SCARP ANALYSIS OF THE CENTENNIAL NORMAL FAULT, BEAVERHEAD COUNTY, MONTANA AND FREMONT COUNTY, IDAHO

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

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in

Earth Sciences

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ABSTRACT

The Centennial Mountains are an east-west trending mountain range in southwest Montana. The Centennial Mountains are bound on the south by the Eastern Snake River Plane, the north-trending Madison Range and fault on the east and the Centennial Valley on the north. The Centennial normal fault offsets the Centennial Mountains on the north down-dropping the Centennial Valley. Approximately 3000 meters of offset along the Centennial normal fault creates the Centennial Mountains.

The present Centennial Mountains are subdivided into two stratigraphically different blocks by the Odell Creek normal fault. The eastern Centennial Mountains are interpreted as the upthrown block of the Odell Creek normal fault exposing Precambrian and Paleozoic rock along the northern face of the range. The western Centennial Mountains are interpreted as the downthrown block of the Odell Creek normal fault exposing Cretaceous and younger rocks. Both eastern and western segments of the Centennial Mountains are then offset along the range bounding Centennial normal fault.

Offset along the Centennial normal fault started approximately 2.1 Ma as evidenced by the displacement of the 2.1 Ma Huckleberry Ridge tuff. It is believed that prior to the emplacement of the 2.1 Ma Huckleberry Ridge tuff, the Centennial Mountains had minimum to no surface relief. The majority of offset along the Centennial normal fault has occurred with in the late Pleistocene with estimated slip rates of 0.65-0.82 mm/yr. The late Pleistocene surface offsets along the Centennial Mountains have an average of 9.1-9.6 meters with similar offset seen along the eastern and western segments.

CHAPTER 1

INTRODUCTION

Purpose

A seismic history full of large-magnitude events within the northern Intermountain Seismic Belt (Smith, 1978) attracts researchers conducting neotectonic and paleoseismologic studies of the western United States. This is a dynamic seismic area that includes the $\mathbf{M_s}$ 7.5 1959 Hebgen Lake, MT (Myers and Hamilton, 1964; Bailey, 1977; Doser, 1985; Savage et al., 1993; Haller, 1993a, 1993b, 1993c, 1993d; Haller et al., 2000; Pierce et al., 2000; O'Neill and Christiansen, 2004; Wong et al., 2005) and $\mathbf{M_s}$ 7.3 1983 Borah Peak, ID earthquakes (Crone and Machette, 1984; Crone, 1988; Wong et al., 2005), among others. Studies of the interaction of Basin and Range extension with the Yellowstone volcanic province in northwest Wyoming and southwest Montana resulted in various tectono-magmatic models explaining the regional deformation patterns and stress fields (Myers and Hamilton, 1964; Anders et al., 1989; Smith and Arabasz, 1991; Pierce and Morgan, 1992). Although southwest Montana has an extensive array of potentially seismogenic normal faults, detailed paleoseismological studies (e.g. trenching) were conducted only on two fault systems: the Hebgen Lake fault system (Figure 1) (Haller et al., 2000; Pierce et al., 2000; Hecker et al., 2000) and the Red Rock/Blacktail faults (Stickney and Bartholomew, 1987; Bartholomew et al., 2004).

Modern neotectonic work on the Centennial normal fault (CNF) is warranted because: 1) the fault lies in an area of high seismic activity and hazard (Figure 2) (Hill and Bartholomew, 1999; Stickney et al., 2000; Wong et al., 2005); 2) the east-west trend of the mountain range relative to the northerly trend of adjacent mountain ranges is an unresolved geologic question; 3) the CNF lies adjacent to the Eastern Snake River Plain (ESRP) forming a "mirror image" across the plain to the Teton Range and Teton normal fault, suggesting a similar tectonic origin related to the Yellowstone parabola of seismic activity (Anders et al., 1989); 4) it is transverse or oblique to northerly Laramide structures in southwest Montana; 5) the fault appears to be structurally segmented into highly *en echelon* as well as imbricate "horsetail" trends (e.g. Alaska Basin) along the eastern segment and more linear along the western segment that may indicate different earthquake rupture histories; and 6) although there has been considerable reconnaissance mapping and some fault scarp profiling along the CNF previous to this study (Witkind, 1972, 1975 b, 1976, 1977, 1980), parts of the fault trace have not been located and a detailed paleoseismology study of the CNF has yet to be undertaken. Through detailed mapping and further fault scarp profiling, this study attempts to better understand the paleoseismic history of the CNF, thus laying ground work for future trench studies.

The research goals of this study are to address the following questions:

1. Is there a difference in earthquake rupture history for the east versus the west CNF as reflected by fault scarp morphology?

2. How does the Odell Creek fault affect the surface trace of the CNF? What type of "segment boundary" is the Odell Creek fault? Does the Odell Creek fault affect the imbricate fault pattern for the eastern CNF? Have the *en echelon* fault segments of the eastern Centennial Mountains ruptured together?

3. Why is the overall trend of the Centennial Mountains east-west while other mountain ranges in southwest Montana trend north and northwest?

4. Does the CNF have a similar tectonic history to the Teton normal fault and why do the two mountain ranges form a mirror image or arrow head across the hotspot track of the ESRP?

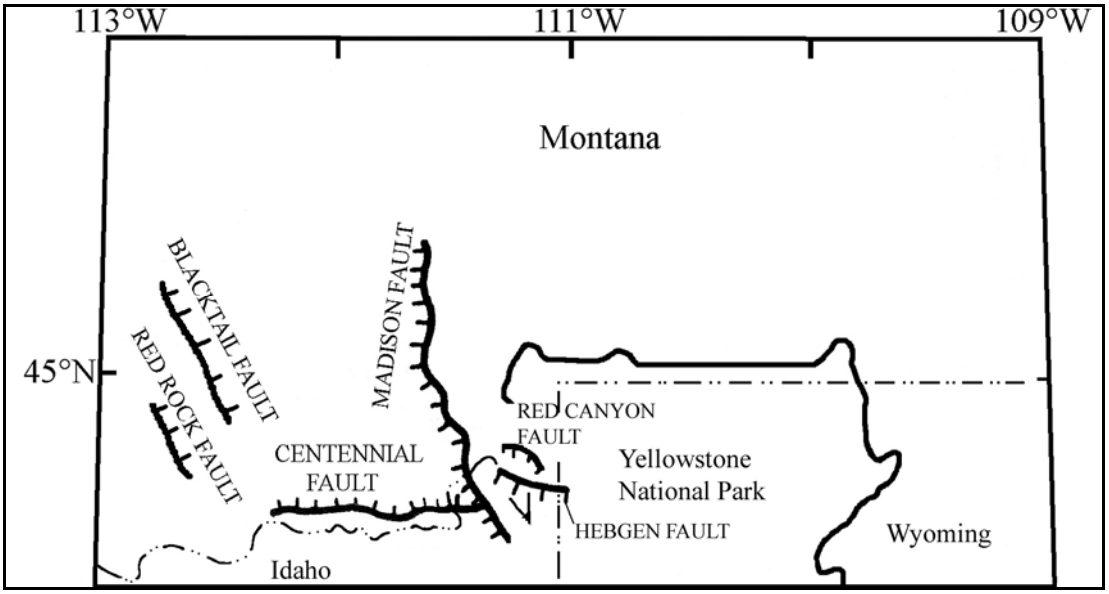

Figure 1. Regional map of southwest Montana showing the location of the Red Rock, Blacktail, Centennial, Madison, Red Canyon and Hebgen faults. The teeth are on downside of faults.

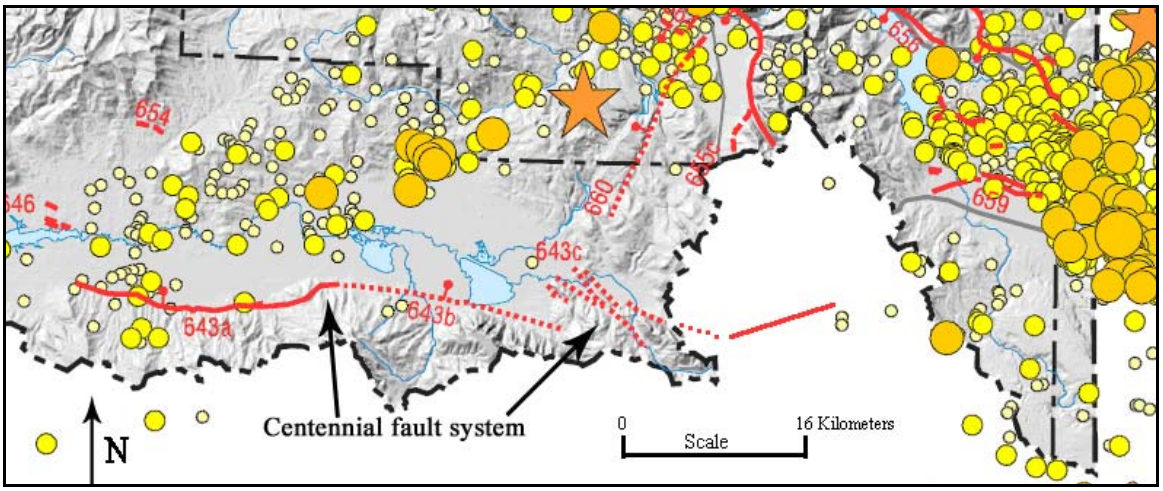

Figure 2. Map showing the Quaternary faults and seismicity for the region. Solid red lines indicate faults offset within the last 15,000 years and the dotted red lines indicate faults with offset within the last 1.6 Ma. The yellow to orange (magnitude increasing the darker the circle) circles represent selected earthquake epicenters from the Montana Bureau of Mines and Geology (MBMG) data base from 1982 to present and are scaled to magnitude. The orange stars are post 1900 earthquake epicenters with magnitudes 5.5 or larger. Note the earthquake activity along the very western end of the CNF (Modified from Stickney et al., 2000).

Regional Setting

The CNF is located within the Centennial Tectonic Belt as defined by Stickney and Bartholomew (1987), which is part of the northern Intermountain Seismic belt (Figure 3) along the north arm of the Yellowstone Tectonic Parabola (Smith, 1978; Anders et al., 1989; Pierce and Morgan, 1990, 1992; Smith and Arabasz, 1991; Christiansen, 2001). The CNF is part of the active Basin and Range extensional province where large regional earthquakes have occurred in historic times.

The research area is located immediately north of the Montana – Idaho border, approximately 40 km west of Yellowstone National Park (Figure 4), encompassing an area of approximately 550 km^2. The overall trend of the Centennial Mountains is nearly east-west in a region dominated by north-south or northwest trending mountain ranges

north of the ESRP. South of the ESRP in the Basin and Range the trend is consistently northerly. Beginning at approximately 2000 m (above sea-level) west of the Henrys Lake basin on the eastern end of the mountain range, the Centennial Mountains rise to 3,050 m at the summit of Sawtell Peak (Witkind, 1977). The mountain crest decreases in elevation westward to a low of approximately 2,750 m near Monida, Montana (Witkind, 1977).

Contemporary seismic activity is concentrated to the northeast and east of Henrys Lake and along the extreme western end of the CNF (Figure 2) (Stickney et al., 2000). The CNF is divided into two portions by the northeast-trending Odell Creek normal fault, which bisects the mountain range into geologically and physiographically distinct east and west segments (Figure 5). While the east and west segments may or may not share a common seismic history, abundant fault scarp evidence of significant Holocene displacement exists along both segments.

Study Area

The CNF trace was mapped at 1:24,000-scale within the research area; additionally, three study areas: the Mud Lake, Odell Creek, and Henrys Lake study areas were mapped at a scale of 1:12,000 to illustrate a greater detail of the fault trace and Quaternary deposits (Figure 4). The three study areas were chosen for their potential to determine if a difference in rupture and seismic history exists for the east versus the west segments of the CNF system. Plate 1 shows the four geographical subdivisions and three study areas for this research. The western section of the CNF is subdivided into the Mud Lake to Winslow Creek Section and western half of the Winslow Creek to Upper Red

Rock Lake Section (Sub-section A). The Odell Creek fault separates the Winslow Creek to Upper Red Rock Lake Section. The eastern segment of the CNF is subdivided into the eastern half of the Winslow Creek to Upper Red Rock Lake Section (Sub-section B), the Red Rock Pass Section and the Henrys Lake Section.

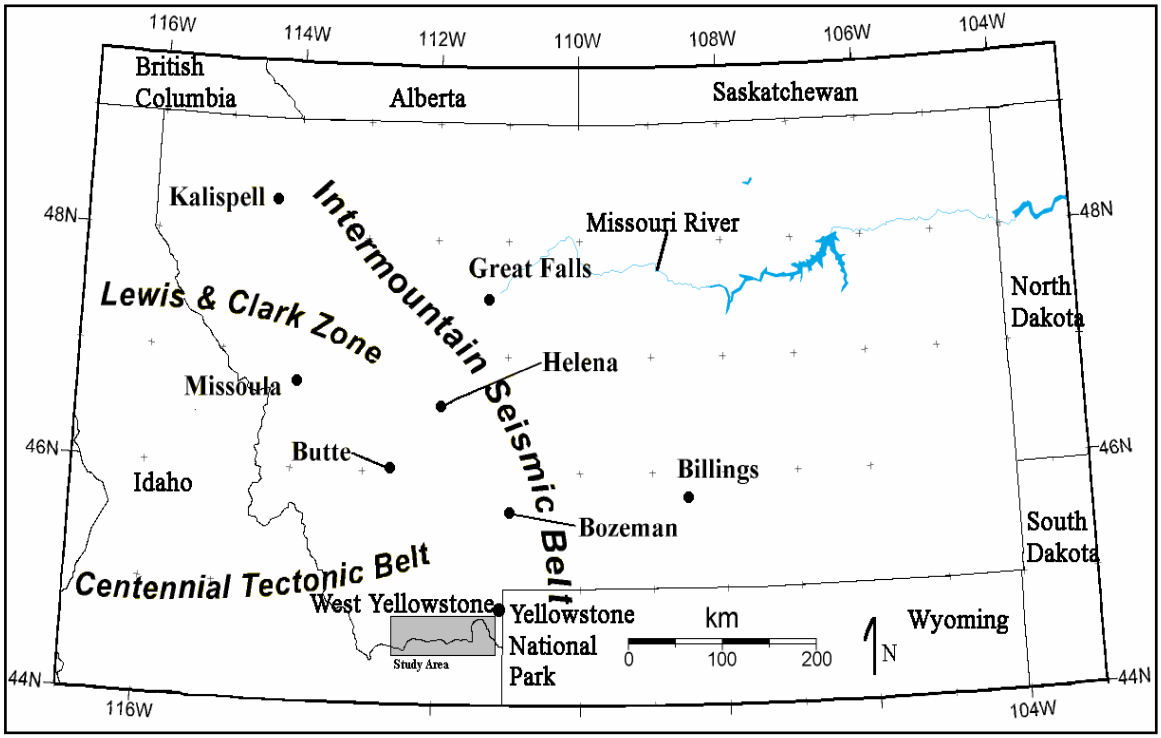

Figure 3. Regional map showing locations of the Intermountain Seismic Belt and Centennial Tectonic Belt (Modified from Stickney et al., 2000).

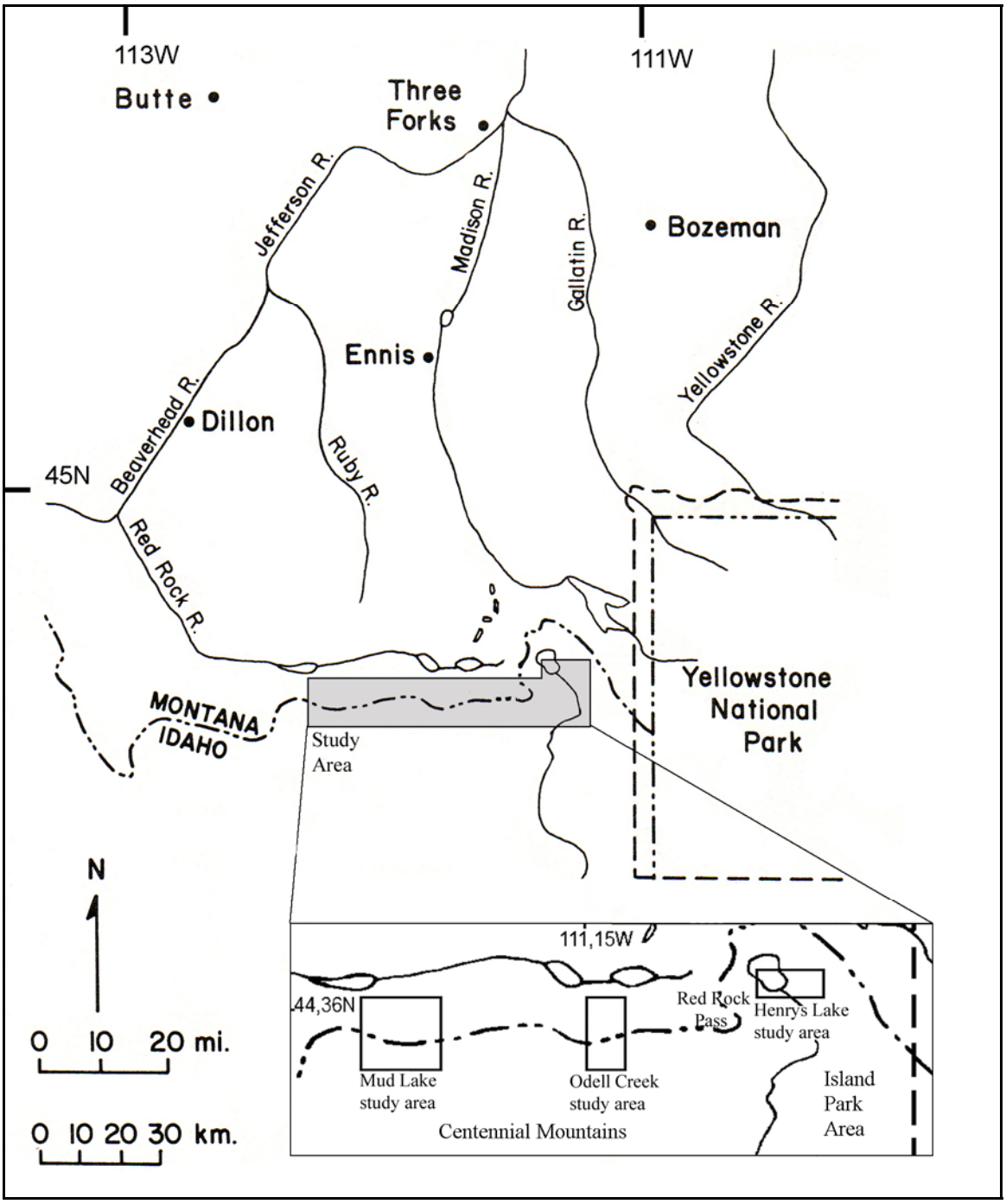

Figure 4. Location map for the research area with enlargement of the three study areas (Mud Lake, Odell Creek and Henrys Lake). From east to west, the four water bodies in the research area are: Henrys Lake, upper and lower Red Rock Lakes, and Lima Reservoir.

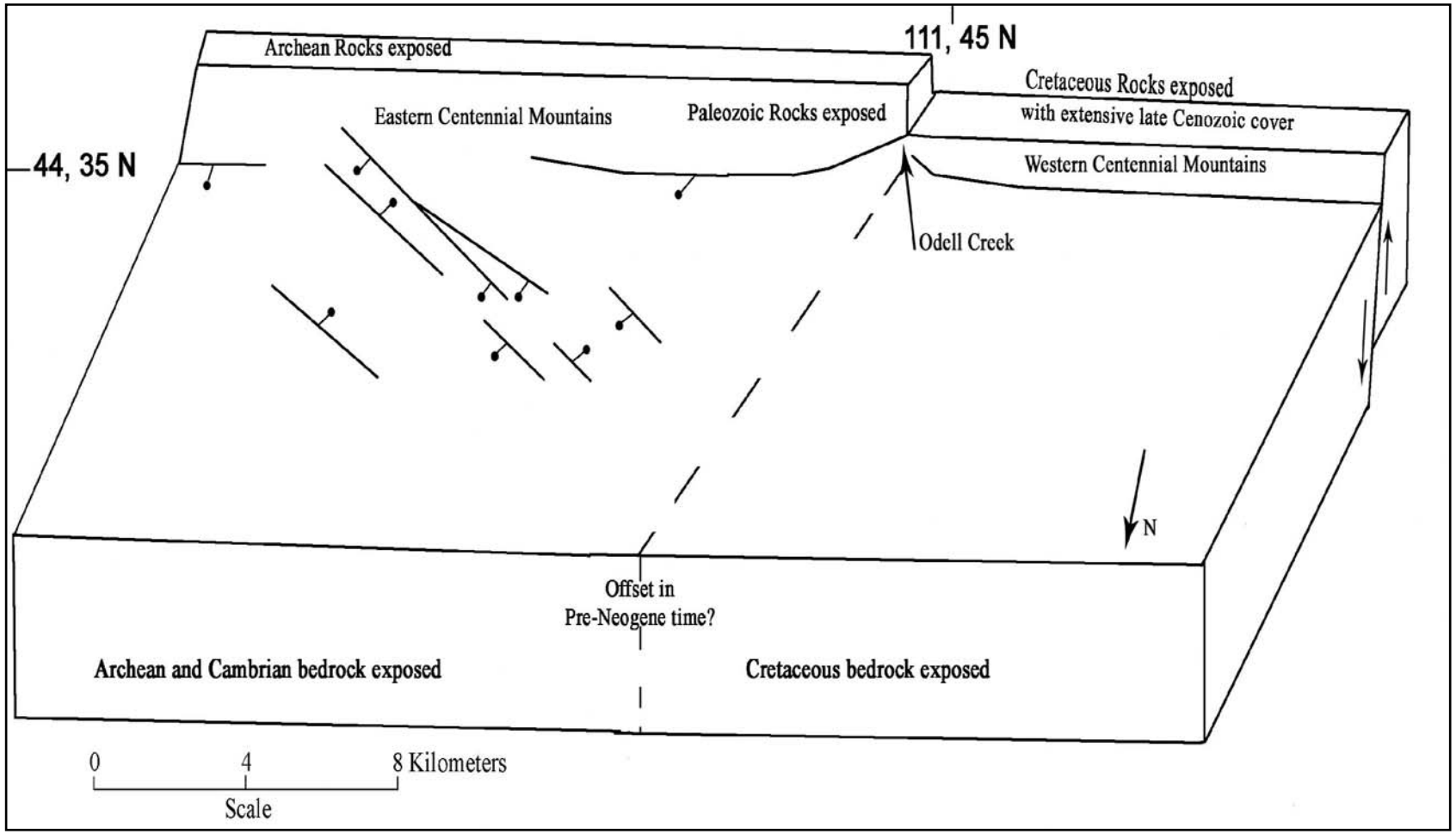

Figure 5. Block diagram depicting the eastern versus western Centennial Mountains divided by the Odell Creek fault with the *en echelon* fault traces located in the eastern Centennial Mountains. The western Centennial Mountains mainly expose Cretaceous rocks whereas the eastern Centennial Mountains expose Archean and Paleozoic rocks. The main CNF trace is drawn in at the base of the Centennial Mountains and the bar-and-ball symbols are on the hanging wall block. The Odell Creek fault does not offset the Quaternary cover in the Centennial Valley.

Local Stratigraphy

Precambrian: The Precambrian basement rocks of the Centennial Mountains are primarily metamorphic and exposed in the core of the eastern Centennial Mountains (Figure 5) (Witkind, 1980). Seven mappable units of the Precambrian sequence were recognized by O'Neill and Christiansen (2004) consisting of Archean tonalitic gneiss, dioritic gneiss, granite and granitic gneiss; Paleoproterozoic mica schist, quartzite, marble, and amphibolite (Plate 1).

Paleozoic: Precambrian rocks are overlain by Paleozoic rocks ranging from Middle Cambrian to Permian in age, with a composite thickness of approximately 950 meters (Witkind, 1980). The Paleozoic section comprises the north face of the eastern Centennial Mountains from Odell Creek on the west to east of Hell Roaring Creek (Witkind, 1980). These units are (stratigraphic order from oldest to youngest): Cambrian Flathead Sandstone, Wolsey Shale, Meagher Limestone, Park Shale, and Pilgrim Limestone; Ordovician Snowy Range and Bighorn Formations; Devonian Jefferson Dolomite; Upper Devonian to Lower Mississippian Three Forks Formation; Mississippian Madison Group; Upper Mississippian to Middle Pennsylvanian Amsden Formation; Pennsylvanian Quadrant Sandstone; and Permian Shedhorn Formation (O'Neill and Christiansen, 2004).

