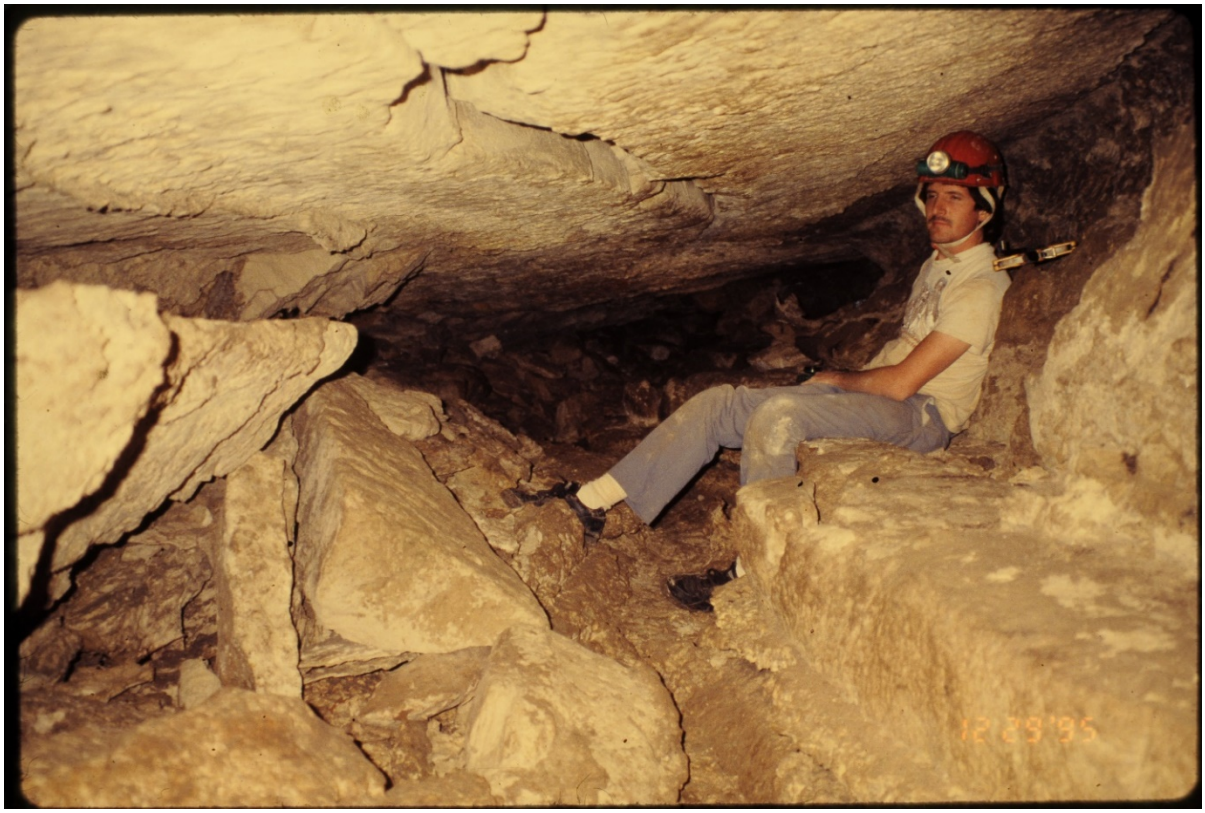
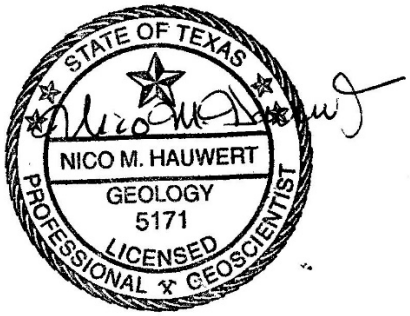
Hydrogeological Study of Airmen's Cave, Travis County, Texas

Balcones Canyonland Preserve Investigative Report IP 202103



Nico Hauwert, Ph.D. Professional Geoscientist 5171
Program Manager Austin Water Balcones Canyonland Preserve
December 16, 2021



Cover Description
BCP biologist Mark Sanders is mapping Airmen's Cave on December 29, 1995. Photo by Nico Hauwert.

Abstract
This report is a study of water sources to Airmen's Cave and evaluation of potential contamination sources that could potentially affect its environmental integrity as a cave ecosystem. Airmen's Cave was discovered in April 1971 and remains to this day by far the longest (10,800 feet) and largest volume cave (140,000 ft^3) in Travis County. Its entrance on a bluff on the south side of Barton Creek was excavated of Barton Creek flood sediment in 1971. As a cliff bluff entrance, the cave has no significant area contributing water to the entrance or surface catchment area, except under rare conditions of surface flooding on Barton Creek that has been observed on game cameras in the cave entrance. Gating of the cave and restricted access since 2012 has eliminated significant trash deposition, graffiti painting, public safety risks, and injury to cave life impacts by people. Only the Entrance/Big Room (120-185 feet into cave) and Formation Room (about 4,000 feet at farthest extent of cave) are known to have active drips to indicate overlying subsurface water sources. The primary water source for life in the cave appears to be the water table of the Barton Springs segment of the Edwards Aquifer that is estimated to be 16-23 feet beneath the floor of the first 1,000 feet of the cave passage. During periods of high water-table conditions, such as in 1992 and 2016, groundwater flows through the cave and discharges as overflow springs into Barton Creek. In 1996, the U.S. Fish and Wildlife Service issued an incidental take Balcones Canyonlands Conservation Plan (BCCP) permit to the City of Austin and Travis County that identifies Airmen's Cave as one of 62 caves required to mitigate for loss of karst habitat in western Travis County. In addition, the permit's habitat conservation plan (Balcones Canyonlands Conservation Plan) stipulates monitoring and management. Management agreements or acquisition from various owners/managers of the surface overlying the cave are required by the federal BCCP permit to ensure access for monitoring and research, in addition to management practices to protect the cave ecosystem and allows that any future discovered threats to the cave ecosystem can be corrected.

Acknowledgements
David Gimnich, Environmental Program Coordinator for Austin Water Wildland Conservation Division, reprojected a shapefile of the 1974 cave map to approximately fit the 1995/1996 cave survey points. Lisa O'Donnell, Senior Biologist for Austin Water Balcones Canyonland Preserve, provided technical review and editing of this report. Abby Gillfillan of Lionheart Places LLC provided geotechnical reports by Terracon Consultants for Brodie Oaks Mall.

Geoscientist Stamp
In accordance with the Texas Board of Professional Geologists rules at 22 Texas Administrative Code, Part 39, Chapter 851, Subchapter C, §851.156, this report is signed and sealed on the title page to assure the user that the work has been performed by or directly supervised by a professional geologist. The computer generated seal appearing on this document was authorized by Nico M. Hauwert, P.G. # 5171, on December 16, 2021.

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Hydrogeological Study of Airmen's Cave

Introduction

Airmen's Cave was a major groundwater conduit carrying recharge from an ancient tributary of Williamson Creek to an ancient Barton Springs near its current location. The current portion of Barton Creek upstream of Loop 360 used to drain to an ancient Williamson Creek and the gravel-filled channels are visible high on the bluffs of Barton Creek near the Loop 1/Mopac crossing. Likely a cave in the ancient creek bottom, hypothesized at or near Driskell Cave in Highway 290 adjacent to Tony Burger Center, began absorbing so much creek flow into the subsurface that the stream tributary became abandoned (Hauwert, 2009). Contemporary Barton Creek downstream of Loop 360 approximately follows the ancient Airmen's Cave flow path and its steep walls resemble the canyon at Hamilton's Pool, which was hypothesized to have been created from collapse and diversion of surface water into a former cave passage, converting it to a surface stream. From December 1991 to December 1992 and again from 2016 to 2017, water levels within the Barton Springs segment of the Edwards Aquifer were sufficiently high such that groundwater continually flowed through Airmen's Cave, primarily discharging from a filled conduit about 200 feet downstream of its current entrance. Smaller overflow springs also discharged further downstream near the mouth of the Barton Lodge tributary of Barton Creek.

Airmen's Cave's current entrance was a 0.5 ft by 0.2 ft fissure in a cliff along Barton Creek in March 1971 that had a strong airflow, suggesting a large cave volume. This cave is named after two Air Force pilots (airmen) who discovered the fissure. They began widening it, and within one month (by April 1) encountered the Entrance/New Room and main cave passage. The largely 4 feet high entrance passage was largely filled with silt and clay (dirt), washed into the entrance from past Barton Creek flood events. Over one ton of sediment was packed into sandbags (Loder, 2004) and dragged out of the passage on a carpet by the two pilots (Russell, 1975). Mike Bradley of Underground Texas Grotto (UT Grotto), a local cave affiliation of the National Speleological Society, spoke with the two airmen during their excavation and informed Wes and Linda Loder, Tracy Blashill, and Bill Russell, who examined and initially commenced mapping the cave.

Within three years the UT Grotto explored and mapped 10,800 feet of cave passage, roughly two miles, making it the longest known cave in Travis County to this day. The major components of the cave, and corresponding horizontal distance through the cave (based on 1995/1996 survey), include the entrance squeeze, a Entrance/New Room (120 ft), One Legged Man Passage (550 ft), Bypass Squeeze (585 Ft), Breakdown Room (827 ft), Aggie Art Gallery (853 feet), 3 Way Passage and William's Maze (866 feet), Crucifixion Rock (1,226 ft), Fault Room (1,342 ft), Walking Passage (1,445 ft), Karen Crawl (1,801 ft), Sherwood Forest (2,614 ft), Poetry Passage (projected to be about 3,200 feet along Airmen's Cave passage from the entrance), the side-passage terminal Empty Room (projected to be about 3,300 ft), and the farthest end at the Formation Room (projected to be about 4,000 ft). The vast majority of Airmen's Cave consists of crawls and squeezes, with the 250-feet long Walking Passage being the exception. As with any cave, the known extent is limited by the amount of effort exerted (Reddell and Russell, 1991). However, despite considerable effort, Airmen's Cave has not been significantly extended since 1974. Part of the challenge is the time and effort to reach most parts of the cave. Airmen's Cave volume was calculated by Bill Russell to be 400,000 ft^3 (Elliott, 1997).

Figure 1. Linda Loder at Airmen's Cave Entrance, early April 1971 (photo credit: Wes Loder).

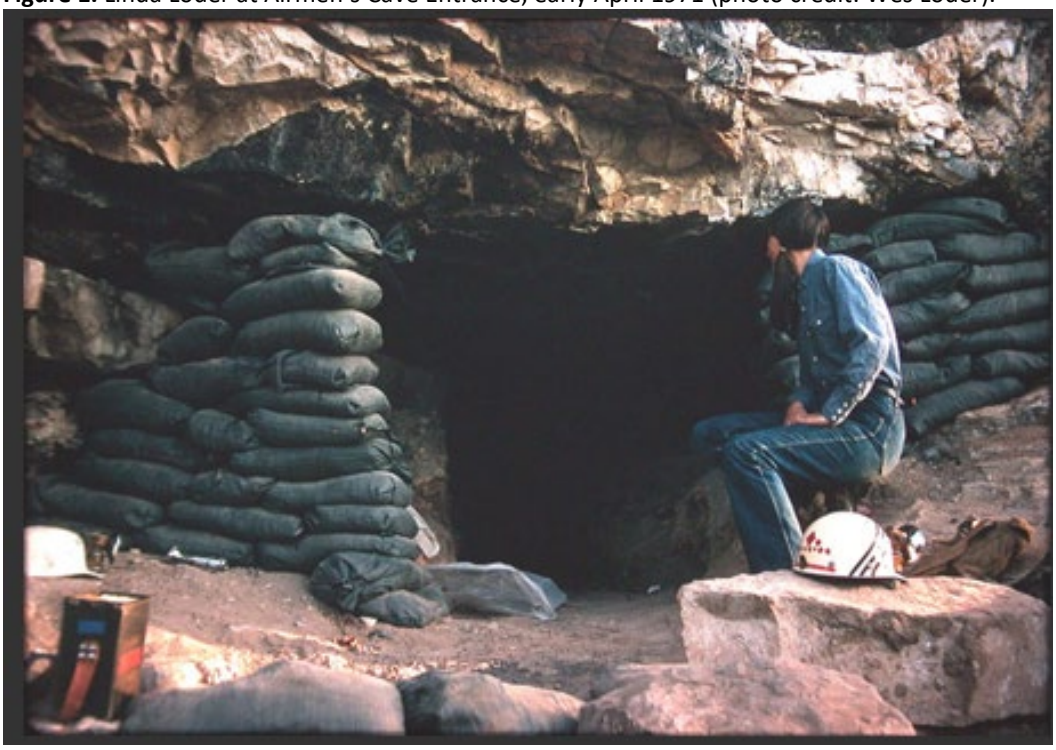


Figure 2. Mark Sanders entering entrance squeeze into Airmen's Cave, December 29, 1995 (photo credit: Nico Hauwert).

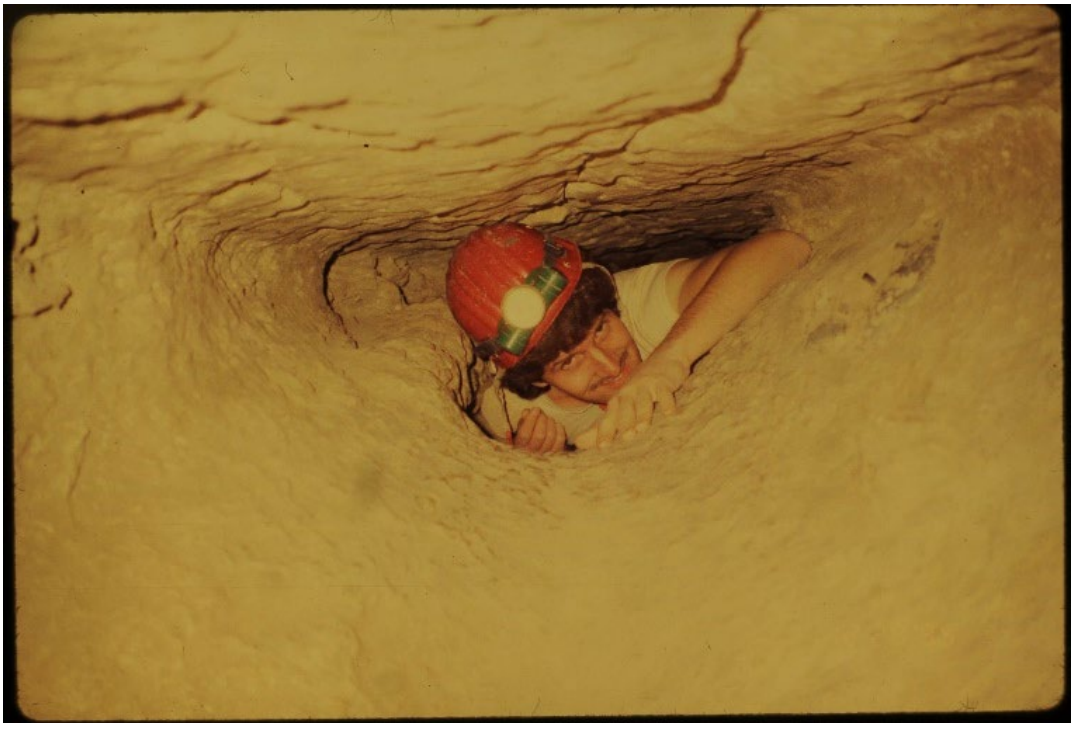


Figure 3. Crawl beyond the Entrance Room, December 29, 1995 (photo credit: Nico Hauwert).

