REPORT

GEOLOGIC HAZARDS EVALUATION

PROPOSED CRIMSON RIDGE PHASE 2 SUBDIVISION
ABOUT 1100 NORTH MORNINGSIDE LANE
EDEN, UTAH

Prepared for

Steven Fenton
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May 15, 2020

Prepared by

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May 15, 2020

Steven Fenton
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Letter of Transmittal: REPORT
Geologic Hazards Evaluation
Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

Dear Mr. Fenton:

Western Geologic & Environmental has completed a Geologic Hazards Evaluation for the proposed Crimson Ridge Phase 2 Subdivision located at about 1100 North Morningside Lane in Eden, Utah and submits the attached report for your review.

If you have any questions regarding this report, please contact us at (801) 359-7222.

Sincerely,
Western Geologic & Environmental LLC

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WG&E Project No. 5378

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1.0 INTRODUCTION

This report presents the results of a geology and geologic hazards review and evaluation conducted by Western Geologic & Environmental LLC (Western Geologic) for the proposed Crimson Ridge Phase 2 subdivision located at about 100 North Morningside Lane in Eden, Utah (Figure 1 – Project Location). The Project consists of a 136.22-acre parcel identified as Weber County Assessor's parcel number 20-005-0021. The Project is on generally east-facing slopes at the base of the Wasatch Range in western Ogden Valley in the S1/2 Section 8 and N1/2 Section 10, Township 6 North, Range 1 East (Salt Lake Base Line and Meridian; Figure 1). Elevation of the site ranges from about 4,948 feet to 5,744 feet above sea level. The property is currently undeveloped land. Based on a Gardner Engineering Concept Map dated September 13, 2019 the property is planned for development of a 43-lot residential subdivision.

2.0 PREVIOUS STUDY

A prior geologic hazards and geotechnical evaluation was conducted for the Pineview Estates at Radford Hills subdivision by Western Geologic (2006) and Earthtec Testing & Engineering (ETE, 2006). This proposed subdivision was subsequently split into two phases and became The Reserve at Crimson Ridge Phase 1 subdivision on the south and the Project (Crimson Ridge Phase 2) on the north, which further includes an additional area on the northeast. Western Geologic (2006) identified potential geologic hazards from earthquake ground shaking, stream flooding, debris flows, and landsliding based on surficial observations, review of geologic mapping and aerial photos, and subsurface data. The 2006 investigation included excavation and logging of one trench across the presumed location of the Ogden Valley southwestern margin fault (aka West Ogden Valley fault; Black and others, 2003) a few hundred feet south of the Project, as well as excavation and logging of 11 test pits in other areas of the development.

With regard to potential geologic hazards at the site, Western Geologic (2006) recommended that: (1) proposed homes be designed and constructed to current seismic standards; (2) site hydrology, runoff, and/or potential for debris-flow hazards be addressed in civil engineering design for the development; and (3) a design-level geotechnical engineering study be conducted to address soil conditions with regard to foundation design and site preparation, provide recommendations to reduce seismic risk, and evaluate stability of slopes along the western site margin. ETE (2006) conducted a slope stability evaluation for the proposed development that found a high risk for landsliding existed for lots along the western margin of the subdivision (along the base of the range front) due to low factors of safety. ETE (2006) further provided recommendations regarding footing and foundation design, seismic design, site grading, surface and subsurface drainage, and pavement construction.

3.0 PURPOSE AND SCOPE

The purpose and scope of this investigation is to identify and interpret surficial geologic conditions at the site to identify potential risk from geologic hazards to the Project. This investigation is intended to: (1) provide preliminary geologic information and assessment of geologic conditions at the site; (2) identify potential geologic hazards that may be present and qualitatively assess their risk to the intended site use; and (3) provide recommendations for additional site- and hazard-specific studies or mitigation measures, as may be needed based on our findings. Such recommendations could require further multi-disciplinary evaluations, and/or may need design criteria that are beyond our professional scope. Our investigation was conducted concurrently with a geotechnical engineering study performed at the Project by Christensen Geotechnical.

3.1 Methodology

The following services were performed in accordance with the above-stated purpose and scope:

- A site reconnaissance conducted by an experienced certified engineering geologist to assess the site setting and look for adverse geologic conditions;
- Review of readily-available geologic maps, reports, and air photos;
- Logging of 15 onsite walk-in test pits and two offsite test pits (near the proposed water tank location further west) to assess subsurface conditions;
- Preparation of three cross-section profiles based on site-specific subsurface data and inferred conditions; and
- Evaluation of available data and preparation of this report, which presents the results of our study.

The engineering geology section of this report has been prepared in accordance with Bowman and Lund (2016) and current generally accepted professional engineering geologic principles and practice in Utah, and meets specifications provided in Chapter 27 of the Weber County Land Use Code within the above stated scope. We do not include discussion of radon hazard potential, as recommended in Bowman and Lund (2016), because radon gas poses an environmental health hazard and indoor levels are heavily influenced by several post-construction, non-geologic factors. The hazard from radon should be evaluated by long-term testing following construction.

3.2 Limitations and Exceptions

This investigation was performed at the request of 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 site-specific observations and compilation of known geologic information. 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 founded 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; its 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.

4.0 HYDROLOGY

The U.S. Geological Survey (USGS) topographic map of the Huntsville Quadrangle shows the site is on the western margin of Ogden Valley about 1,100 feet northwest of the marina for Pineview Yacht Club (Figure 1). An unnamed drainage crosses the northern half of the property and flows eastward into Pineview Reservoir (Figure 1). The creek was flowing at the time of our investigation (in April), although we are uncertain if it is perennial or intermittent. Several smaller ephemeral feeder drainages also flow across portions of the property and into this creek that were all dry at the time of our investigation.

Ogden Valley is dominated in the valley bottom by unconsolidated lacustrine and alluvial basin-fill deposits. Slopes in the site area are mainly in weathered Tertiary-age tuffaceous bedrock overlain by a veneer of unconsolidated Quaternary alluvial and colluvial deposits. Avery (1994) indicates groundwater in Ogden Valley occurs under perched, confined, and unconfined conditions in the valley fill to depths of 750 feet or more. A well-stratified lacustrine silt layer forms a leaky confining bed in the upper part of the valley-fill aquifer. The aquifer below the confining beds is the principal aquifer, which is in primarily fluvial and alluvial-fan deposits. The principal aquifer is recharged from precipitation, seepage from surface water, and subsurface inflow from bedrock into valley fill along the valley margins (Avery, 1994). The confined aquifer is typically overlain by a shallow, unconfined aquifer recharged from surface flow and upward leakage. Groundwater flow is generally from the valley margins into the valley fill, and then toward the head of Ogden Canyon (Avery, 1994).

Groundwater was observed at depths of from 6.8 feet to 10.3 feet below the ground surface (bgs) in test pits TP-3, TP-5, TP-11, TP-14, TP-15, and TP-17 conducted for our investigation, but was not observed in the remaining test pits to their explored depths. Given the above, we anticipate that groundwater at the Project is generally from 10 to 30 feet deep, but appears to be locally less than 10 feet bgs along the unnamed creek and further north along the range front base. Groundwater depths at the site likely vary seasonally from snowmelt runoff and annually from climatic fluctuations. Such variations would be typical for an alpine environment. Perched conditions above less-permeable, clay-rich bedrock layers may also be present in the subsurface that could cause locally shallower groundwater levels. Based on topography, we expect groundwater flow at the site to be generally to the east.

5.0 GEOLOGY

5.1 Surficial Geology

The site is located on the western margin of Ogden Valley, a sediment-filled intermontane valley within the Wasatch Range, a major north-south trending mountain range marking the eastern boundary of the Basin and Range physiographic province (Stokes; 1977, 1986). Surficial geology of the site is mapped by Coogan and King (2016; Figure 2) as Neoproterozoic (Precambrian-age) bedrock of the Maple Canyon Formation (unit Zmcg), Tertiary-age bedrock of the Norwood Formation (unit Tn), Quaternary landslide and colluvial deposits (units Qms and Qmc), Quaternary alluvial-fan deposits (units Qafy and Qafp?), and Quaternary alluvium overlying lacustrine sand from late Pleistocene Lake Bonneville (unit Qafp/Qlsb).

Coogan and King (2016) describe surficial geologic units in the site area on Figure 2 as follows:

***Qh, Qh?** – Human disturbances (Historical).* Mapped disturbances obscure original deposits or rocks by cover or removal; only larger disturbances that pre-date the 1984 aerial photographs used to map the Ogden 30 x 60- minute quadrangle are shown; includes engineered fill, particularly along Interstate Highways 80 and 84, the Union Pacific Railroad, and larger dams, as well as aggregate operations, gravel pits, sewage-treatment facilities, cement plant quarries and operations, brick plant and clay pit, Defense Depot Ogden (Browning U.S. Army Reserve Center), gas and oil field operations (for example drill pads) including gas plants, and low dams along several creeks, including a breached dam on Yellow Creek.

***Qay, Qa2, Qa2?, Qa3, Qa3?, Qa4, Qa4?, Qa4-5, Qa5, Qa6** – Alluvium (Holocene and Pleistocene).* Sand, silt, clay, and gravel in stream and alluvial-fan deposits that are not close to late Pleistocene Lake Bonneville and are geographically in the Huff Creek and upper Bear River drainages; variably sorted; variably consolidated; composition depends on source area; deposits lack fan shape of Qaf and are distinguished from terraces (Qat) based on upper surface sloping toward adjacent streams from sides of drainage, or are shown where fans and terraces are too small to show separately at map scale; Qay is at to slightly above present drainages and not incised by active drainages, so is the youngest unit; generally 6 to 20 feet (2-6 m) thick.

Age-number and letter suffixes on alluvium (undivided, channel, flood plain, terrace, and fan) that is not close to late Pleistocene Lake Bonneville are relative and only apply to the local drainage, with suffix 2 being the second youngest; the relative age is queried where age uncertain, generally due to the height not fitting into the typical order of surfaces. The various numbered deposits listed, Qa2 through Qa6, are 20 to 180 feet (6-55 m) above the Bear River, Saleratus Creek, and Yellow Creek. Qa5 and Qa3? are only used in stacked units (Qa5/Tfb and Qa3?/Tfb).

***Qal, Qal1, Qal2, Qal2?** – Stream alluvium and flood-plain deposits (Holocene and uppermost Pleistocene).* Sand, silt, clay, and gravel in channels, flood plains, and terraces typically less than 16 feet (5 m) above river and stream level; moderately sorted; unconsolidated; along the same drainage Qal2 is lower than Qat2 and has likely been subject to flooding, at least prior to dam building; present in broad plains along the Bear, Ogden, and Weber Rivers and larger tributaries like Deep, Cottonwood, East Canyon, Lost, and Saleratus Creeks, along Box Elder, Heiners, and Yellow Creeks, and in narrower plains of larger tributary streams; locally includes muddy, organic overbank and oxbow lake deposits; composition depends on source area, so in back valleys typically contains many quartzite cobbles recycled from the Wasatch Formation; mostly Holocene, but deposited after regression of Lake Bonneville from the late Pleistocene Provo shoreline; width in Morgan Valley is combined flood plain of Weber River and East Canyon and Deep Creeks; 6 to 20 feet (2-6 m) thick and possibly as much as 50 feet (15 m) along Weber River and thinner in the Kaysville quadrangle; greater thicknesses (>50 feet [15 m]) are reported in Morgan Valley (Utah Division of Water Rights, well drilling database), but likely include Lake Bonneville and older Pleistocene deposits.

Suffixes 1 and 2 indicate ages where they can be separated, with 1 including active channels and 2 including low terraces 10 to 20 feet (3-6 m) above the Weber and Ogden Rivers, and the South Fork Ogden River that may have been in the flood plain prior to damming of these waterways. Qal2 queried in low terraces above Bear River, Saleratus Creek, and Dry Creek where deposits may not be in the flood plain.

***Qaf, Qafy, Qaf3, Qaf3?, Qaf4, Qaf4?, Qaf5** – Alluvial-fan deposits (Holocene and Pleistocene).* Mostly sand, silt, and gravel that is poorly bedded and poorly sorted and that is not close to late Pleistocene Lake Bonneville and is geographically in the Huff Creek and upper Bear River drainages; variably consolidated; includes debris flows, particularly in drainages and at drainage mouths (fan heads); generally less than 60 feet (18 m) thick. Qaf with no suffix used where age uncertain or for composite fans where portions of fans with multiple ages cannot be shown separately at map scale; toes of some fans have been removed by human disturbances, so their age cannot be determined.

Where possible, subdivided into relative ages, indicated by letter and number suffixes (like Qa and Qat suffixes) and relative ages only apply to the local drainage, with unit Qafy being the lowest (youngest) fans and unit 3 may or may not post-date Lake Bonneville. Relative ages of these fans are partly based on heights above present drainages at drainage-eroded edge of fan. The relative age is queried where the age is uncertain, generally due to the height not fitting into the typical order of surfaces. The various deposits listed, Qafy and Qaf3 through Qaf5, are 20 to 140 feet (6-40 m) above and west of Saleratus Creek, and also above Yellow Creek and the Bear River. Qafy fans are active, impinge on present-day floodplains, divert active streams, and overlie low terraces.

***Qac** – Alluvium and colluvium (Holocene and Pleistocene).* Unsorted to variably sorted gravel, sand, silt, and clay in variable proportions; includes stream and fan alluvium, colluvium, and, locally, mass-movement deposits too small to show at map scale; typically mapped along smaller drainages that lack flat bottoms; more extensive east of Henefer where Wasatch Formation (Tw) strata easily weather to debris that “chokes” drainages; 6 to 20 feet (2-6 m) thick. Some deposits are “perched” on benches 80 feet (25 m) and more above present-day drainages like Left Fork Heiners Creek (Heiners Creek quadrangle) and Harris Canyon (Henefer quadrangle). In the Devils Slide quadrangle, some deposits are “perched” on benches about 60 to 130 feet (18-40 m) above Quarry Cottonwood Canyon indicating the alluvium is at least partly Lake Bonneville age and older (see Qab and Qao in tables 1 and 2).

***Qmc** – Landslide and colluvial deposits, undivided (Holocene and Pleistocene).* Poorly sorted to unsorted clay- to boulder-sized material; mapped where landslide deposits are difficult to distinguish from colluvium (slope wash and soil creep) and where mapping separate, small, intermingled areas of landslide and colluvial deposits is not possible at map scale; locally includes talus and debris flow and flood deposits; typically mapped where landslides are thin (“shallow”); also mapped where the blocky or rumpled morphology that is characteristic of landslides has been diminished (“smoothed”) by slope wash and soil creep; composition depends on local sources; 6 to 40 feet (2-12 m) thick. These deposits are as unstable as other landslide units (Qms, Qmsy, Qmso).

***Qafp, Qafp?, Qafb, Qafb?, Qafpb, Qafpb?** – Lake Bonneville-age alluvial-fan deposits (upper Pleistocene).* Like undivided alluvial fans, but height above present drainages appears to be related to shorelines of Lake Bonneville and is within certain limits (see table 1); these fans are inactive, unconsolidated to weakly consolidated, and locally dissected; fans labeled Qafp and Qafb are related to the Provo (and slightly lower) and Bonneville shorelines of late Pleistocene Lake Bonneville, respectively, while unit Qafpb is used where fans may be related to the Provo or Bonneville shoreline (for example Qafpb is ~40 feet [12 m] above Lost Creek Valley), or where fans of different ages cannot be shown separately at map scale; Qafp fans typically contain well-rounded, recycled Lake Bonneville gravel and sand and are moderately well sorted; generally 10 to less than 60 feet (3-18 m) thick. Lake Bonneville-age fans are queried where relative age is uncertain (see Qaf for details); fans labeled Qafpb? are above the Bonneville shoreline and might be Qafo or like Qafm; see the note under Qao about two possible ages of older alluvium (Qao, Qato, and Qafo).

Most of the Lake Bonneville-age fans in the James Peak quadrangle are far from the Bonneville shoreline and their age is inferred from their stratigraphic relationship(s) to coeval Pinedale glacial outwash (see age equality in Table 3).

The channels (Qafp/Qdlb) on the Weber River delta and Lake Bonneville fines (Qafp on Qlfb) probably record scour and fill during the rapid drawdown of the lake as it fell from the Bonneville shoreline to the Provo shoreline.

***Qms, Qms?, Qmsy, Qmsy?, Qmso, Qmso?** – Landslide deposits (Holocene and upper and middle? Pleistocene).* Poorly sorted clay- to boulder sized material; includes slides, slumps, and locally flows and floods; generally characterized by hummocky topography, main and internal scarps, and chaotic bedding in displaced blocks; composition depends on local sources; morphology becomes more subdued with time and amount of water in material during emplacement; Qms may be in contact with Qms when landslides are different/distinct; thickness highly variable, up to about 20 to 30 feet (6-9 m) for small slides, and 80 to 100 feet (25-30 m) thick for larger landslides. Qmsy and Qmso queried where relative age uncertain; Qms queried where classification uncertain. Numerous landslides are too small to show at map scale and more detailed maps shown in the index to geologic mapping should be examined.

Qms without a suffix is mapped where the age is uncertain (though likely Holocene and/or late Pleistocene), where portions of slide complexes have different ages but cannot be shown separately at map scale, or where boundaries between slides of different ages are not distinct. Estimated time of emplacement is indicated by relative-age letter suffixes with: Qmsy mapped where landslides deflect streams or failures are in Lake Bonneville deposits, and scarps are variably vegetated; Qmso typically mapped where deposits are “perched” above present drainages, rumpled morphology typical of mass movements has been diminished, and/or younger surficial deposits cover or cut Qmso. Lower perched Qmso deposits are at Qao heights above drainages (95 ka and older) and the higher perched deposits may correlate with high level alluvium (QTa_) (likely older than 780 ka) (see table 1). Suffixes y and o indicate probable Holocene and Pleistocene ages, respectively, with all

Qmso likely emplaced before Lake Bonneville transgression. These older deposits are as unstable as other slides, and are easily reactivated with the addition of water, be it irrigation or septic tank drain fields.

Qls, Qls?, Qlsp, Qlsb, Qlsb? *– Lake Bonneville sand (upper Pleistocene).* Mostly sand with some silt and gravel deposited nearshore below and near the Provo shoreline (Qlsp) and between the Provo and Bonneville shorelines (Qlsb); Qls mapped downslope from slope break below Provo shoreline beach deposits where thin Lake Bonneville regressional sand may overlie transgressional sand; grades downslope into unit Qlf with decreasing sand content and laterally with more gravel into units Qdlp, Qdlb, and upslope with more gravel into unit Qlgb; Qls and Qlsb queried where grain size or unit identification uncertain; may be as much as 75 feet (25 m) thick, and thickest near Ogden; typically less than 20 feet (6 m) thick in Morgan Valley; may include small deltas and deltas that lack typical delta shape.