Mesozoic: The Mesozoic rocks in the eastern Centennial Mountains are approximately 700 meters thick and are overlain by a veneer of volcanic rocks forming the south-facing dip-slope of the mountain range (Witkind, 1980). Mesozoic rocks in the eastern Centennial Mountains comprise the following formations (stratigraphic order from oldest to youngest): Triassic Dinwoody and Woodside Formations; Jurassic Ellis Group and Morrison Formations; Cretaceous Kootenai; and, Thermopolis and Frontier Formations (O'Neill and Christiansen, 2004). These rocks are primarily siltstone, sandstone, marly limestone and shale forming the higher elevation dip slopes beneath the southward sloping volcanic rocks of the eastern Centennial Mountains (Witkind, 1980).

The Mesozoic rocks in the eastern Centennial Mountains are older than those exposed in the western Centennial Mountains (west of the Odell Creek fault). Specifically, the Cretaceous Frontier Formation is widely exposed along the western Centennial Mountains, whereas older Cretaceous and deeper units lack exposure (O'Neill and Christiansen, 2004). The north face of the western Centennial Mountains exposes interbedded sandstones, siltstones, mudstones, carbonaceous shales and coal seams of the Frontier Formation, capped by volcanic rocks along the crest and south flank of the mountain range (Witkind, 1980; O'Neill and Christiansen, 2004).

Cenozoic: The Cenozoic volcanic rocks exposed in the eastern Centennial Mountains are (stratigraphic order from oldest to youngest): the Eocene Absaroka Volcanic Supergroup, Eocene felsic and mafic volcanic rocks, 2.1 Ma Huckleberry Ridge Tuff and the 640 ka Lava Creek Tuff (Christiansen, 2001). Igneous rocks in the region are mostly widespread volcanic units extending along the south flank of the mountain

range from Sawtell Peak on the east to Monida on the west (Witkind, 1980; O'Neill and Christiansen, 2004). Sawtell Peak is underlain by dark gray, potassium-rich, Tertiary flows and flow breccias, forming the dominant topographic feature in the eastern part of the mountain range (Witkind, 1980; Christiansen, 2001; O'Neill and Christiansen, 2004). The volcanic rocks exposed along the crest of the eastern Centennial Mountains extend eastward and southward and are overlain by rhyolitic ash-flow tuffs of Plio-Pleistocene age, which were likely sourced from eruptions of the Yellowstone volcanic field (Christiansen, 2001).

In contrast, the western Centennial Mountains expose more volcanic rocks than the eastern Centennial Mountains. The highest topographic feature in the western part of the mountain range is Baldy Mountain, capped by lava flows and flow breccias of andesite and basalt (Witkind, 1980). The andesite and basalt are probably of Pliocene or Miocene (?) age, approximately 915 meters thick, and are separated into an upper and lower series by interlayered volcaniclastic rocks approximately 60 meters thick (Witkind, 1980). Similar to the eastern Centennial Mountains, the andesite and basalt are overlain by light-gray rhyolitic ash-flow tuffs of Plio-Pleistocene age that form a southward dip-slope in the footwall of the CNF (Witkind, 1980).

Quaternary deposits along the eastern Centennial Mountains are mostly glacial till and late Pleistocene alluvial fan gravels. Glacial erratics occur in several places in the Centennial Mountains and remnants of widespread glacial deposits occur along the flanks and crest of the mountain range (Witkind, 1980). Younger glacial deposits along the eastern Centennial Mountains include lobate, terminal moraines at the mouth of almost

every valley along the northern range front (Witkind, 1980); the age of most of these moraines is probably Pinedale and Witkind (1975b) has mapped them as Pinedale.

Quaternary surficial deposits along the western Centennial Mountains include landslide, alluvium, talus/boulders, and minor glacial deposits. The western Centennial Mountains contain a much greater area covered by earthflow and landslide material than the eastern Centennial Mountains, forming elongate and hummocky deposits. Witkind (1980) proposed that these earthflows formed due to water saturation during glacial times causing near-surface material to become mobilized. The Cretaceous Frontier Formation is weakly consolidated and prone to land slides in this part of the western Centennial Mountains (O'Neill and Christiansen, 2004).

Methods

The following methods were used to answer the four specific research questions.

Method 1: Mapping

The CNF was remapped at 1:24,000-scale by walking the fault scarp trace and recording way-points with a Magellan® Sport Trak Map handheld GPS with instrument accuracy to within 3 meters. Previously published maps of Witkind (1972, 1975, 1976, 1980), Lonn et al. (2000) and O'Neill and Christiansen (2004) aided in looking for the location of the CNF. The fault location was mapped as accurately as possible by hand-drawing its location on topographic maps in the field coupled with plotting GPS way-points. Additionally, the determination of fault scarp quality and "type" classification of

fault scarp exposure were done in the field. The "type" classifications are definite, inferred, inferred/concealed, and concealed as defined in Table 1.

Three areas chosen for additional study were constrained by quality of fault exposure and the need for refined map locations of Quaternary units. This detailed mapping allowed such features as antithetic fault scarps, grabens and ramp relays to be portrayed on large-scale maps. Previously mapped Quaternary units (Witkind, 1975b) were field checked and updated where modification was needed as per the detailed mapping scale of this project.

Table 1. Explanation for the classification scheme for determination of fault scarps. This classification scheme was developed by the author and was constructed for this research area based on criteria that seemed internally consistent.

Definite Shown as:	Definite must contain at least four of the six following: • Lateral continuity (for a minimum of 100 meters) • Change-in-slope (minimum of 10°) • Lush vegetation (green and vibrant while the surrounding is dry; occurs during the summer) • Natural springs (trickling water at the source) • Far-field surface alignment (minimum 10 meters) • Alluvial fan apex offset (minimum 2 meters)
Inferred Shown as:	Inferred must contain the following: • Lateral continuity (for a minimum of 100 meters) • Change-in-slope (minimum of 10°) • Lush vegetation (green and vibrant while the surrounding is dry and dead; occurs during the summer)
Inferred/concealed Shown as:	Inferred/concealed must contain the following: • Lateral continuity (for a minimum of 100 meters) • Change-in-slope (minimum of 10°)
Concealed Shown as:	Concealed must contain the following: • Lateral continuity beyond the concealed or covered area, or inferred based on geophysics or projection

Method 2: Fault Scarp Profiling

After mapping the location of the CNF, 51 fault scarp profile locations were selected based on the best exposures and preservation of the scarp (Appendix A). Profiles were measured perpendicular to each scarp using an Abney level and 100 m fiberglass measuring tape calibrated to the closest 10 mm, stretched from the hip of the recording person to the hip of the stadia person. The slope angle of each increment was measured to ±0.5º.

Depending on local topography and cover, each profile started approximately 10–15 m from the scarp on the far-field hanging wall and continued approximately 10–15 m beyond the head of the scarp into the far-field footwall, following the procedure recommended by McCalpin (1996). Scarp profile data were then entered into a USGS scarp profile program (Excel format), created by Barton Kiburz (USGS) and provided by M.N. Machette, to calculate surface offset and scarp height.

Method 3: Age Calculations

Age calculations were tried as an experiment and explained below. This experiment did not yield valid results in many cases because the following problems: 1) the scarps are multiple event scarps rather than single event scarps, 2) the surface of the hanging wall is commonly much younger than that of the footwall rather than of the same age, and 3) a good age estimate was not established to constrain the amount of time since offset. Analysis of the vertical surface offset across the fault scarp, obtained from the fault scarp profile data, was performed to determine the estimated age of scarp formation using the linear-plus-cubic diffusion model of Andrews and Bucknam (1987). The

linear-plus-cubic diffusion model is only applicable to fault scarps that contain the following criteria: 1) single-event fault scarp, 2) unconsolidated sediment (not bedrock), 3) good far-field correlation across the fault scarp profile, 4) a strong correlation between a hanging wall and footwall datum, 5) good age estimate (e.g. late Pleistocene deposits), and 6) semi-arid Basin and Range setting. Because the scarps profiled do not meet these qualifications, the results of the calculations are not valid.

The linear-plus-cubic diffusion model is as follows:

$$t = t' \, (SO)^2/K_0$$

where t is the calculated age of scarp, t' is a dimensionless scarp age, SO is the vertical surface offset across the scarp (see Appendix A for values used in this study), and K_0 is the diffusion constant (mass diffusivity) at 0° fan slope. Values of t' are from McCalpin (1996, p.136), and relate the "maximum scarp slope angle (Θ) and the ambient (far-field) angle of the faulted slope (α)" (McCalpin, 1996, p. 135). McCalpin (1996, p. 135) explains the intervals are calibrated for a range in data derived from independently dated scarps and the K_0 values were back calculated from scarps in the Basin and Range province dated from 0.46 to 0.52 m^2/1000 yr.

Several issues exist when utilizing the linear-plus-cubic diffusion model. McCalpin (1996, p.135) states that the linear-plus-cubic diffusion model should not be used if Θ (maximum angle) – α (far-field angle) <10° or if α ≥ 10°, because it is extremely sensitive to minute changes in both Θ and α values. Therefore, K_0 values have only been back-calculated for scarps less than 31° based on dated scarps in the Basin and Range province (McCalpin, 1996, p. 135). However, these values are not necessarily the

most accurate for this study location due to wetter climate conditions, fault scarp preservation (scarps found in materials ranging from glacial till to cloggy slope wash and bedrock) and rupture history. In addition, this model is best utilized when applied to single event fault scarps (~ 3 m or less) that offset Quaternary deposits and is not applicable to fault scarps that offset bedrock. If this model is used on multiple event fault scarps, the diffusion dating will yield an inaccurate fault scarp age. The estimated age for multiple events will include a larger surface offset value than for the most recent event causing the estimated age to appear older than an estimated age for a single event (McCalpin, 1996). This was taken into consideration when applying the linear-plus-cubic diffusion model to fault scarp profiles for multiple event scarps and the ages estimated for these scarps are to be used only as a rough estimate to constrain the last rupture event on the fault scarp profiles in the Centennial Mountains. Only estimated ages for single event scarps are discussed in the thesis. For all estimated calculated ages refer to Appendix C.

CHAPTER 2

OBSERVATIONS

The map relations, range front morphology and fault scarp profile characteristics will be discussed for the following four geographical areas, beginning at the west end of the field area. Area 1: Mud Lake to Winslow Creek Section (Plates 1 and 2); Area 2: Winslow Creek to Upper Red Rock Lake Section (Plates 1 and 3); Area 3: Red Rock Pass Section (Plate 1); and, Area 4: Henrys Lake Section (Plates 1 and 4). The postulated segment boundary at Odell Creek is in the middle of Area 2, between Sub-sections A and B.

Area 1: Mud Lake to Winslow Creek Section

Map Relations

The western end of the CNF surface expression extends approximately 1 km further west than previously mapped by Witkind (1975b) and Lonn et al. (2000). The new section of the CNF was added to the map, just southwest of Mud Lake at 44°36'N, 112°12'W. The fault was extended west based on the break-in-slope, lateral continuity, and juxtaposition of the Tertiary rhyolite and Quaternary colluvium. The western tip looses definition in a young Quaternary alluvial fan, while the eastern tip of this segment dies out in the Cretaceous Frontier Formation.

A transfer zone is formed between the eastern end of the newly mapped segment and the western end of the previously mapped CNF. They overlap approximately 0.5 km

and the distance between the two scarps is also approximately 0.5 km. The CNF scarp reappears in the valley just south of Mud Lake and continues east along the northern side of the Southside Centennial Road. The CNF scarp eventually crosses the Southside Centennial Road where it bifurcates (Figure 6). One branch of the diverging fault scarp extends south of the road and continues east for approximately 1.5 km, while the other branch extends approximately 1 km into the mountain front and dies in the Cretaceous Frontier Formation. Continuing east, the CNF has a single surface expression along the western mountain front.

Figure 6. The upper fault scarp offsets bedrock and lower fault scarp offsetting a late Pleistocene (?) alluvial fan. Photo was taken just south of Mud Lake, looking south at the Centennial Mountains in the distance.

Along the CNF in the Mud Lake to Winslow Creek Section several small antithetic fault scarps are present, forming hanging wall grabens (Figure 7). Each of the

antithetic fault scarps has small (< 0.5 m) surface offset and the individual smaller breaks do not extend laterally for more than 10 to 15 meters. The antithetic fault scarps are present on the valley side of a late Pleistocene alluvial fan, north of the present graben. Where offsetting of the late Pleistocene alluvial fan, the fault trace of the CNF has a maximum surface offset of 1.6 m, this is anomalous. Where the antithetic fault scarps are absent the CNF commonly has a surface offset >7 m offsetting either larger late Pleistocene alluvial fans or bedrock in the footwall block and Quaternary deposits in the haning wall block.

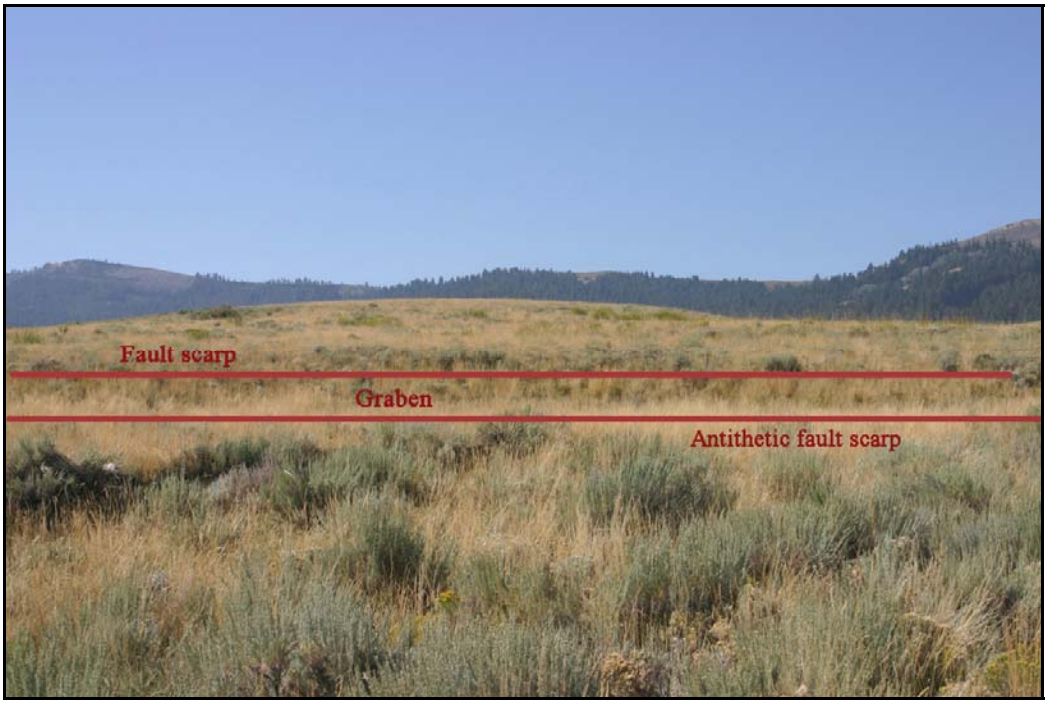

Figure 7. Fault scarp offsetting an alluvial fan located in the western portion of the research area just east of Figure 6. In front of the fault scarp is the graben formed from an antithetic fault scarp. Photo was taken looking south towards the Centennial Mountains.

New units were added to the classification of Quaternary deposits. Quaternary "scarp slump" and "scarp slump/fan" deposits are only found in the Mud Lake to

Winslow Creek Section. They are the result of mass wasting associated with the unstable and incompetent Cretaceous Frontier Formation. These mass wasting deposits are common on the steep fault scarp in bedrock.

The CNF maintains a single fault scarp for the rest of its exposed trace eastward to the Winslow Creek section, at which point the trace overlaps resulting in two fault scarps for approximately 40 m. The lower (northern) fault scarp dies out in a late Pleistocene (?) alluvial fan and is replaced by the upper (southern) fault scarp trace, which becomes the dominant exposure for the eastern trace of the CNF. This small transfer zone occurs in the Cretaceous Frontier Formation.

The surface expression of the CNF is linear in an east-west orientation from Mud Lake to Price Creek (Figure 8). A left-stepping *en echelon* pattern is exhibited between Price Creek and Jones Creek. The left-stepping *en echelon* jogs in conjunction with a small component of inferred right-lateral oblique-slip on the CNF coincide with drainages in the Cretaceous Frontier Formation.

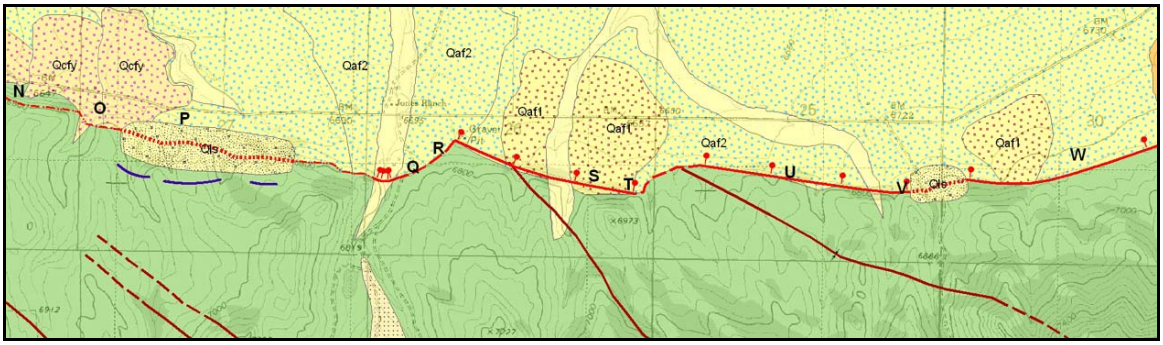

Figure 8. Close up of Plate 1 depicting the left stepping of the CNF (red line in center of figure). Refer to Appendix A for fault scarp profile data and to Appendix B for rock unit names and descriptions.

Range Front Morphology

The range front morphology for the western-most Centennial Mountains consists of a resistant volcanic cap underlain by the Cretaceous Frontier Formation. The Cretaceous Frontier Formation is the main source for the common Quaternary earthflow and landslide deposits. At the fault scarp the Cretaceous Frontier Formation forms elongated triangular facets between broad v-shaped drainages probably active during seasonal run-off. These broad V-shaped drainages continue to the break-in-slope created by the fault scarp of the western CNF. The Cretaceous Frontier Formation is intermingled with Quaternary colluvial deposits along the mid-slope of the western Centennial Mountains. A strong development of young Quaternary alluvial fans and young Quaternary coalesced alluvial fans along with sparse development of Quaternary earthflow and landslide material occurs along the mountain-front break-in-slope adjacent to the fault scarps. Between the range crest and CNF, the overall slope is not very steep and is controlled by the interaction of the unstable and incompetent Cretaceous Frontier Formation with weathering, erosion, and mass wasting processes. The slope becomes steeper along the fault scarps at the base of the mountain front. The slope becomes gentler up-slope from the fault scarps until the base of the resistant volcanic cap at which point the slope steepens.

Profile Characteristics

The profile segments represented by double fault scarps were divided into lower and upper sections for ease of comparison. The fault scarps in the Mud Lake to Winslow Creek Section offset Cretaceous Frontier Formation (only in the footwall block),

Quaternary alluvial fans of inferred late Pleistocene age (Pierce and Scott, 1982; Pierce, 2007, written communication). The surface offsets occurring in bedrock units, such as the Cretaceous Frontier Formation, only have visible bedrock in the footwall blocks (the surface of the hanging wall blocks are mostly buried by Quaternary deposits) and offset surfaces are not correlatable across the fault scarp. This is not a true surface offset. The fault scarps on the Cretaceous Frontier Formation yield apparent "surface offsets" that range from 8.6-48.2 m, with a mean of 27.7 m (Table 2). The surface offsets within Cretaceous rocks are predominantly multiple-event double fault scarps with an average maximum slope angle of 29.5°. The (true) surface offsets on the late Pleistocene alluvial fans range from 0.8-13.6 m, with a mean of 8.4 m. The fault scarp expressions in late Pleistocene fan gravels are predominantly multiple-event single fault scarps with an average maximum slope angle of 24.0°.

Twenty-five profiles were measured along this section and of these the best preserved fault scarps are: A, B, D, E, I, Q, V, W and X (Plate 1 and Appendix A). The poorest preserved fault scarps are: G, L and M. The overall preservation quality of the fault scarps in this portion of the field area is very good, with only minor earthflows/landslide debris covering the scarps.

Table 2. Fault scarp profile variables for the Mud Lake to Winslow Creek section. The double scarp refers to the surface offsets that have both an upper and a lower expression. The single scarp with graben and antithetic scarp refer to the profiles discussed earlier in this chapter. Refer to Appendix A for a complete database for each profile. * indicates apparent surface offset where bedrock in footwall block does not correspond to late Quaternary deposits in hanging wall block.

Profile	Surface Offset (meters)	Scarp Height (meters)	Maximum angle (degrees)	Formation offset	Type of Offset
A Lower Upper	33.60* 15.80* 10.90*	41.30 24.50 27.20	 34.5° (lower) 22.5°(upper)	Bedrock- in footwall block	Double scarp Multiple-event
B Lower Upper	34.70* 14.70* 8.60*	39.10 19.40 13.20	 33.0° (lower) 26.0° (upper)	Bedrock- in footwall block	Double scarp Multiple-event
C Lower Upper	31.20* 18.60* 13.40*	43.70 21.70 20.40	 27.0° (lower) 29.5° (upper)	Bedrock- in footwall block	Double scarp Multiple-event
D	0.80	1.10	16.5°	Late Pleistocene Alluvial fan	Single scarp with graben and antithetic scarp Single event
E	1.40	1.60	21.0°	Late Pleistocene Alluvial fan	Single scarp with graben and antithetic scarp Single event
F Lower Upper	43.90* 20.50* 11.90*	76.80 27.10 18.30	 27.0° (lower) 24.0° (upper)	Bedrock- in footwall block	Double scarp Multiple-event
G	19.30*	48.60	12.5°	Bedrock- in footwall block	Single scarp Multiple-event
H	39.10*	55.80	25.5°	Bedrock- in footwall block	Double scarp with graben and antithetic scarp Multiple-event
I	7.40	8.90	24.0°	Late Pleistocene Alluvial fan	Single scarp Multiple-event
J	32.20*	33.70	36.0°	Bedrock- in footwall block	Single scarp Multiple-event
K	33.10*	55.0	27.5°	Bedrock- in footwall block	Double scarp Multiple-event

Table 2 Continued. Fault scarp profile variables for the Mud Lake to Winslow Creek section. The double scarp refers to the surface offsets that have both an upper and a lower expression. The single scarp with graben and antithetic scarp refer to the profiles discussed earlier in this chapter. Refer to Appendix A for a complete database for each profile. * indicates apparent surface offset where bedrock in footwall block does not correspond to late Quaternary deposits in hanging wall block.

Profile	Surface Offset (meters)	Scarp Height (meters)	Maximum angle (degrees)	Formation offset	Type of Offset
L	45.70*	55.20	35.0°	Bedrock- in footwall block	Single scarp with inferred upper scarp Multiple-event
M	35.20*	71.40	42.5°	Bedrock- in footwall block	Single scarp with inferred upper scarp Multiple-event
N	39.00*	51.00	37.5°	Bedrock- in footwall block	Single scarp Multiple-event
O	48.20*	60.20	31.5°	Bedrock- in footwall block	Single scarp Multiple-event
P	29.90*	41.70	27.5°	Bedrock- in footwall block	Single scarp with inferred upper scarp Multiple-event
Q	11.20	11.30	27.5°	Late Pleistocene Alluvial fan	Single scarp with graben and antithetic scarp Multiple-event
R	30.80*	35.30	32.0°	Bedrock- in footwall block	Single scarp Multiple-event
S	8.10	10.50	23.0°	Late Pleistocene Alluvial gravel	Single scarp Multiple-event
T	11.90	13.70	30.0°	Late Pleistocene Alluvial gravel	Single scarp Multiple-event
U	8.90	13.80	20.5°	Post late Pleistocene Alluvial gravel	Single scarp Multiple-event

Table 2 Continued. Fault scarp profile variables for the Mud Lake to Winslow Creek section. The double scarp refers to the surface offsets that have both an upper and a lower expression. The single scarp with graben and antithetic scarp refer to the profiles discussed earlier in this chapter. Refer to Appendix A for a complete database for each profile. * indicates apparent surface offset where bedrock in footwall block does not correspond to late Quaternary deposits in hanging wall block.

