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# Geologic Mapping of Upper Glen Rose Unit 3 (Lower Cretaceous) in the Onion Creek Basin, Western Hays County, Texas: Implications for Recharge to the Trinity Aquifer

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## ABSTRACT

**Understanding of geologic structure, lithology, and spatial distribution of geologic units that act as barriers to flow (aquitards) is critical for delineating groundwater movement and recharge in karst aquifers. In western Hays County, Texas, the Upper Glen Rose Member of the Trinity Group accounts for most of the surface outcrop and forms what is commonly referred to as the Upper Trinity Aquifer. Surface water/groundwater interactions within the Upper Glen Rose are complex, with numerous karst features pirating surface water flow in some locations, and gravity seeps and springs contributing flow in other locations. While considerable work has been done on the regional lithostratigraphy of the Upper Glen Rose, little is known about its hydrogeologic properties and influence on the surface and groundwater flows. This is especially important for streams flowing over the Upper Glen Rose that may provide recharge to the underlying Middle Trinity Aquifer.**

**This paper presents results of surface and subsurface geologic mapping of a subunit of the Upper Glen Rose known as unit 3, previously identified by Stricklin et al. (1971). Remote sensing, subsurface geophysical log interpretation, measured surface sections, and field mapping methods allowed production of detailed structure and outcrop maps of the study area. These maps, coupled with gain/loss data, show that stream reaches where unit 3 has been breached by erosion frequently overlap with locations of established surface flow losses. However, where unit 3 has not been breached, the stream is generally gaining flow. This suggests that unit 3 may act as an aquitard, preventing downward migration of groundwater into the underlying Middle Trinity Aquifer. Along stream reaches where unit 3 is absent, prominent through-going fractures observed in the stream bed appear to provide a pathway for recharge to the Middle Trinity Aquifer.**

## INTRODUCTION

In western Hays County, Texas, the Trinity Aquifer is a critical groundwater resource, providing water for drinking, business, and agricultural use for thousands of residents. The aquifer is contained within the Trinity Group, an approximately 1000 ft (305 m) package of marine carbonate rock deposited in the Early Cretaceous, and is subdivided into the Upper, Middle, and Lower Trinity aquifers, with the majority of water production from the Middle Trinity Aquifer.



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The source of recharge to the Middle Trinity Aquifer, and its hydraulic relationship to the overlying Upper Trinity Aquifer, is not well understood. Recharge in the Middle Trinity Aquifer was thought to originate tens of miles to the west, or through slow percolation from the Upper Trinity Aquifer (Wierman et al., 2010). However, recent work by Hunt et al. (2016) suggests that some proportion of recharge occurs as rapid localized inputs from surface streams in the Onion Creek Basin in the vicinity of the city of Dripping Springs. From this work, it follows that a more detailed understanding of surface geology is required to determine the mechanism by which surface water recharges, and whether the recharge reaches deeper water-bearing units in the Middle Trinity Aquifer.

This paper presents results of surface and subsurface geologic mapping of units within the Upper Trinity Aquifer, which is composed of the Upper Glen Rose, the upper member of the Glen

Rose Formation. The Upper Glen Rose crops out over much of the Onion Creek Basin and overlies the Middle Trinity Aquifer (Fig. 1). Mapping was focused on a subunit of the Upper Glen Rose known as unit 3, which was previously established by Stricklin et al. (1971). Unit 3 is a fossiliferous, clay rich unit, and was hypothesized in previous work to act as an important barrier to downward vertical flow (Muller, 1990).

## PREVIOUS WORK ON THE UPPER GLEN ROSE FORMATION

Robert Thomas Hill named the Comanche Series of the Lower Cretaceous in the late 19th century and identified critical structural and stratigraphic locations in Central Texas (Reasler, 1997). Numerous geoscientists followed Hill to further our understanding of local Lower Cretaceous geology and paleontology. However, it was Lozo and Stricklin (1956) and Stricklin et al. (1971) who established lithostratigraphic subdivisions of the Lower Cretaceous stratigraphy in Central Texas. The Upper Glen Rose was divided from the Lower Glen Rose by the "*Corbula* bed," a regionally extensive, thin-bedded unit containing abundant fossils of *Eoursivivas harveyi*, a small clam commonly referred to as "*Corbula*." The Upper Glen Rose was further subdivided into eight distinctive geologic subunits (Stricklin et al., 1971). Later authors mapped the Trinity in the area (Barnes 1978a, 1978b; Barnes 1982; Collins, 2002; Barker and Ardis, 1996; Clark et al., 2016) and described and interpreted its lithostratigraphy and hydrostratigraphy (Scott et al., 2007; Ward and Ward, 2007). DeCook (1963) described groundwater resources and the hydrostratigraphic properties of Trinity units within Hays County. Wierman et al (2010) tied much of the geology of Blanco and Hays counties using both surface and well data. The individual subunits of the Upper Glen Rose however were not mapped.

Muller (1990) described the hydrostratigraphy of Upper Glen Rose subunits from Stricklin et al. (1971) in the Dripping Springs area. Muller (1990) identified unit 3 as an aquitard to the perched aquifers in overlying units 4 and 5. Ward and Ward (2007) detailed this portion of the Glen Rose section exposed in the gorge below Canyon Lake in Comal County (Fig. 1). Ward and Ward's (2007) detailed measured section included the Lower Glen Rose upward through the Corbula interval into the basal beds of Unit 4. Rader (2007) discussed the *Orbitolina* and *Porocystis* marker beds in unit 3. Scott et al. (2007) formally proposed the use of Upper Glen Rose Member and Lower Glen Rose Member, separated by the *Corbula* bed. The Upper Glen Rose subunits established by Stricklin et al. (1971) and the stratigraphic nomenclature from Muller (1990), Scott et al. (2007), and Rader (2007) were adopted for this paper.

Hunt et al. (2016) published an analysis of initial findings on surface and groundwater interactions along Onion Creek. In the discussion, the authors suggested that the presence or absence of unit 3, along with local fracturing, may have been factors in explaining losing stream segments observed in the creek in the

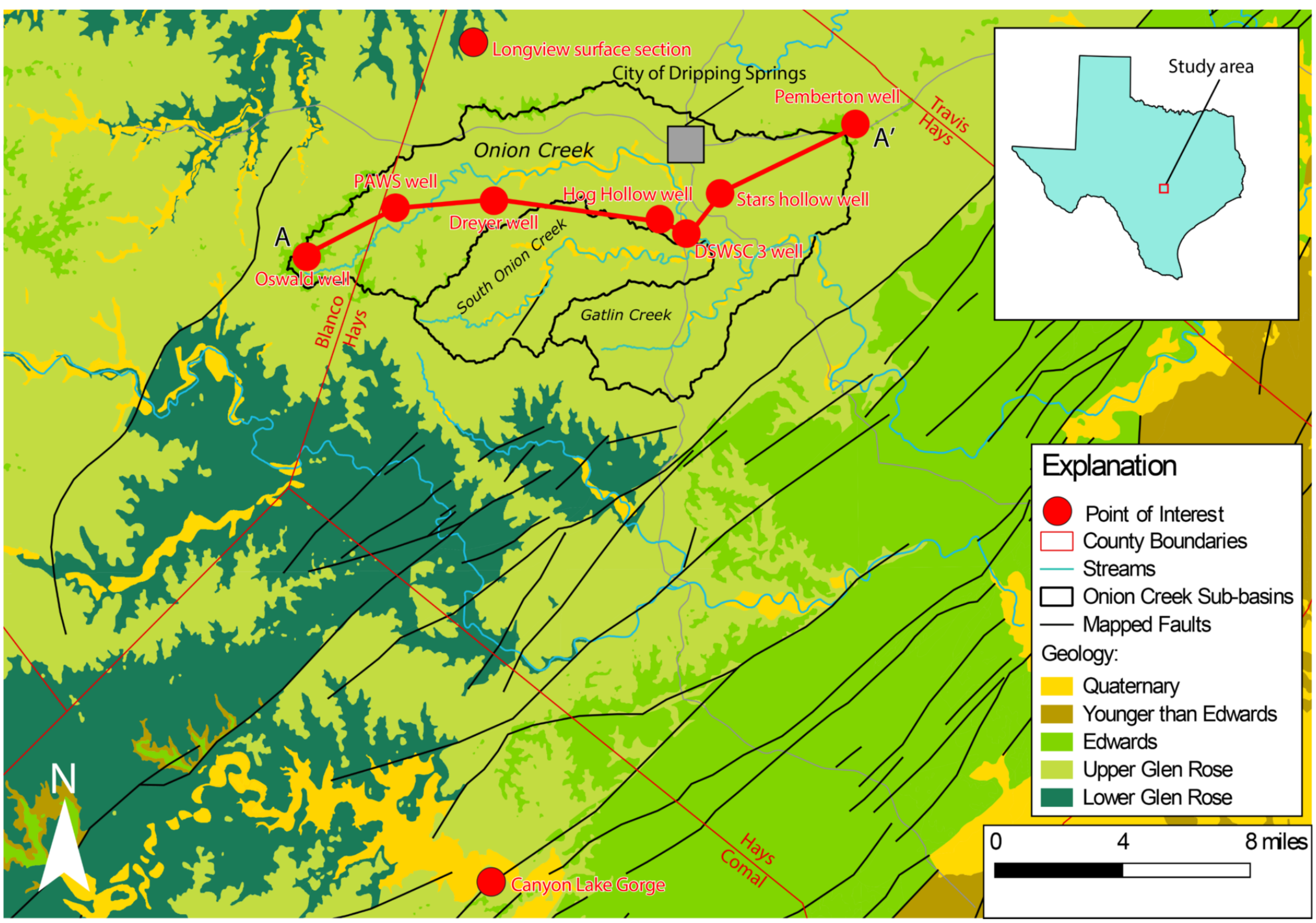



**Figure 1. Map of study area for Upper Glen Rose mapping. Geologic base map data from the Bureau of Economic Geology (2018).**

vicinity of the City of Dripping Springs. Downstream of Dripping Springs, Onion Creek loses a substantial portion of its flow as it flows over the Balcones Fault Zone. This mapping project is the next step in evaluating unit 3 and relating its spatial distribution and possible relevance to the hydrostratigraphy and recharge to the aquifers of the Upper Onion Creek watershed.