Qadb, Qadb? *– Transgressive and Bonneville-shoreline alluvial and deltaic deposits (upper Pleistocene).* Cobbly gravel, sand, silt, and clay deposited above (subaerial) and in Lake Bonneville (subaqueous); typically mapped where shorelines are obscure, so that line cannot be drawn between alluvial fan and delta; include rounded to subangular clasts in a matrix of sand and silt with interbeds of sand and silt; mapped above the Provo shoreline and deposited as lake transgressed to and was at the Bonneville shoreline; typically better sorted delta and lake deposits over poorly sorted alluvial-fan deposits; Qadb prominent along Deep Creek (Morgan quadrangle) and Strawberry Creek (Snow Basin quadrangle); 0 to at least 40 feet (0-12+ m) thick.

Note that the Bonneville-shoreline fan-delta unit (Qadb), at 80 to 100 feet (24-30 m) above present drainages, is typically higher than the related alluvial units (Qab, Qafb) (see table 1). A fan-delta is built when an alluvial fan enters a lake or ocean, and includes both the fan and the delta.

Qla, Qla? *– Lake Bonneville lacustrine deposits and post- and pre-Lake Bonneville alluvial deposits, undivided (Holocene and upper? Pleistocene).* Mostly poorly sorted and poorly bedded sand, silt, and clay, with some gravel; mapped where Lake Bonneville deposits are reworked by later stream action or covered by thin stream and fan deposits, and where lake deposits are thin and overlie older alluvial deposits; unit queried where may be dominantly alluvium; deposits typically eroded from shallow Norwood Formation; mostly mapped near Bonneville shoreline; also mapped in Peterson quadrangle along upper Deep Creek above Bonneville shoreline where lake deposits seem to indicate landslide dam of creek; thickness uncertain.

Qao, Qao? *– Older alluvium (mostly upper Pleistocene).* Sand, silt, clay, and gravel above and likely older than the Bonneville shoreline; mapped on surfaces above Lake Bonneville-age alluvium (Qap, Qab, Qapb); deposits lack fan shape (Qaf) and are distinguished from terraces (Qat) based on upper surface sloping toward adjacent streams from sides of drainage; also shown where areas of fans and terraces are too small to show separately at map scale; composition depends on source area; at least locally up to 110 feet (34 m) thick. Queried where classification or relative age is uncertain (see Qa for details); for example near head of Saleratus Creek.

Qafo, Qafo? *– Older alluvial-fan deposits (mostly upper Pleistocene).* Incised and at least locally dissected fans of mostly sand, silt, and gravel that is poorly bedded and poorly sorted; includes debris flows, particularly in drainages and at drainage mouths (fan heads); older fans are typically above the Bonneville shoreline, with an eroded bench at the shoreline; upstream and above the Bonneville shoreline, unit Qafo is topographically higher than fans graded to the Bonneville shoreline (Qafb), and is typically dissected; generally less than 60 feet (18 m) thick. In Mantua Valley, exposed thickness up to about 100 feet (30 m), but water wells (sections 26 and 27, T. 9 N., R. 1 W.) were still in gravelly to bouldery valley fill at depths of 505 and 467 feet (154 and 142 m), respectively, and red coloration that may indicate Wasatch Formation bedrock was not noted (see Bjorklund and McGreevy, 1973, p. 16).

Qafo queried where relative age is uncertain (see Qaf for details), for example in Mantua quadrangle where it is as high as Qafoe in Morgan Valley (see table 1). Qafo queried in East Canyon graben because the deposits are not dissected and some deposits mantle Qafoe (see also unit Qafm above), resulting in a reversal of relative height and only local incision. These irregular deposits are likely the result of salt movement in the East Canyon graben. Our Qafo is roughly shown to south by Bryant (1990) as Qgp (pediment gravel); farther south he showed Qoa (dissected alluvium) adjacent to the East Canyon fault, which may be the QTaf or Qafoe we mapped.

Amino-acid age estimates presented in Sullivan and Nelson (1992) imply Qafo north of Morgan considerably predates Lake Bonneville and is middle Pleistocene in age (>400 ka). However, the Bonneville shoreline is obscure on this fan, and soil-carbonate age estimates (>70-100 ka) and other amino-acid age estimates (~98-155 ka) in Sullivan and others (1988) imply these older fans are related to Bull Lake glaciation (95,000 to 130,000 years old; see Chadwick and others, 1997; Phillips and others, 1997). As noted under Qao, Qafo deposits may contain two ages (levels) of alluvial surfaces that are not easily recognized in Morgan Valley but are recognized upstream in the Henefer and Lost Creek Valleys (Devils Slide quadrangle) and along the North and South Forks of Ogden River.

Tn, Tn? *– Norwood Formation (lower Oligocene and upper Eocene).* Typically light-gray to light-brown altered tuff (claystone), altered tuffaceous siltstone and sandstone, and conglomerate; unaltered tuff, present in type section south of Morgan, is rare; locally colored light shades of red and green; variable calcareous cement and zeolitization; involved in numerous landslides of various sizes; estimate 2000-foot (600 m) thick in exposures on west side of Ogden Valley (based on bedding dip, outcrop width, and topography). Norwood Formation queried where poor exposures may actually be surficial deposits. For detailed Norwood Formation information see description under heading "Sub-Willard Thrust - Ogden Canyon Area" since most of this unit is in and near Morgan Valley and covers the Willard thrust, Ogden Canyon, and Durst Mountain areas.

Zmcc, Zmcc?, Zmcc1, Zmcc1?, Zmcc2, Zmcc2?, Zmcc3, Zmcc3? *– Maple Canyon Formation, upper (conglomerate) member (Neoproterozoic).* At top (Zmcc3) and bottom (Zmcc1), light-gray coarse-grained, quartzite to pebble and small cobble meta-conglomerate with local tan-weathering, dark gray, meta-graywacke matrix; thin olive-gray, laminated, weakly resistant argillite in middle (Zmcc2); to 500 feet (20-150 m) total thickness; thickness of sub-units varies considerably and these sub-units may be absent locally; conglomerate beds appear thickest in northeast part of Huntsville quadrangle, possibly more than 200 feet (60 m) thick, while middle argillite appears less than 50 feet (15 m) thick; only divided into subunits to show structure in Huntsville quadrangle.

***Zmcg, Zmcg?** – Maple Canyon Formation, Lower (green arkose) member (Neoproterozoic).* Grayish-green, fine-grained arkosic (feldspathic) meta-sandstone and sandy argillite (meta-graywacke), with local quartzite lenses up to 200 feet (60 m) thick; weathers darker gray to brown to greenish-gray and greenish-brown; 500 to 1000 feet (150-305 m) thick and lower thickness would eliminate the need for faulting in southwest part of Huntsville quadrangle. This unit is prone to slope failures.

***Zarx** – Argillite of lower member of Maple Canyon Formation or upper member of Formation of Perry Canyon (Proterozoic).* Greenish-gray argillite to meta-graywacke in poor exposures on east side of Ogden Valley (Zarx and Qdlb/Zarx) and on dip slope west of Ogden Valley; weathering, lack of bedding, and lack of exposures of overlying conglomerate member of Maple Canyon preclude separation of these stratigraphically adjacent units. This unit is prone to slope failures.

***Zpu, Zpu?** – Formation of Perry Canyon, Upper member (Neoproterozoic).* Olive drab to gray, thin-bedded slate to argillite to phyllite to micaceous meta-siltstone to meta-graywacke to meta-sandstone in variable proportions such that unit looks like both the "greywacke-sandstone" and "mudstone" members of previous workers; unit identification based on underlying diamictite in Mantua quadrangle; rare meta-gritstone and meta-diamictite (actually conglomerate?); locally schistose; meta-sandstone contains poorly sorted lithic, quartz, and feldspar grains in silty to micaceous matrix; meta-sandstone is quartzose in outcrops on west margin of Mantua quadrangle (Crittenden and Sorensen, 1985a) and medial zone of sandstone is feldspathic east of Ogden Valley, where mapped and described as argillite member of Maple Canyon Formation by Crittenden (1972) and Sorensen and Crittenden (1979); thickness uncertain, but appears to be about 600 feet (180 m) thick on west flank of Grizzly Peak in the Mantua quadrangle and about 1000 feet (300 m) thick between Ogden Canyon and North Ogden divide. In Ogden Valley typically non-resistant and tan weathering such that gray to green to dark-gray fresh color is seldom seen except in cut slopes and excavations. This unit is prone to slope failures.

Citations, tables, and figures above are not provided herein, but are in Coogan and King (2016).

5.2 Seismotectonic Setting

The property is located at the western margin of Ogden Valley, a roughly 40-square mile back valley described by Gilbert (1928) as a structural trough similar to Cache and Morgan Valleys to the north and south, respectively. The back valleys of the northern Wasatch Range are in a transition zone between the Basin and Range and Middle Rocky Mountains physiographic provinces (Stokes, 1977, 1986). The Basin and Range 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 marked by the Wasatch fault zone at the base of the Wasatch Range. Late Cenozoic normal faulting, a characteristic of the Basin and Range, began between about 17 and 10 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 back valleys are morphologically similar to valleys in the Basin and Range, but exhibit less structural relief (Sullivan and others 1986).

Ogden Valley occupies a structural trough created by up to 2,000 feet of vertical displacement on normal faults bounding the east and west sides of the valley. The Ogden Valley southwestern margin fault (aka West Ogden Valley fault; Black and others, 2003) is shown on Figure 2 (dotted line) trending northwestward across the northwestern part of the site. Sullivan and others (1986) indicate the most recent movement on this fault is pre-Holocene, and Western Geologic (2006) similarly found no evidence for active (Holocene) faulting in one trench across the presumed fault location a few hundred feet south of the Project.

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 7.5 event in 1959 near Hebgen Lake, Montana. 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 event was the 1934 Hansel Valley (M 6.6) event north of the Great Salt Lake. The March 18, 2020 M 5.7 earthquake north of Magna, Utah reportedly showed a style, location, and slip depth consistent with an earthquake on the Wasatch fault system (https://earthquake.usgs.gov/earthquakes/eventpage/uu60363602/executive). Despite being moderate in size (less than magnitude 6.0), this earthquake was felt from southern Idaho to south-central Utah and caused serious damage to multiple buildings (https://www.ksl.com/article/46731630/).

5.3 Lake Bonneville History

Lakes occupied nearly 100 basins in the western United States during late-Quaternary time, the largest of which was Lake Bonneville in northwestern Utah. The Bonneville basin consists of several topographically closed basins created by regional extension in the Basin and Range (Gwynn, 1980; Miller, 1990), and has been an area of internal drainage for much of the past 15 million years. Lake Bonneville consisted of numerous topographically closed basins, including the Salt Lake and Cache Valleys (Oviatt and others, 1992). Sediments from Lake Bonneville comprise much of the unconsolidated deposits in the site vicinity.

Timing of events related to the transgression and regression of Lake Bonneville are indicated in Oviatt (2015). Approximately 30,000 years ago, Lake Bonneville began a slow transgression (rise) to its highest level of 5,160 to 5,200 feet above mean sea level. The lake rise eventually slowed as water levels approached an external basin threshold in northern Cache Valley at Red Rock Pass near Zenda, Idaho. Lake Bonneville reached the Red Rock Pass threshold and occupied its highest shoreline, termed the Bonneville beach, around 18,000 years ago. Headward erosion of the Snake River-Bonneville basin drainage divide, possibly combined with landsliding in the threshold area, then caused a catastrophic incision that caused the lake level to lower by about 425 feet in less than a year (Jarrett and Malde, 1987; O'Conner, 1993). Following the Bonneville flood, the lake stabilized and formed a lower shoreline referred to as the Provo shoreline up to about 16,000 years ago. Climatic factors then caused the lake to regress rapidly from the Provo shoreline, and by about 13,000 years ago the lake had eventually dropped below historic levels of Great Salt Lake. Oviatt and others (1992) deem this low stage the end of the Bonneville lake cycle. Great Salt Lake then experienced a brief transgression between 12,800 and 11,600 years ago to the Gilbert level at about 4,250 feet before receding to and remaining within about 20 feet of its historic average level (Lund, 1990; Oviatt, 2015). The highest Bonneville shoreline is not mapped in the area on Figure 2, but the Project straddles the presumed shoreline elevation (5,160 to 5,200 feet).

6.0 SITE CHARACTERIZATION

6.1 Empirical Observations

On April 15-17, 2020, Mr. Bill D. Black of Western Geologic conducted a reconnaissance of the property to observe geomorphic and surficial conditions. The reconnaissance was conducted in conjunction with the subsurface exploration. Weather varied from cloudy with rain and snow to clear and sunny; temperatures were in the 40s to 50s (°F).

The site is on the western margin of Ogden Valley on slopes overlooking Pineview Reservoir. Native vegetation consists mainly of heavy oak brush with scattered pine trees; interspersed meadow areas are vegetated by sage brush and grasses. An unnamed drainage crosses the northern half of the property and flows eastward into Pineview Reservoir (Figure 1). The creek was flowing at the time of our investigation (in April), although we are uncertain if it is perennial or intermittent. Several smaller ephemeral feeder drainages also flow across portions of the property and into this creek that were all dry at the time of our investigation. An area of thistles associated with cut-bank seepage was observed north and slightly above the floodplain east of where the creek is routed beneath Whispering Pines Lane. The creek bottom appeared heavily vegetated with brush and mature trees. Except for jackstrawed trees in some areas, no other characteristic debris-flow features (such as debris flow levees) were observed along the creek. Three discrete Holocene or historical landslides were observed at the Project: (1) south of the intersection of Whispering Pines Lane and Valley View Drive, which was reportedly a reactivation of an existing landslide caused by road cutting; (2) about 50 feet east of TP-4 for our investigation in the north-facing slopes bounding the creek floodplain; and (3) at the base of the steep slopes in the northwest part of the Project. The latter failure was the largest of the three and showed considerable water runoff from the toe area. No other evidence for geologic hazards was observed at the site during the site reconnaissance.

6.2 Air Photo Observations

Color orthophotography from 2012 and bare earth DEM LIDAR imagery from 2011 (Figures 3A-3B) were reviewed to obtain information about the geomorphology of the Project area. Site-specific surficial geologic mapping is shown on Figure 3C based on our empirical observations, air photo interpretation, and mapping in Coogan and King (2016; Figure 2). The Ogden Valley southwestern margin fault crosses the western side of the Project, but is generally concealed except for a short section corresponding to an east-facing scarp in a stranded alluvial fan that predates or is contemporaneous with Lake Bonneville. The alluvial fan was subsequently downcut and stranded by the creek after Lake Bonneville retreated from Ogden Valley; the only remnants are south of the creek and further west overlooking Pineview Reservoir. Three landslides are evident at the Project as noted in the Empirical Observations section above and shown on Figures 3A-C. Figure 3B shows a slope gradient map from geoprocessed LIDAR data at gradient intervals of <15% (unshaded), 15-25% (in yellow) and >25% (in red). Steep slopes are found mainly in the western part of the Project and bordering the creek. No evidence for other geologic hazards was observed on the air photos at the site or in the area.

6.3 Subsurface Investigation

Six test pits were previously excavated at the Project by Western Geologic (2006), including TP-1, TP-2, TP-3, TP-7, TP-8, and TP-9 as located on Figures 3A-C. These test pits were logged as measured sections and reportedly exposed:

- TP-1: Suspected landslide colluvium comprised of clayey sand (SC), overlying a block of Norwood Formation claystone;

- TP-2: Holocene alluvium/colluvium comprised of gravelly sand (SW), overlying late Pleistocene alluvium/colluvium comprised of sandy gravel to gravelly sand (GW/SW) with rounded to angular cobbles and boulders;

- TP-3: Holocene alluvium/colluvium comprised of clayey sand with gravel (SC), overlying late Pleistocene alluvium comprised of iron-oxide stained clayey sand to sandy clay (SC/CL);

- TP-7: Late Pleistocene to Holocene alluvium comprised of lean clay (CL) with trace silt, gravel and sand, overlying tuffaceous siltstone and sandstone of the Norwood Formation;

- TP-8: Holocene alluvium comprised of gravelly sand (SW) with cobbles; and

- TP-9: Holocene alluvium comprised of sandy clay (CL) with basal cobbles, overlying weathered tuffaceous sandstone of the Norwood Formation.

Fifteen onsite walk-in test pits and two offsite test pits (near the proposed water tank location further west) were also excavated at the Project on April 15-17 to assess subsurface conditions. The test pits were logged by Bill D. Black, P.G. of Western Geologic concurrently with the Project geotechnical investigation conducted by Christensen Geotechnical. Locations of the test pits are shown on Figures 3A-C. The test pit locations were measured using a hand-held GPS unit and by trend and distance methods. The test pits were logged at a scale of 1-inch equals five feet (1:60) following methodology in McAlpin (1996), and digitally photographed at 5-foot intervals to document the exposures. The photos are not provided herein, but are available on request. Logs of the test pits are provided on Figure 4A-I. Stratigraphic interpretations and descriptions are provided on the logs. Groundwater was observed at depths of from 6.8 feet to 10.3 feet bgs in TP-3, TP-5, TP-11, TP-14, TP-15, and TP-17, but was not observed in the remaining test pits to their explored depths (Figures 4B, 4C, and 4F-I). Groundwater depths encountered in the test pits are indicated on Figures 3A-C.

6.4 Cross Sections

Figures 5 through 7 show three cross sections (A-A’, B-B’, and C-C’) across the site as located on Figures 3A-C. Figures 5 and 6 are at a scale of 1 inch equals 50 feet and Figure 7 is at a scale of 1 inch equals 100 feet, with no vertical exaggeration. Units and contacts are based on subsurface data from the test pits (Figures 4A-I) and/or inferred from the geologic mapping on Figure 3C. The topographic profiles are based on geoprocessed 2011 LIDAR data. The LIDAR data provides a snapshot of topographic conditions at the time it was acquired; past, present and future surficial topography may vary. Units and contacts should be considered approximate and inferred, and variations should be expected at depth and laterally. We caution that some portions of the cross sections have limited or no subsurface data. Inferred groundwater levels are shown on the cross sections based on depths encountered in the test pits. Based on our test pit exposures, groundwater at the Project is generally from 10 to 30 feet deep, but appears to be locally less than 10 feet bgs along the unnamed creek and to the north along the range front base.

