberg Member portion of the cave. Measurements of vertical gradient limits from multiple caves developed within the same hydrostratigraphic horizon are necessary to evaluate variation between different caves. However at this time, only vertical gradients from Barker Ranch #1 are available to evaluate the expected vertical gradient at the Grainstone and Kirschberg Member contacts.

In permeable hydrostratigraphic units where perching, lower permeable beds are not present, groundwater tends to sink downward along solution features. Measurements of minimum vertical gradients of 10% at Barker Ranch agree with the lack of laterally extensive perched water observed in cave passages developed within the Kirschberg and Grainstone Members of the Edwards Group, including Whirlpool, lower portions of Maple Run, upper portions of Flint Ridge, District Park Cave, Djerido, and Dunvegan Cave. While these caves do contain cave drips and can laterally transmit flood waters, they show no evidence of perching vadose flows for significant distances.

Where lower permeable (aquitard) beds are directly underlying, groundwater can be travel far at a low hydraulic gradient. Numerous caves and springs that developed within the Dolomitic Member, such as Midnight, Cave X, the lower portion of Flint Ridge Cave, and Backdoor Springs, show significant perching of water for at least several hundred feet distance. Cave streams within the Buttercup Creek area demonstrate that groundwater can be perched at low gradients within the Walnut Formation for three miles (Hauwert and Warton, 1997). Hydrostratigraphic units of the Regional Dense Member, portions of Dolomitic Member, and Walnut Formation (equivalent to Basal Nodular Member in the Edwards Group), as well as the underlying Upper Glen Rose Formation, may perch groundwater at much lower vertical gradients than 10%. Potentially, perching of vadose groundwater could be expected in beds of the Leached Collapsed and Kirschberg Members immediately above the Regional Dense Member and Dolomitic Member, and caves such as Airman's Cave and Flint Ridge Cave may provide examples of perching within these intervals.

II. Methodology

II.1. Geological Mapping

There are no published surface geology maps dividing the Edwards Formation into finer hydrostratigraphic units in North Austin. Therefore, correlation of hydrostratigraphic units that extended into the study area and identification of changes in these units across the project surface area and subsurface was necessary. Geologic mapping of the project area was conducted by City of Austin Watershed Protection Department (CoA WP) staff (Nico Hauwert, Scott Hiers, and Sylvia Pope) in order to identify specific marker beds as well as specific beds that are known to influence groundwater flow (Table 2). Changes in elevation of marker beds across the project area was used to measure stratigraphic dip between the water line project and four caves, where sufficient outcrops of marker beds are present within the same fault blocks. Since geologic faults present in the area will offset the rock units, elevations of marker beds across significant faults lines are not applicable. The study area was mapped using hydrostratigraphic units described by Rose (1972), Small et al. (1996), and Hauwert (2009), including the Georgetown Formation of the Washita Group, Leached/Collapsed Member (if present), Regional Dense Member, Grainstone Member, Kirschberg Member, Dolomitic Member, Comanche Peak Formation, and Walnut Formation that includes the Cedar Park, Bee Caves, and Bull Creek members.

In order to characterize the hydrostratigraphic properties and thickness of units, as well as to measure stratigraphic dip in the Grainstone Member and other deeper units below, borings were required that extended through the Edwards Formation at the highest elevations of the study area. Three bores were drilled in a triangular pattern across the site, two along McNeil Drive and one behind the McNeil High School on or near the proposed north alignment. In order to protect karst species from impacts of the drilling, a drilling plan was prepared by Holt Engineering, Inc. (2010). USFW-permitted karst biologists with Zara Environmental Inc. were present while drilling through the shallow intervals higher in elevation than the four permitted caves. In addition, downhole camera logging was performed to detect voids in the bore holes (Zara, 2010a).

A core was taken from the highest elevation boring. All three were logged with downhole tools for natural gamma, resistivity, caliper, and downhole camera by GeoCam of San Antonio (Appendix C). Each geotechnical hole was drilled 230 feet deep although only bores B and C penetrated into the Glen Rose Formation. CoA geologists Sylvia Pope and Nico Hauwert described the core from hole A (Appendix D). Cuttings were collected at 5 ft intervals from bores B and C by CoA geological technician Justin Camp. All three holes were completely plugged. The geophysical logs and core descriptions were used to distinguish subsurface hydrostratigraphic units. From common intervals between the three holes, the local dip was measured using the three point solution described by Compton (1961).

II.2. Surface Catchment Delineation

On Feb. 9 and 12, 2010, the surface catchment divides, defining surface catchment source areas, for Fossil Garden, No Rent, Weldon, and McNeil Bat Caves were visually located using Trimble XH global positioning system (gps) units by Sylvia Pope, Nico Hauwert, and Scott Hiers of the CoA WP. The gps units have horizontal and vertical accuracy and precision of less than 3 feet. If cases existed where the surface divide was not clear due to flat terrain, the surface catchment was conservatively overestimated to include all possible surface catchment areas. The field delineation of catchment divides was overlapped with two-foot surface contour elevation coverages in ArcGIS to create a shapefile for the surface catchment area. The digital contour coverage served both to verify the field observations and to delineate divides on hillsides that may not be evident in the field.

II.3. Subsurface Catchment Delineation

The subsurface catchment to a cave is a geographic area that potentially contributes groundwater flow to a cave, generally through cave drips, although in some caves through cave streams. The exact boundaries of active subsurface catchments to caves are difficult to locate using simplified approaches and therefore require considerable investigation to delineate drip sources. Furthermore, the application of multiple methods incorporated with a detailed understanding of geological framework increases the confidence in the delineation of subsurface catchment area. The most direct method to delineate whether specific points lie in a subsurface catchment area for a cave drip or cave stream is to inject suitable tracers at specific points on the surface and monitor for the breakthrough at the cave drips. This method has been applied to delineate surface points inside and outside subsurface catchment areas for some caves in South Austin (Cowan et al, 2007, summarized above) and connect cave streams of the Buttercup Creek area of Williamson County with Blizzard Springs three miles away in Travis County (Hauwert and Warton, 1997). There are limits to drip tracing including:

a) A limited number of tracers are appropriate for soil tracing to drips. For injections into *open apertures*, organic dyes such as sodium fluorescein, eosine, rhodamine wt, sulforhodamine b, and possibly pyranine and optical brighteners such as direct yellow 96 and tinopal are generally effective for continuous monitoring. Tracer detection can be achieved using a combination of either charcoal receptors or unbleached cotton receptors (for optical brighteners) and grab water samples. Transport through *soils* tends to sorb the organic tracers such that they likely aren't effective tracing through soils. Chemical tracers such as potassium bromide, ammonium carbonate, and iron standard have all been effectively recovered in soil tracing to cave drips, but require either frequent (autosamplers at interval such as 4 hrs) or continuous sampling (ion selective probes) to ensure the breakthrough pulse is not missed.

b) A large number of traces are required. Soil tracing will not delineate the entire subsurface catchment area without tracing many points both inside and outside the subsurface catchment. Because the degree of subsurface connection is not known

from the surface to these caves, a relatively high mass of tracers is necessary to ensure the tracers can be detected in the cave drips above detection limits.

c) Considerations of cave species is necessary. While tracers can be selected that are relatively safe at low concentrations, for caves containing endangered species on a federal permit, the risk of impacts to cave species may outweigh the advantage of direct tracing. The potential impact from necessary monitoring traffic associated with direct soil tracing is also a consideration in soil tracing of surface catchments. In some cases, such as the evaluation of an accidental release of hazardous materials or roadway runoff, the need to directly trace to cave drips may be higher and the relative risk from the tracers much lower than the expected hazards from the constituents of concern.

d) Soil tracing is very time-intensive and requires specific weather conditions. Soil tracing is also difficult and expensive, generally requiring rain events to flush tracers, automatic samplers to collect drip water for at least a week, and laboratory analysis of the drip water.

For this study, direct tracing on the McNeil Drive site was not conducted; instead, information gained from tracing another cave drip site (Barker Ranch #1) along the same stratigraphic interval (contact of Grainstone and Kirschberg Members) in South Austin is applied here. The subsurface catchment area is conservatively over-estimated using a combination of indirect methods including:

1) **Delineation and characterization of cave drip horizons.** It is important to characterize drips as being diffuse, or drips along widely spaced formations, or discrete drips that focused along fractures or conduits or a few cave formations. The flow rate and persistence of cave drips and cave streams are dependent on the size of the subsurface catchment area as well as the permeability of the subsurface catchment area. A large, persistent, discrete drip will generally have a large subsurface catchment area. Some ephemeral cave drips and streams may be observed only shortly after sufficient rain events or when the soil is relatively saturated. Small distributed diffuse drips that greatly diminish shortly after rain events suggest the drip source is through soils a relatively small area close to the cave footprint.

   The caves were entered during a wet period within a day of a rain event to document the location of caves drips. Where discrete drips are present, cave drips can be measured using a calibrated bucket, a plastic sheet collecting drips over much of the drip area, and even continuously using a rain gauge stationed below the sheet. Where only diffuse drips are present, this methodology cannot be used to even remotely approach the total drip rate. It is important to document if any areas of the caves were not observed and the magnitude of recent rainfall.

   Cave drips are best observed under wet conditions when the soil moisture is relatively saturated and surface drainages carry water in order to define specific

drip horizons where water enters the cave. Diffuse drips are generally fairly obvious if the cave is carefully observed and but approach zero flow as the overlying soil moisture decreases. Discrete drips from specific surface drainages may be present only during rain events. Many discrete drips represent the convergence of soil and epikarst drainage over a large area and may flow for long periods. Observations of cave drips during dry periods are useful to examine the persistence of the cave drips. The presence of discrete drips may be evident by conduits and formation development (particularly rimstone dams, bacon rind formations, large stalactites, large stalagmites, or large columns). Where flow is not observed after rain events from any ceiling and wall conduits and associated formations, it is possible these are abandoned discrete drips or they may become active after larger rain events or higher soil moisture conditions than those observed. Ceiling and wall conduits may no longer be active, and this condition may be indicated by underlying inactive or "dead" formations. A deep cave may have several drip horizons, each drip horizon with a distinct subsurface catchment area.

2) **Mapping elevation of the four cave drips in relation to local surface topography.** All natural flows to caves must originate from sources at higher elevations than cave drips. The subsurface catchment area to the cave is contained within areas of higher elevation than cave drip or if the drip horizons are unknown, the base of cave. All four cave entrances were located using a survey-grade Trimble R8 GPS by the Austin Water Utility. Monuments were set for permanent reference at each cave entrance. The area along the north side of McNeil Drive between Parmer Lane and McNeil Drive cutoff was surveyed by Macias & Assoc., LP, based on the elevation reported for monument J-37-4001. Frequently, the simple analysis of elevation higher than a drip horizon in a cave includes an impossibly large area, with impossibly low gradients, and erratic turns in subsurface flow paths. Further investigation can eliminate areas of higher elevation than the cave drip horizon where source areas are unlikely or impossible.

3) **Elevation gradient from surface to cave drip horizon**. Tracing at Barker Ranch #1 indicated that the farthest injection sites connected to the cave had a gradient of 12% to the cave dip and the farthest sites determined not to connect to the cave had a gradient of 9%. Therefore, the best estimate of subsurface catchment area will include all area with an elevation gradient of 10% around the cave drip horizon that are within the Grainstone and Kirschberg Members. When applying vertical gradients to estimate subsurface catchment areas it is important that these apply only to portions of caves developed within the Grainstone and Kirschberg Members since these are the same hydrostratigraphic units studied at Barker Ranch #1 and not those developed within the Regional Dense Member, Dolomitic Member, Basal Nodular Member/Walnut Formation, and Upper Glen Rose Formation (as described in number 5 below). Rock dip is expected to modify the effect of elevation gradients as well: it is expected that a lower elevation gradient can contribute shallow flow in the down dip direction to a cave drip. The

4) **Mapping cave footprints.** All areas overlying the cave footprint can be assumed to be within the cave subsurface catchment area, because overlying surface connection is likely regardless of whether the cave drips are discrete or diffuse. Three of the four caves (No Rent, Weldon, and McNeil Bat Caves) were surveyed from the entrance pin using traditional cave surveying methods described by Dasher (1994). The cave passages and features were mapped from station to station using a Brunton compass for azimuth and a Sunto tandem from inclination. A steel tape was used to measure the distance from station to station. Cave maps were prepared in Appendix A, along with original cave maps prepared by Mike Warton and others and were compiled by Elliott (1997). Shapefiles of the cave maps were prepared by Shelley Miller of Balcones Canyonland Preserve Wildlands Conservation Division of the Austin Water Utility (CoA BCP). The subsurface catchment area boundaries are at least 164 feet from the cave footprint, therefore including the overlying soils that are the likeliest source for diffuse drips in the cave. The subsurface catchment areas also include the recommended minimum radius for cave cricket foraging areas (BCP, 2007), although cave crickets may forage 300 feet or more from the cave (Taylor et al., 2005).

5) **Identification of subsurface units that typically perch groundwater.** Stratigraphic units such as the Regional Dense Member, rhythmic beds near the top of the Dolomitic Member, the Walnut Formation, and Upper Glen Rose Formation all may perch vadose water. Above these lower permeability beds, vadose flow may occur at relatively low hydraulic gradient with long horizontal component parallel to stratigraphic dip or down fault direction. Horizontal cave development is widespread within the Kirschberg Member, possibly as result of development along an ancient water table, although small flows of water cannot be observed to travel these conduits in any area caves, but tend to infiltrate downward after short distances. Information from both surface geology across the area, in quarries, and in caves, as well as geotechnical boring and core data, were used to characterize the surface and subsurface geology.

6) **Mapping stratigraphic dip.** In unconfined areas of karst aquifers, vadose flows tend to flow downdip direction where stratigraphic dip is present (Palmer, 1977; Ginsberg and Palmer, 2002). Where stratigraphic dip is undetectable (such as less than about 10 feet per mile), vadose and groundwater flows may follow toward down-dropped fault blocks (Hauwert, 2009). While various reports of dip in this area are estimated, actual measurement of stratigraphic dip is needed for the study area. Geologic and stratigraphic dip data were obtained using four methods:

    (a) In areas of relatively low dip, Compton (1962) suggests that “small irregularities in the bedding will cause major local variation in strike” and, consequently “this method is generally unreliable”. Bedding of the Kirschberg and Grainstone Members characteristically sag due to

subsurface collapse (Hauwert, 2009). Dip measurements from outcrops and cave passages are possible but are difficult to extrapolate because of difficulty in measuring small scale dip and local dip and collapse around caves are common and misleading if extrapolated as larger-scale dip. For these reasons, dip measurements from outcrops and caves were not utilized.

(b) Geologic mapping was conducted in the area by COA WP staff to identify specific marker beds as well as specific beds known to influence groundwater flow. Changes in elevation of marker beds across the study area were utilized to measure stratigraphic dip if sufficient outcrops of marker beds are present within the same fault blocks. Since geologic faults are present in the area that offset the rock units, elevations of marker beds across significant faults lines are not applicable.

(c) Three bores were drilled in a triangular pattern across the site, two along McNeil Drive and one behind the McNeil High School near the proposed north alignment. The deep geotechnical boring methodology is described in III.1.

(d) The combined outcrop and borehole data were incorporated in geological cross sections, including one in the direction of maximum dip.

Access to the four endangered species caves is authorized by US Fish & Wildlife permit TE833851-1 in Travis and Williamson Counties for permittees Nico Hauwert, Sylvia Pope, Scott Hiers and accompanying assistants. Mark Sanders of CoA BCP program is authorized for access under a separate USFW permit.

7) **Surface geophysical surveys.** Geophysical surveys can detect subsurface cave extents in advance of construction, locations of geological faults that otherwise may not be detected, and the movement of shallow vadose flows that may potentially contribute to cave drips. Ground-penetrating radar can detect offsets in bedding that define faults. Natural potential and magnetometer methods can detect anomalies associated with shallow water movement. Resistivity surveys show considerable promise for the detection of caves and faults. Geophysical surveys were conducted in linear profiles along McNeil Drive, along a line between the caves and McNeil Drive, and in the vicinity of the four caves to detect subsurface extensions of the caves and subsurface flows to the caves. The results of surveys conducted by Dr. Mustafa Saribudak of Environmental Geophysical Associates are presented in a separate report.

III. Results

III.1. Geology

Access to local Austin White Lime quarries were critical for identification of specific conveyance or perching beds and to correlate known hydrostratigraphic units mapped in the Barton Springs Segment of South Austin. In the South Quarry just southeast of the McNeil Drive study site, the Georgetown Formation contact with the underlying Regional Dense Member and Grainstone Member was observed (Appendix B). In the North Quarry, which is north of the study site across Rattan Creek, the contact of the Grainstone Member and underlying Kirschberg Member was exposed (Appendix B). This interpretation was based on the sequence of a clean white miliolid grainstone underlain by a prominent continuous chert bed, underlain by a chondrodont miliolid grainstone underlain by 4-foot-thick pulverulitic euhedral-crystal dolomite bed. This same sequence was also observed with some variation in Fossil Garden, Weldon, and McNeil Bat Caves; however, in Weldon Cave the chert layer appears to be a micrite bed resembling a chert layer. The contact of the Grainstone and Kirschberg Members in relation to the four investigated caves is shown in Figure 1. A surface geology map is presented in Figure 2. This study allows for the first time the correlation of individual members of the Edwards Group in the Barton Springs Segment with corresponding units in this area of North Austin.

Further study of the subsurface geology below the study site was made possible by three 230-feet deep geotechnical holes (Table 3). The core was compared with outcrops at the Edwards/Walnut/Glen Rose Fm contacts at Loop 360 and Bee Caves Road, South San Gabriel River west of Highway 183 North, and FM 2222 at FM 620 area (Young, 1971; Kirkland et al., 1996). The Kirschberg Member below the miliolid-bearing Grainstone Member, was very similar to the crystalline 70 foot-thick exposures described in the Barton Springs Segment (Hauwert, 2009). In the McNeil core A, the Kirschberg Member was 54 feet thick and contained some gritty miliolid beds not observed south of the Colorado River (Table 4). The Dolomitic Member observed in core A varied considerably from limestone wackestones and mudstones of the Barton Springs Segment. In core A, a 26-foot interval below the Kirschberg Member, a distinctive brown porous dolomite was present. This dolomite unit is present in the same stratigraphic position below the Kirschberg Member of the Edwards limestone and above the Walnut Formation/Basal nodular Member, as the Dolomitic Member of the Edwards Group south of the Colorado River to San Antonio. The brown dolomite also has the same fossil assemblage, particularly toucasia and caprinid. The Dolomitic Member in the Barton Springs Segment is overall a sandy limestone and not dolomite. For the purposes of this report, until further comparisons can be made, the brown dolomite is assumed part of the Edwards Formation as the Dolomitic Member equivalent. A few feet of similar brown dolomite reappears beneath the Comanche Peak Formation, presumably an interfingering of the two units.

Table 3.

Geotechnical Hole	Type	Northing (ft)	Easting (ft)	Elevation (ft msl)
A	Core	10137378.03	3115434.48	882.39
B	Boring	10135768.14	3115084.28	860.28
C	Boring	10136282.28	3116911.22	862.46

Table 4.

Hydrostratigraphic Rock Unit			Alternate Name	Interpreted Thickness (ft)			
Group	Formation	Member		Geotechnical Hole A	B	C	Quarry/ outcrop
Washita	Buda						13*
	Del Rio						45*
	Georgetown						40*
Fredericksberg	Edwards	Regional Dense	Kiamichi				15
		Grainstone		12.5+			
		Kirschberg		54			
		Dolomitic (equivalent)		28.5		31	
	Comanche Pk			22	28	29	
	Walnut	Cedar Park	Basal Nodular Mbr	28	29	29	
		Bee Caves Mbrs		40			
		Bull Creek Mr		48			
		Bee Caves + Bull Creek Mbr		88	88	88	
Trinity	Glen Rose						

*Outlaw, 1947

Forty-eight feet of Comanche Peak Formation and Cedar Park Member of the Walnut Formation are interpreted to underlay the Dolomitic Member equivalent. The Bee Caves and Bull Creek Members of the Walnut Formation were interpreted as 88-feet thick in all three holes. Other units including the oolitic Whitestone lentil and Keys Valley marl have been mapped by Moore (1961) above the Cedar Park Member in this area. The Whitestone lentil and Keys Valley marl were not distinguished in Core A, but with further examination could possibly be interpreted to be present here. The contact of the Walnut Formation and Glen Rose Formation is distinguished by the presence of an oxidized hardground, a shift from calcitic to dolomitic composition, and change in fossil composition (Kirkland et al., 1996) and a sharp increase in natural gamma on geophysical logs (Hauwert, 2009). The Glen Rose Formation was not observed in core A, in cuttings from borings B and C (due to lack of returns from the expected depths), but were interpreted in borings B and C based on natural gamma signature and estimated to be just below the 230 ft total depth in core A.