## STUDY AREA

The study area of this project is the upper Onion Creek watershed (basin) in the vicinity of the City of Dripping Springs, Texas (Fig. 1). The basin occurs mostly in western Hays County, with a small tip of the headwaters extending into eastern Blanco County. The three most important streams in the watershed are Onion Creek, South Onion Creek, and Gatlin Creek (Fig. 1).

Hays County has a population of over 190,000 and is currently one of the five fastest growing counties in the U.S. (Buckingham, 2016). The study area has undergone rapid population growth and development in the last ten years, with numerous new housing and commercial developments presently being built or planned for the near future. Most residents in the study area depend on water pumped from wells in the Trinity Aquifer as their primary source of drinking water. Those wells include many small domestic supply wells and municipal water supply for the City of Dripping Springs.

### Geologic and Structural Setting

Mapping is focused on the desiccated eastern edge of the Edwards Plateau and within the Onion Creek watershed. Structurally it occupies a small part of the stable platform of the widespread, shallow marine Comanche Shelf. The Trinity Group (Lower Cretaceous) makes up the majority of surface outcrop and has a full section thickness of approximately 1000 ft (305 m) over the study area. Trinity strata dip gently 1–1.5° eastward until intersected by the early Miocene-aged Balcones Fault Zone where the section is downthrown towards the Gulf of Mexico and has steeper dips.

Regional uplift to the west exposed the section to erosion, and rapidly flowing Hill Country streams excised the younger strata and cut sharply into the Albian Upper Glen Rose. During the late Tertiary (during or before the Pleistocene), the overlying low permeability sedimentary cover was breached by rapidly eroding streams (Lundelius, 1986). Quaternary terrace deposits overly Trinity strata in Onion Creek and have been mapped by Collins (2002). The gravel contains coarse, poorly sorted limestone clasts cemented with calcium carbonate (caliche). The ancestral Onion Creek deposited a widespread alluvial plain and relic cut-terraces the Dripping Springs area.

The exposed Upper Glen Rose carbonate section is fractured, with very thin beds appearing shattered. Prominent northeast-southwest linear trends are present that can be projected from outcropping Lower Glen Rose units in the Blanco River valley, but no through-going faults have been observed on the ground; the structure possibly masked by the thick Upper Glen Rose. The lithologic makeup of the stratigraphy—thin bedded, nodular limestones and dolomites with interbedded mudstone and claystone—would suggest that faulting was limited by the absence of thick, competent carbonate beds. In this situation that strain is taken up by minor folding perhaps represented at the surface by gentle monoclinal features (Ferrill et al., 2011).

### Hydrostratigraphy

The Trinity Aquifer is composed primarily of carbonate units deposited during the Lower Cretaceous (Fig. 2). Surface water streams flowing over outcropping Trinity strata are closely connected with the aquifer, causing complex surface water/groundwater interactions. Springs discharging from the Trinity provide base flow for these streams. In other locations, stream flow recharges the aquifer directly through karst features such as solution enlarged fractures and sinkholes (Smith et al., 2014).

The Trinity Aquifer is subdivided into three subaquifers: the Upper, Middle, and Lower Trinity Aquifer (Fig. 2). The Lower Trinity Aquifer consists of the Hosston Formation and Sligo Formation (where present) and represents a more deeply confined and isolated aquifer system. Lower Trinity Aquifer water is generally higher in total dissolved solids (TDS), has relatively low yields, and is not the primary target for water supply in the study area. The Lower Trinity is not the focus of this study. The Middle Trinity Aquifer is the primary water-producer in the study area. It is separated from the Lower Trinity by the Hammett shale confining unit. The Middle Trinity Aquifer consists of the Cow Creek Formation, Hensel Formation, and Lower Glen Rose Member, discussed below.

Water quality in the Middle Trinity varies spatially across the study area with TDS ranging from 500–3000 ppm. Gypsum beds occurring in some regions of the study area are often associated with elevated sulfates and TDS. Hunt et al. (2016) noted a trough of low TDS (~500 ppm) in the vicinity of Dripping Springs coincident with the Upper Onion Creek Basin, which may be associated with surface water recharge into the Middle Trinity Aquifer.

The Upper Trinity Aquifer consists of the Upper Glen Rose Member. Groundwater occurs as a series of isolated perched aquifers spatially controlled by topography and the presence of confining clay subunits within the Upper Glen Rose (Muller 1990). Prominent perennial springs sourced from the Upper Glen Rose within the study area include Dripping Springs, Emerald Springs, Horseshoe Springs, and Walnut Springs. These springs and shallow perched zones were historically the sole source of water in the area. Additionally, abundant ephemeral springs and seeps issue from the Upper Glen Rose following rain events and during seasonally wet periods.

#### Cow Creek Formation

The Cow Creek Formation is approximately 80 ft (24 m) thick in the study area and is typically the most productive unit in the Middle Trinity Aquifer. The top 20 ft (6 m) consists of coarse skeletal grainstone that transitions into a crystalline dolomite with depth. Large voids or caves are frequently found at the top of the Cow Creek Formation at the contact with the Hensel Formation and may be associated with conduits which rapidly transmit water through the subsurface.

#### Hensel Formation

The Hensel Formation is 20–60 ft (6–18 m) thick across the study area, decreasing in thickness from west to east. In Blanco County to the west of the study area, the Hensel Formation is composed predominantly of coarse siliciclastic rock from which groundwater may be produced. To the east and over the study area, the Hensel Formation transitions into an argillaceous, dolomitic siltstone with thin dolomites and mudstone beds that may allow it to act as a semi-confining unit.

#### Lower Glen Rose Member

The Lower Glen Rose Member is an approximately 200 ft (60 m) thick carbonate unit in the study area and generally increases in thickness from west to east. In the eastern and southern portions of the study area, the Lower Glen Rose section often contains reefal mound/framebuilder facies buildups. These buildups have been productive aquifers in some locations. In the western portion of the study area along the Hays/Blanco County line, reef buildups are absent and the Lower Glen Rose is typically not a productive aquifer unit.