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. Table 1 below shows a summary of the geologic hazards reviewed at the site, as well as a relative (qualitative) assessment of risk to the Project for each hazard. A "high" hazard rating (H) indicates a hazard is present at the site (whether currently or in the geologic past) that is likely to pose significant risk and/or may require further study or mitigation techniques. A "moderate" hazard rating (M) indicates a hazard that poses an equivocal risk. Moderate-risk hazards may also require further studies or mitigation. A "low" hazard rating (L) indicates the hazard is not present, poses little or no risk, and/or is not likely to significantly impact the Project. Low-risk hazards typically require no additional studies or mitigation. We note that these hazard ratings represent a conservative assessment for the entire site and risk may vary in some areas. Careful selection of development areas can minimize risk by avoiding known hazard areas.

Table 1. *Geologic hazards summary.*

Hazard	H	M	L
Earthquake Ground Shaking	X		
Surface Fault Rupture			X
Liquefaction and Lateral-spread Ground Failure			X
Tectonic Deformation			X
Seismic Seiche and Storm Surge			X
Stream Flooding		X	
Shallow Groundwater		X	
Landslides and Slope Failures	X		
Debris Flows and Floods		X	
Rock Fall			X
Problem Soil and Rock		X	

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. The Utah Geological Survey Quaternary Fault Database (Black and others, 2003; January 2017 update) shows numerous class A faults within 60 miles of the Project that may pose potential seismic sources.

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. Based on

2018 IBC provisions, a site class of D (stiff soil), and a risk category of II, calculated seismic values for the site (centered on 41.279552° N, -111. 828006° W) are summarized below:

Table 2. *Seismic hazards summary.*

Type	Value
S_S	*0.942 g*
S_1	*0.335 g*
S_{MS} (F_a x S_S)	*1.058 g*
S_{M1} (F_v x S_1)	*See ASCE 7-16 Section 11.4.8*
S_{DS} (2/3 x S_{MS})	*0.705 g*
S_{D1} (2/3 x S_{M1})	*See ASCE 7-16 Section 11.4.8*
Site Coefficient, F_a	*= 1.123*
Site Coefficient, F_v	*See ASCE 7-16 Section 11.4.8*
Peak Ground Acceleration, PGA	*= 0.418 g*

The site class should be confirmed by the Project geotechnical engineer based on site-specific data. Given the above information, earthquake ground shaking poses a high risk to the site. Earthquake ground shaking is a regional hazard common to all Wasatch Front areas. The hazard is mitigated by design and construction in accordance with the current adopted building code. We note that IBC 2018 provisions require calculation of the spectral acceleration value (S_{M1}), seismic design value (S_{D1}), and site coefficient (F_v) differently from IBC 2015. In municipalities where IBC 2018 has been adopted, the Project engineer or architect should determine these seismic values in accordance with ASCE 7-16 Section 11.4.8 guidelines.

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 as a large singular rupture or several smaller ruptures in a broad zone. Ground displacement from surface fault rupture can cause significant damage or even collapse to structures located on an active fault.

The Ogden Valley southwestern margin fault (Black and others, 2003) crosses the western part of the Project (Figures 3A-C). The U.S. Geological Survey Quaternary Fault and Fold Database of the United States indicates this structure is a class A, northeast-dipping normal fault with an overall length of 17 kilometers and average strike of N16°W. The most-recent movement on this fault is believed to be middle to late Quaternary. The fault is concealed beneath unfaulted Holocene-age sediments and Western Geologic (2006) found no evidence for active (Holocene-age) faulting in one trench excavated across the presumed fault location a few hundred feet south of the Project. The nearest active fault to the Project is the Weber section of the Wasatch fault zone 5.7 miles to the west (Black and others, 2003).

Given all the above, we rate the risk from surface faulting as low. No additional investigation regarding surface faulting appears needed given the proposed development plan and current paleoseismic information.

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 accelerations (earthquake ground shaking), groundwater conditions, and presence of susceptible soils.

Given subsurface soil conditions observed in the test pits at the site, we do not believe significant areas of sandy soils susceptible to liquefaction are present underlying the site. Weber County GIS mapping also shows the site is in an area of very low liquefaction potential (code 1). Based on this, we rate the risk from liquefaction as low.

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 active normal faults.

The Project is not in close proximity to and on the downthrown side of any mapped active (Holocene) faults. Based on this, we rate the risk from tectonic subsidence as low.

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, we rate the risk from seismic seiches as low.

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.

An unnamed drainage crosses the northern half of the property and flows eastward into Pineview Reservoir (Figure 1). The creek was flowing at the time of our investigation (in April), although we are uncertain if it is perennial or intermittent. Several smaller ephemeral feeder drainages also flow across portions of the property and into this creek that were all dry at the time of our investigation. Federal Emergency Management Agency flood insurance rate mapping (Map Number 49057C0237F, effective 06/02/2015; and Map Number 49057C0239E, effective 12/16/2005) classify the northern part of the Project in "Zone X" (areas of minimal flood hazards) and the southern part in "Zone D" (areas where there are possible but undetermined flood hazards). In areas designated as Zone D, no analysis of flood hazards has been conducted.

Given the above, we rate the risk from stream flooding as moderate. Although seasonal and flash flooding may occur in areas adjacent to the unnamed creek, the current development plan designates this area as open space. The risk would therefore be lower. The hazard from stream flooding should be addressed in the civil engineering design for the development in accordance with all Weber County guidelines. Care should be taken that proper surface drainage is maintained.

7.7 Shallow Groundwater

As discussed Sections 4.0 and 6.3 above, groundwater was observed at depths of from 6.8 feet to 10.3 feet bgs in TP-3, TP-5, TP-11, TP-14, TP-15, and TP-17, but was not observed in the remaining test pits to their explored depths (Figures 4B, 4C, and 4F-I). Groundwater depths encountered in the test pits are indicated on Figures 3A-C. Based on this, we anticipate that groundwater at the Project is generally from 10 to 30 feet deep, but appears to be locally shallower than 10 feet bgs along the unnamed creek and further north along the range front base. Groundwater depths at the site likely vary seasonally from snowmelt runoff and annually from climatic fluctuations. Such variations would be typical for an alpine environment. Perched conditions above less-permeable, clay-rich bedrock layers may also be present in the subsurface that could cause locally shallower groundwater levels.

Given the above, we rate the risk from shallow groundwater as moderate. Care should be taken that proper subsurface drainage is maintained. Foundation and site subsurface drainage should be addressed in the Project geotechnical engineering evaluation.

7.8 Landslides 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 groundwater 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.

Landslide colluvium and/or landslide-prone bedrock is mapped underlying most of the site, three discrete landslides were observed at the Project (as mapped on Figures 3A-C), and steep slopes are at the site that may be prone to instability. We therefore rate the risk from landslides and slope instability as high, although this risk likely lessens with increasing distance eastward from the range front and from the downcut slopes bordering the unnamed creek.

Given the above, we recommend that slope stability be evaluated by the Project geotechnical engineer based on site-specific soil conditions and the data provided in this report. Recommendations should be provided to reduce the landslide hazard risk if factors of safety are determined to be unsuitable. Water, steep man-made cuts, and non-engineered fill materials are often major contributors to slope instability. Care should therefore also be taken to maintain proper site drainage, that site grading does not destabilize slopes at the site without prior geotechnical analysis and grading plans, and that water from man-made sources is minimized in potentially unstable slope areas.

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. Debris flows have historically significant damage in the Wasatch Front area. As discussed in Section 6.1, jackstrawed trees suggestive of possible sediment and water transport from debris flow/flood events were observed in the floodplain of the unnamed creek. However, no other evidence of characteristic debris flows features was observed in the creek floodplain and the test pits showed no deposits believed to be from past debris flows and floods.

Given the above, we rate the risk from debris flows/floods as moderate. Although debris flows and floods may occur in areas adjacent to the unnamed creek, the current development plan designates this area as open space. Given this, the risk would be lower. Care should be taken in the civil engineering design for the development that creek culverts are designed to handle peak flows and possible debris so that they do not become choke points.

7.10 Rock Fall

No significant bedrock outcrops are at the site or in adjacent higher slopes that could present a source area for rock fall clasts, and no boulders likely from rock falls were observed at the site. Based on the above, we rate the hazard from rock falls as low.

7.11 Problem Soil and Rock

Surficial soils that contain certain clays can swell or collapse when wet. Clay-rich soils were observed in the test pits at the Project that could be susceptible to a degree of swell from water adsorption. Given the above, we rate the risk from problem soil as moderate. Soil conditions and specific recommendations for site grading, subgrade preparation, and footing and foundation design should be provided in the Project geotechnical engineering evaluation.

8.0 CONCLUSIONS AND RECOMMENDATIONS

Earthquake ground shaking and landslides are identified as posing a high relative risk to the proposed development. Shallow groundwater, stream flooding and debris flows/floods, and problem soil are identified as posing a moderate risk. The following recommendations are provided with regard to the geologic characterizations in this report:

- ***Seismic Design*** – All habitable structures developed at the property should be constructed to current adopted seismic building codes to reduce the risk of damage, injury, or loss of life from earthquake ground shaking. The Project geotechnical engineer should confirm the ground-shaking hazard and provide appropriate seismic design parameters as needed. We note that earthquake ground shaking is a common hazard for all Wasatch Front areas.

- ***Geotechnical Evaluation*** – A design-level geotechnical engineering study should be conducted prior to construction to assess soil foundation conditions, provide recommendations regarding subsurface drainage, and evaluate slope stability. The stability evaluation should be based on geologic characterizations in this report and site-specific geotechnical data, and provide recommendations for reducing the risk of landsliding if the factors of safety are deemed unsuitable.

- ***Site Modifications and Drainage*** – No unplanned cuts should be made in the slopes at the site without prior geotechnical analyses, and proper surface and subsurface drainage should be maintained.

- ***Civil Engineering Design*** – If areas along the unnamed creek will be developed, we recommend that seasonal stream and flash floods be addressed in the civil engineering design in accordance with all Weber County guidelines. Care should also be taken that creek culverts are designed to handle peak flows and possible sediment and debris so that they do not become overflow choke points.

- ***Excavation Backfill Considerations*** – The test pits may be in areas where a structure could subsequently be placed. However, backfill may not have been replaced in the excavations in compacted layers. The fill could settle with time and upon saturation. Should structures be located in an excavated area, no footings or structure should be founded over the excavation unless the backfill has been removed and replaced with structural fill.

- ***Hazard Disclosures and Report Availability*** – All hazards identified as posing a high risk at the site should be disclosed to future buyers so that they may understand and be willing to accept any potential developmental challenges and/or risks posed by these hazards. This report should be made available to architects, building contractors, and in the event of a future property sale, real estate agents and potential buyers. The report should be referenced for information on technical data only as interpreted from observations and not as a warranty of conditions throughout the site. The report should be submitted in its entirety, or referenced appropriately, as part of any document submittal to a government agency responsible for planning decisions or geologic review. Incomplete submittals void the professional seals and signatures we provide herein. Although this report and the data herein are the property of the client, the report format is the intellectual property of Western Geologic and should not be copied, used, or modified without express permission of the authors.

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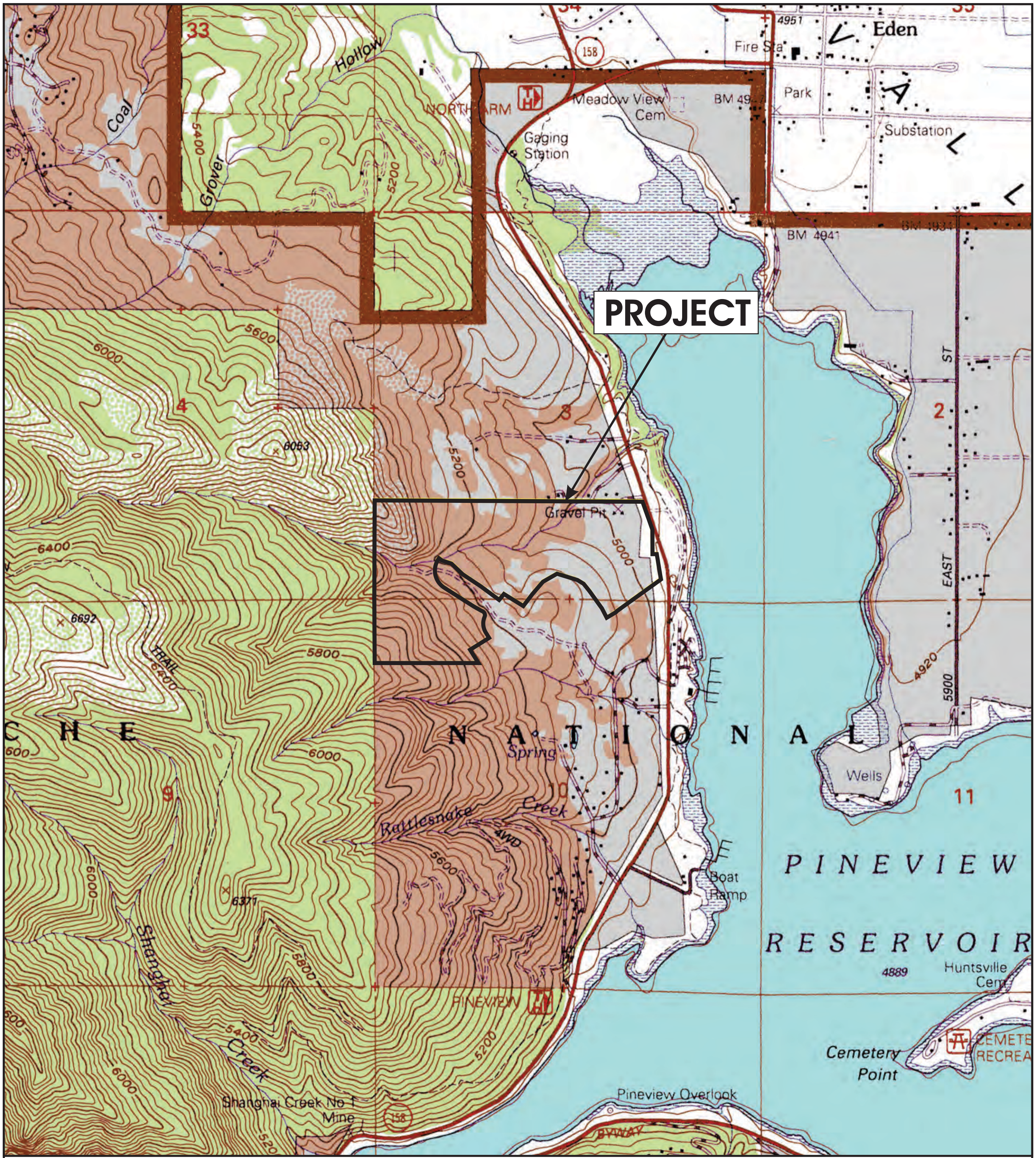
FIGURES



Source: U.S. Geological Survey 7.5 Minute Series Topographic Maps, Utah - Huntsville, 1998;
Project location S1/2 Section 8 and N1/2 Section 10, T6N, R1E (SLBM).

LOCATION MAP

GEOLOGIC HAZARDS EVALUATION

Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

FIGURE 1

WESTERN GEOLOGIC

N
W E
S

0 1000 2000 feet

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

Source: Coogan and King (2016), original map scale 1:100,000.
See text for explanation of nearby surficial geologic units.

GEOLOGIC MAP

GEOLOGIC HAZARDS EVALUATION

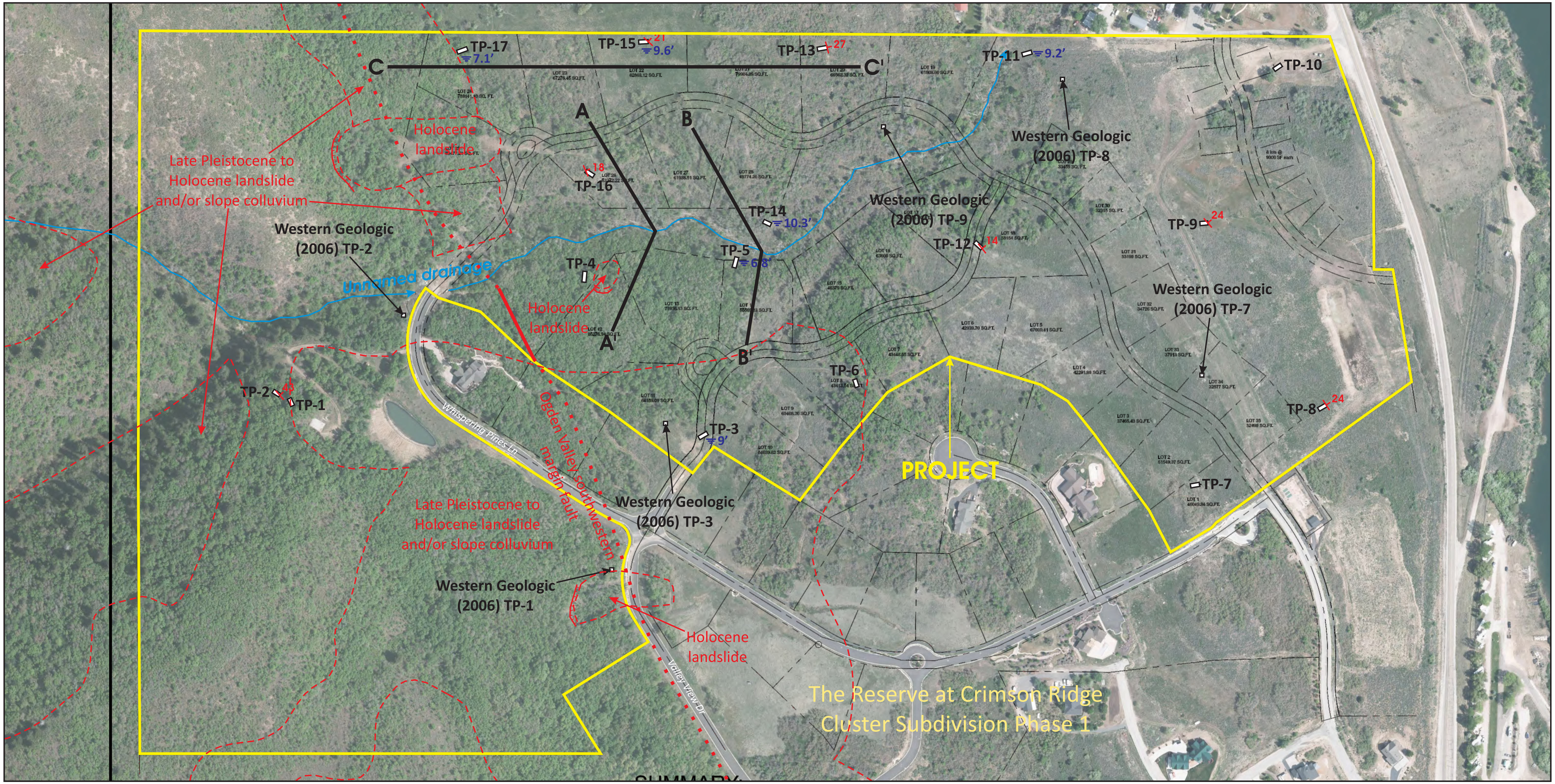
Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

FIGURE 2

WESTERN GEOLOGIC

0 1000 2000 feet

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



Source: Gardner Engineering Concept Map dated 9/20/19 and 2012 high-resolution orthophoto available from Utah AGRC.