The local dip was calculated from 7 downhole geophysical signature correlations between the three geotechnical holes within the interval from the Dolomitic Member equivalent through the Bull Creek Member of the Walnut Formation (Table 5). The calculation of dip assumes the bedding dip is gradual and that the holes are not separated by faults or abrupt dips. No faults were identified between the geotechnical site by field

Table 5. Dip Calculations from Geotechnical Holes

Hydrostratigraphic Unit	**Depth in Core (A)**		**Geophysical Logs**							true dip	Max dip direction
	Core observ Depth (ft)	geophysical log Depth (ft)	Core A Elev **882.388** mid (ft msl)	Bore B Depth (feet)	B Elev **860.28** max (ft msl)	depth offset from B to A (feet)	Bore C Depth (ft) (feet)	C Elev **862.463** min (ft msl)	depth offset from C to A (feet)	(degrees)	(0-360º)
Grainstone/Kirschberg Mbrs	12.5		870								
Kirschberg/Dolomitic Mbrs	66.5	63	819				45	817	18		
Dolomitic/Comanche Pk	85	90	792	53	807	37	76	786	14	0.63	
Comanche Pk		95	787	59	801	36	83	779	12	0.66	
Comanche Pk/Cedar Park	117	117	765	81	779	36	105	757	12	0.66	
Cedar Park Fm		120	762	85	775	35	106	756	14	0.57	24
Cedar Park Fm		131	751	96	764	35	120	742	11	0.66	
Cedar Park/Bee Caves Mbr	147	155	727	120	740	35	144	718	11	0.66	
Bee Caves Mbrs		180	702	145	715	35	171	691	9	0.72	36
Bee Caves/Bull Creek Mbrs		185	697								
Bull Creek Mbr/Glen Rose Fm	below hole	231 estm	651	196	664		220	642	11		

mapping or the surface geophysical survey. The dip calculations from the 7 correlations varied in magnitude from 0.57 to 0.72 degrees, with 4 of the 7 having identical values of 0.66 degrees. The maximum dip direction was graphically determined and varied from N24E to N36E, averaging N30E. The geophysical patterns in bore B were 36 ft±1 ft lower in elevation at core A, over 1,800 feet horizontally and roughly in the maximum down dip direction. Note that the measured dip direction of 30° is perpendicular to dip directions of 120° reported by Outlaw (1947) for the McNeil area.

Rock dip can be independently measured from the outcrop of the stratigraphically higher contact of the Grainstone/Kirschberg Member contact can be mapped on the surface between No Rent and Weldon Caves, inside Weldon Cave, and several other local surface or cave observations of the same contact (Figure 3). Further northeast at 5,000 feet distance from McNeil Drive the same contact is found at an elevation of about 842 ft mean seal level (msl), or 20 feet lower. Using a similar three point method of calculating dip from these three contact observations, a maximum dip of 0.4% (20 feet/5,000 feet) or 0.2 degrees in the direction north 60 east is indicated. The borings indicate a maximum dip direction northeast at 0.7 degrees at N30E. Both measurements of dip consistently indicate a gentle dip or sudden 20 to 36 ft offset to the northeast. Although both dip measurements are reasonably close, it is possible that lower units have a slightly different dip direction and magnitude than higher units, as Outlaw (1947) suggested, that may account for the different results using the two methods.

A geologic cross section was constructed along the line of maximum dip (see Figure 8). Based on the dip observed between core A and borehole B, a constant rock dip would place No Rent Cave completely within the Dolomitic Member, which is not the case. These surface and cave mapping observations of the Grainstone/Kirschberg Member contacts may suggest that bedding dip is nearly flat near McNeil Drive near No Rent Cave, but a discontinuity such as a fault or abrupt change in dip could also potentially be present to the east between the geotechnical holes. It is also possible that bedding layers below the Dolomitic Member equivalent are dipping while higher beds may not. In either case, dip in the layers above the known drip horizons are most relevant for this hydrogeological study, particularly for No Rent Cave where McNeil Drive is closest to the cave. The cross section suggests that bedding is flat in the immediate vicinity of No Rent Cave, but a northeast dip or 20 to 36 ft offset fault or discontinuity may direct subsurface flows to the northeast around McNeil High School.

Cave passages within the Kirschberg Member tend to follow maximum dip or downfault direction (Hauwert, 2009). Note that Weldon Cave extends downward for 85 feet to the northeast parallel to the dip direction measured in this study. McNeil Bat Cave has a side passage of its large circular room extending about 45 feet southeast that orients along strike or directly perpendicular to the maximum dip direction. It is possible that this cave passage trend is influenced by a downdropped fault that is estimated to be about 500 to 1,000 feet southeast of McNeil Bat Cave.

III.2. Sinkhole Development and Surface Catchment

The surface catchment areas are mapped as shown in Figure 4. The catchment areas are presented in Table 6. Most of the caves have a relatively small surface catchment area. All four caves originated as collapsed caves or vadose shafts; only Fossil Garden Cave has pirated sufficient surface catchment to develop as a solution sinkhole.

Table 6. Cave Results Summary

Cave	Entrance Pin Elev (ft msl)	Max. Cave Depth Elliott 1997 (ft)	Max. Cave Depth 2010 (ft)	Cave Elevation Lowest (ft msl)	Cave Elevation Highest (ft msl)	Drip Horizon Location Name	Drip Horizon Elev. (ft msl)	Max Catchment Area Surface (acres)	Max Catchment Area Subsurface (acres)
Fossil Garden	872.73	17	unmapped	856	873	Domes Room	862	5.0	48
Weldon Cave	875.11	37	28	847	875	Rattlesnake Hall	869	1.6	30
						Popcorn City	855		
No Rent Cave	842.04	14	17	825	842	Ceiling Drips	835	0.6	52
McNeil Bat	864.83	25	28	837	865	Bat Room Ceiling	860	1.6	148
						Drip D1	849		
						Rhadine Room	843		

Fossil Garden has multiple cave entrances. The main entrance for accessing the cave is a round vertical shaft with no solution bowl. Two sinkholes with well-defined solution bowls connect to portions of the cave. Theses sinkholes probably originated as collapsed sinkholes of larger rooms, later being solution modified by upslope surface drainage. A few smaller sinkholes east of the cave footprint were included in the surface catchment area. The surface catchment area extends over 500 feet north to a surface divide with Rattan Creek. Parmer Lane is about 300 feet east of No Rent Cave, and is outside its surface catchment area.

No Rent Cave has essentially no solution sinkhole bowl or discrete drainage channels entering the cave entrance. It appears to be a vadose shaft or collapsed ceiling dome intercepted by erosion of the surface around the pre-existing cave. A deeply incised, well defined drainage 200 feet east of the cave would have to see floodwaters deeper than 5 feet to reach the cave entrance. This incised drainage is not included in the surface catchment area to No Rent Cave. The source of surface runoff to No Rent Cave entrance is sheet flow from a 270 feet long by 140 feet wide upslope area.

Weldon Cave has a poorly developed sinkhole catchment near the top of a topographic ridge. Its entrance is a collapsed sinkhole. The surface catchment area is a roughly circular 300 feet-wide area southwest of the entrance.

McNeil Bat Cave has a collapsed sinkhole entrance. McNeil Bat Cave does not have a discrete surface catchment but instead has a diffuse upgradient catchment that captures upgradient sheet flow. It therefore has an immature surface catchment with only a poorly defined solution bowl, as is typical for classic collapsed sinkholes. The sink does not necessarily capture all runoff generated in its surface catchment area defined and it does not appear to ever capture surface flow from a well-defined drainage that is about 110 feet southwest of the entrance that was excluded from the surface catchment area. This

drainage channel (thalweg) is about 2 feet lower than the entrance and the drainage extends only about 500 feet upgradient from its closest approach to McNeil Bat Cave. High water marks observed along this drainage channel did not extend far from the channel.

III.3. Cave Development and Subsurface Catchment

In this section, the caves are investigated to define a subsurface catchment area for Fossil Garden, No Rent, Weldon, and McNeil Bat Caves that conservatively overestimate the surface areas contributing to the cave drips but are not so impossibly large so as to be useless for resource protection management. The subsurface catchment areas for these four caves could be further refined and verified using direct soil tracing and sourcewater sampling if the need becomes sufficiently critical (see section II.3).

III.3.1 Drip Type and Drip Horizon Mapping

Limited observations of the cave drips were made during wet and drier conditions on various days. Upper-level drips were observed in the four caves after rain events. A tipping bucket precipitation station maintained by CoA Watershed Protection four miles west of the study area, one mile south of FM 620 and Anderson Mill Road (Appendix E). Precipitation from January through September 2010 was available from this FM 620 rain gauge. Precipitation was also measured by RainVieux, which utilizes a number of local rain gauge stations to average precipitation for sites between those stations (http://www.vieuxinc.com/rainvieux.html). Larger rain events in 2010 included over 2 inches accumulated Jan. 14-15; between 0.65 to 1.23 inches of rainfall on Feb. 3 and 4, 2010, about 1 inch on Feb 11, about an inch on March 15-16; greater than 2 inches from May 14-17, about three inches on June 9; over 3 inches from June 28-July 2; and over 10 inches from a tropical storm on Sept. 7-8, 2010. All four caves were examined for conduits that could become active during unobserved extreme surface flooding conditions.

Limited observations of the drips in the four caves suggest that the upper-level drips are relatively small, short-lived, diffuse drips that drain from the overlying soils. Discrete drips were observed primarily in the lower portions of Weldon and McNeil Caves. Persistent discrete drips were observed in Weldon Cave primarily in the lower Popcorn City drip room (855 ft msl, Appendix A), but also at one location entering the wet ceiling crawl in the upper level. Discrete, likely continuous drips were observed in the Rhadine Room and east passage of McNeil Bat Cave on Nov. 12, 2010, at a time when the bat population was sufficiently low (4) for access.

The location of drip and dry conduit observations were used to map drip horizons in the caves. Based on the elevation where drips are observed in the accessible and known extent of the four caves after rain events, the largest potential subsurface catchment area for Weldon Cave and Fossil Garden all must exceed 855 feet in elevation (Figure 5). Based on elevation alone, the subsurface catchment area could extend across McNeil Drive in an area approximately 2,000 feet wide along McNeil High School.

III.3.2 **Fossil Garden Cave**

Fossil Garden cave entrances are shafts penetrating through the shallow Grainstone Member. The horizontal passages are developed within the uppermost pulverulitic bed of the Kirschberg Member. Cave drips were observed as diffuse drips across the ceiling (lowermost bed of the Grainstone Member), particularly within the domes room. Fossil Garden Caves has open conduits entering domes in the ceiling over large formations. This suggests that at some time in the past large focused drips may have occurred but these were not observed flowing on post-rain (about 1") inspection on February 12, 2010. The stalagmites underlying the domes did not appear to be actively growing formations. A cave map by Mike Warton from August 3, 1990 (Elliott, 1997, Appendix A) was used to define the known extent of the cave. The drip horizon was measured by subtracting the depth to the ceiling in the entrance shaft from the set entrance pin elevation.

III.3.3 **No Rent Cave**

No Rent Cave was mapped by James Reddell, Marcelino Reyes, and Mike Warton on June 21, 1990 (Elliott, 1997, Appendix A). No Rent Cave was remapped by Nico Hauwert and Mark Sanders, on Nov. 4, 2010 from the surveyed entrance pin to refine the location and elevation of any drip horizons. The cave is entirely developed within the Kirschberg Member of the Edwards Formation.

The drip horizon in No Rent Cave is lower than the drip horizon in the other three caves. Drips in No Rent Cave were dispersed across the room ceiling at an elevation of 835 feet msl. From No Rent Cave, the 835 feet msl surface elevation contour extends 7,000 feet to the northeast, crosses Rattan Creek 4,000 feet northwest, and continues essentially to infinity (or for many miles). To the east the 835 feet msl elevation contour extends beyond Parmer Lane for about 3 miles east to the canyon walls of Bull Creek. It includes all of the 5,400-foot-long study area along the north side of McNeil Drive except for two sections on the western study area totaling about 1,200 feet in length. The area exceeding 835 feet msl around No Rent Cave exceeds 15,000 acres in area and includes a large portion of Travis and Williamson counties. The contiguous land surface higher than the drip horizon elevation of No Rent Cave is so large that alone it is impractical criteria for establishing areas that contribute subsurface flow to the cave.

With further investigation, much of the area exceeding 835 feet elevation msl can be ruled out as possible source area for No Rent Cave. A large area east of No Rent Cave, including the eastern two-thirds of the north side of McNeil Drive in the study area, was eliminated as a possible source area since an unlikely turn in the shallow groundwater flow path was required to circumvent a tributary (Figure 6). Rather than follow such a circuitous route, shallow groundwater above 835 feet msl would instead more likely discharge into the tributary. No perching strata, such as the Regional Dense Member or Grainstone Member, is present at or above the drip horizon in the shallow subsurface here, so shallow groundwater would either infiltrate deeper than the cave drips observed in No Rent Cave or discharge as interflow. Furthermore, areas farther away at the same elevation cannot be source area for the drips since a hydraulic gradient is necessary to move flow over permeable rock. It is possible that the drip water observed in Weldon Cave could flow laterally about 1,100 feet south and 30 feet down to No Rent Cave,

although such lateral flow would require a degree of perching water that is not characteristic of the permeable Kirschberg Member. The subsurface catchment for No Rent Cave is mapped to extend about 800 feet north to the edge of the Weldon Cave subsurface catchment, with a gradient of 5% (800 feet distance over 40 feet vertical height).

A water-quality pond located about 300 feet northeast of No Rent Cave has a bottom elevation of about 850 feet msl, based on two-foot surface contour coverage, from COA GIS Shapefiles (see Figure 8). The pond was not investigated to determine through tracing if it infiltrates water that reaches No Rent Cave. Therefore, it was conservatively assumed that surface areas flowing to the pond are contained within its subsurface catchment area. Consequently, the eastern half of the mapped subsurface catchment area is based on runoff contribution to a water-quality pond that could potentially contribute to drips in No Rent Cave.

McNeil Drive approaches within about 300 to 250 feet south of No Rent Cave, and its elevation approaches but does not exceed No Rent Cave drip elevations. Since the local dip is N30E at 0.7º (see III.1), vadose groundwater is most likely to follow bedding planes from the southwest to northeast. For this reason, the subsurface catchment area for No Rent Cave was extended up to the 835 ft msl surface elevation contour southwest of the cave. Because there is zero gradient between the 835 ft msl elevation contour and the cave drip at the same elevation, the actual surface area contributing to diffuse cave drips observed in No Rent Cave is somewhere within the mapped subsurface catchment area and does not extent far as shown. Due to the proximity of McNeil Drive, additional investigation is necessary to further limit the actual surface area contributing to drips in No Rent Cave.

III.3.4 **Weldon Cave**

Weldon Cave was originally mapped by Mike Warton and others on June 19, 1995 (Elliott, 1997). The cave was remapped on November 4, 2010 by Nico Hauwert and Mark Sanders for this study. Weldon Cave is primarily developed within the Kirschberg Member, with the Grainstone Member serves as a competent roof in the upper levels (Appendix A). For short intervals around rain events, diffuse drips seep through the roof of the upper level. The drips observed in the upper drip horizon are generally all diffuse drips, with the exception of one persistent drip at the end of Diamond Back Hall, at the entrance to a wet ceiling crawl. Nearby, a dome feature in Diamond Back Hall has a horizontal conduit that appears to have historically discharged over a large stalagmite. This formation appears to be inactive, although it is possible that discrete drips still discharge here under rare unobserved conditions. The elevation of the upper drips are approximately 869 ft msl. Note the mapped cave extends about 80 feet to the northeast, and appears to follow the local dip direction of strata or discontinuity indicated by the geotechnical borings.

In the rear of Weldon Cave, within the Popcorn City drip room, a perennial drip cluster flows at an elevation of about 855 feet msl. Mark Sanders of CoA BCP reported drip observations in the lower level of Weldon Cave (Popcorn City drip room) on July 22 and

August 19, 2010, during a relatively dry period. The Weldon Popcorn City drips are considered discrete drips due to their persistent and focused flow. The drips appears on the north side of the room, which is the northernmost point of the cave passage, suggesting the source is likeliest from the north (Appendix A).The popcorn formations that are widespread across the lower levels may have developed by historical seeping of groundwater through pulverulite which here macroscopically appears to be the same calcite-cemented silt-sized dolomite crystals observed in the Barton Springs Segment.

The subsurface catchment area for Weldon Cave was extended 830 feet west, at a gradient as low as 2%, because of increasing topography in this area and the potential of northeast dip, which could increase the subsurface catchment area to the southwest. The most prolific and lowest elevation discrete drips of the Popcorn City Room has a drip horizon elevation of 855 ft msl. The subsurface catchment area was extended about 500 feet north of the cave, where a well-defined drainage descends below the 855 ft msl elevation. The northern and western edge of the surface catchment area mapped as much as 500 to 800 feet from the cave footprint with a low vertical gradient ranging from 0º to 3º in relation to the lower Popcorn City drips. The eastern and southern edges of the subsurface catchment area are over 400 feet from the Weldon cave footprint, with vertical gradients less than 3º than the upper diffuse drips at about 869 ft msl elevation.

III.3.5 **McNeil Bat Cave**

McNeil Bat Cave is a large room ringed by large collapsed blocks and breakdown slopes. The fallen blocks have many numerous fissures that ring the room and descend to lower levels between blocks. Most outstanding about the Bat Room are large columns in the center and perimeter of the room that indicate the previous inflow of water through ceiling fractures that was saturated with calcite. The room is at times home to a large bat colony, evidenced by circular-stained ceiling and thick underlying guano mound. Goat remains are also found in places across the Bat Room. A side passage to the east descends through a squeeze to the Rhadine Room. The mapped portion of the cave passage descends 50 feet southeast and continues to the northwest of the main Bat Room through tight fissure, bedding plane, and inter-block passages. The cave passage trend northwest to southeast and does not follow the northeast trend that Weldon Cave follows, but instead may be trending toward a possible fault about 500 to 1,000 feet southeast. The passage morphology lacks keyhole channeling indicative of cave development under vadose conditions and supports that the passage formed in an earlier phreatic zone. It is interpreted that the cave was developed by ancient groundwater dissolution of calcite cements holding together euhedral dolomitic grains. Most of the cave development probably occurred when the land surface was several hundred feet higher and the cave was near the water table of the Edwards Aquifer. Groundwater velocity may have been sufficiently rapid to erode the loose pulverulitic silt once the calcite cement was removed. As the land surface eroded and the cave was sufficiently shallow, the stress fields resulting from the large cavern room could reach the surface and cause collapse of a small section of the roof.

McNeil Bat Cave was originally mapped by William Russell on January 18, 1963 (Elliott, 1997, Appendix A). The cave was remapped by Nico Hauwert, Justin Camp, and

Mark Sanders on November 12, 2010 (Appendix A). These maps define the known extent of the caves.

McNeil Bat Cave has multiple drip horizons at elevations between 860 and 843 feet msl. The subsurface catchment area was combined for the upper-level drips at elevations of about 860 ft msl and lower-level continuous and discrete drips in the Rhadine Room and passage leading to it.

The upper-level drips can be observed discharging from the lowermost massive bed of the Grainstone Member of the Edwards Formation, which serves as a competent roof for the large room. The elevation of the upper-level drips are about 860 ft msl. Most of the cave is developed within pulverulitic (calcite-cemented euhedral silt-sized dolomite crystals) beds of the underlying Kirschberg Member. McNeil Bat Cave showed widely distributed drips on the roof of the main room and a focused drip in a northwest passage just north of the main Bat Room on February 9, 2010, within 24 hours of rain events. The upper-level drips observed were all small and widely distributed after rains on February 9, 2010, except for a more concentrated drip and travertine at the mouth of a side passage about 30 feet north (left) of the entrance, apparently along a fissure. These upper-level drips were observed to be dry on November 12, 2010. The source of the upper-level drips appear to be more localized from soil-moisture drainage around the cave footprint. Because of the small focused drip observed in McNeil Bat Cave on the northwest fissure on Feb 9 during a wet period, the upper-level drip subsurface catchment area was extended over 800 feet from the entrance to the topographically higher area north and northwest of the cave. The subsurface catchment area includes the entire catchment for the surface drainage that passes near the entrance and includes portions of another surface drainage along the east side of the high school.

The horizontal passage descending to the southeast was not entered on February 9, 2010 to avoid unnecessary disturbance to the dormant bats roosting in the ceiling there. The Rhadine Room and passage leading to it was entered and mapped on November 12, 2010, during which time only four bats were observed in the cave. Drip D1 is located in the descending passage toward the Rhadine Room at an elevation of 849 feet msl and appears to flow at the highest rate of all drips in the cave. The Rhadine Room has continuous drips from a stalactite in the center of the room with a ceiling elevation of about 843 ft msl. The lower-level drips likely originate from the estimated local updip direction for local strata to the southwest. Note that the large Bat Room effectively blocks shallow groundwater flow to the Rhadine Room from the northwest. Discrete drips of this magnitude could originate from the convergence of soil drainage over a large area, could receive focused infiltration along surface channels, such as a minor channel located about 120 feet southwest of the lower drip areas and a deeply incised channel over 500 feet from the lower drip areas.