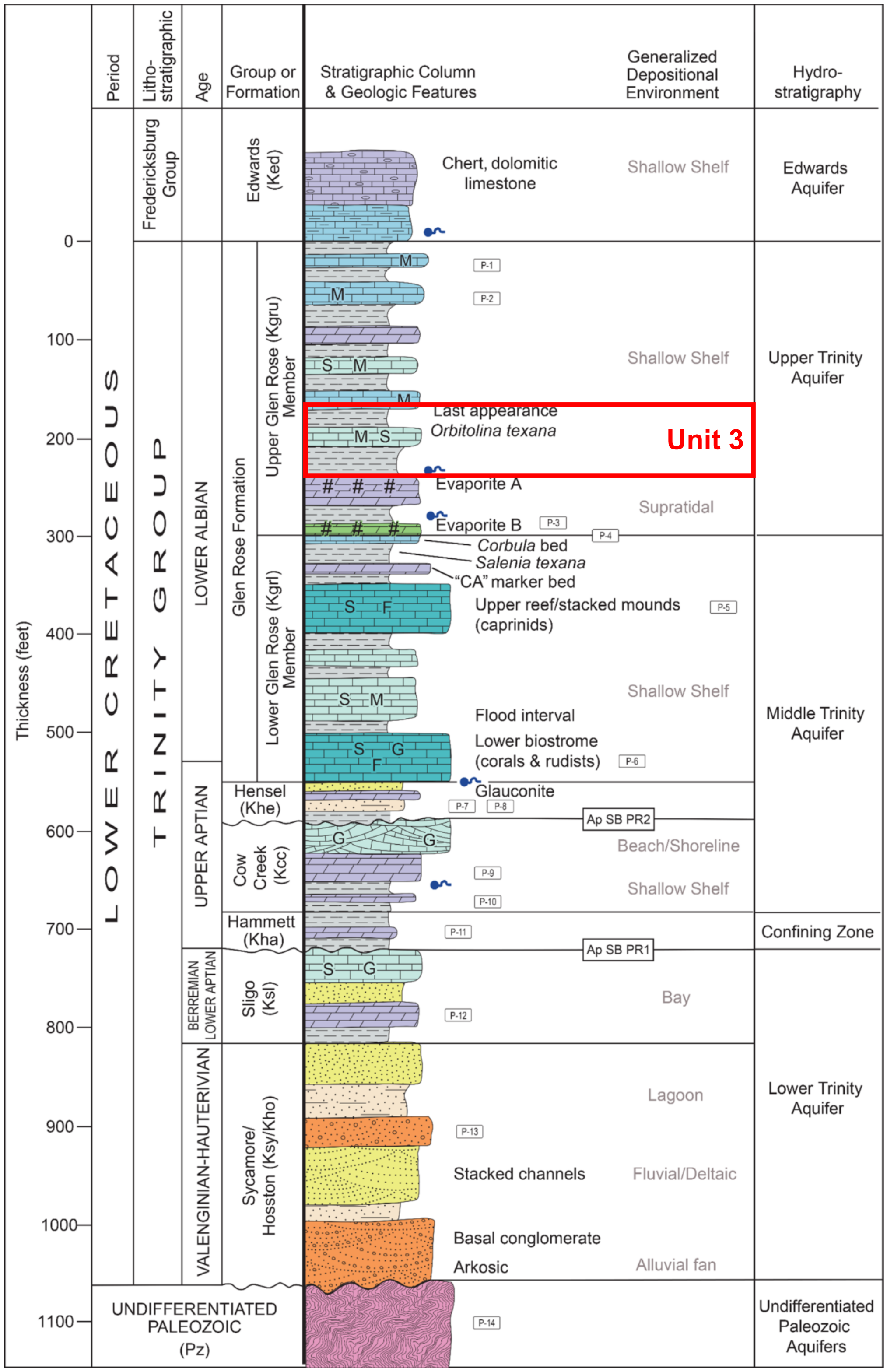



**Figure 2. Stratigraphic column of the Trinity Aquifer (modified after Wierman et al., 2010). Units mapped in this study occur within the Upper Glen Rose Formation, classified hydrostratigraphically as the Upper Trinity Aquifer. Upper Glen Rose strata overlies the Middle Trinity Aquifer, the primary water producing aquifer in the area.**

## METHODS

This study utilized basic field-mapping methods, measured sections, geophysical log analyses, and geographic information system (GIS) analysis to correlate the extent of unit 3. Measured surface sections and outcrops were correlated with an established "type" subsurface section well that allowed mapping with confidence throughout the study area. Georeferenced digital raster grids were produced in contouring software using picks of the top and bottom of unit 3 that allowed the generation of a unit 3 structure map. Additionally, Google Earth™ imagery was utilized to map unit 3 in areas where site access could not be obtained.

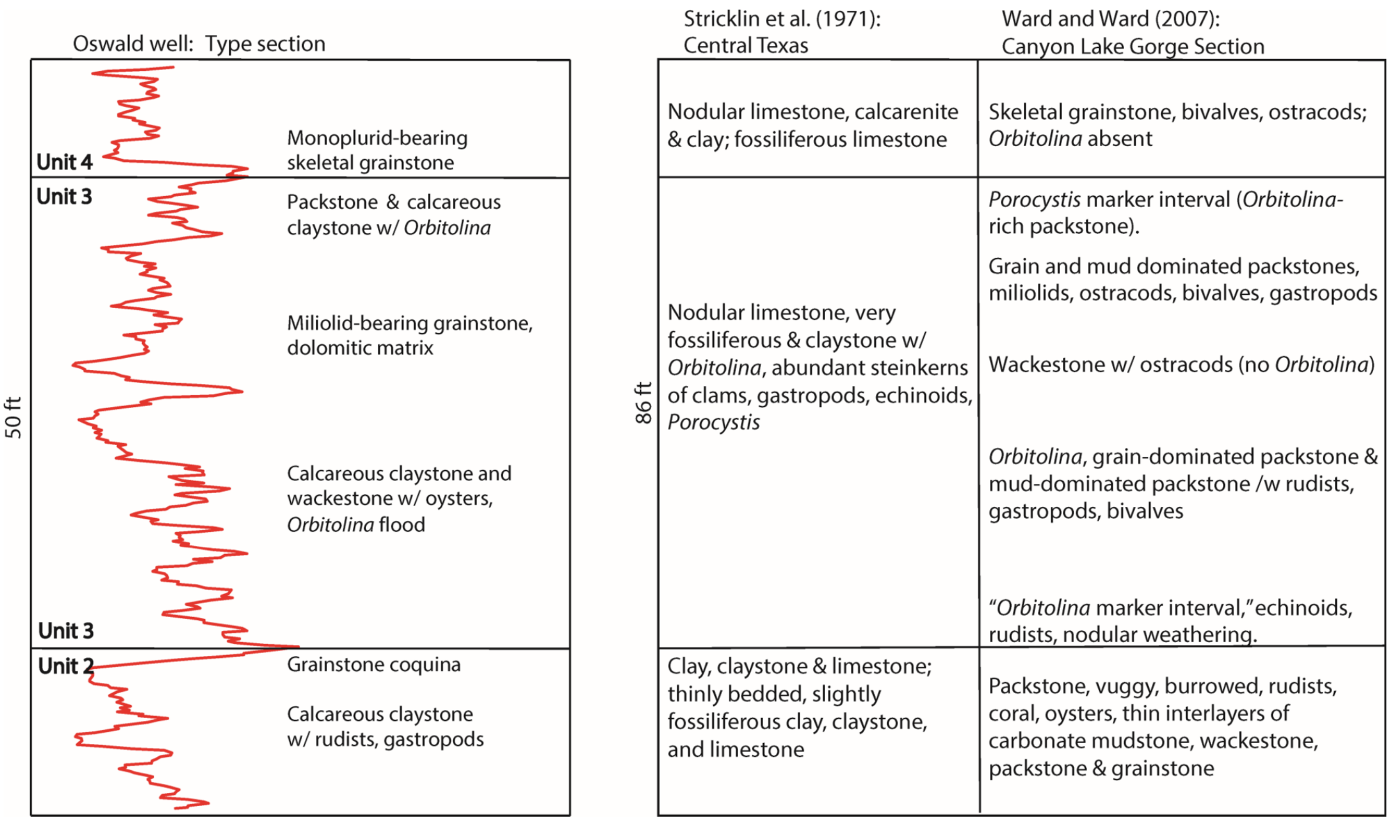



**Figure 3. Oswald well type subsurface section with gamma ray log (red line) correlated to previous surface sections by Ward and Ward (2007) and Stricklin et al. (1971).**

## Subsurface Correlation

The Oswald well drilled in eastern Blanco County was selected as the type subsurface section for unit 3 of the Upper Glen Rose Member (Fig. 1). The well was selected because of its proximity to published surface studies, and because of its data quality including a geophysical log and cuttings samples (Fig. 3). Detailed lithologic descriptions and fossil assemblages from Ward and Ward's (2007) Comal County surface section were correlated to drill cuttings sample descriptions and geophysical logs from wells in the study area.

Drill cutting samples from the Oswald well were examined and described using a binocular microscope. The resulting lithology was annotated on the geophysical log and correlated with the published descriptions from Stricklin et al. (1971). Critical correlation points include: the occurrence and abundance of *Orbitolina*, the presence of claystone and mudstone, fossil assemblages, thickness, and position within the Upper Glen Rose section above the defined contact with the Lower Glen Rose.

Additionally, geophysical logs were analyzed on the Dreyer well and the Hog Hollow well (see Figure 1 for locations) and drill cuttings were collected at 10 ft (3 m) intervals and analyzed (Fig. 4). Geophysical logs were correlated with the Oswald type well primarily using the gamma ray curve and the interpreted cuttings sample descriptions. The sharp increase of natural gamma ray response at the base of unit 3 is interpreted as a clay prone interval and sequence boundary. Geophysical log responses were correlated to the lithology from cuttings where available. Using the correlation procedures established for the above wells, geophysical logs from a total of 36 local wells were correlated in the subsurface. Subsurface picks for unit 3 were then used to generate structure maps and a cross section.

## Surface Correlation

The Upper Glen Rose Member was measured at the Longview surface section in northern Hays County (Fig. 1) from the exposed "*Corbula* interval" to the lower beds of unit 4. The samples were described and correlated with the Oswald well and with published lithologic descriptions.

Field reconnaissance and surface mapping was carried out throughout the study area using public access roads and private property. Key locations were Sundown Ranch, Storm Ranch, along Blue Creek, Creek Road, and E. Mt. Gainor Road. Unit 3 was relatively conspicuous in the field due to the fossiliferous, *Orbitolina*-rich beds it contains. Numerous samples were collected from unit 3. These samples were later analyzed using a binocular microscope for lithologic and faunal assemblage characteristics.