Profile	Surface Offset (meters)	Scarp Height (meters)	Maximum angle (degrees)	Formation offset	Type of Offset
V	13.60	17.70	27.0°	Late Pleistocene Alluvial gravel	Single scarp Multiple-event
W	9.20	13.90	20.0°	Late Pleistocene Alluvial fan	Single scarp Multiple-event
X	11.60	13.50	27.0°	Late Pleistocene Alluvial fan	Single scarp Multiple-event
Y	18.00	24.50	31.5°	Late Pleistocene Alluvial fan	Single scarp with inferred upper scarp Multiple-event

Area 2: Winslow Creek to Upper Red Rock Lake Section

Map Relations

The Winslow Creek to Upper Red Rock Lake (WCURRL) section is divided by the Odell Creek fault into Sub-section A (west) and Sub-section B (east). Sub-section A was mapped as inferred and concealed due to its lack of clear surface expression in the unstable Cretaceous Frontier Formation (footwall block), Tertiary mafic volcanics (footwall block), Quaternary landslide deposits, and young Quaternary alluvial fans. Sub-section B was mapped as definite in some location and the rest as inferred to inferred/concealed. Sub-section B of the WCURRL is 5.6 km long and more linear than

Sub-section A (16 km). Sub-section B offsets Precambrian to Paleozoic rocks in the footwall block and dies out eastward into Precambrian mica schist.

The western edge of Sub-section A has two fault scarp exposures that both dip to the north. The two fault exposures run parallel for ~ 2.5 km and are ~ 1.3 km apart. The upper (southern-mountain ward) fault scarp extends east and is the dominate exposure of the CNF until it reaches the large earthflow and landslide. There are five mappable landslides with hummocky topography obscuring the CNF trace along Sub-section A (Figure 9). One landslide or glacial moraine deposit is offset by a fault trace with sharp break-in-slope and lateral continuity. Profile "AA" was measured at this location and is classified as probably offsetting a glacial moraine of Pinedale age, to give a likely constraint on the age (Pierce, 2007, written communication). The fault trace mapped in the Quaternary landslide deposits is interpreted as a secondary splay of the CNF.

A new optional fault trace interpretation is shown up-slope from another optional obscured CNF trace at the foot of the Centennial Mountains. The new interpretation is located in the Cretaceous Frontier Formation. The new fault scarp interpretation is mapped as inferred/concealed. The placement of the fault trace was based in part on topographic break-in-slope and was not field checked. Although the new fault trace is only an interpretation based on topographic evaluation, the placement supports the continuation of the inferred fault trace to the west and the new inferred fault trace to the east (supported by fault scarp profile data). This new fault trace continues in the same northwest direction as seen along the eastern Centennial Mountains. It links the minor northwest-trending left-stepping *en echelon* pattern seen in map view along the western Centennial Mountains with the more dramatic northwest-trending left-stepping *en*

echelon pattern found in the eastern Centennial Mountains. The addition of the new fault trace offers two interpretations of the CNF for the Baldy Mountain section as shown on the map (Plate 1). The first option is that the main fault trace is further up-slope in the mountain mass Cretaceous Frontier Formation. This assumes that the whole north slope of the range is collapsing and spreading northward across the fault at depth and covering the fault (Pierce, 2007, written communication). The second option is that the main fault trace is at the foot of the range and is obscured by the earthflow and landslide debris.

Figure 9. Behind the Lakeview Cemetery sign is the hummocky topography of the Quaternary landslide in the Cretaceous Frontier Formation. Such landsliding largely obscures the fault in Sub-section A. Lakeview Cemetery is located just west of the village of Lakeview. Photo was taken from Southside Centennial Road looking south towards the Centennial Mountains.

The map location of the eastern boundary of Sub-section A was defined along the mountain-valley break-in-slope. This interpretation differs from Witkind (1975b), who

mapped the CNF across the Odell Creek alluvial fan (Plate 3). This new interpretation was based on break-in-slope, lateral continuity and occurrence of natural springs. The eastern extent of Sub-section A either terminates against or merges into the Odell Creek fault along the apex of the Odell Creek alluvial fan. Neither relationship can be distinguished by field data due to forest and ground cover. This interpretation is reinforced by the gravity study of Sonderegger et al. (1982) which placed the CNF in the same location mapped in this study.

The Odell Creek fault is a significant section of the CNF on the east side of the Odell Creek reentrant in the central part of the Centennial Mountains. The northeast-southwest Odell Creek fault curves to the east and merges with the large newly mapped surface offset that is well exposed just below very steep slopes exposing Paleozoic-Precambrian rocks of the Taylor Mountain block (Figure 10). The Cretaceous Frontier Formation in the western Centennial Mountains is locally in the hanging wall of the Odell Creek fault, whereas Paleozoic strata in the eastern Centennial Mountains are the footwall. A gravity anomaly (Sonderegger et al., 1982) with a similar pattern rounds the corner of the Odell Creek fault and coincides with the main CNF trace aiding the new interpretation of the Odell Creek fault. Previous workers (Witkind, 1975b, 1976; Sonderegger et al., 1982) have continued the northeast-trend of the Odell Creek fault into the Centennial Valley although there is no surface expression of faulting in Quaternary deposits including the 2.1 Ma Huckleberry Ridge tuff, indicating that all offset along the Odell Creek fault occurred pre-2.1 Ma. Three gravity anomalies with a similar northeast trend as the previously mapped Odell Creek fault were interpreted in the Centennial Valley and Cliff Lake area (Sonderegger et al., 1982) and are labeled as such on Plate 1.

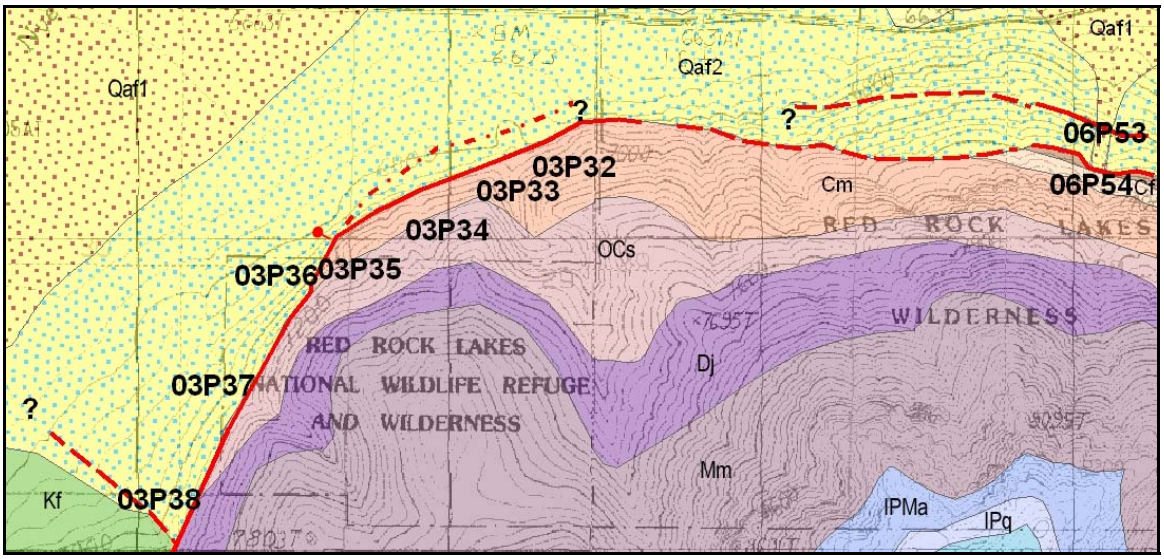

Figure 10. Close up of Plates 1 and 3 depicting the intersection connecting the Odell Creek fault with the CNF (red line in center of figure). North is at the top of the figure. Refer to Appendix A for fault scarp profile data and to Appendix B for rock unit names and descriptions. Profile data shown here was collected by Dr. Ken Pierce (2007, written communication).

Most of Sub-section B is mapped as inferred because this area is forested and part of it could not be accessed in the field due to private land. The northern mapped fault strand is a minor fault offsetting late Quaternary alluvial fan (Witkind, 1975b). The main surface expression of the CNF is located at the base of the steep slopes, the southern fault zone shown on the maps. The solid red line of the CNF (including the locations along the Odell Creek section) was studied and mapped by Dr. Ken Pierce (2007, written communication). This (dashed) fault trace is based on the break-in-slope across Sheep Mountain and Taylor Mountain until it loses surface expression in the Tom Creek drainage. The northern fault trace re-emerges in the Quaternary glacial till and continues east until it bifurcates and loses exposure in the Paleoproterozoic mica schist just past the eastern border of the WCURRL section. Both fault traces are mapped as inferred and can be better constrained with future field investigations.

Range Front Morphology

The range front morphology for Sub-section A of the Centennial Mountains consists of Tertiary volcanic capping including wide spread Quaternary earthflow and landslide deposits. The Tertiary volcanic cover and Quaternary earthflow and landslide deposits constitute the summit of Baldy Mountain and continue down its flanks. On the north face of Baldy Mountain, the Cretaceous Frontier Formation commonly slumps and forms the Quaternary earthflow and landslide deposits that extend to and obliterate this section of the CNF. In the areas just above the new optional fault trace where the Cretaceous Frontier Formation is intact, it locally forms triangular facets. The Quaternary earthflow, landslide, and young and old alluvial fan deposits juxtapose against the inferred/concealed fault trace of the CNF. The morphology of the range front is strongly controlled by the juxtaposition of the unstable and incompetent Cretaceous Frontier Formation with weathering and mass wasting processes. Pierce (2007, written communication) has suggested that this part of the Centennial Mountains maybe collapsing under its own weight and spreading northward. This is supported by the mapped faults (Plate 1) in Tertiary mafic volcanic rocks which may indicate failure of the underlying Cretaceous Frontier Formation.

The range front morphology for Sub-section B of the Centennial Mountains consists of steep sharp cliffs in Precambrian and Paleozoic bedrock above fault scarps in the lower part of the range with Quaternary alluvial and colluvial deposits in the hanging wall block. Long avalanche chutes are common below Sheep Mountain (west) and Taylor Mountain (east) and contain the rocky debris from the steep cliffs above. Between some of the avalanche chutes, blunt steep faced triangular facets exist. There

are u-shaped glacial valleys above the steep fault scarps and were the source for the Quaternary glacial till deposits at the base of the fault scarps along the eastern part of Sub-section B. The morphology in this part of the Centennial Mountains is strongly controlled by the resistant to erosion Precambrian-Paleozoic lithology. In the eastern part of Sub-section B Quaternary glacial till lies juxtaposed against the inferred Precambrian basement and is offset by the CNF.

Profile Characteristics

Sub-section A of the Winslow Creek to Upper Red Rock Lake (west of Odell Creek) fault scarps offset Cretaceous Frontier Formation (footwall block), Quaternary alluvium, landslide and colluvial material. Many of the Quaternary alluvium, landslide and colluvial deposits are classified as late Pleistocene by Pierce (2007, written communication). Apparent "surface offset" on the footwall block comprised of Cretaceous Frontier Formation is 47.4 m (Table 3). The surface offset on inferred Pinedale glacial moraine is 8.8 m and the late Pleistocene stream gravel deposits is 8.0 m. The offset of Cretaceous is predominantly a multiple-event fault scarp with a maximum slope angle of 28.0°. The scarp in the Pinedale glacial moraine is a multiple-event scarp with a maximum slope angle of 20.0°. The scarp in the late Pleistocene stream gravel is a multiple-event scarp with a maximum slope angle of 42.0°.

Sub-section B (east of Odell Creek) fault scarps have Precambrian to Paleozoic bedrock in the footwall and locally offset deposits of glacial till, alluvium and colluvium (Table 4). The surface offset on late Pleistocene alluvial fan ranges from 1.6-5.8 m with a mean of 3.5 m. The scarp in the late Pleistocene alluvial fan may be a single-event

scarp with a maximum slope angle of 28.0°. The late Pleistocene deposits are predominantly multiple-event fault scarps with an average maximum slope angle of 30.0°.

Six fault scarp profiles were measured along this section, of these the best preserved is AD (Plate 1 and Appendix A). The overall quality of fault scarp preservation is very poor for this portion of the field area with the majority of the fault traces concealed by earthflows/landslide material.

Table 3. Fault scarp profile variables for the Winslow Creek to Upper Red Rock Lake Sub-section A. The double scarp refers to the surface offsets that have both an upper and a lower expression. Refer to Appendix A for a complete database for each profile. * indicates apparent surface offset where bedrock in footwall block does not correspond to late Quaternary deposits in hanging wall block.

Profile	Surface Offset (meters)	Scarp Height (meters)	Maximum angle (degrees)	Formation offset	Type of Offset
Z	47.40*	59.80	28.0°	Bedrock- in footwall block	Double scarp Multiple-event
AA	8.80	20.00	20.0°	Glacial moraine (Pinedale?)	Single scarp Multiple-event
AB	8.00	9.80	42.0°	Late Pleistocene stream gravel	Single scarp Multiple-event

Table 4. Fault scarp profile variables for the Winslow Creek to Upper Red Rock Lake Sub-section B. The double scarp refers to the surface offsets that have both an upper and a lower expression. Refer to Appendix A for a complete database for each profile.

Profile	Surface Offset (meters)	Scarp Height (meters)	Maximum angle (degrees)	Formation offset	Type of Offset
AC	5.80	8.80	28.0°	Late Pleistocene/ alluvial fan	Single scarp Multiple-event
AD	3.00	4.30	19.5°	Late Pleistocene/ alluvial fan	Single scarp Single event
AE	1.60	3.20	27.0°	Late Pleistocene/ alluvial fan	Single scarp Single event

Fault scarp profile data collected by Dr. Ken Pierce (2007, written communication) show scarp height on the Precambrian-Paleozoic bedrock (footwall block) ranging from 22-45 m (Table 5). The exposed Precambrian- Paleozoic bedrock surface is predominantly a multiple-event fault scarp. No maximum slope angle was measured. The scarp heights in Quaternary colluvium (?) range from 10-20 m with a mean of 17.5 m. The Quaternary colluvium surface is predominantly a multiple-event fault scarp with a maximum slope angle of 40°. Two surface offsets on Pinedale glacial moraine are 8.4 m and 10.5 m and average 9.5 m and scarp height ranges from 14.2-30 with an average of 20.7 m. The Pinedale glacial moraine is a multiple-event fault scarp with a maximum slope angle of 38°.

Table 5. Fault scarp profile variables for the Winslow Creek to Upper Red Rock Lake Sub-section B as measured by Dr. Ken Pierce (2007, written communication). Est. = visual estimate of scarp height. Approx. = sighting with Abney level by one person.

Profile	Surface Offset (meters)	Scarp Height (meters)	Maximum angle (degrees)	Formation offset	Type of Offset
03P38	N/A	Not measured	N/A	Limestone- in footwall block	
03P37	N/A	Not measured	N/A	Landslide (?)	
03P36	N/A	~22 m	N/A	Bedrock-in footwall block	Multiple-event
03P35	N/A	~20 m est.	N/A	Colluvial debris at base	Multiple-event
03P34, upper of 3 scarps	N/A	~20 m est.	~33° approx.	Colluvium	Multiple-event
03P33	N/A	~10 m	~28° approx.	Colluvium	Multiple-event
03P32	N/A	~12 m	~31° approx.	Alluvial fan	Multiple-event
06P53	N/A	~20 m est.	~40° approx.	Colluvium	Multiple-event
06P54	N/A	~45 m est.	N/A	Bedrock-in footwall block	Multiple-event
02P70	10.5 m	14.2 m	38°	Pinedale lateral moraine	Multiple-event
02P72	8.4 m	18 m	35°	Pinedale lateral moraine	Multiple-event
02P73	N/A	~30?	N/A	Moraine?	Multiple-event

Area 3: Red Rock Pass Section

Map Relations

The Red Rock Pass section is divided into two sections by Hell Roaring Creek. The section from the eastern border of Upper Red Rock Lake to Hell Roaring Creek was remotely mapped due to lack of access on private land, whereas the section east of Hell

Roaring Creek to the eastern extent of the South Fork moraine was accessible and mapped in the field.

The remotely mapped section was evaluated for quality of fault scarp exposure from aerial photography and views from the Southside Centennial Road. The CNF scarp was mapped as "inferred/concealed" based on break-in-slope and lateral continuity.

This portion of the CNF is characterized by northwest-trending, *en echelon* fault traces that offset Precambrian bedrock, 2.1 Ma Huckleberry Ridge Tuff, and Quaternary alluvium and colluvium (Figure 11). On average, individual northwest-trending faults are 5.3 km long and range from 2.6-8 km in length. The overall appearance gives the eastern Centennial Mountains a distinctive left-stepping *en echelon* pattern, similar to but more dramatic than the *en echelon* pattern of the western Centennial Mountains. No fault scarps were observed offsetting Quaternary fan gravels for this part of the CNF.

The fault trace east of Hell Roaring Creek to the eastern margin of the South Fork moraine is approximately 4.8 km long. East of Hell Roaring Creek, the CNF surface trace is inferred to start in a young Quaternary alluvial fan at the break-in-slope at the base of Nemesis Mountain, but no offset in any young Quaternary alluvial fans was observed. The surface trace continues along the mountain-valley break for 1 km to the base of Nemesis Mountain, gaining elevation along the mountain front to the east along the break-in-slope exposing Paleoproterozoic marble. The scarp continues for 3.8 km past (east) Nemesis Mountain, connecting to the eastern margin of Red Rock Pass moraine. A recognizable fault scarp based on break-in-slope, lateral continuity and natural springs facilitated the mapping of the CNF through Red Rock Pass moraine

(Figure 12). Previous mapping (Witkind, 1975b) ended the surface expression of the CNF at the western margin of Red Rock Pass moraine.

There is an absence of a distinctive break-in-slope associated with the CNF through the area east of the Red Rock Pass moraine and it was mapped as inferred/concealed based on a weak expression through the forested terrain. The surface expression is obscured in many places by Quaternary glacial till and colluvium. The Red Rock Pass section ends at the eastern boundary of the South Fork moraine.

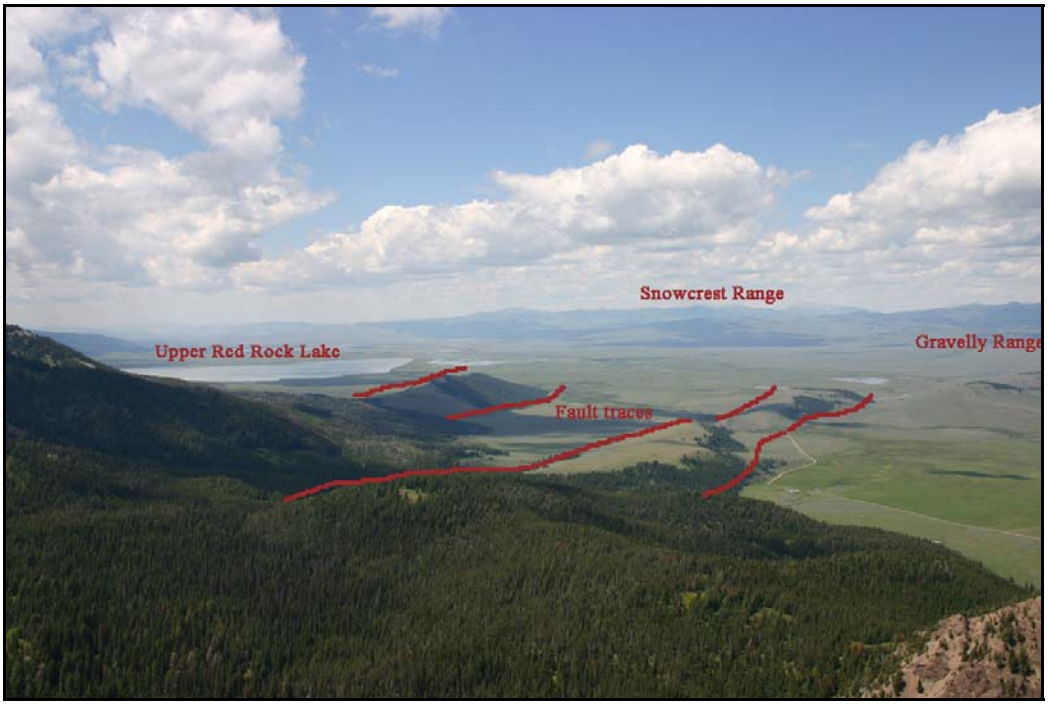

Figure 11. View showing the northwest-striking fault traces just east of Upper Red Rock Lake. Note the Snowcrest and southern Gravelly Ranges in the distance. The fault traces depicted here are part of the northwest trend that comprises the *en echelon* segments of the eastern Centennial Mountains. Photo was taken from the top of Nemesis Mountain looking west-northwest.

Range Front Morphology

The range front morphology for the western part of Red Rock Pass Section of the eastern Centennial Mountains consists of Precambrian- Paleozoic to 2.1 Ma Huckleberry Ridge tuff cored *en echelon* fault blocks. The faulted sides of the *en echelon* blocks consist of moderate to gently sloped surfaces that juxtapose Quaternary deposits at the base of the slope along the fault scarp contact. As the CNF fault trace continues east the *en echelon* fault trace loses expression to a more linear fault trace. This part of the CNF lies parallel to the steep break-in-slope of Nemesis Mountain, offsets the Red Rock Pass moraine, continues east at the steep break-in-slope of the Paleoproterozoic marble and is traced laterally in the late Pleistocene glacial till and colluvium deposits. This eastern part of the section is characterized by a large deposit of Quaternary colluvium and is characteristic of a large talus derived from the topographically higher cliffs.

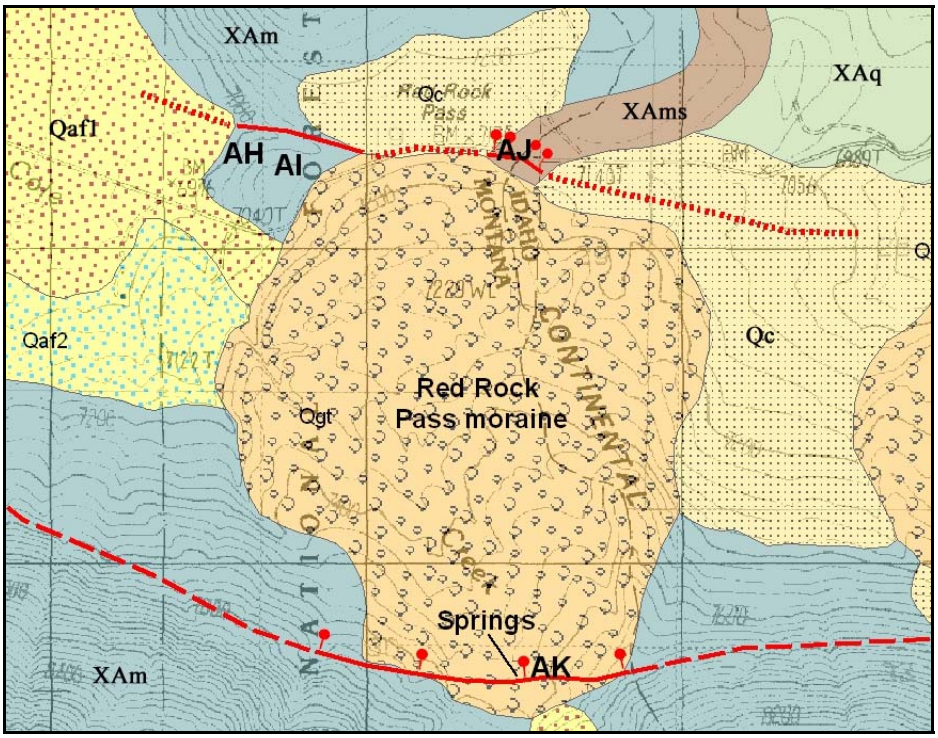

Figure 12. Close up of the map showing the new interpretation of the continuation of the CNF (red line in lower par of figure) across Red Rock Pass moraine. A minor strand of the fault is shown on the upper part of the figure. North is at the top of the figure. Refer to Appendix A for fault scarp profile data and to Appendix B for rock unit names and descriptions.

Profile Characteristics

Fault in the Red Rock Pass area have scarps in Precambrian- Paleozoic rock (only in the footwall block) and Pinedale glacial moraine. The "apparent surface offsets" on the Precambrian- Paleozoic rock ranges from 4.9-38.9 m, with a mean of 18.2 m (Table 6); surface offset on the Pinedale glacial moraine is 11.0 m. The Precambrian- Paleozoic scarps are predominantly multiple-event fault scarps with an average maximum slope angle of 22.5°. The scarp in the Pinedale glacial moraine is predominantly a multiple-event fault scarp with a maximum slope angle of 42.0°.