Figure 4. Bypass Squeeze, December 29, 1995 (photo credit: Nico Hauwert).

Figure 5. Mark Sanders at top of pit leading to Breakdown Room, December 29, 1995 (photo credit: Nico Hauwert).

Figure 6. Graffiti at the passage to the Aggie Art Gallery, December 29, 1995 (photo credit: Nico Hauwert).

Figure 7. One-Legged Man Passage (photo credit: Mark Sanders).

The entrance and initial 600 feet of Airmen's Cave is owned by the City of Austin on the dedicated Barton Creek Greenbelt. In 1996, Airmen's Cave was identified as a mitigation requirement to offset the loss of karst habitat in western Travis County under the City of Austin and Travis County's incidental take permit and the permit's associated habitat conservation plan (Balcones Canyonlands Conservation Plan). Airmen's Cave remains the longest of 62 caves on the permit. Although the Balcones Canyonlands Conservation Plan requires that "Public access to caves and larger karst openings should be strictly regulated using a permit system obtained from the appropriate preserve land manager", the entrance to Airmen's Cave remained accessible for the first 16 years of the permit to experimentally examine if the tight entrance was sufficient to limit only experienced, protective explorers. However, the cave was subjected to extensive graffiti and trash deposition by insensitive explorers, requiring annual cleanups, and hibernating bats were threatened by disturbance. On August 5, 2011 AW BCP biologist Mark Sanders noticed a "major spike in the amount of trash" (including batteries, bug swatter, and multiple urination bottles), an increase in graffiti, and crushed ground beetle (*Rhadine austinica* a BCCP permit species of concern). Several human cave rescues were necessary, such that in 2012 the entrance was gated and access was available by permit only. In addition to increased public safety, the restricted access helps preserve the environmental quality of the cave and meet permit requirements.

Figure 8. Examples of trash removed annually from Airmen's Cave prior to gating in 2012 (photo credit: BCP staff).

Figure 9. Examples of graffiti painted on the cave walls of Airmen's Cave prior to gating in 2012 (photo credit: BCP staff).

Cave Surveys

Airmen's Cave was originally mapped from 1971 through 1974 by members of the UT Grotto, including William Russell, Wes Loder, and Peter Sprouse. The complete survey notes were not obtained, and details of its survey and projection are not known. The original survey did not include inclination, so the actual horizontal distances are shorter than shown on the 1974 map. The 1974 Airmen's Cave footprint was digitized based on the cave in relation to local major roadways and highways shown on the final map. The 1974 cave map was labeled "Airmans Cave," which was a misspelling of Airmen's Cave (Wes Loder, pers. comm.), to credit the two pilots who discovered the cave in 1971. On July 24, 1993, a short, isolated survey was conducted by Nico Hauwert and Geoff Hoese in association with an attempted extension of passage beyond the Empty Room in hopes of connecting with the surface on the tract just west of Ben White Boulevard. In the mid-1990s, cave radio location of the Empty Room in Airmen's Cave was unsuccessfully attempted by Nico

Hauwert and Andy Grubbs, who transmitted radio signals from the cave interior, while Keith Hess and William Russell were positioned with a receiver at the surface near Highway 290/Ben White Boulevard (based on the Empty Room's estimated overlying surface location projected on the 1972 cave map). The cave radio used also had a depth limit of about 100 feet, which is slightly less than the currently measured depth. The cave was resurveyed point to point from the entrance to the end of Sherwood Forest Room (about 2,794 horizontal feet) on December 29, 1995 (by Nico Hauwert and Mark Sanders) and November 30, 1996 (by Nico Hauwert, Randy Brown, and Jim Kennedy) using azimuth, distance between stations, and inclination. The entrance point of Airmen's Cave was located by Trimble Pro XRS global positioning system (gps) to be 3099237, 10060853 (NAD 83 US Survey Feet, Central Texas 4203) by Nico Hauwert on April 14, 2004, postprocessed to be within a horizontal accuracy of about 5.4 feet. The 1995/1996 survey data were processed by Nico Hauwert using Microsoft Excel, which include calculated coordinates and elevations from entrance point gps survey, the distance, azimuth, and azimuth to each survey point. The detailed 1974 survey map was fitted to the 1995/1996 survey points for a second projection.

Cave surveying from point to point over several thousand feet underground is not nearly as precise as a total station gps surface survey, but multiple surveys can be projected and compared for consistency. As shown in Figure 11, the 1971-1974 map projection and 1995-1996 surveys have a difference of about 500 feet on the location of Sherwood Forest, which was the termination of the latter survey. The 1974 map is expected to have an exaggerated length due to lack of inclination measurement. However, the 1995-1996 survey saw a difference between straight distance between stations (2,843 feet) and calculated actual distance (2,814 feet) is only 29 feet, while the discrepancy in the projected location of Sherwood Forest between the two surveys is about 500 feet. The original survey notes from the 1971 to 1974 mapping were not available or tabulated to verify and reproject the survey, and it is possible the two cave survey results are identical but were projected in error with respect the local road landmarks. Without additional verification, either the 1974 map projection and 1995/1996 projections could be valid. A third survey of stations from the entrance and/or a successful cave radio point location would help resolve the actual position of Airmen's Cave below the surface. In 2021, a third team began surveying the cave, but at this time there is no estimated timeline for when the survey results will be completed and available.

Figure 10. 1974 Airmen's Cave map. This is the most detailed mapping of Airmen's Cave to date but excluded inclination measurement and assumes the cave is horizontal. See expanded scan of map in Appendix A.

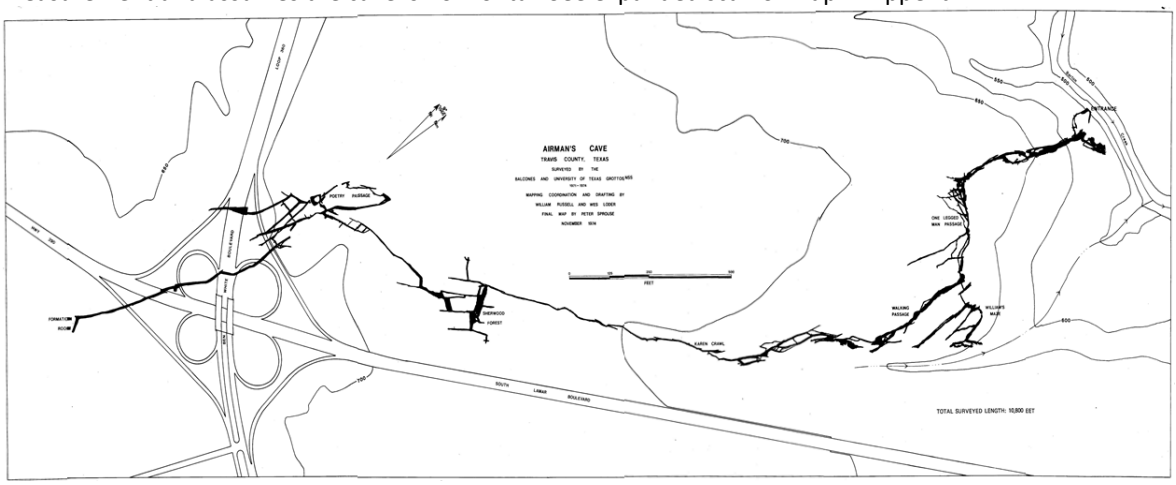
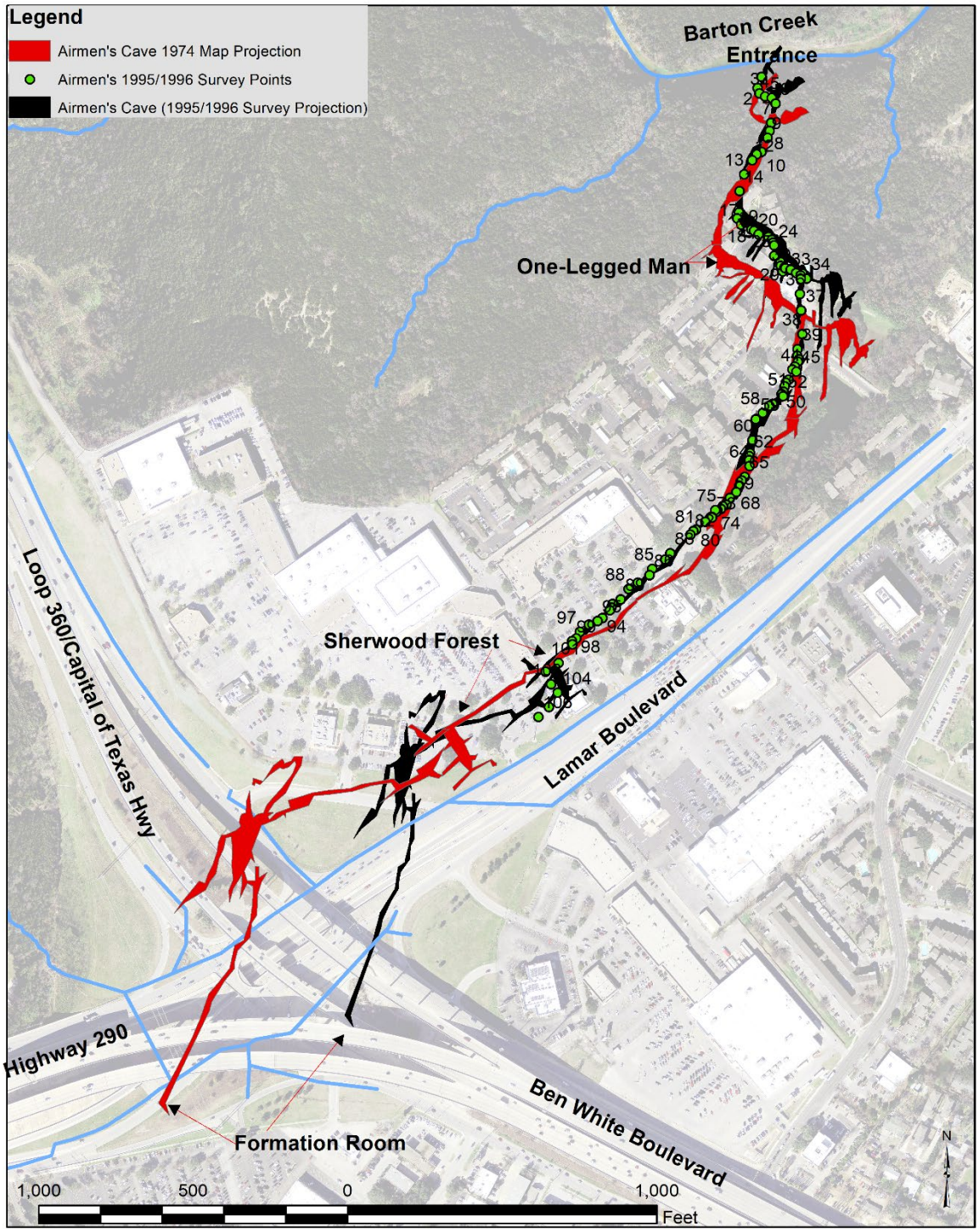


Figure 11. Initial comparison of 1974 cave map with 1995/1996 resurvey.



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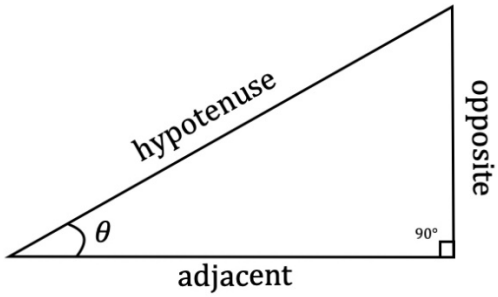
This product has been produced by the Wildland Conservation Division for the sole purpose of geographic reference. No warranty is made by the City of Austin regarding specific accuracy or completeness.

Figure 12. Right-angle triangle diagram from this internet source, illustrating that the length along the hypotenuse side is always larger than the length of the adjacent side, the difference increasing with angle size (Θ). As shown in the cross section based on the 1995/1996 survey as far as Sherwood Forest (Figure 11), Airmen's Cave rises a net of about 30 feet over about 3,000 feet, but has both ascending and descending passages, with a net measured vertical component of 144 feet.



Geology

The surface area over Airmen's Cave was mapped in detail by Small et al. (1996) and Barton Springs/Edwards Aquifer Conservation District (2001) and is periodically updated (Hauwert 2009). This mapping incorporated surface geology along Barton Creek, Airmen's Cave itself, and subsurface data from nearby geophysical logs, including well 58-50-216 within Highway 290 right-of-way across from a Target store just east of the end of Airmen's Cave. Notes on cave geology (fossils, hydrostratigraphic strata, and faulting) were noted by Nico Hauwert from the 1995 and 1996 cave mapping survey. Hauwert and Russell (1996) originally interpreted faulting and cave-level hydrostratigraphic units associated with Airmen's Cave. For this study, more detailed surface outcrop observations over the area of Airmen's Cave were made by Nico Hauwert on April 18 and 25, October 23 and 28, 2021. A measured section from a cliff downstream of Airmen's Cave shows the characteristics and thickness from the lower Georgetown Limestone to the Regional Dense Member (Appendix E). No outcrop is currently visible directly over the majority of Airmen's Cave beyond the section containing the One-Legged Man Passage, or first 600 feet, onward, due to impervious cover. The results of four boring logs conducted by Terracon Consultants. across the Brodie Oaks Mall site in January and February 2020 were provided by Lionheart Places. A surface geologic interpretation is presented in Figure 13.