## Raster Grid Analysis

A raster grid is a digital surface made up of a cell grid with X and Y coordinates that correspond to horizontal coordinates in space. They are commonly used in GIS software to conduct geospatial analysis and are particularly useful for the geosciences. To assist with field mapping, a raster grid analysis was conducted using *Surfer 14* contouring software by Golden Software™ to predict the locations of unit 3 outcrop. Raster grids were created for both the top and bottom of unit 3 using geophysical log picks. These surfaces were intersected with a 1/3 arc-sec Digital Elevation Model (DEM) raster grid from the U.S. Geological Survey National Elevation Dataset (NED) using the raster grid calculator function. The resulting raster grid was then contoured to show

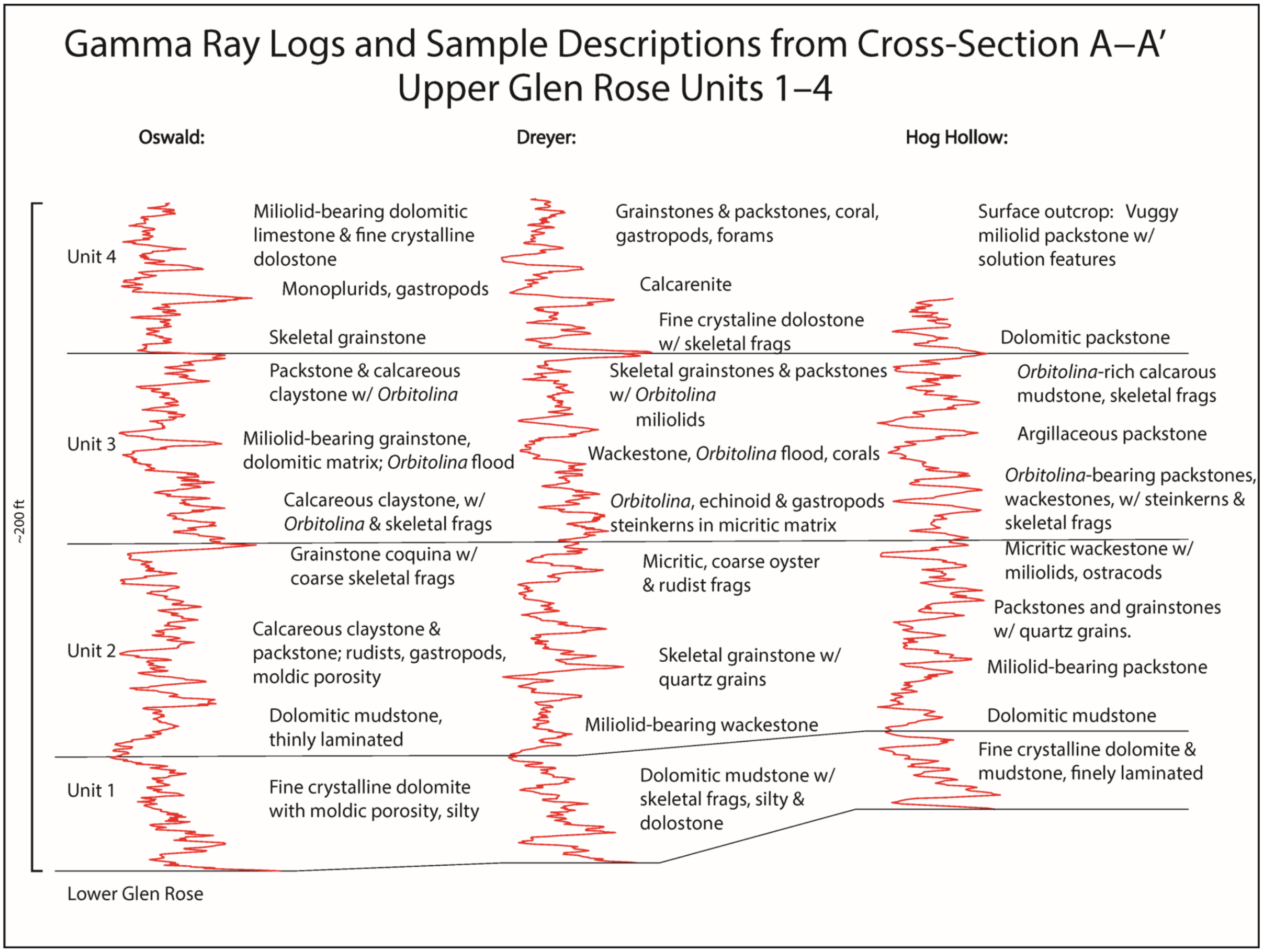



**Figure 4. Subsurface correlation of gamma ray logs.**

the intersection of the top and bottom of unit 3 with the ground surface as predicted by the raster grid analysis. These lines were exported into keyhole markup language (kml) format for use in Google Earth™ to assist with mapping and ground-truthing efforts.

In some cases, unit 3 outcrop was identified remotely using imagery from the Google Earth Imagery™ desktop application. Unit 3 characteristics apparent in satellite imagery included a distinctive off-white color, relatively flat weathering profile, and the frequent occurrence of "borrow pits" cut into the outcrop for use in road base. This imagery, coupled with the raster grid analysis described above, provided a useful method of remotely mapping unit 3 where access for ground truthing was not possible.

## RESULTS AND DISCUSSION

### Longview Unit 3 Measured Section

The base of unit 3 is about 80 ft (24 m) above the contact with Lower Glen Rose as identified by the *Corbula* bed (Fig. 5). Unit 3 was measured to be 48 ft (14.6 m) thick at the Longview section. This agrees with unit 3 picks from subsurface logs across the study area, which shows a consistent unit 3 thickness of about 50 ft (15.2 m).

A prominent fossil-bearing unit is present toward the base of unit 3 (Fig. 6). It is a white-colored, argillaceous, clay-rich interval with abundant steinkerns of "deer heart" clams, gastropods, *Orbitolina*, and has a distinct nodular weathering pattern. This bedding feature and similar fossil assemblages were encountered in many other locations around the study area and proved useful for unit 3 outcrop mapping.

*Orbitolina* was present throughout the unit 3 section, with abundant concentrations of specimens at the top and bottom of the interval. The top of unit 3 was marked by gypsiferous and argillaceous limestone units interlayered with thin-bedded miliolid bearing wackestones. The bottom of unit 4 contained thin bedded grainstones and packstones with abundant skeletal fragments. One of the packstone beds had a distinct, wavy stromatolitic fabric (Fig. 5, sample L17).

### Faunal Assemblage

Perhaps the most diagnostic fossil in unit 3—and certainly the most abundant—is the foraminifera *Orbitolina*. Douglass (1960) placed the, *Orbitolina minuta* in the "upper" Glen Rose and *Orbitolina texana* in the "lower" Glen Rose. Rader (2011) placed the *Orbitulina minuta* in both the Upper and the Lower Glen Rose but restricted the *Orbitolina texana* to the lower member. From the detailed descriptions there is a difference between the two fossils. However, distinguishing between these species is beyond the scope of this work. For the purposes of this paper, the foraminifera is referred to as simply *Orbitolina*.

Within samples of cuttings from local wells, *Orbitolina* was not observed above unit 3. Normally *Orbitolina* are abundant within the cuttings sample when present. *Orbitolina* does occur below unit 3 and within units 1 and 2, although they are not common until close to the contact with the Lower Glen Rose. In outcrop, the *Orbitolina* can be abundant at both the base and the top of unit 3 and is often absent in the middle layers. The Longview surface section is more gypsiferous than the other unit 3 outcrops encountered to the east and south of the study area.

*Porocystis globularis* was common to the unit 3 assemblage (Fig. 7). Other fauna scattered throughout the outcrop as a steinkern or cast include: gastropods: *Strombus*, *Tylostoma*, and *Nerinea*; echinoids: *Loriolia rosana* and *Heteraster* sp.; pelecypods: *Toucasia* and *Monoplurid* fragments, oyster fragments, clam casts, and common casts of the "deer heart" clam *Corbis baneraensis*; and serpulids (worm tubes). These faunal assemblages were useful for mapping unit 3 in the field because other units within the basal Upper Glen Rose section were not as fossiliferous and did not contain similar assemblages.

## Subsurface Unit 3

Unit 3 was picked and correlated across 36 geophysical logs in the study area. These data were then used to generate a structure map and structural cross section of unit 3. The structure map shows that unit 3 dips approximately 25 ft/mi (4.7 m/km) from west to east over most of the study area, diving more steeply into the subsurface to the east as it approaches the Balcones Fault Zone (Fig. 8), forming a monoclinal hinge in the vicinity of the Onion Creek/South Onion Creek confluence.

Cross-section A–A' shows that Upper Glen Rose strata are increasingly eroded by streams from west to east, with unit 3 being fully incised toward the eastern edge of the cross section and in the vicinity of the monoclinal hinge along Onion Creek (Fig. 9). Along the gentle upper limb of the monoclinal structure, stream gradients of Onion Creek, South Onion Creek, and Gatlin Creek are greater than the gentle structural dip of the Upper Glen Rose strata, resulting in the observed incision of unit 3 by these streams. Further eastward as the dip increases past the hinge, dip exceeds stream gradients and incision into and through unit 3 ceases.

## Geologic Map of Unit 3 and Implications for Middle Trinity Recharge

The geologic map (Fig. 10) of the area shows unit 3 outcropping extensively along stream reaches in the upper Onion Creek Basin. Unit 3 is fully eroded along significant portions of Onion Creek, South Onion Creek, and Gatlin Creek. This incised region extends downstream of the confluence of Gatlin Creek and Onion Creek until unit 3, again dipping to the east-southeast is projected in the subsurface as it is intersected by the Balcones Fault Zone.

Overlaying the geologic map with gain/loss data from Hunt et al. (2016) allows evaluation of unit 3 occurrence and its relation to stream losses in the Onion Creek Basin. Stream reaches flowing over areas where unit 3 has been eroded appear to correlate with losing reaches in Onion Creek and South Onion Creek (Fig. 11). The same correlation is not present in Gatlin Creek, where unit 3 has also been extensively incised. However, flow measurements by Hunt et al. (2016) along Gatlin Creek were limited and may have missed losing reaches. Future gain/loss studies should include more monitoring locations along Gatlin Creek.

The association between absence of unit 3 in the stream bed and measured losing stream reaches suggests that unit 3 may be an important control on recharge within the Onion Creek Basin. It is likely that the high clay content observed in unit 3 allows it to act as a confining unit within the Upper Glen Rose, preventing downward migration of surface water into the underlying Middle Trinity Aquifer. Therefore, stream reaches where unit 3 is still intact would be less likely to provide significant recharge to the Middle Trinity Aquifer units.