N
W E
S

0 300 600 feet
Scale 1:3,600 (1 inch equals 300 feet)

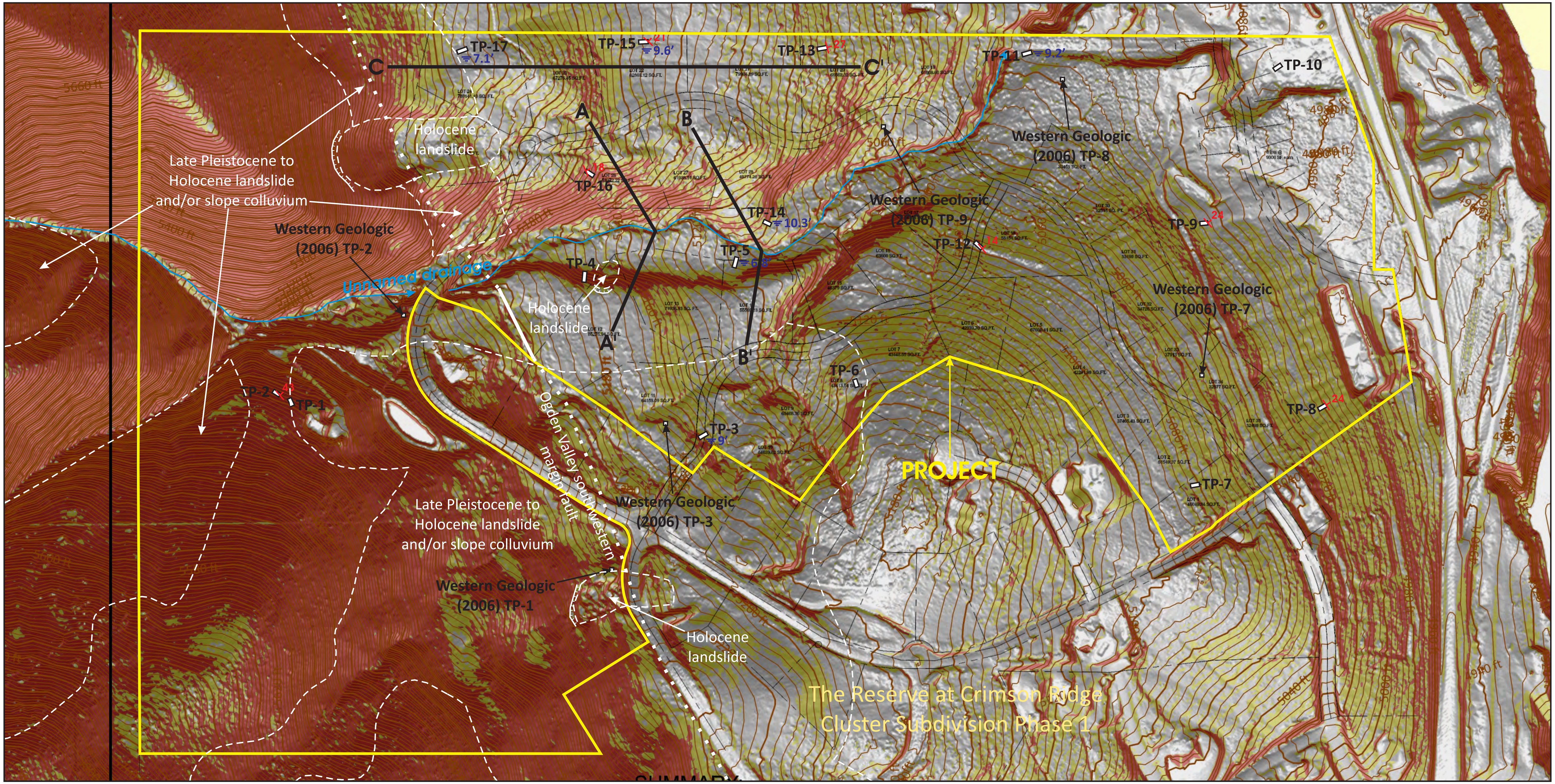
WESTERN GEOLOGIC

2012 AIR PHOTO

GEOLOGIC HAZARDS EVALUATION

Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

FIGURE 3A



Source: Gardner Engineering Concept Map dated 9/20/19 and 2011 geoprocessed LIDAR data available from Utah AGRC; contours generated by Global Mapper, 4-foot interval. Slope steepness <15% unshaded , 15-25% in yellow and >25% in red.

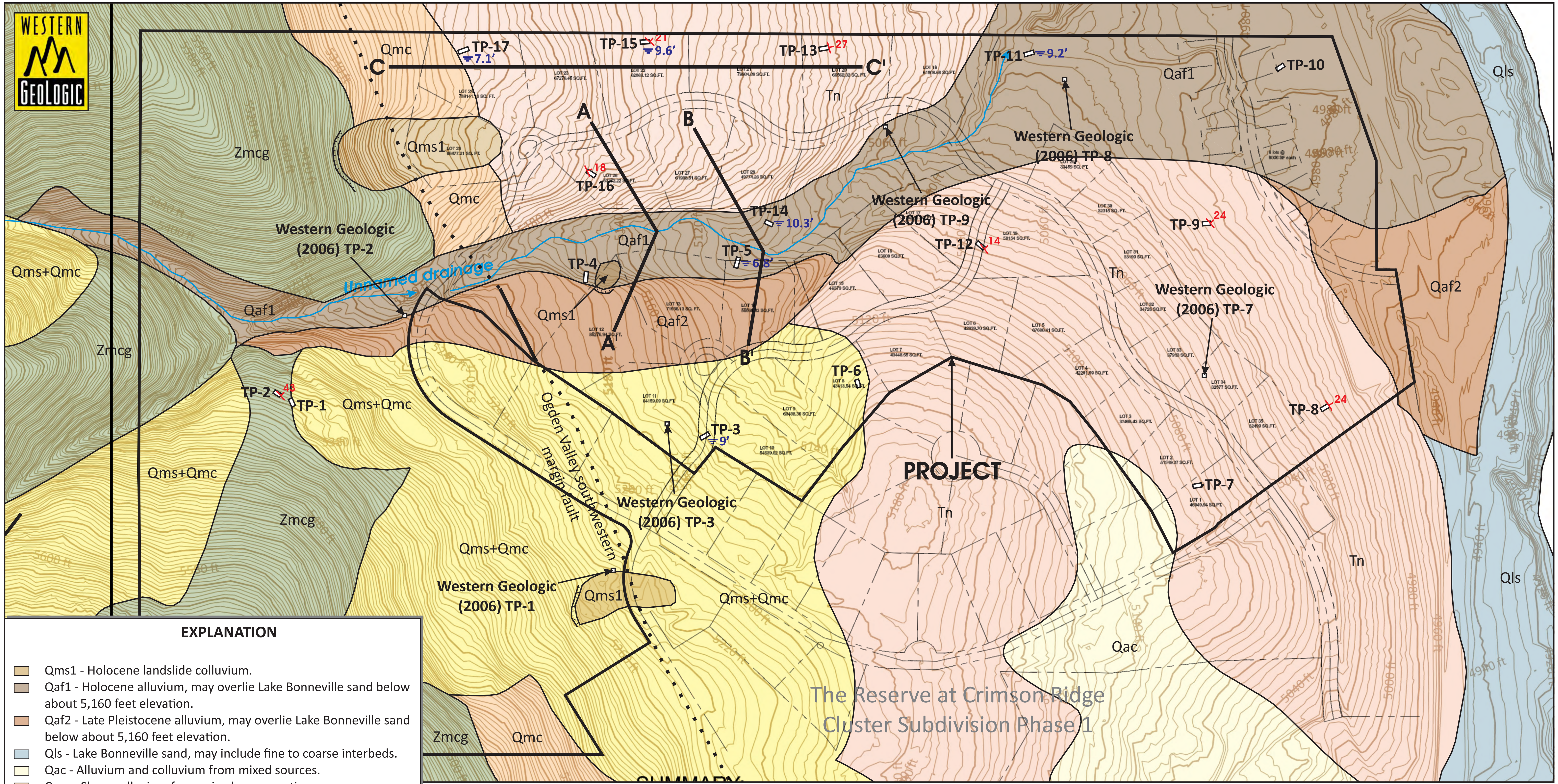
N
W E
S

0 300 600 feet
Scale 1:3,600 (1 inch equals 300 feet)

2011 LIDAR IMAGE

GEOLOGIC HAZARDS EVALUATION
Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

FIGURE 3B



EXPLANATION

▨ Qms1 - Holocene landslide colluvium.

▨ Qaf1 - Holocene alluvium, may overlie Lake Bonneville sand below about 5,160 feet elevation.

▨ Qaf2 - Late Pleistocene alluvium, may overlie Lake Bonneville sand below about 5,160 feet elevation.

▨ Qls - Lake Bonneville sand, may include fine to coarse interbeds.

▨ Qac - Alluvium and colluvium from mixed sources.

▨ Qmc - Slope colluvium from mixed mass wasting sources.

▨ Qms+Qmc - Undifferentiated landslides and slope colluvium.

▨ Tn - Tertiary Norwood Formation and surficial alluvium/colluvium.

▨ Zmcg - Precambrian Maple Canyon Formation.

Quaternary (pre-Holocene age) fault, dotted where concealed.

Landslide scarp.

9' Groundwater and depth below the ground surface.

18 Strike/dip.

Source: Gardner Engineering Concept Map dated 9/20/19; surficial geology modified from Coogan and King (2016) based on field observations, air photo evidence and subsurface data; contours generated by Global Mapper from 2011 geoprocessed LIDAR data, 4-foot interval.

N W E S

0 300 600 feet

Scale 1:3,600 (1 inch equals 300 feet)

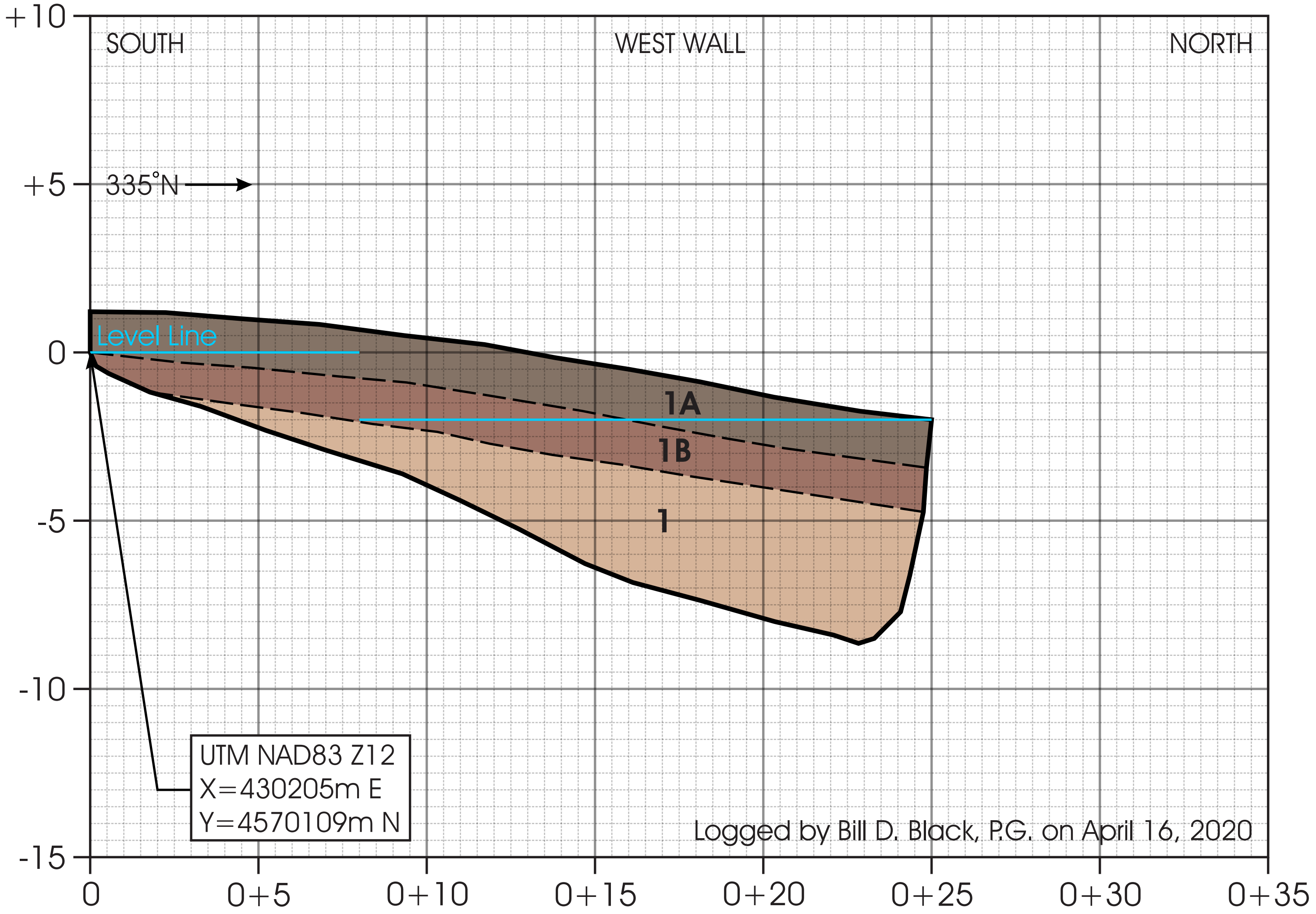
SITE SPECIFIC GEOLOGY

GEOLOGIC HAZARDS EVALUATION

Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

FIGURE 3C

TEST PIT 1

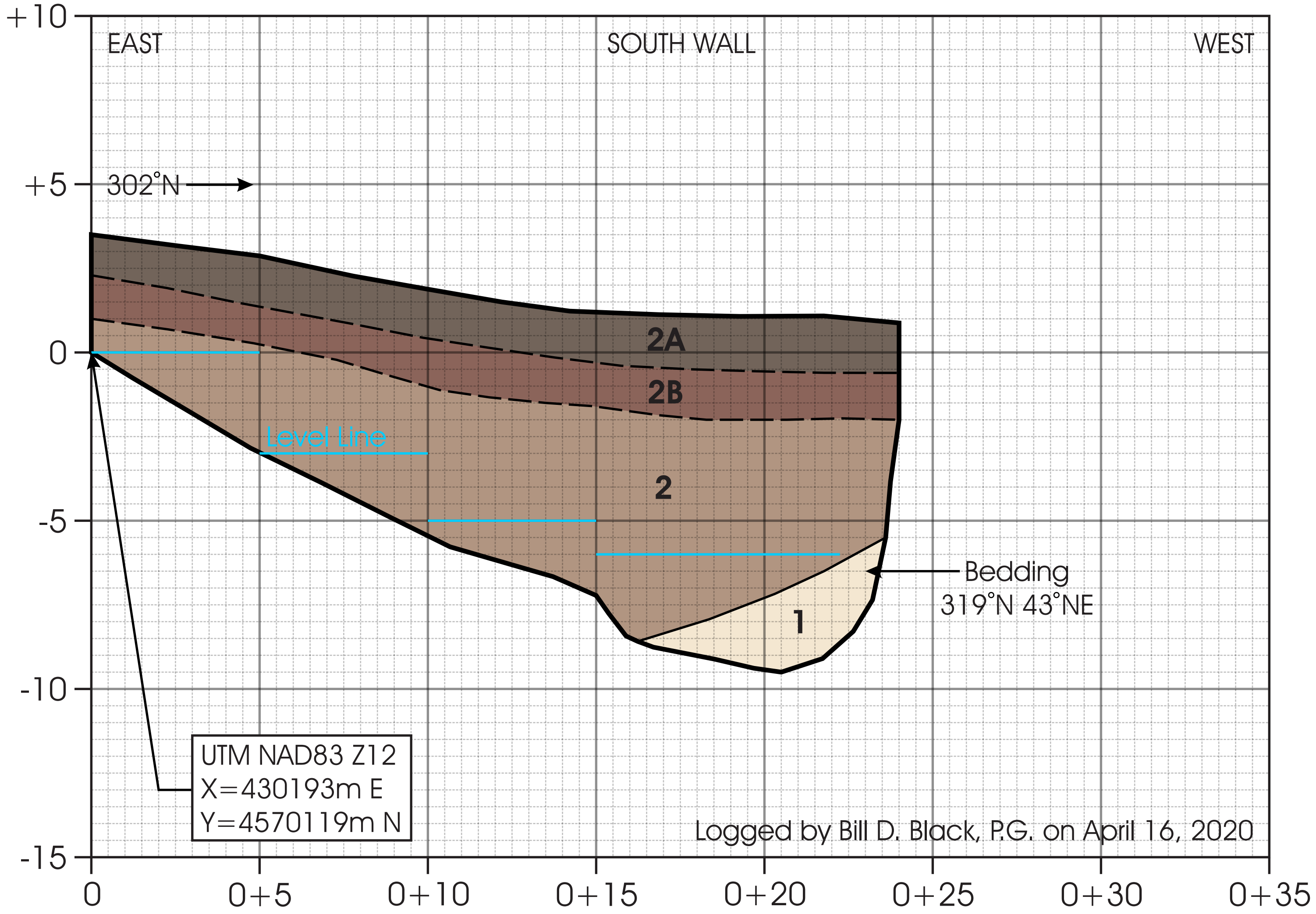


Logged by Bill D. Black, P.G. on April 16, 2020

UNIT DESCRIPTIONS

Unit 1. *Tertiary Norwood Formation (?)* - Brown, weathered claystone, dense, massive, with flecks of white gravel; modern A horizon (1A) and Bt horizon (1B) formed in unit.

