# REPORT

## GEOLOGIC HAZARDS EVALUATION

### THREE FALLS RANCH

### ALPINE CITY, UTAH COUNTY, UTAH

*Prepared for*

Mr. Will Jones
c/o: Pine Valley Realty
50 West Canyon Crest Road
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September 7, 2004

*Prepared by*

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Alpine, Utah 84004

**SUBJECT:** Geologic Hazards Evaluation
Three Falls Ranch
Alpine, Utah County, Utah

Dear Mr. Jones:

Western Geologic is pleased to present this report describing our geologic hazards evaluation for the proposed Three Falls Ranch Subdivision in Alpine, Utah.

It has been a pleasure working with you on this project. Should you have any questions please call.

Sincerely,
Western GeoLogic, LLC

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# EXECUTIVE SUMMARY

A geologic hazards evaluation was conducted for the proposed Three Falls Ranch subdivision in Alpine City, Utah County, Utah. The purpose of this investigation was to identify and interpret surficial geologic conditions at the site and to evaluate any potential geologic hazards to the project.

The investigation was performed by Bill D. Black, a licensed professional geologist and reviewed by Craig Nelson, a licensed professional geologist and certified engineering geologist. The investigation included a site reconnaissance, excavation and logging of seven exploratory trenches in two phases, review of available published and unpublished data, and preparation of this report that presents the results of our study and provides recommendations for development.

The site is at the junction of the Traverse Mountains and the Wasatch Range in northern Utah Valley, and is in a belt of active historical earthquake activity in the Intermountain area. The Fort Canyon fault, which is at the northern end of the Provo section of the active Wasatch fault zone trends across the site. The last large magnitude earthquake on the Provo section occurred about 600 years ago, with an older event about 2,850 years ago. The nearest large historical earthquake to the site was a magnitude 6.6 event in Hansel Valley at the north end of the Great Salt Lake in 1934.

A main trace and an antithetic trace of the Fort Canyon fault is mapped across the central and northern parts of the site based on interpretation of aerial photographs and surficial geology. The faults form a down-dropped area across the surface of the site, but scarps associated with the faults are incompletely exposed or concealed. Given this information, a subsurface exploration program consisting of seven north-trending trenches was developed to determine the location and characteristics of the faulting at the site and provide recommendations for safe development. Trenches 1 through 4 were in the first trenching phase in the lower, western part of the site; trenches 5 through 7 were in the second phase in the upper, eastern part. Trenches 1, 5, and 6 exposed the main fault trace; trenches 4 and 7 exposed the antithetic trace. No evidence of faulting was found in trenches 2 and 3. The amount of displacement and character of the main fault trace varied across the site, from a single fault showing 6.0-7.6 feet of down-to-the-south displacement in trench 1, to a fault zone with a total 3.2-4.1 feet of down-to-the-south displacement in trench 5, to a 70-foot side graben in trench 7 with a net 3.4 feet of down-to-the-south displacement. Displacement along the antithetic fault in trench 4 could not be measured due to surface erosion, but 4.1 feet of down-to-the-north displacement in old alluvium and landslide deposits was measured in trench 7. A radiocarbon age date from a key stratigraphic horizon in trench 1 shows the most-recent event on the Fort Canyon fault occurred slightly after 2,730-2,890 years ago. The age date shows the Fort Canyon fault has been active in the past 10,000 years. Based on evidence exposed in the trenches, a non-buildable zone was defined along the fault using recommended fault setback guidelines published by the Utah Geological Survey.

Due to the large scale of the development, geologic hazards potentially impact every lot at the site, including earthquake ground shaking, surface fault rupture, liquefaction, tectonic subsidence, stream flooding, debris flows, shallow ground-water, landslides, and rock fall. To reduce the risk from these hazards, the report recommends constructing homes to current seismic standards to reduce the potential ground-shaking hazard; locating no structures designed for occupancy within the fault setback zone; evaluation of and recommendations regarding debris flows and stream flooding in the civil engineering design for the development; and conducting a design-level geotechnical engineering study prior to construction for addressing soil conditions, shallow ground water, and slope stability hazards. Data regarding expected debris flow volumes is provided for use in the civil engineering design.

## 1.0 INTRODUCTION

This report presents results of a reconnaissance-level engineering geology and geologic hazards review and evaluation for the proposed roughly 800-acre Three Falls Ranch residential subdivision in Alpine City, Utah County, Utah (figure 1). The site is in Fort Canyon, near the conjunction of the Traverse Mountains and Wasatch Range, in Section 12, Township 4 South, Range 1 East; and Section 7, Township 4 South, Range 2 East (Salt Lake Base Line and Meridian). Elevation of the site ranges from about 5,300 to 6,300 feet above sea level.

## 2.0 PURPOSE AND SCOPE

The purpose of the investigation was to identify and interpret surficial geologic conditions at the site and to evaluate any potential geologic hazards to the project. The following services were performed in accordance with that purpose:

(1) A site reconnaissance conducted by an experienced certified engineering geologist to assess the site setting and look for evidence of adverse geologic conditions,

(2) Excavation and logging of seven exploratory trenches in two phases to identify the presence, location, and recent activity of any faults at the site; assess zones of fault-related deformation; and recommend appropriate fault set-back distances and safe "buildable" areas should faults be discovered.

(3) Review of available geologic maps and reports, and

(4) An evaluation of available data and preparation of this report, which presents the results of our study.

A detailed field review of the trenches and data from the first phase of the study was conducted on April 23 for Greg McDonald, Robert Biek, and Michael Hylland of the Utah Geological Survey. A second field review was conducted on April 26 for the developer, officials from Alpine City, and interested individuals.

This report was prepared in general accordance with the Guidelines for Preparing Engineering Geologic reports in Utah (Utah Section of the Association of Engineering Geologists, 1986), and Guidelines for Evaluating Surface Fault Rupture Hazards in Utah (Utah Section of the Association of Engineering Geologists, 1987).

## 3.0 SITE RECONNAISSANCE AND AIR PHOTOS

On April 19-22 and June 22-24, 2004, Mr. Bill D. Black of Western GeoLogic conducted a site reconnaissance of the western and eastern halves of the property (respectively). Vegetation varies across the site, but generally of grasses, leafy ground cover, oak brush, sage brush, and large pine, aspen, and cottonwood trees. Weather during the initial field reconnaissance was partly cloudy to sunny with scattered rain and snow showers. Weather during the second field reconnaissance was sunny with temperatures in the mid 80's.

1:20,000-scale aerial photographs (U.S. Department of Agriculture, 1972; frames CVX-2MM-26 and CVX-2MM-27) and digital orthophoto quadrangle aerial photography (National Aerial Photography Program, frames 10096 117, 10096 226, and 10096 245; September, 1997; figure 3) were reviewed to obtain information about the geomorphology of the site and surrounding area. The site is in Fort Canyon at the range front near the conjunction of the east-west trending Traverse Mountains and the north-south trending Wasatch Range. Two traces of the Fort Canyon fault are mapped by Machette (1992) and Biek (2003) trending generally east-west across the site; the faults form a wide, deep graben that transects the northern end of Fort Canyon on the photos. However, scarps associated with the faults are not well evident on the photos or in the field.

Streams flow from the west, north, and south into the junction formed by the Fort Canyon fault and Fort Canyon, and combine into Fort Creek which flows south into Alpine City. One small lake is evident on the air photos in the eastern part of the site, east of the junction (figure 3). Southeast of this lake are a group of several old lakes that were dry in the 1997 NAPP photo and at the time of the field reconnaissance. The 1972 air photos show one lake had water, however; Nephs Lake shown on figure 1 was dry on both the 1972 and 1997 photos and at the time of this investigation. Bedrock outcrops are evident on the photos in the north-central part of the site, north of the northern end of Fort Canyon. Several landslides are also evident on the photos, the largest of which is associated with a prominent northeast-facing escarpment south of the small lake (figure 3). No other geologic hazards are evident at the site.

## 4.0 HYDROLOGY

The U.S. Geological Survey (USGS) topographic map of the Lehi Quadrangle shows several surface-water impoundments and streams crossing the property. Schoolhouse Spring and an unnamed spring are also to the east and west of the site. At the time of the first field reconnaissance in April, slopes at the site appeared moist; slopes at the site during the second reconnaissance were dry and hard. Water was evident in three of four trenches excavated in the initial phase of this investigation in April, but was not evident in the trenches excavated in June for the second phase. This evidence suggests portions of the site likely have a shallow water table in spring months which deepens in the summer.

Clark and Appel (1985) indicate subsurface hydrology of the site is dominated by an unconfined aquifer in pre-Lake Bonneville deposits, which is found along the mountain front throughout northern Utah Valley. The shallow aquifer along the mountain front forms a principal recharge area for the primary artesian aquifers in the valley. Ground water generally flows from the mountain fronts to Utah Lake and the Jordan River to the west; based on general topography, regional ground-water flow at the site is expected to be to the south. A downward component of movement also exists throughout the primary recharge area along the mountain front into the confined aquifers. The depth to the shallow unconfined aquifer varies somewhat depending on topography and climatic and seasonal fluctuations. It is influenced by infiltration from precipitation and runoff, and upward leakage from the confined aquifers in the valley.

Surface water is the main source of recharge to the primary aquifers in northern Utah Valley, and is also a source of irrigation water and part of the water supply for municipalities and industry (Clark and Appel, 1985). Surface water sources in northern Utah Valley include Fort, Dry, Battle, Rock, Slate, and Grove Creeks; American Fork; the Provo River; and the Weber-Provo diversion and Duchesne tunnel. Estimated inflow into northern Utah Valley from sources other than American Fork and the Provo River accounts for only about 10 percent of the total (Clark and Appel, 1985). Annual recharge to the principal ground-water aquifers in northern Utah Valley is estimated to be 200,000 acre-feet (Clark and Appel, 1985).

# 5.0 GEOLOGY

## 5.1 Seismotectonic Setting

The property is located in northern Utah Valley near the junction of the Traverse Mountains and the Wasatch Range. Northern Utah Valley encompasses about half of Utah Valley, a north-trending sediment-filled basin about 40 miles long and 10 to 20 miles wide. Northern Utah Valley is bounded by the Wasatch Range on the east, the Traverse Mountains on the north, and the Lake Mountains on the west. The valley lies at the eastern edge of the Basin and Range physiographic province (Stokes, 1977, 1986). The Basin and Range province is characterized by a series of generally north-trending elongate mountain ranges, separated by predominately alluvial and lacustrine sediment-filled valleys and typically bounded on one or both sides by major normal faults (Stewart, 1978). The boundary between the Basin and Range and Middle Rocky Mountains provinces is the prominent, west-facing escarpment along the Wasatch fault zone at the western base of the Wasatch Range. Late Cenozoic normal faulting, a characteristic of the Basin and Range, began between about 17 and 10 Ma (million years ago) in the Nevada (Stewart, 1980) and Utah (Anderson, 1989) portions of the province. The faulting is a result of a roughly east-west directed, regional extensional stress regime that has continued to the present (Zoback and Zoback, 1989; Zoback, 1989).

The Wasatch fault zone is one of the longest and most active normal-slip faults in the world, and extends for 213 miles along the western base of the Wasatch Range from southeastern Idaho to north-central Utah (Machette and others, 1992). The fault zone generally trends north-south and, at the surface, can form a zone of deformation up to several hundred feet wide containing many subparallel west-dipping main faults and east-dipping antithetic faults. Previous studies divided the fault zone into 10 sections, each of which rupture independently and are capable of generating large-magnitude surface-faulting earthquakes (Machette and others, 1992). The central five sections of the fault (Brigham City, Weber, Salt Lake, Provo, and Nephi) have each produced two or more surface-faulting earthquakes in the past 6,000 years (Black and others, 2003). The west-trending Traverse Mountains form a major bedrock salient along the Wasatch Range front separating Salt Lake and Utah Valleys. This salient forms the structural boundary between the Salt Lake City and Provo sections of the Wasatch fault zone (Machette, 1992).

The Provo section of the Wasatch fault zone extends for about 43 miles from the Traverse Mountains south to Payson Canyon. Machette and others (1986) tentatively subdivided the Provo section into three shorter sub-segments: American Fork, Provo (restricted sense) and Spanish Fork. However, subsequent trenching data suggested that these sub-segments had not behaved independently, at least during the last two surface-faulting earthquakes (Machette and others, 1991), and instead likely formed one long fault section. Black and others (2003) indicate three surface-faulting earthquakes occurred on the Provo section in the past 6,000 years: a most-recent event about 600 years ago, a penultimate event about 2,850 years ago, and an antepenultimate event about 5,300 years ago. Mean recurrence (average time between events) is about 2,350 years (Black and others, 2003).

The Wasatch fault zone turns abruptly east as it crosses the Traverse Mountains at the boundary between the Salt Lake City and Provo sections. This part of the fault zone is referred to the Fort Canyon fault by Bruhn and others (1987). The Fort Canyon fault corresponds with the westward projection of the Deer Creek fault, which is a transverse structure and northern tear fault of the east-vergent Charleston-Nebo thrust fault (Machette, 1992). The Fort Canyon fault transfers motion along the Wasatch fault zone about 5 miles to the west, from Utah Valley to the southern part of Salt Lake Valley. Thus, in this part of the fault (at the northern end of the Provo section), the Wasatch fault zone would likely have oblique slip (both downward to the south and laterally to the west).

Machette (1992) and Biek (2003) map two traces of the Fort Canyon fault across the site: a main south-dipping fault trace; and an antithetic, north-dipping, trace. Biek (2003) also shows three northeast-trending en-echelon faults in Tertiary alluvium and Paleozoic bedrock that are truncated by the antithetic fault trace. The faults are mapped from lineaments on air photos and show an uncertain component of tectonic displacement; their age is also uncertain and likely pre-Holocene (Robert F. Biek, Utah Geological Survey, verbal communication, July 2004).

The site is also in the central portion of the Intermountain Seismic Belt (ISB), a generally north-south trending zone of historical seismicity along the eastern margin of the Basin and Range province extending from northern Arizona to northwestern Montana (Sbar and others, 1972; Smith and Sbar, 1974). At least 16 earthquakes of magnitude 6.0 or greater have occurred within the ISB since 1850; the largest of these earthquakes was a $M_S$ 7.5 event in 1959 near Hebgen Lake, Montana. However, none of these earthquakes occurred along the Wasatch fault or other known late Quaternary faults (Arabasz and others, 1992; Smith and Arabasz, 1991). The closest of these events was the 1934 Hansel Valley ($M_S$ 6.6) event north of the Great Salt Lake.

### 5.2 Unconsolidated Deposits and Bedrock

Surficial and bedrock geology of the site was mapped by Biek (2003). Detailed descriptions of geologic units mapped at the site and in the vicinity (figure 2), from youngest to oldest in age, are given below. References shown below are in Biek (2003), and are not repeated in the References Section of this report.

*Qf* – **Artificial fill (Historical).** Engineered fill used in construction of Interstate 15 and other road and railroad beds; larger areas of fill used to create new, level building areas are also mapped based on aerial photographs taken in May 2002; although only larger fill deposits are shown, fill of variable composition may be present in any developed area; variable thickness up to about 90 feet (30 m).

*Qaf1* – **Modern alluvial-fan deposits (Holocene).** Poorly to moderately sorted, non-stratified, clay- to boulder-size sediment deposited principally by debris flows at the mouths of active drainages; upper parts typically characterized by abundant boulders and debris-flow levees that radiate away from the apex of the fan; equivalent to the younger part of Qafy, but differentiated because they form smaller, isolated fans; generally less than 30 feet (9 m) thick.

*Qaly* – **Young alluvial deposits (Holocene to upper Pleistocene).** Moderately sorted sand, silt, clay, and pebble to boulder gravel deposited in river channels and flood plains; locally includes small alluvial fan and colluvial deposits; probably less than 20 feet (6 m) thick.

*Qafy* – **Younger undifferentiated alluvial-fan deposits (Holocene to upper Pleistocene).** Equivalent to modern and level-2 alluvial-fan deposits, but undifferentiated because units are complexly overlapping or too small to show separately; upper parts of fans locally deeply incised; thickness unknown, but likely up to several tens of feet.

*Qc* – **Colluvial deposits (Holocene to upper Pleistocene).** Poorly to moderately sorted, angular, clay- to boulder-size, locally derived sediment deposited by slope wash and soil creep on moderate slopes and in shallow depressions; locally grades upslope into talus deposits and downslope into mixed alluvial and colluvial deposits; because most bedrock is covered by at least a veneer of colluvium, only the larger, thicker deposits are mapped; 0 to about 20 feet (0-6 m) thick.

*Qac, Qaco* – **Alluvial and colluvial deposits (Holocene to upper Pleistocene).** Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment deposited in swales, small drainages, and the upper reaches of larger ephemeral streams by fluvial, slope-wash, and creep processes; older deposits (Qaco) form isolated remnants deeply incised by adjacent streams; Qaco in upper reaches of Fort Canyon show several poorly developed soil horizons and may represent deposition in a sag pond adjacent to the Fort Canyon fault; generally less than 30 feet (9 m) thick.

*Qafo* – **Older alluvial-fan deposits (upper Pleistocene).** Similar to younger undifferentiated alluvial-fan deposits (Qafy), but forms deeply dissected alluvial aprons truncated by, and thus predating, the Bonneville shoreline; upper parts of fans locally receive sediment from minor washes; thickness unknown, but likely up to several tens of feet.

*Qmsh, Qmsy, Qmso, Qms* – **Landslide deposits (Historical to Pleistocene).** Very poorly sorted, clay- to boulder-size, locally derived material deposited by rotational and translational movement; characterized by hummocky topography, numerous internal scarps, and chaotic bedding attitudes; basal slip surfaces most commonly form in the volcanic rocks of Traverse Mountains (Tv) and Tertiary alluvial-fan (Taf) deposits, but are also in lacustrine deposits and regolithic and colluvial sediment derived from the Oquirrh Group and altered Little Cottonwood stock; a small landslide in Manning Canyon Shale is present southwest of Jordan Narrows; Qmsh denotes a small slide at Jordan Narrows with historical movement; younger landslides (Qmsy) may have historical movement, but typically are characterized by slightly to moderately subdued landslide features indicative of early Holocene to late Pleistocene age; older landslides (Qmso) are deeply incised and head scarps and hummocky topography have been extensively modified by erosion and so are likely late Pleistocene in age; a single landslide (Qms) mapped near Potato Hill is of uncertain age; many of these landslides exhibit complex, multiple episodes of movement; query indicates uncertain designation; the northwest-facing slope of Steep Mountain is covered by colluvium that, in low light, clearly shows evidence of creep as wavy, subhorizontal ridges and swales; thickness highly variable.

*Qgob* – **Glacial outwash of the Bells Canyon advance (Pinedale equivalent, 30-10 Ka).** Moderately to well-sorted, subangular to subrounded, clast-supported, pebble to boulder sand and gravel; typically medium to thick bedded; clasts are little weathered and are derived from the Little Cottonwood stock and Mississippian and Pennsylvanian strata of Dry Creek Canyon; mapped north of Alpine where it forms moderately dissected, bouldery surfaces graded to bells Canyon till immediately east of the Lehi Quadrangle; probably 0 to 40 feet (0-12 m) thick.

*Qgod* – **Glacial outwash of the Dry Creek advance (Bull Lake equivalent, 160 to 40 Ka).** Similar to outwash of Bells Canyon, but clasts are deeply weathered; granitic clasts typically have grusified rinds; mapped north of Alpine where it forms a moderately dissected, bouldery surface adjacent to Dry Creek till; also mapped in upper Fort Canyon where it consists entirely of deeply weathered granitic clasts; probably 0 to 80 feet (0-25 m) thick.

*QTa* – **Old alluvial deposits (lower Pleistocene to Pliocene).** Moderately well-sorted, sand, silt, and pebble to boulder gravel deposited by ancestral Dry Creek; locally moderately cemented; clasts consist of grusified granitic boulders and uncommon grusified volcanic clasts, and orthoquartzite blocks; forms remnants overlying marble breccia north of Alpine; 0 to about 100 feet (0-30 m) thick.

*Taf* – **Old alluvial deposits (lower Pleistocene to Pliocene).** Unconsolidated, pebble- to boulder-size, subangular to subrounded orthoquartzite and calcareous sandstone clasts and, especially near the base and top of the deposits, minor volcanic clasts; limestone clasts are rare and appear to be restricted to the upper part of the deposits; clasts of monzogranite or granodiorite of the Little Cottonwood stock are conspicuously absent from these deposits; includes a 300-foot-long (100-m) block of brecciated orthoquartzite near the center of section 11, T. 4 S., R. 1 E. that is interpreted to be a slide block derived from a former nearby mountain front; a single good exposure of the lower part of the deposits in Hog Hollow that dip 20 degrees east reveals subangular to subrounded, pebble- to cobble-size clasts with fewer boulders, medium to thick beds, and clasts that are about 60 percent sandstone and orthoquartzite and about 40 percent grusified volcanic clasts of the Traverse Mountains; mapped south of the Fort Canyon fault at the east end of the Traverse Mountains and southwest of Jordan Narrows; in both areas it unconformably overlies volcanic rocks of the Traverse Mountains; age poorly constrained between Oligocene and Pliocene; thickness uncertain, but likely in excess of 1,000 feet (330 m).

***Tia1, Tia2*** **– Altered monzongranite and granodiorite of Little Cottonwood stock (Tertiary).** Hydrothermally altered and mechanically deformed monzongranite and granodiorite of the Little Cottonwood stock; grades from greenish, highly altered rocks near the Wasatch and Fort Canyon faults to brownish, less altered rocks toward the interior of the pluton; fracture surfaces, even in less altered rocks are commonly coated with epidote; forms partly preserved footwall carapace up to 650 feet (200 m) thick that grades downward into little altered or unaltered monzongranite and granodiorite; Parry and Bruhn (1986) reported a K-Ar age of 17.6 $\pm$ 0.7 Ma on hydrothermal sericite and estimated depths of formation between 4.5 and 7.1 miles (7.2-11.4 km); units and contacts adapted from Evans and others (1997):

> ***Tia1*** **– Fault slip zone.** Consists of cataclasite and phyllonite that each contain two syndeformational mineral assemblages, inlcuidng and early, higher temperature epidote-chlorite-sericite-magnetite assemblage and a later, lower temperature laumonite-prehnite-hematite and clay mineral assemblage found in cross-cutting veins (Parry and Bruhn, 1986); includes pseudotachylyte veins; preserved thickness generally less than 30 feet (10 m).
>
> ***Tia2*** **– Transition zone.** Hydrothermally altered and fractured monzogranite and granodiorite of the Little Cottonwood stock; grades upward into heterogeneously and increasingly deformed and altered rock of fault slip zone, and downward into unaltered Little Cottonwood stock; weathers to grusified soils; about 65 to 650 feet (20-200 m) thick.

***Tv*** **– Volcanic rocks of Traverse Mountains, undivided (Oligocene).** Consists of volcanic breccias, flows, and tuffs which are impractical to map separately throughout most of the Traverse Mountains due to poor exposures; classified as borderline dacite, trachydacite, trachyandesite, and andesite on the TAS diagram of LeBas and others (1986); flows, some of which could be welded tuffs, are more common in the east Traverse Mountains and in the upper part of the section at Camp Williams; probably derived from volcanic centers in the west Traverse Mountains, including Shaggy Peak, a rhyolite plug that yielded a K-Ar age of 33.0 $\pm$ 1.0 Ma (Moore, 1973), the Step Mountain latitic plug or dike, and nearby smaller vents; at least 1,000 feet (330 m) thick.

# 6.0 SURFACE FAULTING INVESTIGATION

Seven trenches were excavated at the site in two phases to evaluate the hazard from surface faulting, identify active faults, and evaluate subsurface geologic conditions. A secondary purpose of the first phase of the trenching investigation was to assess fault activity. Trenches 1 through 4 were excavated in April 2004 in the western part of the site. Trench 1 was excavated across a steep south-facing escarpment presumed to be the main trace of the Fort Canyon fault, and extended for a total distance of about 122 feet. Trenches 2 and 3 were excavated to the east of trench 1 along the estimated strike of the fault, and extended for total distances of 145 feet and 100 feet, respectively. Trench 4 was excavated south of trench 3 across a boulder line presumed to be associated with the antithetic fault, and originally extended for about 256 feet; the trench was subsequently extended an additional 185 feet northward (for a total length of about 441 feet) based on deposits exposed in the trench. Heavy vegetation complicated excavation of trench 4. Shallow ground water was exposed in the floor in the northern end of trenches 1 and 4, and in the southern end of trench 2. Figures 6a-b, 7a-b, 8a-b, and 9a-f are detailed logs of trenches 1-4 at a scale of 1 inch equals 5 feet (1:60). Field reviews conducted in April 2004 involved only the trenches excavated in the first phase.

