Enclosure 1 to E-54844

Report on Mapping of a Trench Through Pedogenic Calcrete (Caliche) across a Drainage and Possible Lineament, Waste Control Specialists Disposal Site, Andrews County, TX.

April 2007

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ATTACHMENT 4-1A
REPORT OF MAPPING OF A TRENCH THROUGH PEDOGENIC CALCRETE (CALICHE) ACROSS A DRAINAGE AND POSSIBLE LINEAMENT, WASTE CONTROL DISPOSAL SITE, ANDREWS COUNTY, TEXAS

Report on Mapping of a Trench Through Pedogenic Calcrete (Caliche) across a Drainage and Possible Lineament, Waste Control Specialists Disposal Site, Andrews County, TX

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ABSTRACT

At the request of the TCEQ, a trench was excavated to "refusal" across the lineament or trend of vegetation, drainage, and color changes (in aerial photographs) about 1 mile northeast of the WCS facilities in Andrews County, TX. The specific purpose of the trench was to check for v-shaped fractures in pedogenic calcrete (caliche) that TCEQ proposed might indicate underlying regional processes, including dissolution. The trench also further characterizes features at the WCS site.

The trench is about 10 ft deep, 110 ft long, and exposes a thick pedogenic calcrete with relatively thin overlying modern soils. The stage of development (IV), thickness, and overall character of the calcic soil indicates it is most like the Mescalero caliche of southeastern New Mexico; the "caprock" of the Ogallala may be at the bottom of the trench, impeding further excavation by backhoe.

No v-shaped fractures were observed in the trench. Fractures found in the calcic soils at depth are fine, irregular to curvilinear, bounded within better cemented areas, and have no preferred orientation similar to the lineament. They indicate local stresses within the calcic soil. Lateral changes of carbonate content, structures, induration, and color have gradational boundaries and indicate that carbonate has been, or still is being, removed from portions of the calcic soils. These effects are most pronounced near the northeastern end of the trench where upper laminar units have been removed by erosion and solution and modern soils rest on lower portions of the profile. Sediment-filled solution pipes and macropores developed in three separate stages, and these indicate partial removal of carbonate from the profile. The developed calcic soil is evidence of relative stability of the surface over a period of time and a broad history of carbonate accumulation.

INTRODUCTION

Purpose of Trench

During a meeting with members of TCEQ on February 19, 2007, it was suggested that aligned surface features (low spots, vegetation, and color trends) shown by aerial photographs in the vicinity of the WCS site could be better characterized by excavating a trench across one of the more prominent examples (Figure 1). The trench was to be excavated to refusal (with a backhoe) through surface materials and pedogenic calcrete (caliche). The *specific purpose* developed at the meeting was to examine the exposed upper pedogenic calcrete for evidence of v-shaped fractures that have been asserted elsewhere to be evidence of dissolution of underlying evaporite units.

Location Selection

The low areas, vegetation trends, and color differences across the WCS site tend to be aligned approximately N55-60°W (azimuth 145-150°) . During the meeting, a relatively prominent low spot about 1 mile northeast of WCS facilities was identified as a good candidate for such a trench, and the location was agreed to be northwest of the main low and perpendicular to the vegetation trend (Figure 1).

Trench Activities

WCS excavated the trench February 26-28, 2007 and cleaned the surfaces by sweeping and blowing the surfaces to better expose the features. Robert M. Holt and Dennis W. Powers examined, mapped, and described the trench March 1-2, 2007. TCEQ personnel were present during this activity. A larger group of TCEQ members examined the trench on March 2, 2007.

Trench Location and Dimensions

The trench location has been plotted relative to WCS facilities (Figure 1). The southwestern end of the trench has coordinates of 32.44830N latitude and 103.05180W longitude (UTM Zone 13 683135.963E m, 3591609.832N m) (NAD27). The northeastern end has coordinates of 34.44859N latitude and 103.05153W longitude (UTM Zone 13, 683160.761E m, 3591642.449N m) (NAD27). The map 0 point (Figure 2) has coordinates of 32.44857N latitude, 103.05150W longitude (UTM Zone 13 683163.622E m, 3591640.283N m) (NAD27). The map 110 ft point has coordinates 32.44833N latitude, 103.05176W longitude (UTM Zone 13 683139.663E m, 3591613.227N m) (NAD27). The maximum depth of the trench is approximately 11 ft, while most of the trench is approximately 10 ft deep. The trench exposes the upper surface of the pedogenic calcrete for an estimated 120 ft, while the exposures were significant enough to be mapped over a length of 110 ft (Figures 2 and 3). The trench is oriented about N42 °E (azimuth 042°).

Trench Activities for Mapping

To prepare the trench for easier mapping, we established a grid on the southeast wall of the trench. String levels were used to establish a 0 level line about mid-height of the trench wall. The string was pulled tight and anchored with nails along the length of the trench. A basic grid at 2.5 ft horizontal and vertical intervals was measured and marked with spray paint. Horizontal markers (stations) along the 0 level line were numbered at 5-ft intervals (Figure 4). On gridded mylar, we recorded the units and features along the length of the southeastern face of the trench at a scale of 2.5 ft/inch for both vertical and horizontal scales. We photographed the full length of the trench and specific features of significance.

The trench mapping was limited to the main purpose of examining the exposed calcrete for the specific features (v-shaped fractures) considered of import for the trench; we recorded features in detail to develop confidence that such fractures were not overlooked. No samples were taken, and more recent surface soils were distinguished only to the level of color changes with some differences in materials. Calcrete features and morphologies were macroscopically identified using the classification of Bachman and Machette (1977). Some of the characteristics, such as carbonate content, are only field estimates.

MAPPING RESULTS

In the following, we present descriptions of the mapping units observed in the trench. The trench map (Figure 2) reveals the basic morphological features and detailed relationships of the trench face described here. We classify pedogenic calcretes in terms of stages using the modifications of Bachman and Machette (1977) and Machette (1985) to the classification developed by Gile et al. (1966). A review of the development of "classic" calcrete stages is in Appendix A. While four units within the trench are clearly pedogenic calcretes (Units 3-6), only Unit 6 (here classified as a Stage IV calcrete) displays some of the "classic" calcrete fabrics identified by Bachman and Machette (1977) and Machette (1985). The other units (Units 3-5) lack some fabrics and textures that are commonly associated with pedogenic calcrete (e.g., nodular textures, distinct carbonate filaments, etc.). We classify the calcrete stage of these units primarily based on apparent carbonate content. The wide dispersal of carbonate throughout these units, the lack of abundant nodular textures, and the presence of numerous solution pipes and sediment filled macropores suggests that Units 3-5 have been degraded to their current stage by repeated solution and redistribution of carbonate in the past.