From the point of highest surface elevation in front of McNeil High School along the north side of McNeil Drive, 1,800 feet southwest of McNeil Bat Cave footprint, the gradient to the lowest Rhadine Room drips is only 1.9º. From the Rhadine Room drip 1,000 ft to McNeil Drive near borehole C (about 860 ft msl), the vertical gradient is only

1.7º. These vertical gradients appear to be too low for actual groundwater flow through the Grainstone Member, based on evidence from other areas presented in I.2. However, because of the down dip (or down drop) slope of rock units to the northeast and the persistence and high rate of the lower McNeil Bat Room drips, and there is no clear criteria in this investigation that allows further refinement of the subsurface catchment area, it is conservatively overestimated to include the maximum possible area (or 843 ft msl surface elevation contour) beyond which no contributing flow is possible (zero gradient from surface and Rhadine Room drips).

With further investigation, it would likely be found that the actual surface area contributing to drips in McNeil Bat Cave are much smaller than are conservatively mapped here and does not actually extend south of McNeil Drive. Note that Borehole C, located about 930 feet southwest of the Rhadine Room along McNeil Drive showed no indication of perched water or flowing conduits within its upper 20 feet, that is higher in elevation that the Rhadine Room drips. The lack of shallow perched water in borehole C does not discount the possibility of convergent perched flow along discrete flow paths. Geophysical surveys by EGA (2010) identified a number of natural potential anomalies along the north side of McNeil drive and the east side of the school that could represent shallow and narrow groundwater flow. The lower discrete drips may potentially receive anthropogenic flow from sources such as sprinklers irrigating the playing fields about 500 feet to the west, and there is evidence to suggest anthropogenic water, rather than convergence of soil-moisture drainage over a large area, may be the source of the lower drips in McNeil Bat Cave:

1) The flowing formations at D1 drip and the Rhadine Room are oddly white, as opposed to the typical dark orange formations found throughout the cave (Appendix D). They contain soda straws rather than stalactites and columns, which suggest that the formations are immature and not blocked by impurities.
2) The remains of a burnt stump is present next to D1 Drip. It appears that quite some time ago, this burning stump may have been put in the cave to reduce bat populations. It seems unlikely that for this purpose burning materials would be placed below an active drip (Mark Sanders, 2010, personal observation).
3) Line leakage from urban infrastructure is not uncommon. A leaking irrigation line was observed during Borehole C drilling.

Additional investigation, such as sourcewater sampling and comparison may help to refine a smaller area with high confidence.

III.4 Groundwater Below Cave Extents

While the Edwards Aquifer is nearly unsaturated in the study area, some groundwater is consistently encountered in boreholes below the vertical depths of the four studied caves. Groundwater may be expected at a shallow depth below the mapped extent of No Rent Cave. Drilling observations from core A, boring B indicate that the tops of the Dolomitic Member equivalent and Comanche Peak Formation serve to perch vadose flows which are present at an elevation of 807 to 831 feet msl. Downhole videos showed a small flow of perched water entering core A at 51.5 ft depth (831 ft msl) and a standing

water depth of 71.5 ft depth (811 ft msl). Water was believed to enter the well at 176 ft depth (706 ft msl), or from the lower Bee Caves member, based on decrease in turbidity observed in the downhole camera survey. Water was added to core A from the drilling process, but not to bores B and C. Downhole videos taken within days after drilling show a small flow of groundwater enters boring B from conduits at a depth of 53 ft (807 ft msl) at the contact of the Dolomitic Member equivalent with the underlying Comanche Peak Formation. Groundwater flowed into borehole B at a depth of 185 ft (675 ft msl), or within the Bee Caves Members of the Walnut Formation. The water depth in bore B after drilling was 61 ft (821 ft msl) on the downhole video survey. Observations of water in bore C was complicated by flow from a leaking irrigation line pouring down the hole beginning the night after the hole was completed. Water-saturated cuttings were recovered from bore C at 195 ft depth (about 667 ft msl) roughly in the middle of the Bull Creek Member of the Walnut Formation. Down hole video taken days after drilling showed the water level in the hole to be 55.7 ft deep. Caliper logs, that measure the hole diameter, indicate that voids in the three holes were detected within the Kirschberg Member and lower in the holes near the contact of the Walnut Formation and underlying Glen Rose Formation. The three McNeil holes encountered the majority of groundwater near their lower depths, within the Walnut Formation.

Note that surface geophysical surveys by EGA (2010) indicate a strong natural potential anomaly, not observed across a similar creek just east of No Rent Cave, which may suggest the presence of shallow groundwater lower than 830 feet msl (or lower than the mapped extent of No Rent Cave). It is possible that, rather than being a discrete anomaly, the natural potential anomaly measured below the creek is a fairly widespread perching of groundwater that lies sufficiently close to the surface beneath the creek incision for detection.

Similarly, three different boreholes drilled in 2010 along Parmer Lane encountered groundwater at elevations of about 837 ft msl about 500 feet south of Fossil Garden Cave, diminishing to 828 feet msl at Parmer Lane and McNeil Drive, and to 822 feet msl about 1,500 feet southeast of McNeil Drive (Zara, 2010b). Walnut Creek flows perennially about 1,000 feet southwest of No Rent Cave, near Parmer Lane, at elevations between about 825 and 830 feet elevation msl, suggesting that some perching beds, such as those in the Dolomitic Member, may be present.

Based on a few water level points from local borings, the perched water may move roughly southeast and discharge into Walnut Creek. Veni (1998) suspected that the uppermost Dolomitic Member may have marked the lower extent of cave development in caves southeast of Parmer Lane and McNeil Drive and played a role in perching spring flow to Walnut Creek.

IV. Conclusions

The surface catchment areas for Fossil Garden, Weldon, No Rent, and McNeil Bat Caves are 5.0, 1.6, 0.6, and 1.6 acres respectively. All four originated as collapsed sinkholes although only Fossil Garden Cave has pirated sufficient surface drainage to mature into a solution sinkhole with a well-developed internal drainage basin. The surface catchments for the four surface catchment areas are all more than 300 feet from McNeil Drive and more than 200 feet from Parmer Lane.

The subsurface catchment areas include the geographic areas that contribute groundwater to cave drips in the mapped portion of the four studied caves. They were conservatively delineated using a combination of methods for Fossil Garden, Weldon, No Rent and McNeil Bat Cave to be 58, 30, 52, and 148 acres respectively in area. The upper-level caves drips were documented after a rainy period and generally only diffuse drips were encountered, indicating those drip sources were soil-moisture drainage of area roughly overlying the cave footprint. The drip horizon in Fossil Garden, Weldon, and McNeil Caves discharged from ceilings composed of Grainstone Member at the contact with the underlying Kirschberg Member. Weldon Cave has a lower discrete drip cluster in its Popcorn City room. McNeil Bat Cave has persistent, discrete drips in its Rhadine Room and passage descending to it that potentially could drain much farther than the cave footprint. Ceiling conduits in Fossil Garden and Weldon Caves suggest the presence of discrete drips that are either abandoned or may be active under unobserved flooding conditions. From wet-weather inspections, drip horizons were identified and their elevations measured relative to mean sea level. Subsurface catchment areas were extended at least 150 feet beyond the underlying the cave footprint. The surface and subsurface geology was mapped using exposures in quarries, caves, land surface, as well as three geotechnical borings or cores. The geological mapping and cores allowed the identification of beds that could serve to convey or perch vadose groundwater above the water table. The cores also were used to measure local stratigraphic dip, which can direct shallow groundwater in down-dip directions. Finally, hydraulic gradients between surface and drip horizons were measured. Based on actual drip source tracing at a research site in South Austin at the same Grainstone and Kirschberg Member contacts, all areas with hydraulic gradients exceeding 10% over the drip horizons were included in the subsurface catchment areas, although frequently surface areas with gradients as low as zero were conservatively included. A much lower gradient may be possible where a low permeability bed can act to perch shallow groundwater, such as deeper in the subsurface below the mapped cave extent of the McNeil cluster or in other areas. Lower hydraulic gradients between surface source areas and cave drips are also possible within permeable hydrostratigraphic units in directions where stratigraphic dip directs vadose flow. Within the permeable Grainstone and Kirschberg Members, source areas that have low gradients to a cave drip, such as 5º, are unlikely to actually contribute to the drip, but may be conservatively included in the maximum subsurface catchment area. This new geological information can help characterize drip sources for other caves in north Travis and Williamson Counties.

The results of this study are consistent with the hypothesis offered by Dr. Veni (1992; 1998), that cave development is localized within the Kirschberg Member and that in the McNeil area, cave and vertical conduits have not integrated within the underlying Dolomitic Member (and Comanche Peak Formation). Consequently local groundwater tends to perch above the Dolomitic Member and Comanche Peak Formation.

V. Recommendations

Further investigation of drip sources may be possible by continuous monitoring specific drip rates and characterizing the drip water-quality and comparing it to type waters such as other cave drips and City of Austin tap water. Continuous monitoring of the drip rates, using a waterproof tipping bucket gauge might help characterize the drip sources, since runoff/soil macropore flow is short lived, soil moisture drainage should follow a predicted recession, and urban sources should stay relatively constant. The source of flow to the Rhadine Room in McNeil Bat Cave can potentially be further examined by extending the rear of the cave in hopes of following the water source. As this work likely requires hand-excavation, prior permission from USFW is required and it is uncertain to predict in advance whether the effort would be fruitful. Direct soil tracing, as discussed in II.3, may be injected at specific locations to refine the subsurface catchment areas mapped here.

Periodic biological assessments of the four caves should be conducted, if access permission can be obtained, to monitor changes in population and ecosystems. Secondary effects of disturbance activities, such as development of fire ant populations, should be considered and mitigated through regular monitoring and hot water treatment of individual mounds as recommended in the BCP Land Management Plan (BCP, 2007). Spills of volatile materials in the area can potentially affect caves from beyond the defined catchment areas. Public education is essential to promote stewardship, necessary for the continued existence for the caves and their inhabitants (BCP, 2007). Opportunities for educational outreach with McNeil High School, correlated with state science education standards, should be offered to promote a mutually beneficial partnership.

Figure 1. Profile Along North Side of McNeil Drive

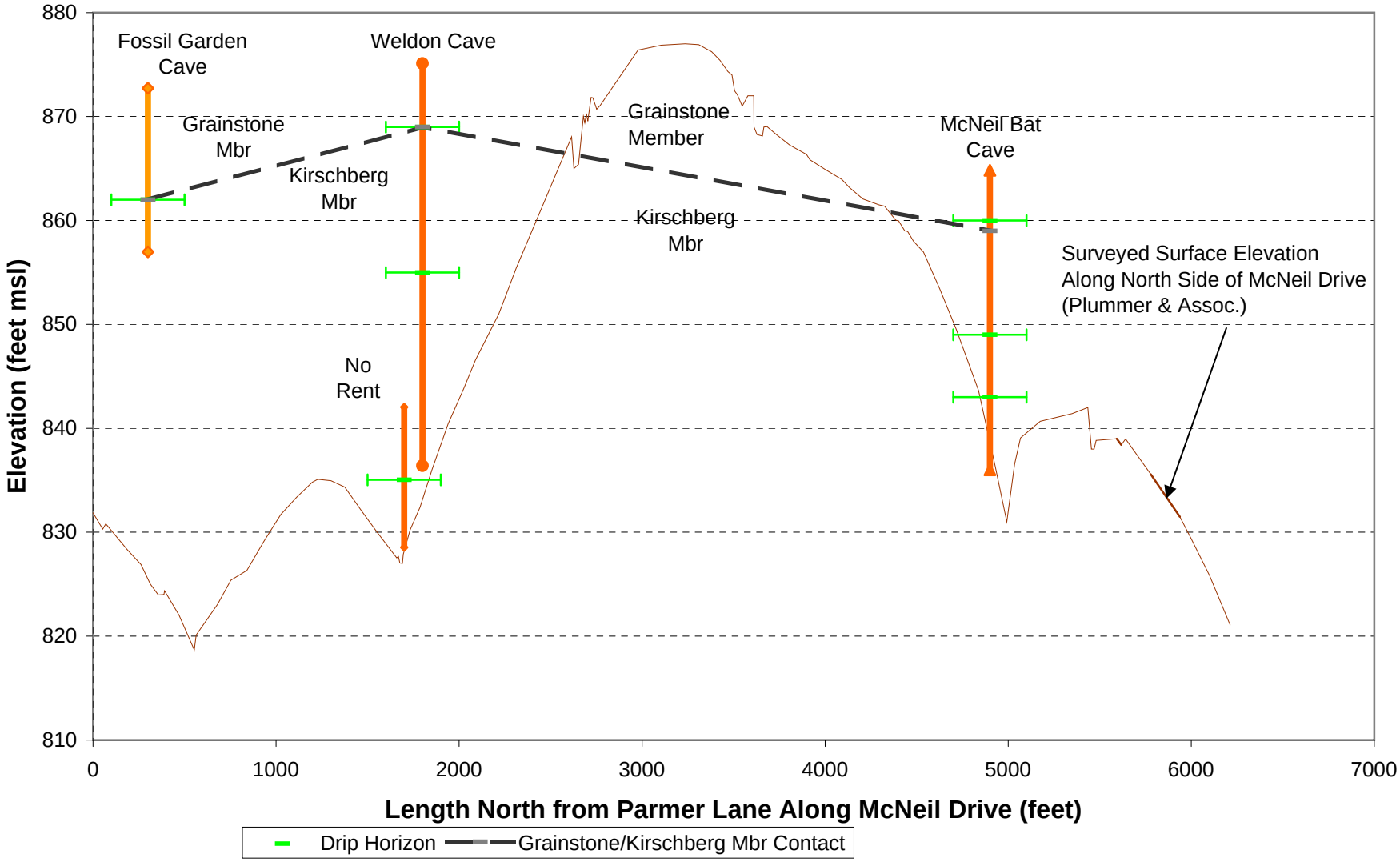
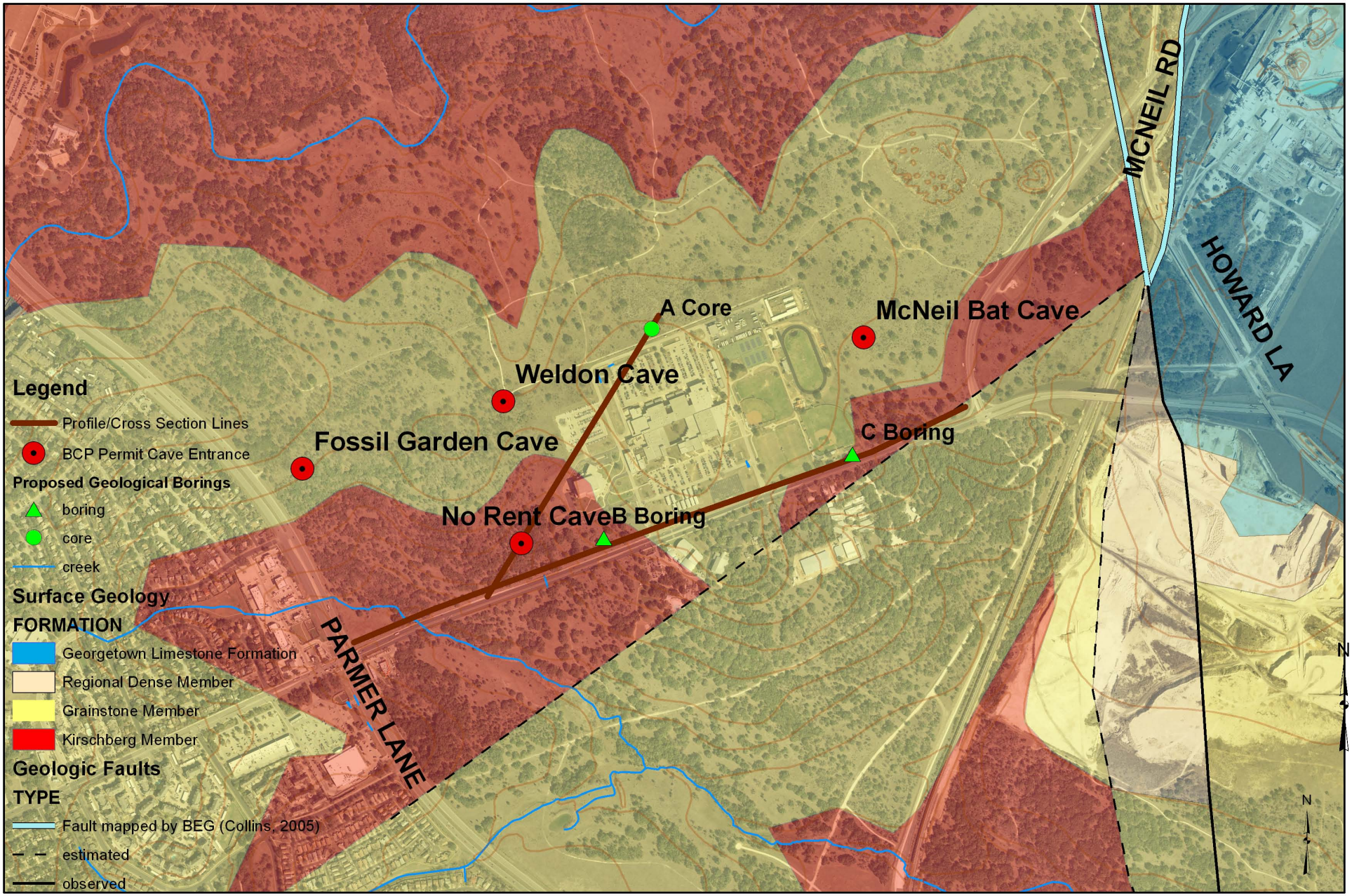
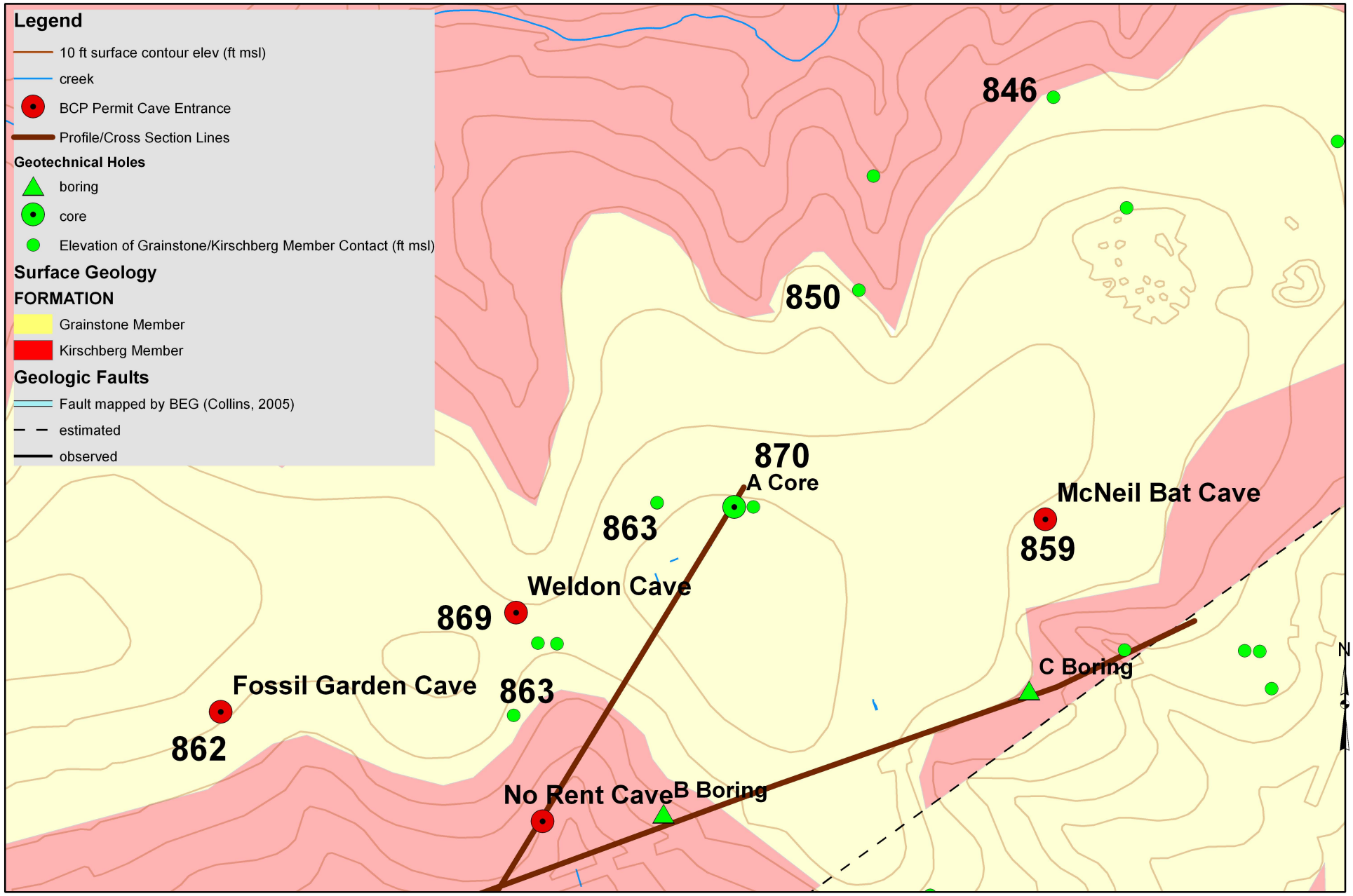


Figure 2. Surface Geology Map of McNeil Drive Study Area



Surface geology mapped and interpreted by Nico Hauwert, Scott Hiers, and Sylvia Pope in 2010 modifying previous mapping by Collins, 2005. Background aerial is 2009.