Trenches 5 through 7 were excavated in June 2004 in the eastern part of the site; no field reviews were conducted of these trenches since the purpose of the second phase was only to relocate the main and antithetic faults in the eastern part of the site. With regard to trenches 5 and 7, no surface expression of the main and antithetic faults was evident. Trench 5 was excavated across the approximate mapped location of the main fault, and extended for a total distance of about 219 feet. Trench 6 was excavated to east of trench 1 across a graben presumed associated with the main fault, and extended for a total distance of 278 feet. Trench 7 was excavated across the approximate mapped location of the antithetic fault, and extended for a total distance of about 642 feet. Heavy vegetation limited access and complicated excavation of trenches 6 and 7. No ground water was observed in trenches 5-7. Figures 10a-c, 11a-d, and 12a-i are detailed logs of trenches 5-7 at a scale of 1 inch equals 5 feet (1:60).

## 6.1 Sequence of Deposition and Faulting in Trenches at Three Falls Ranch

### 6.11 Trench 1

The oldest deposit in trench 1 is comprised of alluvium and colluvium containing large, grusified granite boulders (unit 1), which is overlain by a sequence of debris flood deposits (units 2 and 3, figures 6a-b). A paleosol A horizon is on top of unit 2, and the modern A-horizon soil is forming on unit 3 at the surface. These deposits are displaced 6.0-7.6 feet down to the south by a single surface-faulting earthquake on the main trace of the Fort Canyon fault. The upper most debris flood deposit (unit 3), and a backtilted paleosol A horizon on top of the unit, are buried by colluvium (unit 4) derived from fault-scarp degradation following the event (figure 6a). Unit 4 is buried to the south by a deposit of channel alluvium (unit 5, figure 6b) and fill from grading of a dirt road. During excavation of trench 1, shallow ground water was encountered seeping from unit 1 along the fault trace.

### 6.12 Trenches 2 and 3

Trenches 2 and 3 exposed a similar sequence of deposits to trench 1, but no evidence for faulting. The fault scarp at trench 1 was less evident at the surface eastward, and the fault must have made a more northward bend than anticipated at these trench locations. The oldest unit in trench 2 is alluvium and colluvium, which is also overlain by a sequence of debris floods with topset paleosol A horizons and a deposit of organic-rich channel alluvium (units 1-4, figures 7a-b). Water was encountered in trench 2 in its southern end seeping from the alluvium and colluvium (unit 1, figure 7b), similar to the situation in trench 1. Trench 3 does not expose the alluvium and colluvium found in trenches 1 and 2, but does expose the overlying debris floods and organic-rich alluvium (units 1-3, figures 8a-b). No shallow ground water was encountered in trench 3.

### 6.13 Trench 4

Trench 4 exposes a complex deformational history suggestive of landsliding, as well as evidence for the antithetic fault associated with the Fort Canyon fault. The oldest deposit exposed in trench 1 is glacial outwash containing grusified boulders (unit 1, figures 9d-e) that correlates to the Bull Lake-equivalent Dry Creek Advance (unit Qgob, Geology Section above) 160,000 to 40,000 years ago. Unit 1 is faulted and unconformably in contact with old alluvial-fan sediments (unit 2, figure 9d) in a down-dropped graben. Both units 1 and 2 contain numerous, chaotic, north- and south-dipping shears and brecciated zones, and unit 2 also contains brecciated boulders and cobbles. Unit 1 is unconformably overlain by glacial outwash containing large, rounded, hard boulders interpreted as correlating to the Pinedale-equivalent Bells Canyon Advance (unit Qgod, figure 2; Geology Section above) 30,000 to 10,000 years ago. Unit 3 appeared undeformed in the trench exposure. This suggests units 1 and 2 were possibly deformed by landsliding some time prior to deposition of unit 3, although no evidence of the landslide or source remains.

All these units are displaced down to the north an unknown amount by the antithetic fault (figure 9c), and unit 1 is in fault contact with a younger mudflow (unit 7, figure 9c). The antithetic fault was not evident at the surface, suggesting this location has experienced a considerable amount of erosion that must have removed the fault scarp, as well as units 2 and 3. Unit 7 overlies a depositional sequence of colluvium and debris-flood deposits (units 4-6, figures 9a-b) similar to that found in trenches 1-3, and is also eroded at the surface. The youngest unit exposed in the trench is organic-rich alluvium (unit 8, figure 9a) similar to that found in trenches 1-3. Shallow ground water was encountered seeping from unit 4 in the north trench end.

### 6.14 Trench 5

The oldest deposits exposed in trench 5 are a sequence of debris flows with a topset paleosol A/Bt soil sequence (units 1 and 2, figure 10a). These units are displaced 3.2-4.1 feet down to the south by a single surface-faulting earthquake on the main trace of the Fort Canyon fault, and buried by fault-scarp colluvium (unit 3, figure 10a). Units 2 and 3 are overlain by alluvium and a debris-flow deposit (units 4 and 5) that must have eroded and draped the fault scarp. Unit 5 is overlain by another debris flow (unit 6, figures 10a-c)) and was also eroded along the fault scarp, leaving no surficial evidence of the main fault. No ground water was encountered in the trench.

### 6.15 Trench 6

Trench 6 exposes evidence for landsliding and a deep graben along the main fault. The trench exposed a sequence of alluvium (units 1 and 2) overlain by a landslide deposits containing blocks of organics and organic-filled cracks (unit 3, figure 11a). A paleosol A horizon was evident on top of unit 2, and the modern A-horizon soil is forming on unit 3 at the surface (figure 11a). All these units are displaced more than 9.3 feet down to the south by a single surface-faulting earthquake on the main fault, and also backtilted into the fault zone to form a 65 to 70-foot wide graben (figure 11b). Net displacement across the graben is an estimated net 3.4 feet down to the south. Unit 3 and a topset paleosol A horizon are buried by colluvium derived from fault-scarp erosion following the event (unit 4, figure 11b). Unit 4 is in turn overlain by organic-rich alluvium deposited in the graben (unit 5, figures 11b-c). The modern A-horizon soil is forming on top of units 3 and 5 south of the fault zone (figures 11b-d). No ground water was encountered in the trench, although surface water was evident in a drainage along the north side of the road a few tens of feet south of the south trench end.

### 6.16 Trench 7

Trench 7 exposed a sequence of poorly bedded alluvium (unit 1, figure 12e) overlain by a clay-rich landslide deposit that is exposed the entire length of the trench (unit 2, figures 12a-i). Between 295 and 300-feet horizontal (figure 12e), these units are displaced 4.0 feet down to the north by the antithetic fault associated with the Fort Canyon fault. Similar to other trench exposures at the site, erosion has removed all surficial evidence of the fault scarp and the scarp-derived colluvium. The landslide deposit was very tough and required special backhoe teeth to cut, and consisted of a lower fat clay that polished to a near-mirror finish when cut by the backhoe and an upper clay-rich colluvium containing brecciated boulders and cobbles. No ground water was encountered in the trench.

## 6.2 Radiocarbon Dating

Four bulk soil samples were taken from trench 1 for radiocarbon dating to determine ages of sediments exposed in the trench. Two samples from key horizons in the trench were submitted for analysis; the remaining two were reserved as backup. We report ages from the radiocarbon results as uncalibrated ages before present (yr. B.P.), calibrated ages (2-sigma error) also follow the uncalibrated results in parentheses (cal. yr. B.P.). Sample preparation, lab analyses, and calibration was performed by Beta Analytic; radiocarbon ages reported by the lab used conventional techniques with $C_{13}/C_{12}$ corrections. No mean residence time (MRT) correction was applied to the age dates to account for soil formation time; based on the soil thickness and sample depth, a subtraction of 50 to 100 years may be appropriate to correlate these age dates with calibrated ages determined elsewhere on the Provo section of the Wasatch fault zone.

Sample TFRT1-RC1 was a bulk soil sample taken from the upper 1-2 inches of a backtilted buried soil on unit 3 buried by the most-recent event colluvial wedge on the Fort Canyon fault (figure 6a). The sample showed a measured age of 2,680 ± 70 yr. B.P. (2,730-2,890 cal. yr. B.P.). This indicates the most-recent event on the Fort Canyon fault occurred shortly after 2,730 to 2,890 years ago, which correlates well with timing for the penultimate event on the Provo section (about 2,850 years ago). The age data show the Fort Canyon fault has been active in the past 10,000 years, but also that surface rupture from the most-recent event on the Provo section 600 years ago must not have propagated this far north. Sample TFRT1-RC3 was a bulk soil sample taken from the upper 1-2 inches of a buried soil on an underlying debris flow (unit 2), and showed a measured age of 4,540 ± 80 yr. B.P. (5,370-5,460 cal. yr. B.P.). This age is near the timing for the antepenultimate event on the Provo section of 5,300 years ago. However, no evidence was found in the trench of an older colluvial wedge formed from this event, which suggests that only one of the last three surface-faulting earthquakes on the Provo section may have ruptured the Fort Canyon fault at the site. The latter age also shows that 2,480-2,730 years passed between deposition of debris-flow units 2 and 3 in trench 1 (figure 6a).

# 7.0 GEOLOGIC HAZARDS

Assessment of potential geologic hazards and the resulting risks imposed is critical in determining the suitability of the site for development. A discussion and analysis of geologic hazards follows. Due to the large area of the site and lot size, figure 4 also shows a summary of potential for each geologic hazard by lot.

## 7.1 Earthquake Ground Shaking

Ground shaking refers to the ground surface acceleration caused by seismic waves generated during an earthquake. Strong ground motion is likely to present a significant risk during moderate to large earthquakes located within a 60 mile radius of the project area (Boore and others, 1993). Seismic sources include mapped active faults, as well as a random or "floating" earthquake source on faults not evident at the surface. Mapped active faults within this distance include: the East and West Cache fault zones; the Brigham City, Weber, Salt Lake, and Provo sections of the Wasatch fault zone; the East Great Salt Lake fault zone; the Morgan Fault; the West Valley fault zone; the Oquirrh fault zone; and the Bear River fault zone (Black and others, 2003).

The extent of property damage and loss of life due to ground shaking depends on factors such as: (1) proximity of the earthquake and strength of seismic waves at the surface (horizontal motions are the most damaging); (2) amplitude, duration, and frequency of ground motions; (3) nature of foundation materials; and (4) building design. Peak accelerations (% of gravity) at the site for 10% and 2% probabilities of exceedance in 50 years are estimated at 20 to 25 %g, and 80 to 100 %g respectively for NEHRP B-C boundary (firm rock) sites (Frankel and others, 1996). Horizontal accelerations on the 10 percent in 50-year map were typically used in building design prior to 2003.

Given this information, earthquake ground shaking is a risk for all the lots at the subject site (figure 4a). The hazard from earthquake ground shaking can be adequately mitigated by design and construction of homes in accordance with appropriate building codes.

## 7.2 Surface Fault Rupture

Movement along faults at depth generates earthquakes. During earthquakes larger than Richter magnitude 6.5, ruptures along normal faults in the intermountain region generally propagate to the surface (Smith and Arabasz, 1991) as one side of the fault is uplifted and the other side down dropped. The resulting fault scarp has a near-vertical slope. The surface rupture may be expressed either as a large, singular scarp, or several smaller ruptures comprising a fault zone. Ground displacement from surface fault rupture can cause significant damage or even collapse to structures located across a rupture zone.

Surface faulting is a potential hazard at the site (figure 4B). Trenches 1, 5, and 6 expose evidence for the main trace of the Fort Canyon fault; trenches 4 and 7 expose evidence for the antithetic fault trace. Trench 1 (figure 1a) shows a single main fault with a measured displacement of 6.0-7.6 feet down to the south, a fault trend and apparent dip of N70°W 47° SW, and a trench trend of N34°E. Trench 5 (figure 10a) shows a northern and southern fault (22 feet apart), with measured displacements of 3.2-4.1 feet and about 1.6 feet down to the south (respectively), fault trends and apparent dips of N76°W 55° SW and N65°W 37° SW (respectively), and a trench trend of N35°E. Trench 6 (figures 11a-b) shows a 67-foot wide zone of deformation and single main fault trace with a displacement greater than 9.3 feet down to the south, a fault trend and apparent dip of N65°W 44° SW, and a trench trend of N15°E. Trench 4 shows an antithetic fault of unknown down to the north displacement, a fault trend and apparent dip of N89°W 65°NE, and a trench trend of N30°E. Trench 7 (figure 12e) shows an antithetic fault with 4.0 feet down to the north displacement, a fault trend and apparent dip of N70°W 64° NE, and a trench trend of N57°E. Accounting for fault and trench trend differences (which would create lower "apparent" dips), real fault dips would be: 57 degrees for the main fault in trench 1, 68 and 46 degrees for the faults in trench 5 (respectively), 52 degrees for the main fault in trench 6, 77 degrees for the antithetic fault in trench 4, and 80 degrees for the antithetic fault in trench 7.

Based on the above results and our current understanding that surface fault rupture and deformation tend to follow past patterns, we recommend a setback zone around the main and antithetic fault traces as shown on figure 5. The setback zone is based on fault setback guidelines in Christenson and others (2003). A minimum of 15-foot setback is used where calculated distances (based on the above) would be less than 15 feet.

The fault setback for the downthrown block side of the fault is calculated using the following formula:

$$\mathbf{S = U\,(2D + F/\tan\theta)}$$

where:

*S = Setback distance from active faults*

*U = Criticality factor (1.5 for single-family residences)*

*D = Expected fault displacement per event (assumed to be equal to the vertical displacement measured for each past event or, if not measurable, the maximum estimated single-event displacement of 10.8 feet is used.)*

*F = Maximum depth of footing or subgrade portion of the building (8 feet)*

*$\theta$ = Dip of the fault (degrees)*

The fault setback for the downthrown block side of the faults is calculated using the same parameters by the following formula:

$$S= U (2D)$$

Based on the above formula, the setback distances are as follows: 23 feet north and 31 feet south (total 54 feet wide) from the mapped main fault trace in trench 1; a minimum 15 feet north and south of the northern and southern fault traces (total 52 feet wide) from the main fault traces in trench 5; setbacks from the main fault in trench 6 are 32 feet north to the edge of the zone of deformation (total 99 feet wide) for the main fault in trench 6; 35 feet north and 32 feet south of the antithetic fault in trench 4; and 15 feet north and south of the antithetic fault in trench 7. A summary of lots potentially impacted by the fault and setback zones is shown on figure 4b.

## 7.3 Liquefaction and Lateral-spread Ground Failure

Liquefaction occurs when saturated, loose, cohesionless, soils lose their support capabilities during a seismic event because of the development of excessive pore pressure. Earthquake-induced liquefaction can present a significant risk to structures from bearing-capacity failures to structural footings and foundations, and can damage structures and roadway embankments by triggering lateral spread landslides. Earthquakes of Richter magnitude 5 are generally regarded as the lower threshold for liquefaction. Liquefaction potential at the site is a combination of expected seismic (earthquake ground shaking) accelerations, ground water conditions, and presence of susceptible soils.

Although shallow ground-water was encountered (at a depth of about 10 feet) in trenches in the western part of the site in April, sediments susceptible to liquefaction were exposed in only one trench (trench 4, unit 3a; figure 9f) at the site. No evidence was found in the trenches, to the depth excavated, for prior liquefaction or lateral spread landslides in the recent geologic past. Based on this, the hazard from liquefaction for most of the site is rated as low. The liquefaction hazard is rated as high in the area of glacial deposits, as shown on figure 4c. Evaluation of and recommendations regarding liquefaction should be addressed in a geotechnical engineering evaluation during the subdivision approval process.

## 7.4 Tectonic Deformation

Tectonic deformation refers to subsidence from warping, lowering, and tilting of a valley floor that accompanies surface-faulting earthquakes on normal faults. Large-scale tectonic subsidence may accompany earthquakes along large normal faults (Lund, 1990). Tectonic subsidence is believed to mainly impact those areas immediately adjacent to the downthrown side of a normal fault. The area between the main and antithetic fault traces at the site would be particularly susceptible to tectonic subsidence. Lots in this area have a high hazard rating as shown on figure 4d.

## 7.5 Seismic Seiche and Storm Surge

Earthquake-induced seiche presents a risk to structures within the wave-oscillation zone along the edges of large bodies of water, such as the Great Salt Lake. Given the elevation of the subject property and distance from large bodies of water, the risk to the all the lots at the subject property from seismic seiches is rated as low (figure 4e).

## 7.6 Stream Flooding

Stream flooding may be caused by direct precipitation, melting snow, or a combination of both. In much of Utah, floods are most common in April through June during spring snowmelt. High flows may be sustained from a few days to several weeks, and the potential for flooding depends on a variety of factors such as surface hydrology, site grading and drainage, and runoff. Portions of the site are in mapped drainages that would be impacted by stream flooding. For lots in these areas, the potential hazard from stream flooding is rated as high (figure 4f). Sheet and rill flow may also be a localized seasonal concern. Therefore, site hydrology and runoff should be addressed by the civil engineering design for the development.

## 7.7 Shallow Ground Water

Two springs are shown on the topographic map for the Lehi Quadrangle to the east and west of the site. Ground water was also observed in trenches in the western part of the site in April, although the water may have been from seasonal water-table fluctuations. No ground water was observed in trenches in the eastern part of the site in June; however, conversely the lack of shallow ground water could also be a seasonal fluctuation. Based on this, shallow ground water could pose a constraint for portions of the development, as shown on figure 4g. Areas with a low hazard on figure 4g are lots that are located at higher elevations and not in areas of anticipated shallow water tables. Evaluation of and recommendations regarding shallow groundwater should be addressed in a geotechnical engineering evaluation during the subdivision approval process.

## 7.8 Landslide and Slope Failures

Slope stability hazards such as landslides, slumps, and other mass movements can develop along moderate to steep slopes where a slope has been disturbed, the head of a slope loaded, or where increased ground-water pore pressures result in driving forces within the slope exceeding restraining forces. Slopes exhibiting prior failures, and also deposits from large landslides, are particularly vulnerable to instability and reactivation.

The geologic map (figure 2) shows a large landslide deposit (Qmso) and head scarp in the central part of the site around and above Nephs Lake, and two smaller landslide deposits and associated head scarps in the western part of the site. Landslide deposits were also exposed in trenches 6 and 7 at the site, which are in or on the edge of the large landslide.

Slopes particularly at risk appear to be those underlain by Tertiary alluvial-fan deposits (unit Taf, figure 2). The hazard from landsliding is rated as high for lots in these areas (figure 4h). Stability of the slopes in these areas should be evaluated in a geotechnical engineering evaluation prior to the subdivision approval process, and recommendations for reducing the risk from landsliding should be provided if the factor of safety is determined to be unsuitable. Care should also be taken that site grading does not destabilize the slopes without prior geotechnical analysis and grading plans.

### 7.9 Debris Flows

Debris flow hazards are typically associated with unconsolidated alluvial fan deposits at the mouths of large range-front drainages, such as those along the Wasatch Front. Portions of the site are located in mapped alluvial fans, and debris-flow and flood deposits were exposed in all but trench 7 at the site. The hazard is rated as high for lots in areas in alluvial-fan deposits in and bordering the fault zone and Fort Canyon (figure 4i).

Figure 13 shows drainage lengths for drainages at the site from topography, and six alluvium units from mapping by Biek (2003). Table 1 shows channel lengths of the above, unit areas in square feet, and calculated single-event sediment totals in cubic yards at assumed bulking rates of 2 cubic yards per linear foot of channel ($yd^3/ft$), 5 $yd^3/ft$, and 11 $yd^3/ft$. A value of 2 $yd^3/ft$ corresponds to typical measured debris-flow bulking rates for recent flows along the Wasatch Front (Richard Giraud, Utah Geological Survey, verbal communication, July 2004); a value of 5 $yd^3/ft$ corresponds to the bulking rate for a debris flow in North Ogden in 1991, where debris damaged several homes in the Cameron Cove subdivision (Mulvey and Lowe, 1991); a value of 11 $yd^3/ft$ corresponds to the bulking rate for the Rudd Canyon debris flow in 1983, which damaged 35 homes in Farmington, Utah (Lowe and others, 1989). Table 1 also shows maximum debris totals for each alluvium unit at varying flow thicknesses and percent coverage (amount of area of that unit covered by debris). Single-event debris totals from a drainage bulking rate of 5 $yd^3/ft$ and alluvium unit value of 3-ft thickness/30% coverage compare favorably on table 1, and are our preferred maximum expected debris totals from a single event at the site. Thicknesses of individual flows exposed in trenches at the site generally ranged between 2 and 4.5 feet. The trenching data also suggest the debris-flow events may be infrequent.

***Table 1.*** *Channel lengths, single-event sediment totals, alluvium unit areas, and maximum sediment volumes at varying flow thickness and area coverage at Three Falls Ranch.*

| | | *Single-event sediment totals* | | | |
|---|---|---|---|---|---|
| **Drainage Number** | *Length (feet)* | *2 cu. yd/ft* | *5 cu. yd/ft* | *11 cu. yd/ft* | *...Bulking Rate* |
| 1 | 3,968.2 | 7,936.4 | 19,841.0 | 43,650.2 | |
| 2a | 3,072.4 | 6,144.8 | 15,362.0 | 33,796.4 | |
| 2b | 4,104.0 | 8,208.0 | 20,520.0 | 45,144.0 | |
| 2c | 4,081.7 | 8,163.4 | 20,408.5 | 44,898.7 | |
| 2d | 4,647.0 | 9,294.0 | 23,235.0 | 51,117.0 | |
| 3a | 2,905.3 | 5,810.6 | 14,526.5 | 31,958.3 | |
| 3b | 2,616.6 | 5,233.2 | 13,083.0 | 28,782.6 | |
| 3c | 3,392.3 | 6,784.6 | 16,961.5 | 37,315.3 | |
| 3d | 2,602.5 | 5,205.0 | 13,012.5 | 28,627.5 | |
| 4a | 1,152.2 | 2,304.4 | 5,761.0 | 12,674.2 | |
| 4b | 1,270.5 | 2,541.0 | 6,352.5 | 13,975.5 | |
| 4c | 1,238.3 | 2,476.6 | 6,191.5 | 13,621.3 | |
| 5 | 704.8 | 1,409.6 | 3,524.0 | 7,752.8 | |
| 6a | 2,851.8 | 5,703.6 | 14,259.0 | 31,369.8 | |
| 6b | 4,987.0 | 9,974.0 | 24,935.0 | 54,857.0 | |
| 6c | 5,907.9 | 11,815.8 | 29,539.5 | 64,986.9 | |
| 6d | 4,971.6 | 9,943.2 | 24,858.0 | 54,687.6 | |
| 6e | 6,012.5 | 12,025.0 | 30,062.5 | 66,137.5 | |
| 6f | 6,080.5 | 12,161.0 | 30,402.5 | 66,885.5 | |
| 6g | 6,227.1 | 12,454.2 | 31,135.5 | 68,498.1 | |
| 6h | 6,249.3 | 12,498.6 | 31,246.5 | 68,742.3 | |
| 6i | 4,433.1 | 8,866.2 | 22,165.5 | 48,764.1 | |
| 6j | 4,783.6 | 9,567.2 | 23,918.0 | 52,619.6 | |
| 6k | 3,993.9 | 7,987.8 | 19,969.5 | 43,932.9 | |
| 7a | 6,114.9 | 12,229.8 | 30,574.5 | 67,263.9 | |
| 7b | 6,725.5 | 13,451.0 | 33,627.5 | 73,980.5 | |
| 7c | 1,806.5 | 3,613.0 | 9,032.5 | 19,871.5 | |
| 7d | 12,394.8 | 24,789.6 | 61,974.0 | 136,342.8 | |
| 7e | 2,264.1 | 4,528.2 | 11,320.5 | 24,905.1 | |
| 7f | 2,179.3 | 4,358.6 | 10,896.5 | 23,972.3 | |
| 8 | 12,179.0 | 24,358.0 | 60,895.0 | 133,969.0 | |
| 9a | 4,044.5 | 8,089.0 | 20,222.5 | 44,489.5 | |
| 9b | 6,389.3 | 12,778.6 | 31,946.5 | 70,282.3 | |
| 9c | 5,943.5 | 11,887.0 | 29,717.5 | 65,378.5 | |
| 9d | 15,259.5 | 30,519.0 | 76,297.5 | 167,854.5 | |
| 9e | 15,566.4 | 31,132.8 | 77,832.0 | 171,230.4 | |