TEST PIT 2



Logged by Bill D. Black, P.G. on April 16, 2020

UNIT DESCRIPTIONS

Unit 1. *Precambrian Maple Canyon Formation* - Fractured, pale gray, thinly bedded, dense, fine-grained sandstone (?) with carbonate infill.

Unit 2. *Pleistocene colluvium* - Brown to dark-brown, massive, moderate to high density, lean clay (CL) with sand, gravel and blocks of unit 1; modern A horizon (2A) and Bt horizon (2B) formed in unit.

Scale 1 inch equals 5 feet with no vertical exaggeration

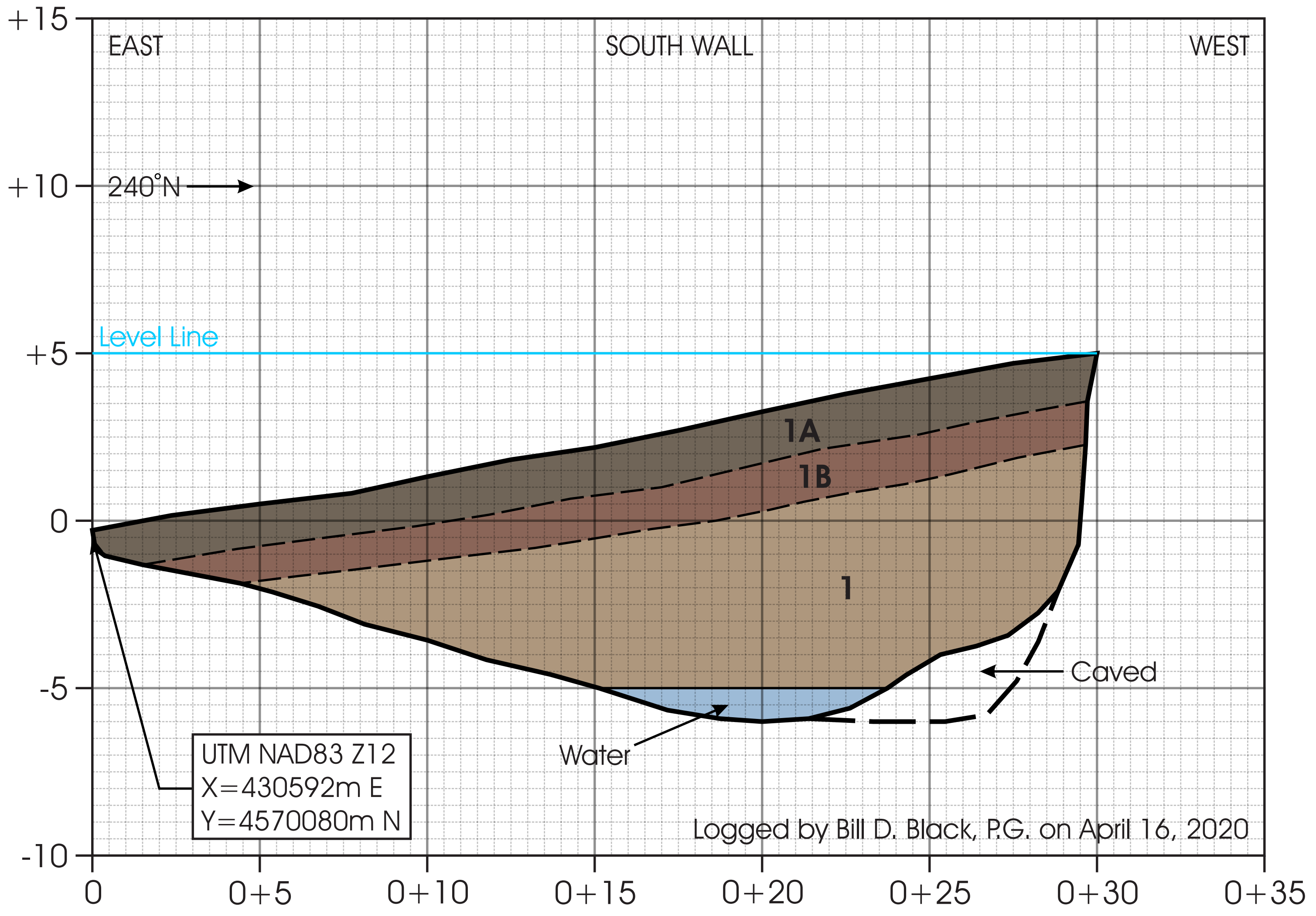
WESTERN GEOLOGIC

TEST PIT LOGS, SHEET 1

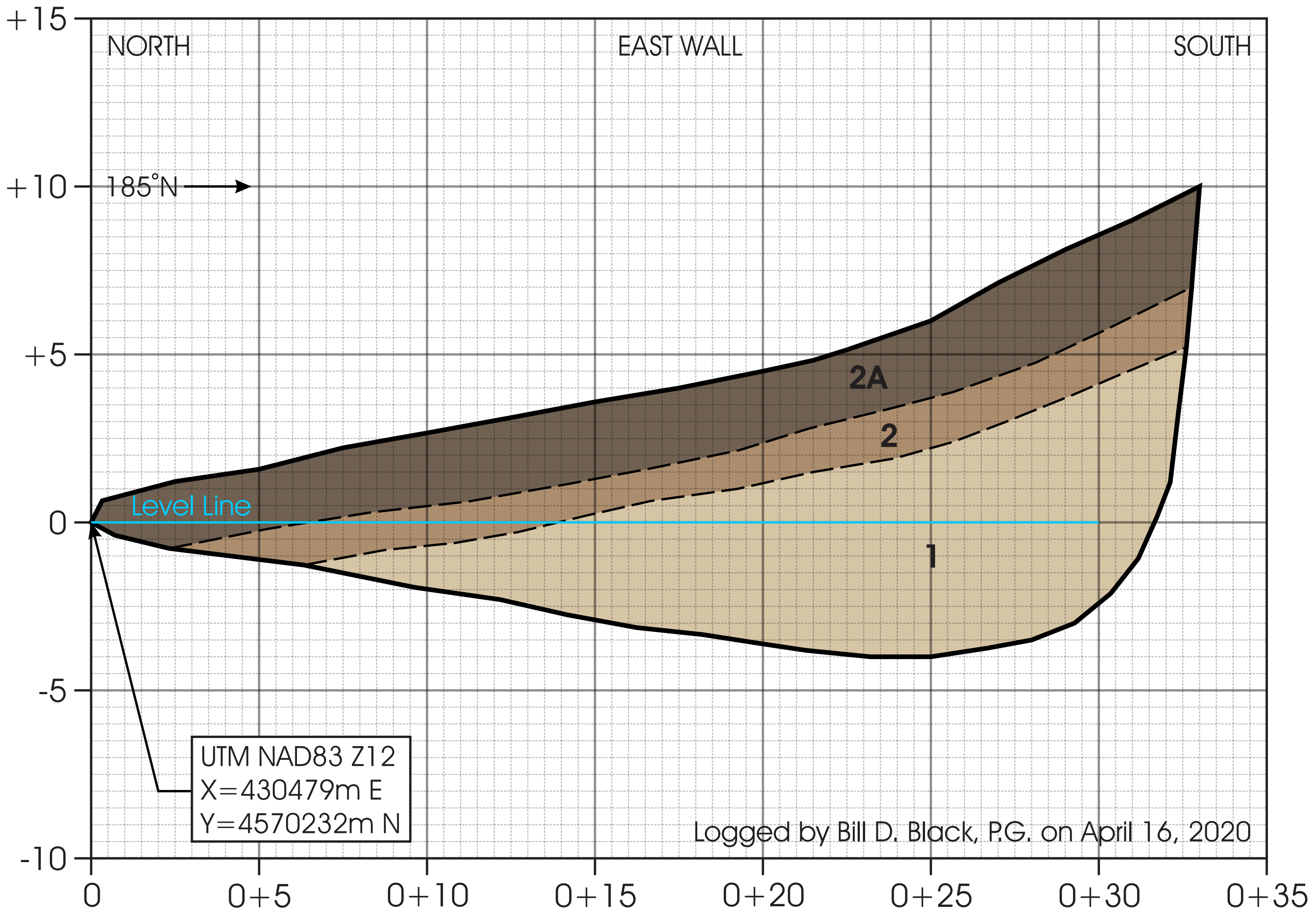
GEOLOGIC HAZARDS EVALUATION
Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

FIGURE 4A

TEST PIT 3



TEST PIT 4



UNIT DESCRIPTIONS

Unit 1. *Late Pleistocene to Holocene colluvium* - Reddish-brown, orange-brown and brown, moderate density, generally massive, sandy lean to fat clay (CL/CH) with gravel and cobbles in upper part; clasts subround with stage II carbonate; modern A horizon (1A) and Bt horizon (1B) formed in unit, test pit caving beneath soil horizons.

UNIT DESCRIPTIONS

Unit 1. *Late Pleistocene alluvium* - Light brown, moderate density, poorly bedded, sandy gravel (GW) with clay, cobbles and boulders up to 2 feet across; clasts subangular to subround with stage II carbonate.

Unit 2. *Early to mid-Holocene alluvium* - Brown to dark brown, moderate density, generally massive, clayey sand (SC) with gravel and trace round to subround cobbles with stage II carbonate; modern A horizon (2A) formed in unit.

Scale 1 inch equals 5 feet with no vertical exaggeration

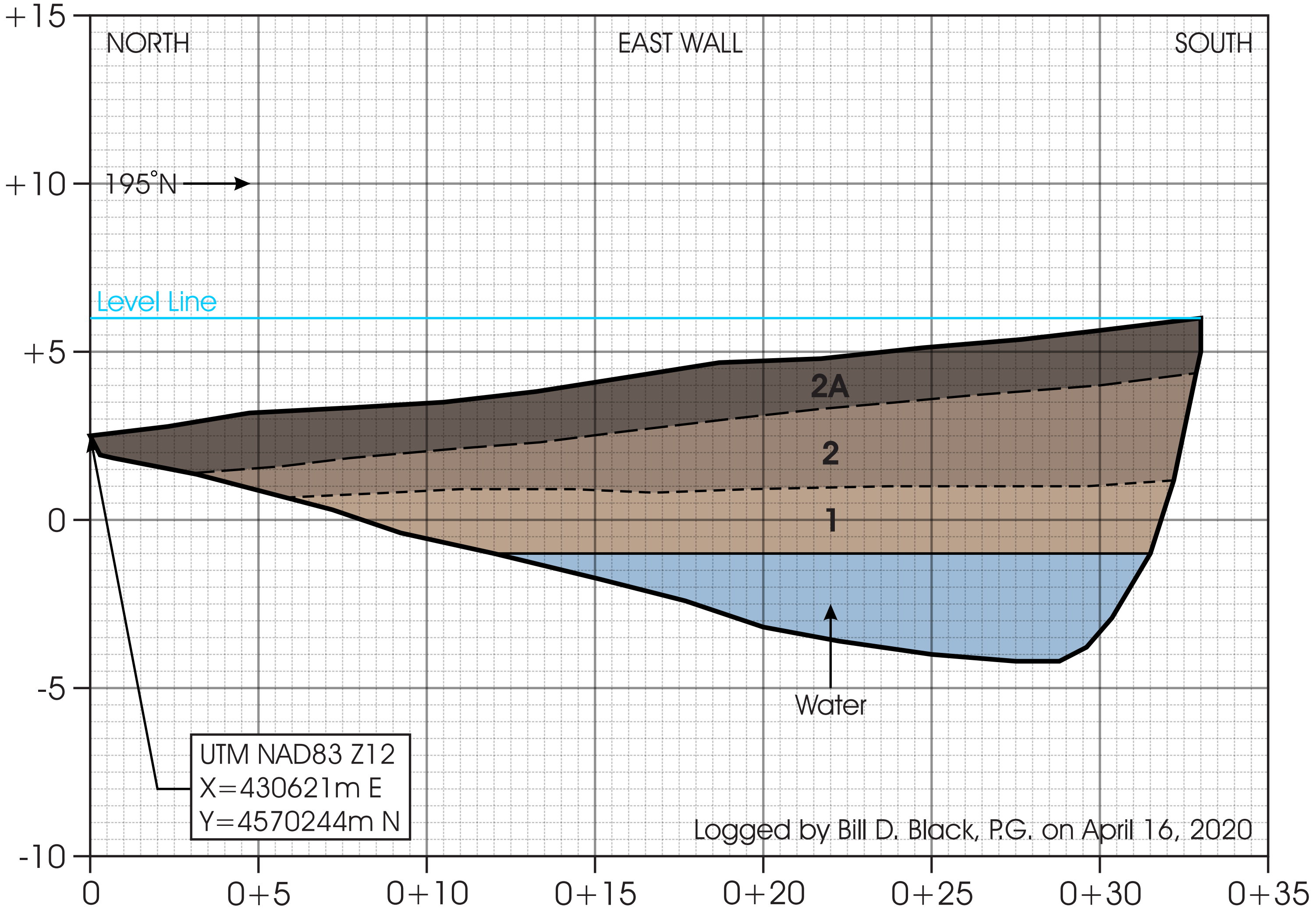
WESTERN GeoLogic

TEST PIT LOGS, SHEET 2

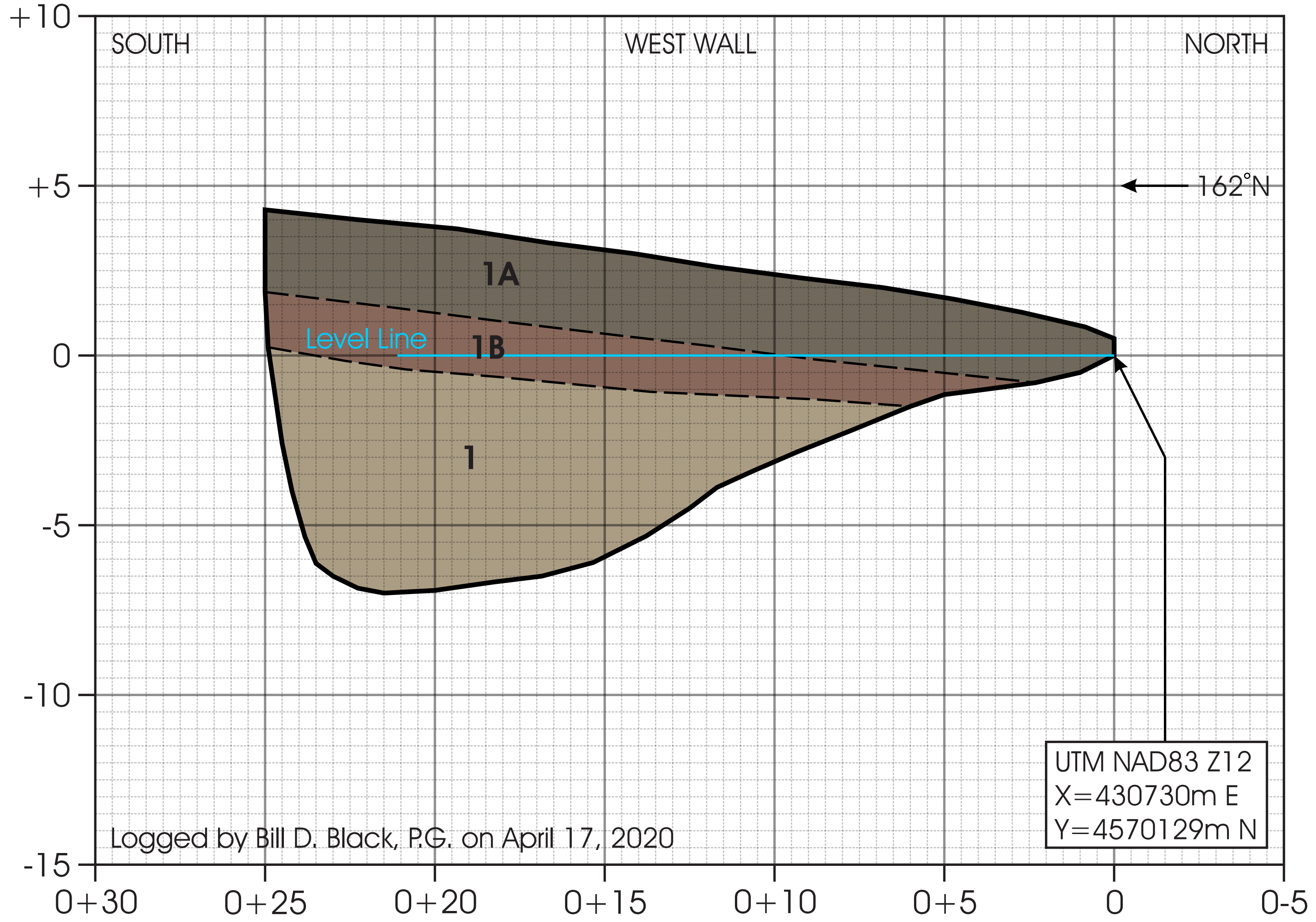
GEOLOGIC HAZARDS EVALUATION
Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

FIGURE 4B

TEST PIT 5



TEST PIT 6



UNIT DESCRIPTIONS

Unit 1. *Late Pleistocene alluvium* - Light brown, moderate to low density, poorly bedded, sandy gravel (GW) with clay, cobbles and trace boulders; clasts subangular to round with stage II carbonate.

Unit 2. *Early to mid-Holocene alluvium* - Brown to dark brown, low density, generally massive, clayey sand (SC) with silt and gravel; root penetrated and organic enriched; modern A horizon (2A) formed in unit.

UNIT DESCRIPTIONS

Unit 1. *Late Pleistocene to Holocene colluvium* - Olive-brown, reddish-brown and dark-grayish-brown, moderate density, generally massive, lean clay (CL) with trace sand and gravel; tuffaceous sandstone clasts in lower part; modern A horizon (1A) and Bt horizon (1B) formed in unit.