Numerous springs issue from subunits of the Upper Glen Rose at different elevations. Dripping Springs and Walnut Springs are two prominent Upper Glen Rose springs discharging from unit 4 strata above unit 3. It is likely that their location in the section is due to the confining characteristics of unit 3 that perch groundwater in the overlying unit 4. Other important Upper Glen Rose springs such as Emerald Spring and Tingari Spring issue from unit 1 and unit 2, below unit 3 (Fig. 11). Because they occur beneath the unit 3 confining beds, the provenance of unit 1 and 2 springs is less certain. Measured hydraulic heads in the Middle Trinity are well below the spring outflow elevations, making it unlikely that the springs are artesian Middle Trinity springs. Emerald Spring lies close to the confluence of South Onion Creek and Onion Creek and at a lower elevation than upstream reaches of South Onion Creek where unit 3 has been incised. This suggests that the South Onion Creek Basin could be contributing flow to Emerald Spring by way of shallow groundwater movement along the basal units of the Upper Glen Rose (units 1 and 2).

Along stream reaches where unit 3 is fully incised, unit 1 and unit 2 outcrops are extensively fractured (joint sets). At least two prominent karst features pirate flow from Onion Creek and occur along strike with these fracture sets: Bigote Swallet and Howard Ranch Swallet (Fig. 11). At the Longview section, multiple collapse solution features were observed in outcrop (Fig. 12). These swallets, fractures, and solution features may provide a pathway for surface water to travel downward through Upper Glen Rose units 1 and 2 and into the Lower Glen Rose and other Middle Trinity Aquifer units. This is particularly likely in places where streams have incised Upper Glen Rose strata to a thin section, which is the case along many stream reaches in the study area. Along these reaches, units 1 and 2 have been eroded to less than 50 ft (15.2 m) in thickness, and Onion Creek surface water would only have to travel a short vertical distance to reach Middle Trinity Aquifer strata.

## SUMMARY AND CONCLUSIONS

Using both surface exposures and geophysical logs this study has mapped the Upper Glen Rose unit 3 with a high degree of confidence over the study area. The uniform lithology and the widespread occurrence of *Orbitolina* fossils contribute to the high-confidence of the surface and subsurface mapping. Onion Creek and its primary tributaries incise the outcropping Upper Glen Rose section, eroding unit 3 in portions of the study area and expose the more permeable Upper Glen Rose units 1 and 2. Measured surface water flow losses correlate well with stream reaches where unit 3 has been fully eroded. The nodular, thin bedded dolomites and limestones are extensively fractured and there are numerous swallets and other solution features associated with fracturing in the creek bed. The absence of unit 3 and the presence of these fractured carbonates may provide an opportunity for surface water to directly enter the Lower Glen Rose, a subunit of the Middle Trinity Aquifer.

## ONGOING AND FUTURE WORK

Additional studies are needed to further refine our understanding of surface water recharge to the Middle Trinity Aquifer in the study area. Ongoing dye tracing studies are under way and preliminary data have corroborated the hydrologic connection of the surface water in Onion Creek and units of the Middle Trinity

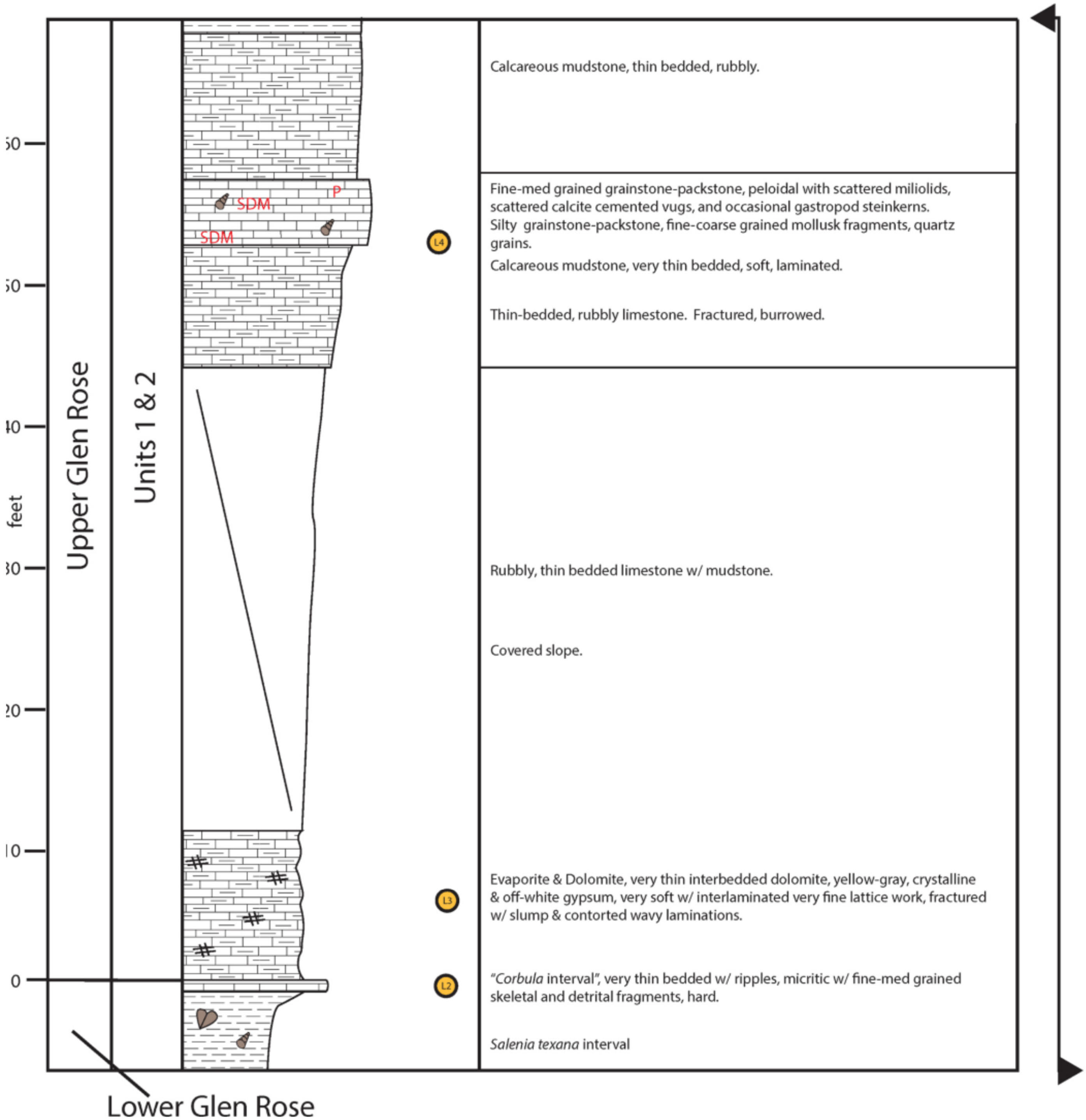
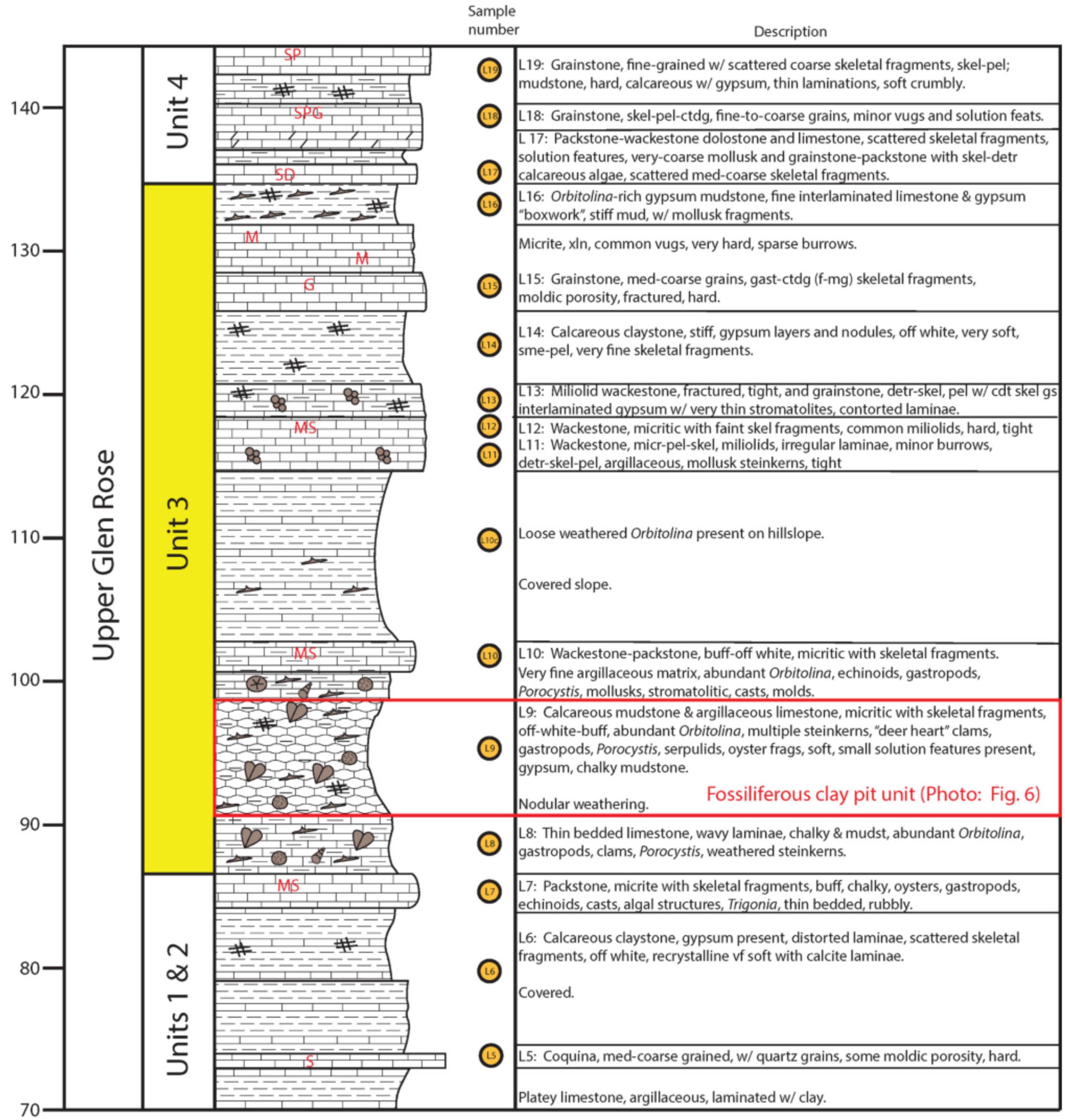