Figure 13. Surface Geological Interpretation over Airmen's Cave. Modified from Small, Hanson, and Hauwert (1996).

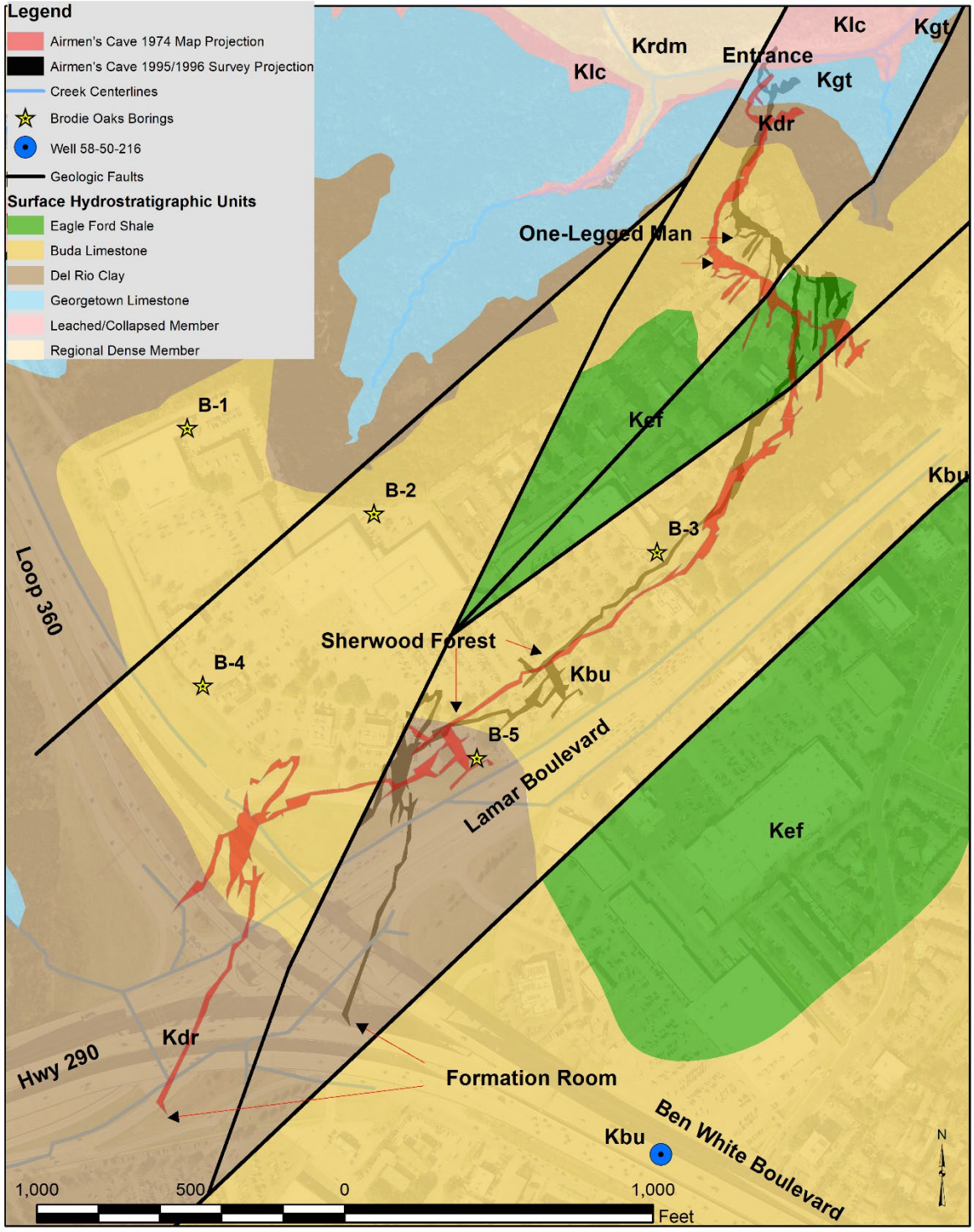


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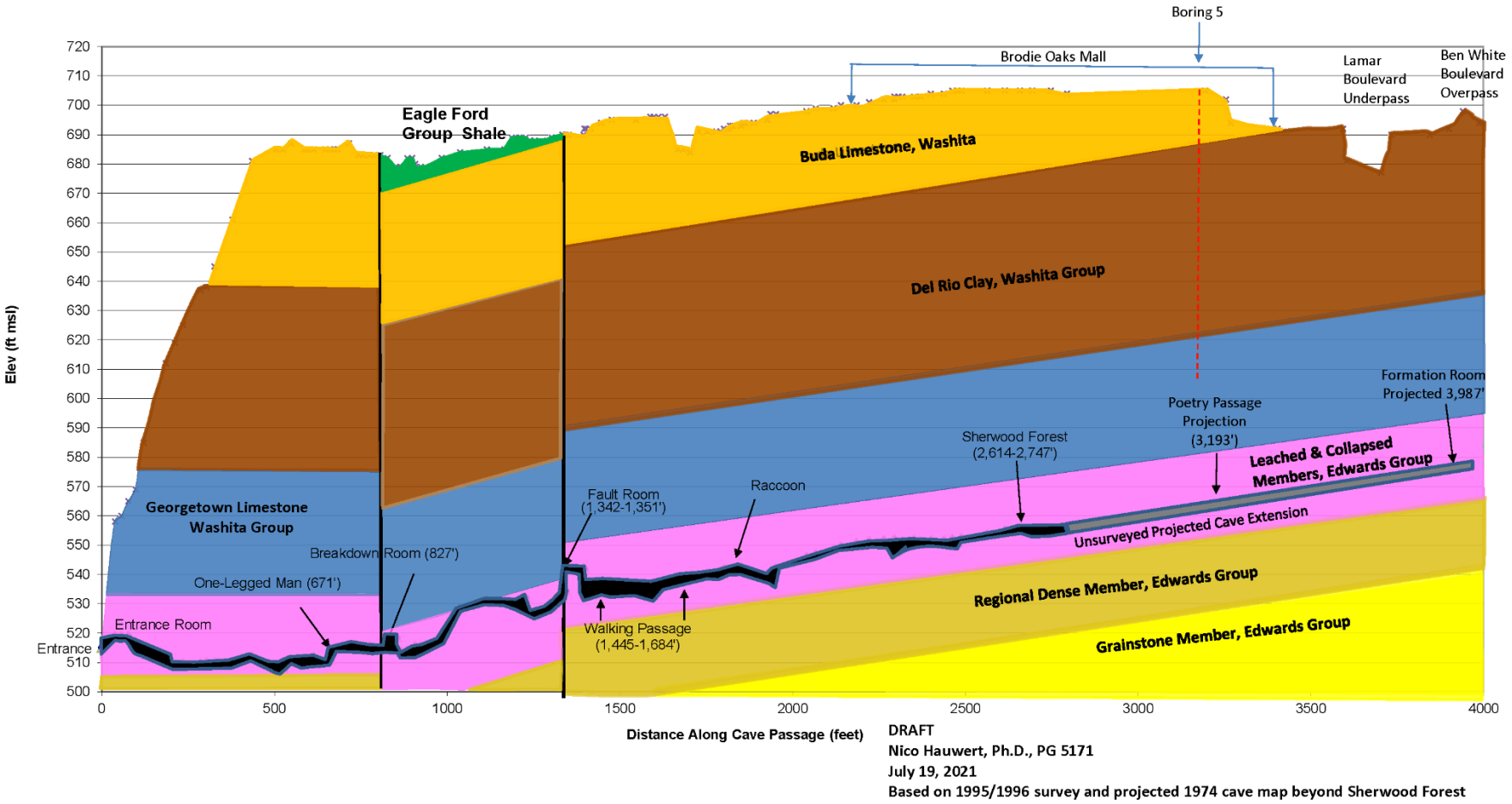
Figure 14. Geological Profile Along Airmen's Cave



DRAFT
Nico Hauwert, Ph.D., PG 5171
July 19, 2021
Based on 1995/1996 survey and projected 1974 cave map beyond Sherwood Forest

Table 1. Local Boring and Well Geological Interpretation

Boring/ Well ID	Longitude	Latitude	Surface Elevation (feet msl)	Total Depth (feet)	Depth to Buda Limestone (feet)	Depth to Del Rio Clay (feet)	Depth to Georgetown Limestone (feet)	Elevation of Top of Del Rio Clay (elev. feet msl)	Elevation of Top of Georgetown Limestone (elev. feet msl)	Thickness of Unconsolidated Material/Pavement (feet)	Thickness of Del Rio Clay (feet)
B-1	-97.7972	30.2388	708	100	10	19	80	689	628	10	61
B-2	-97.7953	30.2380	703	100	5	19	---	684	< 603	5	81
B-4	-97.7971	30.2365	705	100	---	2	60	> 703	639	2	58+
B-5	-97.7943	30.2358	702	100	---	13	65	> 689	635	13	52+
58-50-216	-97.7936	30.2322	692	580	10	43	107	649	585	10	64

Not all of the interpretations presented in the Terracon geotechnical report (Appendix C) were incorporated in the geological interpretation presented here, including:

- Boring B-3 was reportedly not drilled and was not included in the interpretation presented in this report.
- Borings B-1, B-2, and B-4 are within about 100 feet of observable outcrop, and the descriptions and stratigraphic interpretations were largely incorporated in the surface geological interpretation. Boring B-2 had an anomalous Del Rio Clay thickness of over 81 feet, that is significantly greater than the observed thickness of 60 to 64 feet in boring B-1, nearby well 58-50-216, and outcrop observations. The interpreted contact of Del Rio Clay and underlying Georgetown Limestone in boring B-2 at an elevation lower than 603 feet mean sea level (msl) is consistent with local outcrop observations. Outcrop of Buda Limestone is visible near the 660 feet msl elevation. Consequently, it is interpreted that 21 feet of "*shaley fat clay, tan to gray with infrequent limestone seams"* as Buda Limestone in boring B-2 instead of Del Rio Clay.
- Boring B-5 was described as tan to brown flat clay beginning at 13 feet depth, with gypsum deposits below 33-feet depth and becoming gray to brown below 53 feet, then a clayey shale from 58 to 64 ft. A transition zone of interbedded shale and limestone was described between 64 to 67 feet depth, overlying a limestone from 67 to total depth of 85 feet. The stratigraphic units were interpreted by Terracon Consultants (2020) as Eagle Ford Shale over the Buda Limestone. This boring is located about 100 feet from the projected position of Airmen's Cave in the vicinity of Sherwood Forest based on both 1974 and 1995-1996 cave mapping surveys. However, while the boring rock characteristics are consistent with the geological interpretation presented here, I reinterpret that the stratigraphic units are actually Del Rio Clay over Georgetown Limestone rather than Eagle Ford Shale over Buda Limestone for these reasons:
  1) Tan flat clay is characteristic of Del Rio Clay. The Eagle Ford is a dark gray consolidated shale.
  2) The eroded thickness of the tan clay and shale in boring B-5 is at least 51 to 54 feet thick, which is locally consistent with the roughly 60-feet thick Del Rio Clay rather than the 40 to 47-feet thick Eagle Ford Shale.

3) A hard (indurated) shale bed is visible in lower Del Rio Clay outcrop downslope and just north of Brodie Oaks Mall, consistent with gray to dark gray, highly fractured, clayey shale at 58 to 64 feet depth in boring B-5.
4) The Del Rio Clay exposure was visible at the surface by Nico Hauwert around 1995 during intersection improvements.
5) The B-5 boring encountered about 20 feet of limestone at a depth of about 617 ft msl elevation, and with local thickness of either Buda or Limestones of about 40 feet, the Terracon Consultants interpretation of Buda Limestone in the base of the boring would position Airmen's Cave within the lower Del Rio Clay, which is clearly not the case based on geological observations within the cave (Figure 14). Instead toucasia fossils observed by Nico Hauwert in the ceiling of Sherwood Forest on November 30, 1996 clearly places the cave passage within the Leached and Collapsed Members of the Edwards Group, the top of which is about 40 feet below the Del Rio Clay.

The general structure is interpreted to be subparallel scissor faults with a bedding dip to the north. The pronounced stratigraphic dip of more soluble hydrostratigraphic members (Leached and Collapsed Members) of the Edwards Group to the northeast and orientation of geologic faults strongly influenced the localization and dissolution of Airmen's Cave. The cave passages are perched above the Regional Dense Member of the Edwards Group, which is more clay-rich and thin bedded, and unlikely to develop extensive horizontal conduits, but may form pits connecting to underlying conduit systems within the lower Grainstone and Kirschberg Members.

Water Sources

As a horizontal cave on a bluff about 20 feet above the channel of Barton Creek, Airmen's Cave has no significant surface catchment basin, except during rare occasions of Barton Creek flooding that inundate the entrance area. Airmen's Cave entrance elevation of about 515 feet msl is roughly 20 feet higher than the main channel of Barton Creek. Under extreme flood events, flood waters have been documented entering the cave entrance through game camera photographs near the entrance.

The 40 feet-thick Buda Limestone commonly bears groundwater in monitoring wells and tributaries that breach the Buda Limestone, and the underlying Del Rio Clay typically has perennial springs. Barton Lodge Spring, in the upstream head of the tributary to Barton Creek immediately downstream of Airmen's Cave, perennially drains from the Buda Limestone. However, formations, such as stalactites, stalagmites, rimstone dams, draperies and soda straws are absent in most of Airmen's Cave, suggesting that infiltration through the Del Rio Clay from either the overlying groundwater of the Buda Limestone or surface or is not significant, except possibly near the entrance around Barton Creek and the last known room in the cave (Formation Room) below Ben White Boulevard right-of-way. Elliott (1997) noted: "Formations are found only at the entrance and the extreme end of the cave." Consequently, the lack of cave drip areas and layer of Del Rio Clay over most of the cave suggests that traditional overlying subsurface catchment areas are either generally not present, or are complex to define. It is possible that ceiling drips occur under some wet conditions that were not yet observed or documented. A detailed description of ceiling drips and formations formed from dripping water are described below.