| | | | | | |
|---|---|---|---|---|---|
| 9f | 13,467.7 | 26,935.4 | 67,338.5 | 148,144.7 | |
| 9g | 8,140.3 | 16,280.6 | 40,701.5 | 89,543.3 | |
| 9h | 6,556.0 | 13,112.0 | 32,780.0 | 72,116.0 | |
| 9i | 10,105.7 | 20,211.4 | 50,528.5 | 111,162.7 | |
| 9j | 11,324.7 | 22,649.4 | 56,623.5 | 124,571.7 | |
| 9k | 11,752.9 | 23,505.8 | 58,764.5 | 129,281.9 | |
| 9l | 11,920.9 | 23,841.8 | 59,604.5 | 131,129.9 | |
| 9m | 7,211.6 | 14,423.2 | 36,058.0 | 79,327.6 | |
| 9n | 8,469.3 | 16,938.6 | 42,346.5 | 93,162.3 | |
| 9o | 11,593.8 | 23,187.6 | 57,969.0 | 127,531.8 | |
| 9p | 12,368.5 | 24,737.0 | 61,842.5 | 136,053.5 | |
| 9q | 13,438.6 | 26,877.2 | 67,193.0 | 147,824.6 | |
| 9r | 14,455.9 | 28,911.8 | 72,279.5 | 159,014.9 | |
| 9s | 6,040.5 | 12,081.0 | 30,202.5 | 66,445.5 | |
| 10a | 3,216.3 | 6,432.6 | 16,081.5 | 35,379.3 | |
| 10b | 3,631.8 | 7,263.6 | 18,159.0 | 39,949.8 | |
| 10c | 3,645.8 | 7,291.6 | 18,229.0 | 40,103.8 | |
| 10d | 4,390.1 | 8,780.2 | 21,950.5 | 48,291.1 | |
| 10e | 4,606.9 | 9,213.8 | 23,034.5 | 50,675.9 | |
| 10f | 5,000.0 | 10,000.0 | 25,000.0 | 55,000.0 | |
| 10g | 5,399.3 | 10,798.6 | 26,996.5 | 59,392.3 | |
| 10h | 6,116.7 | 12,233.4 | 30,583.5 | 67,283.7 | |
| 10i | 7,662.9 | 15,325.8 | 38,314.5 | 84,291.9 | |
| 10j | 6,156.6 | 12,313.2 | 30,783.0 | 67,722.6 | |
| 10k | 5,547.9 | 11,095.8 | 27,739.5 | 61,026.9 | |
| 10l | 5,622.1 | 11,244.2 | 28,110.5 | 61,843.1 | |
| 11 | 1,231.9 | 2,463.8 | 6,159.5 | 13,550.9 | |
| 12 | 1,067.0 | 2,134.0 | 5,335.0 | 11,737.0 | |
| 13 | 853.3 | 1,706.6 | 4,266.5 | 9,386.3 | |
| 14 | 467.3 | 934.6 | 2,336.5 | 5,140.3 | |
| 15 | 781.3 | 1,562.6 | 3,906.5 | 8,594.3 | |
| 16 | 1,073.7 | 2,147.4 | 5,368.5 | 11,810.7 | |
| 17 | 799.1 | 1,598.2 | 3,995.5 | 8,790.1 | |
| 18 | 979.1 | 1,958.2 | 4,895.5 | 10,770.1 | |
| 19 | 348.2 | 696.4 | 1,741.0 | 3,830.2 | |
| 20 | 1,130.4 | 2,260.8 | 5,652.0 | 12,434.4 | |
| 21a | 1,591.1 | 3,182.2 | 7,955.5 | 17,502.1 | |
| 21b | 1,682.0 | 3,364.0 | 8,410.0 | 18,502.0 | |
| 21c | 1,957.3 | 3,914.6 | 9,786.5 | 21,530.3 | |
| 22 | 2,316.5 | 4,633.0 | 11,582.5 | 25,481.5 | |

| | *Max. cu. yd sediment at flow thickness and % area coverage* | | | | | |
|---|---|---|---|---|---|---|
| **Alluvium Unit** | *Area (sq. ft)* | *2 ft/20%* | *3 ft/30%* | *4 ft/40%* | *5 ft/50%* | *6 ft/50%* |
| 1 | 985,343.0 | 14,597.7 | 32,844.8 | 58,390.7 | 91,235.5 | 109,482.6 |
| 2 | 2,331,656.7 | 34,543.1 | 77,721.9 | 138,172.2 | 215,894.1 | 259,073.0 |
| 3 | 950,852.1 | 14,086.7 | 31,695.1 | 56,346.8 | 88,041.9 | 105,650.2 |
| 4 | 237,877.9 | 3,524.1 | 7,929.3 | 14,096.5 | 22,025.7 | 26,430.9 |
| 5 | 414,064.3 | 6,134.3 | 13,802.1 | 24,537.1 | 38,339.3 | 46,007.1 |
| 6 | 953,452.2 | 14,125.2 | 31,781.7 | 56,500.9 | 88,282.6 | 105,939.1 |

Evaluation of and recommendations regarding the hazard from debris flows and floods to specific lots at the site should be addressed by the civil engineering design for the development. The evaluation and recommendations should be based on the information presented in this report.

### 7.10 Rock Fall

Potential bedrock sources that could pose a rock fall hazard are in steep slopes bordering the northern part of the site, however few large boulders were observed at the surface of the site. Most boulders at the site appear to be glacial talus. Lots bordering the mountain front in the northern part of the site are shown with a high hazard for potential rock falls on figure 4j. Heavy vegetation and uneven terrain may restrict rock falls to the mapped drainages, and thus localized rock fall remediation strategies such as deflection berms or ditches may be effective and should be considered to protect lots in these areas. The developer and individual landowners should also be willing to accept the risk from rock falls as an inherent hazard.

### 7.11 Snow Avalanche

A hazard from snow avalanches may exist due to proximity of the site to mountainous areas with south-, west- and north-facing slope aspects. Lots bordering the steep mountain front in the northern part of the site have a high hazard from snow avalanches figure 4k). The developer and individual landowners should be willing to accept the risk from snow avalanches as an inherent hazard in these areas of the site.

### 7.12 Radon

Radon comes from the natural (radioactive) breakdown of uranium in soil, rock, and water and can seep into homes through cracks in floor slabs or other openings. The site is located in a "Moderate" radon-hazard potential area (Black, 1993). A moderate hazard rating indicates that indoor radon concentrations would likely be between 2 and 4 picocuries per liter of air, which is below the action level recommended by the Environmental Protection Agency. However, actual indoor radon levels can be affected by non-geologic factors such as building construction, maintenance, and weather. Indoor testing following construction is the best method to characterize the radon hazard and determine if mitigation measures are required.

## 7.13 Swelling and Collapsible Soils

Surficial soils that contain certain clays can swell or collapse when wet. Clay-rich and vesicular sediments were observed in trenches at the site that may have a high potential for swelling and/or collapse. A geotechnical engineering evaluation should be performed during the subdivision approval process to address soil conditions and provide specific recommendations for site grading, subgrade preparation, and footing and foundation design

## 7.14 Volcanic Eruption

No active volcanoes, vents, or fissures are mapped in the region. Based on this, no volcanic hazard likely exists at the site and the risk to the project is low.

# 8.0 CONCLUSIONS AND RECOMMENDATIONS

Earthquake ground shaking, surface fault rupture, liquefaction, tectonic deformation, stream flooding, landslides, debris flows, rock falls, and snow avalanches are identified geologic hazards at the site. However, not all of the site is affected by every hazard, as summarized on figure 4. Based on this evaluation, we recommend the following:

- Proposed homes should be designed and constructed to current seismic standards to reduce the potential ground-shaking hazard.
- No structures designed for occupancy should be located within the fault setback zones shown on figure 5. It is generally accepted practice to allow streets, driveways, yards, and other non-occupied structures to be constructed within these areas.
- The civil engineering design for the development should address site hydrology and runoff, evaluate and provide recommendations regarding hazards from debris flows and floods, and provide designs for potential rock-fall mitigation strategies such a berms or ditches as needed.
- A design-level geotechnical engineering study should be conducted prior to construction to address soil conditions at the site for use in foundation design, site grading, and drainage; and provide recommendations regarding building design to reduce risk from seismic acceleration and, if needed, liquefaction. The geotechnical study should also include slope-stability analyses of slopes in mapped Tertiary alluvium and landslide deposits to determine factors of safety and provide recommendations to reduce the risk from landsliding if needed. The geologic information included in this report should be used in developing the slope model.
- The information in this report should be made available to potential homeowners so that they can better understand and be willing to accept potential risks from inherent geologic hazards at the site such as rock fall.

The site is considered suitable for the proposed development if the recommendations in this report are followed.

## 8.1 Excavation Backfill Considerations

The exploratory trenches may be in areas where structures could subsequently be placed. The backfill was *not* placed in the trench in compacted layers as engineered fill. The trench fill is likely to settle with time and upon saturation. No footings or structural supports should be founded over a trench excavation unless the backfill has been removed and replaced with structural fill or other recommendations from the geotechnical report are followed.

# 9.0 LIMITATIONS

This investigation was performed at the request of Mr. Will Jones (the Client) using the methods and procedures consistent with good commercial and customary practice designed to conform to acceptable industry standards. The analysis and recommendations submitted in this report are based upon the data obtained from compilation of known geologic information and site-specific subsurface information from trenching. This information and the conclusions of this report should not be interpolated to adjacent properties without additional site-specific information. In the event that any changes are later made in the location of the proposed site, the conclusions and recommendations contained in this report shall not be considered valid unless the changes are reviewed and conclusions of this report modified or approved in writing by the engineering geologist.

This report has been prepared by the staff of Western GeoLogic for the Client under the professional supervision of the principal and/or senior staff whose seal(s) and signatures appear hereon. Neither Western GeoLogic, nor any staff member assigned to this investigation has any interest or contemplated interest, financial or otherwise, in the subject or surrounding properties, or in any entity which owns, leases, or occupies the subject or surrounding properties or which may be responsible for environmental issues identified during the course of this investigation, and has no personal bias with respect to the parties involved.

The information contained in this report has received appropriate technical review and approval. The conclusions represent professional judgment and are based upon the findings of the investigations identified in the report and the interpretation of such data based on our experience and expertise according to the existing standard of care. No other warranty or limitation exists, either expressed or implied.

The investigation was prepared in accordance with the approved scope of work outlined in our proposal for the use and benefit of the Client; it's successors, and assignees. It is based, in part, upon documents, writings, and information owned, possessed, or secured by the Client. Neither this report, nor any information contained herein shall be used or relied upon for any purpose by any other person or entity without the express written permission of the Client. This report is not for the use or benefit of, nor may it be relied upon by any other person or entity, for any purpose without the advance written consent of Western GeoLogic.

In expressing the opinions stated in this report, Western GeoLogic has exercised the degree of skill and care ordinarily exercised by a reasonable prudent environmental professional in the same community and in the same time frame given the same or similar facts and circumstances. Documentation and data provided by the Client, designated representatives of the Client or other interested third parties, or from the public domain, and referred to in the preparation of this assessment, have been used and referenced with the understanding that Western GeoLogic assumes no responsibility or liability for their accuracy.

The independent conclusions represent our professional judgment based on information and data available to us during the course of this assignment. Factual information regarding operations, conditions, and test data provided by the Client or their representative has been assumed to be correct and complete. The conclusions presented are based on the data provided, observations, and conditions that existed at the time of the field exploration.

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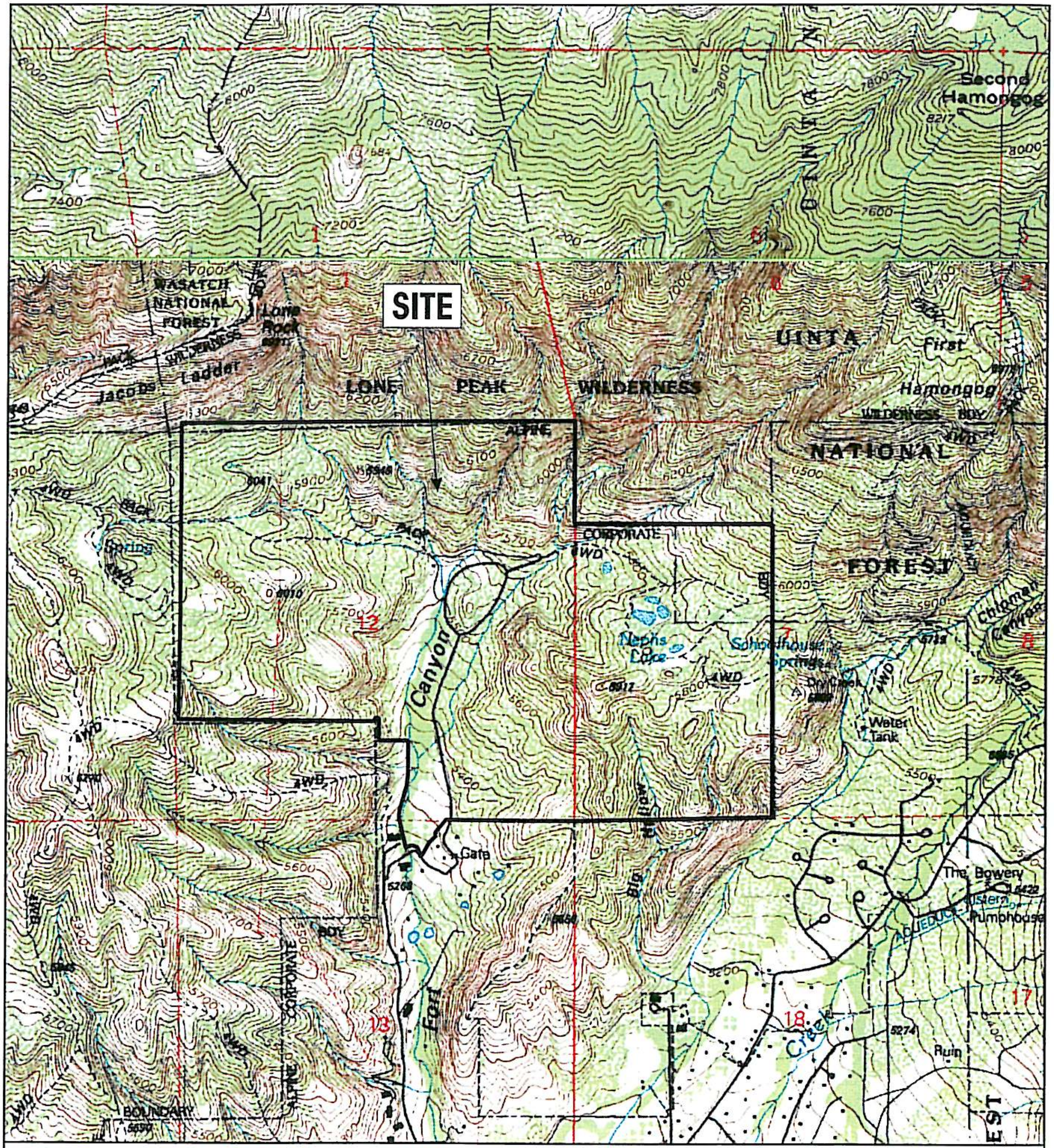


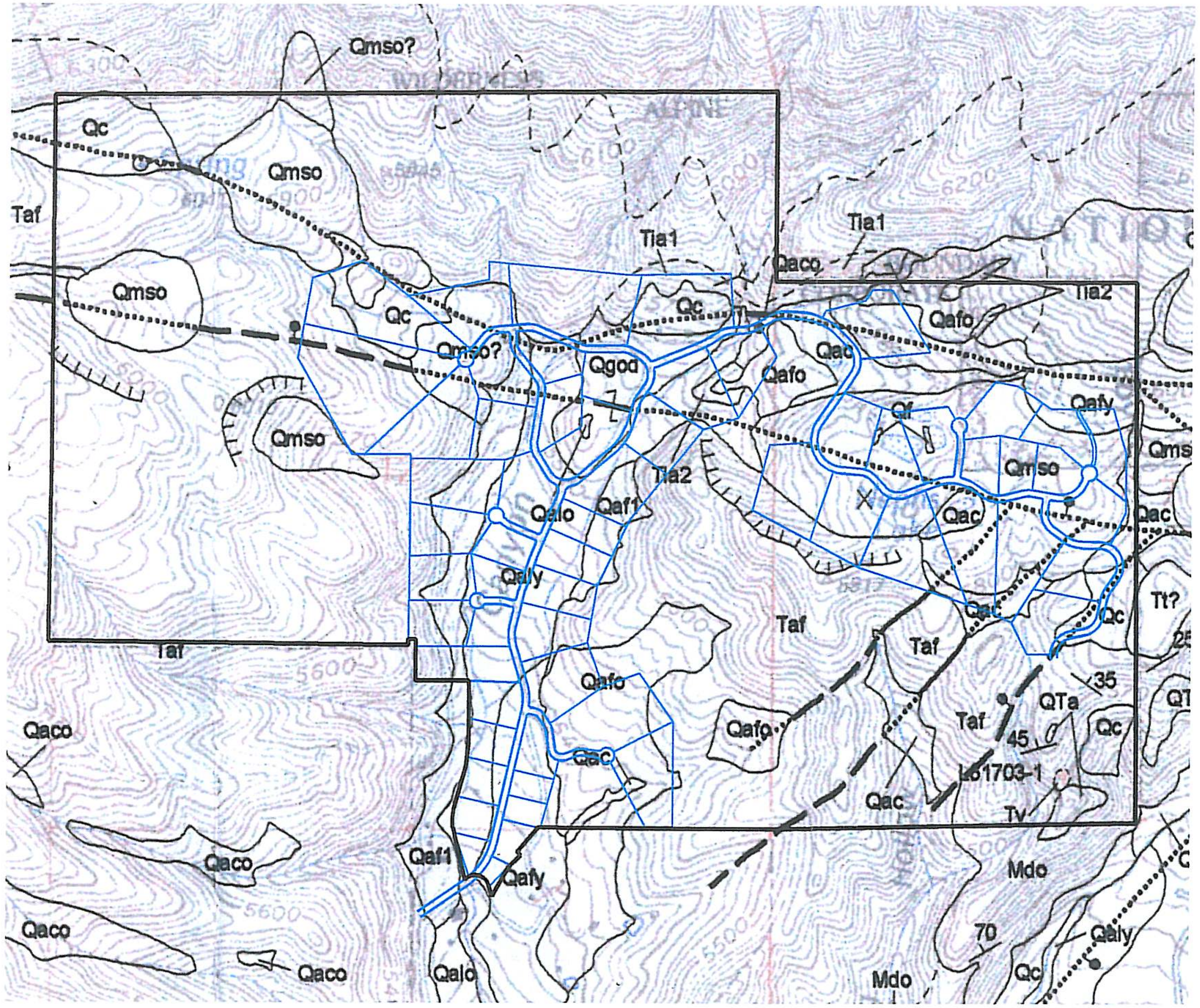

Source: U.S. Geological Survey 7.5 Minute Series Topographic Maps, Utah - DRAPER, 1963; and LEHI, 1994.

Scale 1:24,000
(1 inch = 2000 feet)

## LOCATION MAP

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City,
Utah County, Utah

FIGURE 1




Source: Biek, R.F., 2003, Interim geologic map of the Lehi Quadrangle, Salt Lake and Utah Counties, Utah: Utah Geological Survey Open-File Report 416.

**MAP UNIT DESCRIPTIONS**

Qf - Artificial fill
Qc - Colluvial deposits
Qac - Alluvial and colluvial deposits
Qaly - Young alluvial deposits
Qalo - Older alluvial deposits
$Qaf_1$ - Modern alluvial-fan deposits
Qafy - Younger undifferentiated alluvial-fan deposits
Qafo - Older alluvial-fan deposits
Qmso - Colluvial deposits over older mass-movement deposits
Qgod - Glacial outwash
Qta - Ols alluvial deposits

Taf - Alluvial-fan deposits
$Tia_1$ - Altered monzogranite and granodiorite of Little Cottonwood Stock
Tv - Volcanic Rocks pf Traverse Mountains, undivided

See report text for map unit descriptions

**MAP SYMBOLS**

Landslide scarp, hatchures on down-dropped side

Normal fault, dashed where approximately located, dotted where concealed and approximately located; query indicates uncertain presence; bar

N W E S

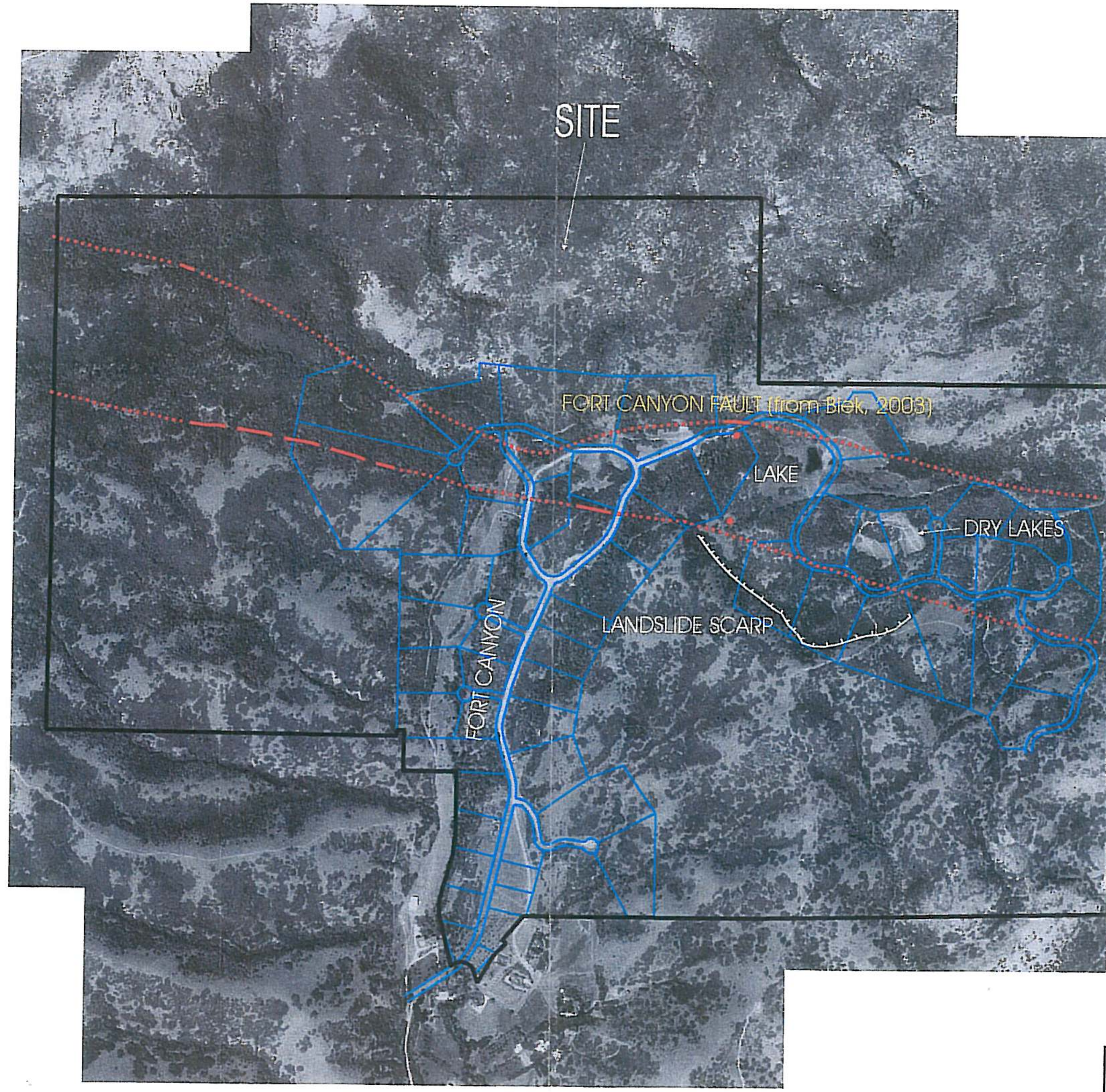
Scale 1:12,000
(1 inch = 1,000 feet)

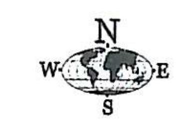
**GEOLOGIC MAP**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 2**

WESTERN GEOLOGIC



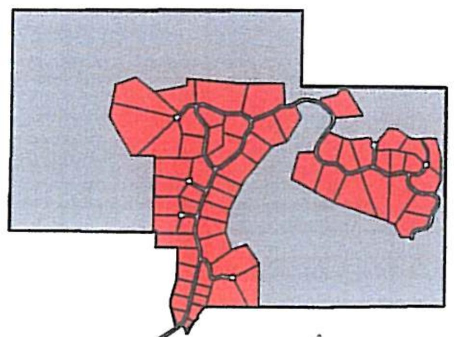

Scale 1:12,000
(1 inch = 1,000 feet)

**AIR PHOTO**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

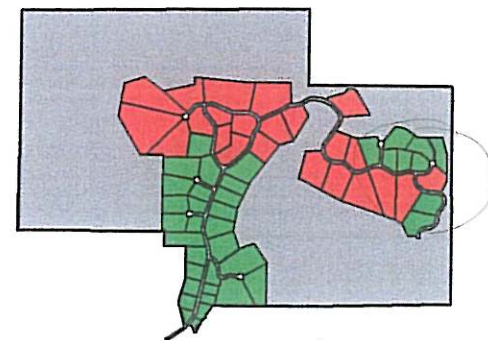
**FIGURE 3**

4a. Earthquake Ground Shaking



Building Code mitigation / Structural

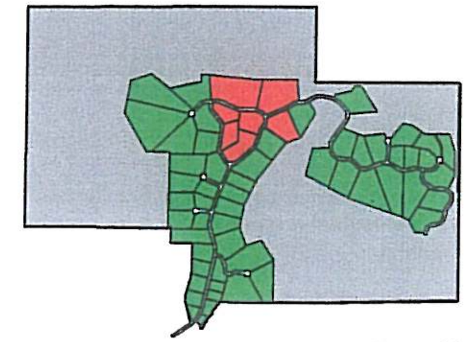
4b. Surface Fault Rupture



Should be red

Trenching / Setbacks Development

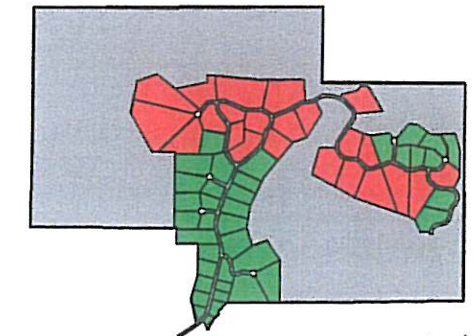
4c. Liquefaction and Lateral-spread Ground Failure



Pre-building Permit study

4d. Tectonic Deformation

Subsidence (UGS)

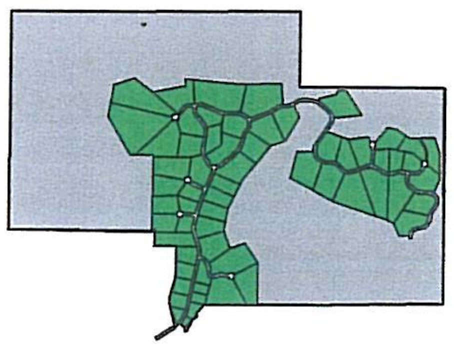


Deformation ⇒ setbacks

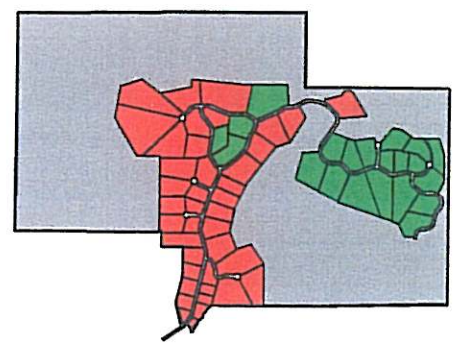
(ail'ved) Subsidence ⇒ nothing generally done, accepted hazard.

disclose on plat.