Scale 1 inch equals 5 feet with no vertical exaggeration

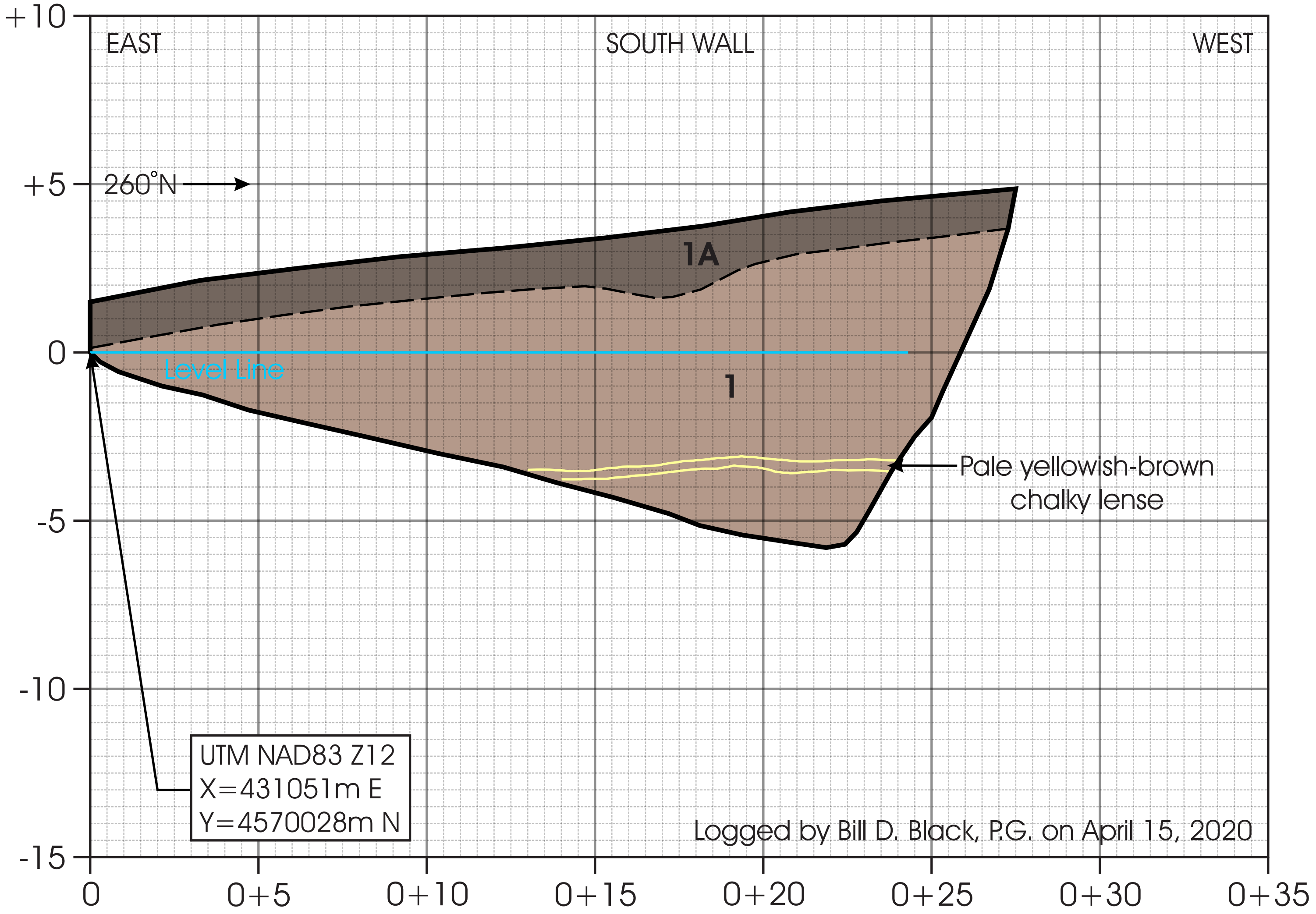
WESTERN GEOLOGIC

TEST PIT LOGS, SHEET 3

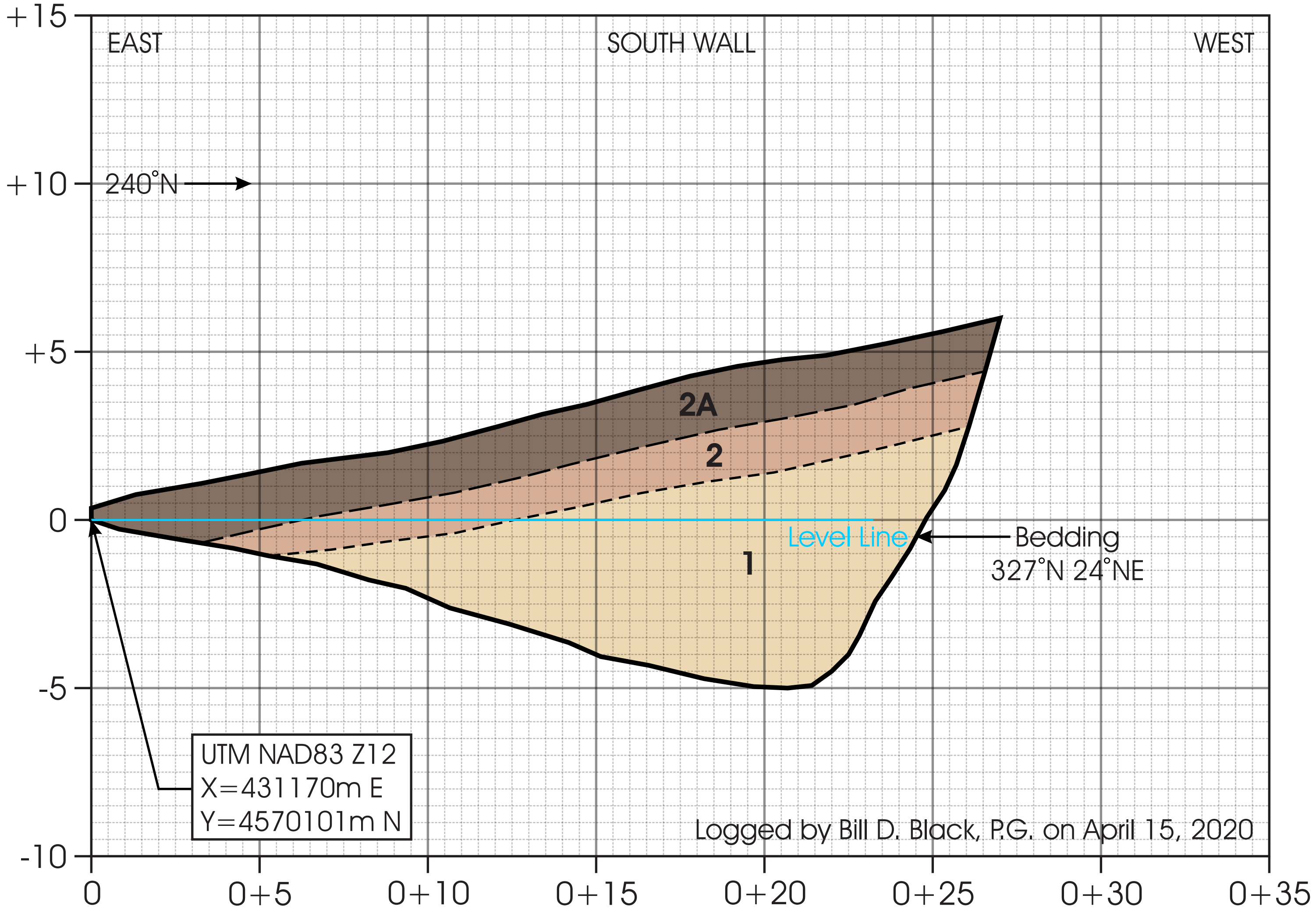
GEOLOGIC HAZARDS EVALUATION
Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

FIGURE 4C

TEST PIT 7



TEST PIT 8



UNIT DESCRIPTIONS

Unit 1. *Early Holocene alluvium and colluvium* - Pale-brown, grayish-brown and brown to dark-brown, moderate density, poorly bedded to massive, sandy lean to fat clay (CL/CH) with gravel and subangular to subround cobbles with strong stage II carbonate, density increases downward; modern A horizon (1A) formed in unit; may be weathered Tertiary Norwood Formation below chalky lense.

UNIT DESCRIPTIONS

Unit 1. *Tertiary Norwood Formation* - Pale-brown to orange-brown weathered tuffaceous sandstone, dense, poorly to well bedded.

Unit 2. *Early Holocene alluvium and colluvium* - brown to dark brown, low density, generally massive, clayey sand (SC) with silt and gravel; root penetrated and organic enriched; modern A horizon (2A) formed in unit.

Scale 1 inch equals 5 feet with no vertical exaggeration

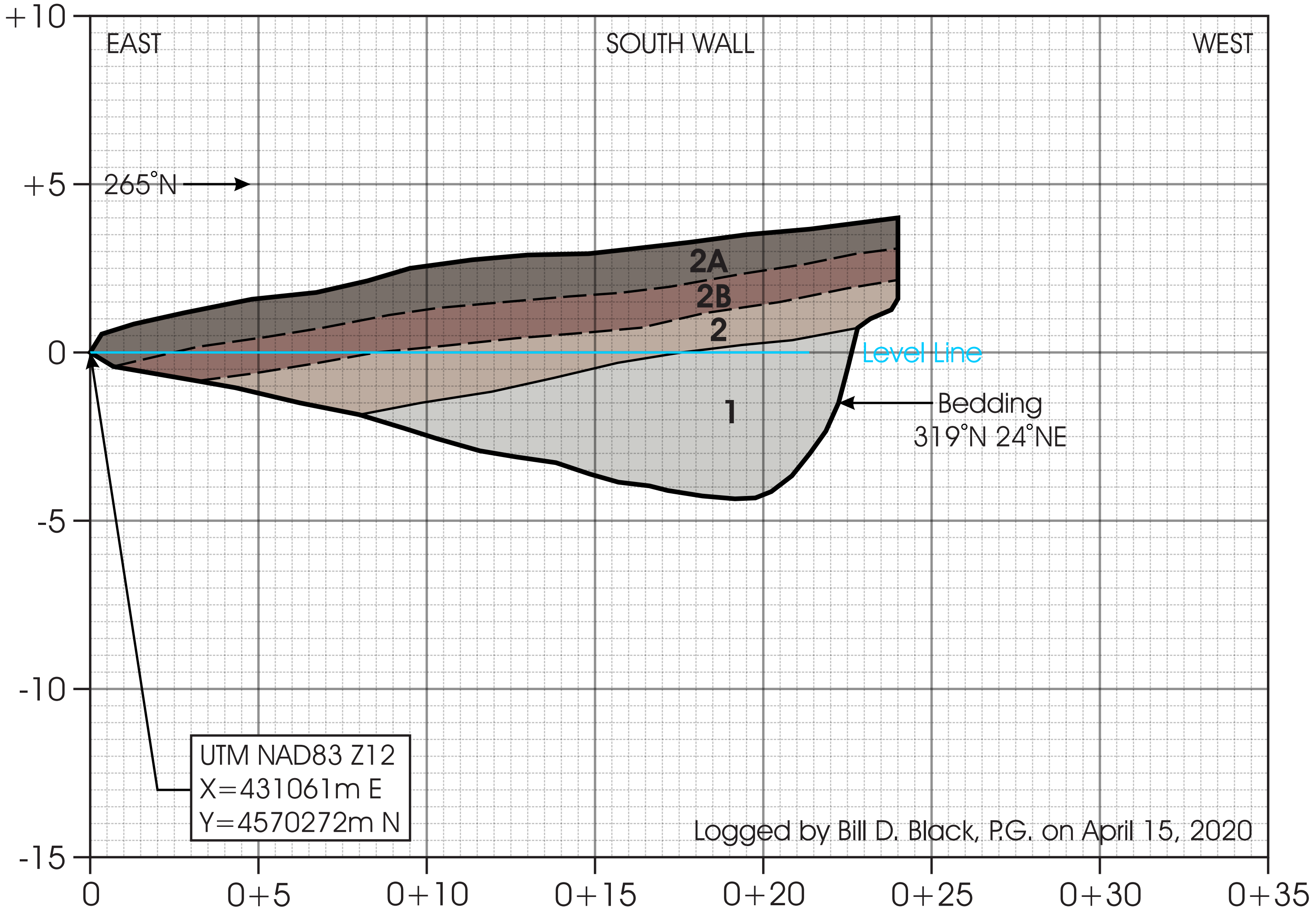
WESTERN GEOLOGIC

TEST PIT LOGS, SHEET 4

GEOLOGIC HAZARDS EVALUATION
Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

FIGURE 4D

TEST PIT 9

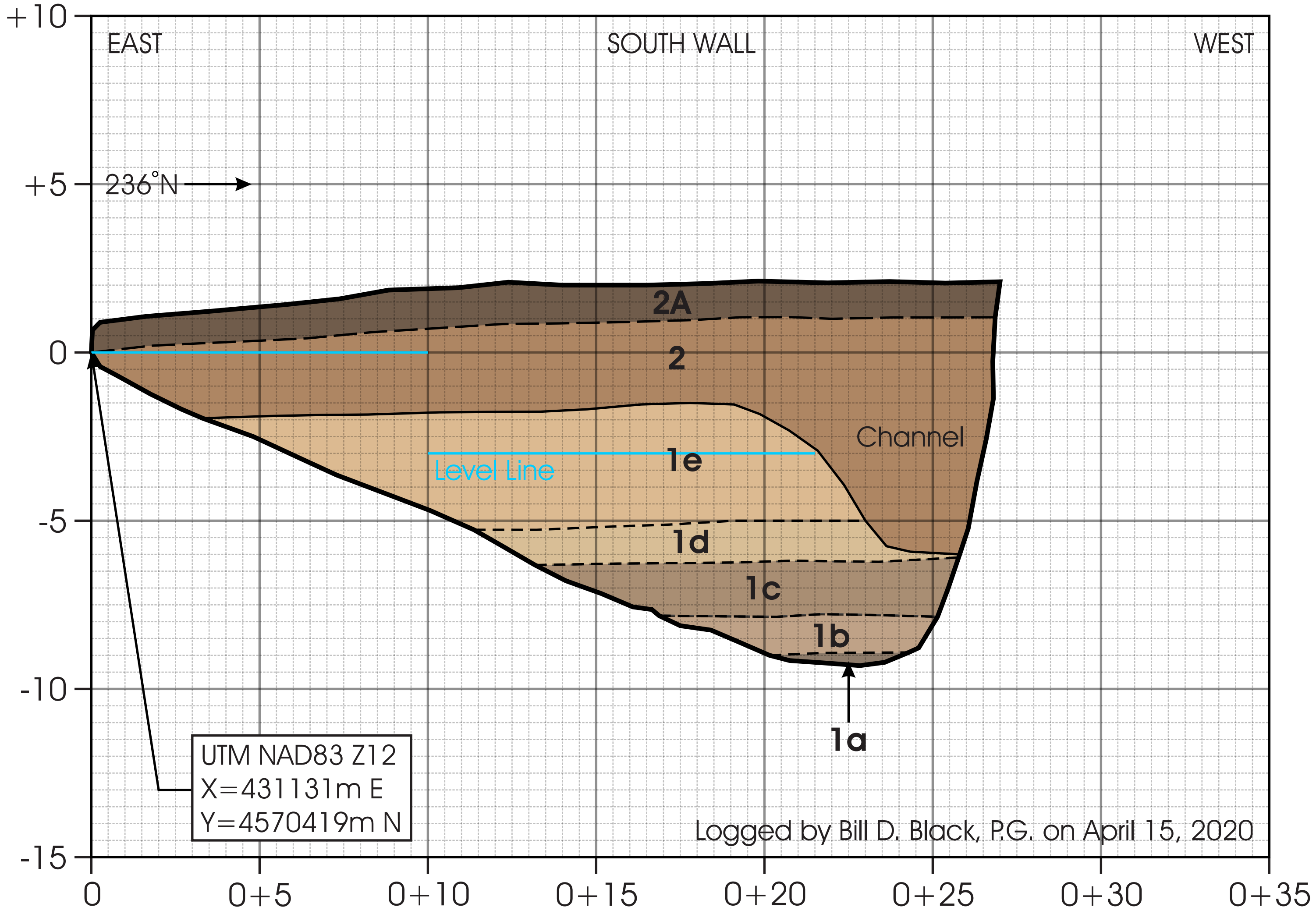


UNIT DESCRIPTIONS

Unit 1. *Tertiary Norwood Formation* - Greenish-gray, dense, well-bedded, weathered tuffaceous sandstone.

Unit 2. *Early to mid-Holocene alluvium and colluvium* - Brown, reddish-brown, and dark-brown, low to moderate density, poorly bedded to massive, clayey sand to sandy clay (SC/CL) with gravel, cobbles and boulders; clasts subround to subangular with stage II carbonate, include tuffaceous sandstone; modern A horizon (2A) and Bw/Bt horizon (2B) formed in unit.

TEST PIT 10



UNIT DESCRIPTIONS

Unit 1. *Late Pleistocene Lake Bonneville sediments* - Sequence of well-bedded, moderate density, brown to reddish-brown, clay to gravel comprised of: 1a, lean clay (CL); 1b, gravelly sand to sandy gravel (SW/GW); 1c, lean clay (CL); 1d, coarse sand (SW) with gravel and cobbles; and 1e, silty sand (SM) with gravel.

Unit 2. *Holocene alluvium* - Brown, moderate density, poorly bedded, clayey gravel (GM) with sand and cobbles; clasts round to subangular with stage II carbonate, channel in west test pit end; modern A horizon (2A) formed in unit.