Figure 3. Elevation of Grainstone/Kirschberg Member Contacts



Geologic mapping by Nico Hauwert, Scott Hiers, and Sylvia Pope CoA WPD

Figure 4. Surface Catchment Areas for Fossil Garden, Weldon, No Rent, and McNeil Bat Caves



Figure 5. Subsurface Catchment Areas for Fossil Garden, Weldon, No Rent, and McNeil Bat Caves

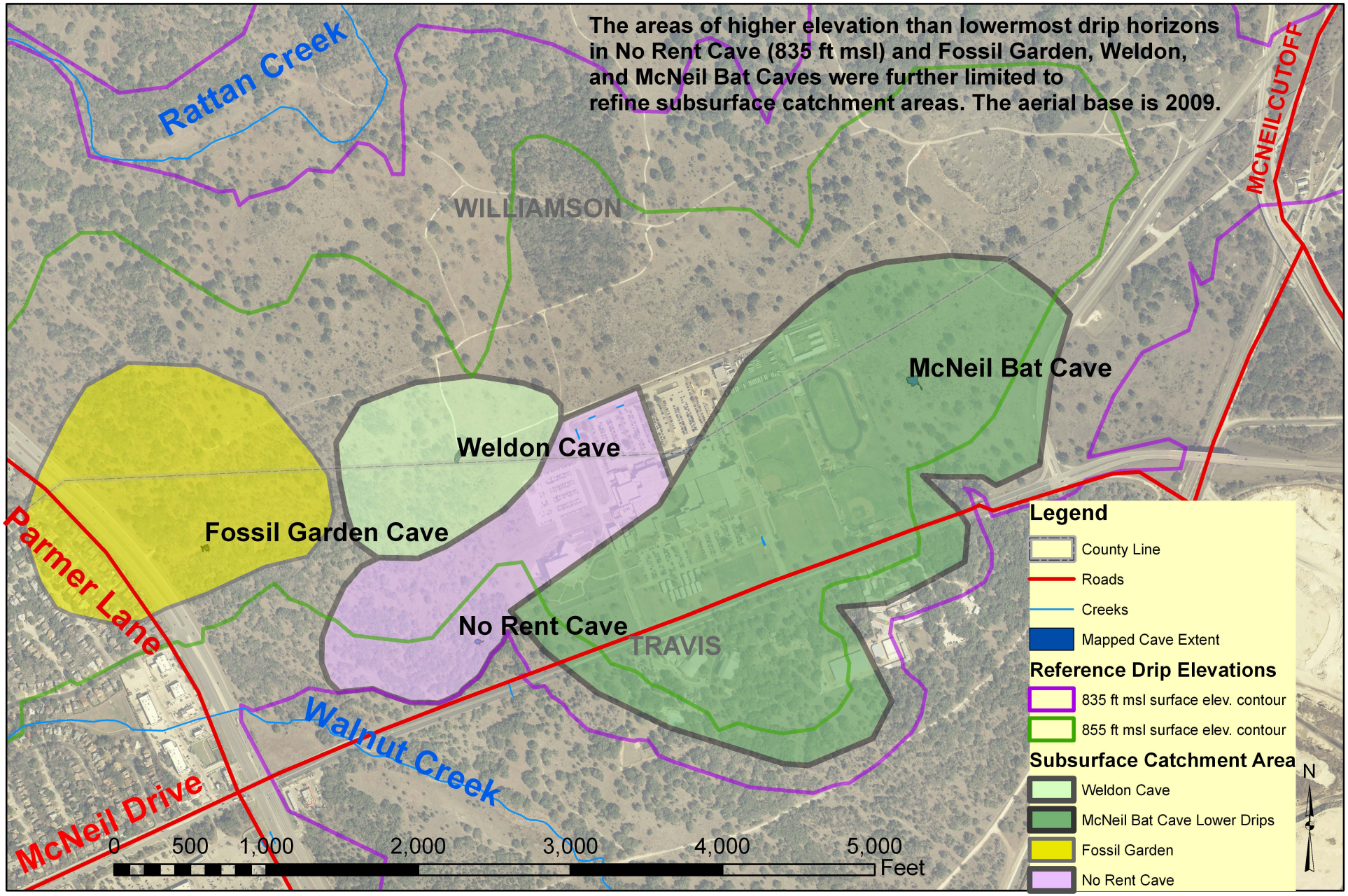


Figure 6 Subsurface Catchment Area for No Rent Cave

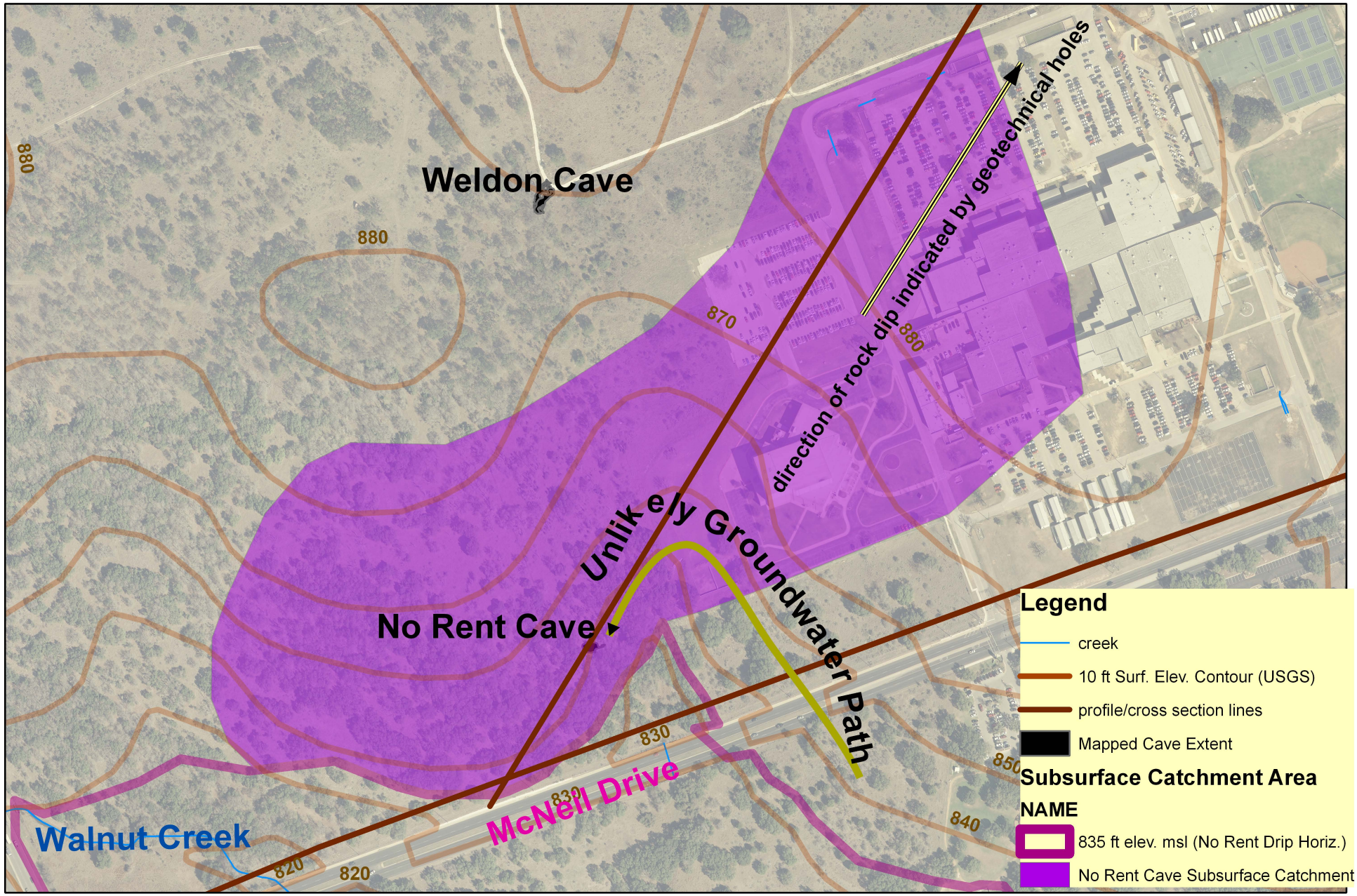


Figure 7. Further Detail Near No Rent Cave

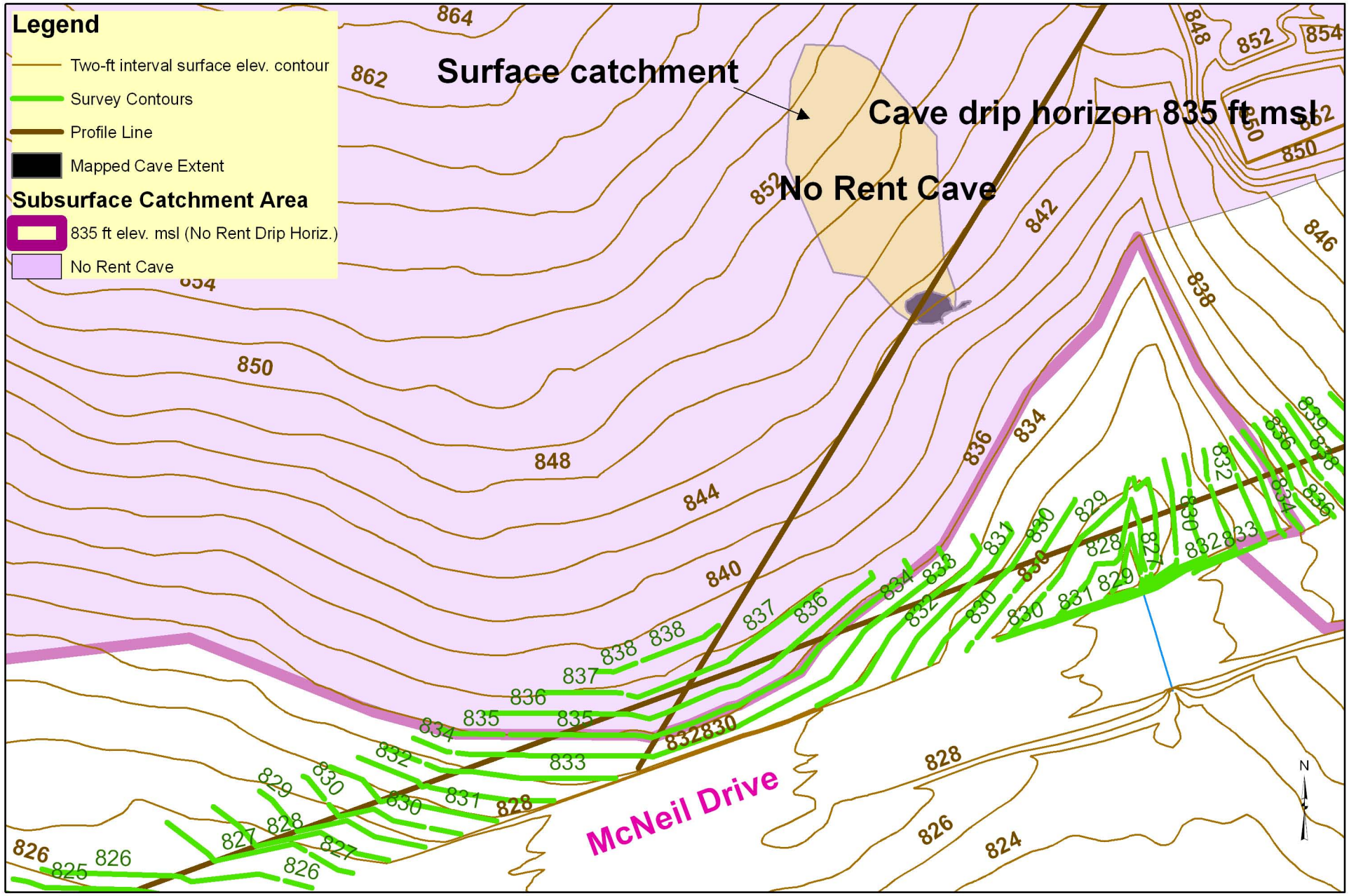
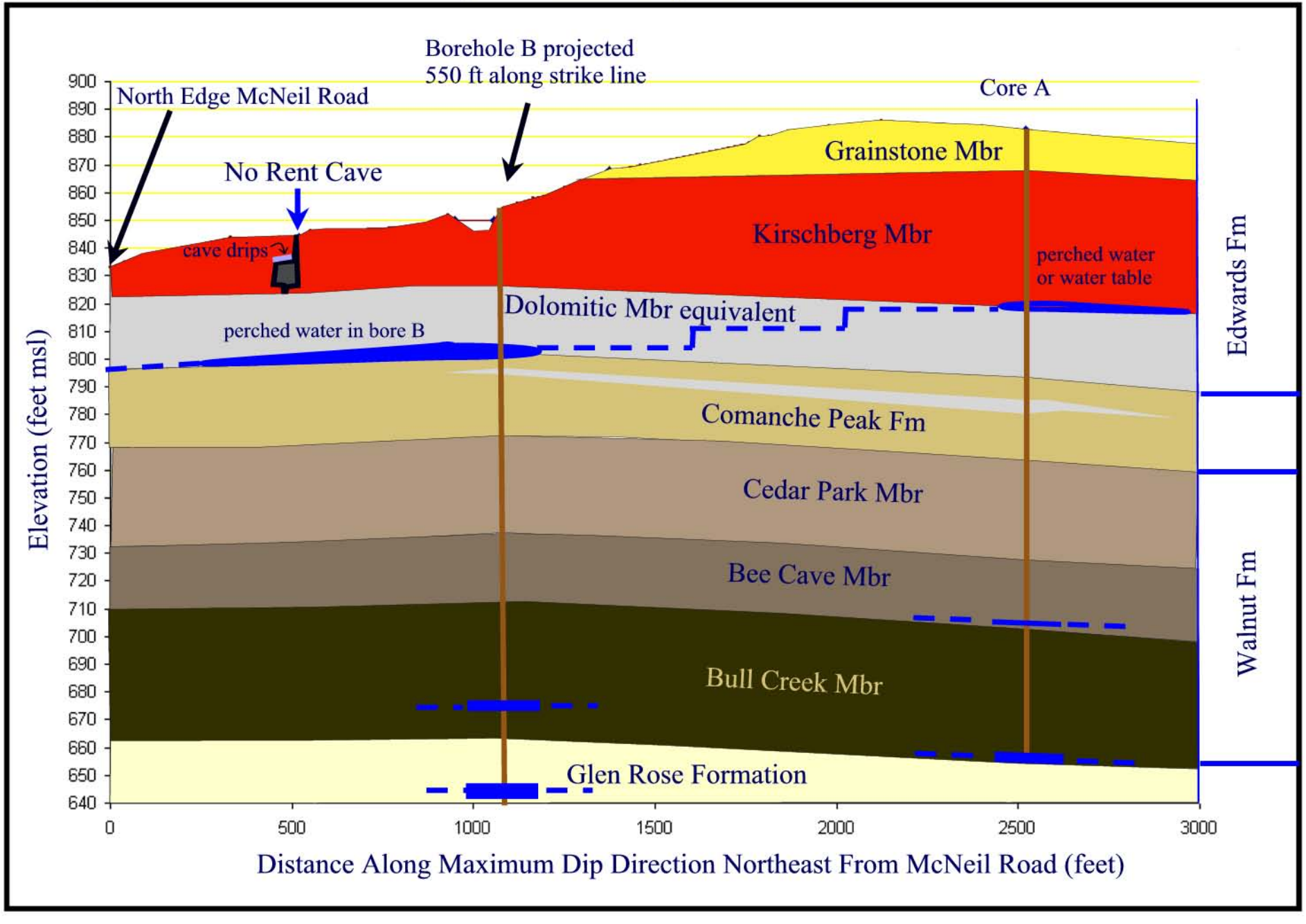