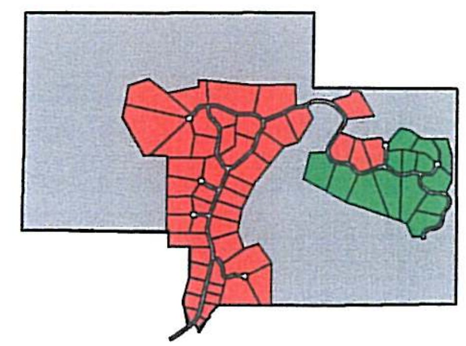
4e. Seismic Seiche and Storm Surge



4f. Stream Flooding

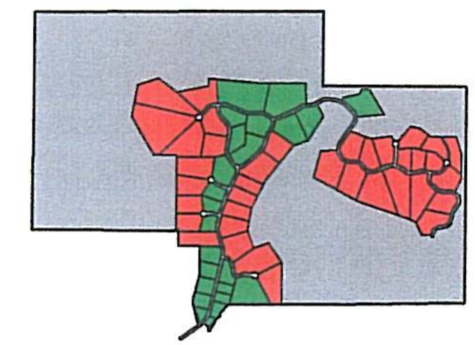


4g. Shallow ground water



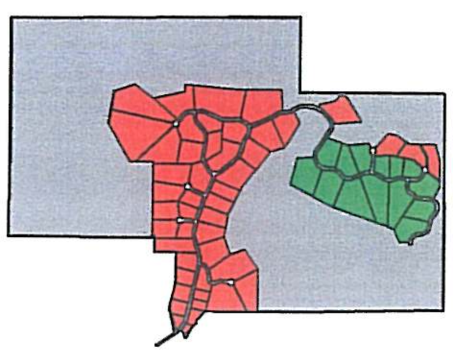
pre-building permit

4h. Landslide and Slope Failures



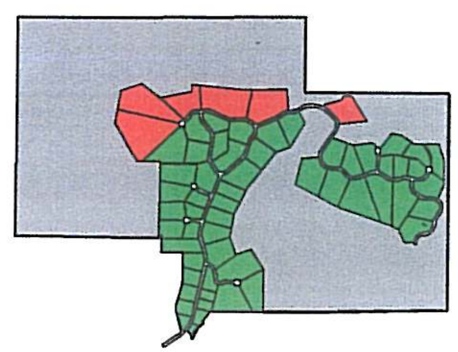
Development Study

4i. Debris Flows



Development Study

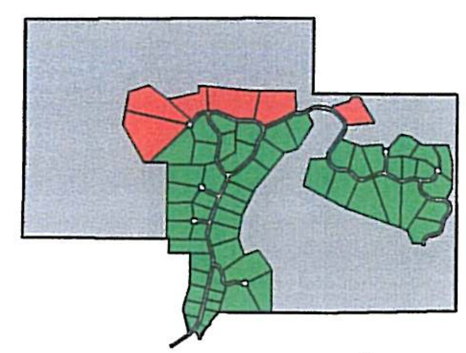
4j. Rock Fall



Geologic Study

pre-building permit

4k. Snow Avalanche



Geologic Study

pre-building permit

EXPLANATION

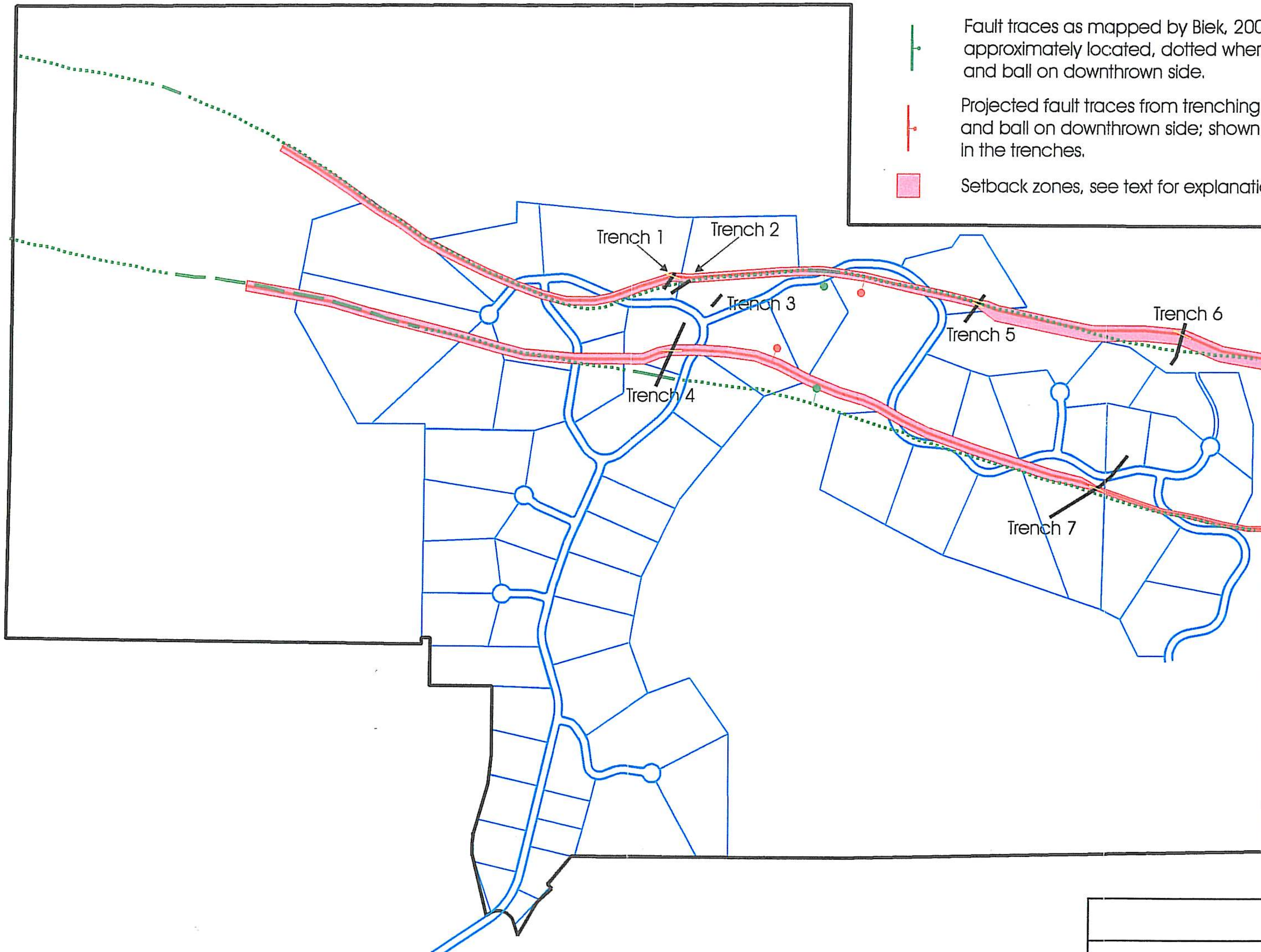
Lots in red have a high potential for the hazard
Lots in green have a low potential for the hazard
Gray indicates areas not assessed
Lot boundaries as of August 2004 and subject to change

WESTERN GEOLOGIC

**HAZARDS SUMMARY**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City,
Utah County, Utah

**FIGURE 4**




WESTERN GEOLOGIC

**FAULT & SETBACK MAP**

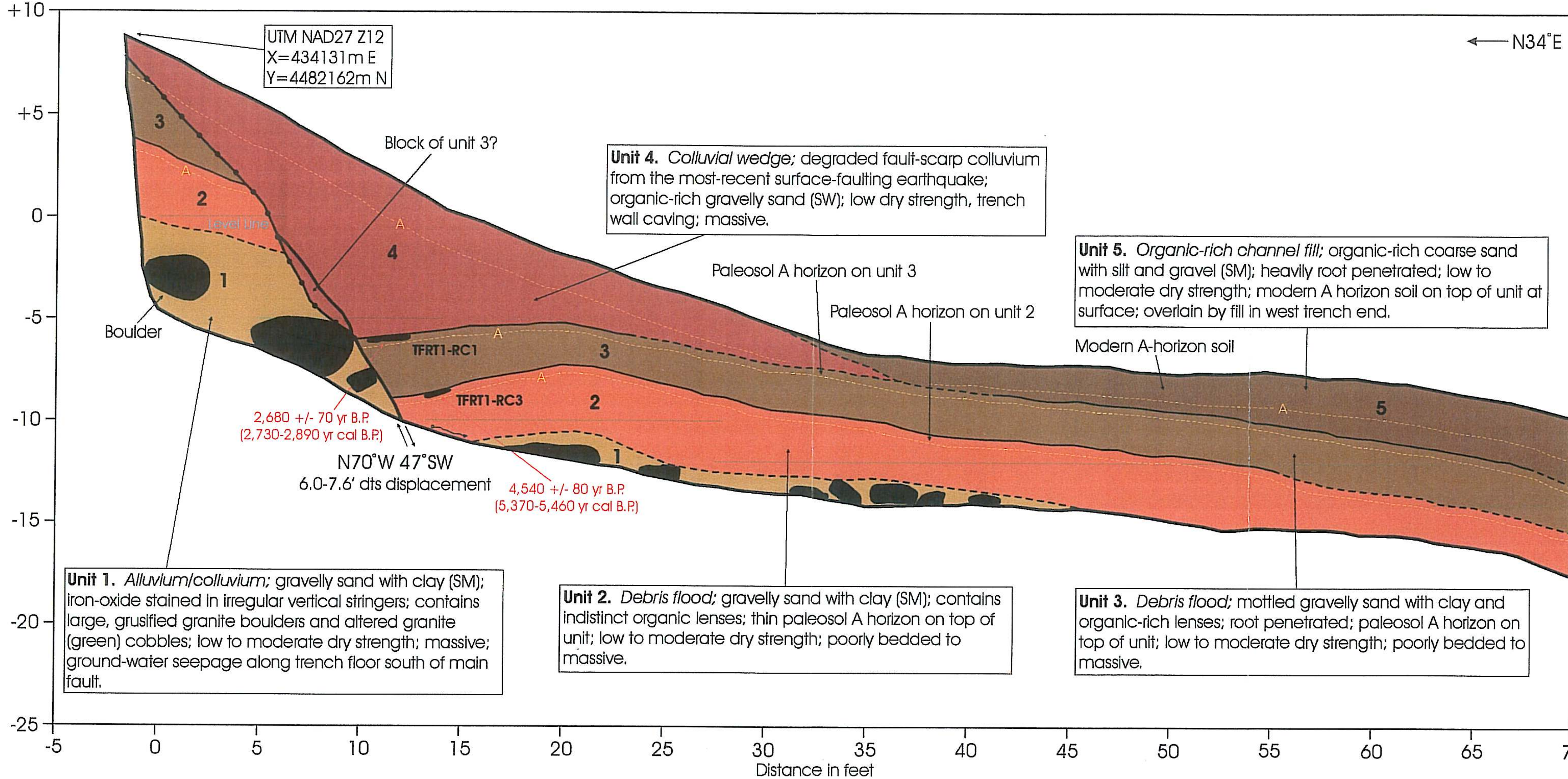
**GEOLOGIC HAZARDS EVALUATION**

Three Falls Ranch

Alpine City,

Utah County, Utah

**FIGURE 5**




WESTERN GEOLOGIC

LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

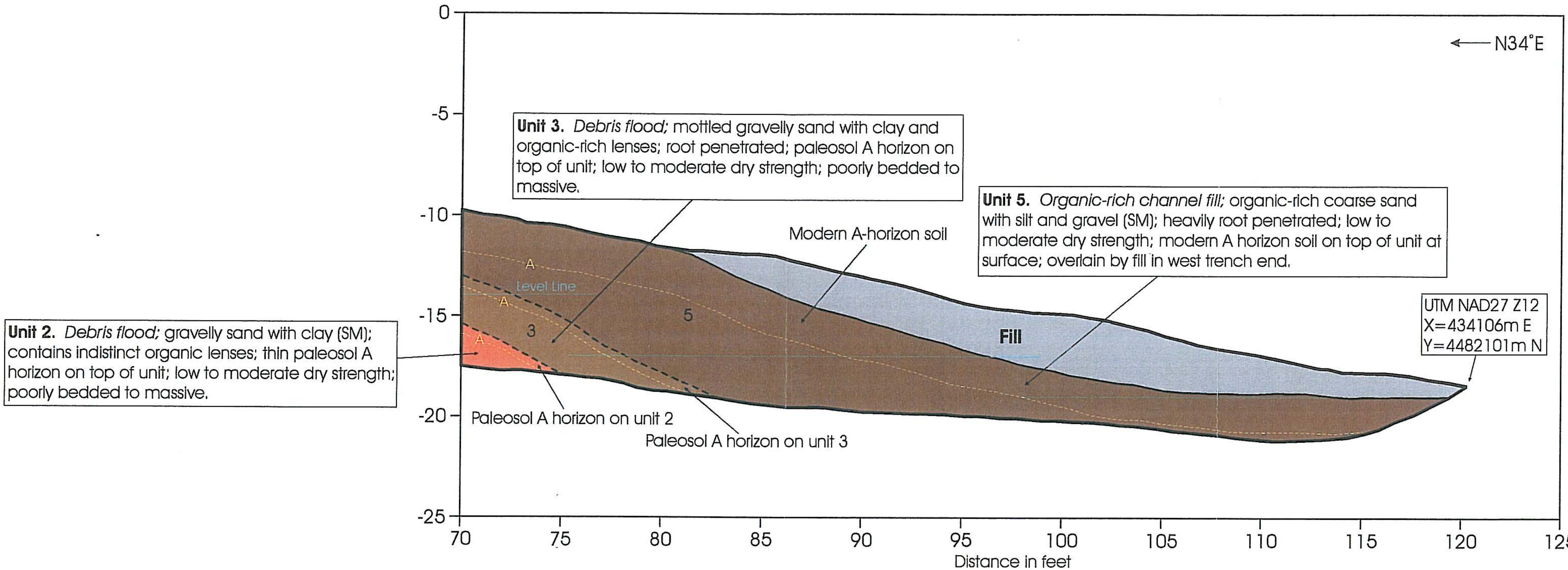
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on April 22, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

**TRENCH 1 LOG (-5' to 70')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 6a**

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STATE OF UTAH

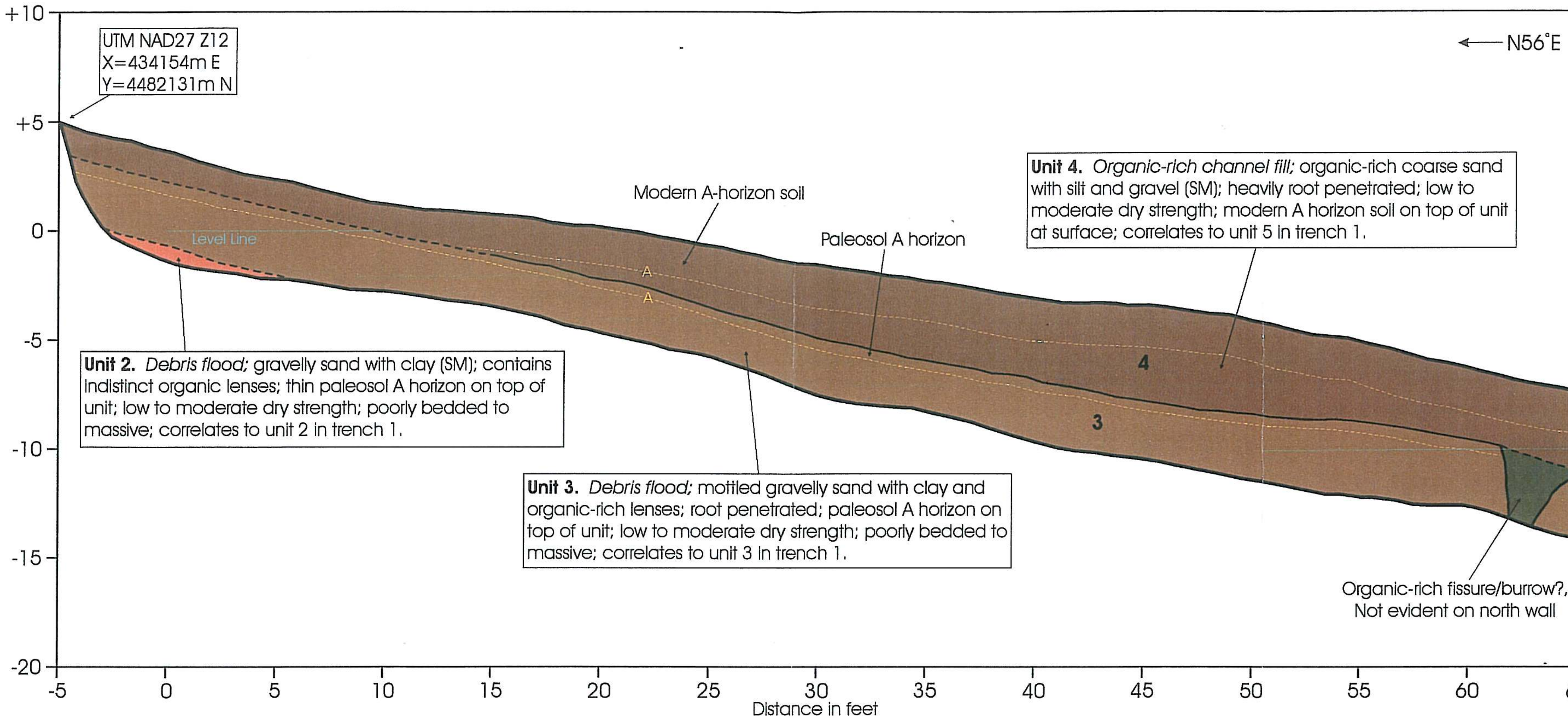
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
April 22, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

**TRENCH 1 LOG (70' to 125')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 6b**

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LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

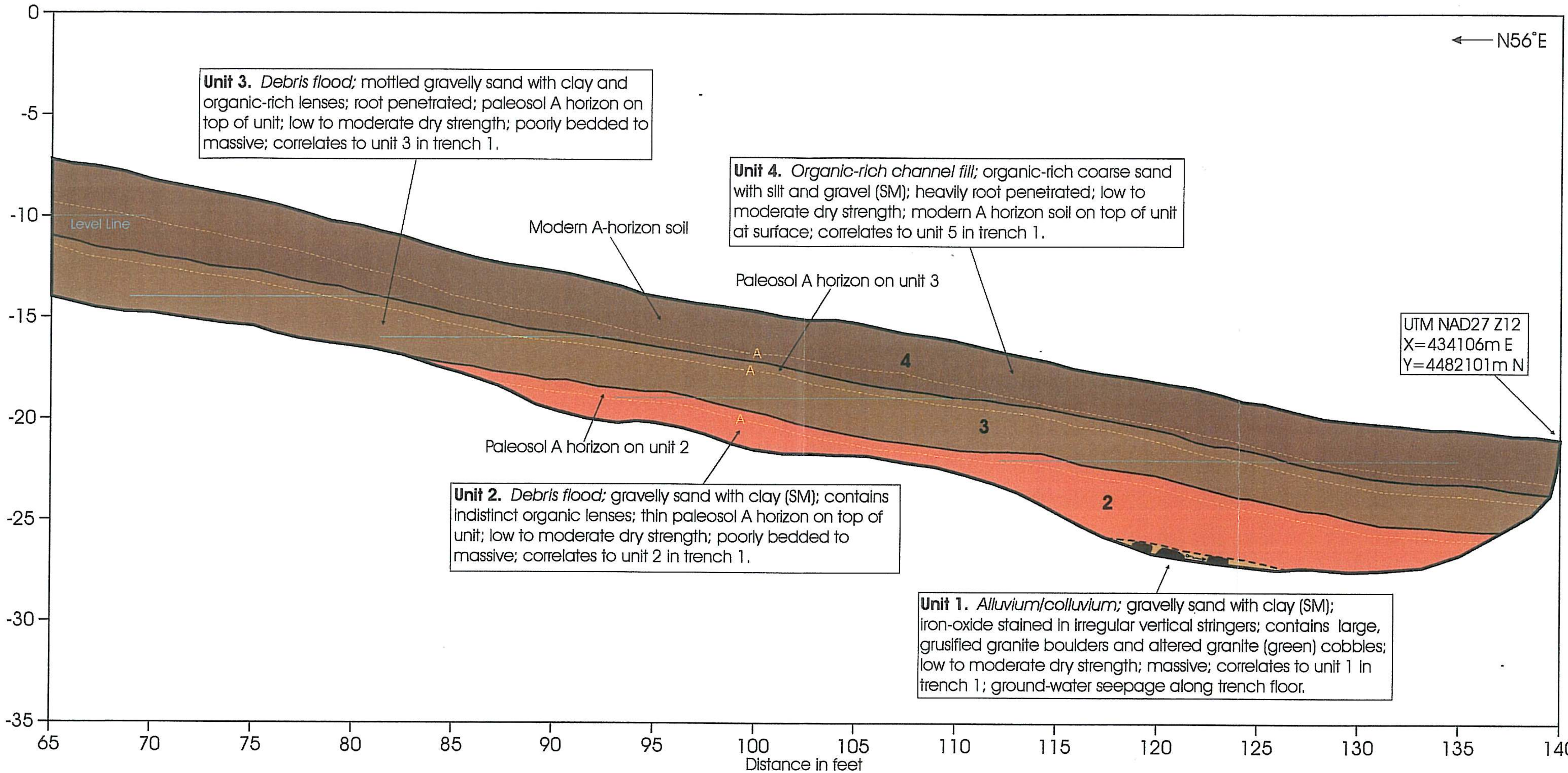
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
April 22, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