Unit 1 – Upper Soil

The uppermost soil is within the modern root zone and is a gray (10YR 5/1), calcareous, silty sand that includes some organic matter (Figures 2 and 5). There is some clay within the soil, and it shows some weakly developed peds. A few pebbles of calcrete are found locally. Although the lower contact is somewhat gradational from Unit 2, Unit 1 appears to be a separate soil from Unit 2. Unit 1 thins to the south or right in Figure 2.

Unit 2 – Lower Soil

The lower soil unit is a calcareous, pale brown (10YR 6/3), silty sand. The soil has a weak columnar structure with incipient cutans. Stratification was not observed within the soil. Unit 2 is thickest where the upper surface of the pedogenic calcrete has been eroded or dissolved. It also thickens above some solution pits containing Unit 9. Elsewhere, it is absent or occurs as a thin veneer above the calcrete. To the north, subrounded calcrete pebbles are locally abundant along topographic depressions on the top of the calcrete (Figure 5). The lower contact with calcrete units is sharp.

Unit 3 – Stage III Calcrete

Unit 3 is interpreted to be a Stage III calcrete based on apparent carbonate content. It contains no visible nodules, a common feature in a Stage III calcrete. Unit 3 is white (10YR 8/1.5) and has been extensively bioturbated, with abundant root molds and casts (Figure 5). It is moderately soft or crumbly and is very porous. The calcrete is developed within very fine to fine sand containing minor amounts of silt. It locally displays a blocky fabric. The lower contact was not observed, and the upper contact with Unit 2 is sharp and locally erosional. The boundary with Unit 4 is gradational and is not considered to be a depositional boundary. This unit has likely suffered extensive carbonate solution and redistribution and may have been derived from a higher stage calcrete (e.g., Unit 5). Unit 3 occurs under the area where the laminar zone (Unit 6) has been removed by some combination of erosion and solution, suggesting that infiltration may have been more concentrated at this location.

Unit 4 – Stage I-II Calcrete

Unit 4 is classified as a Stage I to Stage II calcrete based on apparent carbonate content. It is pink (5YR 7/3) and appears to have developed within very fine to fine sand (Figure 6). Nodules are rare, and carbonate appears to be well disseminated throughout the unit. Unit 4 is poorly cemented, soft to very soft (south side), and very porous due to apparent leaching of carbonate. It is massive at the top and becomes mottled at the base, and local zones display a blocky texture. Some carbonate stringers occur near the top of the unit. Root casts and molds are locally abundant. Granules to small pebbles of carbonate and local pebbles of chert are disseminated throughout the unit. Some carbonate pebbles may be remnants of nodules. The lower contact of Unit 4 was not observed. The upper contact with Unit 6 is diffuse. Contacts with zones containing Unit 5 are gradational. Unit 4 is penetrated by three generations of solution pipes and macropores filled with clastic materials (Units 7, 8, and 9), and contacts with these features are gradational to sharp. As with Unit 3, this unit likely developed from a higher stage calcrete (e.g., Unit 5) following dissolution and redistribution of carbonate.

Unit 5 – Stage III+ Calcrete

Several zones within Unit 4 are distinctive and have been differentiated into Unit 5 because of higher apparent carbonate content, whiter color (pinkish white – 5YR 8/2), and greater induration (Figure 7). We classify Unit 5 as a stage III+ calcrete based on apparent carbonate content. It is moderately fractured with irregular to curvilinear, subvertical fractures with variable orientations. A few fractures have thin carbonate skins. They range up to ~1.5 ft long. The boundaries of the areas of Unit 5 are gradational with Unit 4.

Unit 5 fractures are very narrow, their aperture does not increase upward, and they are limited by the unit boundaries. They are not v-shaped and do not fit the specifications of the target fractures. Their orientations are highly variable, suggesting that they formed in response to very localized stresses, not some broader stress field or large scale external control. They most likely formed due to localized stresses during calcrete formation, solution, and carbonate redistribution.

We interpret Unit 5 to be a relict of the original calcrete that was modified by carbonate dissolution and redistribution to form Unit 4. Truncation of the fracturing at boundaries, as well as gradational boundaries, is more consistent with removal or redistribution of carbonate in the surrounding material than with preferential cementation of Unit 5 within Unit 4.

Unit 6 – Stage IV Calcrete

Unit 6 is a white (10YR 8/1), thickly laminated to very thinly bedded, stage IV calcrete (Figure 8). It is much harder than the underlying material and is fractured into tabular blocks and, locally, equidimensional blocks. The size of tabular blocks varies, with smaller pieces overlying more permeable materials contained in solution pipes and macropores. The upper 1 ft is locally reworked into blocky to subrounded cobble- to pebble-sized clasts. The laminar structure becomes more diffuse downward, and the unit displays local carbonate stringers near the base. The parent material for Unit 6 is very fine to medium, subangular to subrounded sand. The upper surface shows erosion on the north side of trench, and the unit has been completely removed by dissolution and erosion above Unit 3. The lower contact is diffuse to gradational, and other contacts are gradational to sharp. Unit 6 appears to have at least two stages of development, with the lower, less distinctive zone interrupted by pits filled with light red sandstone (Unit 7).

Unit 7 – Sandstone

Unit 7 occurs within solution pipes and in irregular zones with gradational boundaries (Figures 9 and 10). It is a light red (2.5YR 6/6), moderately-well cemented sandstone consisting of well-sorted, subrounded to rounded, very fine sand. It is moderately-well cemented with carbonate and displays a tabular to blocky structure. Carbonate-lined root casts occur locally. Carbonate stringers of various orientations are common, and subhorizontal to horizontal carbonate stringers are abundant near the top of some pipes and zones. Contacts with other units are gradational to sharp, and some sharp boundaries display well developed laminar carbonate rinds. Some occurrences of Unit 7 (between Stations at 70 ft and 85 ft) are partially bounded by very calcareous, pink (5YR 8/3) halos consisting of similar sandstone. The upper portion of solution pipes is more calcareous, suggesting that these features formed before the laminar zone was completely developed. Zones displaying gradational contacts may represent original calcrete parent material.