**Figure 5. Longview measured surface section. See Figure 1 for location. Continued on FACING PAGE.**




Aquifer (Watson et al., 2018). In addition, aquifer testing and other studies such as geochemistry can further our understanding of recharge in the study area. The fractures occurring over much of the Upper Onion Creek Basin should be studied in more detail, as they may provide a possible flow path for surface water to recharge the Middle Trinity Aquifer. Additionally, mapping of unit 3 should be extended to other basins where it outcrops, such as the Barton Creek catchment to see if similar surface water recharge is occurring.

## ACKNOWLEDGMENTS

The authors extend thanks to the generous property owners who provided land access across the study area.

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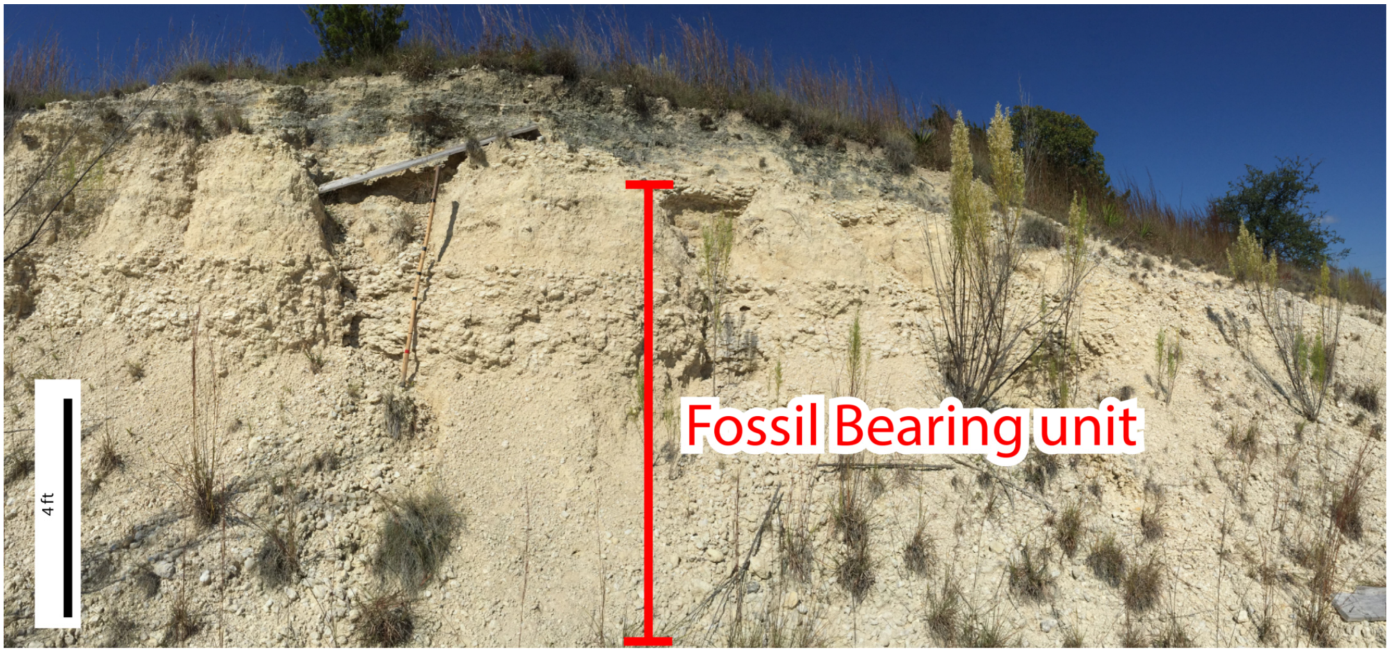
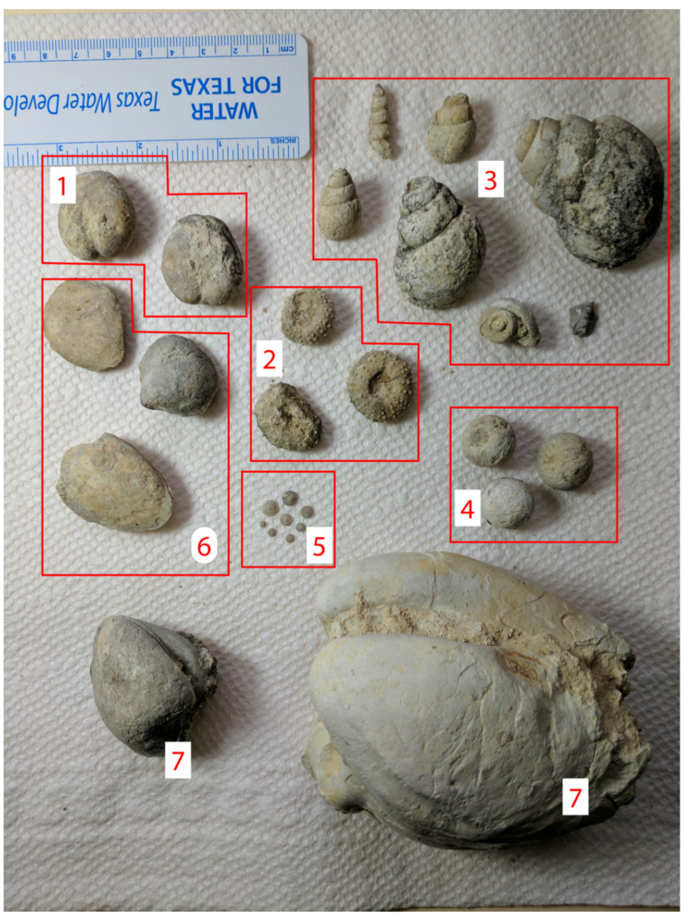



**Figure 6.** Photo of "clay pit" subunit of unit 3 at the Longview measured surface section located in Figure 5.



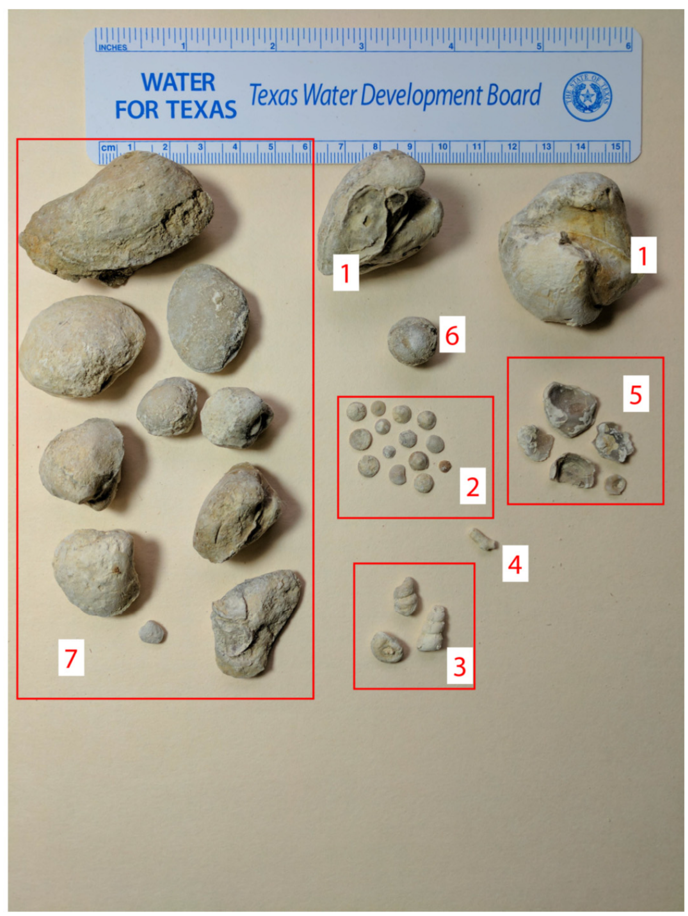




**Figure 7.** Left: Unit 3 faunal assemblages observed on E. Mt. Gainor Road. (1) *Heteraster* sp., (2) *Loriolia rosana*; (3) gastropods, including *Tylostoma* and *Strombus*, (4) *Porocystis globularis*, (5) *Orbitolina*, (6) various bivalves, and (7) "deer heart" clams. Right: Unit 3 faunal assemblage collected at Longview measured section. (1) "deer heart" clam, (2) *Orbitolina*, (3) gastropod fragments, (4) coral fragment, (5) oyster fragments, (6) *Porocystis globularis*, and (7) various bivalves.