Scale 1 inch equals 5 feet with no vertical exaggeration

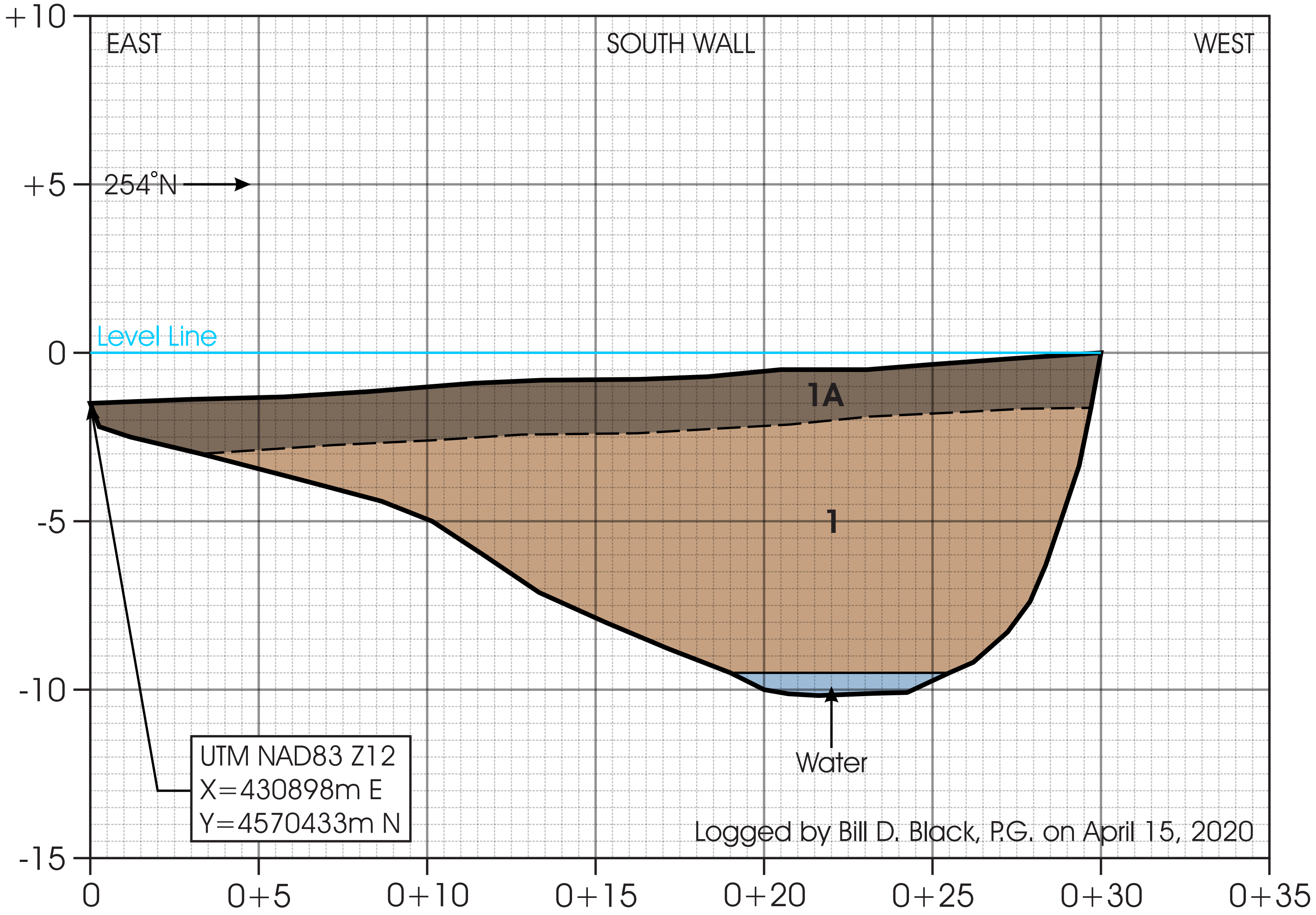
WESTERN
GeoLogic

TEST PIT LOGS, SHEET 5

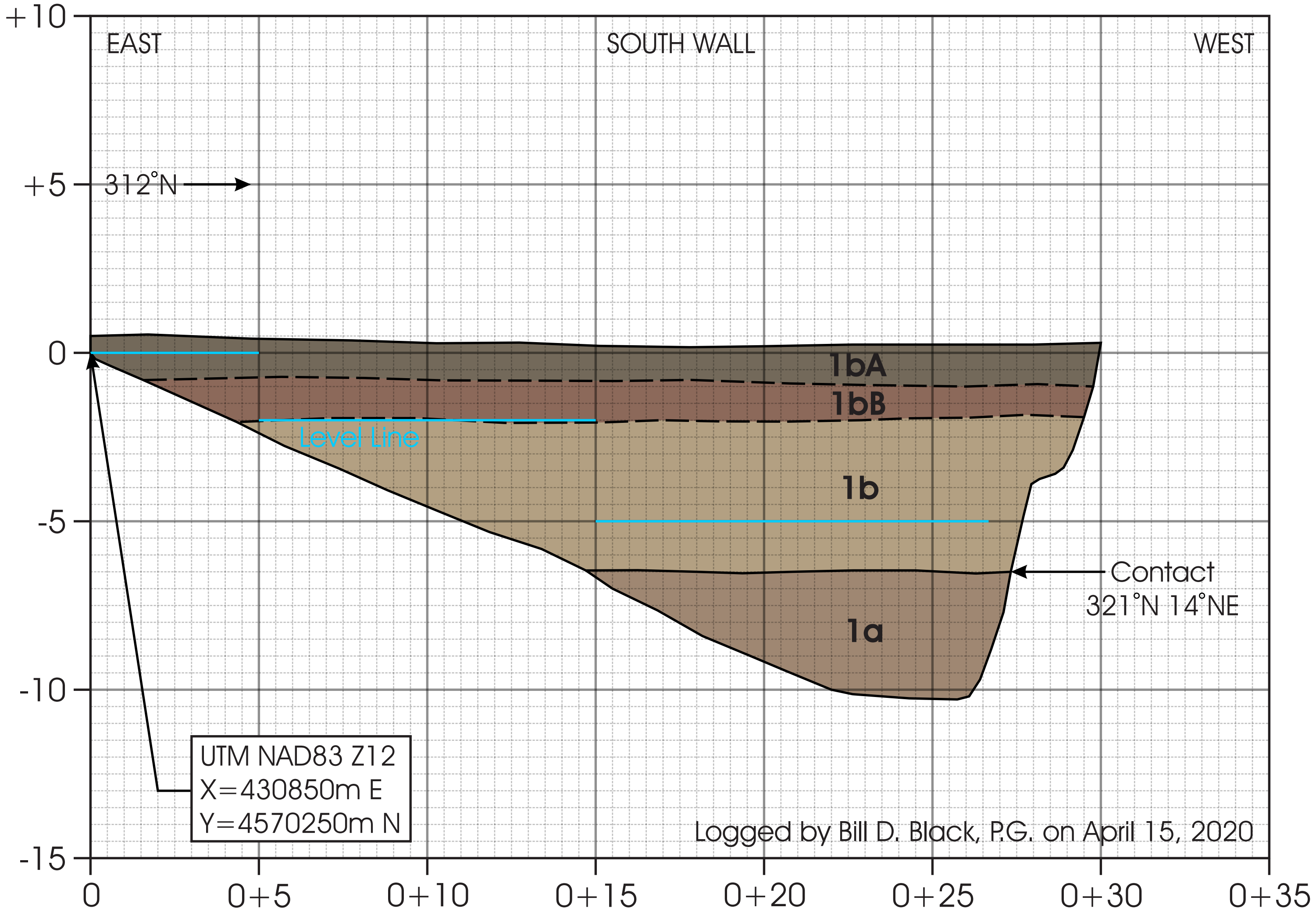
GEOLOGIC HAZARDS EVALUATION
Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

FIGURE 4E

TEST PIT 11



TEST PIT 12



UNIT DESCRIPTIONS

Unit 1. *Early to mid-Holocene alluvium* - Brown to dark-grayish-brown, moderate density, poorly bedded to massive, sandy gravel to gravelly sand (GW/SW) with trace cobbles and boulders; clasts subangular to subround with stage II carbonate; modern A horizon (2A) formed in unit.

UNIT DESCRIPTIONS

Unit 1. *Tertiary Norwood Formation* - Sequence of poorly to well bedded, moderate to high density, weathered tuffaceous bedrock comprised of a lower (1a) brownish-orange fractured siltstone, and an upper (1b) pale-brown to dark-brown, clayey sandstone to sandy claystone; modern A horizon (1bA) and Bw/Bt horizon (1bB) formed at surface.

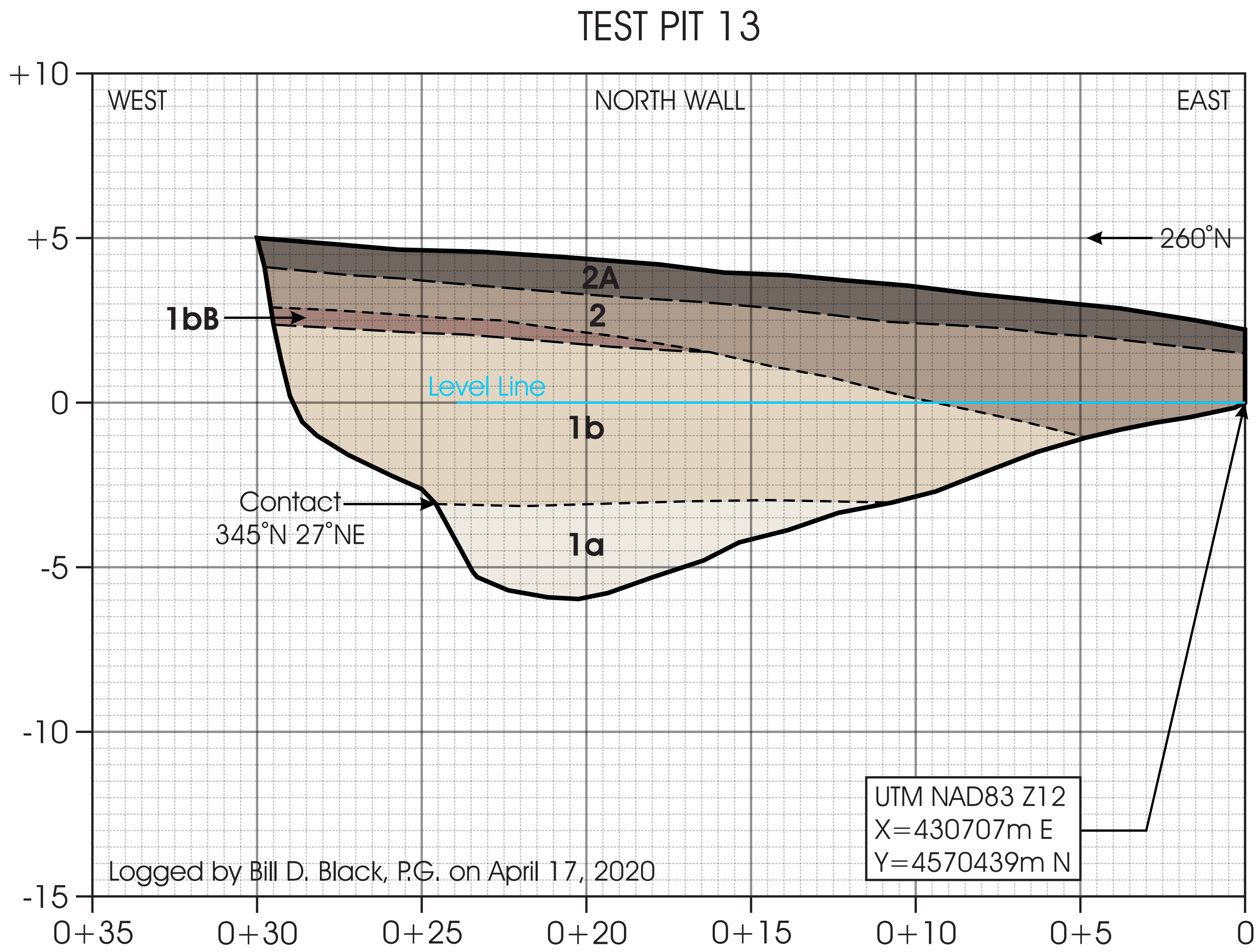
Scale 1 inch equals 5 feet with no vertical exaggeration

WESTERN GEOLOGIC

TEST PIT LOGS, SHEET 6

GEOLOGIC HAZARDS EVALUATION
Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

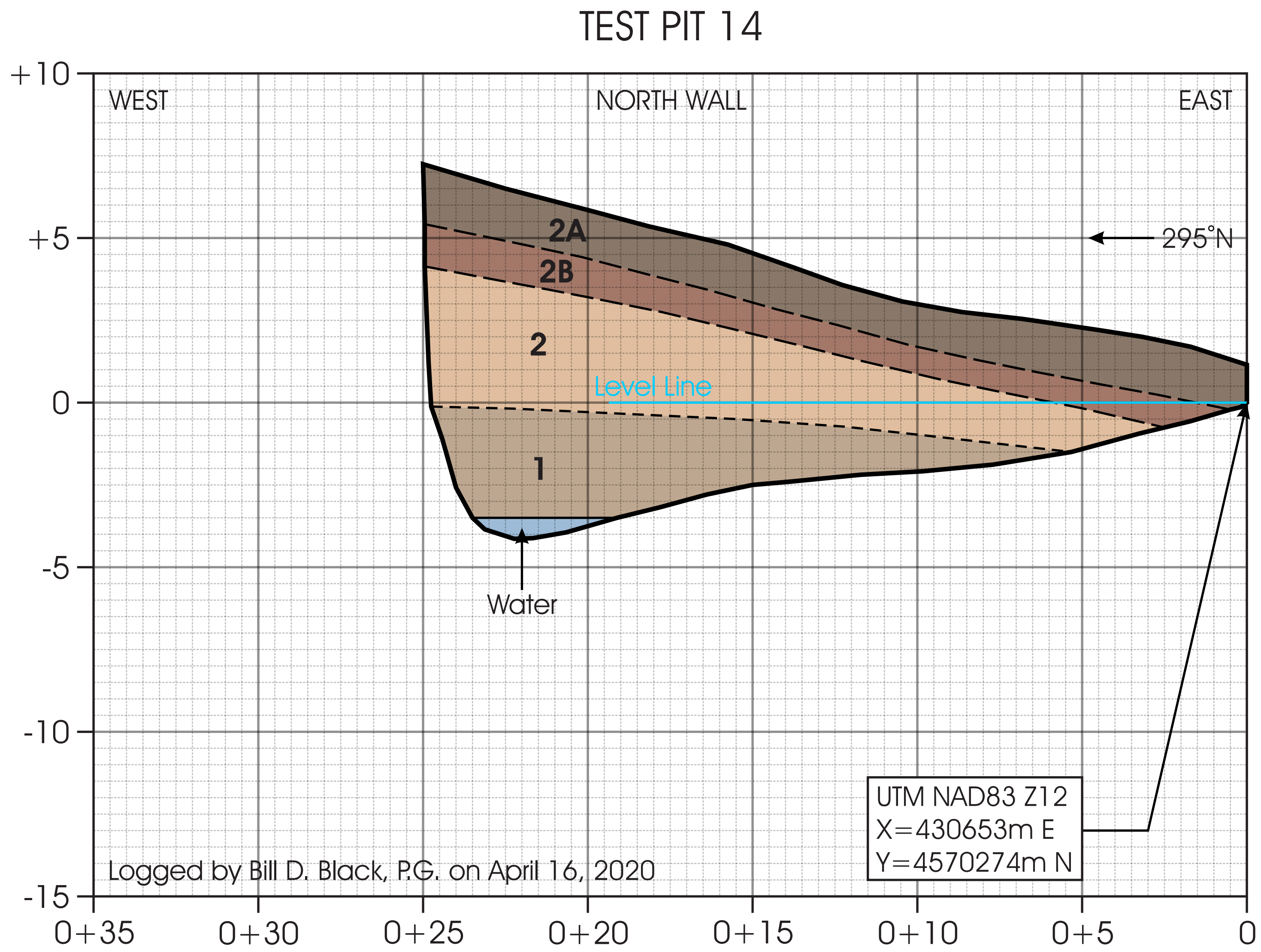
FIGURE 4F



UNIT DESCRIPTIONS

Unit 1. *Tertiary Norwood Formation* - Sequence of weathered, moderate to high density, poorly to well bedded, tuffaceous bedrock comprised of (1a) very-pale, green to reddish-brown claystone, and (1b) pale-orange-brown to pale-grayish-brown, conglomerate; Bt horizon formed in unit (1bB).

Unit 2. *Early Holocene alluvium* - Brown to dark-brown, moderate density, poorly bedded to massive, sandy clay (CL) with gravel, cobbles and small boulders; clasts subround to subangular with strong stage II carbonate; modern A horizon (2A) formed in unit.



UNIT DESCRIPTIONS

Unit 1. *Older Pleistocene alluvium* - Reddish-brown, dense, generally massive, clayey sand (SC) with pea gravel.

Unit 2. *Late Pleistocene alluvium* - Orange-brown, brown, and dark-brown, moderate density, generally massive, sandy clay to clayey sand (CL/SC) with gravel and trace cobbles; clasts subangular with stage II carbonate; modern A horizon (2A) and Bt horizon (2B) formed in unit.

Scale 1 inch equals 5 feet with no vertical exaggeration

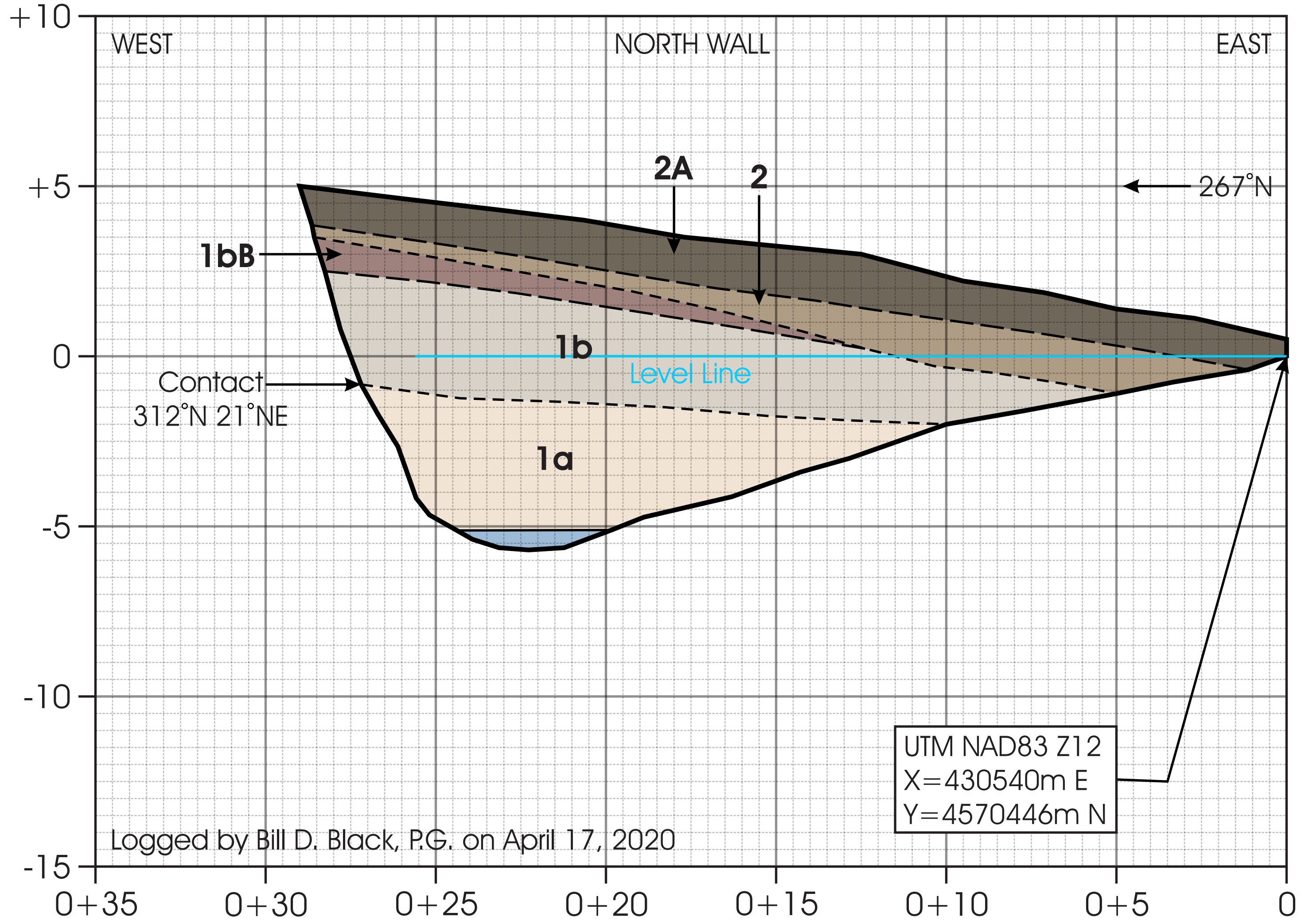
WESTERN GeoLogic

TEST PIT LOGS, SHEET 7

GEOLOGIC HAZARDS EVALUATION
Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