Gile et al. (1981, p. 74) describe similar pipes as a normal part of the development of calcic soils. They infer that increased effective moisture is necessary and that the pipes are associated with pluvials for Pleistocene-age calcretes. They associate the development and shape of the pipes with burrowing or root zones, and they also suggest that the funnel shape may occur because of wetting is less frequent at greater depth. Laminar horizons and plugged carbonate zones adjacent to the pipes may also funnel infiltrating water toward these developing pipes, flushing carbonate and encouraging plant root growth. Laminar carbonate may rim the pipe. Bt horizons overlying the calcic soils extend down into the pipes.

The Mescalero in southeastern New Mexico displays pipes very well (e.g., Powers, 1993), with a very clear contrast between the white calcrete and the overlying reddish brown Berino soil. The most common association observed is for these pipes to be developed on Mescalero that is Stage III or, less commonly, Stage IV.

Unit 8 – Silty Sandstone

Unit 8 consists of poorly cemented, light gray (5YR 7/1) silty sandstone (Figure 11). Unit 8 sandstones are poorly sorted, including pebbles or clasts of tabular, hard, sandy laminated calcrete (Unit 6). Carbonate cements are well-disseminated through the sandstones. They fill macropores that are nearly circular in cross-section and depths of about 2.5-3 ft below the zero line. A thin (to ~ 1/4 inch) carbonate rind surrounds the macropores. The degree of cementation in these sandstones suggest that they formed later than Unit 7 sandstones, and the greater carbonate content and color suggest these formed earlier than pipes and macropores containing Unit 9.

Unit 9 – Silty Sand

Unit 9 occurs within pipes and macropores of varying size. The contacts of these pipes and macropores are generally sharp, and there are local carbonate rinds around the contacts to ~ 1/4 inch thick. Unit 9 consists of poorly sorted, pinkish gray (5YR 6/2), silty sand with granules to small pebbles of calcrete, some of which show laminar calcrete structures (Figure 12). Pipes with this material closer to the surface can show connections to the overlying relatively modern gray soil (Unit 2). Pipes containing Unit 9 often occur above pipes containing Unit 7. There are several macropores filled with Unit 9 that do not show connections to the surface within the trench. Subhorizontal thin laminations are visible in one of the deeper examples. Modern roots are also common in these units.

INTERPRETATION OF MAPPING UNITS

The calcic units exposed in the trench reflect a complicated history of carbonate accumulation, exposure, erosion, and carbonate solution and redistribution. The massive character, widely disseminated carbonate, and lack of typical pedogenic calcrete features (e.g., nodules and filaments) in Units 3-5 suggest that they are various retrograde stages of a more uniform calcic soil. Apparent carbonate contents are consistent with Stage I-III development of Bachman and Machette (1977) and Machette (1985). Differences in color, apparent carbonate content, and carbonate distribution suggest that Units 4 and 3 have been extensively altered by reorganization and loss of carbonate. Occurrences of Unit 5 are likely relicts of less altered calcrete. Unit 6 is a laminar, well-cemented Stage IV calcrete that shows evidence of being dissolved and brecciated near the top, without evidence of re-cementation. It has been removed by erosion along the northern part of the trench, where the trench intersects the lineament. Unit 6 developed in several generations, as pipes filled with Unit 7 sandstone appear not to penetrate the upper surface and are often overlain by laminar carbonate. Some parent material, irregular zones of sandstone (Unit 7) with gradational contacts, may remain within the calcic soils.

At least three generations of sediment-filled solution pipes and macropores formed during and after the accumulation of the calcic soils. The first generation (Unit 7) of pipes formed prior to the complete development of the upper Stage IV calcrete (Unit 6). The second generation consists only of macropores filled with poorly-cemented silty sandstone (Unit 8). Carbonate is highly disseminated throughout this sandstone, and the cements likely developed during the redistribution of carbonate in the lower calcic soils (Units 3-5). The latest generation of pipes and macropores is filled with uncemented silty sand (Unit 9) containing pebbles of Stage IV laminar calcrete derived from Unit 6. These features likely formed in higher permeability areas where fluids were focused during unsaturated flow. As a result, pipes containing silty sand (Unit 9) are often collocated with pipes containing sandstones of Unit 7. Because Unit 9 sands appear to contain less carbonate than Units 7 and 8, pipes and macropores containing Unit 9 likely developed after the retrograding of Units 3-5. Because Unit 9 sands differ in color from the lower soil (Unit 2), they were likely emplaced prior to the erosion of the Stage IV calcrete at the north end of the trench.

The presence of sediment within macropores indicates that they became well-connected to surficial sediment sources after they developed. Some of these sediments were carried into the macropores and deposited from flowing water (e.g., Unit 9).

DISCUSSION

The calcic soils exposed in the trench are likely age equivalent to the Mescalero caliche which developed across the Mescalero Plain in New Mexico. Bachman and Machette (1977) and Machette (1985) have compared and contrasted the features associated with the pedogenic Mescalero caliche and the pedogenic calcrete(s) of the Miocene Ogallala Formation ("caprock") of eastern New Mexico and west Texas. The maximum stage of development for the Mescalero caliche is generally V, although it also can be found laterally continuous with less developed or retrograde stages (e.g., Powers, 1993). The Ogallala caprock is much more indurated in general than the Mescalero and commonly shows multiple episodes of brecciation and recementation that classify it as Stage VI. Calcic soils within the Blackwater Draw Formation are reported as Stage II and III horizons (Holliday, 1989). The Mescalero is considered to have begun to develop after 600,000 years ago, based on the finding of the Lava Creek B ash underlying the calcrete (Izett and Wilcox, 1982). The Ogallala caprock is older, with Hawley (1993), for example, placing it at least as old as 2.3 Ma. Blackwater Draw calcic soils are likely between these two episodes. The degree of induration and stage of development is, however, a function more of the time period over which the soil horizon developed and is not related to the age of the soil. In this case, the mapped soil unit in the trench at WCS has the characteristics more common to the Mescalero than to either of the other possible candidates. The more indurated carbonate at the base of the trench may be part of the Ogallala caprock, but it was not exposed sufficiently to determine its characteristics.