The 1995/1996 cave survey by Hauwert notes the following water signs, formations, and cave life (troglophiles) at surveyed distances through the cave:

- 120 feet Entrance (Big) Room: ceiling drips
- 613 ft: Fracture fill (fin) on west wall (not active drip)
- 714 ft: Fracture fill (fin) formation
- 1,164 ft.: Gypsum flowers on walls
- 1,200 ft: Fracture fill (fin)
- 1,302 ft.: Fracture fill (fin) on right wall
- 1,395 ft.: Fault with ground rock and calcite deposition
- 1,446 feet: Walking passage with fin (fracture fill) in ceiling
- 1,588 feet: raccoon scat
- 1,630 feet: Walking Passage with gypsum flowers in ceiling
- 1,850 feet: Large raccoon
- Formations beyond the 1995/1996 surveyed extent (Sherwood Forest)
- 3,300 ft (projected): Empty Room dry gypsum stalactites
- 4,000 ft (projected): Formation Room active formations and ceiling fissure drip

Entrance or Big Room: The Entrance Room has numerous dispersed ceiling drips and abundance of life including tricolored bats hibernating through the winter, raccoons observed on game cameras entering the cave, and a porcupine observed in July 2020 at the nearby cave extension conduit on Barton Creek bluff. In the initial 1971-1974 exploration of Airmen's Cave, Wes Loder noted this "Big Room" was the only place in the cave where active formations were found, likely prior to the later discovery of the Formation Room at the end of Airmen's Cave.

Figure 16. Entrance Room on with tricolor bat and drips in background, December 29, 1995 (photo credit: Nico Hauwert).

Figure 17. Expanded view of Entrance or "New" Room, December 29, 1995 (photo credit: Nico Hauwert).

Empty Room: The Empty Room has an 18 cm ceiling with gypsum needles and clayey mud floor with gypsum needles. Fault N2E orientation and 70˚W dip with dogtooth calcite fill. No active drip flow has been observed, and the room appears to be relatively dry.

Formation Room: The Formation Room is the farthest explored extent in Airmen's Cave. Photographs of the Formation Room from February 11, 2021 by Ethan Perrine are presented in Appendix B. A pool of water was sampled on August 16, 2021 by Ethan Perrine and submitted to LCRA lab for analysis (Appendix D). Active drips were observed both from a ceiling fissure and stalactites although the drip rate was not measured. The water-quality results show very high sulfate (1500 mg/l) and high chloride concentrations (91.3 mg/l) compared to typical levels for both parameters of 10-40 mg/l in the Edwards Aquifer. Calcium concentrations of 535 mg/l was higher than typical Edwards Aquifer concentration of about 300 mg/l. Low concentrations were found of constituents that are associated with urban contamination such as *E. coliform* < 1 colony/100 ml, ammonia 0.086 mg/l, phosphorus <0.008 mg/l. The water quality results are consistent with seepage through the Del Rio Clay, which is known to contain highly soluble gypsum (calcium sulfate). The projected surface area over this location is the northeast corner of Lamar Boulevard and Ben White Boulevard/Highway 290, where Hauwert observed shallow surface exposure of the Del Rio Clay associated with Ben White Boulevard improvements around 1995. A surface drainage overlies this area (Figure 13). Although the drip rate may be low, the appearance of formations (soda straws, stalactites, bacon rinds, stalagmites, rimstone dams) and water pools suggest a discrete source of overlying water such as the surface, Buda Limestone groundwater, or moisture drainage from the Del Rio Clay possibly along an extrapolated fault. It is estimated that the Del Rio Clay extends to the surface and the Buda Limestone is absent above the Formation Room. However, a U.S. Geological Survey monitoring well (state well number 58-50-216) located about 1,100 feet southeast of the Formation Room, within the Ben White Boulevard underpass, has about 40 feet of Buda Limestone (top of Del Rio Clay elevation about 649 ft msl), according to geophysical logs. Likely a down-dropped fault parallels Lamar Boulevard east of the Formation Room. The Buda Limestone further east or south of the Formation Room could be a water source for the Formation Room drips. There is outcrop of Georgetown Formation in a drainage about 800 feet northwest of the Formation Room according to the 1974 Airmen's Cave map projection and about 1,100 feet west of the 1995/1996 map projection. This outcrop of Georgetown Formation northwest of the Ben White Boulevard and Lamar Boulevard intersection has an estimated maximum elevation of about 640 feet msl is higher and potentially updip of the Formation Room at projected 560 feet msl and could potentially be a source of water for the drips there. Attempts could be made to test various hypothesized sources to the Formation Room using organic dyes or chemical tracers (Hauwert and Cowan 2013), if access permission could be gained. Any attempts to trace through the Del Rio Clay with organic dyes would likely be unsuccessful as the dyes would be much more easily sorbed by the overlying clays than the water flushed with it, and a non-detection might be inconclusive regarding hydraulic connection.

Figure 19. Formation Room, September 3, 2004 (photo credit: Scott Serur).

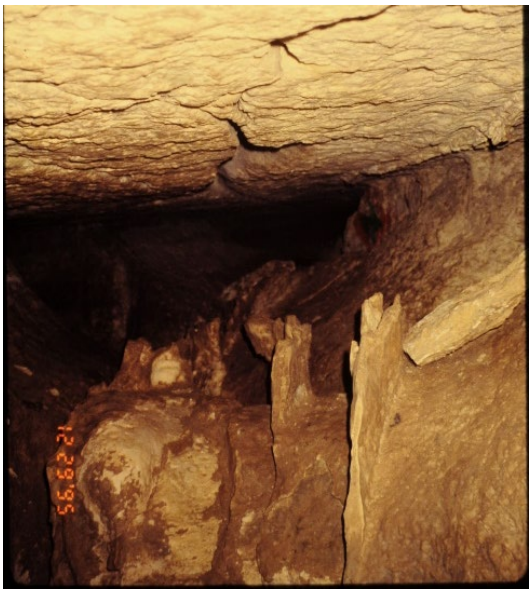
Figure 20. Formation Room, February 11, 2021 (photo credit: Ethan Perrine).

Figure 21. Lamar Boulevard Underpass north of Ben White Boulevard where the 1995/1996 cave survey projects the main cave passage of Airmen's Cave leading to the Formation Room passes beneath. According to the 1974 cave map, the same passage passes under the underpass on the opposite side of this intersection. The posted depth of the underpass is 16 feet 6 inches (photo credit: Google Maps 2021).

Figure 22. A surface drainage overlying the Formation Room of Airmen's Cave where active drips are observed. Del Rio Clay was observed in excavations on this side of the intersection around 1995, October 5, 2021 (photo credit: Nico Hauwert).

Fracture Fill Formations (fins): The timing of the dry fracture fill deposition pre-dates the solutional development of the cave by groundwater and is not reflective of recent groundwater flow along the fractures. The source of the ancient water hasn't been studied but could potentially be slow seepage from overlying formations or from deeper sources (hypogene).

Figure 23. Fins (remnant fracture fill) in Airmen's Cave as result of past precipitation of mineralized water flow through fractures and subsequent erosion of surrounding bedrock, but not recent water flow, December 29, 1995 (photo credit: Nico Hauwert).



Inactive Drapery Formations: Draperies are similar to stalactite in origin but calcium is precipitated against a wall rather than from an open ceiling. Drapery formations are visible along a fault in Airmen's Cave. They show no sign of recent flow, even in 1995 photos.

Figure 24. Inactive drapery formations along apparent fault about 1,400 feet into Airmen's Cave, December 29, 1995 (photo credit: Nico Hauwert).

Gypsum formations: The gypsum (calcium sulfate) formations in Airmen's Cave include gypsum flowers and needle-like stalactites. The appearance of dry gypsum formations throughout Airmen's Cave appears to be precipitation of moisture drainage seeping over time from the Del Rio Clay, which characteristically contains gypsum seams in local outcrops. None of these gypsum formation sites corresponded to wet cave passage, such that there is no evidence of significant drainage through the Del Rio Clay from the surface or Buda Limestone.

Water-Table Source: All life requires water, so what are the water sources supplying life in Airmen's Cave? Recent (2021) game camera footage from shallow portions of Blowing Sink Cave in South Austin shows a porcupine licking condensation off rock surfaces (https://www.youtube.com/watch?v=-lXlSv_jRy4). Hauwert (1994) presented a geologic cross section through the rear portion of Airmen's Cave and showed the measured water table below Airmen's Cave to be between 490 and 494 feet msl on July 1-2, 1993. Airmen's Cave as far back as the One-Legged Man passage (about 510 ft msl) and Breakdown Room (about 513 ft msl) is only about 16 to 23 feet higher than this July 1993 measured water level and the Walking Passage, with floor elevation of about 532 ft msl, is roughly 40 feet above this measured water table of the Edwards Aquifer. Under rare years of higher-than-average rainfall when the water table is high, groundwater flows through the cave as an overflow spring of the Edwards Aquifer. Likely in yet explored passages, open conduits connect the known passage to the water table, through which animals can potentially descend. In 1992 and 2016, cavers who explored the cave stream within Airmen's Cave believed the source of the flow was roughly 1,000 feet into the cave near 3 Way Passage and William's Maze (866 feet into cave, floor elevation about 513 ft msl) and Crucifixion Rock

(1,226 ft into cave, floor elevation about 525 feet msl.) Beyond the Fault Room the cave passages ascends to elevations of 535 to 550 feet msl and projected higher past Sherwood Forest and the water table is less likely to reach these elevations in this area (Figure 14). Although no analysis of cave fauna data was available for this report, Drew Thompson of the Austin Water Balcones Canyonlands Preserve reported that the number and diversity of cave fauna observed are greatly diminished beyond the 3-Way Passage near William's Maze. A large raccoon was observed in Airmen's Cave during the 1996 cave mapping about 1,850 feet into the cave.

When phreatic groundwater flows through Airmen's Cave, such as the time period from approximately December 1991 to December 1992, and in 2016, the main discharge of the cave stream does not pass through the main entrance, which historically was probably a smaller side in feeder, but from a conduit on a cliff of Barton Creek about 200 feet north of the Main Entrance. Likely this lesser known conduit was the historic main cave passage (Figure 24).

Some of the flow along Airmen's Cave is likely through conduits that parallel a smaller offset fault further east. On May 17, 1992, Nico Hauwert measured 2 springs within 30 feet of the mouth of Barton Lodge Tributary assumed to be northmost discharges of Airmen's Cave flow, at over 13 gallons/minute. Three springs discharging on the north bluff of Barton Lodge tributary, flowing south into the tributary measured a higher rate at 35 gallons/min, 8.8 gallons/min and 7.5 gallons/min. The springs seemed to be discharging localized flow from both directions along a fault into Barton Lodge Tributary.

Figure 25. Justin Shaw indicating main groundwater discharge from Airmen's Cave about 200 feet downstream of the cave's entrance, July 23, 2016 (photo credit: Drew Thompson).

Figure 26. Patti Calabrese observing groundwater discharging from the south bluff into the Barton Lodge Tributary near its mouth, July 23, 2016 (photo credit: Drew Thompson).

Figure 27. Groundwater flows through the Entrance (New) Room, July 23, 2016 (photo credit: Drew Thompson).

Figure 28. Groundwater flows Upstream from the Entrance (New) Room, July 23, 2016 (photo credit: Drew Thompson).

Figure 29. Water Flowing through the Bypass Squeeze, July 23, 2016 (photo credit: Drew Thompson)

Figure 30. Patti Calabrese passes a low air space passage, July 23, 2016 (photo credit: Drew Thompson).

On April 18, 2016, five pounds of eosine dye were poured into the Danz Creek tributary of Slaughter Creek upstream of State Highway 45 SW, about 7 miles southwest of Airmen's Cave. Monitoring for the dye within the flowing cave passage of Airmen's Cave through a charcoal packet placed in the water from June 6, 2016 and recovered on July 22, 2016 (46 days) showed about 1 part per billion of eosine dye accumulated on the carbon over that interval. This result indicates the aquifer water source is likely the Manchaca Groundwater Basin and not the nearby Sunset Valley Groundwater Basin as mapped by Hauwert (2009). This groundwater basin originates from recharge as far south as the Blanco River during droughts and discharges from Main Barton, Eliza, and Old Mill Springs but not Upper Barton Springs.

Other Local Potential Contamination Sources

A historic Brodie glass landfill, active from 1930-1940, is located about 1,200 feet north of the Poetry Passage and Empty Rooms, at the rear of Airmen's cave. It is located primarily within the City of Austin Barton Creek Greenbelt. To best of my understanding, the landfill material remains in place, but was capped with an impervious cover to prevent the generation of leachate from rainwater infiltration. The uppermost 10 feet of fill described in boring B-1 appears to be associated with surface disturbance associated with this feature in 1940 aerial photos. There is no evidence of leachate infiltrating into the known extent of Airmen's Cave from this landfill.

A water well (state well number 58-50-209) was located roughly 80 feet north of the 1995/1996 cave map projection of Sherwood Forest, at the historic H.E. Brodie homestead visible on aerial photographs from 1940

to 1977. The well was reportedly 330 feet deep, penetrating through the Del Rio Clay into the underlying Edwards Aquifer. It is not known if and how the well was plugged. There is no evidence of infiltrating groundwater in the known extent of Airmen's Cave near this former well. 1983 aerial photographs show the construction of Brodie Oaks Mall underway.

In 2021, Brodie Oaks Mall has submitted a PUD application to the City of Austin for redevelopment that proposes a 36% reduction in impervious cover, including:

- A subsurface excavation for underground parking is proposed that will leave at least 20 feet of Del Rio Clay over the Georgetown Limestone. Because the some Del Rio Clay will remain in place to restrict flow and the structure would not regularly fill with water, the subsurface parking structure is not anticipated to be a source of contamination for Airmen's Cave.
- concrete supports are proposed to extend into the Georgetown Limestone in order to stabilize the structures. Prior to drilling the supports, geotechnical borings will be drilled at the support locations to verify site geology and examine if any voids are present. While in at least two known creek channel sites (Antioch Cave in Onion Creek and Horseshoe Bend Sink in Dahlstrom Ranch) across the Barton Springs Segment of the Edwards Aquifer, natural shaft fissures have developed along fractures from the top of the Georgetown Limestone to the underlying Edwards Aquifer. However in this location, the presence of Del Rio Clay cover under Brodie Oaks Mall would be expected to suppress vertical solution development here.

This report is not intended to be a comprehensive site assessment of all potential contamination sources. Even where surface sources of contamination are not anticipated, it will be critical to conduct regular monitoring of Airmen's Cave to detect any impairment of water quality and quantity that may potentially affect the cave ecosystem.