Six profiles were measured along this section; of these the best preserved fault scarps are AJ and AK (Plate 1 and Appendix A). The poorly preserved fault scarps are

AF, AG, AH and AI. The overall quality of fault scarp preservation is "good" for this portion of the field area with minor earthflows/landslide material covering the scarps. The best preserved fault scarp offsets glacial moraine and is relatively high in elevation along the CNF.

Table 6. Fault scarp profile variables for the Red Rock Pass section. The single scarp with graben and antithetic scarp refer to the profiles discussed earlier in this chapter. Refer to Appendix A for complete database for each profile. * indicates apparent surface offset where bedrock in footwall block does not correspond to late Quaternary deposits in hanging wall block.

Profile	Surface Offset (meters)	Scarp Height (meters)	Maximum angle (degrees)	Formation offset	Type of Offset
AF	35.80*	55.60	27.0°	Bedrock-marble (only in footwall block)	Single scarp Multiple-event
AG	38.90*	60.40	31.0°	Bedrock-marble (only in footwall block)	Single scarp Multiple-event
AH	5.20*	7.10	12.0°	Bedrock-in footwall block	Single scarp with graben and antithetic scarp Multiple-event
AI	4.90*	4.30	15.5°	Bedrock-in footwall block	Single scarp with graben and antithetic scarp Multiple-event
AJ	6.20*	7.80	28.0°	Bedrock-in footwall block	Single scarp Multiple-event
AK	11.00	12.00	42.0°	Glacial moraine (Pinedale?)	Single scarp Multiple-event

Area 4: Henrys Lake Section

Map Relations

The Henrys Lake section extends for approximately 12 km starting at the eastern boundary of the South Fork moraine. The eastern termination of the CNF lies at the intersection with US Highway 20 east of Henrys Lake. The linear east-west CNF trace changes direction to northeast-southwest at Bootjack Creek and continues along a linear trend to Henrys Lake. The CNF cuts across Tertiary Absaroka Volcanic Supergroup, the upper member of the 2.1 Ma Huckleberry Ridge Tuff and upper member of the Lava Creek Tuff, Quaternary glacial till (Pinedale?), alluvial fan gravel (Bull Lake?) and colluvium indicating young and recent rupture (Figure 13) (Witkind, 1975a).

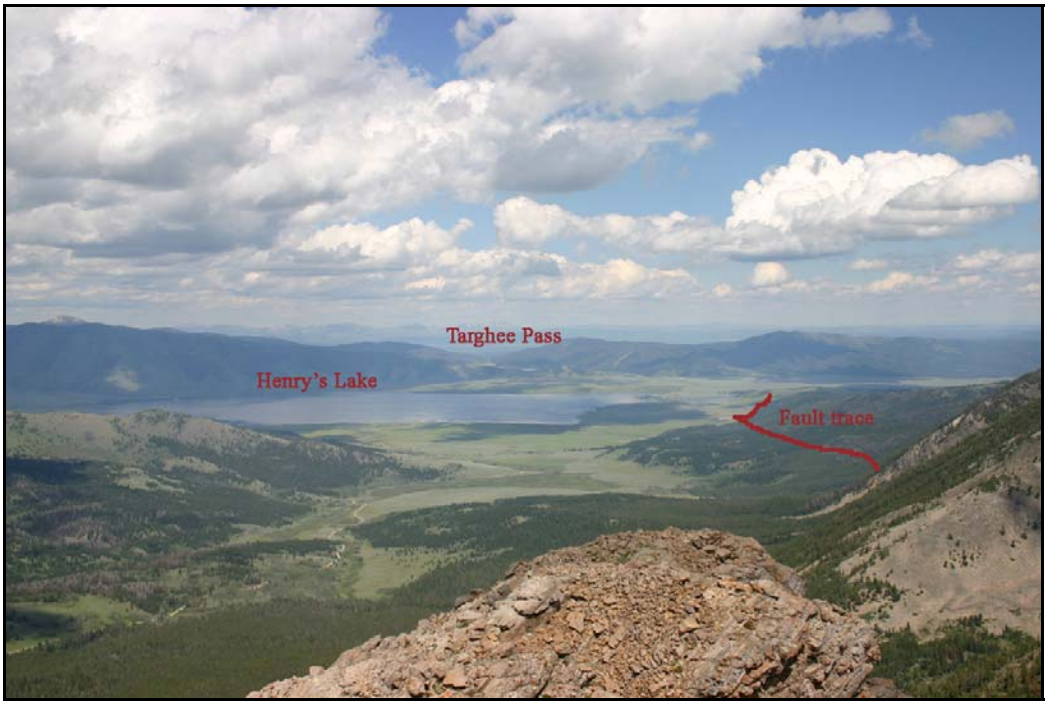

Figure 13. View to the east showing the fault trace from Rock Creek moraine to south side of Henrys Lake with Targhee Pass in the background. Photo was taken from the top of Nemesis Mountain looking northeast.

Approximately 2 linear kilometers of the CNF is covered by Quaternary colluvium from the eastern border of South Fork moraine to the western border of Rock Creek moraine. This section is mapped as "inferred" based on break-in-slope and lateral continuity. At the start of the Rock Creek moraine, the CNF has a definitive fault scarp, offsetting Quaternary glacial moraines (Pinedale?). The definitive break-in-slope may be traced laterally for ~ 4.2 km as it offsets Absaroka volcanic rocks and the upper member of the 2.1 Ma Huckleberry Ridge Tuff.

The CNF changes direction at Bootjack Creek and extends laterally for 3.2 km where it crosses the Southside Centennial Road. At this location the CNF is mapped as "inferred/concealed" for 2.9 km. The inferred/concealed trace traverses the upper member of the 2.1 Ma Huckleberry Ridge Tuff, upper member of the Lava Creek Tuff and alluvial fan gravel.

The CNF re-appears with a definitive surface expression at the eastern side of Henrys Lake State Park (Plate 4). The upper fault scarp surface expression of the CNF is ~ 1.5 km long, offsetting either the alluvial fan gravel of Bull Lake (?) age (Witkind, 1975a) or alluvial fan of Bull Lake to Pinedale in age (?) (Pierce, 2007, written communication). Along this segment of the CNF, 0.5 km-long synthetic and antithetic faults parallel the main strand of the CNF (Figure 14). The synthetic faults create a 0.2 km-wide ramp relay and the antithetic faults create a 0.2 km-wide graben. The CNF and antithetic faults surface lose surface expressions eastward near US Highway 20.

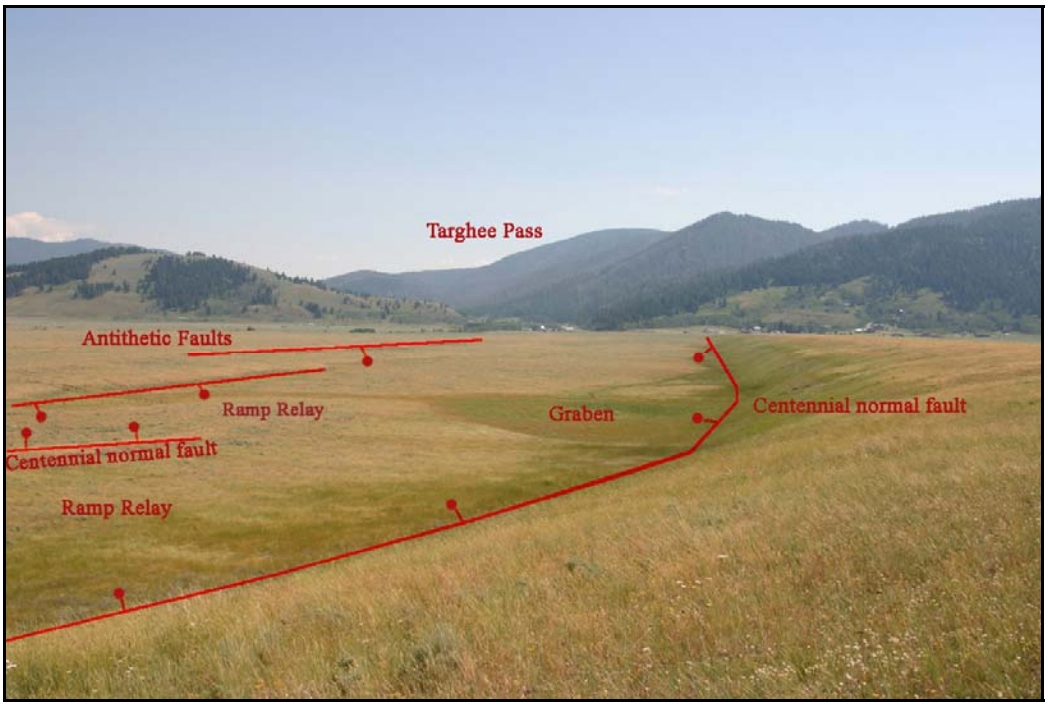

Figure 14. The CNF, antithetic faults, ramp relay and graben along Henrys Lake in the eastern section of the Henrys Lake section. Photo was taken from the top of the upper fault scarp looking northeast; the Targhee Pass is located in the background. Note there is no range front on the footwall block of the CNF in this area.

Range Front Morphology

The range front morphology of the eastern Centennial Mountains consists of a resistant and wide-spread deposit of Tertiary Absaroka Volcanic Supergroup. The CNF offsets the Tertiary Absaroka Volcanic Supergroup and the 2.1 Ma Huckleberry Ridge tuff forming moderately steep scarps. Basin-ward large Quaternary alluvial fans extend westward to Henrys Lake. The range-front stops at Bootjack Pass. There is no range-front in the Henrys Lake area.

Profile Characteristics

Surface scarps in 2.1 Ma Huckleberry Ridge tuff ranges from 2.2-21.6 m, with a mean of 12.0 m (Table 7). The surface offsets on Bull Lake (?) alluvial fan gravels range from 5.9-21.6 m, with a mean of 11.29 m. The 2.1 Ma Huckleberry Ridge tuff scarps are multiple-event fault scarps with an average maximum slope angle of 34.0°. Scarps in Bull Lake (?) alluvial fan gravel (Witkind, 1975a) or glacial deposits as young as Pinedale/late Pleistocene (?) (Pierce, 2007, written communication) are predominantly multiple-event fault scarps with an average maximum slope angle of 26.0°.

Thirteen profiles were measured along this section, of these the best preserved fault scarps are AN, AO, AP, AR, AS, AU, AV and AW (Plate 1 and Appendix A); the poorly preserved fault scarp is AQ. The overall preservation quality of the fault scarps is "very good" for this portion of the field area with no earthflows/landslide material covering the scarps.

Table 7. Fault scarp profile variables for the Henrys Lake section. The double scarp refers to the surface offsets that have both an upper and a lower expression. The single scarp with graben and antithetic scarp refer to the profiles discussed earlier in this chapter. Refer to Appendix A for complete database for each profile. * indicates apparent surface offset where bedrock in footwall block does not correspond to late Quaternary deposits in hanging wall block.

Profile	Surface Offset (meters)	Scarp Height (meters)	Maximum angle (degrees)	Formation offset	Type of Offset
AL	2.20*	5.40	42.0°	2.1 Ma Huckleberry Ridge tuff in footwall block	Single scarp Single event
AM	21.60*	27.30	29.0°	2.1 Ma Huckleberry Ridge tuff in footwall block	Single scarp Multiple-event
AN	12.20*	14.40	31.0°	2.1 Ma Huckleberry Ridge tuff in footwall block	Single scarp Multiple-event

Table 7 Continued. Fault scarp profile variables for the Henrys Lake section. The double scarp refers to the surface offsets that have both an upper and a lower expression. The single scarp with graben and antithetic scarp refer to the profiles discussed earlier in this chapter. Refer to Appendix A for complete database for each profile. * indicates apparent surface offset where bedrock in footwall block does not correspond to late Quaternary deposits in hanging wall block.

Profile	Surface Offset (meters)	Scarp Height (meters)	Maximum angle (degrees)	Formation offset	Type of Offset
AO Lower Upper	7.70 2.20 4.80	8.80 3.00 5.50	 19.0° (lower) 29.0° (upper)	Alluvial fan gravel (Bull Lake or Late Pleistocene?)	Double scarp Multiple-event
AP	9.80	10.80	36.0°	Alluvial fan gravel (Bull Lake or Late Pleistocene?)	Single scarp Multiple-event
AQ	8.30	8.20	19.5°	Alluvial fan gravel (Bull Lake or Late Pleistocene?)	Single scarp Multiple-event
AR	8.30	9.10	21.0°	Alluvial fan gravel (Bull Lake or Late Pleistocene?)	Single scarp Multiple-event
AS	11.30	12.40	20.0°	Alluvial fan gravel (Bull Lake or Late Pleistocene?)	Single scarp Multiple-event
AT Lower Upper	12.90 5.60 13.60	14.10 6.20 14.10	 14.5° (lower) 25.0° (upper)	Alluvial fan gravel (Bull Lake or Late Pleistocene?)	Double scarp with ramp relay Multiple-event
AU	19.50	19.30	28.0°	Alluvial fan gravel (Bull Lake or Late Pleistocene?)	Single scarp with graben and antithetic scarp Multiple-event
AV	21.60	21.50	26.0°	Alluvial fan gravel (Bull Lake or Late Pleistocene?)	Single scarp with graben and double antithetic scarp Multiple-event
AW	7.60	8.00	24.5°	Alluvial fan gravel (Bull Lake or Late Pleistocene?)	Single scarp with small graben and antithetic scarp Multiple-event
AX	5.90	5.90	27.0°	Alluvial fan gravel (Bull Lake or Late Pleistocene?)	Single scarp with graben and antithetic scarp Multiple-event

CHAPTER 3

INTERPRETATIONS

Rupture History

A primary research question of this project centers on the difference in rupture history for the east versus the west CNF as reflected by fault scarp morphology. The Odell Creek fault divides the Centennial Mountains into east and west segments. Where profiled, both the east and west segments have a similar amount of surface offset for late Pleistocene/Pinedale age deposits. The pre-2.1 Ma Huckleberry Ridge tuff tectonic activity is responsible for the large stratigraphic differences between the eastern versus the western Centennial Mountains. The Centennial Mountains display a different structural level east of the Odell Creek fault than that to the west. Pre-2.1 Ma tectonic activity shows that the eastern Centennial Mountains were probably uplifted more than the western CNF based on the age of rock exposed. The tectonic implication of this is that offset was occurring along the Odell Creek fault resulting in large age and stratigraphic differences of the east (Paleozoic) versus the west (Cretaceous) Centennial Mountains. This is in contrast to a similar offset on the east and west CNF of the 2.1 Ma Huckleberry Ridge tuff (Plate 5). However, post deposition of the 2.1 Ma Huckleberry Ridge tuff, the offset along both east and west segments of the CNF has been the same.

Eastern Centennial Mountains

The eastern Centennial fault scarp profiles reveal surface offset values ranging from 1.6 to 11.0 m measured at 6 locations for late Pleistocene/Pinedale and from 5.9 to 21.6 m measured at 10 locations for late Pleistocene/Bull Lake (?) deposits (Table 8). The average surface offset for the late Pleistocene deposits is 6.7 m, which may represent 2-3 earthquake events. The average surface offset for late Pleistocene/Bull Lake deposits is 11.3 m, which may represent 3-4 earthquake events based on historic surface ruptures in the Basin and Range Province. Recent large magnitude earthquakes (>7.0M_w) have yielded surface offsets of 1.5-3.0 m (e.g. 1915 Pleasant Valley, 1954 Dixie Valley, 1959 Hebgen Lake, and 1983 Borah Peak) (Crone and Machette, 1984; Wallace, 1984; Pierce et al., 2000; Wong et al., 2005). Based on these examples, the upper limit for displacement for one event is approximately 3.0 m for the Basin and Range which gives a conservative estimate for surface offset along the CNF. The bedrock fault scarp profiles reveal apparent surface offset values ranging from 4.9 to 38.9 m measured at 8 locations (Table 9). The average apparent surface offset for the bedrock scarp is 15.9 m, but this is probably only a minimum value for creation of the escarpment in that the footwall block has been buried with younger deposits.

Tables 8 and 9 summarize the surface offset, estimated calculated ages, inferred number of earthquake events, rock type and estimated age (ka, Ma) based on the rock that is offset along the eastern CNF. With increasing surface offset and age, it is reasonable to assume a greater number of paleoearthquake events. For the eastern Centennial profiles, a strong correlation exists between increased offset and older age. This correlation is strong because almost all of the estimated calculated ages fit into the

constraints provided by the age of rock that is offset. Ages calculated from this study based on Andrews and Bucknam (1987) linear-plus-cubic diffusion model for the eastern Centennial Mountains range from 600 yrs (youngest) to 172 ka (oldest) (McCalpin, 1996) representing late Pleistocene to Bull Lake age deposits. The 172 ka profile is older than the maximum Bull Lake age (140 ka) constraint but is reasonable since it is a multiple-event age calculation, which should be older than the actual age of offset. The most accurate estimated ages are for profiles AE and AD, both representing single event scarps. The remaining profiles in the Centennial Mountains are multiple-event scarps which were taken into consideration for the estimated ages calculated herein. Stickney et al., (2000) date the most recent earthquake event for the eastern Centennial Mountains at <1.6 Ma.

Table 8. Comparison of the eastern Centennial profile surface offset to the calculated ages. Ages represent amount of time since the last surface rupturing earthquake event. The 0.46 m^2/1000 yr and 0.52 m^2/1000 yr values represent the upper and lower K_0 values from the linear-plus-cubic diffusion model. Estimated number of earthquakes is based on a maximum surface offset of 3.0 m per event. The rock type and estimated age (ka) from rock type help to constrain the amount of time possible for offset to occur.

Profile	Surface Offset (m)	Calculated Age (yrs)		Est. Number of Earthquakes	Rock Type offset	Est. age (ka) from rock type
		0.46 m^2/1000 yr	0.52 m^2/1000 yr			
AE	1.60	600	500	1	Late Pleistocene	12,000-14,000
AD	3.00	13,400	12,000	1	Late Pleistocene	12,000-14,000

Table 9. Comparison of the bedrock units of the eastern Centennial profile surface offset estimated number of earthquakes. The estimated number of earthquakes is based on a maximum surface offset of 3.0 m per event. The rock type and estimated age (Ma) from rock type help to constrain the amount of time possible for offset to occur.

Profile	Surface Offset (m)	Est. Number of Earthquakes	Rock Type offset	Est. age (Ma) from rock type
AN	12.20	4	Footwall Bedrock- 2.1 Ma Huckleberry Ridge tuff	2.1 Ma
AM	21.60	7	Footwall Bedrock- 2.1 Ma Huckleberry Ridge tuff	2.1 Ma

Estimate slip rates for the most recent activity were calculated for the eastern Centennial Mountains based on the surface offset values and the known age of the offset deposit surface (Table 10). There is some debate as to the actual age of the glacial deposits in the Henrys Lake basin. If interpreted as Bull Lake age (Witkind, 1975a) then the estimated slip rates for the Henrys Lake basin are quite low, but if interpreted as possibly younger Pinedale or late Pleistocene age (Pierce, 2007, written communication) then the estimated slip rates are higher and comparable to the estimated slip rates for deposits of the same age in the western Centennial Mountains.

Table 10. Comparison of the estimated slip rates calculated for the eastern Centennial Mountains and the Henrys Lake Basin based on two options of age for offset alluvial fan.

Profile	Surface offset (meters)	Deposit Age	Est. slip rate (mm/yr) based on 12 ka	Est. slip rate (mm/yr) based on 14 ka	Deposit Age	Est. slip rate (mm/yr) based on 130 ka	Est. slip rate (mm/yr) based on 140 ka
AE	1.6	Late Pleistocene	0.13	0.11	n/a	n/a	n/a
AD	3.0	Late Pleistocene	0.25	0.21	n/a	n/a	n/a
AX	5.9	Late Pleistocene	0.49	0.42	Bull Lake	0.05	0.04

Table 10 Continued. Comparison of the estimated slip rates calculated for the eastern Centennial Mountains and the Henrys Lake Basin based on two options of age for offset alluvial fan.

Profile	Surface offset (meters)	Deposit Age	Est. slip rate (mm/yr) based on 12 ka	Est. slip rate (mm/yr) based on 14 ka	Deposit Age	Est. slip rate (mm/yr) based on 130 ka	Est. slip rate (mm/yr) based on 140 ka
AW	7.6	Late Pleistocene	0.63	0.54	Bull Lake	0.06	0.05
AO	7.7	Late Pleistocene	0.64	0.55	Bull Lake	0.06	0.06
AQ	8.3	Late Pleistocene	0.69	0.59	Bull Lake	0.06	0.06
AR	8.3	Late Pleistocene	0.69	0.59	Bull Lake	0.06	0.06
02P70	8.4	Late Pleistocene	0.70	0.60	n/a	n/a	n/a
AP	9.8	Late Pleistocene	0.82	0.70	Bull Lake	0.08	0.07
02P72	10.5	Late Pleistocene	0.88	0.75	n/a	n/a	n/a
AK	11.0	Late Pleistocene	0.92	0.79	n/a	n/a	n/a
AS	11.3	Late Pleistocene	0.94	0.81	Bull Lake	0.09	0.08
AT	12.9	Late Pleistocene	1.08	0.92	Bull Lake	0.10	0.09
AV	19.5	Late Pleistocene	1.63	1.39	Bull Lake	0.15	0.14
AU	21.6	Late Pleistocene	1.80	1.54	Bull Lake	0.17	0.15

Western Centennial Mountains

The western Centennial fault scarp profiles reveal surface offset values ranging from 0.8 to 18.0 m measured at 15 locations for late Pleistocene and Pinedale deposits (Table 11). The average surface offset for the late Pleistocene and Pinedale deposits is 9.1 m, which represents approximately 3 earthquake events. The bedrock fault scarp

profiles reveal apparent surface offset values ranging from 19.3 to 48.2 m for multiple-event single scarps measured at 15 locations (Table 12). The average surface offset for the multiple-event single scarps in bedrock is 36.4 m, which may represent 12 earthquake events. Several of the bedrock fault scarp profiles represent scarps that contain two surfaces. For these circumstances the bedrock fault scarp profiles reveal surface offset values ranging from 14.7 to 20.5 m for lower scarps and 8.6 to 13.4 m for upper scarps. The average surface offset for the lower scarps is 17.4 m and the average for the upper scarps is 11.2 m. The lower scarps represent 5-6 events and the upper scarps represent approximately 4 events.

Tables 11 and 12 summarize the surface offset, estimated calculated ages, inferred number of earthquake events, deposit type and estimated age (ka, Ma) based on the deposit that is offset for the eastern CNF. For the western Centennial profiles, a weaker correlation exists between increasing offset and older ages. This correlation is weaker because several of the estimated calculated ages do not fit into the constraints provided by the age of deposit that is offset. Ages calculated from this study based on the linear-plus-cubic diffusion model for the eastern Centennial Mountains range from 1000 yrs (youngest) to 97 ka (oldest) (McCalpin, 1996) representing late Pleistocene and Pinedale age deposits. Several of the estimated ages calculated are much older than the upper constraint (14,000 ka) for late Pleistocene and Pinedale deposits. The most accurate estimated ages are for profiles D, E, T and I, representing estimated ages that lie in the constraints for the type of deposit offset. Profiles D and E are single event fault scarps and the calculated ages of 1000 and 2000 yrs, respectively, are the most accurate. The rest of the profiles are multiple-event scarps which were taken into consideration for the

estimated ages calculated for this study. Stickney et al. (2000) date the oldest earthquake event for the western Centennial Mountains at <15 ka which fits with the results found in this research.

Table 11. Comparison of the western Centennial profile surface offset to the calculated ages. These ages are the amount of time since the last surface rupturing earthquake event. The 0.46 m^2/1000 yr and 0.52 m^2/1000 yr values represent the upper and lower K_0 values from the linear-plus-cubic diffusion model. The estimated number of earthquakes is based on a maximum surface offset of 3.0 m per event. The rock type and estimated age (ka) from rock type help to constrain the amount of time possible for offset to occur.

Profile	Surface Offset (m)	Calculated Age (yrs)		Est. Number of Earthquake	Rock Type offset	Est. age (ka) from rock type
		0.46 m^2/1000 yr	0.52 m^2/1000 yr			
D	0.80	1000	900	1	Late Pleistocene	12,000-14,000
E	1.40	2000	1800	1	Late Pleistocene	12,000-14,000

Table 12. Comparison of the bedrock units of the eastern Centennial profile surface offset estimated number of earthquakes. The estimated number of earthquakes is based on a maximum surface offset of 3.0 m per event. The rock type and estimated age (Ma) from rock type help to constrain the amount of time possible for offset to occur. * indicates apparent surface offset where bedrock in footwall block does not correspond to late Quaternary deposits in hanging wall block.