It is widely understood that pedogenic calcrete can only develop on a stable soil surface (e.g., Bachman and Machette, 1977). Here, the presence of an upper (exposed in the trench) and a lower (the caprock at the base of the trench) calcrete suggests that the region has been stable for a long period of time. Limited fracturing in the calcrete indicates only localized stresses, and there are no v-shaped extensional or other larger, consistent fractures that would indicate regional stress or dissolution since this calcic soil developed. If this soil is similar to or related to the Mescalero, this would indicate a period of about 0.5 Ma. Most of the other calcic soils in the region are this old or older. The limited fracturing observed in the trench is not oriented with respect to the general lineament trend, nor are the fractures found of consistent orientation that might indicate such a regional feature.

The calcic soils exposed in the trench reflect a complicated history of pedogenic carbonate accumulation followed by carbonate solution and redistribution. Widely dispersed carbonate within lower calcrete units suggests redistribution of carbonate in the vadose and/or phreatic zones. It is likely that the caprock underlying the trench strongly influenced the development of features found at the trench location. During past periods of high infiltration, waters ponding on the surface of the caprock likely contributed to the dissolution and redistribution of carbonate within Units 3-5. Three generations of solution pipes and macropores indicate significant vadose zone dissolution and downward infiltration of surface soils during and following the development of the calcic soils. Calcic soils have been disrupted by erosion and solution, especially at the northeastern end of the trench which crosses a modern topographic low associated with the lineament. The dissolution features found in the trench exposures suggest that the trench area has been a topographic low since the time these calcic soils accumulated.

The trench location is in a vegetated topographic low area across the lineament trend. Bachman (1976) proposed that similar aligned vegetated depressions nearby in New Mexico represent the interdune areas between longitudinal or seif dunes that are no longer present. The features found in the trench are consistent with such a hypothesis.

The specific purpose of the trench was to check for v-shaped extensional fractures in the pedogenic calcrete. None were found. Small areas with irregular vertical fracturing were found in the trench and were mapped in Unit 5. The fractures terminate at the boundary of the mapped zones. They do not display consistent orientations that would indicate regional control or a relationship to the broader lineament.

CONCLUSIONS

No "v-shaped" fracturing is evident within the pedogenic calcrete in the trench, and there is no fracturing consistent with regional stress systems or dissolution and subsidence.

The trench exposed well-developed pedogenic calcrete with some morphologies consistent with Stage IV development. The calcic soil is most similar to the Mescalero caliche that is more commonly exposed in southeastern New Mexico. The base of the trench may expose the top of the Ogallala "caprock," but the exposures were insufficient to reveal diagnostic fabrics.

Calcrete units exposed within the trench show varying degrees of dissolution, erosion, and redistribution of carbonate. Three generations of sediment-filled solution pipes and macropores formed during and following the development of the calcic soils exposed in the trench. Relationships between calcic soils, sediment-filled pipes and macropores, and surficial soils indicate that the lineament has been a topographic low since these calcic soils began to accumulate.

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FIGURES

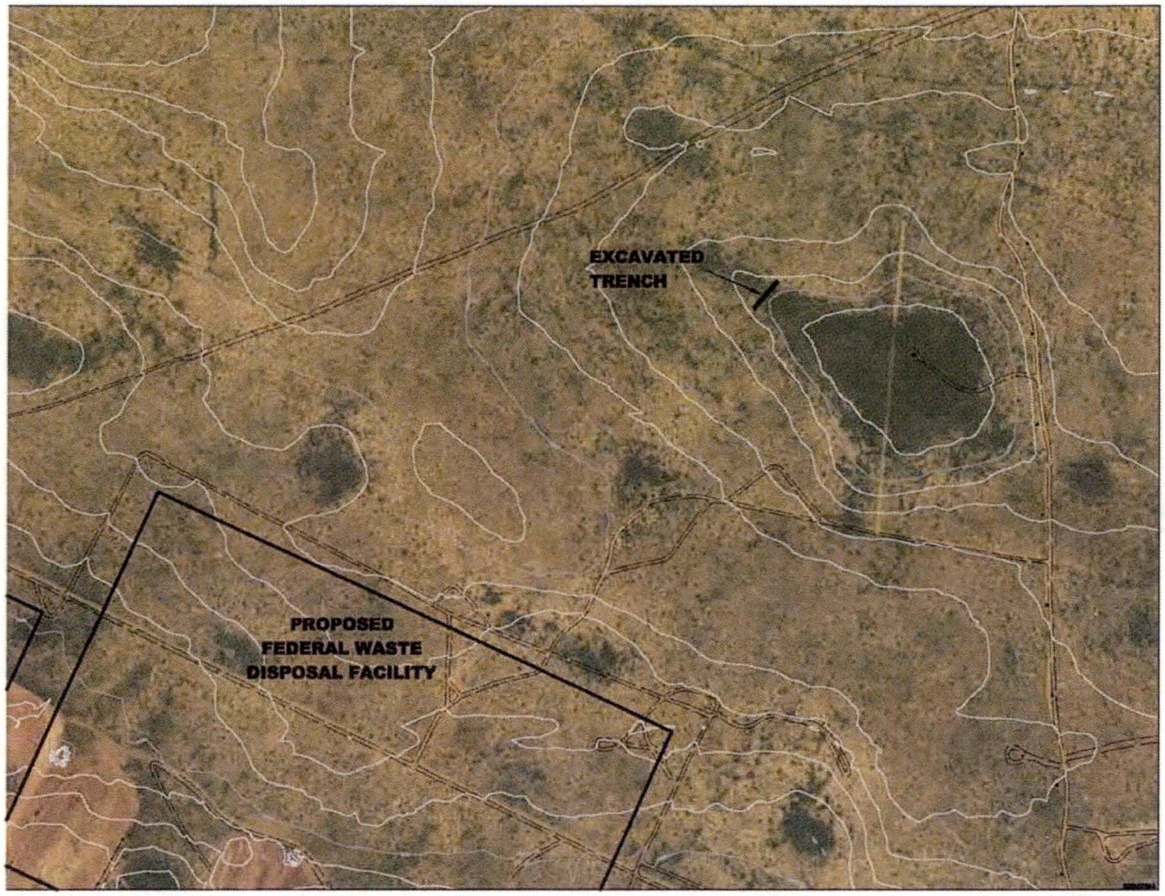
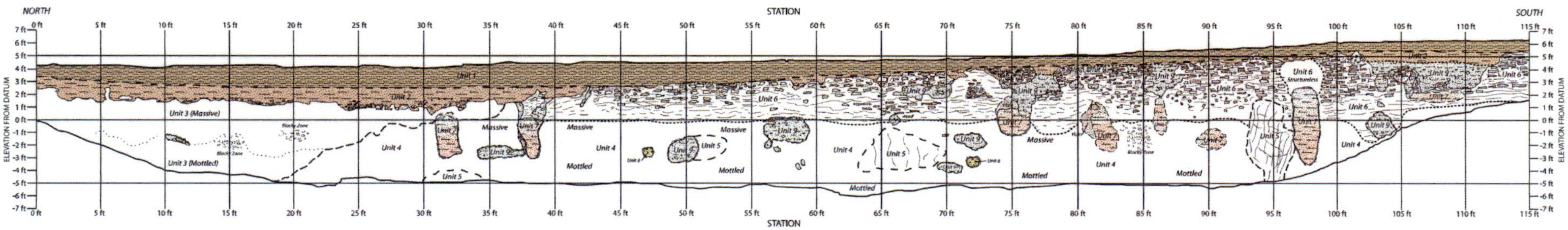