FIGURE 4G

TEST PIT 15

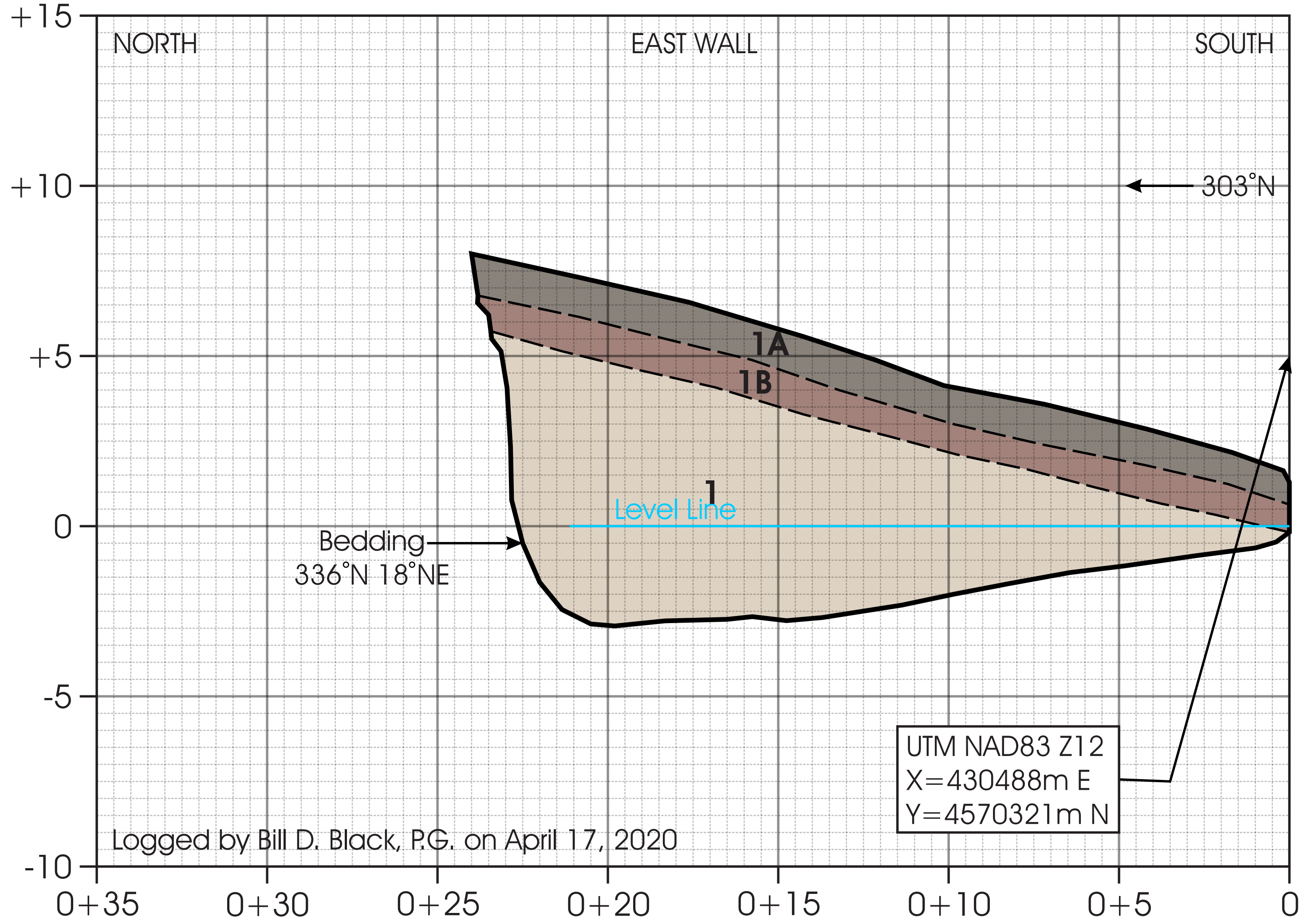


UNIT DESCRIPTIONS

Unit 1. *Tertiary Norwood Formation* - Sequence of weathered, moderate to high density, poorly to well bedded, tuffaceous bedrock comprised of: 1a, pale-brown conglomerate, and 1b, pale-greenish-gray claystone; Bt horizon formed in unit (1bB).

Unit 2. *Early Holocene alluvium* - Brown to dark-brown, moderate density, poorly bedded to massive, sandy clay (CL) with gravel, cobbles and small boulders; clasts subround to subangular with strong stage II carbonate; modern A horizon

TEST PIT 16



UNIT DESCRIPTIONS

Unit 1. *Tertiary Norwood Formation* - Olive, white, pale-brown, and orange- to dark-brown, weathered tuffaceous conglomerate with stage III carbonate; modern A horizon (1A) and Bk horizon (1B) formed in unit.

Scale 1 inch equals 5 feet with no vertical exaggeration

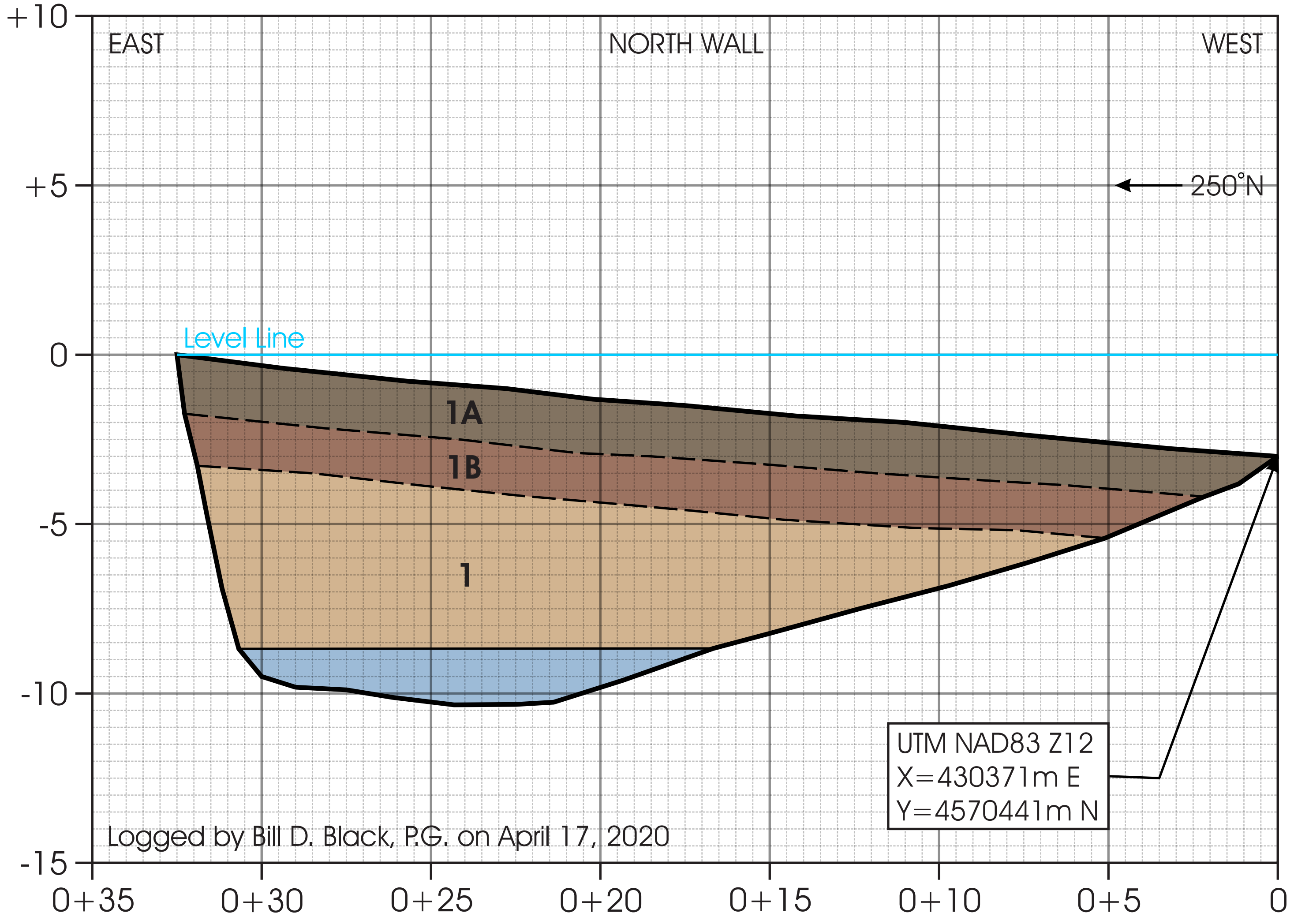
WESTERN GEOLOGIC

TEST PIT LOGS, SHEET 8

GEOLOGIC HAZARDS EVALUATION
Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

FIGURE 4H

TEST PIT 17



UTM NAD83 Z12
X=430371m E
Y=4570441m N

Logged by Bill D. Black, P.G. on April 17, 2020

UNIT DESCRIPTIONS

Unit 1. *Tertiary Norwood Formation* - Orange-brown, poorly bedded to massive, moderate to high density, weathered claystone; modern A horizon (1A) and Bw/Bt horizon (1B) formed in unit.

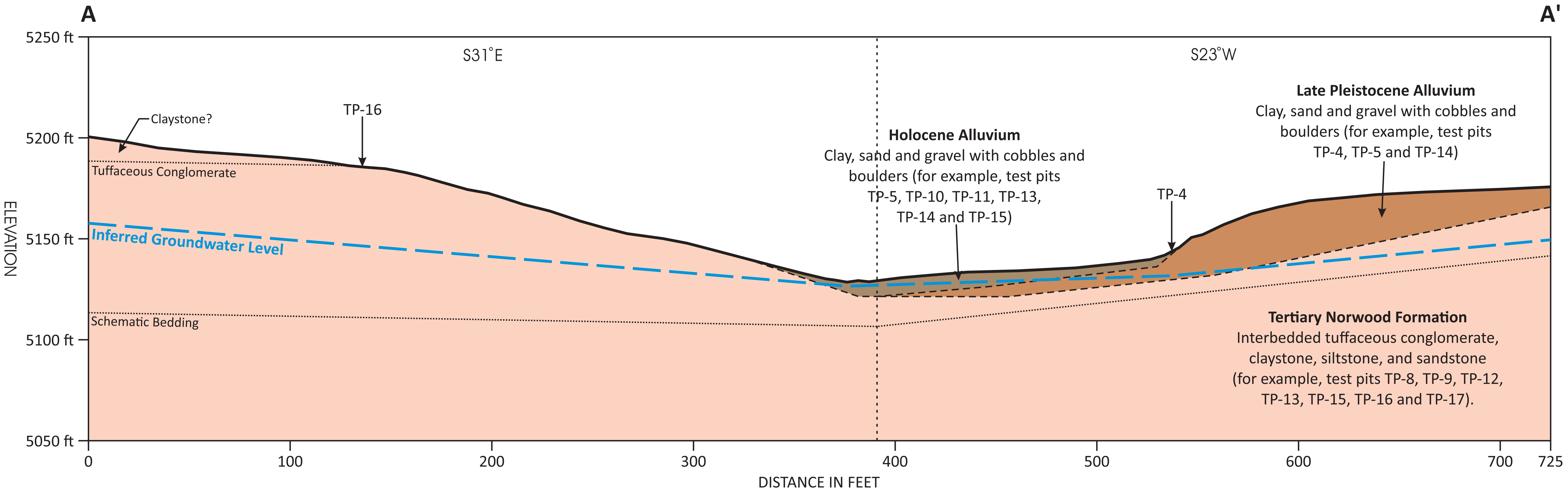
Scale 1 inch equals 5 feet with no vertical exaggeration

WESTERN
GEOLOGIC

TEST PIT LOGS, SHEET 9

GEOLOGIC HAZARDS EVALUATION
Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

FIGURE 4I



SCALE: 1 inch = 50 feet
(no vertical exaggeration)
Unit and textural contacts
are approximate and inferred

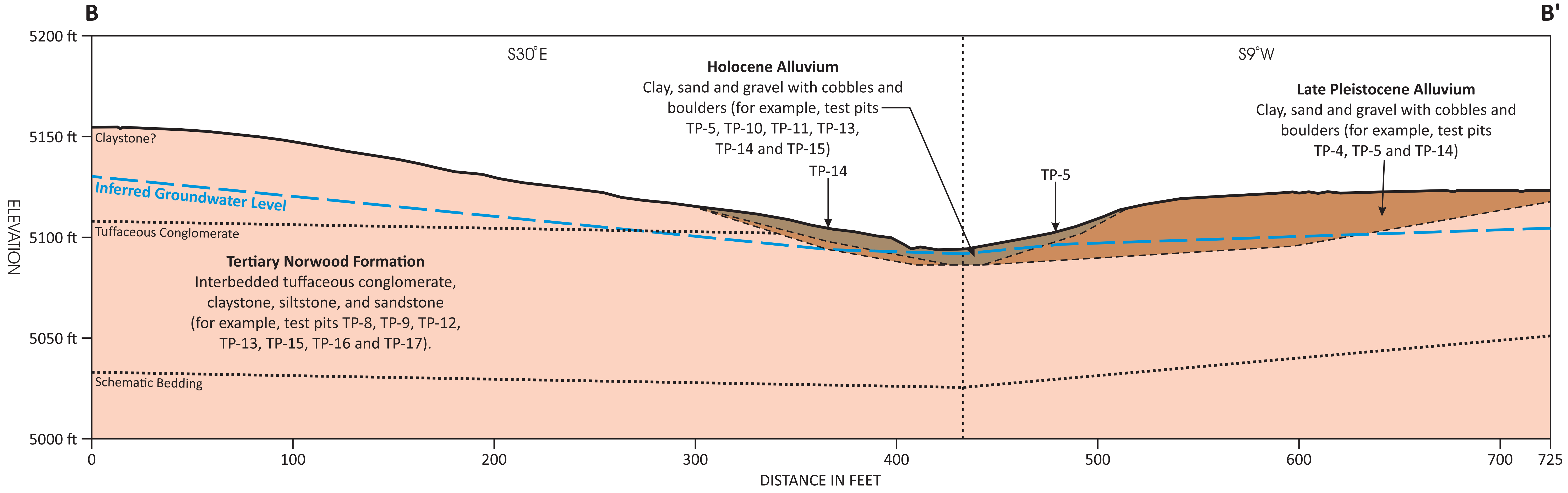
WESTERN
GEOLOGIC

CROSS SECTION A-A'

GEOLOGIC HAZARDS EVALUATION

Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

FIGURE 5



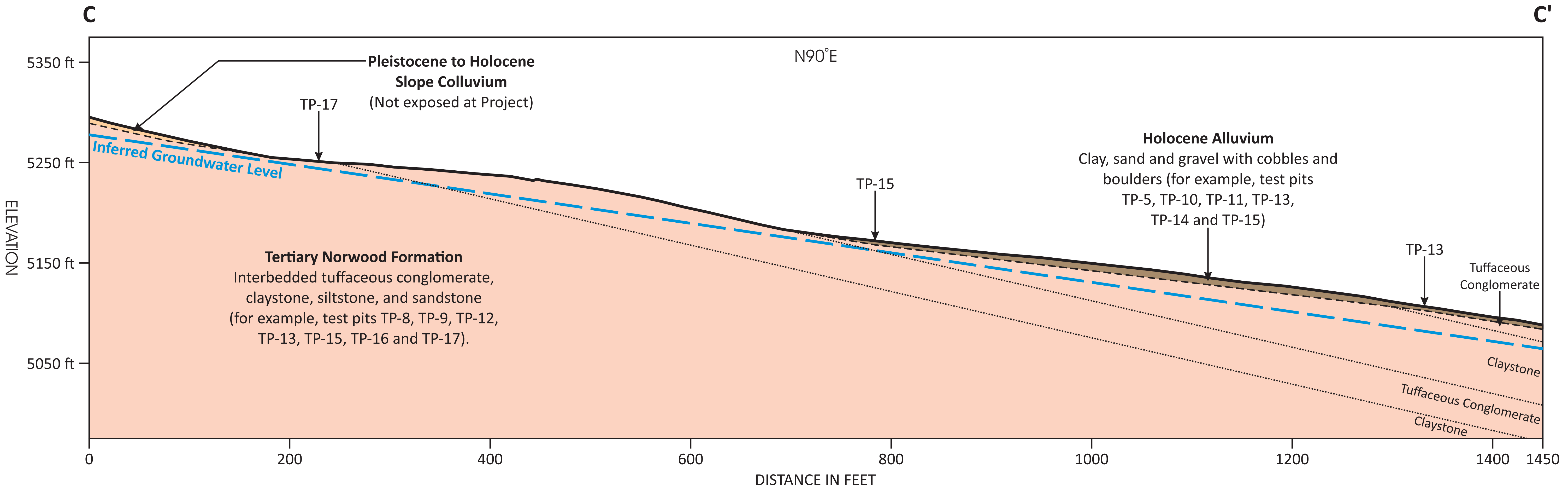
SCALE: 1 inch = 50 feet
(no vertical exaggeration)
Unit and textural contacts
are approximate and inferred

CROSS SECTION B-B'

GEOLOGIC HAZARDS EVALUATION

Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

FIGURE 6



SCALE: 1 inch = 100 feet
(no vertical exaggeration)
Unit and textural contacts
are approximate and inferred

CROSS SECTION C-C'

GEOLOGIC HAZARDS EVALUATION

Proposed Crimson Ridge Phase 2 Subdivision
About 1100 North Morningside Lane
Eden, Utah

FIGURE 7