Profile	Apparent Surface Offset (m)	Est. Number of Earthquakes	Rock Type offset	Est. age (Ma) from rock type
G	19.30*	6	Footwall Bedrock-Cretaceous	65.5 Ma
P	29.90*	10	Footwall Bedrock-Cretaceous	65.5 Ma
R	30.80*	11	Footwall Bedrock-Cretaceous	65.5 Ma
C Lower Upper	31.20* 18.60* 13.40*	10 6 4	Footwall Bedrock-Cretaceous	65.5 Ma
J	32.20*	11	Footwall Bedrock-Cretaceous	65.5 Ma
K	33.10*	11	Footwall Bedrock-Cretaceous	65.5 Ma

Table 12 Continued. Comparison of the bedrock units of the eastern Centennial profile surface offset estimated number of earthquakes. The estimated number of earthquakes is based on a maximum surface offset of 3.0 m per event. The rock type and estimated age (Ma) from rock type help to constrain the amount of time possible for offset to occur. * indicates apparent surface offset where bedrock in footwall block does not correspond to late Quaternary deposits in hanging wall block.

Profile	Apparent Surface Offset (m)	Est. Number of Earthquakes	Rock Type offset	Est. age (Ma) from rock type
A Lower Upper	33.60* 15.80* 10.90*	11 5 4	Footwall Bedrock-Cretaceous	65.5 Ma
B Lower Upper	34.70* 14.70* 8.6*	12 5 3	Footwall Bedrock-Cretaceous	65.5 Ma
M	35.20*	12	Footwall Bedrock-Cretaceous	65.5 Ma
N	39.00*	13	Footwall Bedrock-Cretaceous	65.5 Ma
H	39.10*	14	Footwall Bedrock-Cretaceous	65.5 Ma
F Lower Upper	43.90* 20.50* 11.90*	15 6 4	Footwall Bedrock-Cretaceous	65.5 Ma
L	45.70*	16	Footwall Bedrock-Cretaceous	65.5 Ma
Z	47.40*	16	Footwall Bedrock-Cretaceous	65.5 Ma
O	48.20*	17	Footwall Bedrock-Cretaceous	65.5 Ma

Estimated slip rates for the most recent activity were calculated for the western Centennial Mountains based on the surface offset values and the known age of the rock being offset (Table 13).

Table 13. Comparison of the estimated slip rates calculated for the western Centennial Mountains based on age of rock offset.

Profile	Surface offset (meters)	Rock type	Est. slip rate (mm/yr) based on 12,000 ka	Est. slip rate (mm/yr) based on 14,000 ka
D	0.8	Late Pleistocene	0.07	0.06
E	1.4	Late Pleistocene	0.12	0.10
I	7.4	Late Pleistocene	0.62	0.57
AB	8.0	Pinedale	0.67	0.57
S	8.1	Late Pleistocene	0.68	0.58
AA	8.8	Late Pleistocene	0.73	0.63
U	8.9	Late Pleistocene	0.74	0.64
W	9.2	Late Pleistocene	0.77	0.66
Q	11.2	Late Pleistocene	0.93	0.80
X	11.6	Late Pleistocene	0.97	0.83
T	11.9	Late Pleistocene	0.99	0.85
V	13.6	Late Pleistocene	1.13	0.97
Y	18.0	Late Pleistocene	1.50	1.29

The eastern and western CNF exhibit distinctly different fault geometries (e.g. highly *en echelon* left-stepping faults on the east and slightly *en echelon* left-stepping faults on the west) and overall surface displacements values (e.g. hundreds of meters of basement bedrock escarpment on the east and a recognizable scarp in Cretaceous bedrock on the west). The northwest-trending, left-stepping *en echelon* scarp along the eastern Centennial Mountains has an average surface offset of 9.6 m for the late Pleistocene/Pinedale or Bull Lake (?) age deposits. The more linear slightly left-stepping *en echelon* east-west scarp along the western Centennial Mountains has an average surface offset of 9.1 m for late Pleistocene and Pinedale deposits. Based only on the similar surface offset values, the western Centennial Mountains are about as active as the eastern Centennial Mountains resulting in a similar number of estimated earthquake events. The western Centennial Mountains bedrock has fault escarpments 30-50 m high

perhaps indicating a pulse of activity since Cretaceous time. The eastern Centennial Mountain basement bedrock is a more resistant rock and the main escarpment is hundreds of meters high. It may be possible that the eastern Centennial Mountains have been tectonically active for a longer amount of time than the western Centennial Mountains based on the age of the rock exposed at the surface. But Baldy Mountain on the western CNF is actually higher than Taylor Mountain on the eastern CNF suggesting uplift of the footwall block has been comparable on both the east and west CNF. Also, based on the average estimated slip rate the eastern and western Centennial Mountains, a similar rate of activity for late Pleistocene/Pinedale deposits exists. The eastern Centennial Mountains have an average estimated slip rate of 0.82 mm/yr for 12,000 yr datum and 0.70 mm/yr for 14,000 yr datum. The western Centennial Mountains have an average estimated slip rate of 0.76 mm/yr for 12,000 yr datum and 0.65 mm/yr for 14,000 yr datum. If the eastern Centennial Mountains are subdivided into late Pleistocene and Bull Lake age deposits then an estimated slip rate of 0.49 mm/yr for 12,000 yr datum and 0.42 mm/yr for 14,000 yr datum (late Pleistocene) and 0.09 mm/yr for 130,000 yr datum and 0.08 mm/yr for 140,000 yr datum (Bull Lake) exists.

Therefore, it can be concluded that the eastern versus western Centennial Mountains do have a different rupture history if the Bull Lake age is used to determine the estimated slip rate implying that each segment did not rupture at the same time. But this is for a part of the fault that is not along a present range front. If the late Pleistocene age is used for both the east and west then it can be concluded that a similar rupture history occurred across the entire range front. It cannot be ruled out that the highly segmented and/or disjointed eastern CNF system has accommodated a smaller amount of

extension along an array of *en echelon* faults than the western CNF based on average surface offset for late Pleistocene age deposits. The calculated ages and estimated slip rate give only a rough estimate for the latest earthquake event and activity.

Regarding pre-late Pleistocene displacement, it may be that the eastern Centennial Mountains had pre-existing elevation due to the offset on the Odell Creek fault before offset started along the CNF. A sector of the Odell Creek fault has since merged and become one with the main CNF which can accommodate some of the stratigraphic separation seen along the fault trace of the Odell Creek fault. There is strong evidence that pre-existing northeast and northwest trends of weakness would have aided in the initial rupture along the CNF in the eastern Centennial Mountains (discussed later). Therefore, the initial offset along the Centennial Mountains may have occurred in the eastern part of the range front along the Odell Creek fault as represented by the difference in age of bedrock along the eastern and western segments.

Odell Creek Fault

The tectonic history of the Odell Creek fault is complex and not fully understood. The Odell Creek fault: 1) lies parallel to the direction of Laramide shortening north of the Centennial Valley (O'Neill and Christiansen, 2004); 2) is parallel to a major crustal shear zone, the Madison mylonite zone (Erslev, 1982, 1983; Erslev and Sutter, 1990; Dueker et al., 2001); 3) is parallel to the Paleoproterozoic suture trend of southwest Montana (O'Neill and Christiansen, 2004); 4) parallels several gravity anomalies with the same northeast-trend in the Centennial Valley and Cliff Lakes area (Schofield, 1981;

Sonderegger et al., 1982); and 5) stratigraphically offsets Cambrian (footwall) from Cretaceous (hanging wall) in the Odell Creek area (Witkind, 1975b; O'Neill and Christiansen, 2004).

It is also important to characterize what the Odell Creek fault does not do. The Odell Creek fault does not: 1) offset Laramide thrust faults northeast of the Centennial Valley (O'Neill and Christiansen, 2004), 2) appear to offset the Madison Mylonite Zone (covered by laterally continuous 2.1 Ma Huckleberry Ridge tuff) (O'Neill and Christiansen, 2004); 3) appear to offset the Archean and Paleoproterozoic rocks north of the Centennial Valley (covered by laterally continuous 2.1 Ma Huckleberry Ridge tuff) (O'Neill and Christiansen, 2004); 4) offset the Quaternary fill in the Centennial Valley or the 2.1 Ma Huckleberry Ridge tuff in the Cliff Lakes area (O'Neill and Christiansen, 2004); and 5) continue as a northeast-trending fault, but instead merges with the CNF to form a true corner uplift (Pierce, 2007, written communication).

The Odell Creek fault affects the surface trend of the CNF by separating the segmented northwest-trending, left-stepping *en echelon* fault scarps in the eastern Centennial Mountains from the more continuous and linear, east-west trending fault with minor left-stepping *en echelon* scarps in the western Centennial Mountains. The Odell Creek fault exhibits characteristics of a rupture, geometric, structural and behavioral segment boundary separating the CNF into east and west segments for surface offsets older than late Pleistocene. The earthquake/rupture and geometric segment boundaries are evident in the change of *en echelon* fault surface patterns for the eastern and western Centennial Mountains. The Odell Creek fault forms an earthquake/rupture segment boundary for pre-late Pleistocene seismic activity as evident by the exposed rock along

the respectable segments of the Centennial Mountains. The stratigraphic separation of the Cretaceous rocks on the west from the Paleoproterozoic and younger rocks on the east along with the amount of apparent surface offset on the west (30-50 m) and east (hundreds of m) shows the Odell Creek fault to be a pre-existing tectonic feature. The Odell Creek fault displays greater displacement and an older tectonic history than the CNF. All surface offsets along the CNF from late Pleistocene to present show the Odell Creek fault as a true corner uplift that has merged with the CNF, therefore ceasing to act as a cross-cutting segment boundary.

The pre-late Pleistocene Odell Creek fault was a structural discontinuity to the CNF before it merged with the eastern CNF. The area of overlap is now a reactivated fault surface. The Odell Creek fault was an older structural discontinuity as evidenced by the fact that the eastern Centennial Mountains are more structurally complex and structurally higher than the western Centennial Mountains. It is possible that the Odell Creek fault could have been active during the Laramide orogeny as a tear or oblique-slip fault, lying sub-parallel to the regional direction of shortening. Also, a mid-Miocene phase of extension (discussed later) could have reactivated the Odell Creek fault with dip-slip displacement, prior to Yellowstone volcanism and the current neotectonic phase of extension. Although it may not be possible to quantify the earlier phases of movement on the Odell Creek fault, it is clear that pre-Quaternary displacement did occur because: 1) there is considerable stratigraphic separation across the fault (east to west, juxtaposing Cretaceous and Precambrian rock units); and 2) gravity contours in the Centennial Valley (Sonderegger et al., 1982) suggest compatible down-to-the-northwest offset prior to the CNF.

A minimum of 3000 m of vertical displacement exists between the footwall block and the hanging wall block of the eastern CNF based on a gravity and magnetic investigations (Schofield, 1980, 1981; Sonderegger et al., 1982). The Odell Creek fault is thought to continue northward into the Centennial Valley as represented by gravity anomaly F from the gravity and magnetic investigation of Sonderegger et al. (1982), suggesting a pre-CNF extensional history of the Odell Creek fault. Gravity anomaly F connects the exposed Odell Creek fault with the gravity anomaly in the Elk Lake area to the northeast (Plate 1), though the 2.1 Ma Huckleberry Ridge tuff is not offset in the Elk Lake area. It is inferred that all of these features are the expression of the Odell Creek fault across the central Centennial Valley (Schofield, 1981; Sonderegger et al., 1982). The Odell Creek fault and the Elk Creek segment both strike N30°E, which lies in the same orientation as the pre-existing Laramide orogeny thrust faulted Tendoy Mountains and Snowcrest and Gravelly Ranges located to the north of the study area. High seismicity has been observed along a N35°E trend from Cliff Lake into the Madison Valley; Cliff Lake lies just north of Elk Lake and could be considered connected (Bailey, 1977). The Odell Creek fault has been suggested to be a major Laramide age structure that connects the ESRP to the Madison Valley with an estimated offset of 1800 m (Sonderegger et al., 1982). It is believed by Sonderegger et al. (1982) that the Odell Creek fault has been overlooked because much of it lies beneath the Neogene sediments in the Centennial Valley and the Elk Creek segment is covered by Tertiary mafic volcanics and the 2.1 Ma Huckleberry Ridge Tuff.

The Odell Creek fault shows discontinuous behavioral characteristics in regards to slip rates, seismic behavior, and sense of displacement. For example, Stickney et al.

(2000) reported a slip rate of 0.2-1.0 mm/yr for the western Centennial Valley section with the most recent activity <15 ka; the eastern Centennial Mountains has a slip rate of 1.0-5.0 mm/yr for the Red Rock Lakes section and <0.2 mm/yr for the Red Rock Pass section, both of which are reported as having <1.6 Ma for the most recent activity (Stickney et al., 2000). The slip rates reported by Stickney et al. (2000) are based on geomorphic and paleoseismic estimates. The estimated slip rates calculated from this study for the western Centennial Mountains show a slip rate of 0.07-1.50 mm/yr for late Pleistocene rocks based on 12,000 yr and a slip rate of 0.06-1.29 mm/yr for late Pleistocene rocks based on 14,000 yr with an average slip rate of 0.76 mm/yr (12,000 yr datum) and 0.65 mm/yr (14,000 yr datum). The estimated slip rates calculated from this study for the eastern Centennial Mountains show a slip rate of 0.13-1.80 mm/yr for late Pleistocene rocks based on 12,000 yr and a slip rate of 0.11-1.54 mm/yr for late Pleistocene rocks based on 14,000 yr with an average slip rate of 0.82 mm/yr (12,000 yr datum) and 0.70 mm/yr (14,000 yr datum). The slip rates calculated for the Bull Lake deposits along the Henrys Lake portion of the CNF show a slip rate of 0.05-0.17 mm/yr for rocks based on 130,000 yr and a slip rate of 0.04-0.15 mm/yr for rocks based on 140,000 yr with an average of 0.09 mm/yr (130,000 yr datum) and 0.08 mm/yr (140,000 yr datum).

In summary the Odell Creek fault exhibits characteristics of many varying types of segment boundaries for paleoseismic and tectonic activity older than late Pleistocene. These segment boundaries cease to exist for late Pleistocene to present tectonic activity as evident by the true corner uplift that resulted from the merger of the Odell Creek fault with the CNF. Estimated slip rates for late Pleistocene offset and average surface offset

along the entire CNF show that the east and west segments are experiencing about the same rate of tectonic uplift therefore are not affected by the Odell Creek fault as a segment boundary.

East-West Trend

The third research question concerns the overall trend of the CNF and Centennial Mountains. The CNF is the only fault in southwest Montana with an overall east-west trend. This is anomalous in an area characterized by northward trending normal faults caused by Late Cenozoic extension. An explanation for the east-west trend can be offered by the model proposed by Myers and Hamilton (1964). The Myers and Hamilton (1964) model states the CNF formed as a result of regional down-warping along the northern border of the Yellowstone tectonic parabola. Regional down-warping into the ESRP now forms the south dip-slope of the Centennial Mountains. The release of stress along the northern hinge of the down-warp resulted in creation of the CNF and down-dropping of the hanging wall block to form the Centennial Valley (Myers and Hamilton, 1964). Repeated earthquake events, as illustrated previously by fault scarp profile data (Tables7-11), occurred along the CNF creating the overall appearance of an east-west trend in an actual northwest-trending *en echelon* fault system.

The continued neotectonic seismic activity along a northwest trending faults in the region is supported by the model of Stickney and Bartholomew (1987) and Lageson and Stickney (2000). The model suggest extension occurring north of the ESRP is the result of the subsidence in the ESRP (maximum subsidence occurring along the oldest

portions of the ESRP in southern Idaho and least subsidence along the youngest portions of the ESRP near the "top" of the Yellowstone parabola) and along northwest-trending faults with T-axes oriented S45°W (Stickney and Bartholomew, 1987; Lageson and Stickney, 2000). Upon closer examination of the CNF each fault trace is actually oriented in a northwest direction (more dramatic along the eastern range front) compatible with southwest-oriented T-axes. This *en echelon* pattern is also compatible with distributed dextral displacement (probably compartmentalized and of very small magnitude) along the entire CNF system, possibly resulting from differential subsidence of the footwall into the ESRP (greater to the west).

Comparison with the Teton Range

The Centennial Mountains appear to form a mirror image with the Teton Range relative to the ESRP. The Centennial Mountains and Teton Range have a similar overall geometry with respect to the ESRP, namely in that both range-front normal faults dip away from the ESRP and their footwall blocks dip into the ESRP (Myers and Hamilton, 1964). This interpretation led Myers and Hamilton (1964) to suggest subsidence into the ESRP for both mountain blocks as the primary cause for their existence. A comparison of this study with a previous study on the Teton normal fault supports that the two faults have a similar tectonic history (Smith et al., 1993; Byrd et al., 1994). The tectonic history of the two ranges began with the migration of Yellowstone hotspot magmatism into the upper ESRP and eventually Wyoming (Pierce and Morgan, 1992).

The fault surface offset geometry of the two fault systems is similar in style. Furthermore, a mirror-image *en echelon* pattern exists, with a left-stepping pattern for the eastern CNF and a right-stepping pattern for the central and southern sections of the Teton normal fault (Smith et al., 1993; O'Neill and Christiansen, 2004). The western CNF and northern Teton normal fault have a linear pattern parallel to the topography of the range fronts (Smith et al., 1993). The valley floors for each mountain range appear to be asymmetric and dip moderately toward the footwall block (Sonderegger et al., 1982; Smith et al., 1993).

Both mountain ranges also lie within the "most active belt II" of neotectonic seismic activity around the Yellowstone hotspot track (Pierce and Morgan, 1992; Lageson and Ruleman, 2000; Rodgers et al., 2002). The "active belt" starts west of the Centennial Mountains in the Lost River Range, site of the 1983 Borah Peak earthquake. The seismic zone between the 1983 Borah Peak event and the 1959 Hebgen Lake earthquake is characterized as an independent seismic zone named the "Centennial Tectonic Belt" by Stickney and Bartholomew (1987). This zone forms part of the parabolic pattern of seismicity along the northern ESRP, with its vertex at Yellowstone Park (Anders et al., 1989; Smith and Arabasz, 1991; Anders and Sleep, 1992). The zone continues south from Yellowstone Park into western Wyoming to the vicinity of Jackson. Just north of Jackson there is a notable gap in seismicity coincident with the 70 km long Teton normal fault (Smith and Arabasz, 1991). The historical seismicity in the "active zone" in central Idaho implies a NNE-SSW extensional strain yielding a strain rate on the order of 10^{-16}/sec (Smith and Arabasz, 1991). In the Hebgen Lake/Yellowstone Park region the extensional strain rate is three times greater at 1.1×10^{-15}/sec (4.7 mm/yr

deformation rate) and a horizontal principal strain axis trends more northerly (Smith and Arabasz, 1991). The "active zone" south of Yellowstone Park has much smaller extensional strain rates of 10^{-17}/sec and deformation rates of 0.07 to 1.2 mm/yr (Smith and Arabasz, 1991). The sparse data for the Teton region implies a northwest-southeast direction of horizontal extensional strain (Machette et al., 2001) possibly reflecting subsidence into the ESRP, where in southeastern Idaho, the better resolved extensional strain is nearly east-west (Smith and Arabasz, 1991).

While both the Teton Range and Centennial Mountains lie in a seismic gap of more than 50 km long immediately south and north of the Yellowstone region, the faults forming the two mountain ranges have been active throughout the Quaternary producing well-preserved fault scarps up to 50 m high and at least 55 km long (Smith and Arabasz, 1991; Smith et al., 1993). The stratigraphically highest dip-slope for each mountain range consists of 2.1 Ma Huckleberry Ridge tuff; these rocks form the western dip slope of the Teton Range and the southern dip slope of the Centennial Mountains (Love et al., 1992; Smith et al., 1993; Byrd et al., 1994; O'Neill and Christiansen, 2004).

Despite their similarities, many differences exist between the Centennial Mountains and Teton Range. The first is that the Teton Range has a geometric and kinematic ancestry to pre-existing Laramide structures in northwest Wyoming. The Teton Range has exploited the Cache Creek thrust that subtended the ancestral Teton-Gros Ventre uplift (Lageson, 1987; Perry et al., 1992), whereas the Centennial Mountains seem to have no tie to pre-existing Laramide features and, in fact, the Centennial Mountains cut across or reactivate Laramide features in southwest Montana (i.e. Odell Creek fault?).

The main difference between the fault histories between the two ranges is the timing of initial offset. The Teton Range is suggested to have begun its latest phase of tectonic history as early as 5 to 13 Ma (Pierce and Morgan, 1992; Love et al., 1992; Pierce and Good, 1992; Smith et al., 1993), whereas the Centennial Mountains may have a much younger initiation of ~ 2 Ma (Sonderegger et al., 1982; Christiansen, 2001). This young age of initiation for the CNF is largely bracketed by the 2.1 Ma Huckleberry Ridge Tuff which forms the southern dip-slope of the Centennial Mountains and yet, is projected to be a minimum of 1,525 to 1,830 m below the surface of the Centennial Valley (Christiansen, 1979; Mannick, 1980; Sonderegger et al., 1982). Jackson Hole basin varies in depth from west to east from 500 to 1,500 m next to the Teton fault to 2,000 to 2,500 m over the center of the basin and 1,000 m on the west side of Blacktail Butte (Byrd et al., 1994). This variance suggests that Jackson Hole was filled with two distinct sedimentary basins based on varying gravity lows representing lower Mesozoic and Precambrian rock. The lower Mesozoic basin includes Miocene volcaniclastic and lacustrine strata, the 2.1 Ma Huckleberry Ridge Tuff and Quaternary glacial deposits (Byrd et al., 1994). Previous studies, (Smith et al., 1993; Byrd et al., 1994) suggest that 2.5 to 3.5 km of offset has occurred along the Teton fault as recently as 2.1 Ma based on the 10° post-emplacement westward tilt of the Huckleberry Ridge Tuff while ~ 3 km of offset has occurred along the CNF since the 2.1 Ma Huckleberry Ridge Tuff emplacement (Schofield, 1981). Smith et al. (1993) suggest estimated Holocene slip rates of 0.46 to 1.6 mm/yr for the Teton fault while this study shows estimated late Pleistocene slip rates of 0.76 mm/yr (12 ka datum) and 0.65 mm/yr (14 ka datum) for the western Centennial Mountains and 0.82 mm/yr (12 ka datum) and 0.70 mm/yr (14 ka

datum) for the eastern Centennial Mountains. Byrd et al., (1994) shows post glacial offsets of up to 38 m in 13,400-17,000 yr glacial moraines while this study shows 8.4 m to 11 m in 12,000-14,000 yr glacial moraines.

The geometry of the two mountain ranges is also different. The Teton normal fault seems to be controlled by pervasive east-dipping foliation in the Precambrian basement (Lageson, 1987, 1992, 1998, 1999). There is no relationship for basement control on the range-bounding normal fault along the length of the Centennial Mountains. The Odell Creek fault is the only location that seems to have basement control in the Centennial Mountains. The Odell Creek fault is believed to be of Laramide age based upon the ages of the rocks involved, following an inherited Precambrian structural weakness in the N30°E to N40°E orientation (Sonderegger et al., 1982). There are three distinct segments to the Teton normal fault. The northern segment extends south from the bifurcation north of Jackson Lake to the north side of Moran Bay (Figure 15) (Smith et al., 1993; Byrd et al., 1994). The central fault segment extends from Moran Bay to Taggart Lake and contains the largest fault scarps (+30 m) at the base of the Teton Range and has a component of left-lateral offset associated with the large fault scarps (Lageson, 1992; Smith et al., 1993; Machette et al., 2001). The Teton normal fault sharply rotates about 25 degrees counter-clockwise between the southern and middle segments. The southern segment strikes N30E from the south end of the mountain range to Taggart Lake (Lageson, 1992). The Quaternary surface offset increases from the north and south ends with a maximum offset in the central segment of the Teton normal fault. The Quaternary, (especially the late Pleistocene surface) offset remains approximately the same across the CNF, while the pre-Quaternary offset seems much larger along the eastern CNF due to

the exposed Paleoproterozoic rocks. The eastern CNF also displays a more distinct component of left-stepping *en echelon* fault segments with inferred right-lateral oblique slip.