Figure 1 – General location of the trench relative to the WCS facilities. The short black line indicates the approximate location of the trench across the trend of vegetation, depressions, and color changes. The vegetative trend is about N55-60°W. The WCS facilities are southwest of the trench location about 1 mile.



EXPLANATION OF SYMBOLS

- Carbonate rind surrounding macropore or solution pipe
- Blocky calcrete texture
- Fractures
- Calcrete pebbles
- Sharp contact
- Gradational contact
- Diffuse contact

GEOLOGIC DESCRIPTIONS

Unit 1 – Surficial soil; silty sand; gray (10YR 5/1); within root zone of surface grasses; contains minor amounts of organic matter; displays weak pedogenic fabrics; contains local pebbles of calcrete; trace clay; lower contact diffuse to gradational.

Unit 2- Silty sand; pale brown (10YR 6/3); calcareous; no apparent stratification; localized weak columnar structure near base; shows some clay illuviation and possible weak cutans; locally bioturbated and shows root casts and molds; lower contact with Unit 3, Unit 4, or Unit 6 sharp; lower contact with Unit 9 diffuse to sharp; lower contact is erosional with localized accumulations of calcrete pebbles along the northern part of the trench.

Unit 3 – Calcrete; stage III; white (10YR 8/1.5); moderately soft to crumbly; very porous; generally appears massive in the upper part and mottled in the lower part; locally shows a blocky fabric; abundant root molds and casts; local pebbles of chert; host material very fine to fine sand with minor amounts of silt; lower contact not observed; lateral contact with Unit 4 gradational.

Unit 4 – Calcrete; Stage I-II; pink (5YR 7/3); poorly cemented; soft to very soft (south side) due to apparent leaching of carbonate; carbonate is widely dispersed throughout the unit; generally massive at the top to mottled at the base; nodules rare; local zones with a blocky texture; likely a degraded stage III calcrete; locally bioturbated; contains root casts and molds; localized carbonate stringers near the top; contains granules to small pebbles of carbonate and caliche; local pebbles of chert; host material very fine to fine sand; contains local zones of reddish-brown sand; lower contact not observed; lateral contacts diffuse to sharp.

Unit 5 – Calcrete; stage III+; pinkish white (5YR 8/2); host silt to very fine sand; massive and structureless; moderately fractured; fractures are typically subvertical, irregular to curvilinear, between 1 – 4 ft long, with variable orientations; fractures are most abundant near contacts with other units; contacts with other units gradational to sharp.

Unit 6 – Calcrete; stage IV; white (10YR 8/1); thickly laminated to very thinly bedded, fractured into tabular blocks and local equidimensional blocks, the size of tabular blocks varies with smaller pieces often overlying more permeable materials contained in solution pipes and macropores, laminar structure becomes more diffuse downward, displays local carbonate stringers near the base; upper 1 ft locally reworked into blocky to subrounded cobble- to pebble-sized clasts; host material very fine to medium, subangular to subrounded sand; upper surface shows erosion (north side of trench); lower contact diffuse to gradational; other contacts gradational to sharp.

Unit 7 – Sandstone; very fine sand, well sorted, subrounded to rounded, some dark grains, moderately well cemented with carbonate; light red (2.5YR 6/6); displays tabular to blocky structure; local carbonate-lined root casts; occurs within solution pipes and in irregular zones within calcrete units; abundant subhorizontal to horizontal carbonate stringers near the top of some Unit 7 zones; local subvertical carbonate stringers; contacts gradational to sharp; some sharp boundaries display well developed carbonate rinds; some zones containing Unit 7 are partially bounded by very calcareous, pink (5YR 8/3), halos consisting of similar sandstone.

Unit 8 – Silty sandstone; poorly cemented; poorly sorted; light gray (5YR 7/1); abundant pedogenic carbonate; contains subangular to subrounded pebbles of laminated calcrete; occurs in roughly circular macropores; 1/8 – 1/4 inch carbonate rinds bound macropores; contacts are sharp.

Unit 9 – Silty sand; poorly sorted; pinkish gray (5YR 6/2); contains granules to small pebbles of calcrete, some calcrete pebbles appear to be laminated; occurs in macropores and solution pits; most occurrences of Unit 9 are structureless, one occurrence (Station 35 ft) shows

Figure 2 – Trench map. The map is of the southeast face of the trench. The grid is 5 ft, and there is no vertical exaggeration.

Figure 3 – Trench overview. Photo taken toward the northeast showing general units and basic grid marking used to map the trench.