**TRENCH 2 LOG (-5' to 65')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 7a**




LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

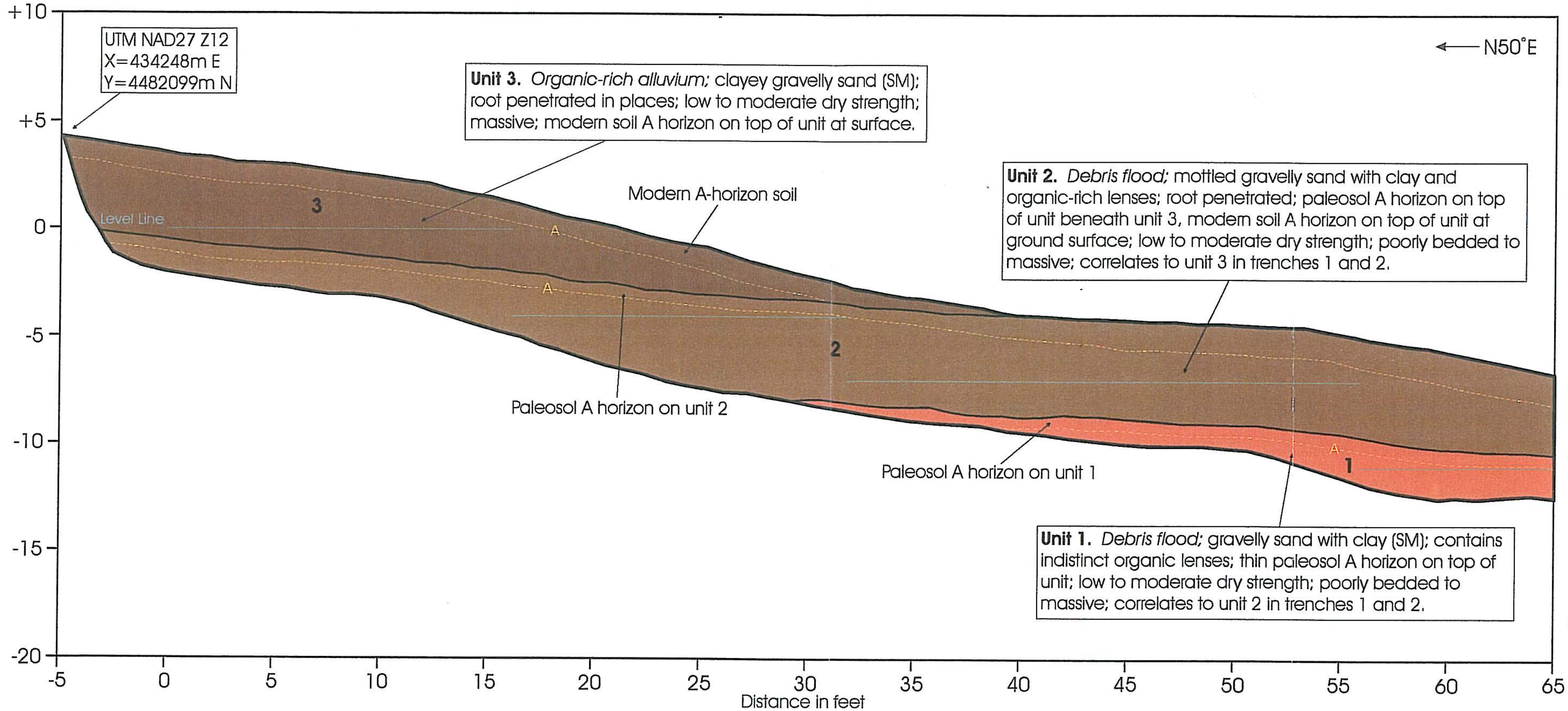
Trench logged by Bill Black, P.G. on
April 22, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

WESTERN GEOLOGIC

**TRENCH 2 LOG (65' to 140')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 7b**




LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

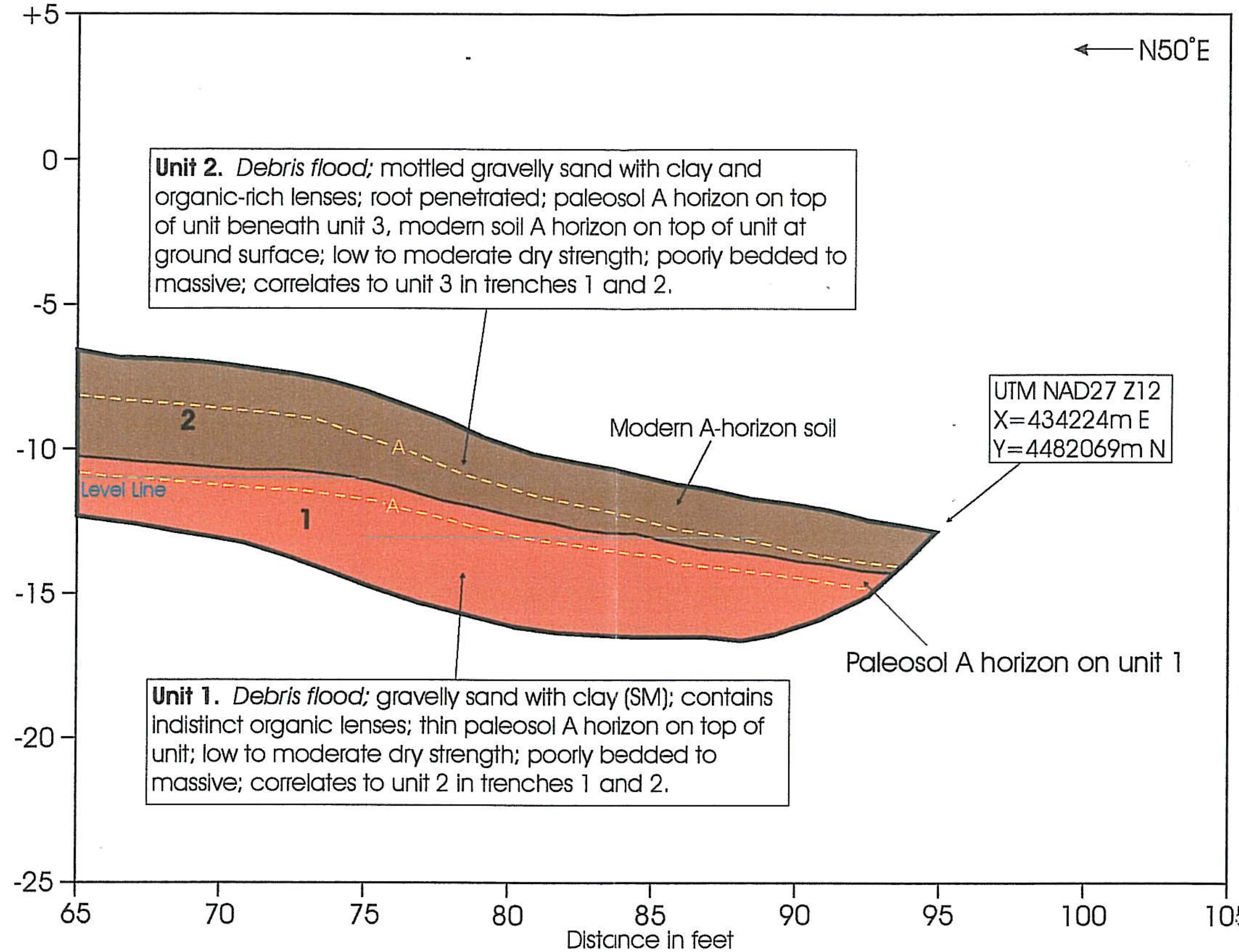
Trench logged by Bill Black, P.G. on
April 22, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

**TRENCH 3 LOG (-5' to 65')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 8a**

WESTERN GEOLOGIC




LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

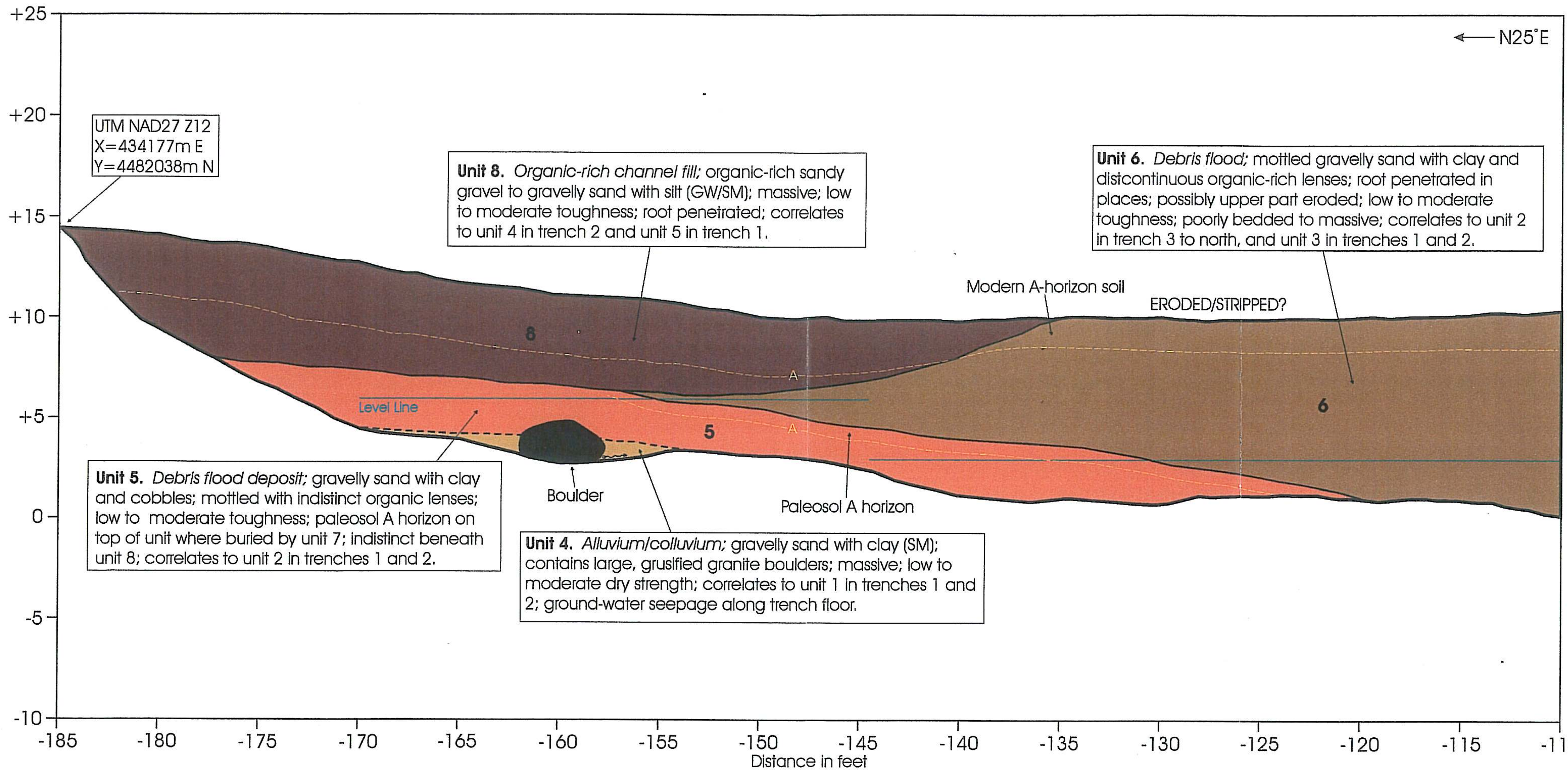
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
April 22, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

**TRENCH 3 LOG (65' to 105')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City,
Utah County, Utah

**FIGURE 8b**




WESTERN GEOLOGIC

LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

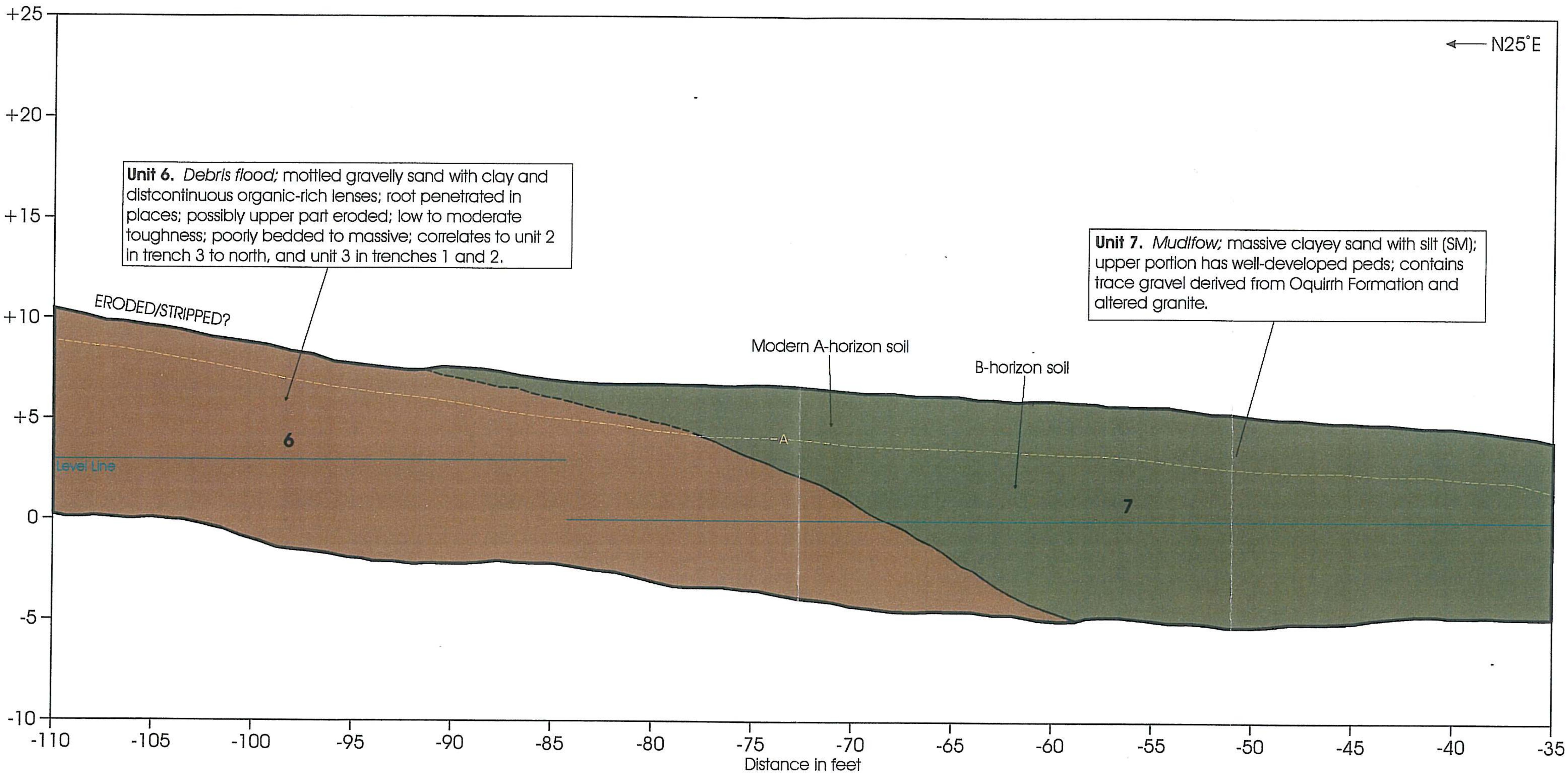
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
April 22-23, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

**TRENCH 4 LOG (-185' to -110')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 9a**




LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

WESTERN GEOLOGIC

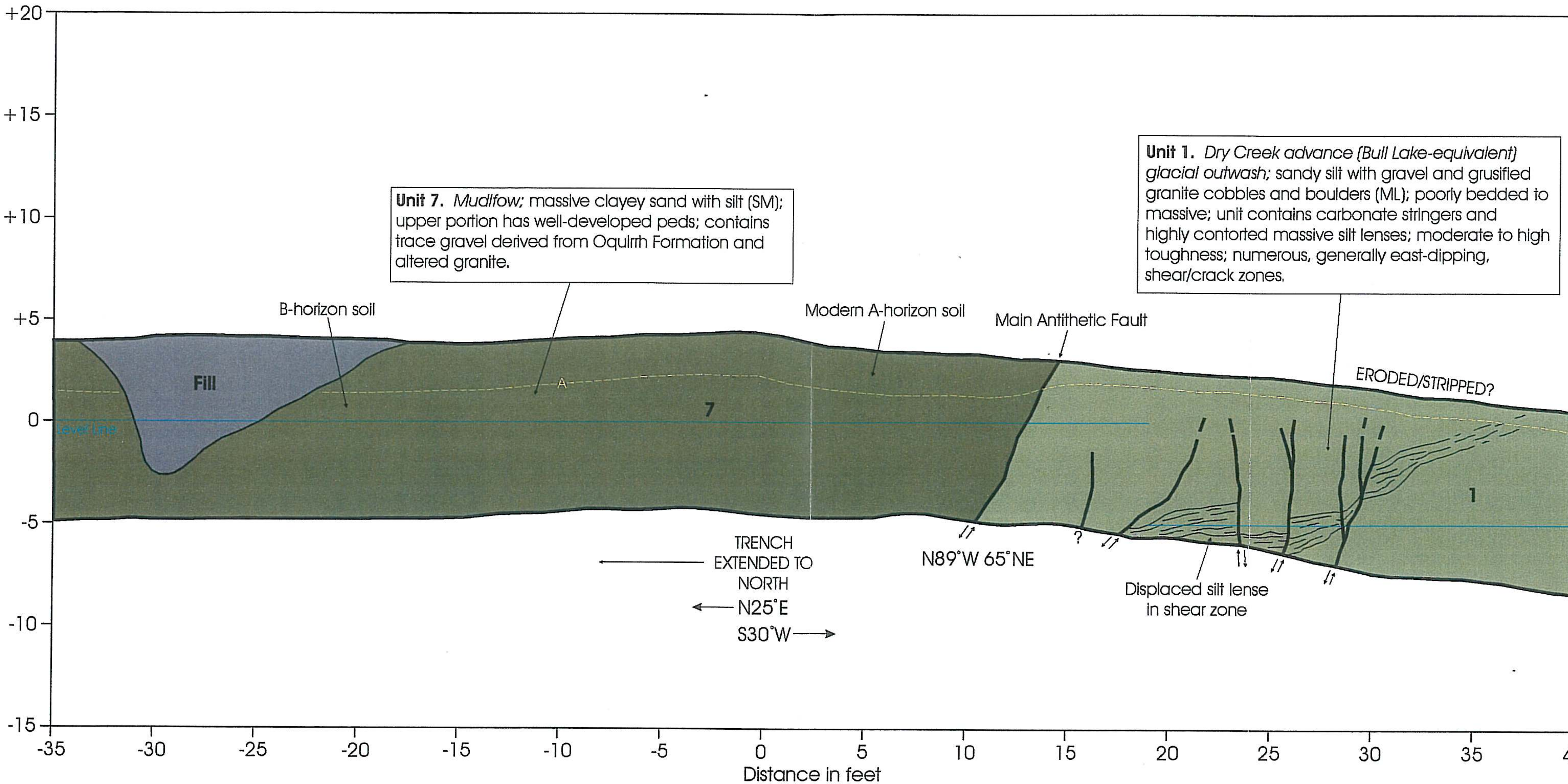
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
April 22-23, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

## TRENCH 4 LOG (-110' to -35')

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City,
Utah County, Utah

**FIGURE 9b**




WESTERN GEOLOGIC

LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

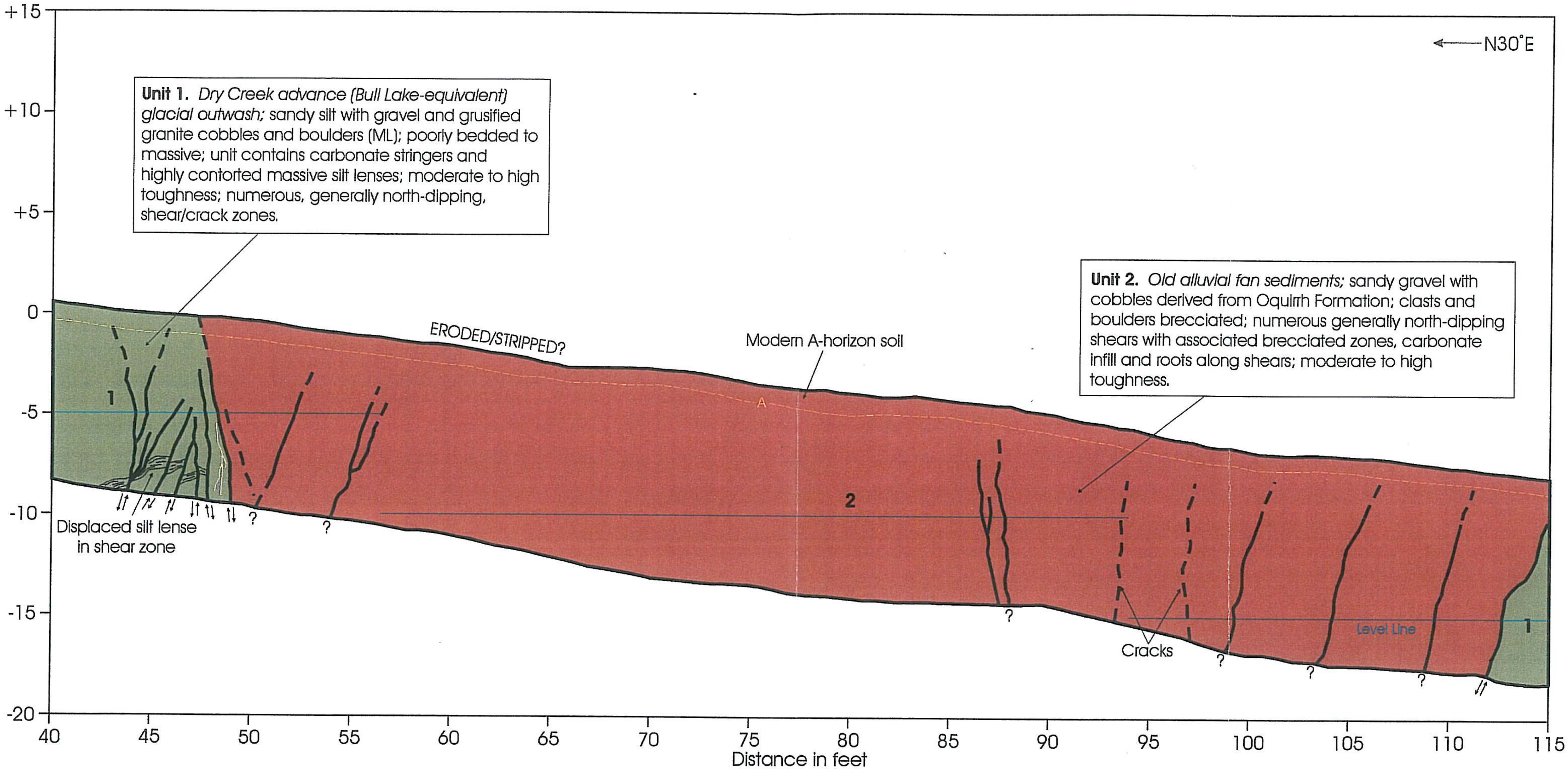
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
April 22-23, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

**TRENCH 4 LOG (-35' to 40')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 9c**




LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

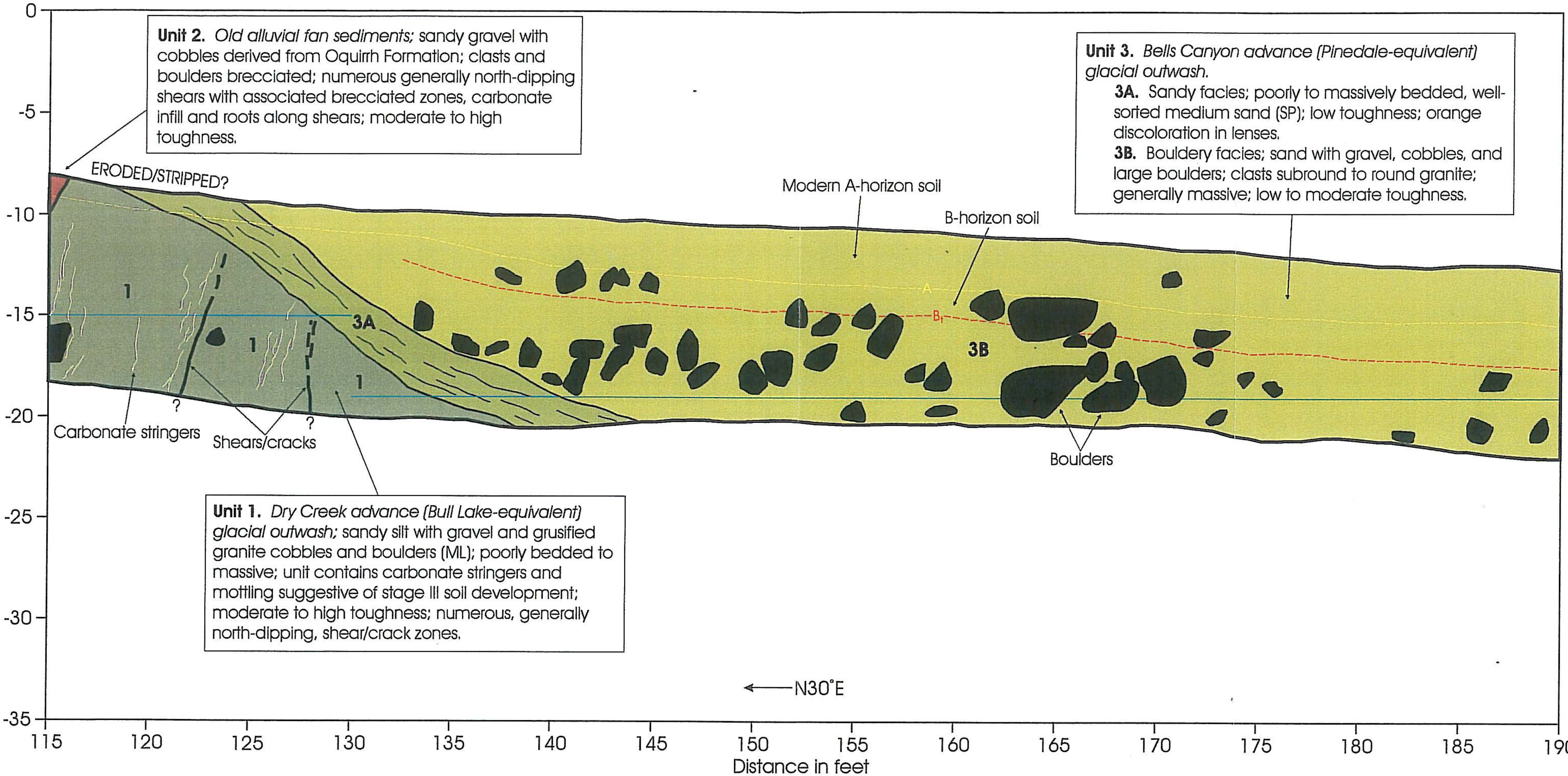
Trench logged by Bill Black, P.G. on
April 22-23, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