Figure 8. Cross Section Along Maximum Dip Line Through No Rent Cave to Core A



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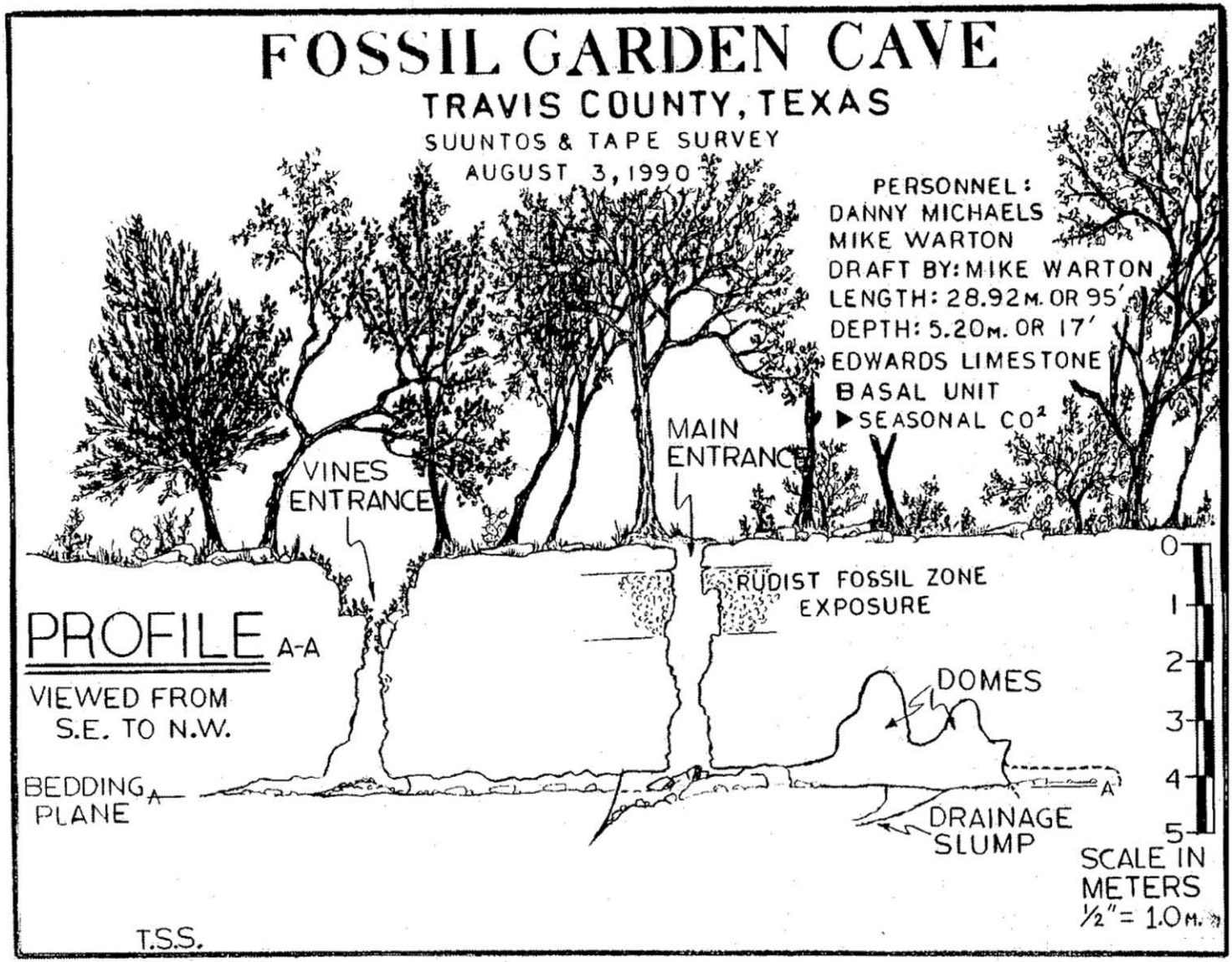
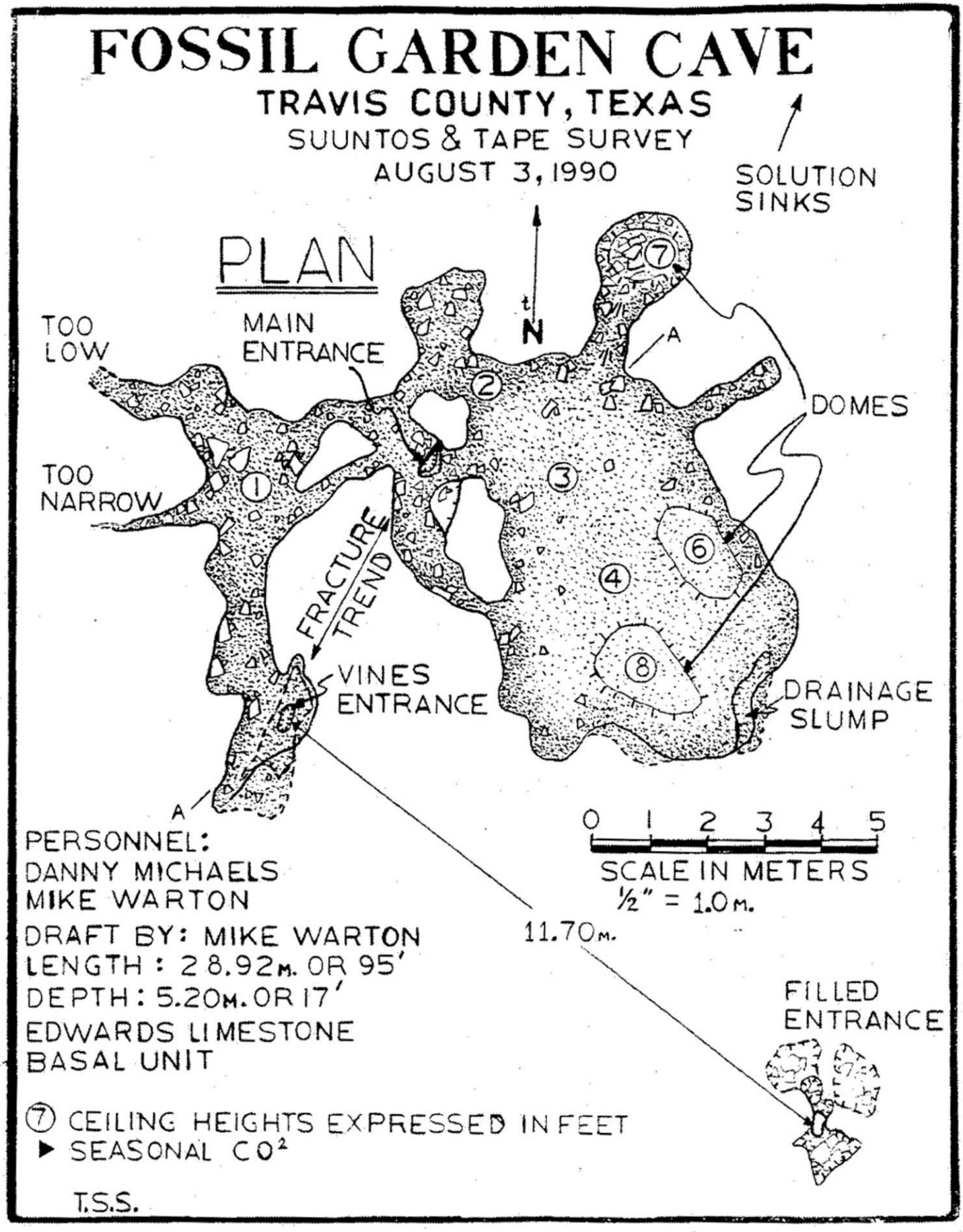
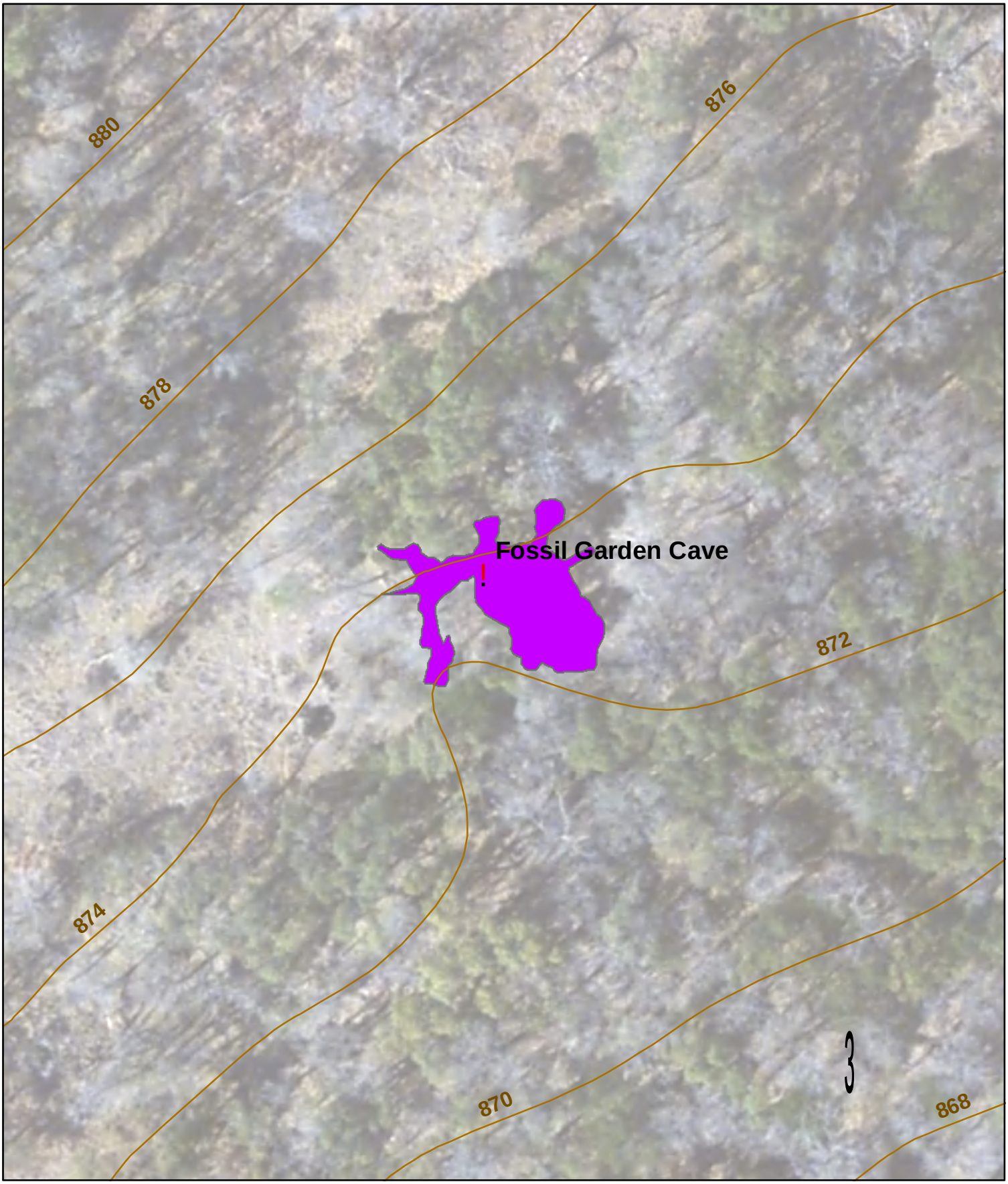
Appendix A.

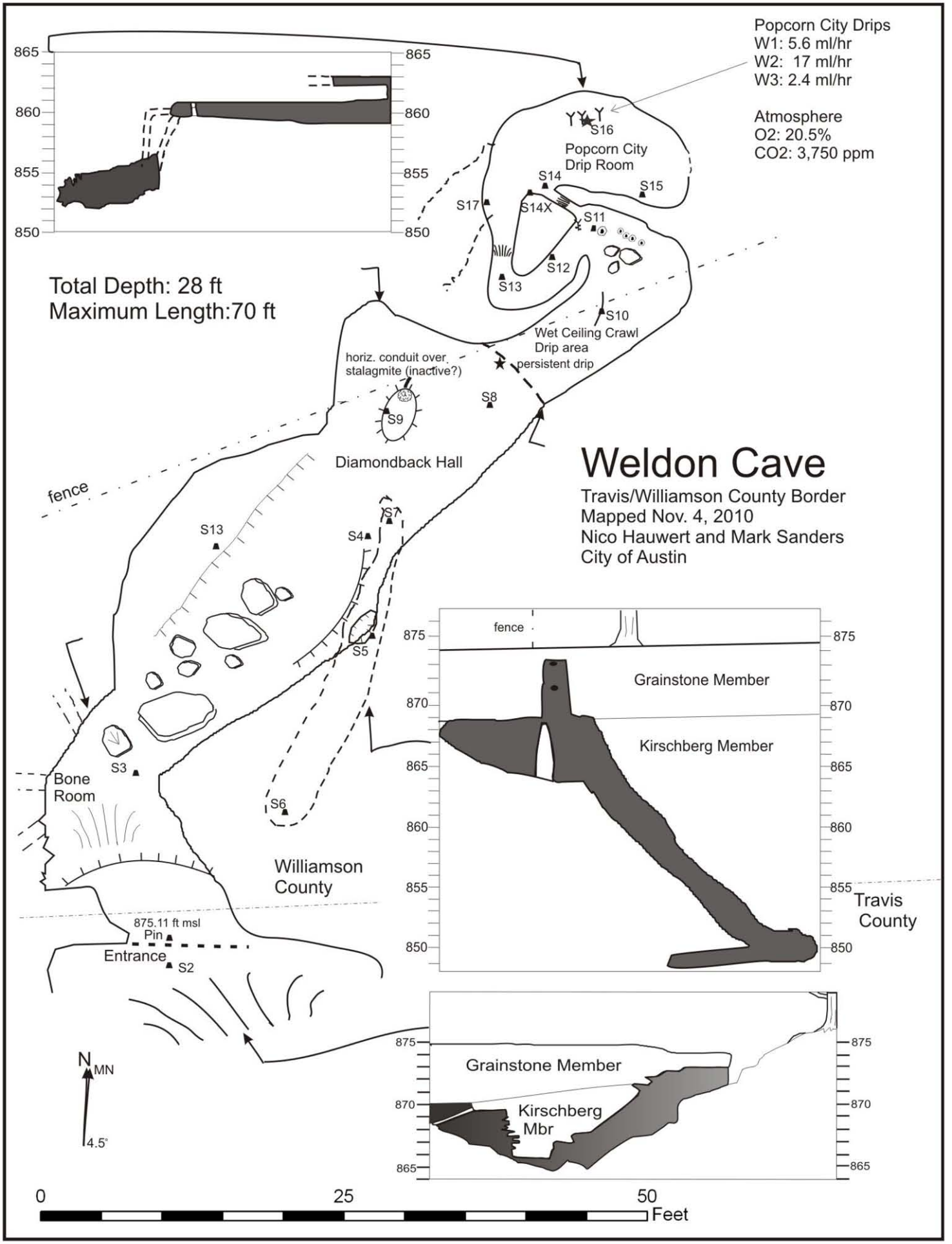
Cave Maps

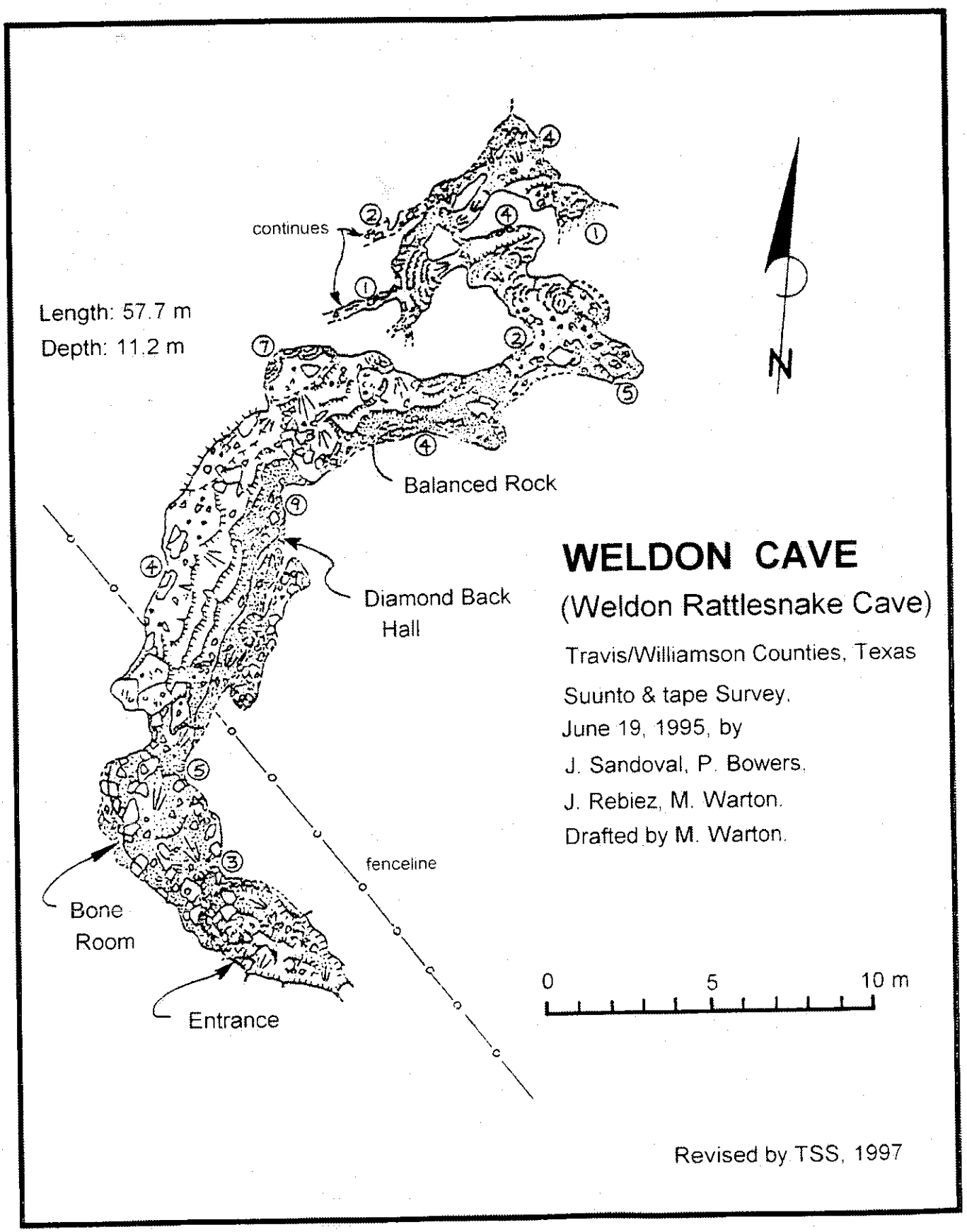

FOSSIL GARDEN CAVE
TRAVIS COUNTY, TEXAS
SUUNTOS & TAPE SURVEY
AUGUST 3, 1990
PERSONNEL:
DANNY MICHAELS
MIKE WARTON
DRAFT BY: MIKE WARTON
LENGTH: 28.92M. OR 95'
DEPTH: 5.20M. OR 17'
EDWARDS LIMESTONE
BASAL UNIT
SEASONAL CO²
MAIN ENTRANCE
VINES ENTRANCE
RUDIST FOSSIL ZONE EXPOSURE
PROFILE A-A
VIEWED FROM S.E. TO N.W.
DOMES
BEDDING PLANE
A
A'
DRAINAGE SLUMP
0
1
2
3
4
5
SCALE IN METERS
½" = 1.0M.
T.S.S.


FOSSIL GARDEN CAVE
TRAVIS COUNTY, TEXAS
SUUNTOS & TAPE SURVEY
AUGUST 3, 1990
SOLUTION SINKS
PLAN
N
TOO LOW
MAIN ENTRANCE
TOO NARROW
DOMES
FRACTURE TREND
VINES ENTRANCE
DRAINAGE SLUMP
A
A
1
2
3
4
6
7
8
0 1 2 3 4 5
SCALE IN METERS
½" = 1.0 m.
PERSONNEL:
DANNY MICHAELS
MIKE WARTON
DRAFT BY: MIKE WARTON
LENGTH : 28.92 m. OR 95'
DEPTH : 5.20 m. OR 17'
EDWARDS LIMESTONE
BASAL UNIT
11.70 m.
FILLED ENTRANCE
⑦ CEILING HEIGHTS EXPRESSED IN FEET
▶ SEASONAL CO²
T.S.S.

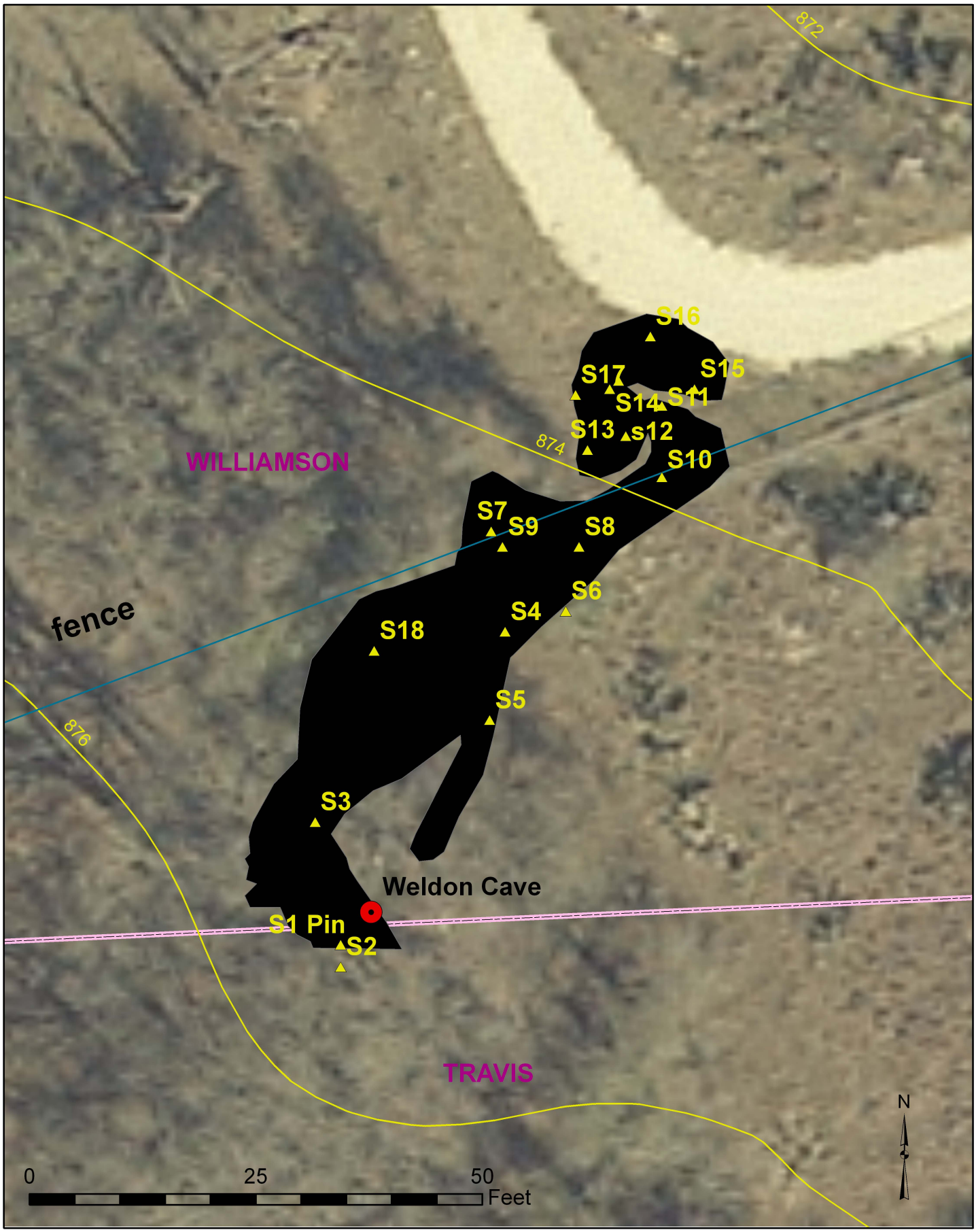
Fossil Garden Cave Subsurface Extent

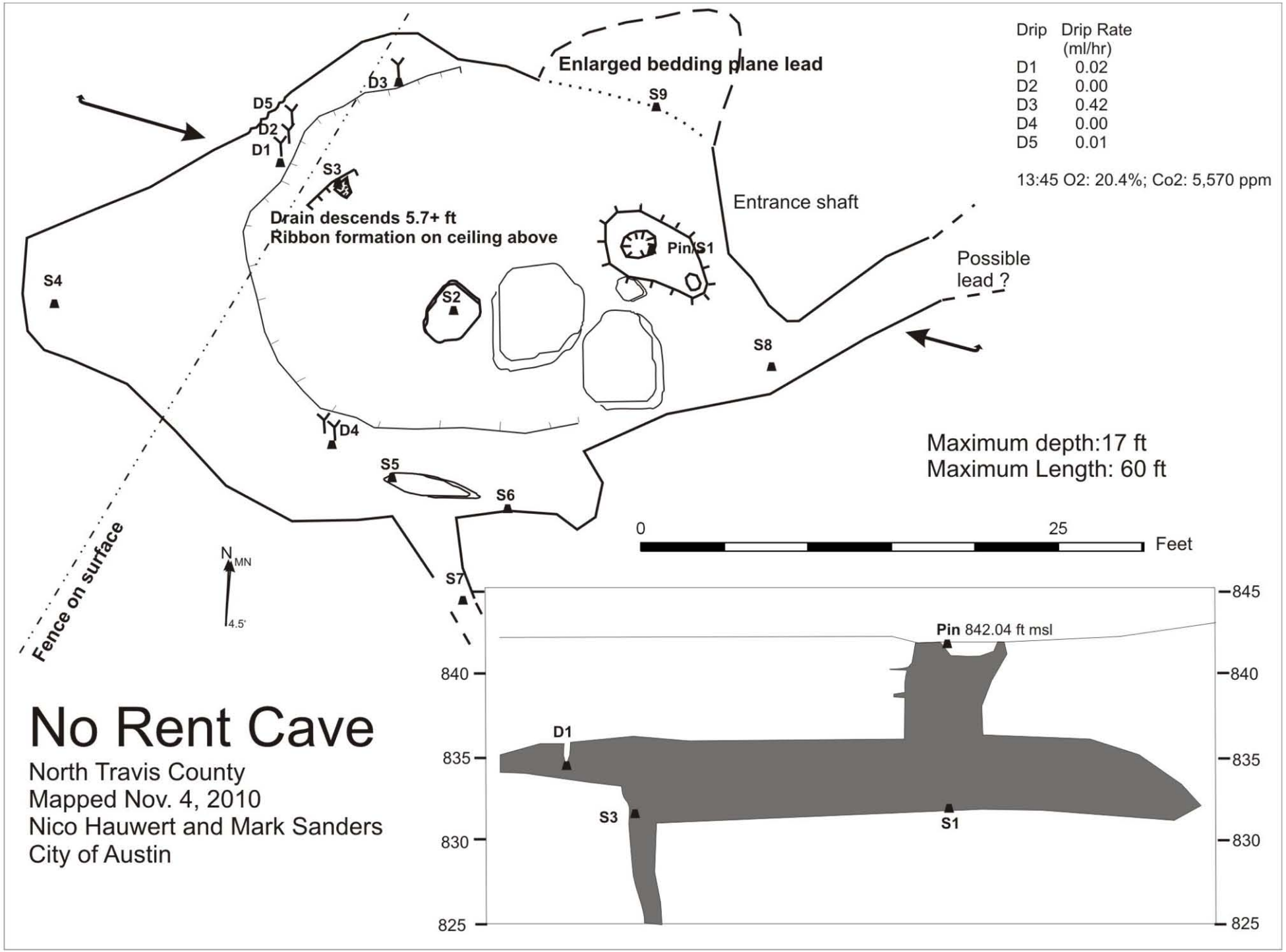



Popcorn City Drips
W1: 5.6 ml/hr
W2: 17 ml/hr
W3: 2.4 ml/hr
Atmosphere
O2: 20.5%
CO2: 3,750 ppm
Popcorn City
Drip Room
S16
S14
S15
S17
S14X
S11
S12
S13
S10
Wet Ceiling Crawl
Drip area
persistent drip
horiz. conduit over
stalagmite (inactive?)
S8
S9
Diamondback Hall
Total Depth: 28 ft
Maximum Length:70 ft
Weldon Cave
Travis/Williamson County Border
Mapped Nov. 4, 2010
Nico Hauwert and Mark Sanders
City of Austin
fence
S13
S4
S7
S5
S3
Bone
Room
S6
Williamson
County
875.11 ft msl
Pin
Entrance
S2
N
MN
4.5°
fence
Grainstone Member
Kirschberg Member
Travis
County
Grainstone Member
Kirschberg
Mbr
865
870
875
850
855
860
0
25
50
Feet