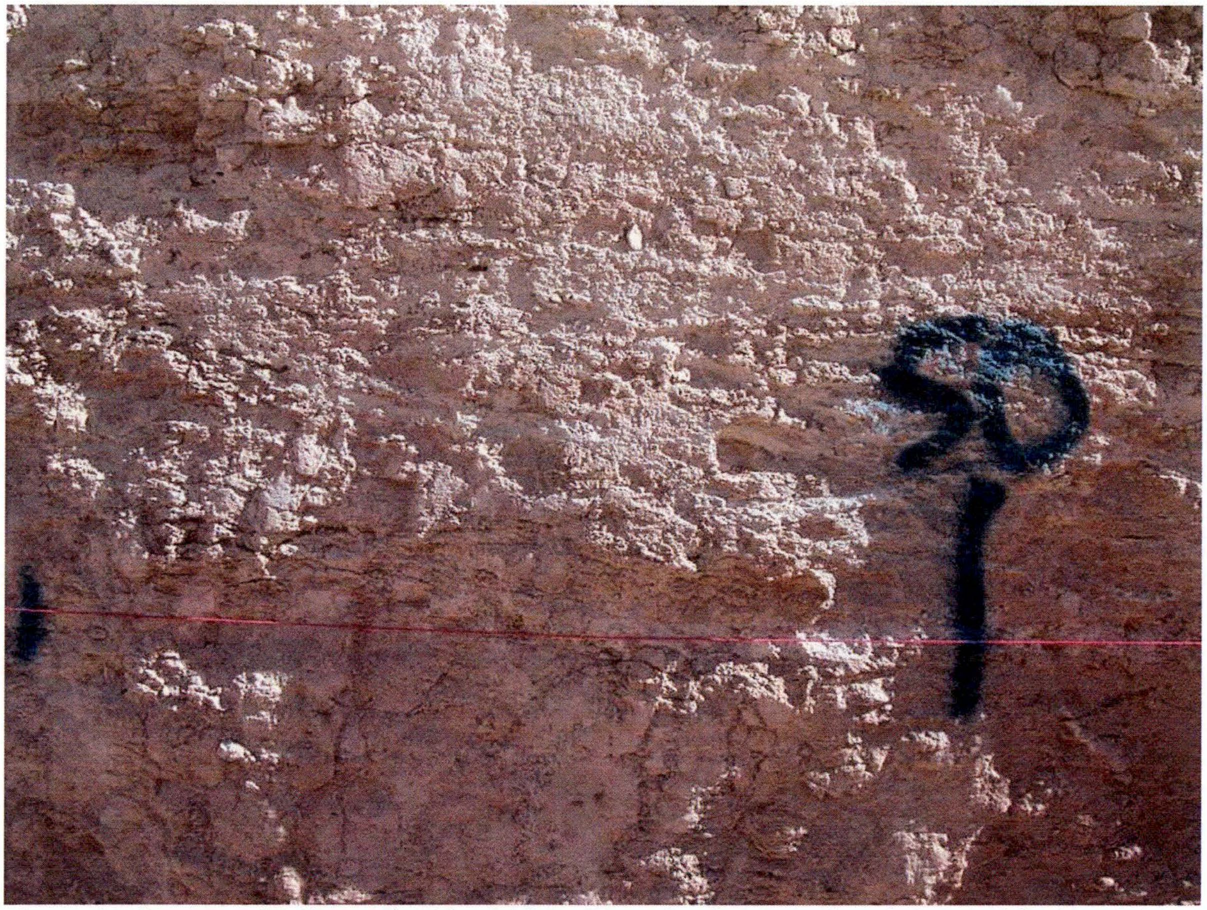


Figure 4 – Horizontal 0 line and grid marking. The red string was placed about midpoint of the depth of the trench and leveled across the trench using multiple string levels. It was anchored at intervals with nails and marked with paint at 2.5 ft intervals. Footages were numerically indicated at 5 ft intervals along the 0 line.

Figure 5 – Stage III calcrete, erosional surface, and modern soils. The surficial soil (Unit 1) occurs above the upper horizontal blue line and consists of silty sand. It is distinguished from the lower soil (Unit 2) by a darker color. The lower soil (Unit 2) contains calcrete pebbles derived from local erosion of calcrete. The calcrete (Unit 3) here has few soil structures but has abundant root casts, shown partly here by subhorizontal white carbonate.

Figure 6 – Stage I-II calcrete (Unit 4). Unit 4 occurs between the horizontal 0 line (red string) and the base of the trench. The upper part of Unit 4 is massive, while the lower part is mottled. Laminae associated with Unit 6 begin at about the 0 line. A solution pipe containing well-cemented sandstone (Unit 7) in the lower part and silty sand (Unit 9) in the upper part occurs on the left.