WESTERN GEOLOGIC

## TRENCH 4 LOG (40' to 115')

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 9d**




WESTERN GEOLOGIC

LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

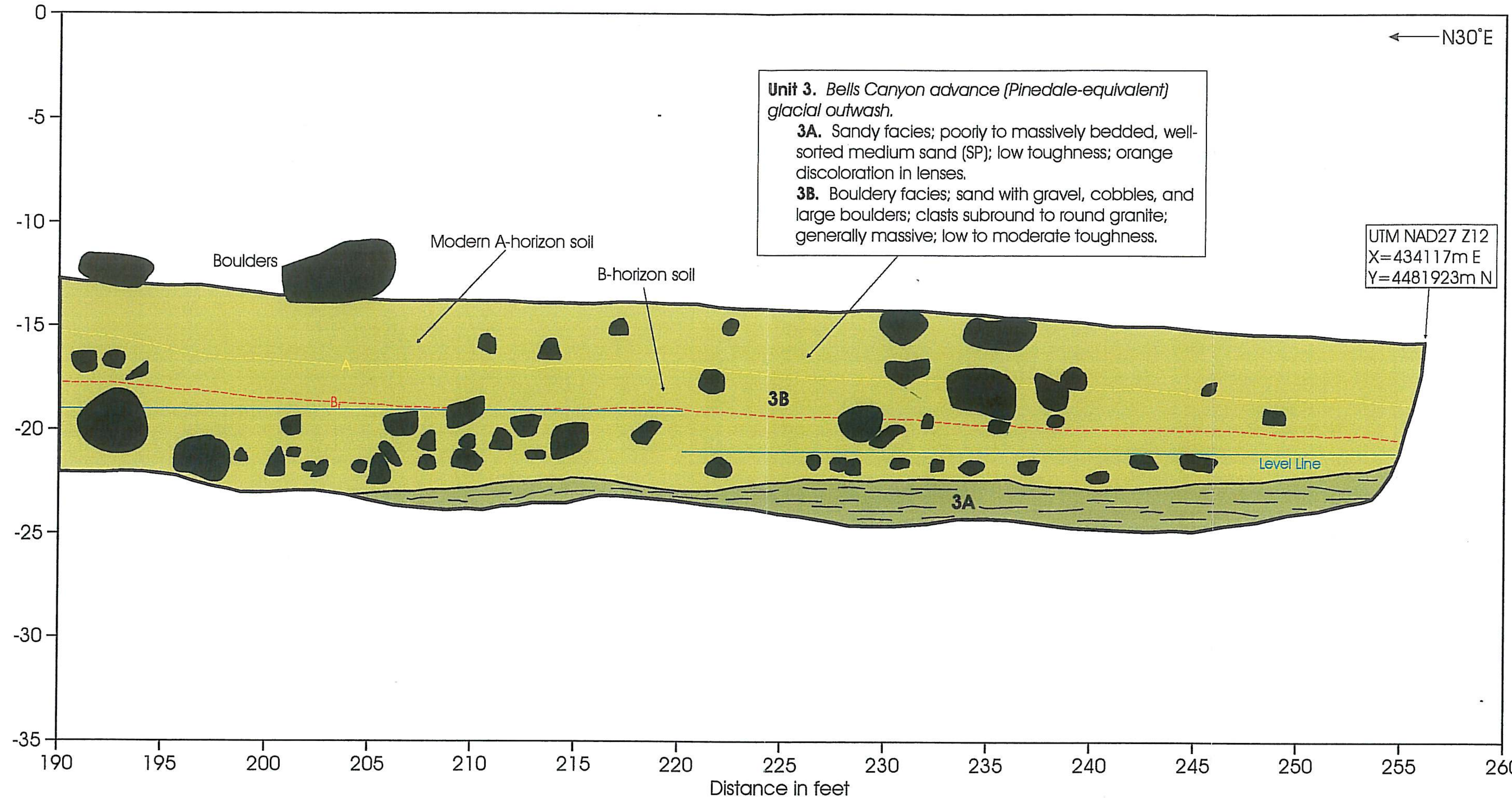
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
April 22-23, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

**TRENCH 4 LOG (115' to 190')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 9e**




LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

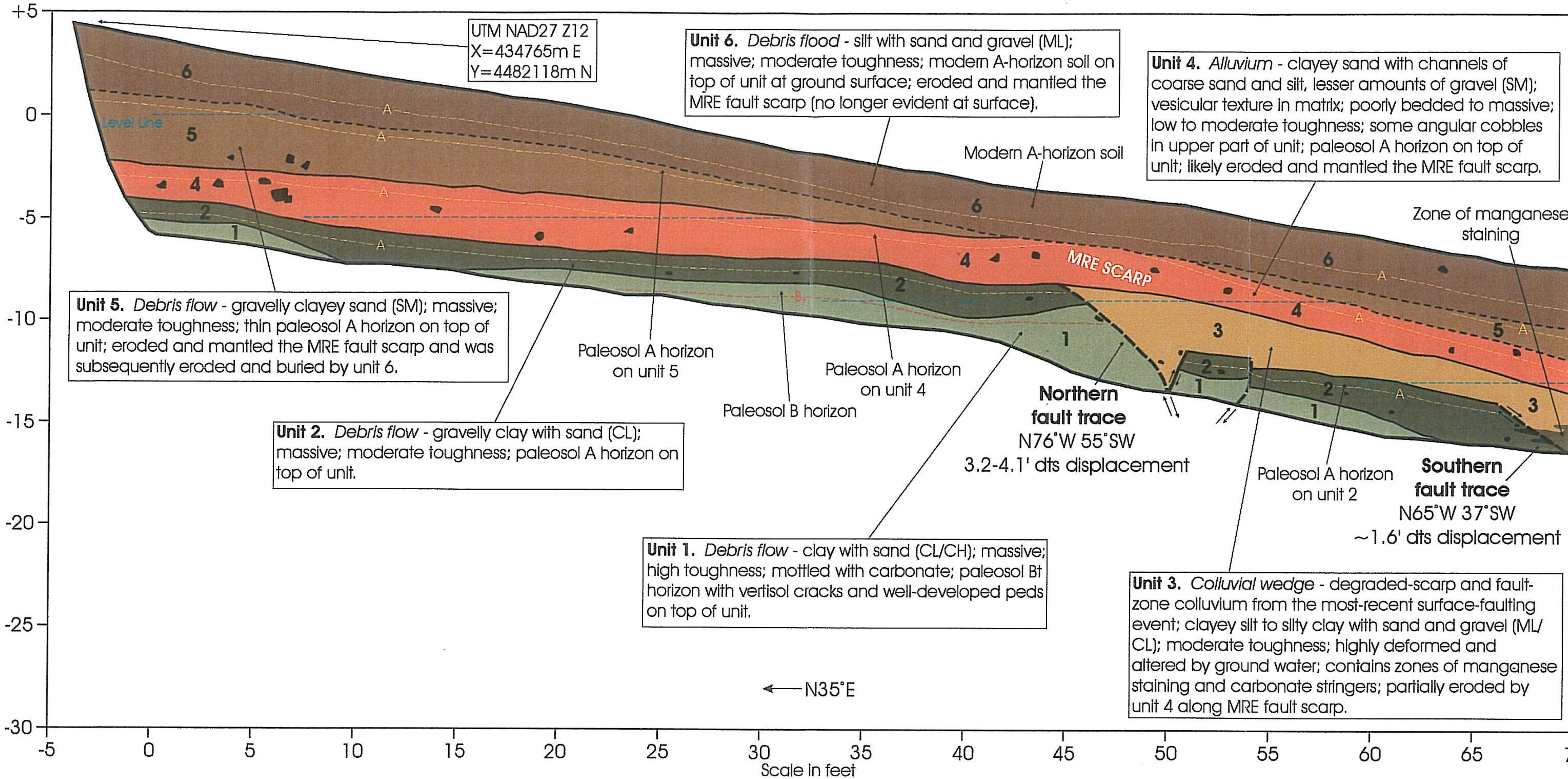
Trench logged by Bill Black, P.G. on
April 22-23, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

WESTERN GEOLOGIC

## TRENCH 4 LOG (190' to 260')

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 9f**




WESTERN GEOLOGIC

LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

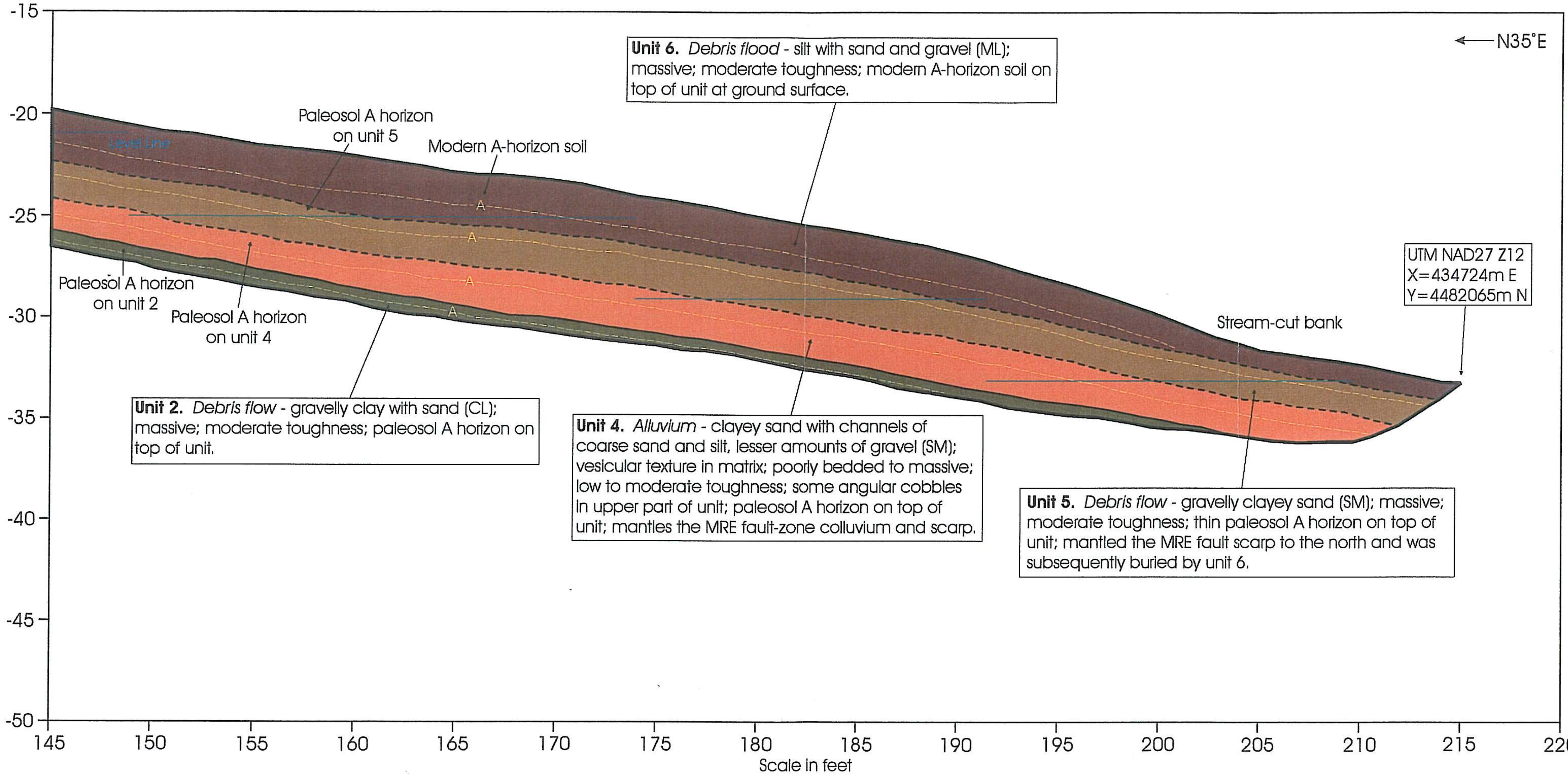
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on June 22, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

## TRENCH 5 LOG (-5' - 70')

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 10a**




WESTERN GEOLOGIC

LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

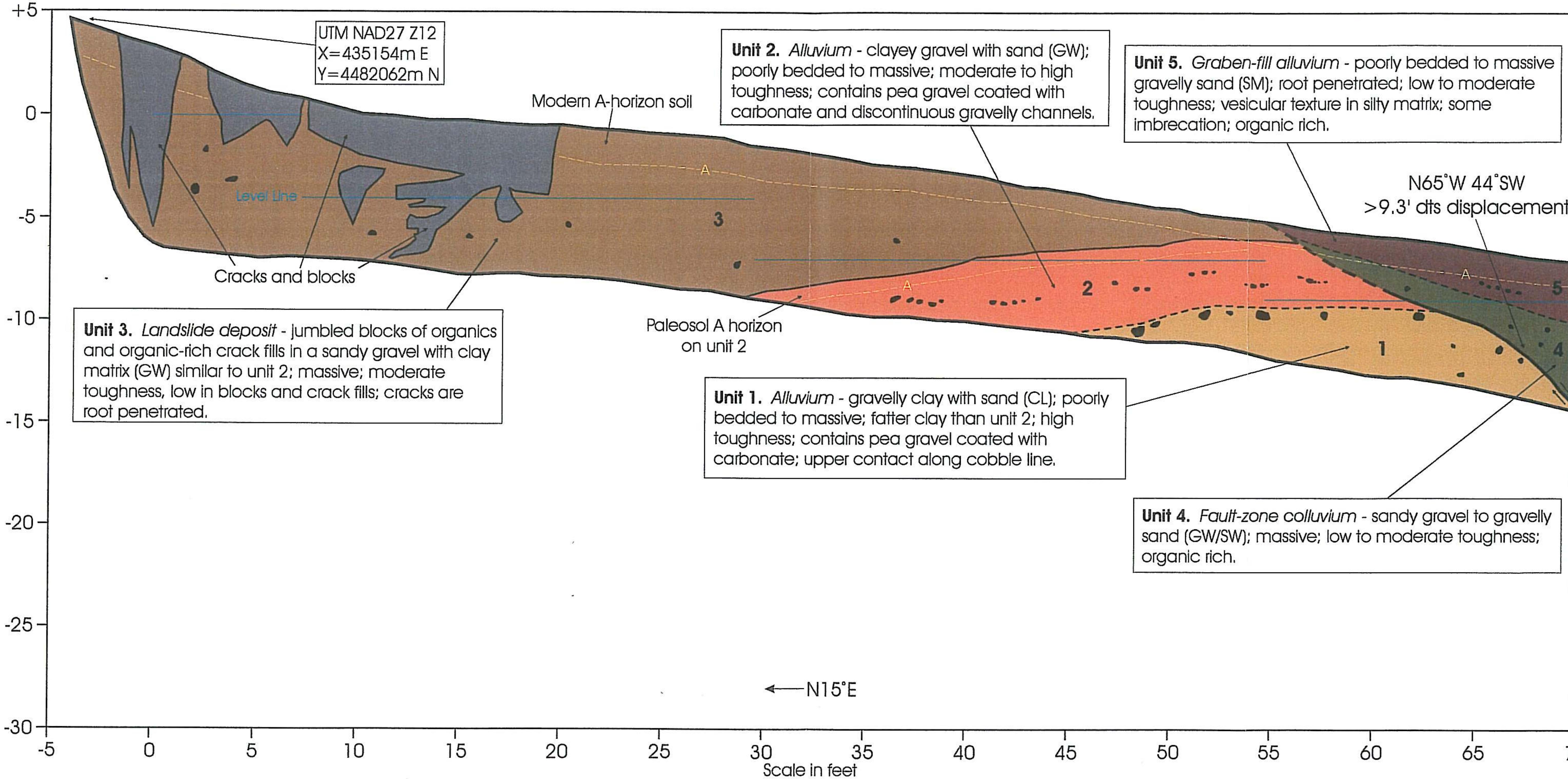
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
June 22, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

**TRENCH 5 LOG (145' to 220')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 10c**




WESTERN GEOLOGIC

LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

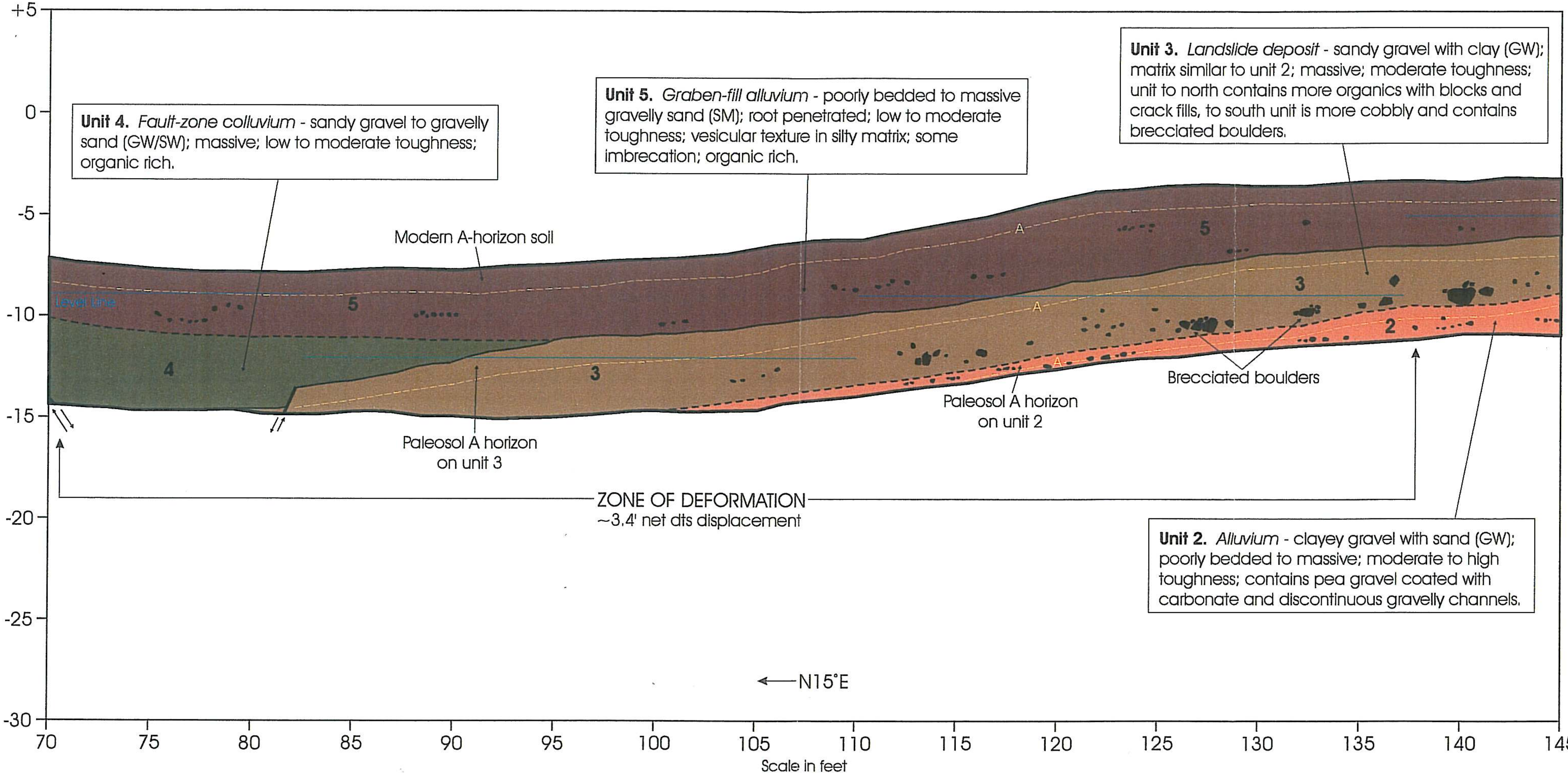
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
June 23-24, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

**TRENCH 6 LOG (-5' - 70')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 11a**




WESTERN GeoLogic

LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

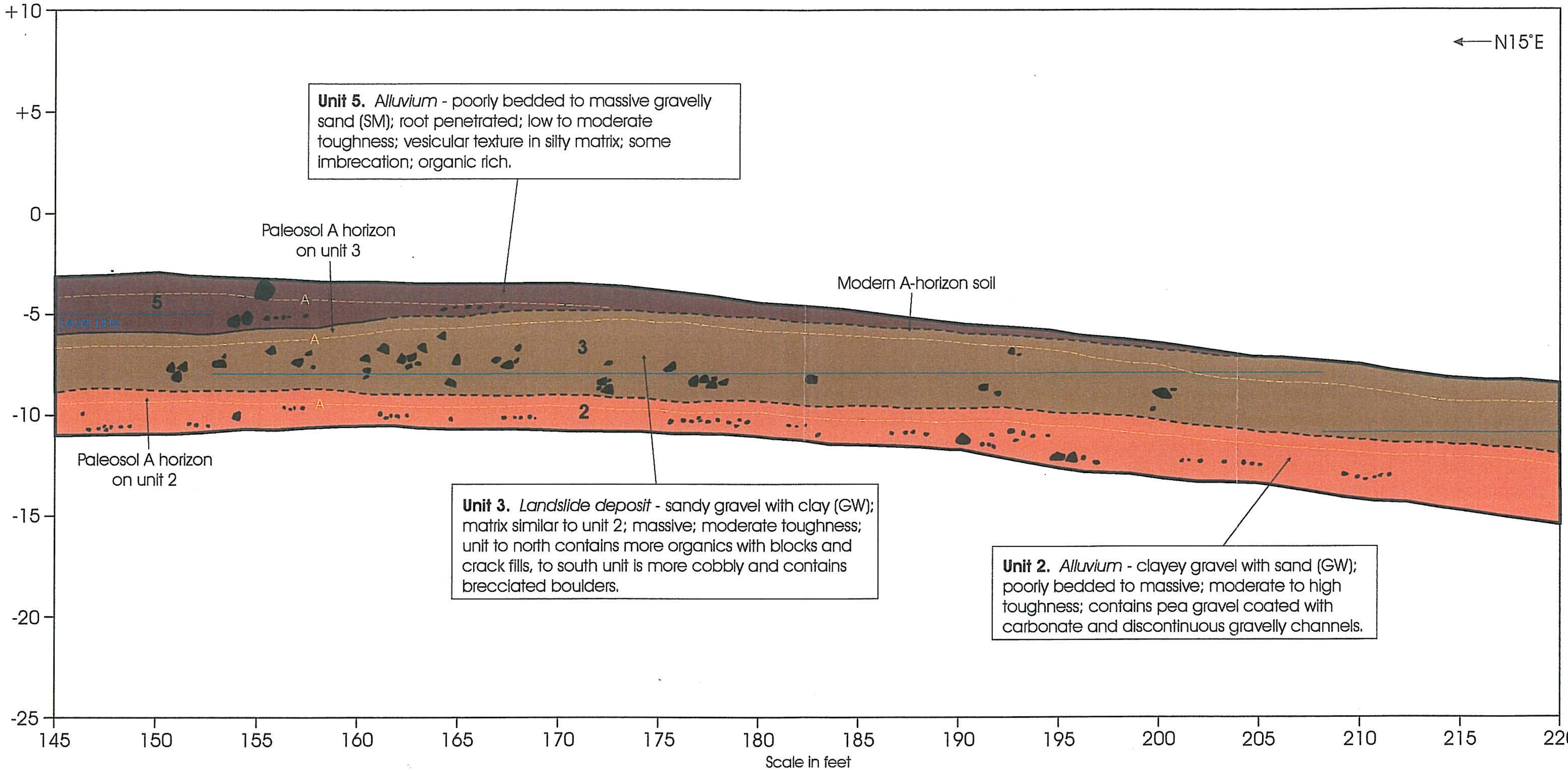
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
June 23-24, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

**TRENCH 6 LOG (70' - 145')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 11b**




LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
June 23-24, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