Conclusions

This report compiles information on overlying geology, cave drips, and other information to examine water sources for Airmen's Cave that support the cave ecosystem. Sources of contamination and management practices that potentially affect the water sources of the cave are also examined. Wet, active ceiling drips suggest groundwater entering Airmen's Cave near the entrance (Entrance Room) and at the farthest passage point of the cave in the Formation Room. The remainder of the known extent of Airmen's Cave lacks active drips or formation that would indicate an overlying source of water. During rare high Edwards Aquifer water table conditions, groundwater enters Airmen's Cave from below and flows through the cave from the Manchaca Groundwater Basin of the Barton Springs Segment of the Edwards Aquifer. The surface over the first 600 feet of Airmen's Cave is relatively undisturbed Barton Creek Greenbelt. The remaining 4,000-feet of Airmen's Cave is overlain by urban infrastructure and impervious cover. The majority of the cave is also overlain by the Del Rio Clay, which tends to serve as a protective layer and tends to perch infiltrating water above it to the local creeks. However, there is no indication from observations throughout the cave since the initial discovery of Airmen's Cave in 1971 that the two known active drip location in the Entrance/Big Room and Formation Room have diminished or been impacted from surface disturbance. There is no evidence of urban contamination in the single water-quality sample collected from the Formation Room. The primary

water source for life in the cave is interpreted to be the shallow water table below the cave (roughly 20 feet beneath the first quarter or 1,000 feet of the cave extent) and condensation of moisture from the water table of the Manchaca Groundwater Basin of the Barton Springs Segment of the Edwards Aquifer. The source of water to the drips in the Formation Room could originate from (1) surface drainage along a drainage southeast of the Ben White Boulevard and Lamar Boulevard seeping enhanced by a fault through the Del Rio Clay, (2) Buda Limestone groundwater drainage through the Del Rio Clay from the southeast (3) perched groundwater flow within the Georgetown Limestone from potentially updip surface drainage roughly 1,000 feet west or northwest of the Formation Room. Because of a deep underpass cut through the Del Rio Clay along Lamar Boulevard and lack of Edwards Aquifer outcrop water source area northeast of the Ben White Boulevard and Lamar Boulevard intersections, it is unlikely that the existing Brodie Oaks Mall and Retreat at Barton Creek Apartment Complex areas are water sources for Airmen's Cave or the Formation Room drips.

Recommendations

Based on the data at hand, because of the overlying Del Rio Clay and lack of active drips in the majority of the cave the overlying surface does not appear to currently provide water source except possibly in the Entrance Room and the rear of the known extent at the Formation Room. The water table of the Edwards Aquifer is likely at a shallow depth below the initial portion of the cave and is a viable water source that at times flows through the cave. The following is recommended for continued monitoring, to preserve the water quality in the cave, and to comply with federal BCCP permit:

- Additional cave mapping and/or cave radio location would help determine the precise cave location
- Monitoring of cave fauna, cave cricket exits, drip rate and water quality of both Entrance Room and Formation Drip should continue.
- Faunal surveys conducted since 1997 from 3 survey zones in the cave should be analyzed to examine temporal and geographical trends in the cave ecosystem.
- In accordance with the 1996 incidental take permit issued by the U.S. Fish and Wildlife Service to mitigate for loss of karst habitat in western Travis County, the City of Austin and Travis County will seek acquisition or management agreements for 62 caves, including Airmen's Cave. This is needed not only to ensure continued protection, but continued monitoring and management as outlined in the Balcones Canyonlands Conservation Plan, land management plans, and any approved updates to these documents.
- There are three primary entities with ownership estimated overlying portions of Airmen's Cave (noting the previously discussed potential error in cave mapping):
    - The entrance and first 600 feet are owned by the City of Austin. The City of Austin has a 2007 land management plan for the Barton Creek Greenbelt and Barton Creek Wilderness that includes Airmen's Cave (https://www.traviscountytx.gov/images/tnr/Docs/draft_plan/tier_iii_city_of_austin_barton_creek.pdf). Land management of this portion of Airmen's Cave and overlying surface is most likely to affect the quality of drips in the Entrance/New Room. The Barton Creek Greenbelt is managed by Austin Parks and Recreation Department and Airmen's Cave is managed by the Austin Water Balcones Canyonland Preserve Program, as described in the 2007 management plan. As directed in the 1996 Habitat Conservation Plan and 2016 BCP Karst Land Management Plan, no pesticide applications should be made within 105 m (350 feet) of the cave entrance, except boiling water treatment for

red imported fire ants, without special consideration and written approval from the BCCP Secretary.
- From 600 to about 2,100 feet, the cave may underlie an apartment complex currently named the Retreat at Barton Creek (formerly Barton Lodge).
- The portion of Airmen's Cave from roughly 2,100 feet to about 3,500 is overlain by the existing Brodie Oaks Mall.
- The remainder of the cave from roughly 3,500 to 4,000 feet is overlain by Texas Department of Transportation Lamar Boulevard and possibly Ben White Boulevard.

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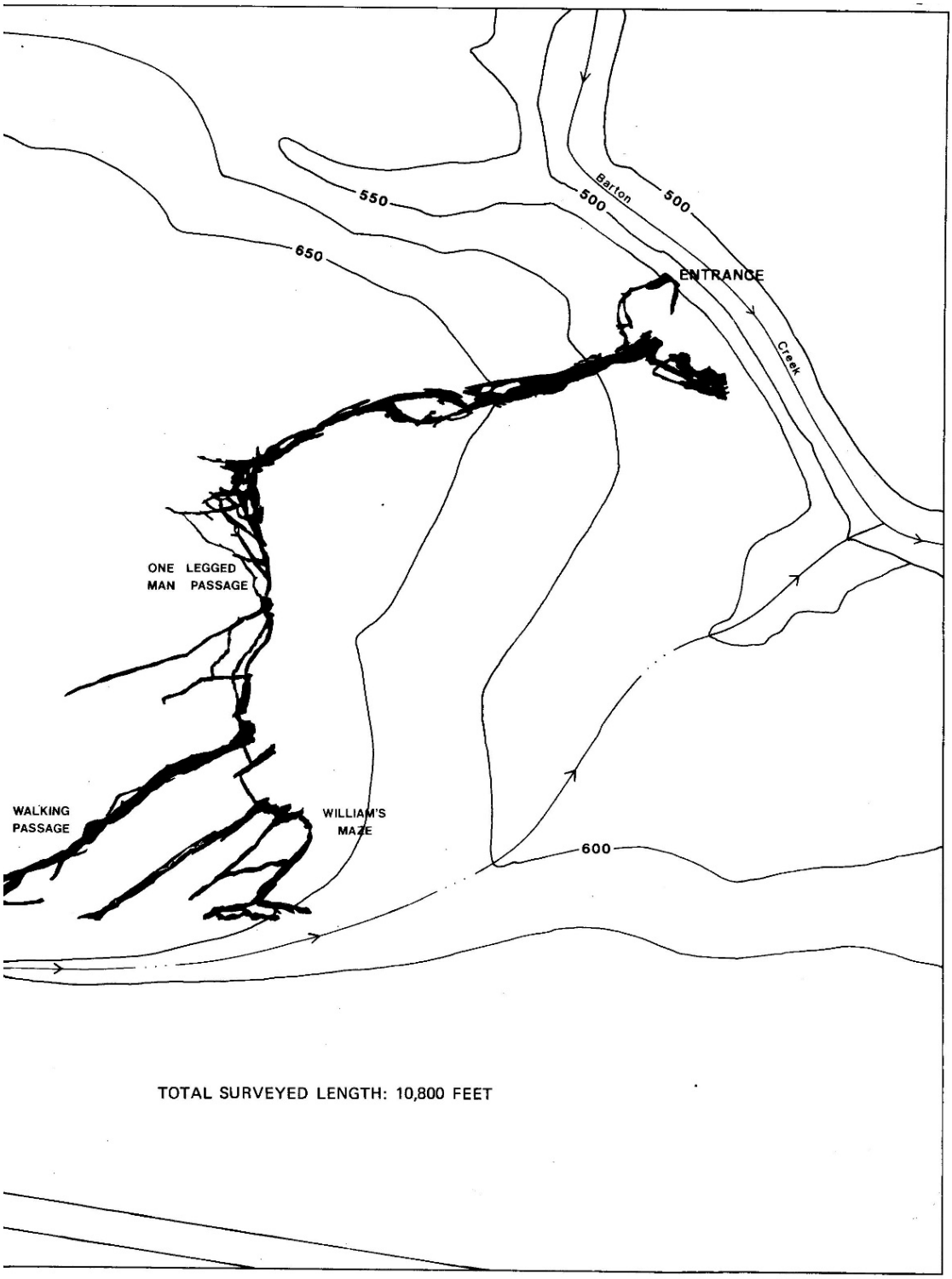
Appendix A Detail Scan of 1974 Airmen's Cave Map



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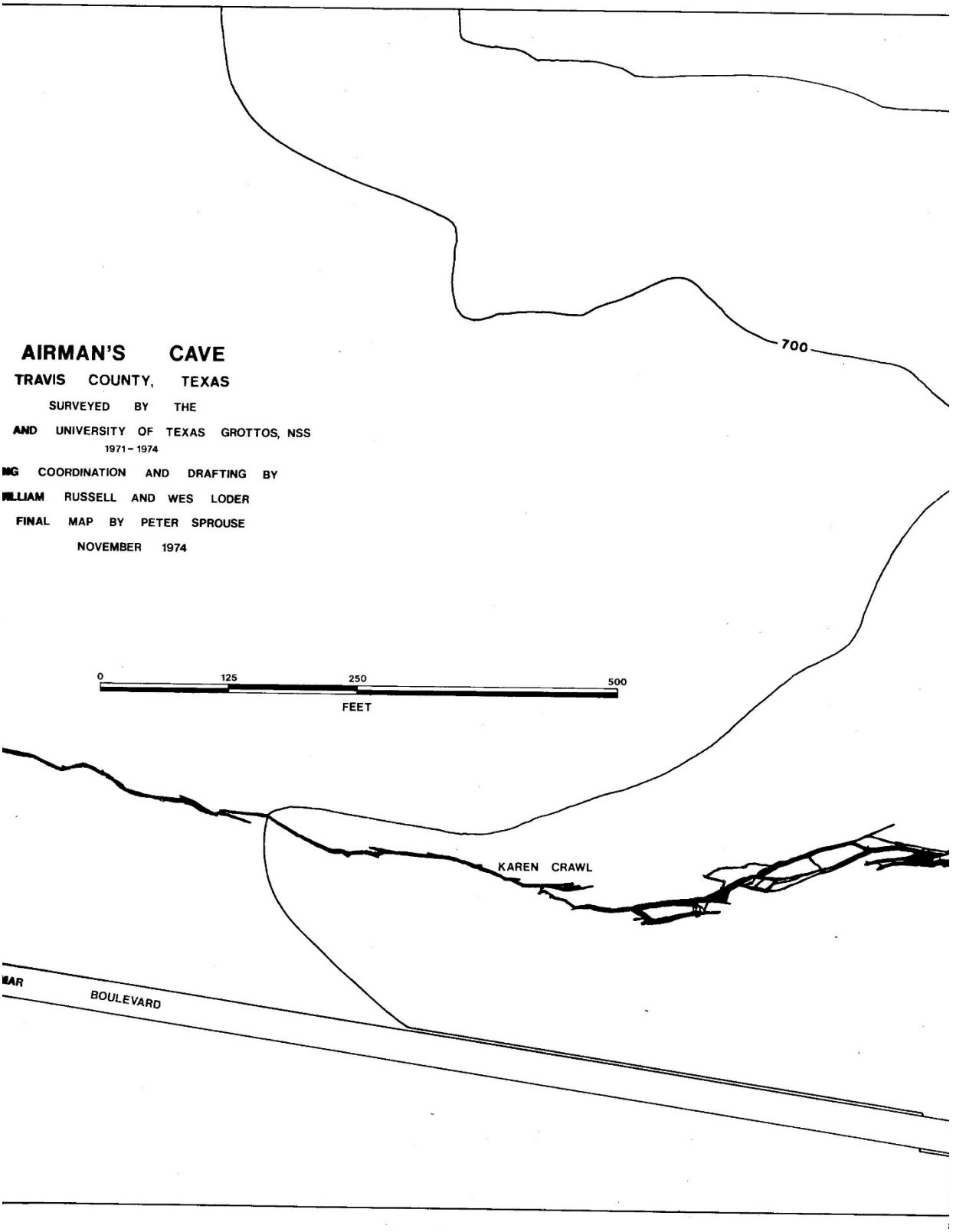
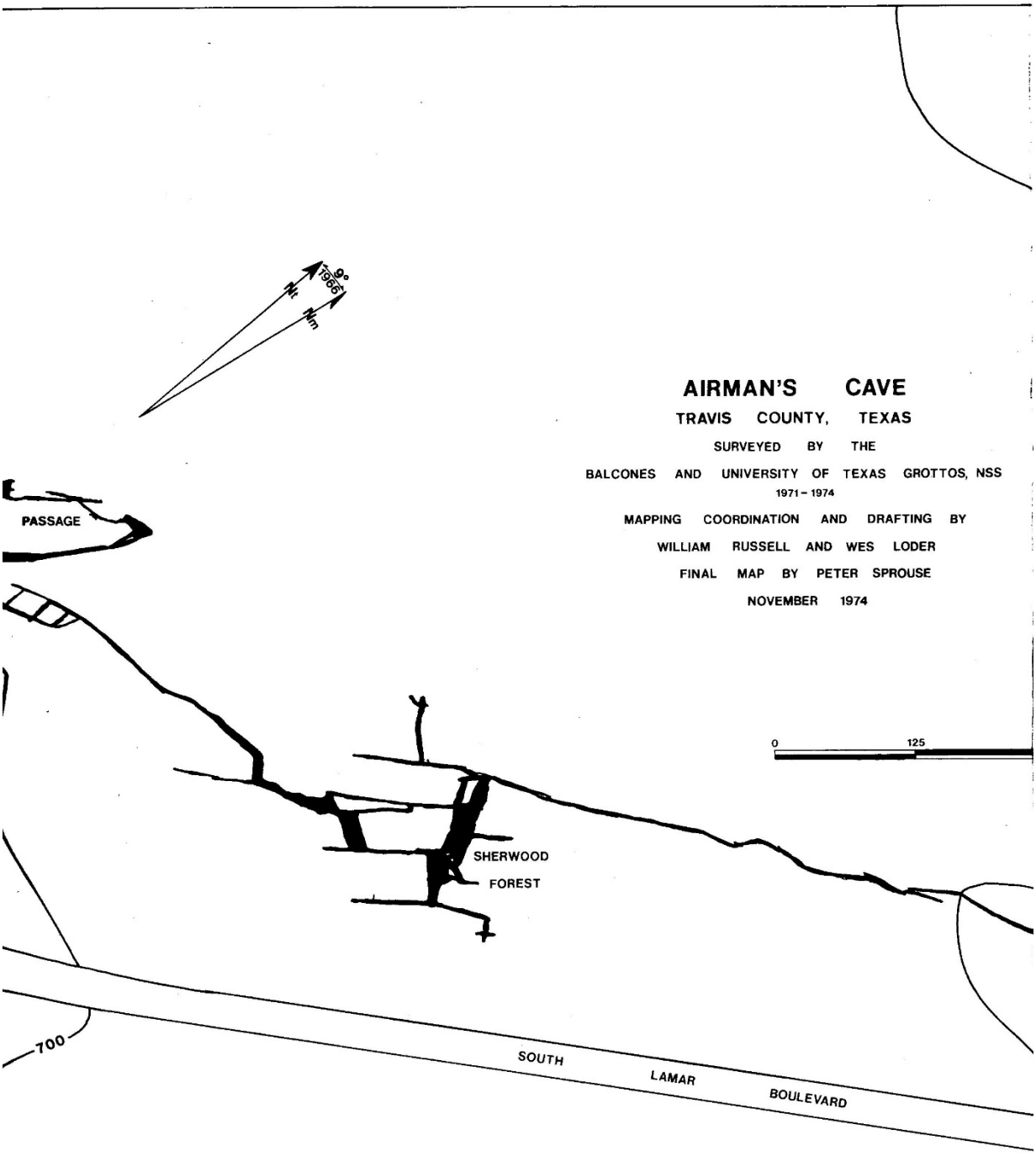