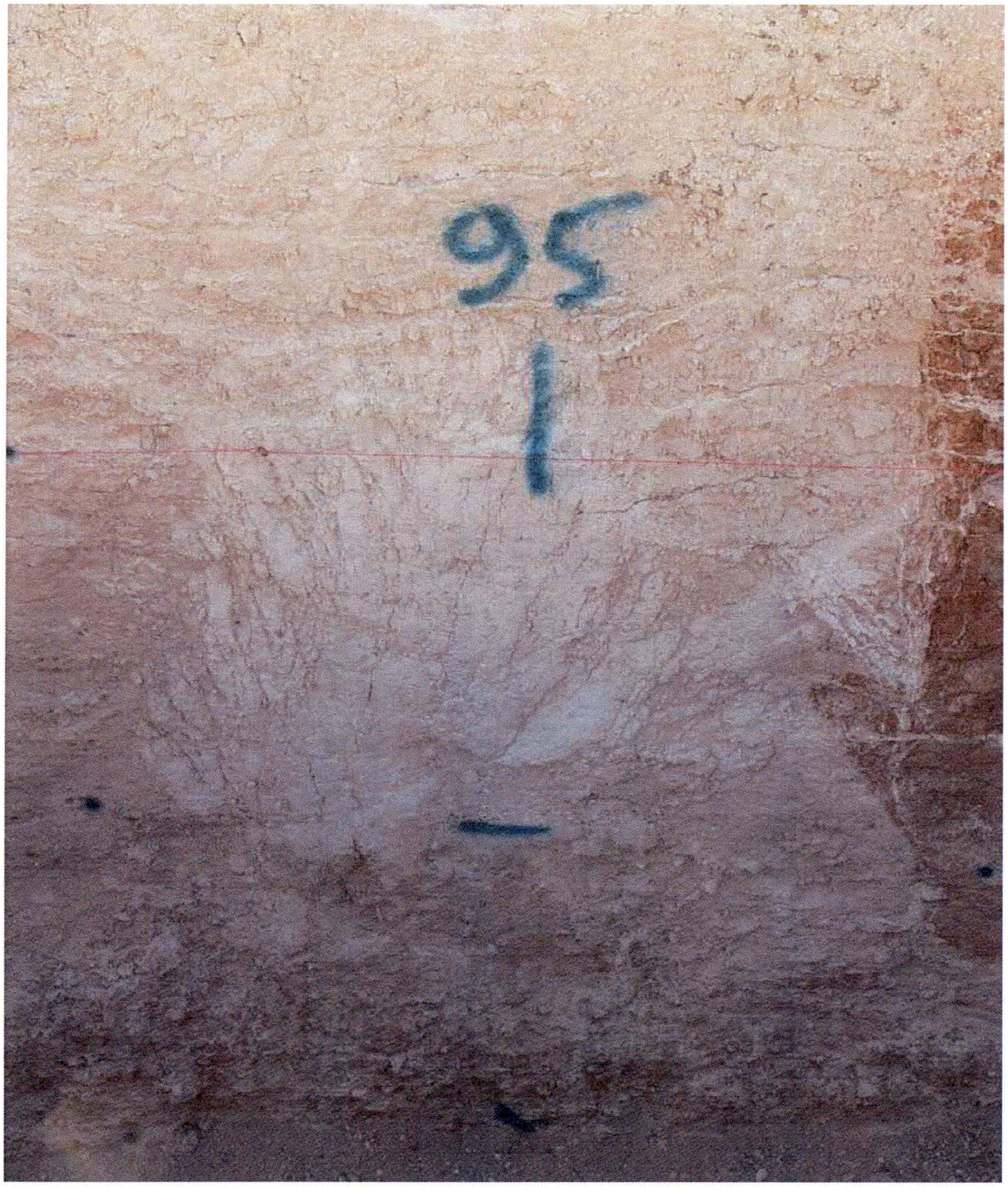


Figure 7 – Stage III+ calcrete (Unit 5). The block of Unit 5 at 95 ft, from about +0.5 to -2.5 ft, shows the whiter color, greater induration, and curvilinear fractures that terminate at the color and induration boundary. These fractures have variable orientations and are not parallel to the general lineament (Figure 1). Unit 4 surrounds the area of Unit 5. The side of a pipe filled with well-indurated sandstone (Unit 7) appears on the right side of the picture.

Figure 8 – Stage IV calcrete (Unit 6). Typical characteristics of Unit 6 are shown: thickly laminated to very thinly bedded carbonate at the base becoming fracture into tabular and equidimensional blocks upward. The upper part of an older pipe filled with well-indurated sandstone is at the lower left and shows some laminar development through the upper part.

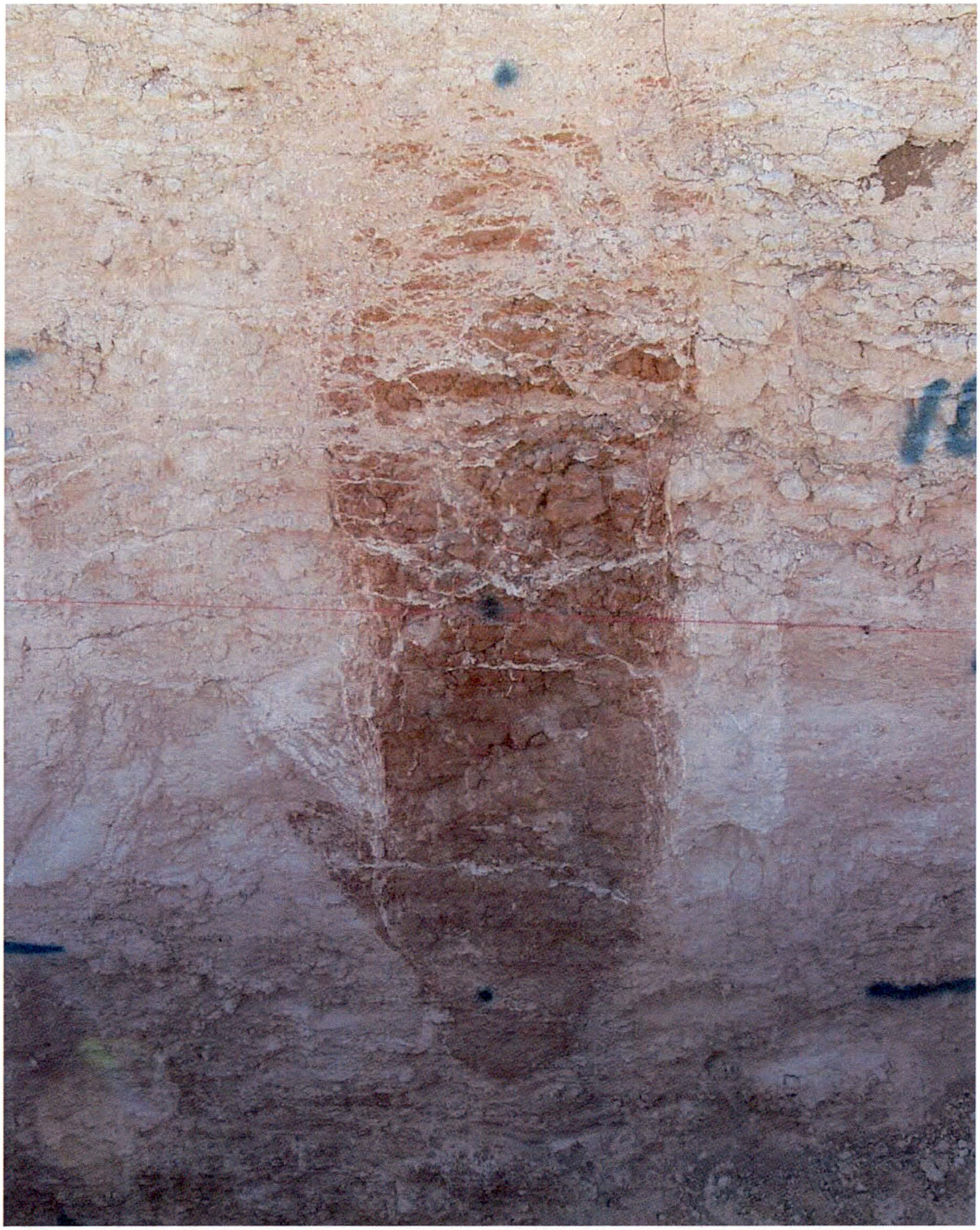


Figure 9 – Pit filled with well-indurated sandstone (Unit 7). This pit, at 97.5 ft, is ~ 5 ft deep (from +2.5 to -2.5 ft, shown by blue dots). Laminar rinds have developed around the sides, and the upper laminar zone of Unit 6 has engulfed the upper part, indicating that the pipes formed during the development of Unit 6.