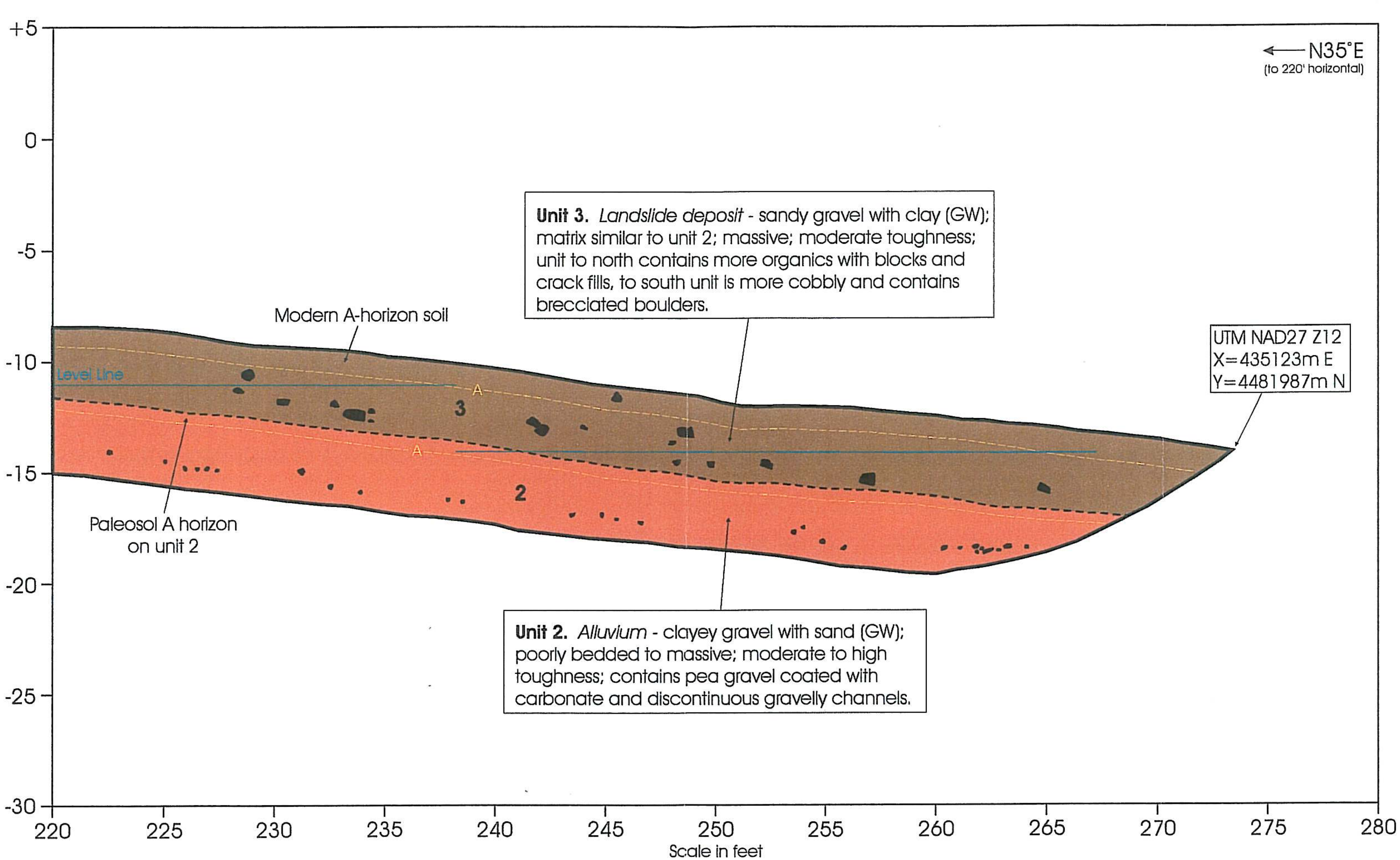
WESTERN GEOLOGIC

## TRENCH 6 LOG (145' - 220')

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 11c**

WESTERN GEOLOGIC




LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

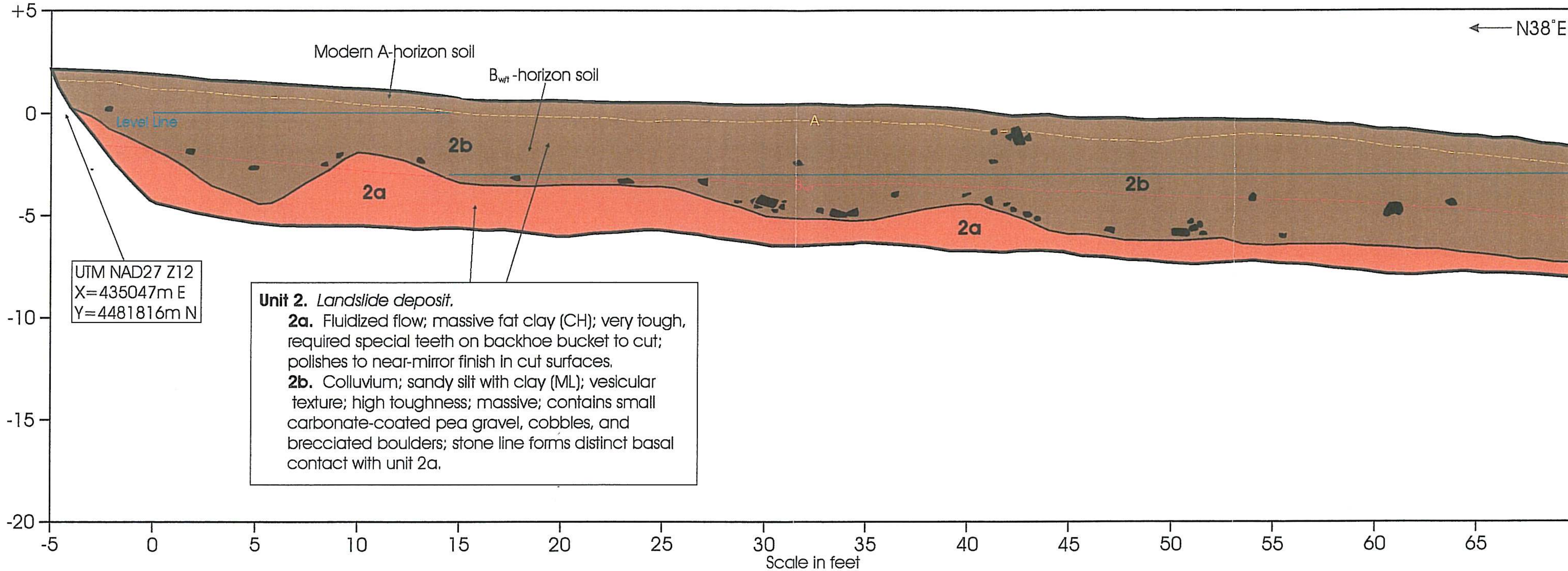
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
June 23-24, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

**TRENCH 6 LOG (220' - 280')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 11d**




WESTERN GEOLOGIC

LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

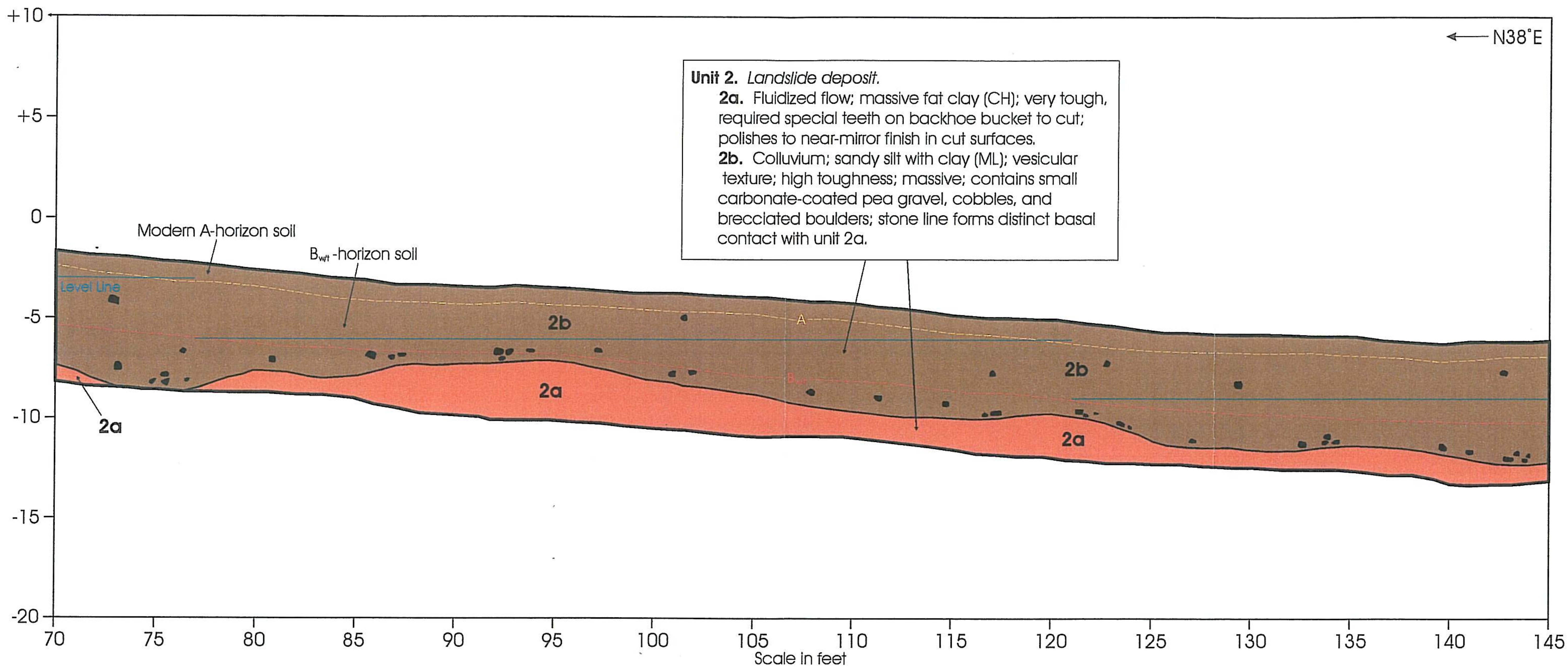
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
June 24-25, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

**TRENCH 7 LOG (-5' - 70')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 12a**




LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

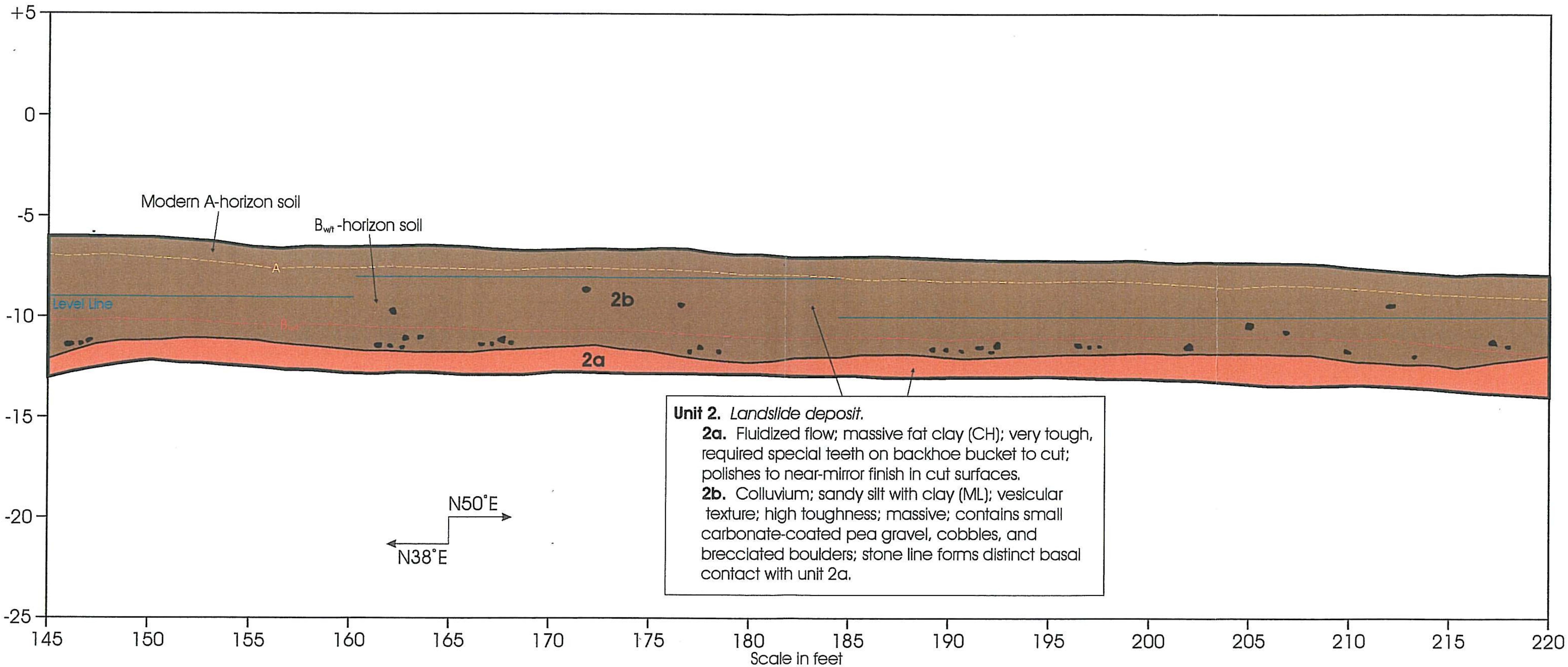
Trench logged by Bill Black, P.G. on
June 24-25, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

WESTERN GEOLOGIC

**TRENCH 7 LOG (70' - 145')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 12b**

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LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

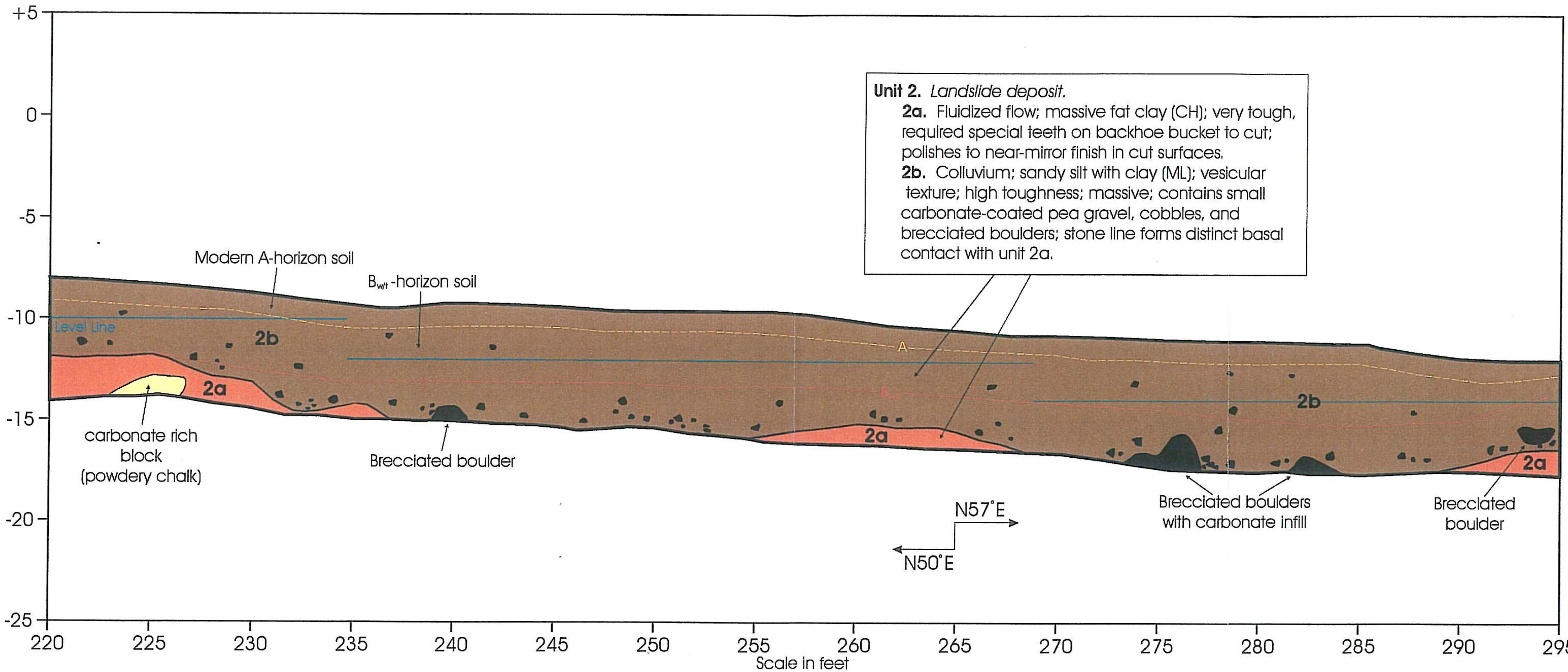
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
June 24-25, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

**TRENCH 7 LOG (145' - 220')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 12c**




LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

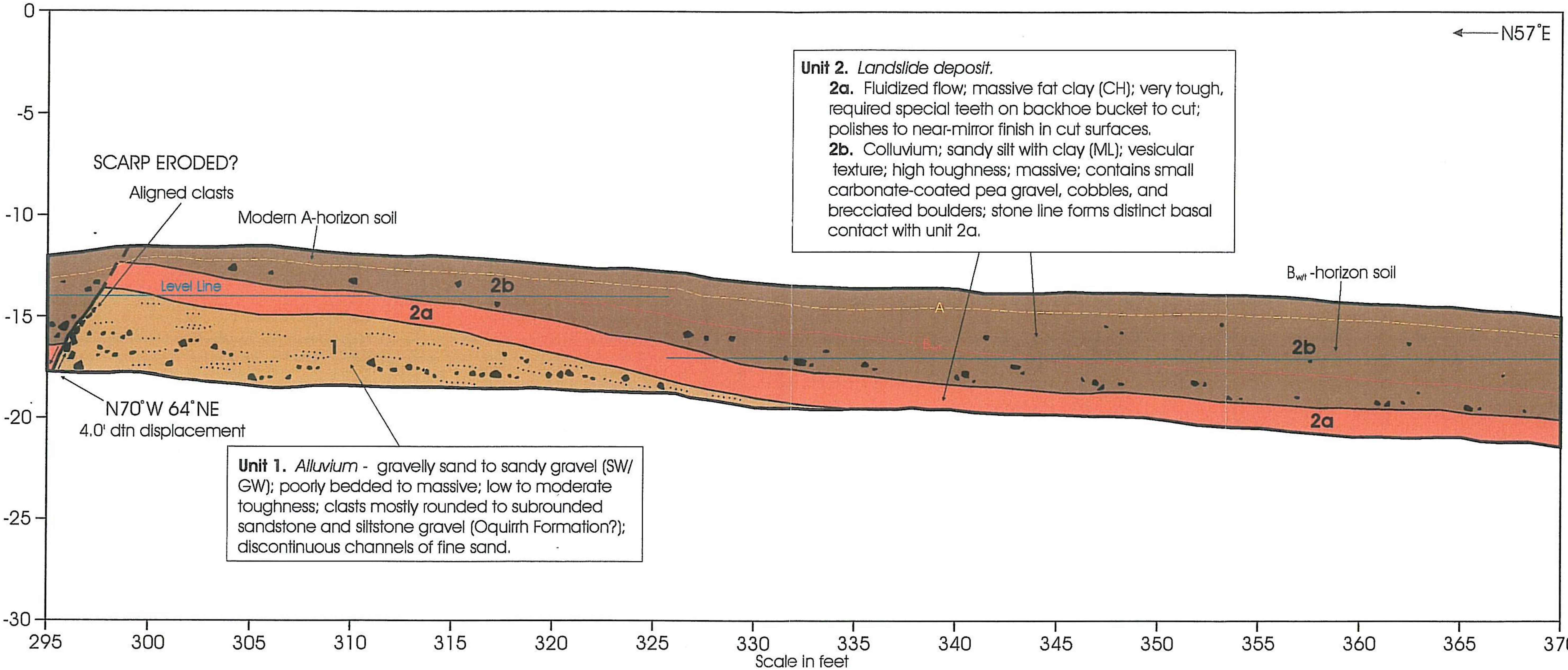
Trench logged by Bill Black, P.G. on
June 24-25, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

WESTERN GEOLOGIC

## TRENCH 7 LOG (220' - 295')

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 12d**




LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

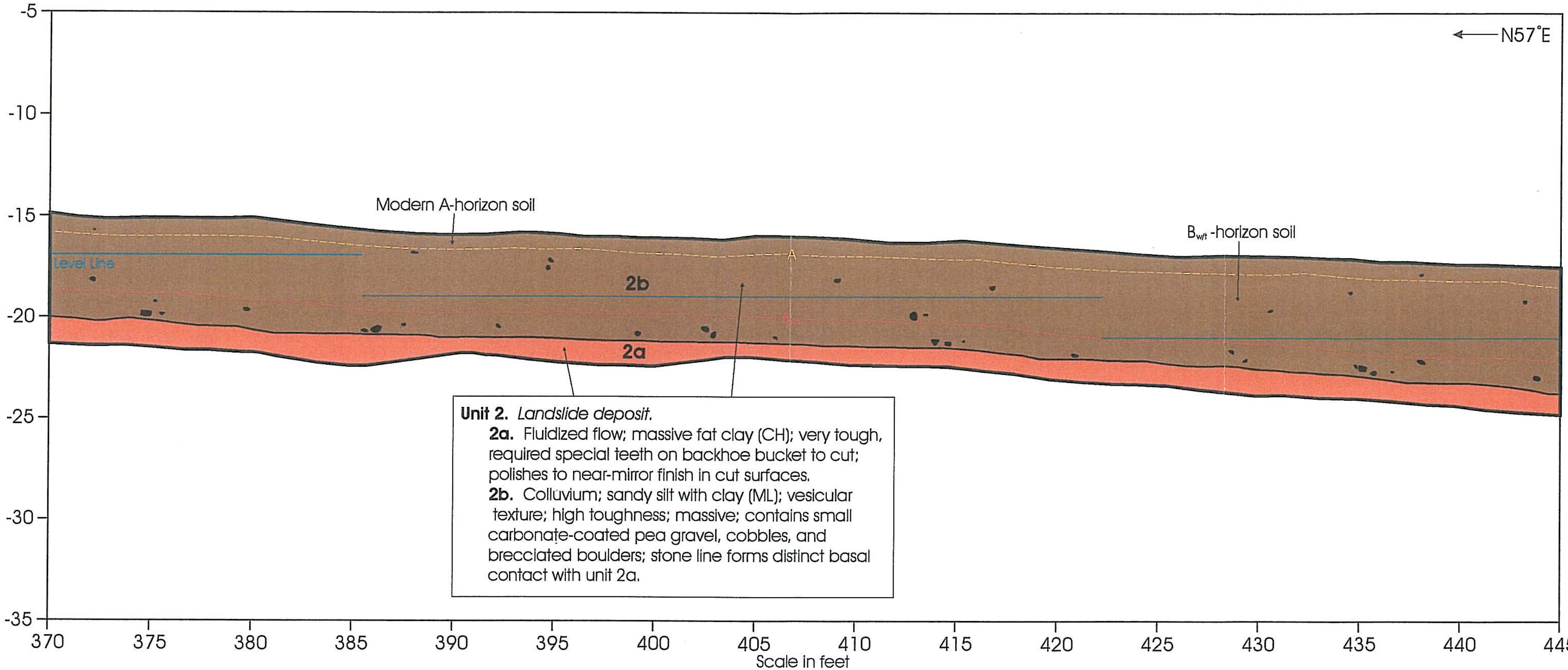
Trench logged by Bill Black, P.G. on
June 24-25, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