AIRMAN'S CAVE
TRAVIS COUNTY, TEXAS
SURVEYED BY THE
AND UNIVERSITY OF TEXAS GROTTOS, NSS
1971 - 1974
ING COORDINATION AND DRAFTING BY
ILLIAM RUSSELL AND WES LODER
FINAL MAP BY PETER SPROUSE
NOVEMBER 1974
700
0
125
250
500
FEET
KAREN CRAWL
AR
BOULEVARD


9°
1985
Mt
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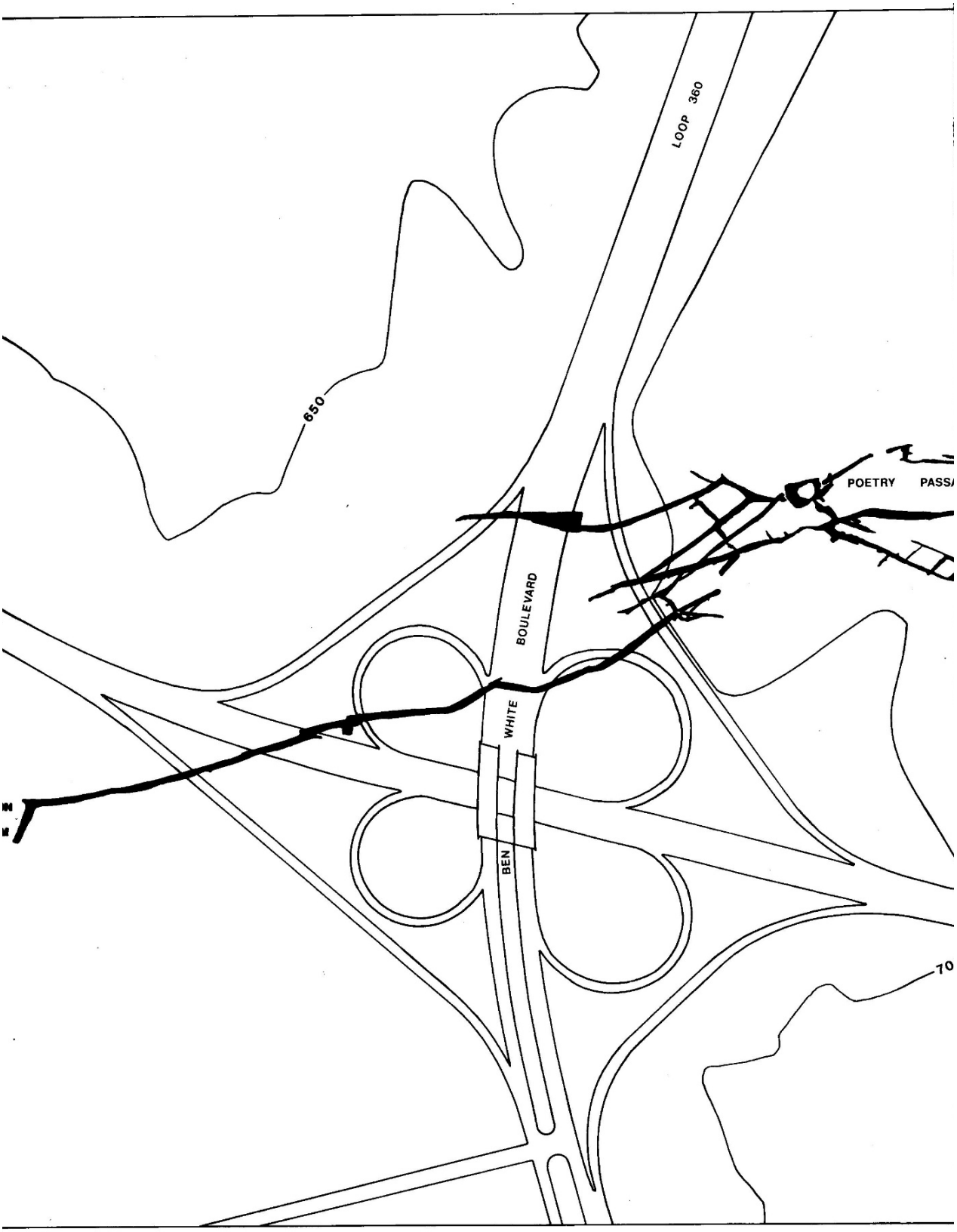
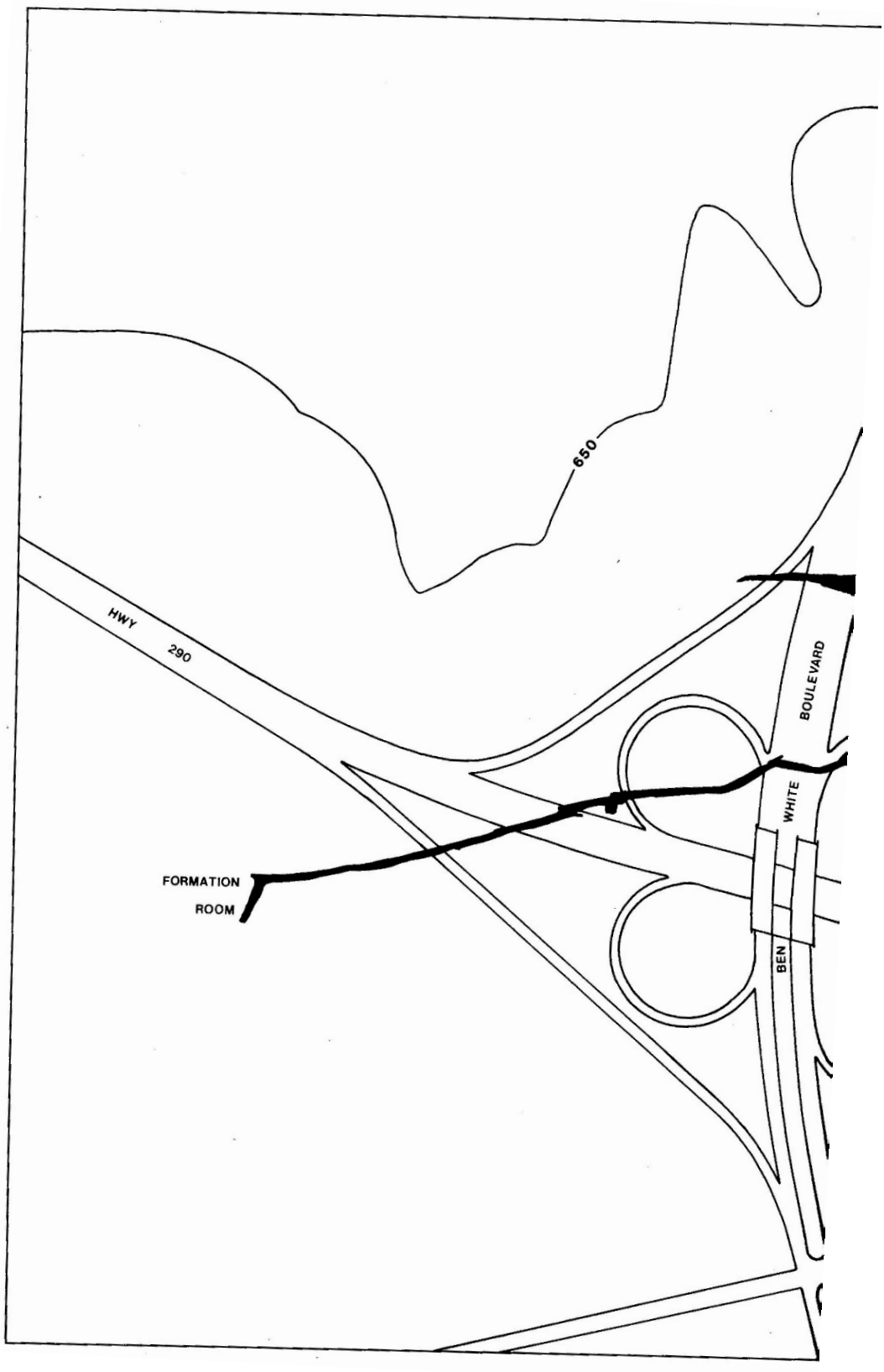
AIRMAN'S CAVE
TRAVIS COUNTY, TEXAS
SURVEYED BY THE
BALCONES AND UNIVERSITY OF TEXAS GROTTOS, NSS
1971 - 1974
MAPPING COORDINATION AND DRAFTING BY
WILLIAM RUSSELL AND WES LODER
FINAL MAP BY PETER SPROUSE
NOVEMBER 1974
PASSAGE
0
125
SHERWOOD
FOREST
700
SOUTH LAMAR BOULEVARD


LOOP 360
650
POETRY
BOULEVARD
WHITE
BEN
70


650
HWY 290
BOULEVARD
WHITE
BEN
FORMATION
ROOM

Appendix B. Geotechnical Borings by Terracon Consultants, Inc.

BORING LOG NO. B-1

PROJECT: Brodie Oaks Redevelopment

CLIENT: Barshop & Oles Co
Austin, TX

SITE: S Lamar Blvd and Capital of Texas Hwy
Austin, TX

LOCATION See Exploration Plan

Latitude: 30.2388° Longitude: -97.7972°

Approximate Surface Elev.: 708.0 (Ft.) +/-

MODEL LAYER	DEPTH	ELEVATION (Ft.)	LOCATION / DESCRIPTION	FIELD TEST RESULTS	RECOVERY (%) RQD (%)	STRENGTH TEST: TEST TYPE	STRENGTH TEST: COMPRESSIVE STRENGTH (tsf)	STRENGTH TEST: STRAIN (%)	WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ATTERBERG LIMITS LL-PL-PI	PERCENT FINES
	0.7	707.5+/-	**ASPHALT**, ~2½" of Asphalt over ~6" of Base Material	7-6-3 N=9					15			
1			**SANDY LEAN CLAY WITH GRAVEL (CL)**, brown to gray to light brown, stiff to very stiff, Possible Fill	1.5 tsf (HP) 3-7-11 N=18					14 14		31-14-17	53
	8.0	700+/-		7-10-13 N=23					9		46-22-24	40
	10.0	698+/-	**CLAYEY GRAVEL WITH SAND (GC)**, light tan to pale brown, very dense, Residual	10-10-50/5"								
4			**LIMESTONE (BUDA FORMATION)**, light tan to pale brown, extremely fractured, weathered, with frequent marly/clayey seams/layers		47 0							
	19.0	689+/-			30 13							
			CLAYEY SHALE (DEL RIO FORMATION), tan to brown, slightly fractured		80 40	UC	11.27	2.9	17	116		
					97 88							
					98 43	UC	11.02	4.3	22	106		
	36.0	672+/-			98 90							
5			**SHALE (DEL RIO FORMATION)**, dark gray to gray, slightly to moderately fractured		100 100							
					100 57	UC	3.88	1.5	15	118		
					100 85							

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Dry Augered to 10 feet; Air Rotary from 10 to 100 feet

Abandonment Method:
Boring backfilled with Auger Cuttings and/or Bentonite
Surface Capped with Asphalt

See Exploration and Testing Procedures for a description of field and laboratory procedures used and additional data (If any).

See Supporting Information for explanation of symbols and abbreviations.

Elevations were interpolated from Google Earth Pro.

Notes:

WATER LEVEL OBSERVATIONS

No free water observed

Terracon
5307 Industrial Oaks Blvd Ste 160
Austin, TX

Boring Started: 02-05-2020 | Boring Completed: 02-08-2020

Drill Rig: CME 55 | Driller: Austin Geo-Logic

Project No.: 96195345

BORING LOG NO. B-1

PROJECT: Brodie Oaks Redevelopment

CLIENT: Barshop & Oles Co
Austin, TX

SITE: S Lamar Blvd and Capital of Texas Hwy
Austin, TX

LOCATION See Exploration Plan
Latitude: 30.2388° Longitude: -97.7972°
Approximate Surface Elev.: 708.0 (Ft.) +/-

MODEL LAYER	GRAPHIC LOG	DEPTH	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	FIELD TEST RESULTS	RECOVERY (%) RQD (%)	STRENGTH TEST: TEST TYPE	STRENGTH TEST: COMPRESSIVE STRENGTH (tsf)	STRENGTH TEST: STRAIN (%)	WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ATTERBERG LIMITS: LL-PL-PI	PERCENT FINES
5				60				100/90	UC	23.11	3.8	14	122		
								100/83							
				65				100/88	UC	49.97		15	117		
				70				100/57							
6		75.0	633+/-	75				100/92	UC	24.65		14	125		
7		80.0	628+/-	80				100/68	UC	27.82		9	137		
				85				95/23	UC	123.47		8	141		
				90				93/67	UC	415.33		9	138		
				95				93/17	UC	266.45		4	148		
		100.0	608+/-	100											

SHALE (DEL RIO FORMATION), dark gray to gray, slightly to moderately fractured *(continued)*

- becomes clayey below ~68 feet

TRANSITION ZONE, Interbedded Stratum 5 shale and Stratum 7 limestone

LIMESTONE (GEORGETOWN FORMATION), gray to light gray, moderately to highly fractured

with marly/clayey seams from ~94 to 95 feet

Boring Terminated at 100 Feet

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Dry Augered to 10 feet; Air Rotary from 10 to 100 feet

Abandonment Method:
Boring backfilled with Auger Cuttings and/or Bentonite
Surface Capped with Asphalt

See Exploration and Testing Procedures for a description of field and laboratory procedures used and additional data (If any).