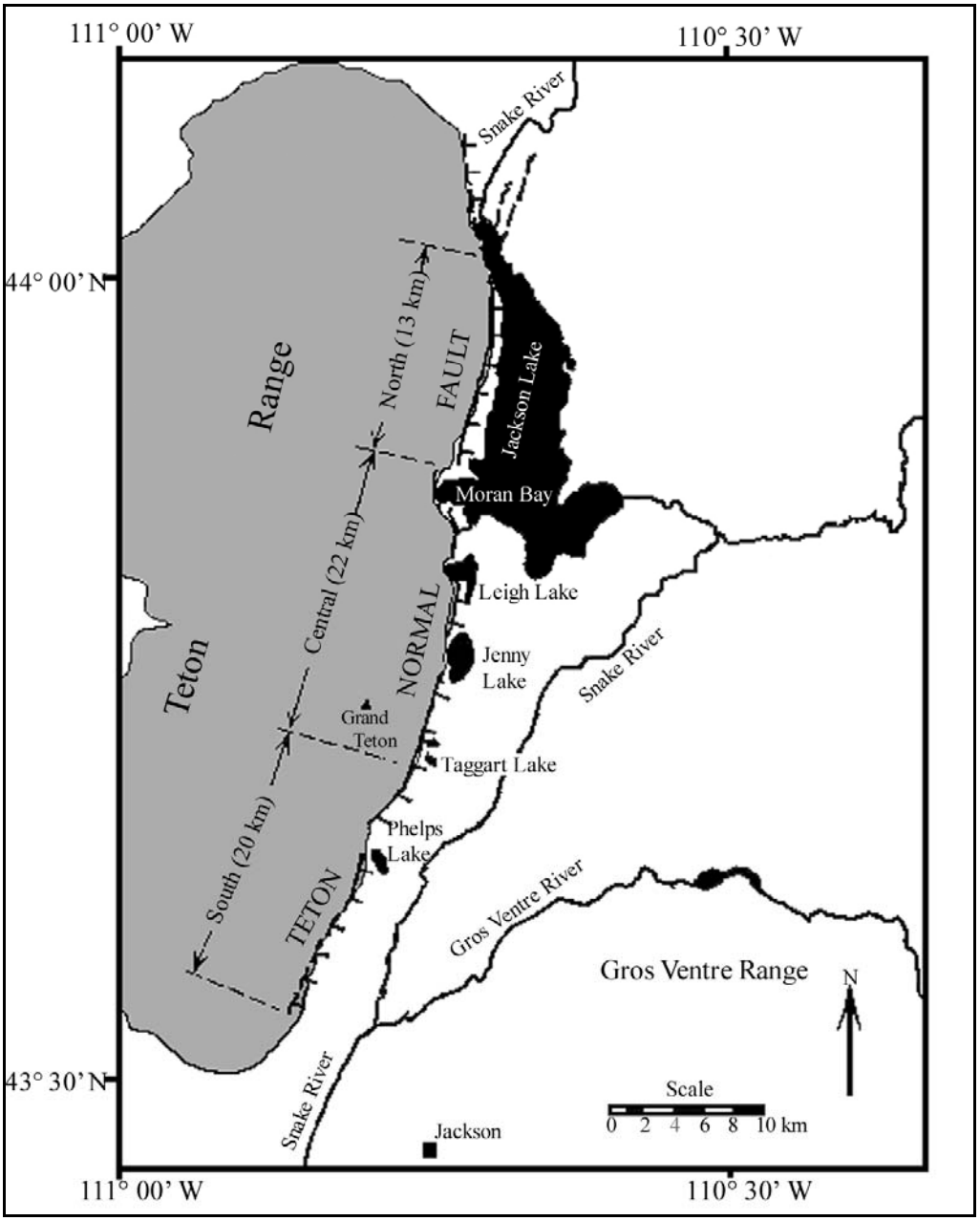

Figure 15. Map of the Teton Range, Teton normal fault, and Jackson Hole region showing the Quaternary expression of the Teton normal fault and segment boundaries (Modified from Smith et al., 1993).

CHAPTER 4

DISCUSSION

Tertiary Extension

The extensional history of southwest Montana during the Paleogene and Neogene ranged from moderate magnitude (approximately 25% extension) to large magnitude (100% or greater extension), depending on the style of tilting and extension applied to the region (i.e. major block-bounding faults with small rotation versus low-angle detachment faults and/or rotated normal faults) (Stewart, 1998). This history has been simplified into four phases discussed herein.

Eocene Phase

The Eocene extensional phase is characterized by the formation of metamorphic core complexes, such as the Bitterroot and Anaconda metamorphic core complexes (Figure 16). These metamorphic core complexes are believed to be the result of detachment faulting associated with widespread magma emplacement and partial melting in the middle crust, coinciding with a change from the regional contraction during the Sevier-Laramide orogeny to extension during the Middle Eocene and Oligocene in east-central Idaho and southwest Montana (Janecke, 1992; Stewart, 1998; Foster et al., 2001; O'Neill et al., 2004). The Bitterroot and Anaconda metamorphic core complexes are suggested to be part of a continuous, tectonically integrated system originating at the Idaho-Montana state line (O'Neill et al., 2004) and continuing east towards Anaconda,

Montana. The Idaho-Bitterroot batholith region records the transition from Late Cretaceous contractional magmatism and metamorphism to Eocene extension and metamorphic core complex development (Foster et al., 2001; O'Neill et al., 2004). The Anaconda metamorphic core complex expands the previously defined region of Tertiary brittle/ductile crustal extension eastward (O'Neill et al., 2004).

The metamorphic core complexes are located north of the research area and do not directly affect the Centennial Mountains, Centennial Valley or CNF. The metamorphic core complexes are important because the extension occurring along them shows the transition from Sevier/Laramide contraction to the beginning stages of the extensional tectonic setting to the north that will ultimately move south linking the Paleogene and Neogene extension in southwest Montana.

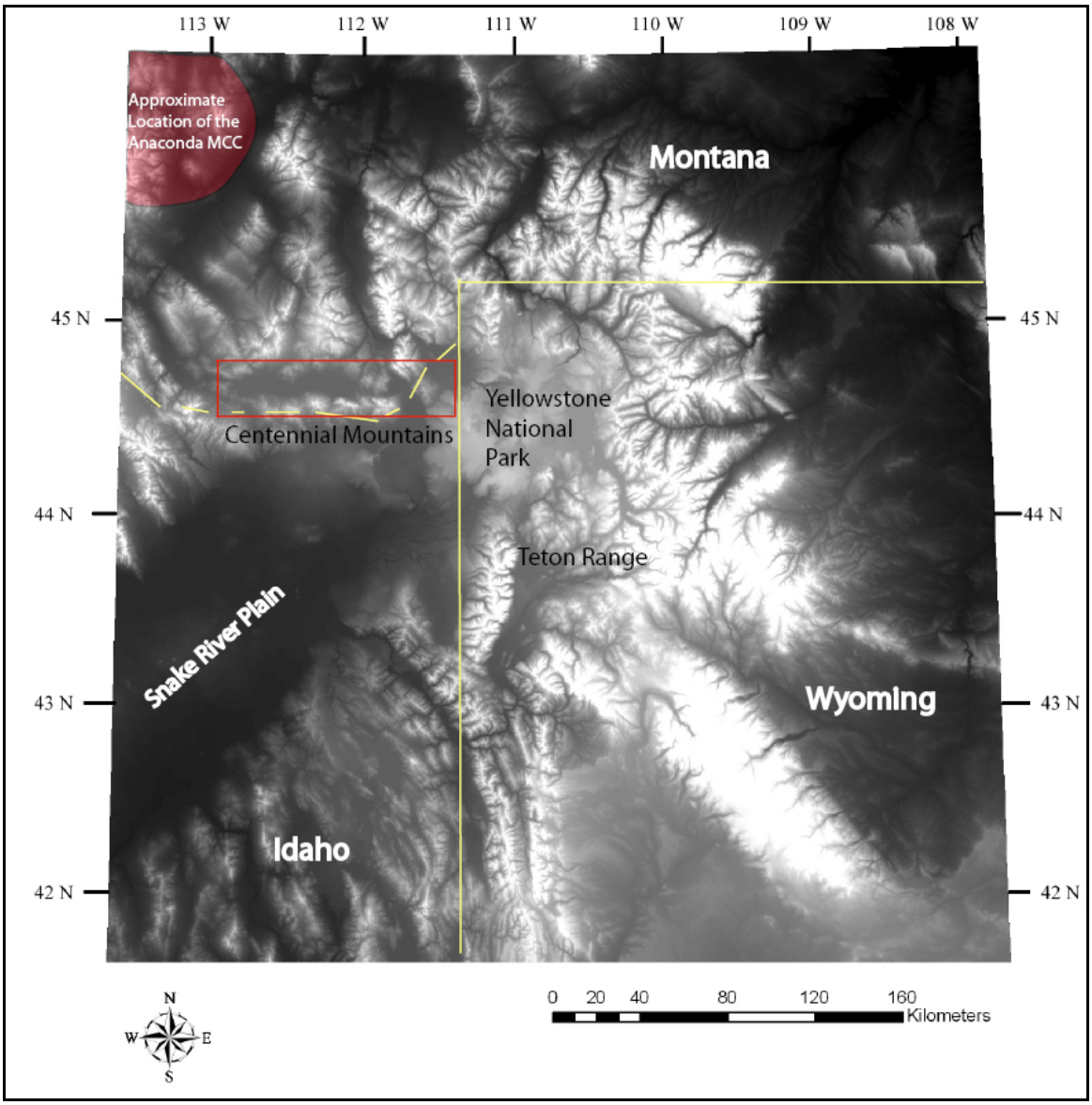

Figure 16. DEM showing the area of first phase extension for the greater Yellowstone region. Red box shows the approximate location of the research area. Yellow lines show the approximate state boundaries for Montana, Idaho and Wyoming. Also labeled are the Snake River Plain, Yellowstone National Park, the Centennial Mountains and the Teton Range for reference. The red area represents approximate location of the Anaconda Metamorphic Core Complex which resulted from the Eocene Phase of extension.

Renova Phase

The Renova phase is characterized by Late-Middle Eocene to Oligocene extension in a 100 ± 25 km wide, north to north-northwest-trending rift zone north of ESRP between 116°W and 114°W longitude (Figure 17) (Janecke, 1994). The Bitterroot mylonite zone of the Eocene Bitterroot metamorphic core complex defines the western most extent of the rift zone and has an estimated minimum extension of 25 km across the Bitterroot/ Big Hole area (Janecke, 1994). The initial slip on the extension faults within the rift zone was closely associated with the rhyolitic volcanism during the waning phase of Challis magmatism and the gravitational collapse of the previously thickened crust of the Sevier orogen (Bennett, 1986; Janecke, 1994). An enormous amount of sediment was deposited into the half-grabens that resulted from extension of the rift zone. The Renova basin is hypothesized to be filled with axial-fluvial deposits from streams draining the rift zone (Janecke, 1994). Flood-plain mudstones and siltstones interfingered with volcanic rocks are suggested to have originated from the half grabens in eastern Idaho (Janecke, 1994; Sears and Fritz, 1998). The possible depocenter for the Renova basin is located east of the rift zone, in the area of the Centennial Mountains and northward (Janecke, 1994; Janecke et al., 2000) . The Renova Formation was deposited in a broad lowland basin under relatively quiet conditions that were followed by tectonic uplift resulting in the correlations of the Renova Formation across the present mountains in southwest Montana and eastern Idaho (Janecke, 1994).

The belt of Paleogene extension existed just west of the present day location of the Centennial Mountains, Centennial Valley and CNF. The Renova Formation which resulted from the erosion of the half grabens to the west was deposited in the research

area before tectonic activity started to occur along the CNF. The Renova Formation has since been eroded from the Centennial Mountains due to the tectonic uplift along the CNF and probably exists in the Centennial Valley at depth.

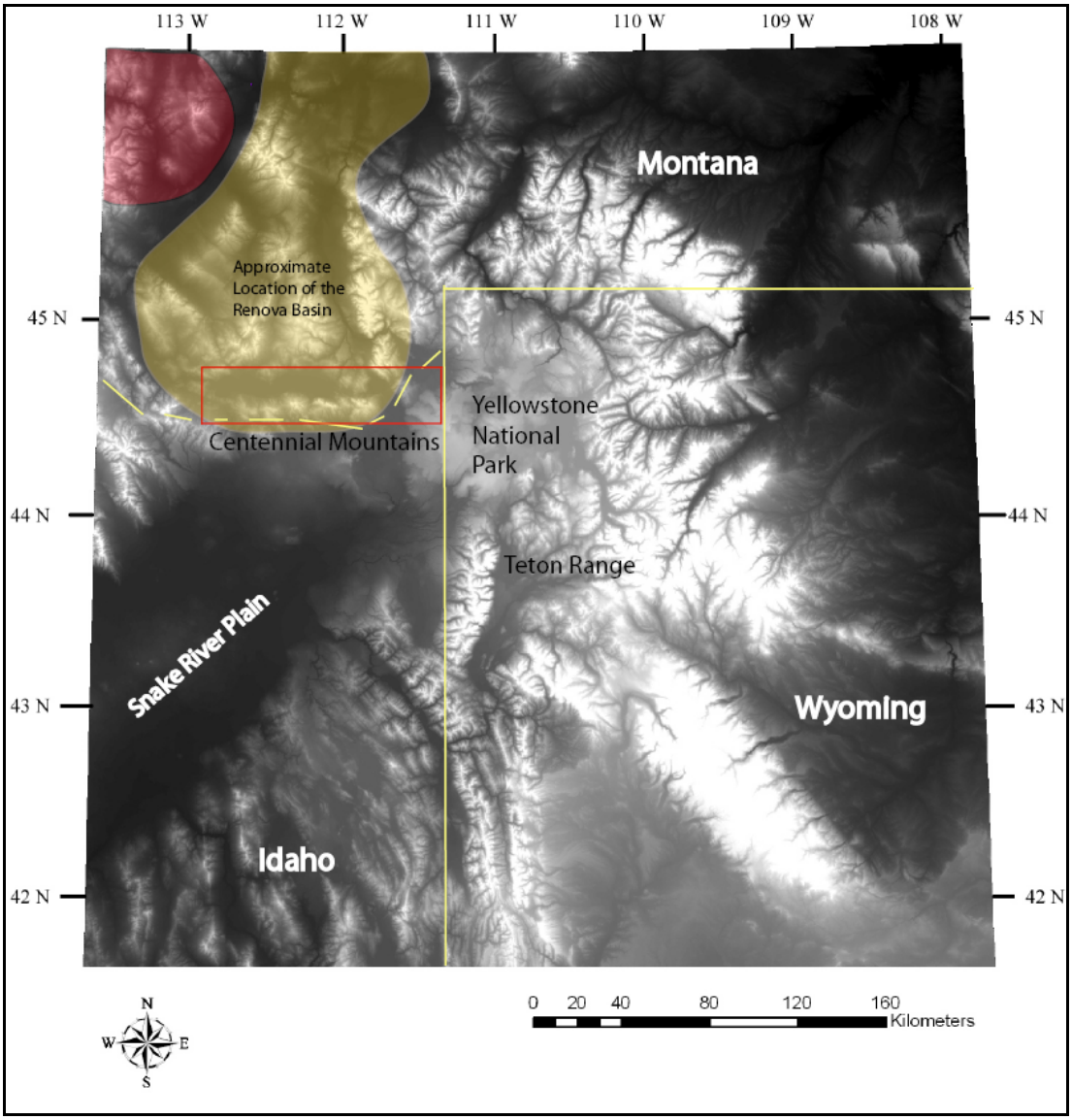

Figure 17. DEM showing the first two phases of extension for the greater Yellowstone region. Red box shows the approximate location of the research area. Yellow lines show the approximate state boundaries for Montana, Idaho and Wyoming. Also labeled are the Snake River Plain, Yellowstone National Park, the Centennial Mountains and the Teton Range for reference. The red area represents approximate location of the Anaconda Metamorphic Core Complex, and the tan area represents approximate location of the Renova Basin which resulted from the Renova Phase of extension.

Mid-Miocene Phase

The mid-Miocene phase of extension is characterized by the formation of northeast-trending faults, the onset of basin and range extension in the northern Rocky Mountains, the Columbia River flood basalts, and the onset of Yellowstone hotspot activity along the ESRP in southeastern Idaho (Pierce and Morgan, 1992) (Figure 18). The Columbia River flood basalt and initial onset of the Yellowstone hotspot caused development of the northeast-trending rift system in southwestern Idaho and continued in a northeast-trending wide belt until about 10 Ma (Pierce and Morgan, 1992). The northeast-trending rift system diverted drainages into the newly formed rift which resulted in re-deposition of the Renova Formation along the northeast-trending grabens (Sears, 1995). Extension along the grabens continued and offset the Renova Formation, creating angular unconformities for future deposits such as the Sixmile Creek Formation.

Basin and Range extensional topography in the northern Basin and Range Province, resulting in crustal adjustment along northeast-trending faults that developed concurrent with the north margin of what would eventually be the Yellowstone hotspot track (Fritz and Sears, 1993; Sears et al., 1995; Sears, 1995; Thomas et al., 1995). The northeast-trending faults consist of several *en echelon* half grabens containing tilted remnants of pre-hotspot volcanic and sedimentary rocks of the Renova Formation (Sears et al., 1995; Sears, 1995; Thomas, 1995).

The onset of the northeast-trending faults shows the tectonic advancement of the extensional regime from eastern Idaho towards the north and east. The northeast-trending faults do not directly affect the Centennial Mountains, Centennial Valley or CNF but the region around them. The Odell Creek fault does strike in the same

northeast-trending direction down-dropping the western Centennial Mountains relative to the eastern Centennial Mountains. This sense of offset (hanging wall down to the west) is similar to other northeast-trending faults from this phase of extension (Sears and Fritz, 1998). Since the exact age of the Odell Creek fault had not been determined, offset along the Odell Creek fault could have occurred during this phase. Basin and Range extension does not directly affect the Centennial Mountains, Centennial Valley or CNF at this time either but is active south of the research area moving in a northward direction.

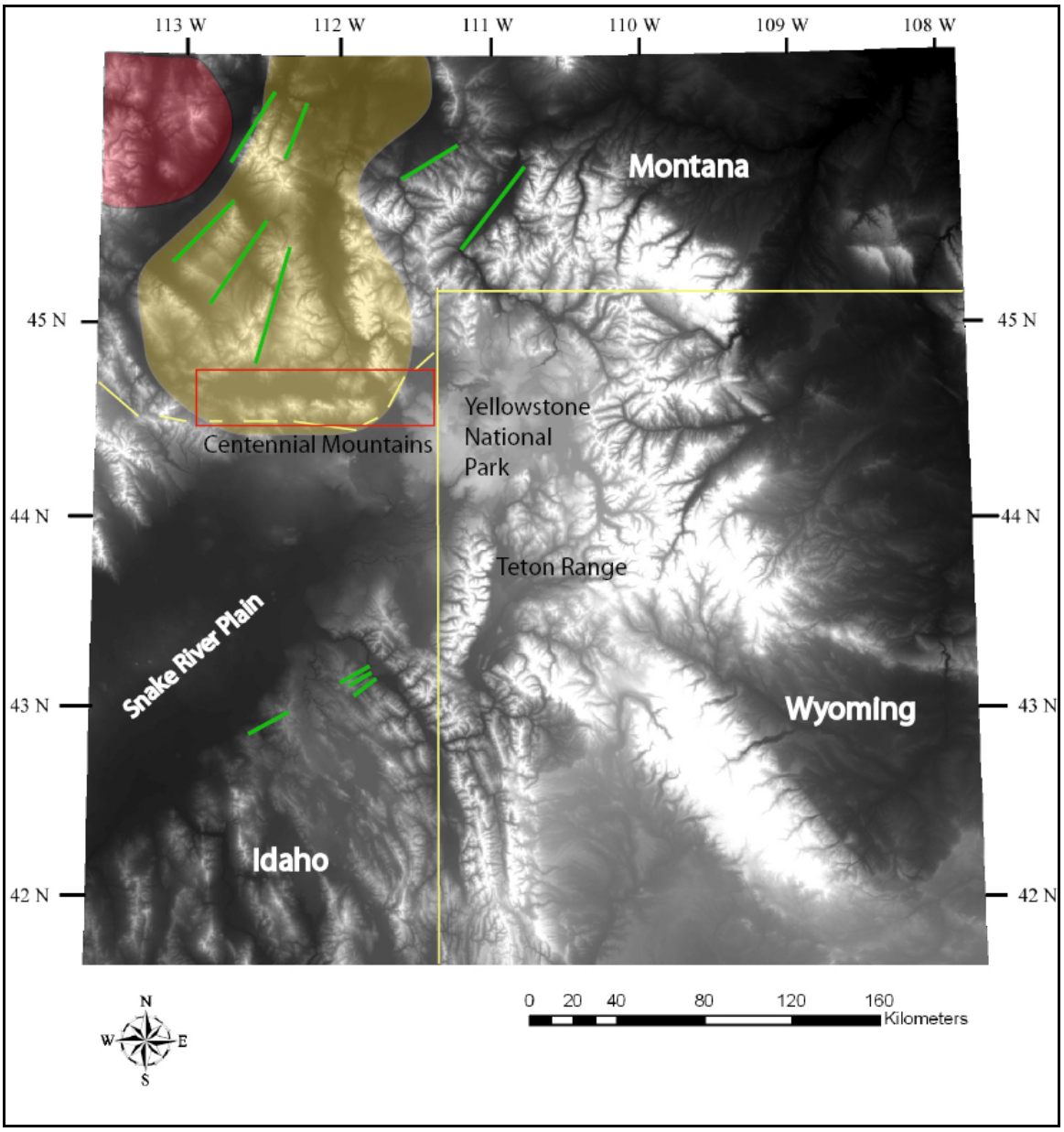

Figure 18. DEM showing the first three phases of extension for the greater Yellowstone region. Red box shows the approximate location of the research area. Yellow lines show the approximate state boundaries for Montana, Idaho and Wyoming. Also labeled are the Snake River Plain, Yellowstone National Park, the Centennial Mountains and the Teton Range for reference. The red area represents approximate location of the Anaconda Metamorphic Core Complex, tan area represents approximate location of the Renova Basin, and green lines represent the various northeast-trending extensional faults associated with the mid-Miocene Phase of extension prior to arrival in the area of the Yellowstone hotspot.

Neotectonic Phase

The Neotectonic phase (latest Cenozoic) of extension is characterized by the formation of northwest-trending faults, the Teton Range, and the Centennial Mountains (Figure 19). Towards the end of the Miocene, crustal adjustments along the Yellowstone hotspot track were dominated by northwest-trending extensional faults which cut the earlier formed northeast-trending structures (Thomas et al., 1995; Stickney et al., 2000). The northwest-trending faults are the most seismically active faults in southwest Montana and are proposed to be initiated by crustal adjustments associated with the formation of the Heise volcanic field (7 to 4 Ma) (Stickney et al., 2000).

Northward tilting in the region north of the ESRP reflects the outer slope of the Yellowstone thermal anomaly during the 6.5 to 4.3 Ma Heise volcanism (Pierce and Morgan, 1992; Fritz and Sears, 1993; Thomas et al., 1995). Deformation correlative with the Heise volcanic field resulted in local block faulting which disrupted the local drainage (Fritz and Sears, 1989, 1993). Prior to this disruption Fritz and Sears (1989, 1993) conclude there was a south-flowing drainage system between the Red Rock and Madison faults, the present day research area. The drainage system was completely reversed to northward flow by the time 6 Ma basalt flowed down it and was subsequently broken by Basin and Range faulting along the CNF and surrounding normal faults (Pierce and Morgan, 1992; Fritz and Sears, 1993). Much of the tectonic displacement along the northwest-trending faults may have occurred after the deposition of the 2.1 Ma Huckleberry Ridge tuff (Thomas et al., 1995). The 2.1 Ma Huckleberry Ridge tuff was deposited in the eastern Centennial Mountains and Valley area and shows major post-depositional displacement along the CNF up to 3000 m (O'Neill and Christiansen, 2004).