WESTERN GEOLOGIC

**TRENCH 7 LOG (295' - 370')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 12e**




WESTERN GEOLOGIC

LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

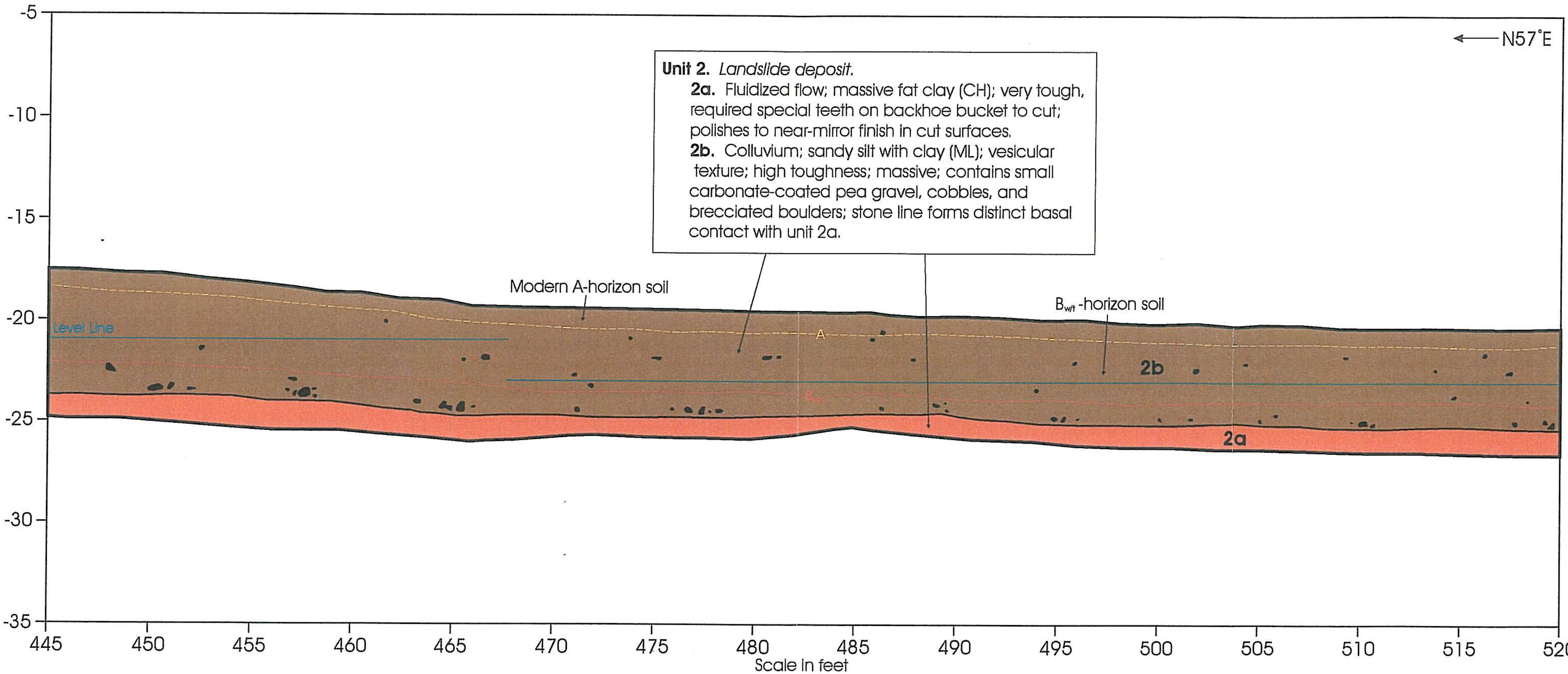
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
June 24-25, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

**TRENCH 7 LOG (370' - 445')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 12f**




WESTERN GEOLOGIC

LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

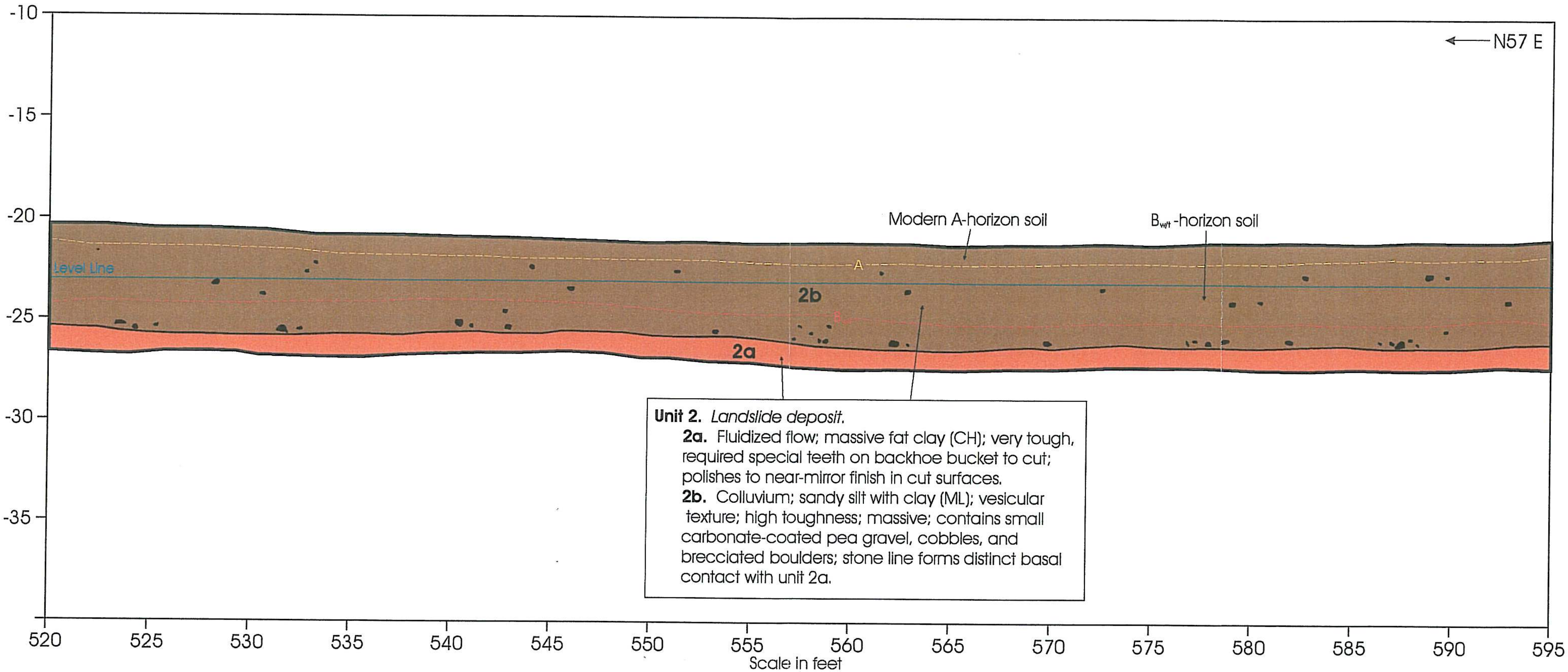
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
June 24-25, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

**TRENCH 7 LOG (445' - 520')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 12g**




WESTERN GEOLOGIC

LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

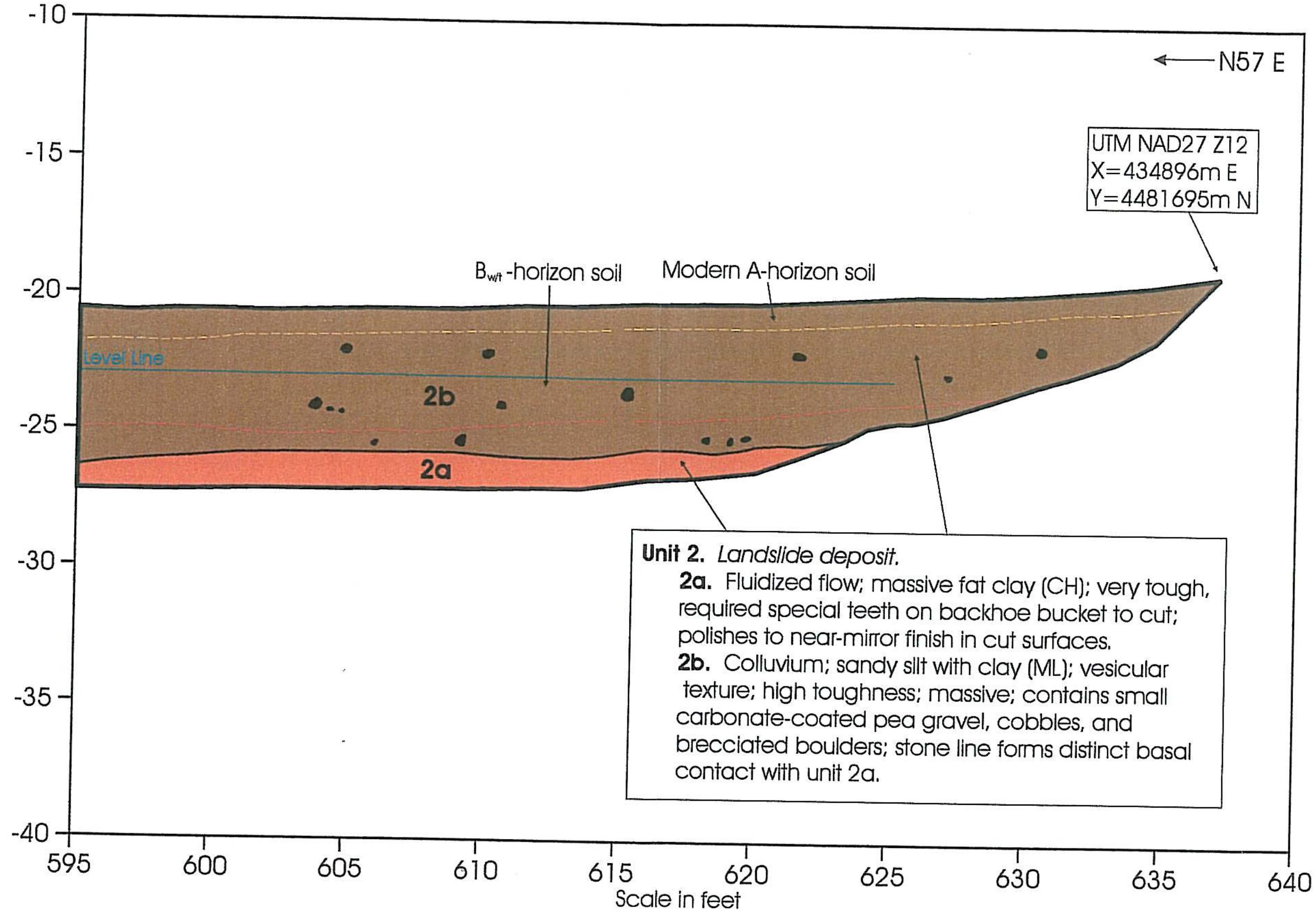
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
June 24-25, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

**TRENCH 7 LOG (520' - 595')**

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 12h**




LICENSED PROFESSIONAL GEOLOGIST
BILL DUANE BLACK
NO. 5224898-2250
STATE OF UTAH

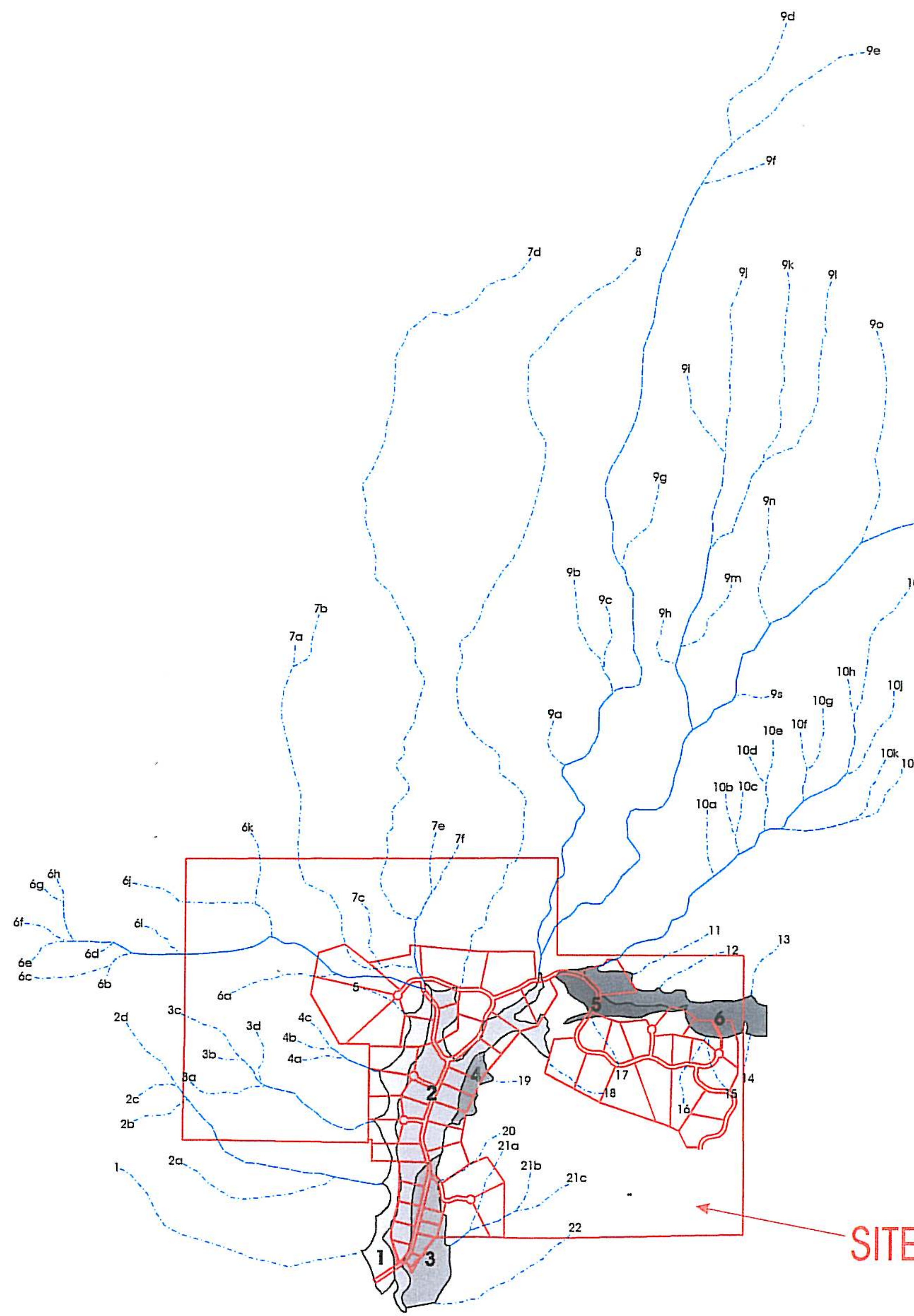
SCALE: 1 inch = 5 feet
(no vertical exaggeration)
East Trench Wall Logged

Trench logged by Bill Black, P.G. on
June 24-25, 2004
Reviewed by Craig V Nelson, P.G., R.G., C.E.G.

# TRENCH 7 LOG (595' - 640')

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 12i**




Drainages numbered 1 through 22 with small-case letters denoting sub-drainages; drainages include all perennial and ephemeral streams and significant swales. See table in text for drainage lengths.

Alluvial deposits numbered 1 through 6 and include surficial-geologic units Qafy, Qaf1, Qaly, and Qac on figure 2. See table in text for alluvium areas.

N W E S

Scale 1:24,000
(1 inch = 2,000 feet)

## DRAINAGES AND ALLUVIUM

**GEOLOGIC HAZARDS EVALUATION**
Three Falls Ranch
Alpine City
Utah County, Utah

**FIGURE 13**

BETA ANALYTIC INC.
DR. M.A. TAMERS and MR. D.G. HOOD
UNIVERSITY BRANCH
4985 S.W. 74 COURT
MIAMI, FLORIDA, USA 33155
PH: 305/667-5167 FAX: 305/663-0964
E-MAIL: beta@radiocarbon.com

# REPORT OF RADIOCARBON DATING ANALYSES

Mr. Craig Nelson — Report Date: 5/24/2004

Western Geologic — Material Received: 5/4/2004

| Sample Data | Measured Radiocarbon Age | 13C/12C Ratio | Conventional Radiocarbon Age(*) |
|---|---|---|---|
| Beta - 191946 | 2680 +/- 70 BP | -25.2 o/oo | 2670 +/- 70 BP |

SAMPLE : TFRT1-RC12
ANALYSIS : Radiometric-Advance delivery (bulk low carbon analysis on sediment)
MATERIAL/PRETREATMENT : (organic sediment): acid washes
2 SIGMA CALIBRATION : Cal BC 940 to 780 (Cal BP 2890 to 2730)

| Sample Data | Measured Radiocarbon Age | 13C/12C Ratio | Conventional Radiocarbon Age(*) |
|---|---|---|---|
| Beta - 191947 | 4540 +/- 80 BP | -24.9 o/oo | 4540 +/- 80 BP |

SAMPLE : TFRT1-RC3
ANALYSIS : Radiometric-Advance delivery (bulk low carbon analysis on sediment)
MATERIAL/PRETREATMENT : (organic sediment): acid washes
2 SIGMA CALIBRATION : Cal BC 3510 to 3420 (Cal BP 5460 to 5370) AND Cal BC 3390 to 3000 (Cal BP 5340 to 4950)
Cal BC 2980 to 2940 (Cal BP 4930 to 4880)

Dates are reported as RCYBP (radiocarbon years before present, "present" = 1950A.D.). By International convention, the modern reference standard was 95% of the C14 content of the National Bureau of Standards' Oxalic Acid & calculated using the Libby C14 half life (5568 years). Quoted errors represent 1 standard deviation statistics (68% probability) & are based on combined measurements of the sample, background, and modern reference standards.

Measured C13/C12 ratios were calculated relative to the PDB-1 international standard and the RCYBP ages were normalized to -25 per mil. If the ratio and age are accompanied by an (*), then the C13/C12 value was estimated, based on values typical of the material type. The quoted results are NOT calibrated to calendar years. Calibration to calendar years should be calculated using the Conventional C14 age.

## CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-25.2:lab. mult=1)

**Laboratory number:** **Beta-191946**

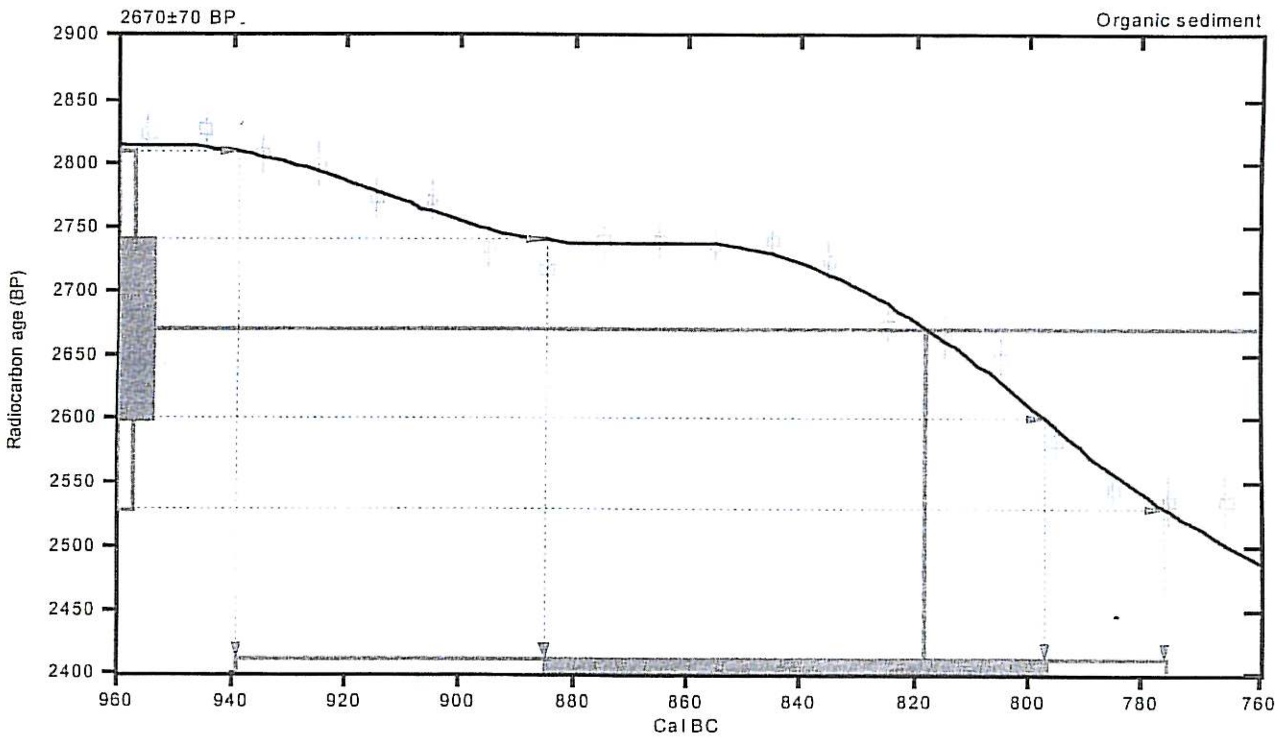
**Conventional radiocarbon age:** **2670±70 BP**

**2 Sigma calibrated result: (95% probability)** **Cal BC 940 to 780 (Cal BP 2890 to 2730)**

Intercept data

Intercept of radiocarbon age with calibration curve: Cal BC 820 (Cal BP 2770)

1 Sigma calibrated result: (68% probability) Cal BC 880 to 800 (Cal BP 2840 to 2750)





References:

*Database used*
*Intcal98*
*Calibration Database*
*Editorial Comment*
*Stuiver, M., van der Plicht, H., 1998, Radiocarbon 40(3), pxii-xiii*
*INTCAL98 Radiocarbon Age Calibration*
*Stuiver, M., et. al., 1998, Radiocarbon 40(3), p1041-1083*
*Mathematics*
*A Simplified Approach to Calibrating C14 Dates*
*Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2), p317-322*



**Beta Analytic Radiocarbon Dating Laboratory**

*4985 S.W. 74th Court, Miami, Florida 33155 • Tel: (305)667-5167 • Fax: (305)663-0964 • E-Mail: beta@radiocarbon.com*

# CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-24.9:lab. mult=1)

**Laboratory number:** **Beta-191947**

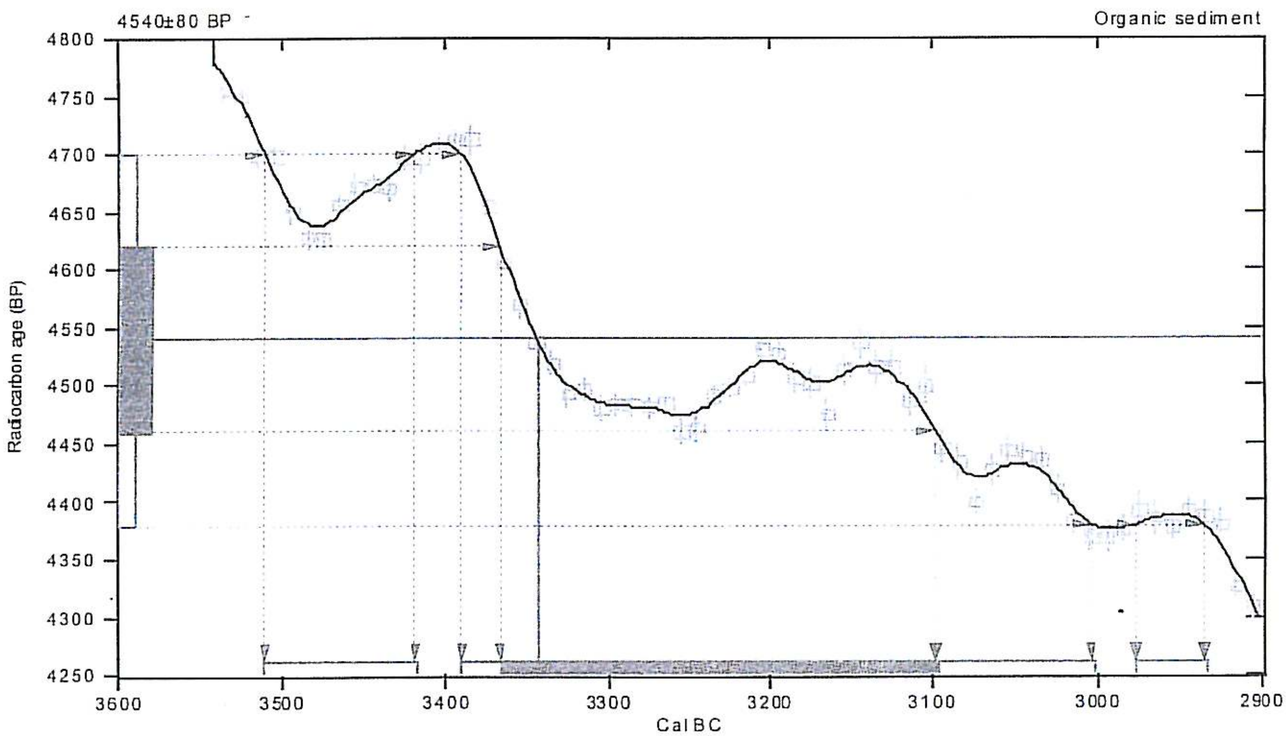
**Conventional radiocarbon age:** **4540±80 BP**

**2 Sigma calibrated results:** **Cal BC 3510 to 3420 (Cal BP 5460 to 5370) and**
**(95% probability)** **Cal BC 3390 to 3000 (Cal BP 5340 to 4950) and**
**Cal BC 2980 to 2940 (Cal BP 4930 to 4880)**

Intercept data

Intercept of radiocarbon age with calibration curve: Cal BC 3340 (Cal BP 5290)

1 Sigma calibrated result: Cal BC 3370 to 3100 (Cal BP 5320 to 5050)
(68% probability)





References:

*Database used*
*INTCAL98*
*Calibration Database*
*Editorial Comment*
*Stuiver, M., van der Plicht, H., 1998, Radiocarbon 40(3), pxii-xiii*
*INTCAL98 Radiocarbon Age Calibration*
*Stuiver, M., et. al., 1998, Radiocarbon 40(3), p1041-1083*
*Mathematics*
*A Simplified Approach to Calibrating C14 Dates*
*Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2), p317-322*



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