continues
Length: 57.7 m
Depth: 11.2 m
Balanced Rock
Diamond Back
Hall
fenceline
Bone
Room
Entrance
N
WELDON CAVE
(Weldon Rattlesnake Cave)
Travis/Williamson Counties, Texas
Suunto & tape Survey,
June 19, 1995, by
J. Sandoval, P. Bowers,
J. Rebiez, M. Warton.
Drafted by M. Warton.
0
5
10 m
Revised by TSS, 1997

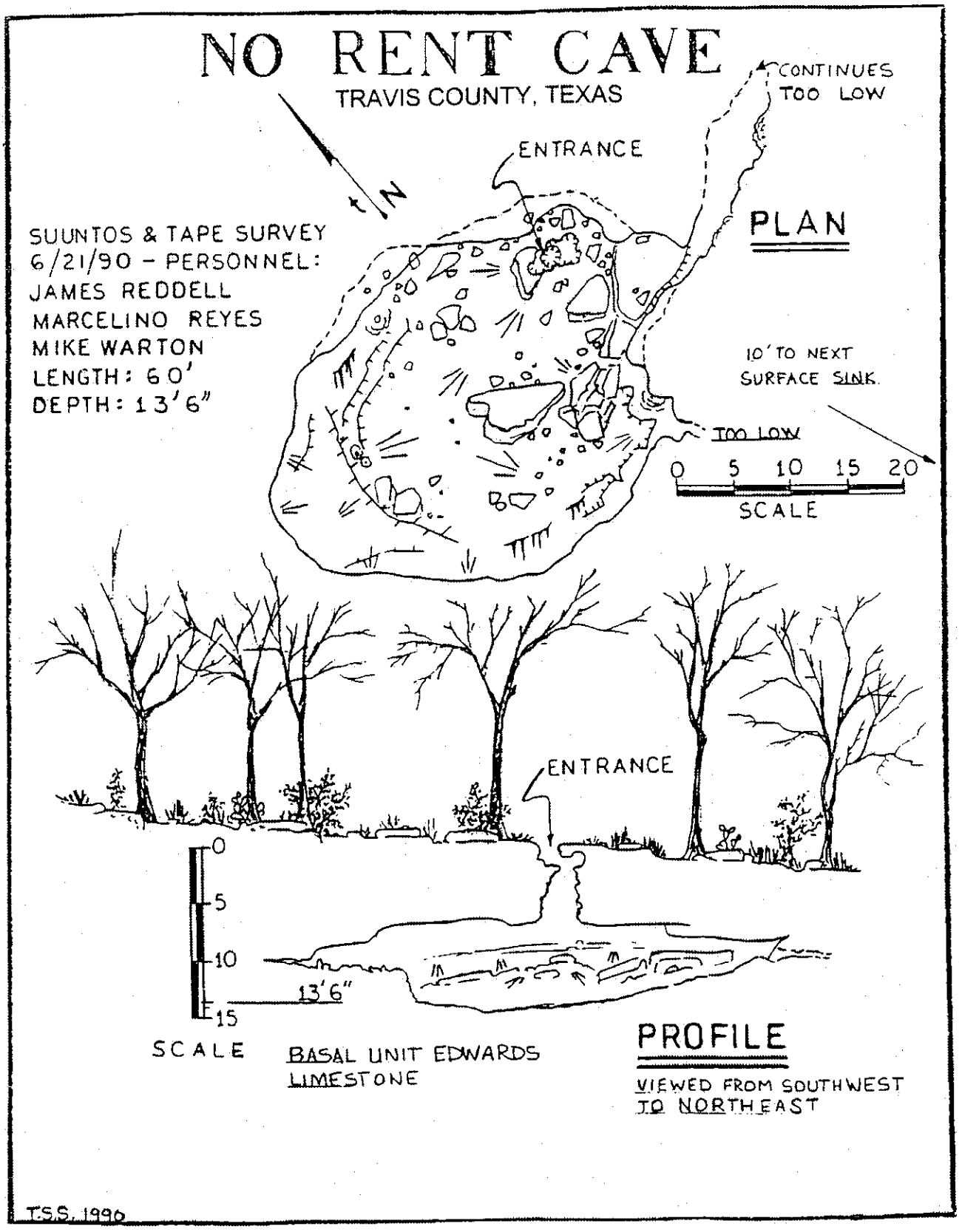
Weldon Cave Footprint (2010 map)



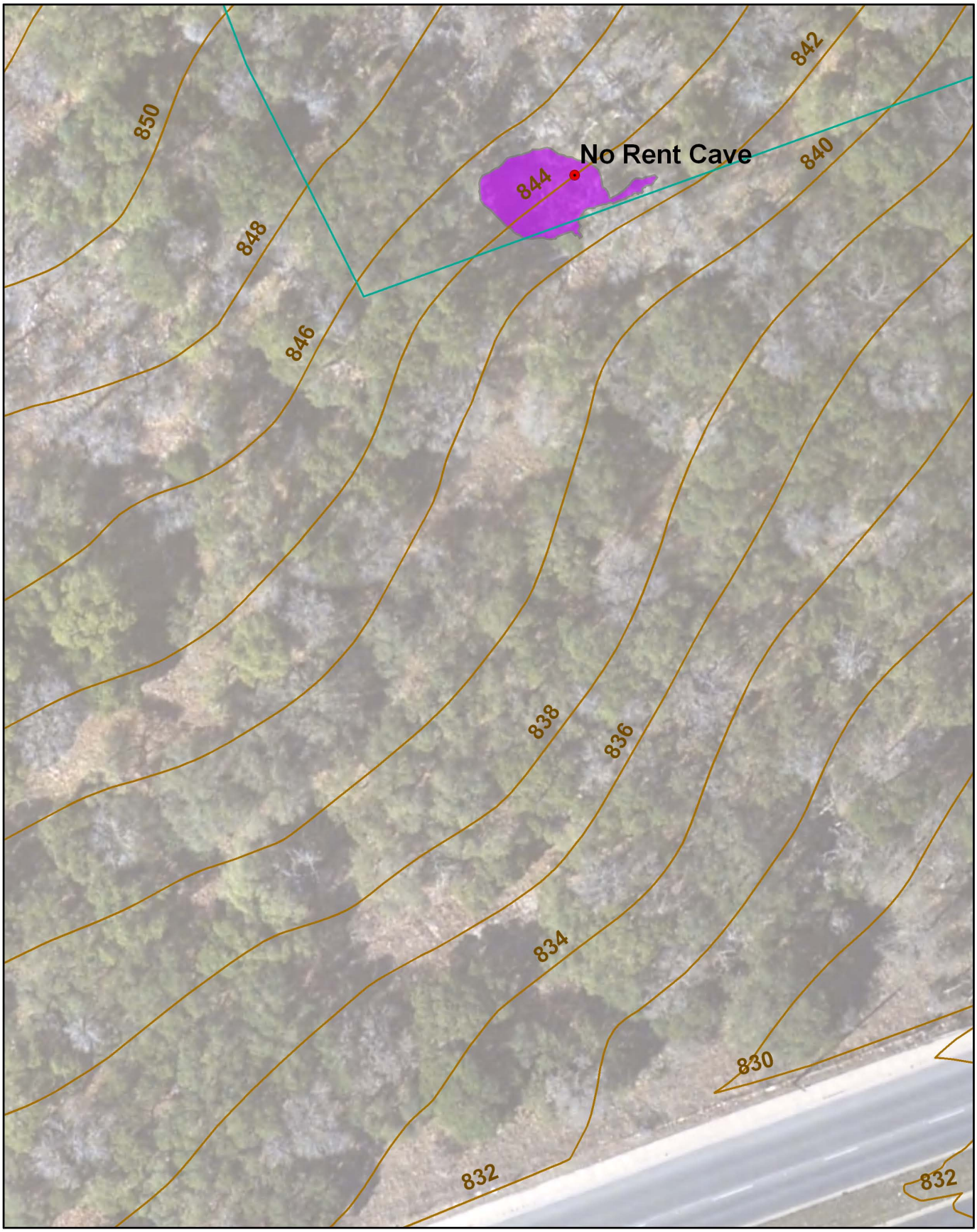


No Rent Cave

North Travis County
Mapped Nov. 4, 2010
Nico Hauwert and Mark Sanders
City of Austin


NO RENT CAVE
TRAVIS COUNTY, TEXAS
CONTINUES TOO LOW
ENTRANCE
N
SUUNTOS & TAPE SURVEY
6/21/90 - PERSONNEL:
JAMES REDDELL
MARCELINO REYES
MIKE WARTON
LENGTH: 60'
DEPTH: 13'6"
PLAN
10' TO NEXT SURFACE SINK.
TOO LOW
0 5 10 15 20
SCALE
ENTRANCE
0
5
10
13'6"
15
SCALE
BASAL UNIT EDWARDS LIMESTONE
PROFILE
VIEWED FROM SOUTHWEST TO NORTHEAST
T.S.S. 1990

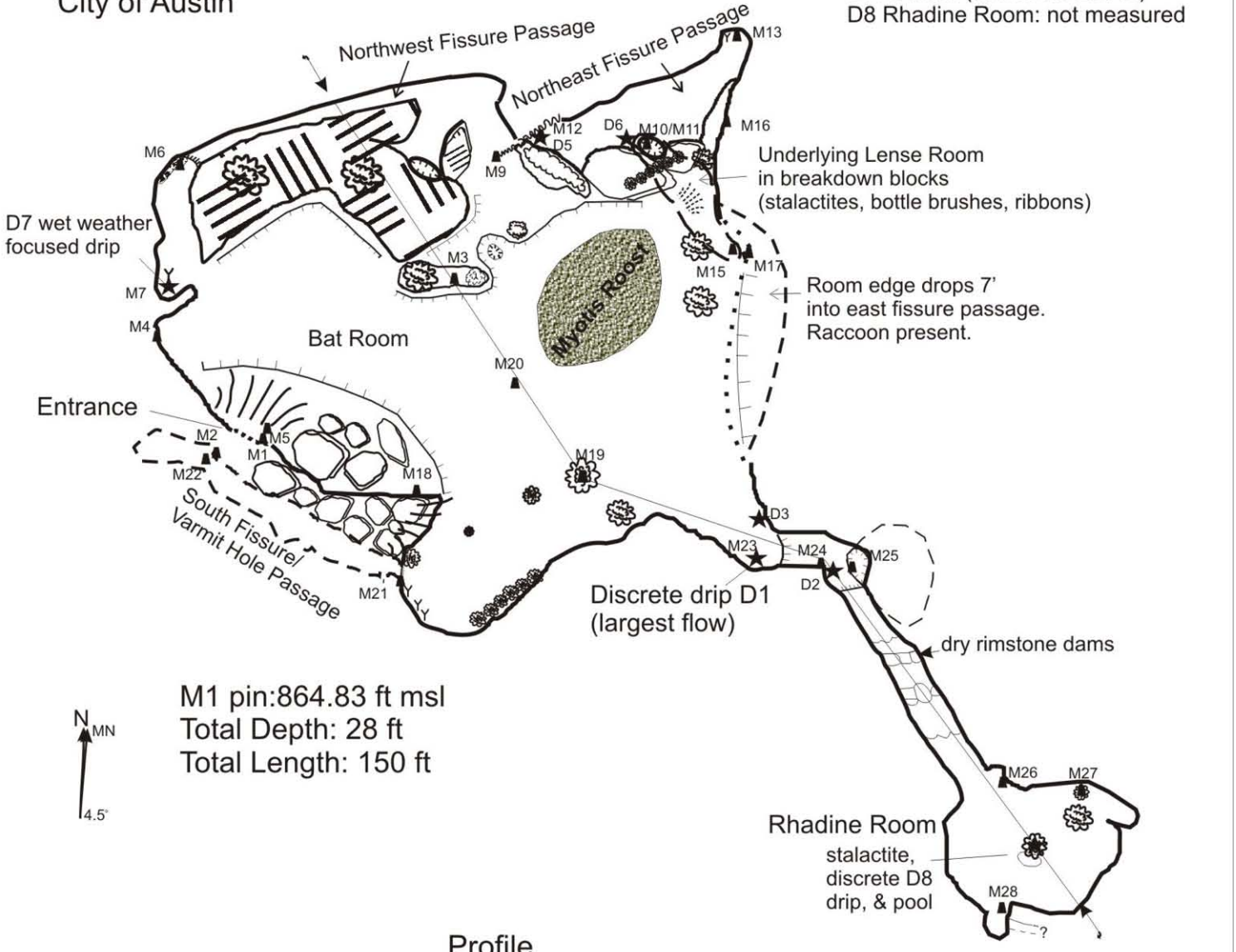
No Rent Cave Subsurface Extent



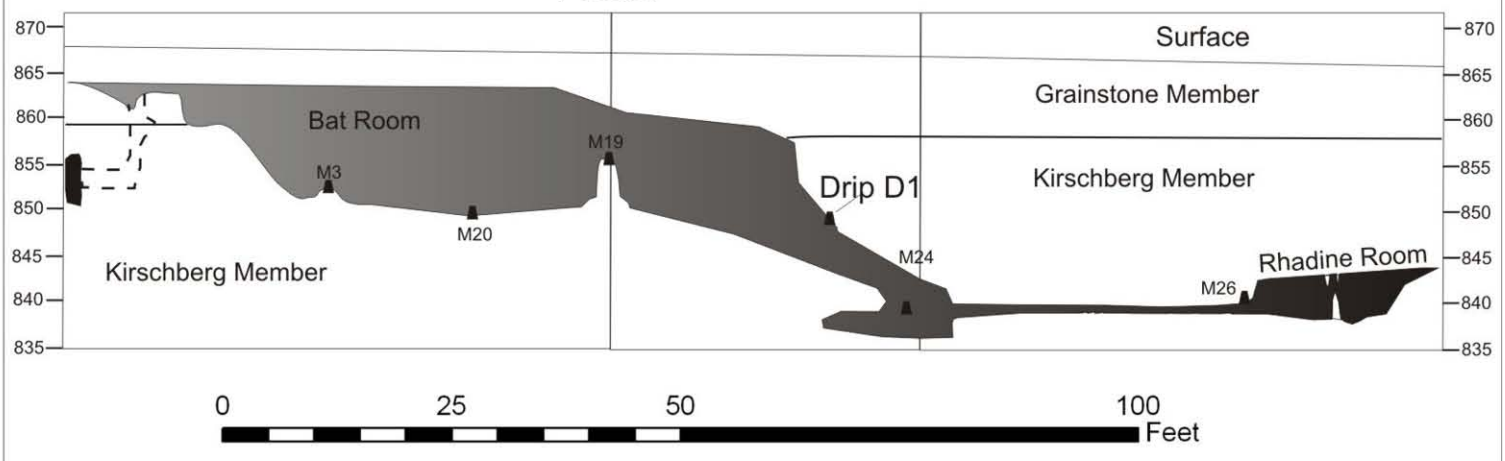
McNeil Bat Cave

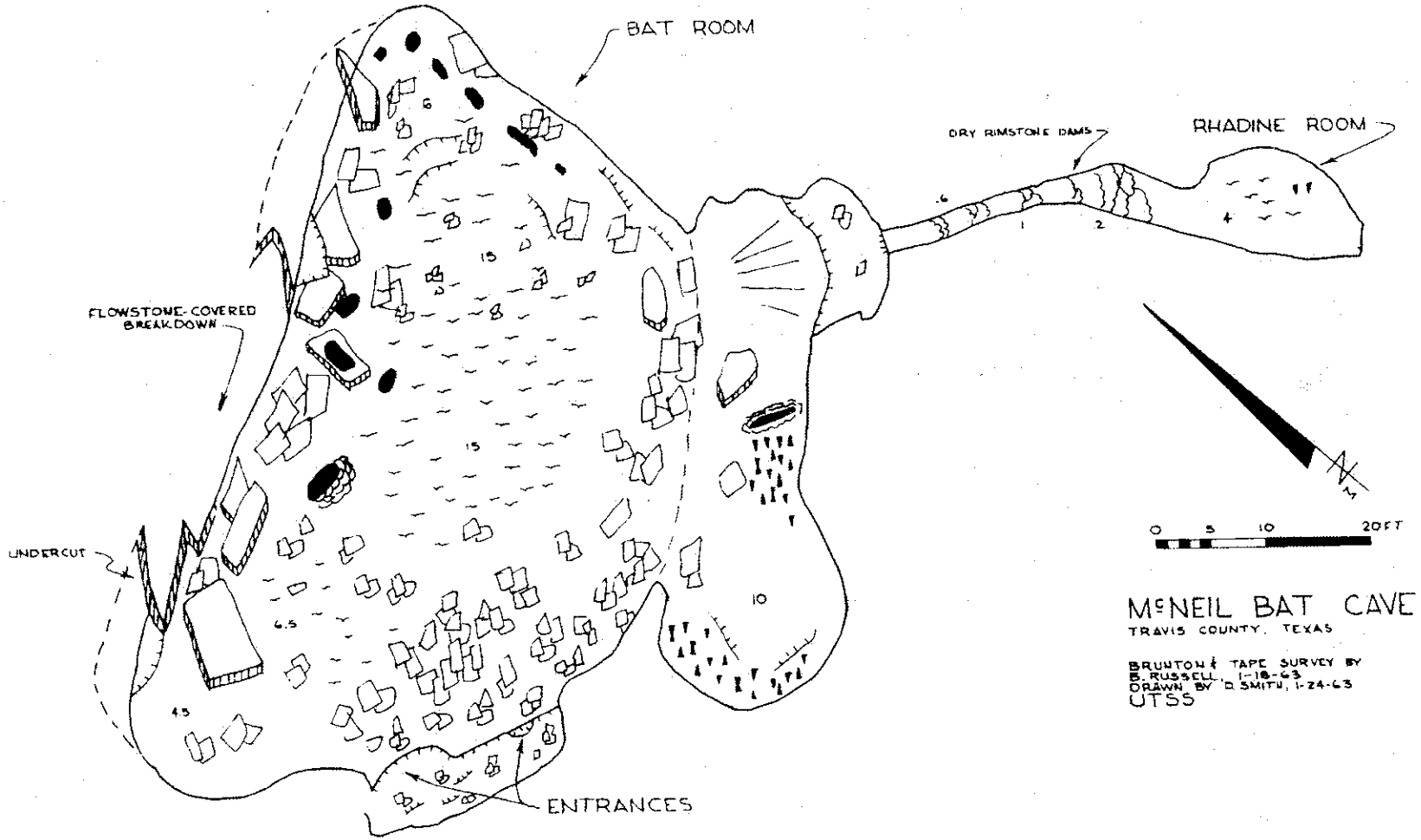
North Travis County
Mapped Nov. 12, 2010
Nico Hauwert, Justin Camp, and Mark Sanders
City of Austin