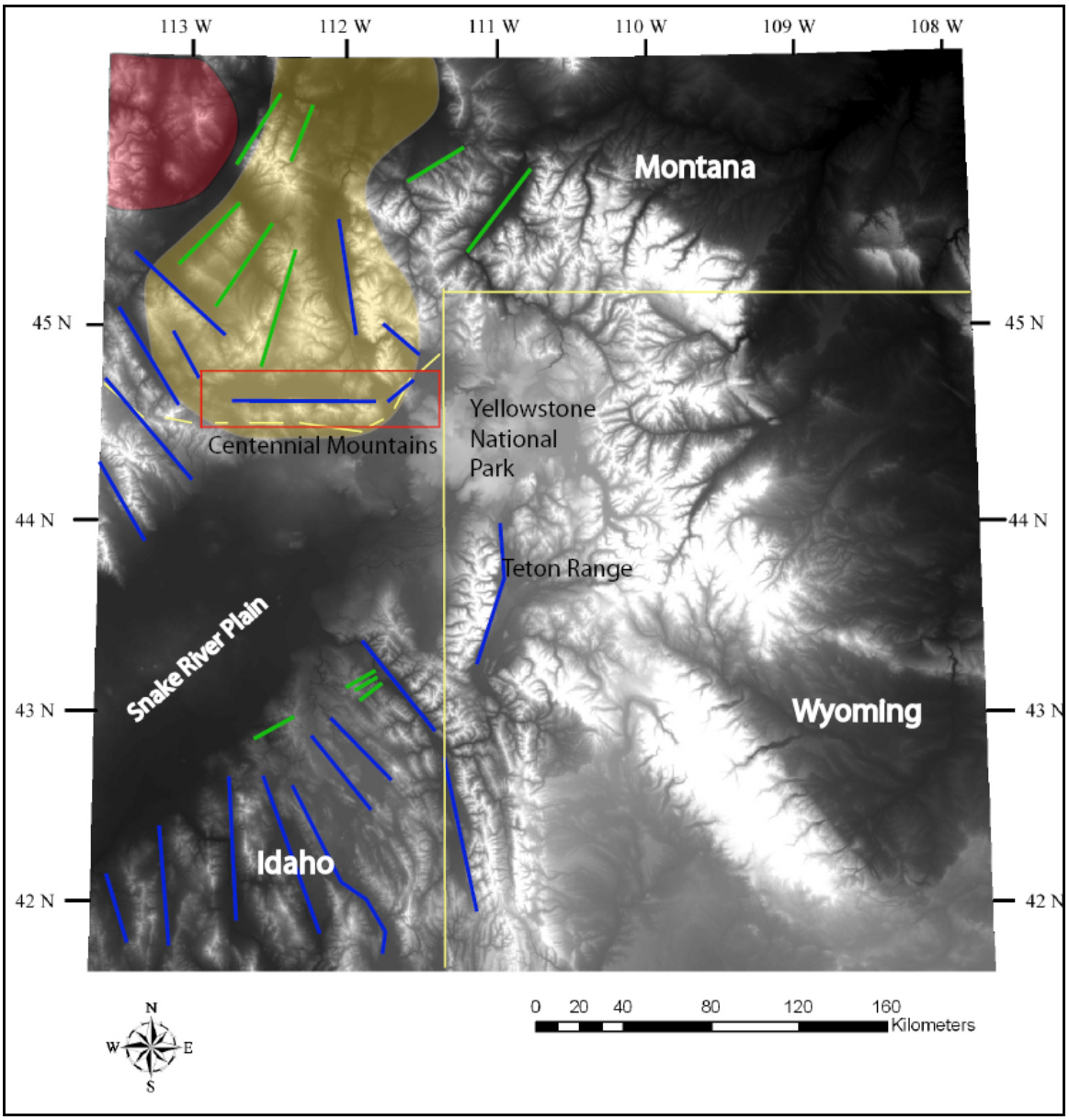

Figure 19. DEM showing all four phases of extension for the greater Yellowstone region. Red box shows the approximate location of the research area. Yellow lines show the approximate state boundaries for Montana, Idaho and Wyoming. Also labeled are the Snake River Plain, Yellowstone National Park, the Centennial Mountains and the Teton Range for reference. The red area is the Anaconda Metamorphic Core Complex, tan area is the Renova Basin, green lines are northeast-trending faults, and blue lines represent the various northwest-trending extensional faults associated with the Neotectonics Phase (latest Cenozoic) of extension. Note the faults in southern Idaho are Tertiary in age and now inactive.

During the most recent phase of neotectonic deformation, approximately the last 5 Ma, the Teton Range has risen significantly as a result of extension along the north-northeast and north-south striking Teton normal fault. The Teton Range has experienced crustal extension since the Neogene-Quaternary time; the extension occurred by backsliding on the original Cache Creek thrust along the northwest end of the ancestral Laramide Teton-Gros Ventre uplift (Lageson, 1987, 1992). Over the past 17,000 years several large ground-rupturing earthquakes have occurred along the Teton normal fault producing well preserved, 3-52 m high fault scarps (Pierce and Good, 1992; Byrd et al., 1994). These fault scarps extend for 55 km along the range front with a total throw of 2.5 to 3.5 km across the Teton normal fault (Gilbert et al., 1983; Byrd et al., 1994; Love et al., 2003). The Teton normal fault is the product of up to 38 m of offset preserved in 13,400-17,000 year glacial moraines (Byrd et al., 1994), implying that much if not all of the 38 m displacement has accumulated since Pinedale deglaciation. Estimates for the initiation of displacement on the Teton normal fault range from 13 Ma to as recently as 5 Ma (Pierce and Good, 1992; Byrd et al., 1994; Love et al., 2003). Byrd et al. (1994) suggest a model for the Teton normal fault from geophysical data that shows Laramide age structures being offset across the fault with these structures influencing the structural and topographic expression of the footwall and hanging wall blocks. Paleomagnetic analyses on the 2.1 Ma Huckleberry Ridge Tuff shows an overall westward tilt of ~ 10° across the Teton normal fault, suggesting that much of the throw across the fault has been in the past 2.1 m.y. (Pierce and Good, 1992; Byrd et al., 1994).

The Centennial Mountains may have exhibited minimal topography before the Huckleberry Ridge Tuff was erupted out of Yellowstone at 2.1 Ma. The 2.1 Ma

Huckleberry Ridge Tuff was deposited on the low ancestral Centennial Mountains, across the Centennial Valley and against the southern margin of the Gravelly Range. This is evidenced by 150 meters of preexisting topographic relief found at the contact between the 2.1 Ma Huckleberry Ridge Tuff-Precambrian contact on the northwest side of Deer Mountain (Christiansen, 1979; Mannick, 1980). Movement along the CNF has displaced the 2.1 Ma Huckleberry Ridge Tuff a minimum of 1,525 to 1,830 meters during the last 2.1 m. y. (Sonderegger et al., 1982). The Centennial Mountains had sufficient elevation by 1.3 Ma to prevent deposition of the Mesa Falls ash in the upper Centennial Valley (Sonderegger et al., 1982; Christiansen, 2001). By 0.6 Ma when the Lava Creek Tuff was erupted from the Yellowstone caldera, there was enough elevation along the Centennial Mountains to completely block the ash flow from invading the Centennial Valley and it is only found along the southeastern slopes of the Centennial Mountains and in the Henrys Lake area (Witkind, 1975b; Sonderegger et al., 1982; O'Neill and Christiansen, 2004).

The four phases of extension have influenced the Centennial Mountains and surrounding area for much of the Paleogene, Early-Middle Miocene, and Latest Cenozoic. The Centennial Mountains exist presently as a result from the most recent phase of extension and continue to adjust to the tectonic regime resulting from the interactions of the Yellowstone hotspot with Basin and Range extension. The extensional domain in southwest Montana for the four phases is bounded by the Lewis and Clark line to the north, the ESRP to the south, the Idaho batholith to the west, and the Rocky Mountain front to the east (Sears and Fritz, 1998).

Seismic Hazard

The CNF and Centennial Mountains are among Montana's highest seismic hazards (Hill and Bartholomew, 1999; Stickney et al., 2000; Wong et al., 2005). Through analysis of fault scarp profile data and estimated age of offset rock, estimated slip rates have been calculated for the CNF. If offset alluvial fan southeast of Henrys Lake is of Pinedale glacial deposits, then post late Pleistocene surface offsets average 12.3 m preserved in 12,000-14,000 year deposits. A maximum surface offset of 3 m for a M_w 7.0 or greater earthquake event, suggest that the Centennial Mountains have had anywhere from 1 to 5 M_w 7+ earthquakes in the past 12,000-14,000 years. This is a significant amount of earthquake activity in a short amount of time. If the alluvial fan southeast of Henrys Lake is inferred to be Bull Lake glacial deposits, then post Bull Lake surface offsets average 12.3 m preserved in 130,000-140,000 yr deposits. The Bull Lake deposits have had anywhere from 1 to 5 M_w 7+ earthquakes in the past 130,000-140,000 years. This is a more reasonable amount of earthquake activity in an area that is lacking a mountain range and would be indicative of eastward migration of the CNF into the Henrys Lake area.

The western and eastern Centennial Mountains have estimated average slip rates of 0.65-0.76 mm/yr and 0.70-0.82 mm/yr, respectively for all fault scarps of late Pleistocene age. It can be inferred that the east and west have a similar seismic hazard based on late Pleistocene age slip rate estimates. The main conclusion from this research is that the CNF as a whole has had multiple M_w 7+ earthquakes in the last 12,000-14,000 years as evidenced by well preserved fault scarps.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Conclusions

1. There is a difference in structural history for the east versus the west Centennial Mountains. The eastern Centennial Mountains experienced greater uplift and erosion in contrast to the western Centennial Mountains based on the exposure of Paleozoic rocks on the crest of the eastern Centennial Mountains; whereas across the Odell Creek fault, Cretaceous rocks are present near the crest in the western Centennial Mountains. However, the eastern and western CNF currently have similar estimated slip rates based on measurements of late Pleistocene age deposits, suggesting a more recent similar rupture history. The fault scarp morphology shows that the western CNF has a recognizable scarp in Cretaceous bedrock that indicates the fault location. The eastern CNF escarpment in bedrock is hundreds of meters higher than the western CNF. The fault scarp morphology shows that the eastern and western CNF have similar late Pleistocene surface offsets for late Pleistocene age deposits, while the eastern CNF contains the only probable Bull Lake deposits at a site without a range front expression. A few fault scarp surface offsets of less than 3 m yielded values that might be used to calculate age. These estimated ages range from 600 to 2000 yrs. Age constraints were determined from Bull Lake expressing no range front and late Pleistocene

deposits offset in the eastern Centennial Mountains, while Pinedale and late Pleistocene deposits are offset in the western Centennial Mountains. The estimated age calculations help to narrow down the age of last offset along the CNF.

2. The Odell Creek fault appears to have been a boundary that separated the CNF into two segments exhibiting different earthquake, geometric, structural and behavioral characteristics. These characteristics were significant before initiation of offset along the CNF. In the last ~14,000 years, tectonic activity across this segment boundary has been similar. A short section of the Odell Creek fault forms a jog in the CNF and accommodates offset along the CNF in the Sheep Mountain and Taylor Mountain area.
3. The CNF commonly strikes northwest not east-west as observed for the overall range. This northwest trend is the result of the interaction with the pre-existing northeast and northwest-trending extensional faults from the earlier tectonic activity of southwest Montana. These northeast and northwest-trending faults were reactivated during the regional down-warping event associated with the migration of the ESRP into the research area. The associated stress from the regional down-warping caused the Centennial Mountains uplift to rupture along the northern part of the range in a southwest extension direction (T-axis S45°W). This resulted in the down-dropping of the hanging wall to the north and the uplift of the footwall to the south, forming the Centennial Valley and the Centennial Mountains, respectively.

4. The CNF has a tectonic history similar to the Teton normal fault. Each of the normal faults originated with the migration of the Yellowstone hotspot into the region. The hanging wall fault blocks were down dropped creating the Centennial Valley and Jackson Hole. The fault surface offset geometry is similar in style with each normal fault having an *en echelon* pattern. The two faults causing the mountain ranges have been active since the late Cenozoic. Each fault has well-preserved fault scarps offsetting late Pleistocene deposits up to ~10 m for the CNF and up to ~20 m for the Teton fault. Both faults are at least 55 km long.

Recommendations for Future Research

To gain a better understanding of the CNF and its seismic history, several techniques are recommended for future research. In Quaternary tectonic studies, soils are useful for estimating the ages of both faulted surficial deposits and colluvial wedges on the fault-scarp slopes, so an understanding of soil development can be useful in interpreting fault-scarp soils (Berry, 1990). Suggestions for future CNF soil analysis should include the *quantitative index of soil development* from Harden (1982) for locations along the western segment from Mud Lake to the Odell Creek in areas where the soil development is occurring along the base of the Frontier Formation and the Quaternary alluvial fan gravels. For sampling locations along the eastern CNF, areas where glacial moraines are offset, the Red Rock Pass or the Rock Creek moraine and Mt Taylor area would be the best choice. In addition to studying soil development, an investigation into the thickness of carbonate coats on gravels should be included (Pierce

and Scott, 1982). For sampling locations along the CNF, one should focus on all fault scarp profile locations where late Pleistocene alluvial fans are offset.

Cosmogenic ^{3}He and ^{10}Be ages can be measured on surface boulders from the glacial moraine sequence deposited by the retreat of Pinedale and in some places Bull Lake, as well as dating rupture events of alluvial fault scarps in conjunction with analyzing scarp morphology (Licciardi et al., 2001; Phillips et al., 2003). The best locations for collecting samples from glacial deposits are Red Rock Pass and Rock Creek Moraine. The best locations for collecting boulders from offset alluvial fans along the western segment are just west of Price Peet Creek and directly across the road from the Jones Ranch (Appendix A for profile data: D, E, I, and Q).

Valley-floor width to valley height ratios, mountain-front sinuosity, and degree of alluvial fan development have been used to determine inferred slip rates derived from tectonic activity rates for other range-bounding normal faults and would be appropriate to apply to the Centennial Mountains. A key factor is the difference in resistance of bedrock to erosion, including the resistant Paleozoic rocks in the Taylor Peak area and the erodable Cretaceous Frontier Formation in the western CNF. Valley-floor width to valley height ratios yield values comparable to the range of differing uplift rates, for example the eastern vs. the western segments of the CNF (Keller and Pinter, 2002). The various calculations can be done from topographic maps and then field checked, especially along the western segment of the CNF.

Spatial relationships between older and younger fans, as well as degree of stream entrenchment, can directly relate offset rates (McCalpin, 1996; Keller and Pinter, 2002). The best locations for field observations on late Pleistocene alluvial fan development are

along the western segment of the CNF between Mud Lake and Been Creek Road. The best fault scarp profile locations for this are: D, E, I, AB, S, AA, U, W, Q, X, T, V and Y.

Trenching along the Hebgen Lake and Red Canyon faults was performed by the USGS and Montana State University during the summer of 2000 and resulted in detailed analysis of the Hebgen Lake fault scarp along with its paleoseismic history (Haller et al., 2000; Pierce et al., 2000; Hecker et al., 2000). The most efficient and accurate method of dating the CNF is trenching, and a similar study should be conducted along the western segment from Mud Lake to the Odell Creek. Trenching at profile locations D, E, H, and Q would be optimal where recognizable grabens have formed. The next choice in location would be at the base of the offset alluvial fans since there is easily erodible material along those fault scarps. For this type of environment, trenching at profile locations I, Q, S, T, U, W, and Y would be optimal.

Further research needs to be completed on actual dating of the fault scarps. Pierce and Colman (1986) and Oemisch (2004) have worked on the geomorphological dating of scarps in temperate climate using a modified diffusion model (GD-Model, Oemisch, 2004). The best locations for conducting geomorphological dating are along the western segment of the CNF from Mud Lake to Jones Ranch.

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APPENDICES

APPENDIX A:

THE CENTENNIAL FAULT PROFILE DATA

Location of fault profile, data associated with the profile, picture of profile (red line indicates approximate location of profile), description of the profile, rating of profile (Excellent (has at least three or four of the following) = lateral continuity, break in slope, lush vegetation, springs, far-field surface alignment, alluvial fan apex offset, and wet spots. Good = lateral continuity, break in slope, lush vegetation, and wet spots. Fair = lateral continuity and break in slope. Poor = either lateral continuity or break in slope.), and graph depicting the fault profile.

Profile: A – A'

Starting location: 44°36'04" N, 112°10'19"W
Ending location: 44°35'58" N, 112°10'21"W

Station number	Slope in degrees	Distance (meters)
0-1	+0.5	11.82
1-2	+2.0	11.80
2-3	+2.5	11.79
3-4	+5.0	11.32
4-5	+16.5	7.74
5-6	+17.0	4.75
6-7	+17.5	5.76
7-8	+22.0	4.40
8-9	+30.0	4.25
9-10	+34.5	3.70
10-11	+33.0	4.15
11-12	+33.5	4.65
12-13	+27.0	4.07
13-14	+19.5	3.92
14-15	+19.5	5.46
15-16	+16.5	6.61
16-17	+15.0	7.45
17-18	+13.0	6.57
18-19	+13.5	6.13
19-20	+12.0	6.11
20-21	+17.0	5.38
21-22	+22.5	3.96
22-23	+22.5	4.47
23-24	+16.0	3.40
24-25	+18.5	3.33
25-26	+22.0	4.21
26-27	+16.5	6.50
27-28	+16.5	5.37
28-29	+11.0	4.87
29-30	+6.5	5.51

30-31	+6.5	5.36
31-32	+4.0	5.27
32-33	+1.0	4.86

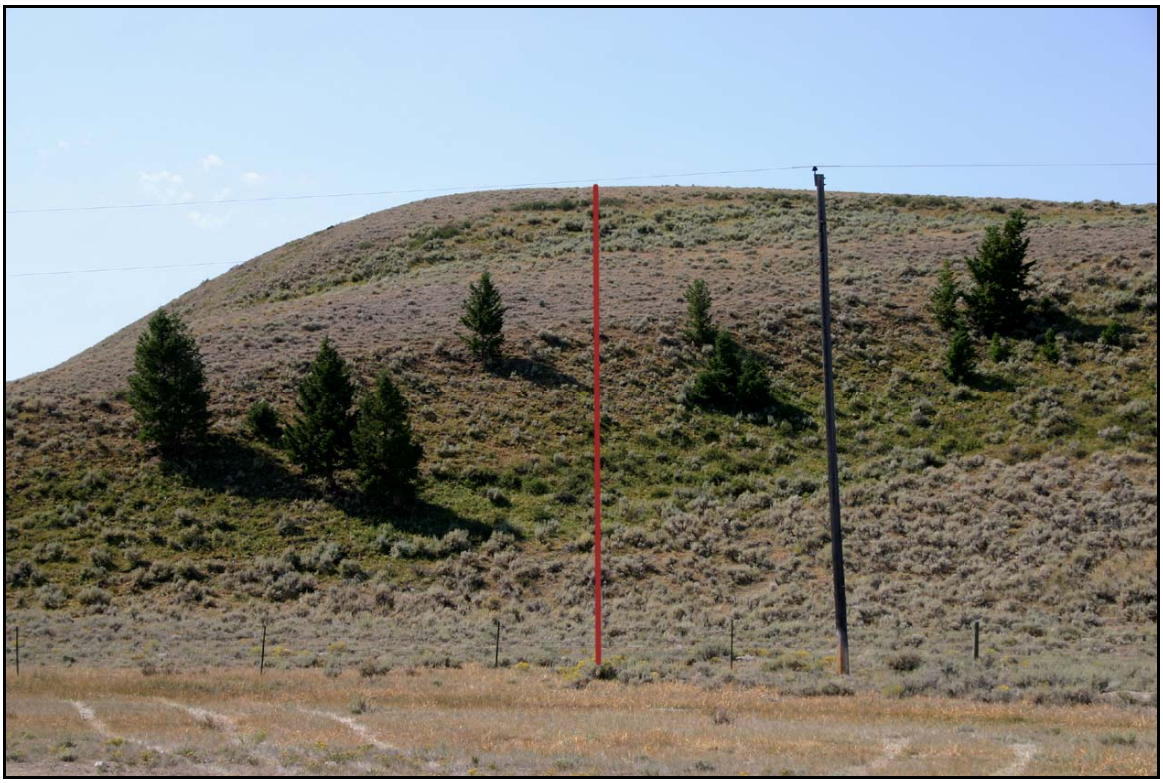
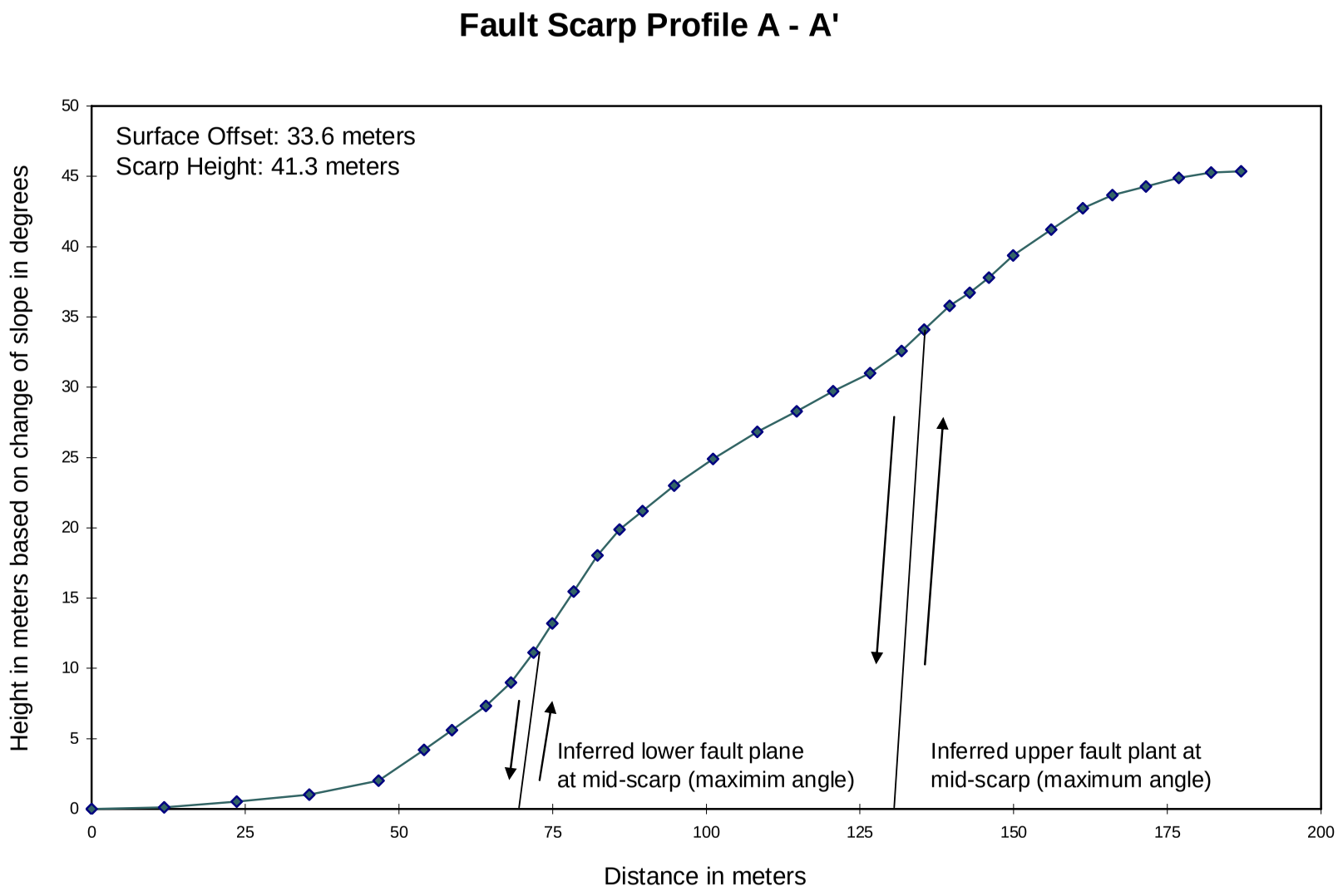


Figure 20. Fault profile A – A', starting location: 44°36'04" N, 112°10'19"W; ending location: 44°35'58" N, 112°10'21"W, looking south.

Profile A – A' starts approximately 0.8 kilometer east of Mud Lake. The hanging wall far field toe of the profile is moderately flat and covered in sagebrush with some wetland grass. The lower fault plane is inferred at stations 9 – 10 where the slope is +34.5°. At the top of the lower fault scarp the topography flattens before the start of the upper fault scarp. The upper fault plane is inferred at stations 22 – 23 where the slope is +22.5°. The upper fault scarp rounds at the top of the hill and then flattens as one moves south into the footwall of the profile.