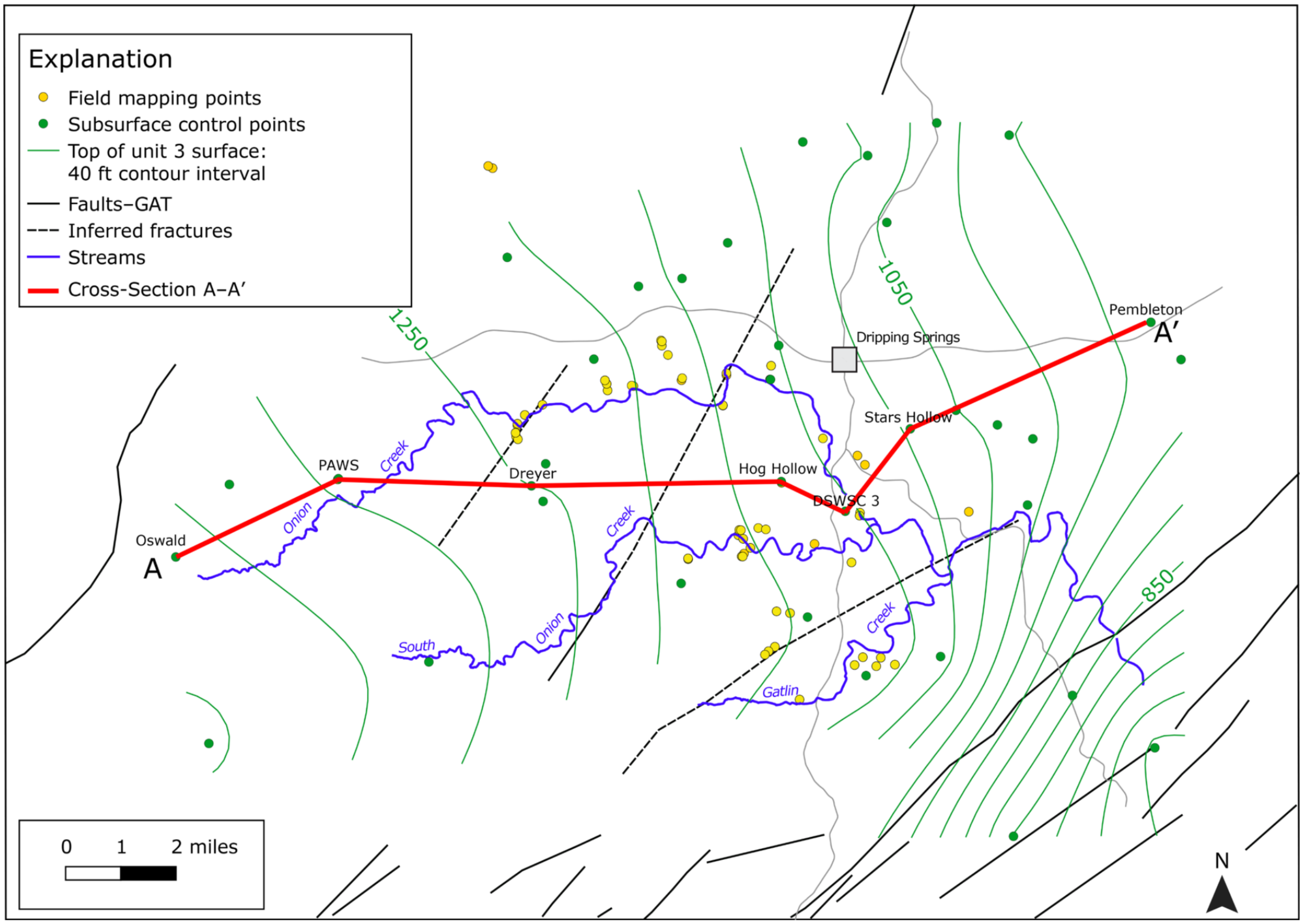



**Figure 8. Structure contour map at the top of unit 3. Line A–A′ denotes the path of the structural cross section presented in Figure 9.**

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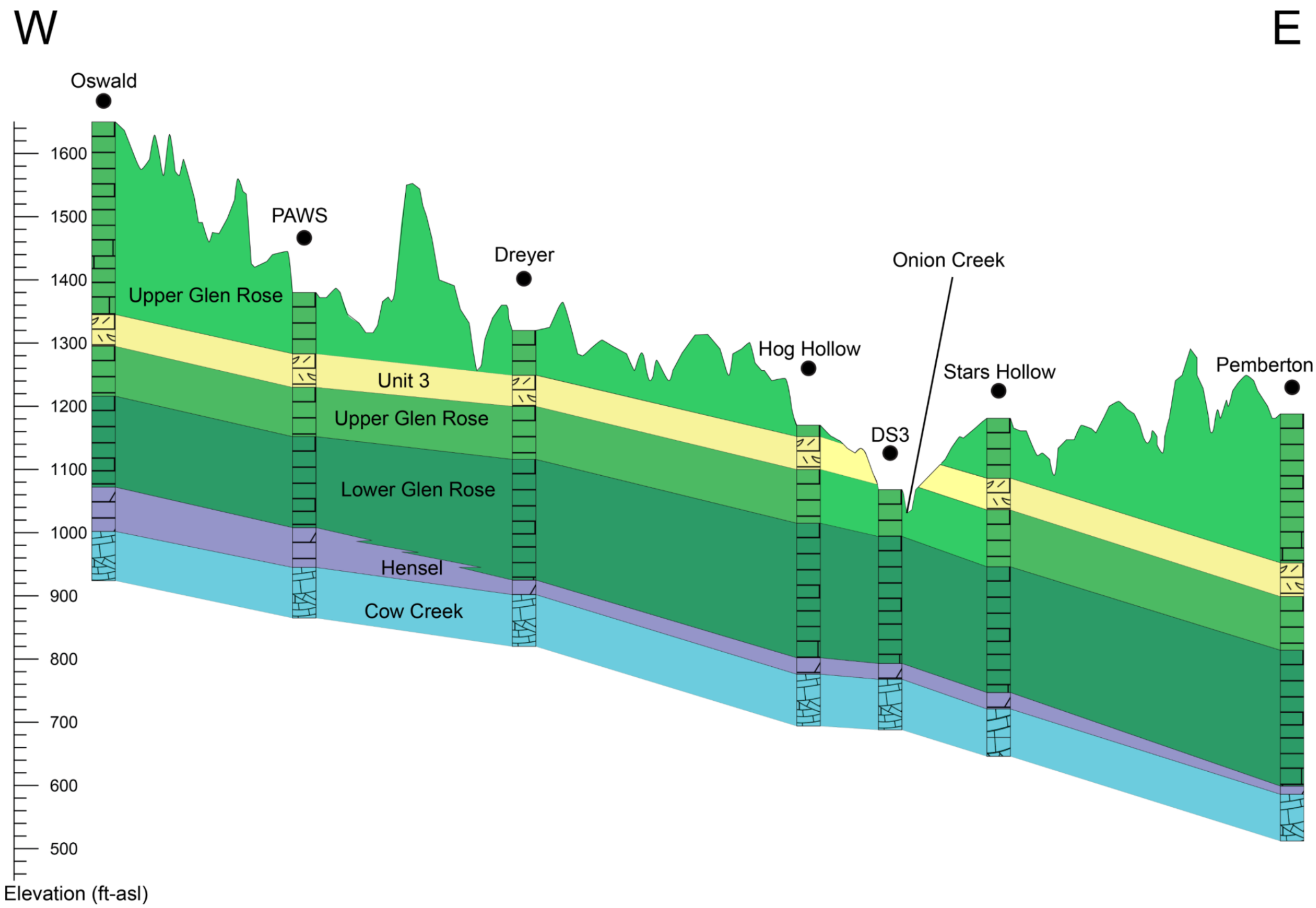


**Figure 9. Structural cross-section A–A'. Areas where unit 3 has been fully incised are shown in map view in Figure 10 (dark green).**