Drip Rates
D1: 750 ml/hr
D2: 58 ml/hr
D3: 0 ml/hr
D5: 0.6 ml/hr
D6: 0 ml/hr
D7: 0 ml/hr (flowed on 2/9/10)
D8 Rhadine Room: not measured

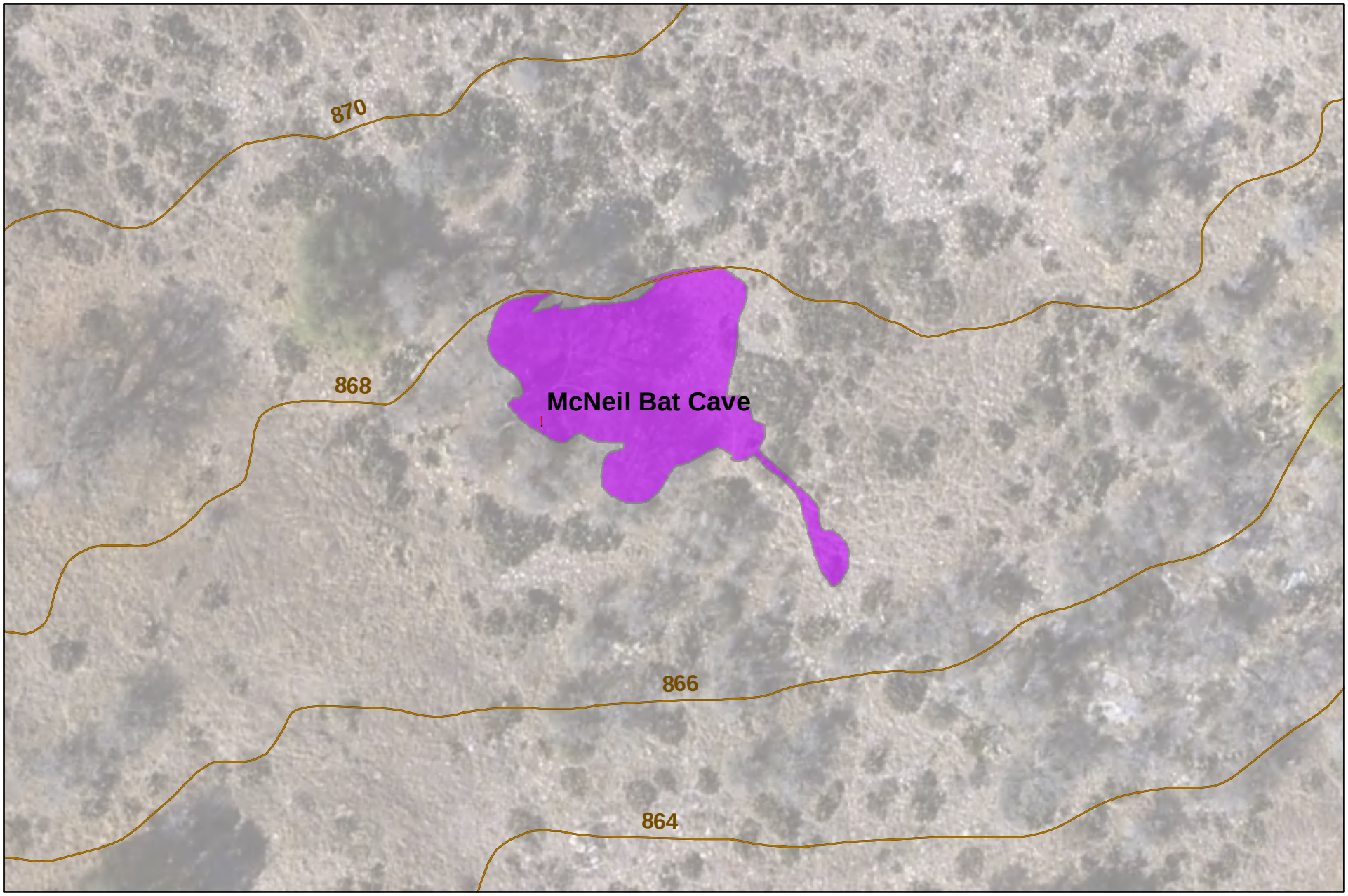


Profile




BAT ROOM
DRY RIMSTONE DAMS
RHADINE ROOM
FLOWSTONE-COVERED BREAKDOWN
UNDERCUT
ENTRANCES
6
15
15
6.5
10
4.5
.6
1
2
4
0 5 10 20 FT
McNEIL BAT CAVE
TRAVIS COUNTY, TEXAS
BRUNTON & TAPE SURVEY BY B. RUSSELL, 1-18-63
DRAWN BY D. SMITH, 1-24-63
UTSS

McNeil Bat Cave Subsurface Extent



0 50 100 Feet

3

Appendix B.

Photographs





Water droplets and a solitary bat cling to the ceiling of the main room. In this case, the widely distributed nature of drips and short-duration of drip after rain events in the cave suggest the source is probably near the cave footprint.

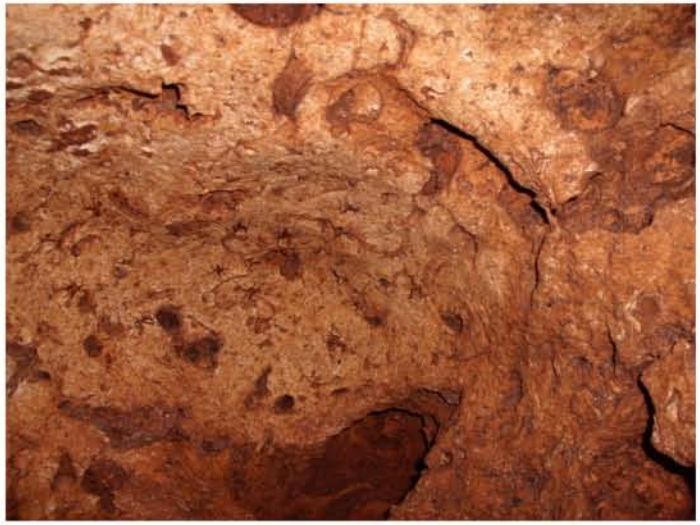


Mammal skull on the floor of the main room. Recent mammal scat was also present.



Continuation of Fossil Garden Cave south, which the cave map shows as connecting to second sinkhole entrance, but is currently blocked with rocks and debris.

Fossil Garden Cave, February 16, 2010, Sheet C



The ceiling and entrance shaft of Fossil Garden Cave has an abundance of caprinid and toucasia fossils in the massive miliolid bed, interpreted to be the lowermost Grainstone Member.



The cave extent is developed in the uppermost Kirschberg Member, similar to Weldon and McNeil Bat Cave. In the main room of Fossil Garden Cave a well developed channel in the floor appears to transport runoff from the entrance to lower drains.



Active formations carrying drips in the main room of Fossil Garden Cave. Two domes in the main room have conduits that did not carry large, persistent flows, although it is possible they are activated under some flood conditions.

Fossil Garden Cave, February 16, 2010, Sheet B





Scott Hiers and Sylvia Pope at the main entrance to Fossil Garden Cave. The sinkhole has captured significant upslope catchment and has matured from a collapsed sinkhole into a 5-acre internal drainage basin.



A second sinkhole opening into Fossil Garden Cave, largely blocked with debris.



The entrance shaft out of Fossil Garden Cave.

Fossil Garden Cave Photos, Feb. 16, 2010, Sheet A



Entrance to Weldon Cave, a collapsed sinkhole lacking discrete drainages.



Wall in Weldon Cave showing ceiling composed of miliolid foramifera (Grainstone Member) underlain by micrite bed resembling chert, burrowed pulverulite, and thicker pulverulite bed containg chrondrodonts and toucasia (underlying Kirschberg Member).





Ceiling of Weldon Cave on February 9, 2010 after rain event. Drips are diffusely distributed across most of the Grainstone Member ceiling.

Weldon Cave Sheet A



Diffuse ceiling drips were observed across Diamond Back Room on Feb. 9, 2010, that were dry on Nov 4, 2010.



This 3-inch tall horizontal conduit in the drip horizon ceiling suggests possible discrete flow in the past, although there is no sign of flow from it on this date.



A lower passage below Diamond Back Room appeared completely dry on Feb. 9, 2010.



This stalagmite underlies the conduit (pictured above) and dome, suggesting that discrete flow dripped to it in the past, although the formation no longer appears to be actively growing.

Weldon Cave Photos Sheet B



Discrete drip at the end of Diamond Back Hall and entrance to wet ceil crawl passage on Nov. 4, 2010.



Column observed beyond wet ceiling crawl toward squeeze to Popcorn City Drip Room. Note the healed break, suggesting shifting of the floor in the past.



Abundant popcorn formations covering pulverulite beds in the lower Popcorn City Drip room. The popcorn deposits result from seepage between dolomite crystals of calcite-saturated groundwater.



Drips measured in the north ceiling of the Popcorn City Drip Room on Nov. 4, 2010.

Weldon Cave Photos Sheet C, Nov. 4, 2010



No Rent Cave entrance is a shaft. McNeil Road is visible in the background.



Diffuse drips in the ceiling of No Rent Cave, which is entirely developed within the Kirschberg Member.



Drips in the ceiling of No Rent Cave on Feb. 9, 2010.



Unexplorered vertical drain in the floor of No Rent Cave.

No Rent Cave Photos Feb. 9, 2010



Entrance to McNeil Bat Cave, a classic collapsed sinkhole entrance with no discrete drainage channels.



Well defined drainage about 200 ft from the entrance. Although not draining to the cave entrance, this drainage could potentially focus infiltration within the subsurface catchment area.



Massive column inside McNeil Bat Cave.





Views of large columns supporting ceiling within McNeil Bat Cave. The columns may be evidence of discrete drips in the past but did not appear active on February 9, 2010 and other visits. The ceiling is the drip horizon for the cave and is composed of the competent Grainstone Member.

McNeil Bat Cave Photos Feb. 9, 2010 Sheet A





The sequence of hard, massive, cross bedded miliolid foramifera grainstone, underlying chert bed, and white massive pulverulitic bed is identical to the contact of the Grainstone Member and underlying Kirschberg Member mapped in the Barton Springs Segment..







Rimstone dams and other active formations suggest possible discrete drip in the northwest fissure passage, although the flow was not sufficiently discrete to quantify on Feb. 9, 2010. The subsurface catchment area may extent considerably beyond the cave footprint in the upslope topogrographic area to the north.

McNeil Bat Cave Photos Feb. 9, 2010, Sheet B









D1, D2, and D3 drips in descending passage southeast of Bat Room toward Rhadine Room. The unusual light tone of the drips distinguish it from older orange-toned drips, perhaps suggesting a different water source. Photos by Mark Sanders, CoA BCP Div.

McNeil Bat Cave Photos Sheet C, Nov. 12, 2010









Active drips, inactive stalagtites, and rimstone pools of the lowermost Rhadine Room. Photos by Mark Sanders, CoA BCP Div.

McNeil Bat Cave Photos Sheet D, Nov. 12, 2010

Austin White Lime – South Quarry – North Wall



Georgetown Formation: nodular, lt yellow limestone with marcasite stains, ammonites, graphae, and kingena waconesis.

Regional Dense Mbr Edwards Fm- 15.5 ft thick

Grainstone Member of Edwards Limestone: 20+ ft-thick miliolid grainstone with toucasia



In this portion of the Northern Segment, the Regional Dense Member (RDM) of the EdwardsLimestone directly underlies the Georgetown Formation. Groundwater seeps along the top of the RDM, demonstrating its ability to locally perch groundwater. In this quarry the RDM is a light tan mudstone with orange burrow wisps. The top of a 3.5 ft thick toucasia wackestone bed is positioned in center of the RDM.

Photos and interpretation by Scott Hiers

McNeil North Quarry. Exposure of Grainstone and Kirschberg Members in McNeil North Quarry. It is interpreted to be the same contact visible in Fossil Garden, Weldon, and McNeil Bat Caves.





Closeup of red, oxidized horizon about 5 ft above the base of the Grainstone Member (black chert bed)



Photos and interpretation by Nico Hauwert



Black chert horizon marking contact between Grainstone and underlying Kirschberg Member

Appendix C.

Downhole Geophysical Logs

GEO CAM

Water Well Logging & Video Recording Services

Geo Cam, Inc. 126 Palo Duro, San Antonio, TX 210-495-9121

Borehole: McNEIL HS CORE A

Logs: GAMMA, RESISITIVITY, CALIPER, SPR

Project: McNEIL HS CORE A
Client: HOLT ENGINEERING
Location: N30° 27' 03.9" W97° 44' 03.2"

Date: 08-20-10
County: TRAVIS
State: TX

BOREHOLE DATA

Drilling Contractor: HOLT
Elevation: 897' GPS
Depth Ref: G.L.

Driller T.D. (ft) : 230'
Logger T.D. (ft) : 230'
Date Drilled: 08-20-10

BIT RECORD				CASING RECORD		
RUN	BIT SIZE (in)	FROM (ft)	TO (ft)	SIZE/WGT/THK	FROM (ft)	TO (ft)
1	3"	0	TD	NA		
2						
3						

Drill Method: CORING
Hole Medium:
Viscosity:

Weight:
Mud Type:
Rm: at: Deg C

Fluid Level (ft) : 65'
Time Since Circ:

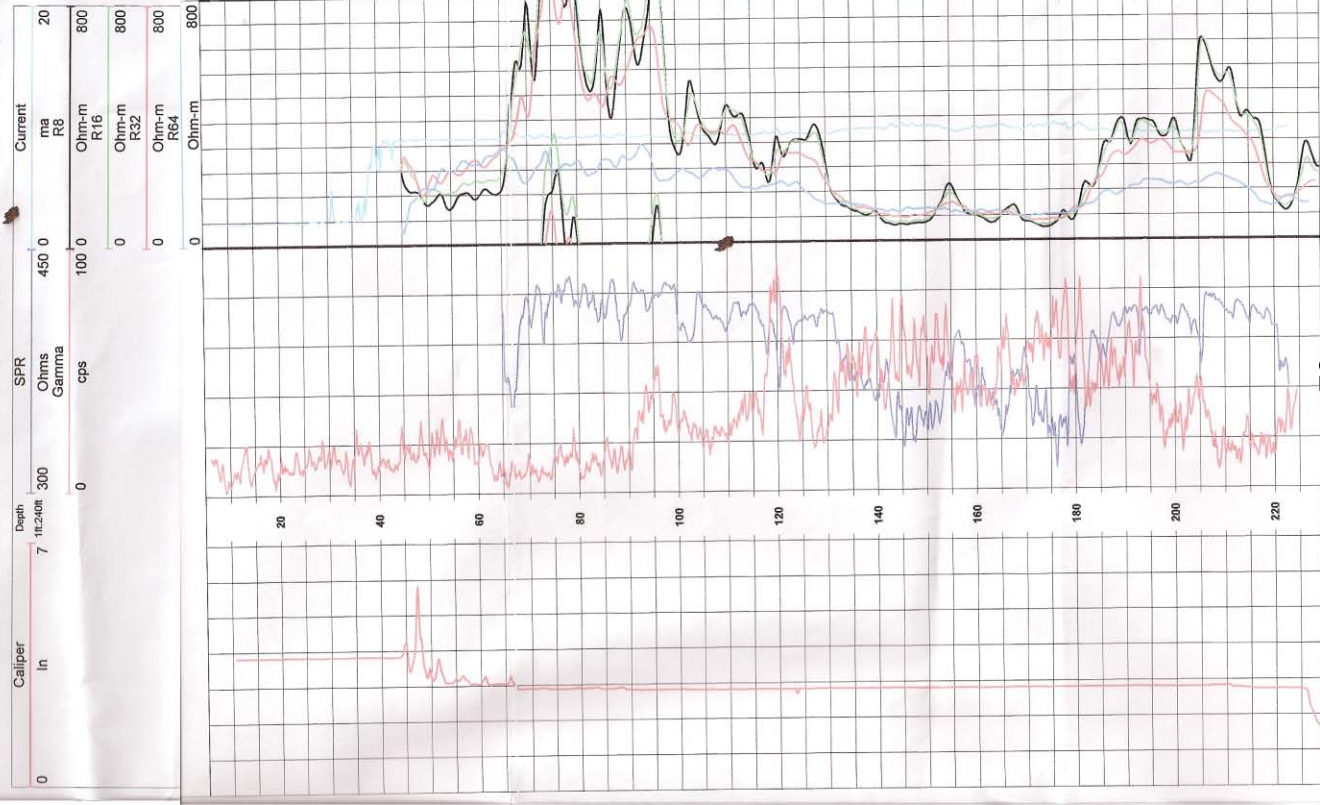
GENERAL DATA

Logged by: Robert C. Becknal
Witness:

Unit/Truck: 03

LOG TYPE	RUN NO	SPEED (ft/min)	FROM (ft)	TO (ft)	FT./ IN.
GAMMA	2	22			20
RESISITIVITY, SPR	2	22			20
CALIPER	2	22			20

Comments:



GEO CAM

Water Well Logging & Video Recording Services

Geo Cam, Inc. 126 Palo Duro, San Antonio, TX 210-495-9121

Borehole: McNEIL HS BORE B

Logs: GAMMA, RESISITIVITY, CALIPER, SPR

Project: McNEIL HS BORE B
Client: HOLT ENGINEERING
Location: N30° 26' 48.5" W97° 44' 08.2"

Date: 08-20-10
County: TRAVIS
State: TX

BOREHOLE DATA

Drilling Contractor: BEE CAVE
Elevation: 897' GPS
Depth Ref: G.L.

Driller T.D. (ft) : 230'
Logger T.D. (ft) : 227'
Date Drilled: 08-20-10

BIT RECORD				CASING RECORD		
RUN	BIT SIZE (in)	FROM (ft)	TO (ft)	SIZE/WGT/THK	FROM (ft)	TO (ft)
1	3"	0	TD	NA		
2						
3						

Drill Method: CORING
Hole Medium:
Viscosity:

Weight:
Mud Type:
Rm: at:

Fluid Level (ft) :
Time Since Circ:
Deg C

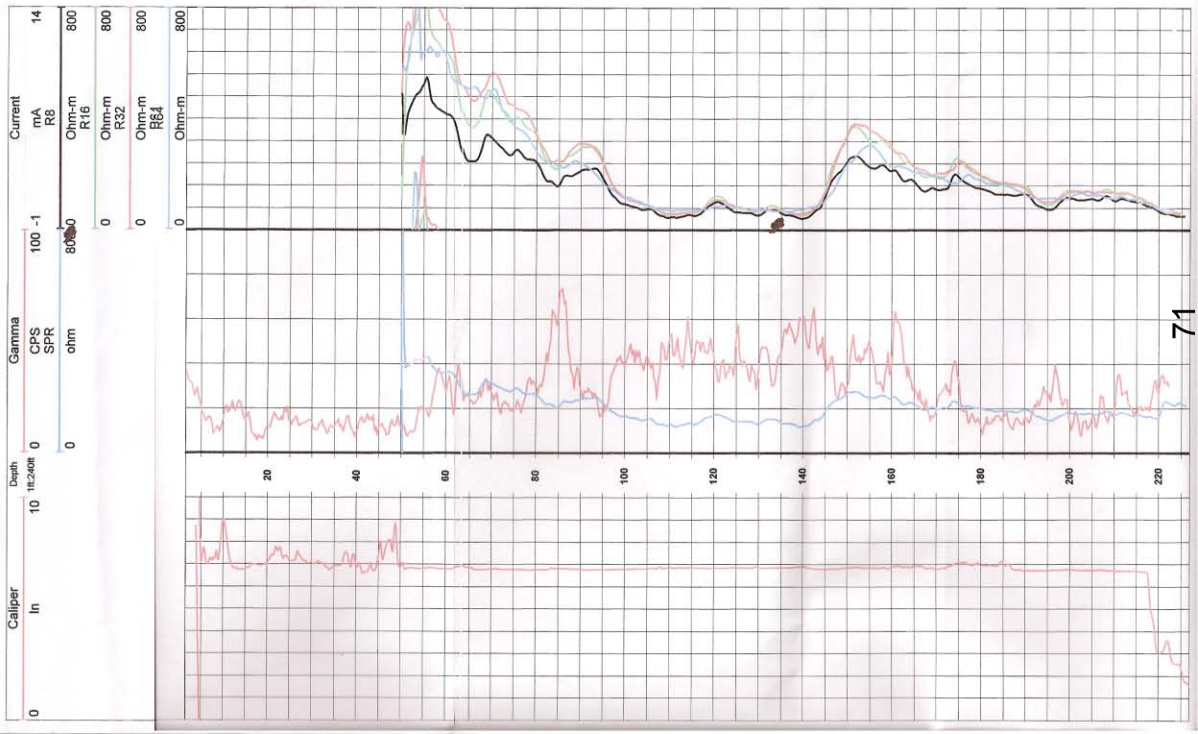
GENERAL DATA

Logged by: Robert C. Becknal
Witness:

Unit/Truck: 03

LOG TYPE	RUN NO	SPEED (ft/min)	FROM (ft)	TO (ft)	FT./ IN.
GAMMA	2	22			20
RESISITIVITY, SPR	2	22			20
CALIPER	2	22			20

Comments:



GEO CAM

Water Well Logging & Video Recording Services

Geo Cam, Inc. 126 Palo Duro, San Antonio, TX 210-495-9121

Borehole: McNEIL HS BORE C

Logs: GAMMA, RESISITIVITY, CALIPER, SPR

Project: McNEIL HS BORE C
Client: HOLT ENGINEERING
Location: N30° 26' 52.8" W97° 43' 47.4"

Date: 08-20-10
County: TRAVIS
State: TX

BOREHOLE DATA

Drilling Contractor: BEE CAVE
Elevation: 897' GPS
Depth Ref: G.L.