See Supporting Information for explanation of symbols and abbreviations.

Elevations were interpolated from Google Earth Pro.

Notes:

WATER LEVEL OBSERVATIONS

No free water observed

Terracon
5307 Industrial Oaks Blvd Ste 160
Austin, TX

Boring Started: 02-05-2020 | Boring Completed: 02-08-2020
Drill Rig: CME 55 | Driller: Austin Geo-Logic
Project No.: 96195345

BORING LOG NO. B-2

PROJECT: Brodie Oaks Redevelopment

CLIENT: Barshop & Oles Co
Austin, TX

SITE: S Lamar Blvd and Capital of Texas Hwy
Austin, TX

LOCATION See Exploration Plan

Latitude: 30.238° Longitude: -97.7953°

Approximate Surface Elev.: 703.0 (Ft.) +/-

MODEL LAYER	DEPTH	ELEVATION (Ft.)	DESCRIPTION
1	0.5	702.5+/-	**ASPHALT**, ~3" of Asphalt over ~3" of Base Material
	3.0	700+/-	**GRAVELLY FAT CLAY WITH SAND (CH)**, brown to gray to light brown, Possible Fill
	5.0	698+/-	**CLAYEY SAND WITH GRAVEL (SC)**, tan to light brown, Residual
4			**LIMESTONE (BUDA FORMATION)**, light tan to pale brown, highly to extremely fractured, weathered, with marly/clayey seams - with clayey layers/possible voids below ~10 feet
	19.0	684+/-	
5			**SHALEY FAT CLAY**, tan to gray, with infrequent limestone seams; **(Weathered Portion of Del Rio Formation)**
	40.0	663+/-	
			CLAYEY SHALE (DEL RIO FORMATION), gray to light gray

DEPTH (Ft.)	SAMPLE TYPE	FIELD TEST RESULTS	RECOVERY (%) / RQD (%)	TEST TYPE	COMPRESSIVE STRENGTH (tsf)	STRAIN (%)	WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ATTERBERG LIMITS LL-PL-PI	PERCENT FINES
0		8-10-11 N=21					11		40-15-25	44
		8-50/5"					13			
5		45-50/3"					13		53-17-36	46
			80/0	UC	487.19		0	154		
10			66/0							
15			50/0							
20			58/18	UC	5.13	3.9	22	105		
25			100/75				17		68-16-52	
30			90/67	UC	8.63	3.4	13	115		
35			100/67	UC	30.13		8	118		
40		5-11-14 N=25								
45		13-27-38 N=65					17		52-18-34	
50		11-21-23 N=44								
55		14-25-36 N=61								

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Dry Augered to 5 feet; Air Rotary from 5 to 38 feet; Dry Augered from 38 to 100 feet

Abandonment Method:
Boring backfilled with Auger Cuttings and/or Bentonite Surface Capped with Asphalt

See Exploration and Testing Procedures for a description of field and laboratory procedures used and additional data (If any).

See Supporting Information for explanation of symbols and abbreviations.

Elevations were interpolated from Google Earth Pro.

Notes:

WATER LEVEL OBSERVATIONS

No free water observed

Terracon
5307 Industrial Oaks Blvd Ste 160
Austin, TX

Boring Started: 01-29-2020 | Boring Completed: 01-31-2020

Drill Rig: CME 55 | Driller: Austin Geo-Logic

Project No.: 96195345

BORING LOG NO. B-2

PROJECT: Brodie Oaks Redevelopment

CLIENT: Barshop & Oles Co
Austin, TX

SITE: S Lamar Blvd and Capital of Texas Hwy
Austin, TX

LOCATION See Exploration Plan

Latitude: 30.238° Longitude: -97.7953°

Approximate Surface Elev.: 703.0 (Ft.) +/-

MODEL LAYER	GRAPHIC LOG	DEPTH	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	FIELD TEST RESULTS	RECOVERY (%) RQD (%)	STRENGTH TEST: TEST TYPE	STRENGTH TEST: COMPRESSIVE STRENGTH (tsf)	STRENGTH TEST: STRAIN (%)	WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ATTERBERG LIMITS: LL-PL-PI	PERCENT FINES
5															
			CLAYEY SHALE (DEL RIO FORMATION), gray to light gray *(continued)*												
				60			14-26-36 N=62								
				65			14-29-43 N=72								
				70			18-32-45 N=77								
				75			14-24-36 N=60								
		80.0	623+/-												
			SHALE (DEL RIO FORMATION), gray to light gray	80			17-37-50/4"								
				85			29-38-46 N=84								
				90			22-31-38 N=69								
				95			27-39-50/3"								
		100.0	603+/-												
			Boring Terminated at 100 Feet	100			20-32-46 N=78								

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Dry Augered to 5 feet; Air Rotary from 5 to 38 feet; Dry Augered from 38 to 100 feet

Abandonment Method:
Boring backfilled with Auger Cuttings and/or Bentonite
Surface Capped with Asphalt

See Exploration and Testing Procedures for a description of field and laboratory procedures used and additional data (If any).

See Supporting Information for explanation of symbols and abbreviations.

Elevations were interpolated from Google Earth Pro.

Notes:

WATER LEVEL OBSERVATIONS

No free water observed

Terracon
5307 Industrial Oaks Blvd Ste 160
Austin, TX

Boring Started: 01-29-2020 | Boring Completed: 01-31-2020

Drill Rig: CME 55 | Driller: Austin Geo-Logic

Project No.: 96195345

BORING LOG NO. B-4

PROJECT: Brodie Oaks Redevelopment

CLIENT: Barshop & Oles Co
Austin, TX

SITE: S Lamar Blvd and Capital of Texas Hwy
Austin, TX

LOCATION See Exploration Plan

Latitude: 30.2365° Longitude: -97.7971°

Approximate Surface Elev.: 705.0 (Ft.) +/-

MODEL LAYER	GRAPHIC LOG	DEPTH	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	FIELD TEST RESULTS	RECOVERY (%) RQD (%)	STRENGTH TEST: TEST TYPE	STRENGTH TEST: COMPRESSIVE STRENGTH (tsf)	STRENGTH TEST: STRAIN (%)	WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ATTERBERG LIMITS: LL-PL-PI	PERCENT FINES
		0.8	704+/-												
		2.0	703+/-				5-2-2 N=4					23			
							4.5 tsf (HP)								
				5			4.0 tsf (HP)					17		61-26-35	97
							4.5 tsf (HP)		UC	1.80	3.4	12	112		
							4.5 tsf (HP)					6			
				10											
1							4.5 tsf (HP)					23			
				15											
							4.5 tsf (HP)		UC	7.70	10.1	20	103		
				20											
							4.5 tsf (HP)					20		71-21-50	99
				25											
		28.0	677+/-				4.5 tsf (HP)					16		63-18-45	
				30				100/97							
				35				100/100	UC	4.19	1.1	21	108		
5				40				100/100							
				45				100/100	UC	2.64	8.6	20	121		
				50				100/100							
				55											

ASPHALT, ~2" of Asphalt over ~8" of Base Material

SANDY FAT CLAY WITH GRAVEL (CH), tan to light brown, soft, Possible Fill

FAT CLAY (CH), tan to brown, very stiff to hard, with gray seams **(Weathered Portion of Del Rio Formation)**

- with gypsum deposits below ~18 feet

CLAYEY SHALE (DEL RIO FORMATION), dark gray to gray, slightly fractured

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Dry Augered to 30 feet; Air Rotary from from 30 to 100 feet

Abandonment Method:
Boring backfilled with Auger Cuttings and/or Bentonite
Surface Capped with Asphalt

See Exploration and Testing Procedures for a description of field and laboratory procedures used and additional data (If any).

See Supporting Information for explanation of symbols and abbreviations.

Elevations were interpolated from Google Earth Pro.

Notes:

WATER LEVEL OBSERVATIONS

No free water observed

Terracon
5307 Industrial Oaks Blvd Ste 160
Austin, TX

Boring Started: 02-12-2020 | Boring Completed: 02-14-2020

Drill Rig: CME 45 | Driller: Austin Geo-Logic

Project No.: 96195345

BORING LOG NO. B-4

PROJECT: Brodie Oaks Redevelopment

CLIENT: Barshop & Oles Co
Austin, TX

SITE: S Lamar Blvd and Capital of Texas Hwy
Austin, TX

LOCATION See Exploration Plan

Latitude: 30.2365° Longitude: -97.7971°

Approximate Surface Elev.: 705.0 (Ft.) +/-

MODEL LAYER	GRAPHIC LOG	DEPTH	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	FIELD TEST RESULTS	RECOVERY (%) RQD (%)	STRENGTH TEST: TEST TYPE	STRENGTH TEST: COMPRESSIVE STRENGTH (tsf)	STRENGTH TEST: STRAIN (%)	WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ATTERBERG LIMITS: LL-PL-PI	PERCENT FINES
5		60.0	645+/-	60				100/100	UC	8.54	3.4	11	125		
6		66.0	639+/-	65				100/83							
7		100.0	605+/-	70				100/35	UC	263.86		5	142		
				75				100/50							
				80				100/40	UC	264.56		7	141		
				85				100/17	UC	124.15		3	121		
				90				100/0							
				95				100/23	UC	131.23		5	143		
				100				100/15	UC	379.68		2	154		

CLAYEY SHALE (DEL RIO FORMATION), dark gray to gray, slightly fractured *(continued)*

TRANSITION ZONE, Interbedded Stratum 5 shale and Stratum 7 limestone

LIMESTONE (GEORGETOWN FORMATION), gray to light gray, highly fractured, with marly seams

- becomes extremely fractured from ~80 to 90 feet

Boring Terminated at 100 Feet

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Dry Augered to 30 feet; Air Rotary from from 30 to 100 feet

Abandonment Method:
Boring backfilled with Auger Cuttings and/or Bentonite
Surface Capped with Asphalt

See Exploration and Testing Procedures for a description of field and laboratory procedures used and additional data (If any).

See Supporting Information for explanation of symbols and abbreviations.

Elevations were interpolated from Google Earth Pro.

Notes:

WATER LEVEL OBSERVATIONS

No free water observed

Terracon
5307 Industrial Oaks Blvd Ste 160
Austin, TX

Boring Started: 02-12-2020 | Boring Completed: 02-14-2020

Drill Rig: CME 45 | Driller: Austin Geo-Logic

Project No.: 96195345

BORING LOG NO. B-5

PROJECT: Brodie Oaks Redevelopment

CLIENT: Barshop & Oles Co
Austin, TX

SITE: S Lamar Blvd and Capital of Texas Hwy
Austin, TX

LOCATION See Exploration Plan

Latitude: 30.2358° Longitude: -97.7943°

Approximate Surface Elev.: 702.0 (Ft.) +/-

MODEL LAYER	GRAPHIC LOG	DEPTH	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	FIELD TEST RESULTS	RECOVERY (%) RQD (%)	STRENGTH TEST: TEST TYPE	STRENGTH TEST: COMPRESSIVE STRENGTH (tsf)	STRENGTH TEST: STRAIN (%)	WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ATTERBERG LIMITS: LL-PL-PI	PERCENT FINES
		0.9	701+/-												
		2.0	700+/-												
1				5			16-13-14 N=27					5			
							7-6-7 N=13					11		41-15-26	62
							5-5-9 N=14					11			
							5-4-4 N=8					12			
				10			3-6-10 N=16					22		62-19-43	99
		13.0	689+/-												
				15			5-14-21 N=35					20			
				20			5-10-13 N=23					24		64-18-46	99
				25			6-9-13 N=22					18			
				30			6-10-15 N=25					23			
2				35			15-16-31 N=47					18		58-18-40	
				40			10-14-24 N=38								
				45			9-18-29 N=47					19		63-19-44	98
				50			7-13-50/6"								
				55			5-14-26 N=40								

ASPHALT, 6" of Asphalt over 4½" of Base Material

FILL - CLAYEY GRAVEL WITH SAND (GC), pale brown to light tan, medium dense

GRAVELLY FAT CLAY WITH SAND (CH), dark brown to brown to gray, stiff

- becomes very stiff below ~8 feet

FAT CLAY (CH), tan to brown, very stiff to hard, with ferrous seams and gray seams

(Weathered Portion of Eagle Ford Formation)

- with gypsum deposits below ~33 feet

- becomes gray to brown below ~53 feet

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Dry Augered to 60 feet; Air Rotary from 60 to 85 fee

Abandonment Method:
Boring backfilled with Auger Cuttings and/or Bentonite
Surface Capped with Asphalt

See Exploration and Testing Procedures for a description of field and laboratory procedures used and additional data (If any).

See Supporting Information for explanation of symbols and abbreviations.

Elevations were interpolated from Google Earth Pro.

Notes:

WATER LEVEL OBSERVATIONS

No free water observed

Terracon
5307 Industrial Oaks Blvd Ste 160
Austin, TX

Boring Started: 02-12-2020 | Boring Completed: 02-13-2020

Drill Rig: CME 45 | Driller: Austin Geo-Logic

Project No.: 96195345

BORING LOG NO. B-5

PROJECT: Brodie Oaks Redevelopment

CLIENT: Barshop & Oles Co
Austin, TX

SITE: S Lamar Blvd and Capital of Texas Hwy
Austin, TX

LOCATION See Exploration Plan

Latitude: 30.2358° Longitude: -97.7943°

Approximate Surface Elev.: 702.0 (Ft.) +/-

MODEL LAYER	GRAPHIC LOG	DEPTH	ELEVATION (Ft.)	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	FIELD TEST RESULTS	RECOVERY (%) RQD (%)	STRENGTH TEST: TEST TYPE	STRENGTH TEST: COMPRESSIVE STRENGTH (tsf)	STRENGTH TEST: STRAIN (%)	WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ATTERBERG LIMITS: LL-PL-PI	PERCENT FINES
		58.0	644+/-												
2			**CLAYEY SHALE (EAGLE FORD FORMATION)**, dark gray to gray, highly fractured	60			19-31-50/6"					19			
		64.0	638+/-					38/38	UC	5.98	3.5	13	121		
3		67.0	635+/-	65				97/93	UC	368.67		3	181		
			TRANSITION ZONE, Interbedded Stratum 2 shale and Stratum 4 limestone												
4			**LIMESTONE (BUDA FORMATION)**, gray to light gray, slightly fractured - becomes light tan/pale brown, with tan clay seams from ~70 to 75 feet	70				100/83	UC	473.16		2	180		
				75				100/95	UC	463.40		3	152		
			- becomes highly fractured below ~80 feet	80				100/30	UC	95.37		3	151		
		85.0	617+/-	85											
			Boring Terminated at 85 Feet												

Stratification lines are approximate. In-situ, the transition may be gradual.