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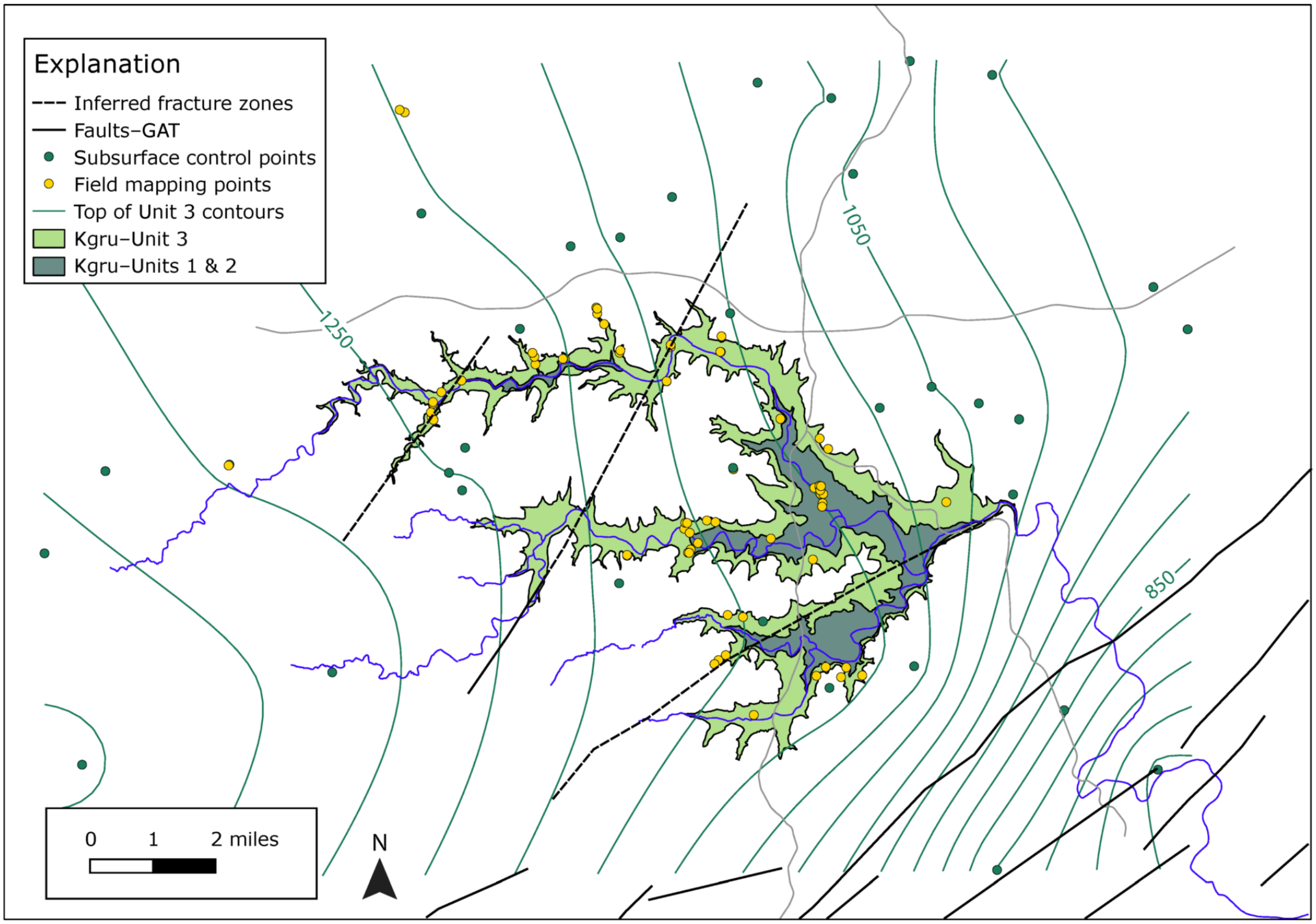


**Figure 10. Geologic map of Upper Glen Rose outcrop, including unit 3 (green).**

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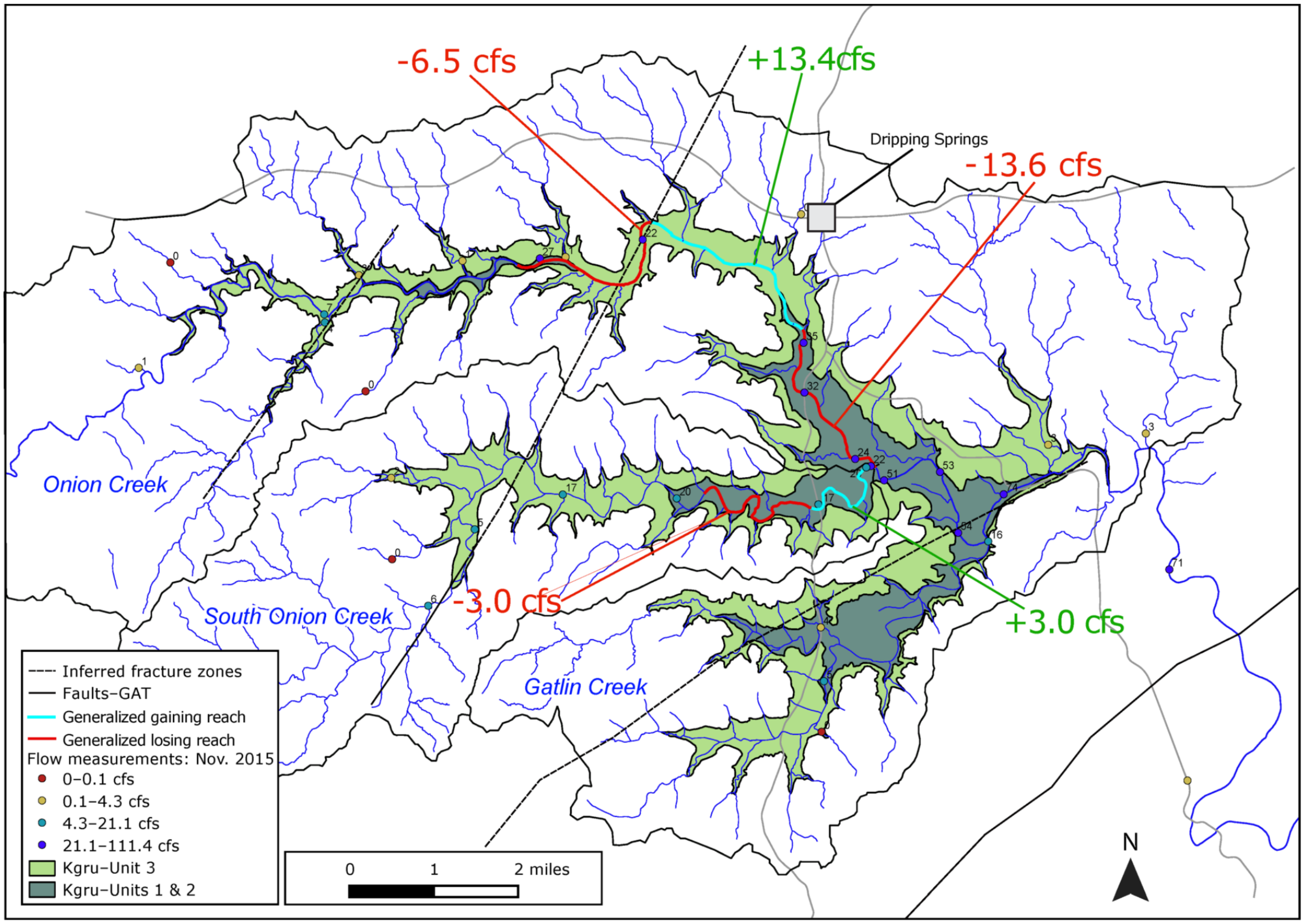


**Figure 11. Geologic map with November 2015 gain/loss data from Hunt et al. (2016) overlaid. Prominent losing stream reaches occur in areas where unit 3 has been fully incised.**

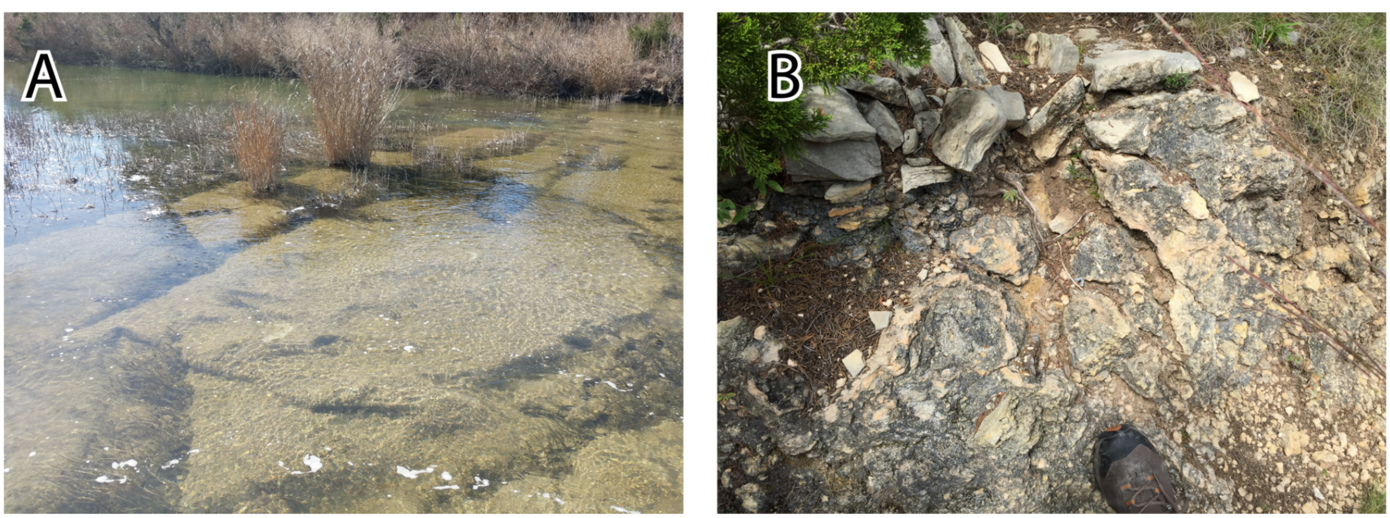


**Figure 12. (A) Fractures in creek bed of Onion Creek at Tingari Ranch. (B) Solution feature in unit 1 at the Longview measured section.**