Driller T.D. (ft) : 230'
Logger T.D. (ft) : 227'
Date Drilled: 08-18-10

	BIT RECORD			CASING RECORD		
RUN	BIT SIZE (in)	FROM (ft)	TO (ft)	SIZE/WGT/THK	FROM (ft)	TO (ft)
1	6"	0	TD	NA		
2						
3						

Drill Method: AIR ROTARY
Hole Medium:
Viscosity:

Weight:
Mud Type:
Rm: at:

Fluid Level (ft) : 42'
Time Since Circ:
Deg C

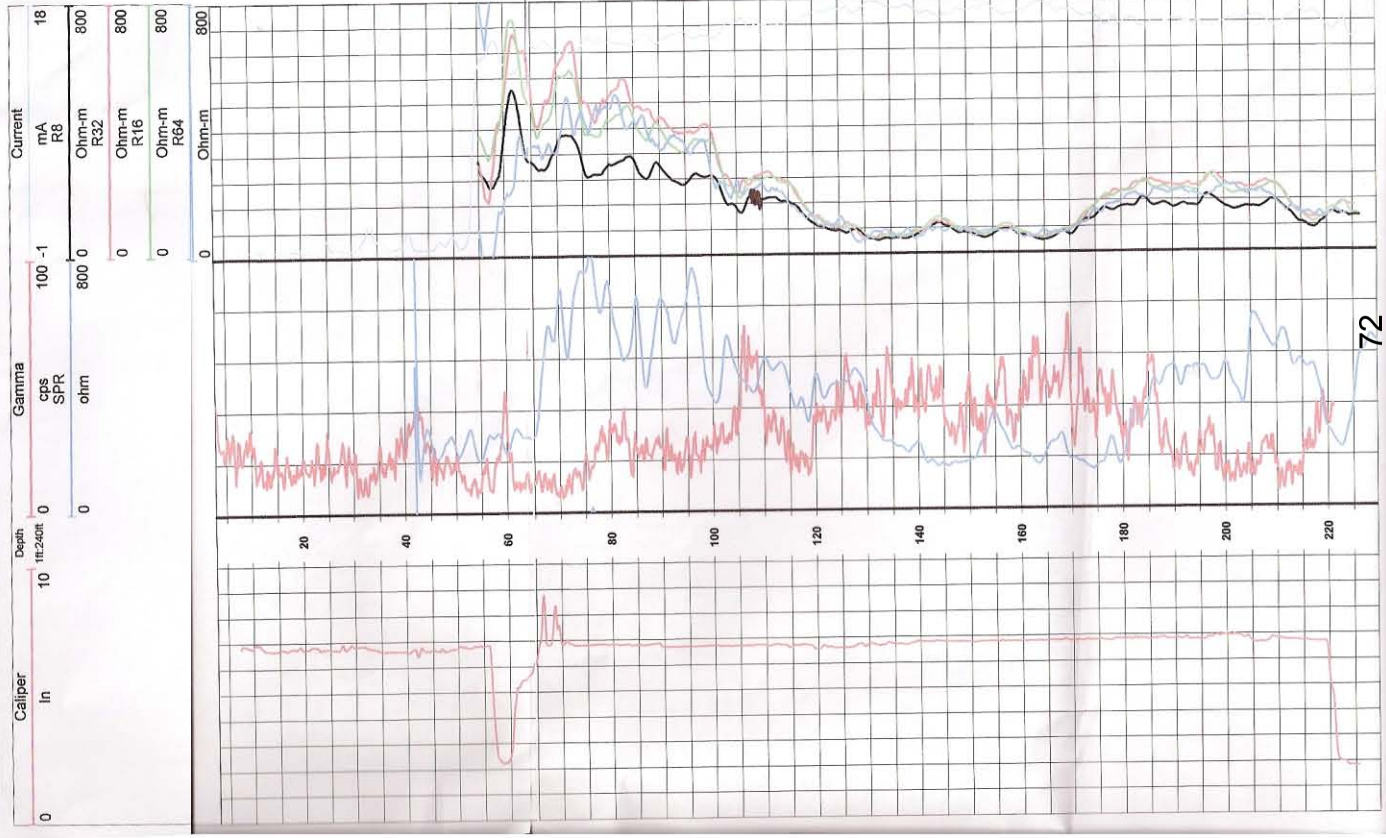
GENERAL DATA

Logged by: Robert C. Becknal
Witness:

Unit/Truck: 03

LOG TYPE	RUN NO	SPEED (ft/min)	FROM (ft)	TO (ft)	FT./ IN.
GAMMA	2	22	221	3	20
RESISITIVITY, SPR	2	22	226	8	20
CALIPER	2	22	42	229	20

Comments:



Appendix D.

Core Descriptions

Core A Description

Location: Robinson Ranch Behind McNeil H.S.
Drilled 8/13/10-8/19/10
Geologists: Nico Hauwert/Sylvia Pope/Scott Hiers
Geological Assistant: Justin Camp

Depth

0-1.5 ft: soil, bedrock interface. Miliolid grainstone. Calcite & terra rosa infill of voids. Calcite cemented matrix, turritella, crystalline yellow areas, possible dissolved caprinids. Yellowish mottled color texture in places. Munsell color description: v. light gray N8.

1.5'-3.2 ft: Miliolid grainstone, crystalline calcite rhombohedral infill of voids, large orange specs and reddish dissolved fossil molds. 3.0' possible turitella. Munsell color: v. light gray N8, light brown 5yr 5/6 infill & in voids.

3.2-3.5 ft: Possible burrows with mottled wavy texture.

3.5-5 ft: White miliolid grainstone. 20% water loss. Munsell color: yellowish gray 5Y 8/1 (yellowish gray).

5.0-6.3 ft: Burrowed fill, yellow milliloid grainstone matrix. Munsell color: yellowish gray 5Y 8/1.

6.3-12.5 ft. Miliolid grainstone and crystalline calcite sparite, some light yellow transluscent. Oncolite structures in clay and calcite-filled fractures, burrows, and voids. Munsell color: 5'-7': 5y 81; 8': light brown 5Y 7/2 in voids; 8'-9': v. light gray N8, Some white (White N9), crystal and v. light gray N8 infill; 10'-12.5': v. light gray N8, 5% yellowish gray 5Y 8/1.

12.5-20 ft: lt brown to light gray, friable pulverulite (sparite) with cladophyllia, capinid (13'), possible chondrodonts, and very small unidentified fossils (possible gastropods). Laminar striated structures – possible algal mats. Calcite cemented dolomite crystals with silty sugary texture. Sand filled worm burrow in white micrite. Munsell color v. light gray N8, 5% yellowish gray 5Y 8/1; 13.5'-20': yellowish gray 5Y 8/1

20-21.2 ft: light brown to tan crystalline pulverulite with caprinids. Munsell color: 20' yellowish gray 5Y 7/2.

21.2-25.0 ft. Tan to white miliolid grainstone. Many pores filled with lt greenish transluscent mineral (calcite?). Caprinids. 20 mm voids possible caprinid molds or burrows. 100% water loss at 24 ft.

25-30 ft: Tan sandy miliolid grainstone with possible chrondrodonts. Aragonite needles. No rock recovery 25.2-30 ft. ZARA downhole camera revealed three voids about 0.4 ft in width, "washout" horizons, vuggy mesocavern, and 1mm "popcorn" in voids. 0.8 ft Red terra rosa clay/ minerals from void fill. Munsell color: 25': yellowish gray 5Y 8/1; 29': yellowish gray 5Y 7/2 (clay)

30-34.0 ft: Lt brown sandy, vuggy, miliolid grainstone. Crumbly, gritty texture resembling pulverulite Red clay and lt green calcite/aragonite void fill. Burrows w/ calcite fill. Laminar structures. Dedolomitized. Munsell color: 30'-31': yellowish gray 5Y 8/1; 34': v. light gray N8

35-40 ft: (1.8/5ft recovered) Red terra rosa and gray, sandy clay. Lt gray milliliod grainstone, highly fossiliferous with turritella, possible chondrodont, cladophyllia. Dark gray specks. Ca dissolution around miliolids, creating moldic porosity. Munsell color: 35'-40: yellowish gray 5Y 7/2, some light brown 5Y 7/2 (clay)

40-45 ft: Miliolid grainstone, fossiliferous, cladophyllia tubes, caprinids, calcite replacement. Moldic porosity from calcite dissolution of milliliods, cladophyllia, and caprinids. Gray & tan billow structures resembling burrows. Munsell color: 40'-42': slightly darker than yellowish gray 5Y 7/2; some v. light gray N8 at 41'; 43'-45: yellowish gray 5Y 8/1

45-46.2 ft: Lt tan gray possibly crystalline dolomitic fossilferous. Cladophyllia and capinids. 45.8' yellow-spotted horizon. 46.2 light greenish gray specks. Munsell color: yellowish gray 5Y 7/2

46.2-55 ft: sandy, miliolid packstone with crystalline matrix. Cladophyllia pores, calcite crystals, abundant caprinids. High moldic porosity at bottom of core. Bedding plane void observed at 47.8 ft in downhole camera. Munsell color: 45'-50': yellowish gray 5Y 7/2; 51': no recovery; 52'-53': v. light gray N8; 54-55': yellowish gray 5Y 7/2**.**

55-60ft: Red clay smeared over porous micrite. Caprinid molds and casts. Chondrodonts. 0.2 ft calcite crystals. Munsell chart: light olive brown 5Y 5/6; 56'-60': yellowish gray 5Y 8/1

60-65ft: Friable micrite. Extensive calcite replacement. Sparry calcite. Miliolids, black specks, sugary texture. Water encountered during drilling at 60 ft.

65-66.5 ft: soft unconsolidated material, either clay or pulverulite. Static water level: 65.5 on 8/19/10.

66.5–69.2 ft: pulverulitic crystalline dolomite. Munsell color: yellowish gray 5Y 7/2, same infill.

69.8-70 ft: lt brown, dolomitized, caprinid packestone.

70-75 ft: Tan caprinid/toucasia/monopleura packstone with small fragments of smooth micrite. Lighter tone than <70'. Fossil molds open or calcite filled. Munsell color: 71'-72: yellowish gray 5Y 8/1; 73'-74': yellowish gray 5Y 7/2.

75-80 ft: yellow/light brown/gray mottled, burrowed wackestone, matrix replaced w/ dolomite, few possible turritella and caprinid. 77 ft lt yellow sugary crystalline layer. Munsel color: 75'-78': light gray N7; 79': yellowish gray 5Y 7/2. No reaction to 10% H_2SO_4.

80-85ft: yellow/light brown, gray burrowed dolomite. Some burrows calcite filled. Matrix dolomite replaced. Munsell color: 80'-81': yellowish gray 5Y 8/1; 82'-85':50% yellowish gray 5Y 7/2; 50% yellowish gray 5Y 8/1.

85-91.8 ft: light brown, light yellow, burrowed wackestone with dolomite matrix. Few caprinids, and calcite geodes. Brown dolomitized caprinid wackestone/packstone, with possible cladophyllia tubes, and possible burrows at 87.5-88.6ft. Munsell color: 85'-87': 70% yellowish gray 5Y 8/1; 30% yellowish gray 5Y 7/2; 88': yellowish gray 5Y 7/2; 89': light gray N7; 90'-91': light gray N7;

91.8-92.0 ft: megacalcite fill of bedding plane void.

92-95 ft: light yellow/brown, burrowed, granular grainstone, some tubular fossils resembling cladophyllia. Unidentified beaked clams superficially resembling kingena waconesis. Possible gastropod at 93 ft. Yellowish/orange weathered stylolitized beds or burrows at 95 ft. Hardground interval? Munsell color: 92'-95': yellowish gray 5Y 8/1

95-99.6 ft: light tan yellow/orange mottled, oxidized sandy matrix and light gray granular, gritty, wackestone. Calcite filled geodes. Unidentified clam/brachiopod shell fragment, possibly neithea. Munsell color: 95'-99': slightly darker than yellowish gray 5Y 8/1.

99.6-102.6 ft: Return of brown-colored crystalline dolomite, fossilferous packestone and toucasia packstone. Small turritella gastropods. Munsell color: 102.5': yellowish gray 5Y 7/2. No reaction to 10% H_2SO_4.

102.6-110ft: Siltstone/mudstone wackestone, light gray chalky calcite geode. 104' small unidentified clam. Orange burrows and billowy orange wisps. Munsell color: 103'-105': yellowish gray 5Y 8/1. Some iron stained infill (light brown 5Y 7/2).

110-115ft: Crème clayey mudstone/wackestone. Abundant black micro fossil fragments (< 2mm). Calcite seams, stylolites, organic seams w/ fibrous thickness, burrowed. Coated grains. Flat shell resembling chondrodonts. 113-114' bioturbated with filled burrows. Munsell color:110'-115': slightly lighter than yellowish gray 5Y 8/1. Reacts to 10% H_2SO_4.

115-120ft: microfossils, organic seams, calcite, slightly sandy. Munsell color: 116': yellowish gray 5Y 8/1; 117'-120': v. light gray N8. Reacts to 10% H_2SO_4.

120-128ft: Dark gray crumbly mudstone/wackestone and orange granular packstone. Large worm burrows, with sandy, microfossil burrow fill. Flat shell resembling

chondrodonts. Black organic seams. Microfossils, possibly turritella. Light gray clasts. calcite crystals. Munsell color: slightly darker than v. light gray N8. Reacts to 10% H_2SO_4.

128-135ft: Light gray, fissile micrite. Dark gray shaly wisps, organic seams, calcite infill, and/or thin shells resembling chondrodonts. Toucasia mold. Unidentified clams. Turritella. Stylolites. Calcite geode. Bioturbated. Hydrocarbon odor. Augen structures or interclasts. Color lighter tone than higher, and not as grainy. Munsell color: 125.5'-127' V. light gray N8; 128'-130' V. light gray N8 with dark gray N3 infill; 130'-135' v. lt. gray N8, medium dark gray N4, and dark gray N3 infill;135'-140' v. lt. gray N8, some dark gray N3 infill. Reacts to 10% H_2SO_4.

135-140ft: Light gray, fissile micrite. Stratified marl layers. Fiberous dark seam. Chondrodont mold. Marly. Large intraclasts. Sandy material. Munsell color: 135'-140': v. lt. gray N8, some dark gray N3 infill. Reacts to 10% H_2SO_4.

140-145ft: Light gray micrite. Possible chondrodont. Gastropod mold. Marly. Bioturbated. Red oxidized grains, gastropod molds, marl seams, hydrocarbon odor. Dry calcite seams. Clasts. Munsell color: some lt gray N7, predominantly v. light gray N8. Reacts to 10% H_2SO_4.

145-150ft: Dark gray, fossiliferous bioturbated wackestone-packstone with very friable mud matrix. No voids, shaly, biomicrite, alternating bioturbated layers of marl. Soft. Light gray intraclast of micrite at 148.5 ft. Texagryphaea mucronata molds. Munsell color: 146.5'-147': med. light gray N6; 148'-150': light gray N7. Reacts to 10% H_2SO_4.

150-155ft: Light gray wackestone/packstone and biomicrite. Exogyra or mucronata molds, abundant unidentified clams, ooids. Very friable clay-rich limestone. Light gray biomicrite intraclasts. Turritella mold. Dark calcite filled burrow. Black soft seam. Munsell color: 150'-153': mix of v. light gray N8 & med. gray N5 with med. dark gray N4 infill at 153'**.** Reacts to 10% H_2SO_4.

155-169.8ft: Light gray, fossiliferous, bioturbated wackestone-biomicrite. Very friable clay-rich limestone. Dark gray ooids or forams. Possible molds of echinoid, exogyra, pelecepods, and ceratostream texanum. Small unidentified clams. Burrows. Laminations. Few coal particles and seams. Wispy augen structures. Calcite replacement of fossils. A few burrows, soft and crumbly in shale seams. Partial calcite-filled geode. Munsell color: 155-160' v. light gray N8 with med. light gray N6 infill; 160'-165' v. light gray N8 with med. gray N5 & dark gray N3 infill; 166'-170' v. light gray N8 with med. light gray N6 & dark gray N3 infill. Reacts to 10% H_2SO_4.

169.8-178ft: Gray, clay-rich, friable, bioturbated wackestone-packstone. Fissile and laminated. Exogyra and pelecepod molds. Dark gray well preserved mucronata in 3" shale layer. Possible ceratostream texanum at 173'. Burrows. Munsell color: 170'-174' med. light gray N6; 175' med. dark gray N4; 177' dark gray N3. Reacts to 10% H_2SO_4.

178-185ft: Gray granular (silt-sized), fissile biomicrite. Gray intraclasts. Burrows, fossil molds. 182' – dark gray, pyrite. Few stylolites. Pelecypod & exogyra molds. Eye-shaped shell cross section at 183'. Pillowy balloon-shaped soft sediment structures. Munsell color: 178'-182': med. light gray N6; 184' v. light gray N8. Reacts to 10% H_2SO_4.

185-190ft: Gray laminated poorly sorted grainstone-packstone. Dark ooids or foraminifera. Shell fragment likely ceratostreum texanum. Wispy dark bedding possible burrow structures. 188' Large calcite-filled burrow. Stylolites. Glauconite. Light gray wackestone, bioturbated-infill from upper strata at 189'. Munsell color: 185'light gray N7. Reacts to 10% H_2SO_4.

190-196ft: Light gray grainstone with dark ooids or foraminifera and abundant small fossils. Calcite-filled coral-like tubes and floating dk grayish specks and shell fragments from 190-192'. Friable gray bioturbated wackestone, with infill from upper dark gray strata and crystalline seams from 192-193'. Light gray oolitic or foram packstone from 194.5 to 196'. Munsell color: v. light gray N8. Reacts to 10% H_2SO_4.

196-198 ft: Yellowish gray burrowed packstone-grainstone, dark gray infill, intraclasts. Fossils include gastropods, pelecypods, turritella molds. 196'- 5% porosity, round ooilitic or foram grains, occasional styolites. High moldic porosity from 196.5-197.5' Calcite crystals and geode infill. Munsell color: yellowish gray 5Y 8/1. Reacts to 10% H_2SO_4.

198-206 ft: Light gray fossiliferous wackestone, thinly laminated dark grains and wispy layers. Gastropod and caprinid molds. Dense shale partings. Mud matrix with unidentified grains and dark gray specks, possibly dictyoconus. Augen structures or eye-shaped shell cross section. Stylolites. 0.15-ft thick organic seam and gastropod mold at 202.5'. Possible filled burrows, shale partings, crystalline veins, geodes at 203'. Munsell color: 200'-203': v. light gray N8. Reacts to 10% H_2SO_4.

206-214ft: Light gray silty miliolid grainstone-wackestone. Molds of gastropod, caprind, and Texagraphaea. Moldic porosity about 10%. Friable and fissile, core breaks into 0.1' disks. Large clam burrow. Coated grains. Light gray wackestone, porosity 5% - sugary, crystalline veins, fossil molds, sandy at 206.5. Fractured. Geodes from 209-210'. Munsell color: 205'-210' 5y 5/2, for matrix and infill; 210'-212' yellowish gray 5Y 8/1. Reacts to 10% H_2SO_4.

214-214.4 ft: Creamy friable mudstone with dark seams and stylolites. Reacts to10% H_2SO_4.

214.4-217 ft: Gray miliolid wackestone with silty matrix and miliolid grainstone. Munsell color: med. gray N5 with dark gray N3 infill. Reacts to10% H_2SO_4.

217-220ft: massive foraminifera packstone-grainstone. No void porosity. Decrease in microfossils. Possible Dictyoconus. Bio wackestone, stylolites, shale partings, black grains. Munsell color: light gray N7. Reacts to10% H_2SO_4.

220-226ft: Light gray burrowed wackestone-micrite. Silt matrix. <5% void porosity. Laminar black organic seams, possibly plant remains. Ostracod molds. Few black grains. Stylolites. Possible Texagryphaea mold. Cream fill. Wavy laminations. Pyrite. Munsell color: yellowish gray 5Y 8/1 with dark gray N3 burrows. Reacts to10% H_2SO_4.

226-230 ft: light creamy gray wackestone with silty matrix Black seams and stylolites. Dark gray granular burrow fill. Tiny brown spots resembling dictyoconus. Munsell color: light gray N7. Reacts to10% H_2SO_4.

230ft: Total depth.

Appendix E.

Rainfall Data

2010 Rainfall