Hammer Type: Automatic

Advancement Method:
Dry Augered to 60 feet; Air Rotary from 60 to 85 fee

Abandonment Method:
Boring backfilled with Auger Cuttings and/or Bentonite
Surface Capped with Asphalt

See Exploration and Testing Procedures for a description of field and laboratory procedures used and additional data (If any).

See Supporting Information for explanation of symbols and abbreviations.

Elevations were interpolated from Google Earth Pro.

Notes:

WATER LEVEL OBSERVATIONS

No free water observed

Terracon
5307 Industrial Oaks Blvd Ste 160
Austin, TX

Boring Started: 02-12-2020 | Boring Completed: 02-13-2020

Drill Rig: CME 45 | Driller: Austin Geo-Logic

Project No.: 96195345

Appendix C. Water Quality Results

Environmental Laboratory Services
The Solution Lab

LCRA Environmental Laboratory Services
3505 Montopolis Drive
Austin, TX 78744
Phone (512)730-6022
Fax (512)730-6021

Analytical Results

Client ID: BCPWCD-AUWAT
Lab ID: Q2122072001
Sample ID: AIRMANS FORMATION POOL
Project ID: FLINT RIDGE

Date Collected: 08/16/2021 14:45
Date Received: 08/17/2021 12:45
Location:
Facility:
Sample Point:

Matrix: Aqueous
Sample Type: SAMPLE

ALKALINITY (SM2320B, Alkalinity)

Parameter	Results	Units	MRL	LOD	ML	DF	Prepared	By	Analyzed	By	Qualifier
Total Alkalinity (CaCO3)	94.4	mg/L	20.0	20.0		1	08/19/2021 00:00	ME	08/19/2021 00:00	ME	

AMMONIA AS N (E350.1 NH3-N by SemiAuto Col)

Parameter	Results	Units	MRL	LOD	ML	DF	Prepared	By	Analyzed	By	Qualifier
Nitrogen, Ammonia (as N)	0.0862	mg/L	0.0200	0.00800		1	08/18/2021 00:00	ME	08/18/2021 00:00	ME	

E-COLI by IDEXX (SM9223B, IDEXX)

Parameter	Results	Units	MRL	LOD	ML	DF	Prepared	By	Analyzed	By	Qualifier
Ecoli	<1.00	MPN/100mL	1.00	1.00		1	08/17/2021 17:10	ERR	08/17/2021 17:10	ERR	H
Ecoli Holding Time	26.4	HOURS	0.0	0.0			08/17/2021 17:10	ERR	08/17/2021 17:10	ERR	N,H

INORGANICS (E200.7 Prep/E200.7 Metals, Trace Elements)

Parameter	Results	Units	MRL	LOD	ML	DF	Prepared	By	Analyzed	By	Qualifier
Boron Dissolved	<0.0200	mg/L	0.0500	0.0200		1	08/18/2021 17:10	ERR	08/31/2021 22:53	FM	
Iron Dissolved	<0.0200	mg/L	0.0500	0.0200		1	08/18/2021 17:10	ERR	08/31/2021 22:53	FM	
Magnesium Dissolved	17.9	mg/L	0.200	0.0700		1	08/18/2021 17:10	ERR	08/31/2021 22:53	FM	
Potassium Dissolved	6.76	mg/L	0.200	0.0700		1	08/18/2021 17:10	ERR	08/31/2021 22:53	FM	
Sodium Dissolved	145	mg/L	0.200	0.0700		1	08/18/2021 17:10	ERR	08/31/2021 22:53	FM	

INORGANICS (E200.7 Prep/E200.7 Metals, Trace Elements)

Parameter	Results	Units	MRL	LOD	ML	DF	Prepared	By	Analyzed	By	Qualifier
Calcium Dissolved	535	mg/L	0.400	0.140		2	08/18/2021 17:10	ERR	09/01/2021 19:38	FM	

INORGANICS (E200.8, ICP-MS Prep/E200.8, ICP-MS)

Parameter	Results	Units	MRL	LOD	ML	DF	Prepared	By	Analyzed	By	Qualifier
Aluminum Dissolved	0.00376	mg/L	0.00500	0.00150		1	08/18/2021 17:08	ERR	08/19/2021 15:20	FO	
Arsenic Dissolved	<0.000700	mg/L	0.00100	0.000700		1	08/18/2021 17:08	ERR	08/19/2021 15:20	FO	
Cadmium Dissolved	<0.000400	mg/L	0.00100	0.000400		1	08/18/2021 17:08	ERR	08/19/2021 15:20	FO	
Copper Dissolved	0.000427	mg/L	0.00100	0.000400		1	08/18/2021 17:08	ERR	08/19/2021 15:20	FO	
Lithium Dissolved	0.110	mg/L	0.00200	0.000700		1	08/18/2021 17:08	ERR	08/19/2021 15:20	FO	N
Lead Dissolved	<0.000400	mg/L	0.00100	0.000400		1	08/18/2021 17:08	ERR	08/19/2021 15:20	FO	
Nickel Dissolved	0.00256	mg/L	0.00100	0.000400		1	08/18/2021 17:08	ERR	08/19/2021 15:20	FO	
Zinc Dissolved	<0.00150	mg/L	0.00500	0.00150		1	08/18/2021 17:08	ERR	08/19/2021 15:20	FO	

INORGANICS (E200.8, ICP-MS Prep/E200.8, ICP-MS)

Parameter	Results	Units	MRL	LOD	ML	DF	Prepared	By	Analyzed	By	Qualifier
Strontium Dissolved	1.66	mg/L	0.0100	0.00400		10	08/18/2021 17:08	ERR	08/19/2021 15:56	FO	

Environmental Laboratory Services
The Solution Lab

LCRA Environmental Laboratory Services
3505 Montopolis Drive
Austin, TX 78744
Phone (512)730-6022
Fax (512)730-6021

Analytical Results

Client ID:	BCPWCD-AUWAT	**Date Collected:**	08/16/2021 14:45	**Matrix:**	Aqueous
Lab ID:	Q2122072001	**Date Received:**	08/17/2021 12:45	**Sample Type:**	SAMPLE
Sample ID:	AIRMANS FORMATION POOL	**Location:**			
Project ID:	FLINT RIDGE	**Facility:**			
		Sample Point:			

INORGANICS (E300.0, Anions)

Parameter	Results	Units	MRL	LOD	ML	DF	Prepared	By	Analyzed	By	Qualifier
Sulfate Dissolved	1500	mg/L	25.0	10.0		25	08/24/2021 13:28	FO	08/24/2021 13:28	FO	

INORGANICS (E300.0, Anions)

Parameter	Results	Units	MRL	LOD	ML	DF	Prepared	By	Analyzed	By	Qualifier
Chloride DIssolved	91.3	mg/L	10.0	4.00		10	08/19/2021 19:55	FO	08/19/2021 19:55	FO	
Bromide Dissolved	0.384	mg/L	0.200	0.0800		10	08/19/2021 19:55	FO	08/19/2021 19:55	FO	
Fluoride Dissolved	0.931	mg/L	0.100	0.0400		10	08/19/2021 19:55	FO	08/19/2021 19:55	FO	

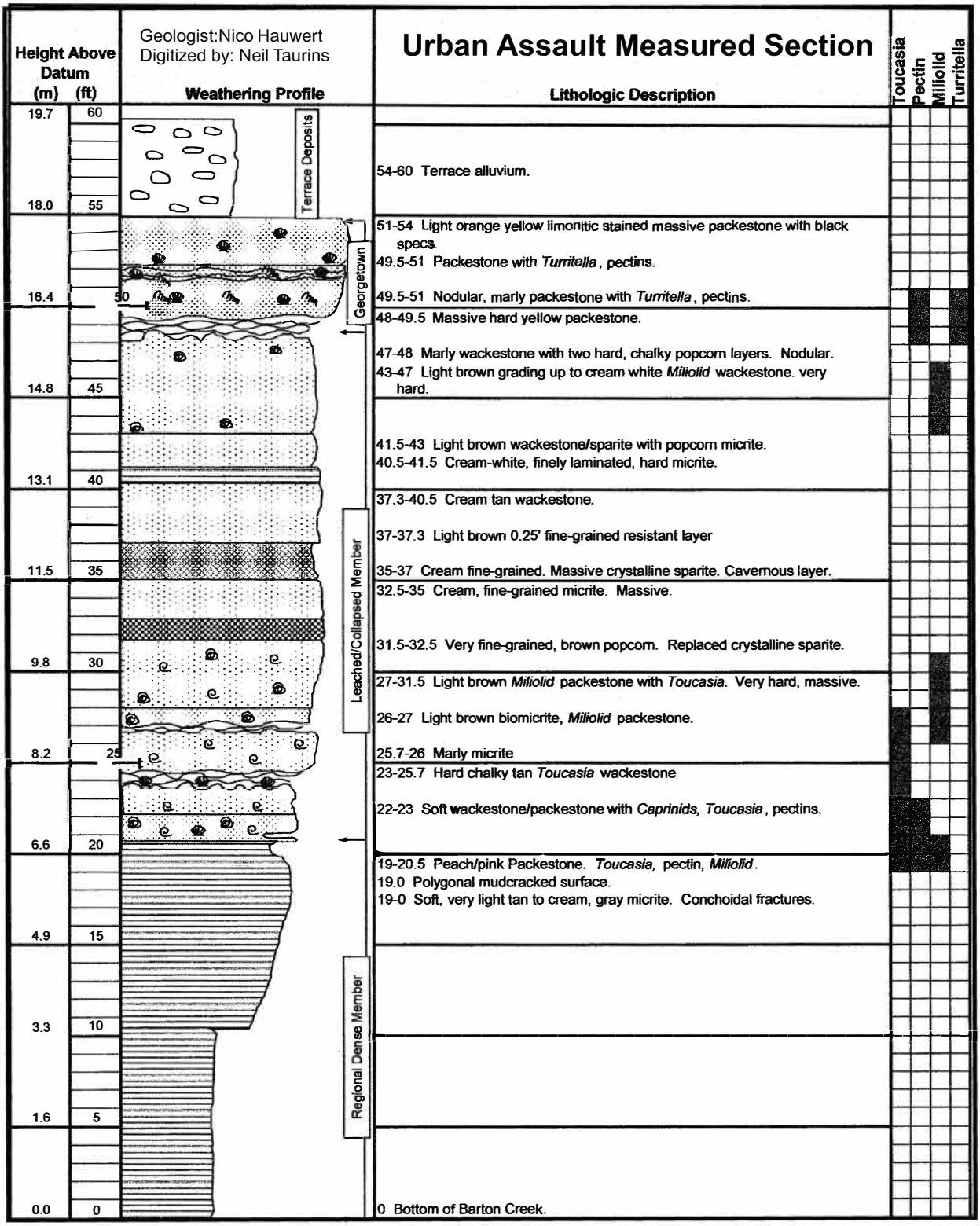
ORGANIC CARBON, DISSOLVED (SM5310C, Total Organic Carbon)

Parameter	Results	Units	MRL	LOD	ML	DF	Prepared	By	Analyzed	By	Qualifier
Total Organic Carbon,Dissolved	3.17	mg/L	0.5	0.2		1	08/18/2021 00:00	FM	08/18/2021 00:00	FM	

TOTAL PHOSPHATE AS P (E365.4 / E351.2 Water Prep/E365.4 Phosphorus, Total)

Parameter	Results	Units	MRL	LOD	ML	DF	Prepared	By	Analyzed	By	Qualifier
Phosphorus, Dissolved (As P)	<0.00800	mg/L	0.0200	0.00800		1	08/30/2021 13:56	ML	09/01/2021 00:00	ME	

Appendix D. Measured Section Along Barton Creek


Urban Assault Measured Section
Geologist:Nico Hauwert
Digitized by: Neil Taurins
Height Above Datum (m) (ft)
Weathering Profile
Lithologic Description
Toucasia
Pectin
Miliolid
Turritella
Terrace Deposits
Georgetown
Leached/Collapsed Member
Regional Dense Member
19.7 60
18.0 55
16.4 50
14.8 45
13.1 40
11.5 35
9.8 30
8.2 25
6.6 20
4.9 15
3.3 10
1.6 5
0.0 0
54-60 Terrace alluvium.
51-54 Light orange yellow limonitic stained massive packestone with black specs.
49.5-51 Packestone with Turritella, pectins.
49.5-51 Nodular, marly packestone with Turritella, pectins.
48-49.5 Massive hard yellow packestone.
47-48 Marly wackestone with two hard, chalky popcorn layers. Nodular.
43-47 Light brown grading up to cream white Miliolid wackestone. very hard.
41.5-43 Light brown wackestone/sparite with popcorn micrite.
40.5-41.5 Cream-white, finely laminated, hard micrite.
37.3-40.5 Cream tan wackestone.
37-37.3 Light brown 0.25' fine-grained resistant layer
35-37 Cream fine-grained. Massive crystalline sparite. Cavernous layer.
32.5-35 Cream, fine-grained micrite. Massive.
31.5-32.5 Very fine-grained, brown popcorn. Replaced crystalline sparite.
27-31.5 Light brown Miliolid packestone with Toucasia. Very hard, massive.
26-27 Light brown biomicrite, Miliolid packestone.
25.7-26 Marly micrite
23-25.7 Hard chalky tan Toucasia wackestone
22-23 Soft wackestone/packestone with Caprinids, Toucasia, pectins.
19-20.5 Peach/pink Packestone. Toucasia, pectin, Miliolid.
19.0 Polygonal mudcracked surface.
19-0 Soft, very light tan to cream, gray micrite. Conchoidal fractures.
0 Bottom of Barton Creek.
Turritella
Toucasia
Burrows
Caprinid
Texigryphaea
Pectin
Miliolid
Chondrodont
Arcostrea
Ammonite
Clam
Wackestone/Micrite
Grainstone
Sparite/Crystalline
Nodular
Packestone
Fissile/Laminated
Wavy/Laminated