Figure 10 – Possible parent material (Unit 7), occurring below the 0 line at the 90 ft mark, is surrounded by and shot through with carbonate. It may be the remnants of limited sediment present before the calcic soil surrounded it. The sandstone is also similar to pipe fillings designated as Unit 7.

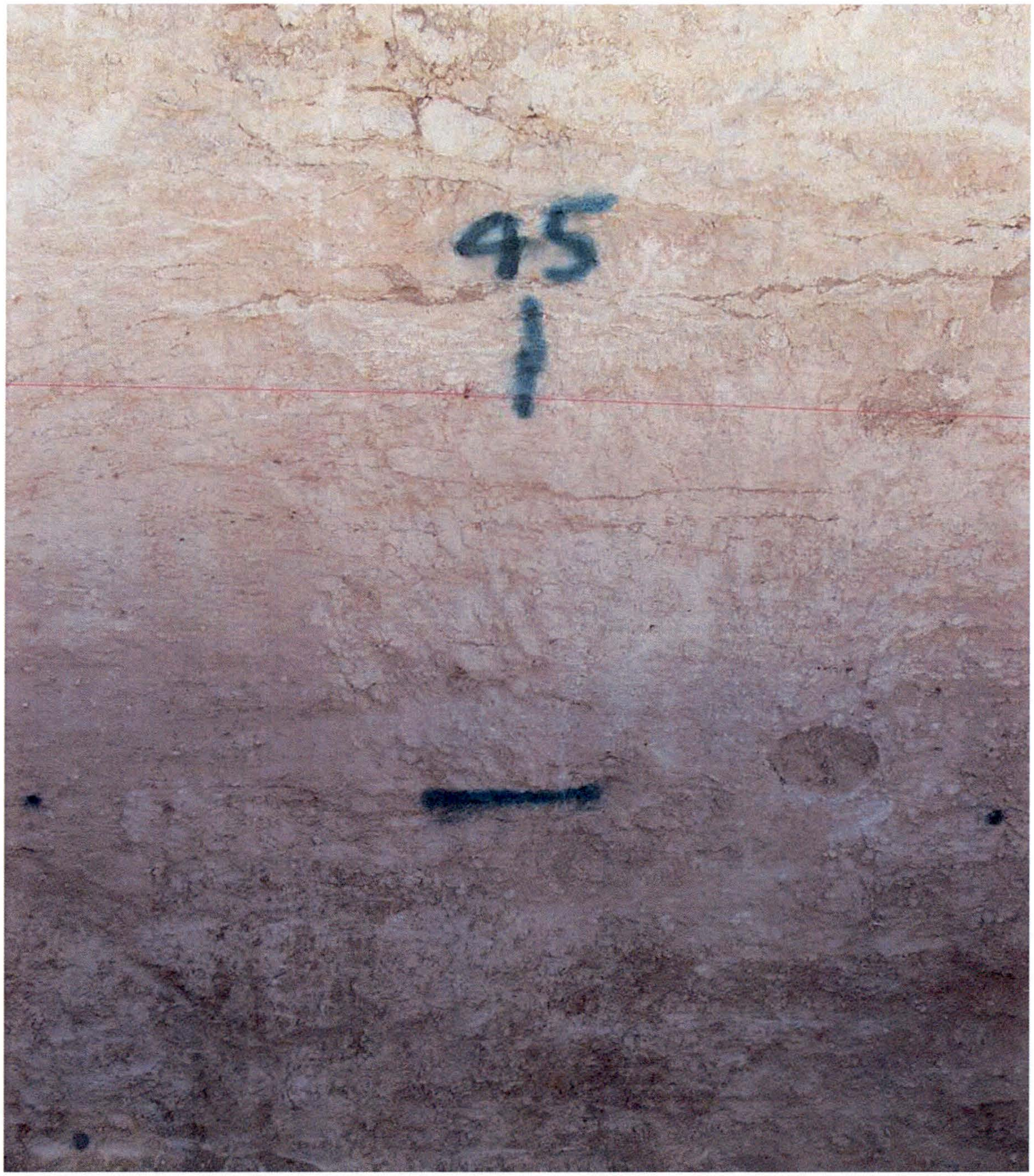


Figure 11 – Silty sandstone (Unit 8). The nearly circular macropore at ~46 ft, -2.5 ft, is filled with silty sandstone and shows a very thin rind around the perimeter. These are interpreted as later than the reddish brown sandstone-filled pipes.

Figure 12 – Silty Sand (Unit 9). Silty sand fills pipes and macropores at various depths through the calcic soil. Here the upper example shows two relationships: 1) it shows the connection with the more modern soils (Unit 2), and 2) collocation with an earlier pipe filled with well-indurated sandstone (Unit 7), a common feature along the upper calcic soil. A number of these show infiltration into the upper zones of an earlier pipe filled with well-indurated sandstone (Unit 7). Modern roots are common in Unit 9.

APPENDIX A

REVIEW OF PEDOGENIC CALCRETE DEVELOPMENT

Pedogenic calcretes evolve a general set morphological characteristics through time that can be categorized in terms of stages (e.g., Gile et al., 1966; Bachman and Machette, 1977; Machette, 1985). Bachman and Machette (1977) and Machette (1985) present six stages of development of carbonate morphology in pedogenic calcretes. In areas where rainfall is insufficient to flush carbonate through the system, carbonate cements begin to accumulate at the depth of infiltration in the soil parent material. Under a continuous regime of these conditions, carbonate begins to accumulate in thin films and as coatings on grains (Stage I). With continued infiltration, the films and coatings accumulate and thicken, eventually nodules form (Stage II). Eventually, pore throats can be filled or bridged, with carbonate cements becoming sufficient to impede infiltration (Stage III). When infiltration is sufficiently impeded, cements begin to form laminar deposits on top of the plugged horizon (Stage IV). Laminar deposits can build into a thick, well-indurated sequence on top of the basic plugged horizon (Stage V). With climatic changes, the pedogenic calcrete may be destroyed by increased rainfall. Shorter duration changes result in disruption of the calcrete fabric, especially near the surface, and renewed drier conditions and carbonate accumulation can re-cement these breccias, preserving the evidence of multi-generational development of the calcrete (Stage VI).