This profile is rated: excellent


Fault Scarp Profile A - A'
Surface Offset: 33.6 meters
Scarp Height: 41.3 meters
Inferred lower fault plane
at mid-scarp (maximim angle)
Inferred upper fault plant at
mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
30
35
40
45
50
0
25
50
75
100
125
150
175
200

Profile: B – B’

Starting location: 44°36’04’’N, 112°10’20’’W
Ending location: 44°35’58’N, 112°10’22’’W

Station number	Slope in degrees	Distance (meters)
0-1	+1.5	5.42
1-2	-0.5	7.92
2-3	+2.0	8.28
3-4	+1.5	7.87
4-5	+1.5	6.55
5-6	+3.0	6.86
6-7	+9.0	3.35
7-8	+14.0	3.15
8-9	+23.0	3.96
9-10	+26.5	3.10
10-11	+30.0	3.18
11-12	+32.0	3.02
12-13	+32.0	3.25
13-14	+30.0	2.18
14-15	+33.0	2.72
15-16	+31.0	2.69
16-17	+27.0	2.91
17-18	+18.5	4.09
18-19	+18.5	3.62
19-20	+13.0	3.56
20-21	+18.0	3.71
21-22	+15.5	4.91
22-23	+14.0	3.89
23-24	+11.0	3.66
24-25	+7.0	3.07
25-26	+9.0	3.23
26-27	+12.0	3.84
27-28	+13.0	3.63
28-29	+11.5	3.45
29-30	+10.0	4.10
30-31	+10.0	4.01
31-32	+19.5	2.60
32-33	+26.0	2.91
33-34	+25.0	3.33
34-35	+23.0	2.59
35-36	+23.0	2.97
36-37	+15.0	4.75
37-38	+24.5	1.85
38-39	+22.0	2.67
39-40	+15.0	4.11

40-41	+16.5	4.42
41-42	+16.5	3.45
42-43	+13.0	4.06
43-44	+9.0	3.23
44-45	+4.5	4.29
45-46	+5.5	4.41
46-47	+2.5	4.57
47-48	+1.0	4.72
48-49	-2.0	3.96

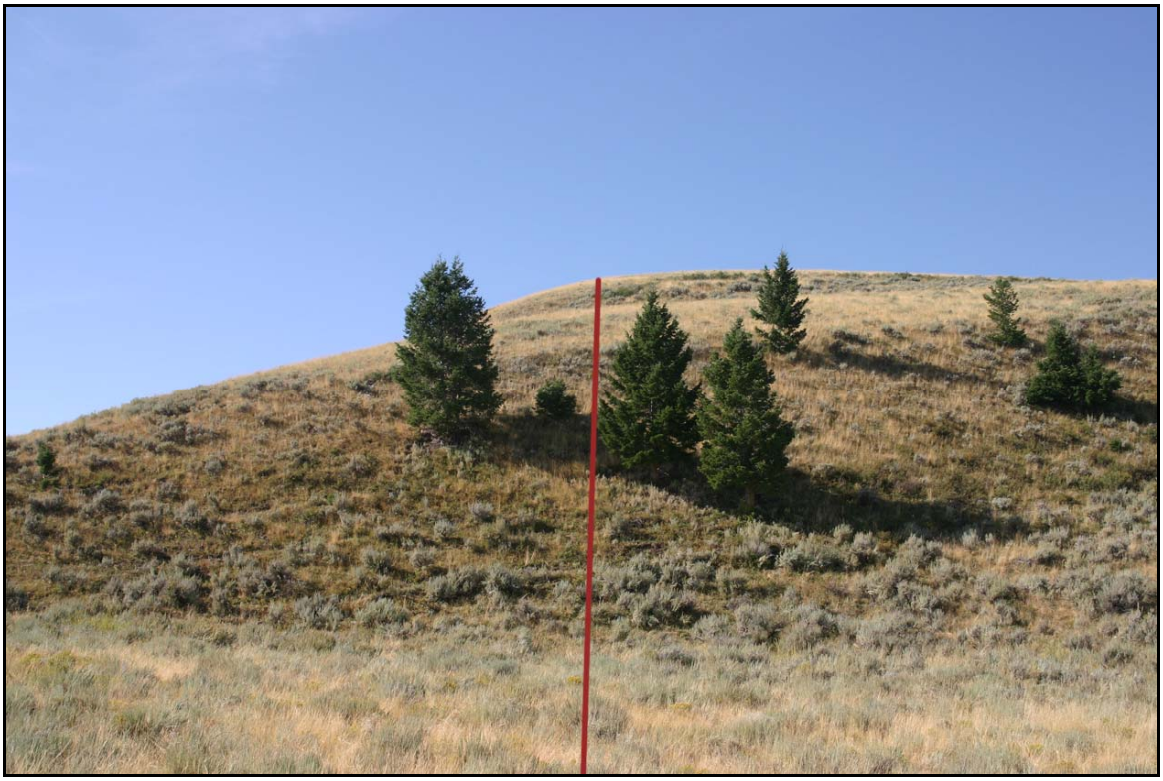
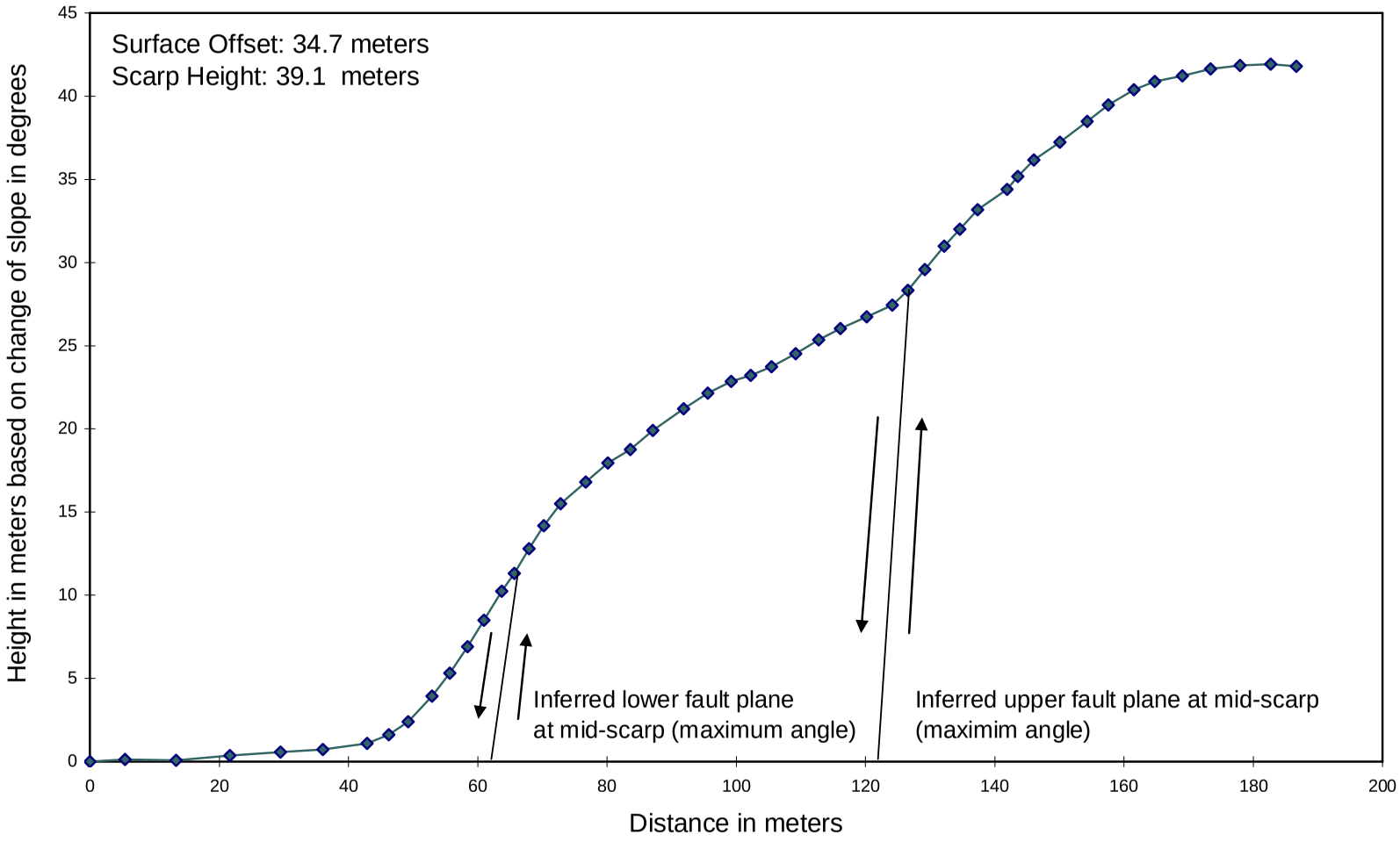


Figure 21. Fault profile B – B', starting location: 44°36'04''N, 112°10'20''W; ending location: 44°35'58'N, 112°10'22''W, looking south.

Profile B – B' starts immediately to the west of profile A – A'. The hanging wall far field toe of the profile is flat and starts directly east of the slump (right side of picture). The profile extends up-slope between the tall tree on the east and the small tree on the west. The lower fault plane is inferred at stations 14 – 15 where the slope is +33.0°. At the top of the lower fault scarp the topography flattens before the start of the upper fault scarp. The upper fault plane is inferred at stations 32 – 33 where the slope is +26.0°. The upper fault scarp rounds at the top of the hill and then flattens as one moves south into the footwall of the profile.

This profile is rated: excellent.

Fault Scarp Profile B - B'



Profile: C – C’

Starting location: 44°36’05” N, 112°10’05”W
Ending location: 44°35’53” N, 112°10’09”W

Station number	Slope in degrees	Distance (meters)
0-1	+0.0	6.60
1-2	+1.0	6.60
2-3	-1.0	6.42
3-4	+1.5	6.90
4-5	+3.0	6.60
5-6	+0.0	6.50
6-7	+5.0	6.65
7-8	+5.0	6.05
8-9	+5.5	6.65
9-10	+6.5	5.30
10-11	+8.5	4.85
11-12	+10.0	4.30
12-13	+10.5	4.02
13-14	+10.5	3.85
14-15	+10.5	3.26
15-16	+12.5	5.33
16-17	+12.5	4.45
17-18	+9.5	4.00
18-19	+9.5	3.63
19-20	+9.0	4.05
20-21	+10.0	4.46
21-22	+8.5	5.45
22-23	+9.0	6.10
23-24	+10.0	4.50
24-25	+13.0	4.80
25-26	+11.0	3.50
26-27	+13.0	3.14
27-28	+14.0	3.10
28-29	+17.0	3.16
29-30	+25.0	2.18
30-31	+25.0	2.80
31-32	+27.0	2.03
32-33	+24.5	2.19
33-34	+17.5	1.57
34-35	+19.0	1.71
35-36	+19.0	1.95
36-37	+16.0	2.45
37-38	+10.0	3.70
38-39	+4.5	4.65
39-40	-2.0	5.59

40-41	+6.0	3.35
41-42	+14.0	2.10
42-43	+13.0	2.20
43-44	+13.0	4.30
44-45	+16.0	3.47
45-46	+20.0	2.55
46-47	+18.5	4.04
47-48	+21.5	3.00
48-49	+25.0	2.55
49-50	+22.5	3.10
50-51	+25.5	2.50
51-52	+25.0	2.20
52-53	+23.5	2.94
53-54	+27.0	2.60
54-55	+25.0	2.45
55-56	+28.5	2.60
56-57	+29.5	2.81
57-58	+25.0	2.68
58-59	+21.5	2.80
59-60	+18.0	2.50
60-61	+17.0	3.55
61-62	+14.0	4.10
62-63	+9.5	6.45
63-64	+7.0	6.63
64-65	+6.0	8.06
65-66	+7.0	7.60
66-67	+7.5	7.20
67-68	+6.5	7.66
68-69	+2.5	7.22
69-70	+0.5	6.18

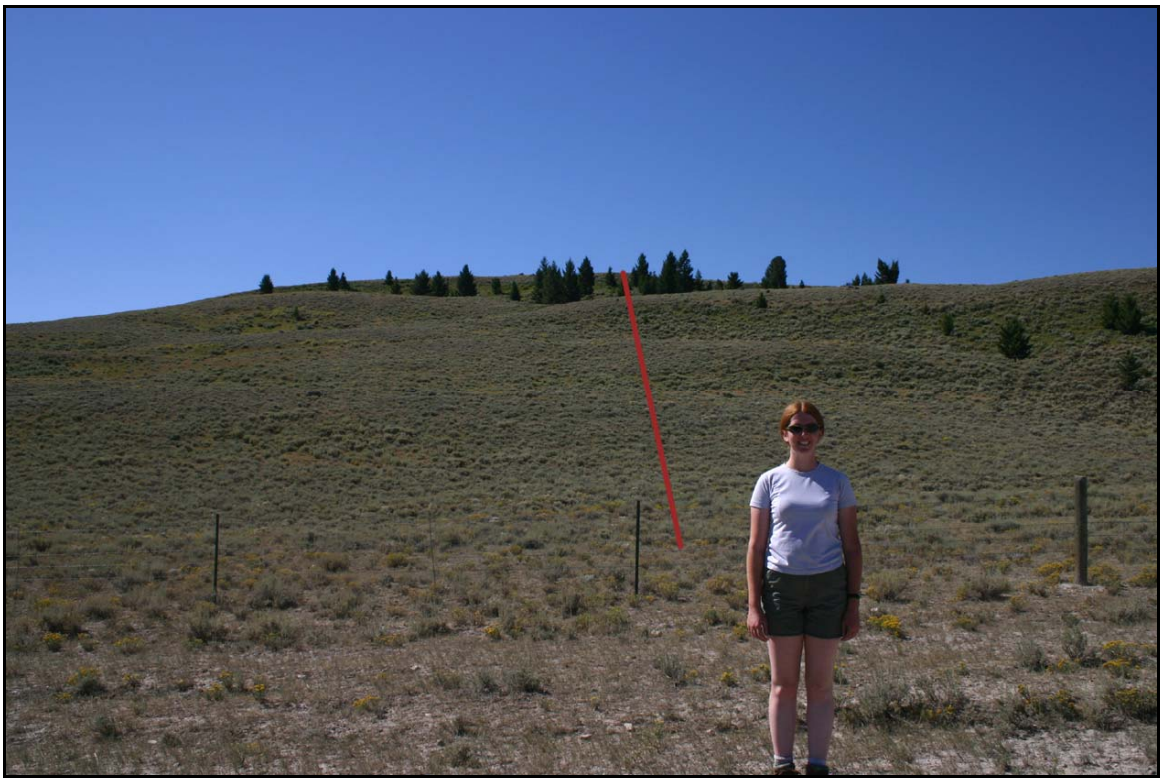
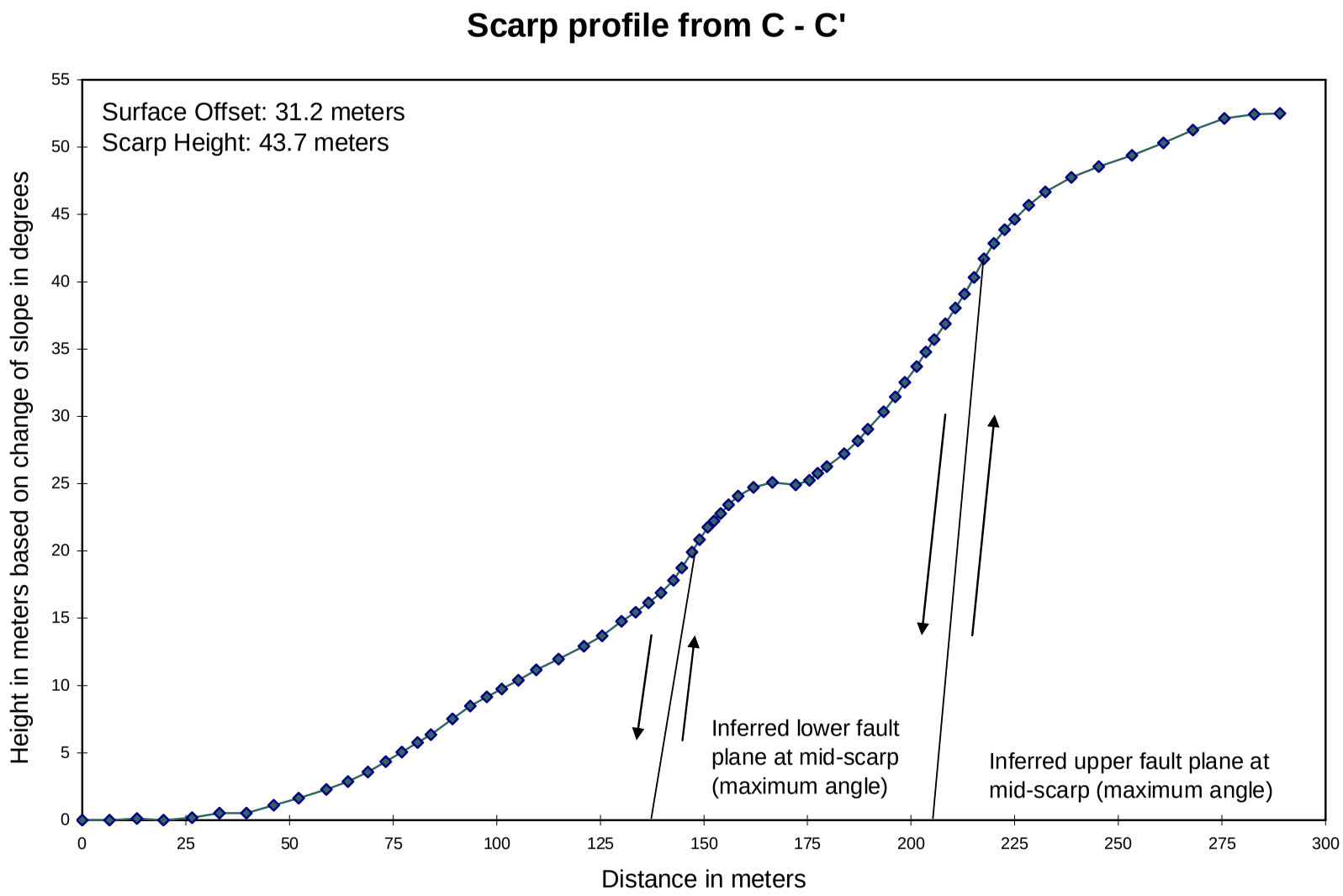


Figure 22. Fault profile C – C', starting location: 44°36'05" N, 112°10'05"W; ending location: 44°35'53" N, 112°10'09"W, looking south.

Profile C – C' starts just east of profile B – B'. The hanging wall toe of the profile starts out flat but quickly encounters the edge of the alluvial fan/slump; there is gentle slumping at the base of the lower fault scarp. The lower fault plane is inferred at station 31 – 32 where the slope is +27.0°. At the top of the lower scarp the topography flattens out before starting up the upper fault scarp. The upper fault plane is inferred at station 57 – 58 where the slope is +29.5°. A small creek is coming out from the hill slope just east of this profile, possibly issuing from the fault plane.

This profile is rated: fair


Scarp profile from C - C'
Surface Offset: 31.2 meters
Scarp Height: 43.7 meters
Height in meters based on change of slope in degrees
Distance in meters
Inferred lower fault plane at mid-scarp (maximum angle)
Inferred upper fault plane at mid-scarp (maximum angle)
0
5
10
15
20
25
30
35
40
45
50
55
0
25
50
75
100
125
150
175
200
225
250
275
300

Profile: D – D’

Starting location: 44°35’56” N, 112°09’37”W
Ending location: 44°35’53” N, 112°09’37”W

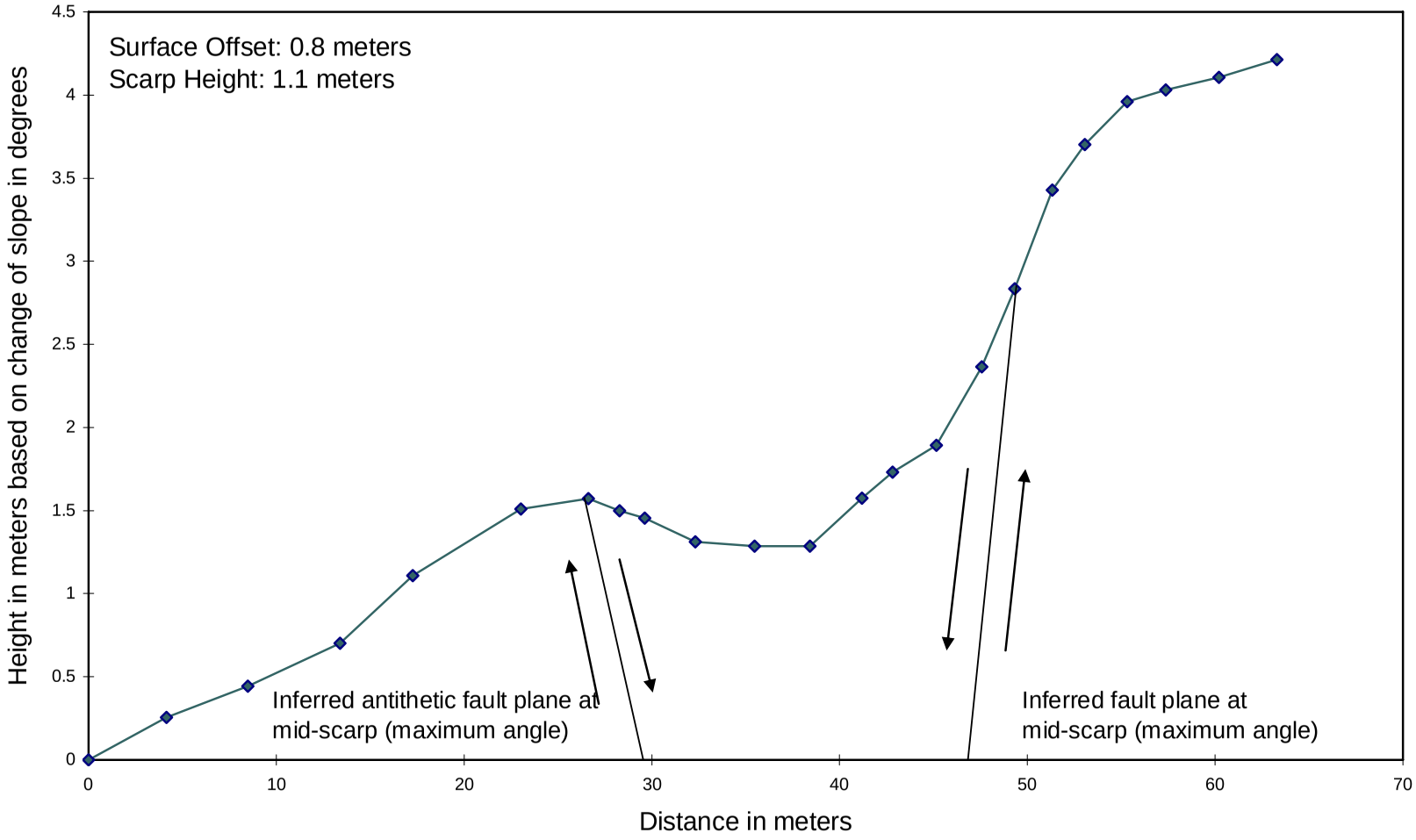
Station number	Slope in degrees	Distance (meters)
0-1	+3.5	4.17
1-2	+2.5	4.32
2-3	+3.0	4.93
3-4	+6.0	3.89
4-5	+4.0	5.79
5-6	+1.0	3.58
6-7	-2.5	1.68
7-8	-2.0	1.32
8-9	-3.0	2.72
9-10	-0.5	3.15
10-11	+0.0	2.96
11-12	+6.0	2.78
12-13	+5.5	1.63
13-14	+4.0	2.34
14-15	+11.0	2.46
15-16	+15.0	1.82
16-17	+16.5	2.10
17-18	+9.0	1.75
18-19	+6.5	2.26
19-20	+2.0	2.07
20-21	+1.5	2.82
21-22	+2.0	3.10

Figure 23. Fault profile D – D', starting location: 44°35'56" N, 112°09'37"W; ending location: 44°35'53" N, 112°09'37"W, looking south.

Profile D – D' is located to the east of profile C – C'. This profile is for a fault scarp that offsets an inactive alluvial fan. The far field toe of the profile starts relatively flat and then decreases in slope as the profile moves south. This decrease in slope is represented by an antithetic fault plane inferred at stations 6 – 7 where the slope is -2.5°. The profile continues through the graben until it starts to increase in slope again. The fault plane on the main fault is inferred at stations 16 – 17 where the slope is +16.5°. The fault scarp rounds at the top and then flattens as one moves south into the footwall of the profile.

This profile is rated: excellent

Fault Scarp Profile D - D'



Profile: E – E’

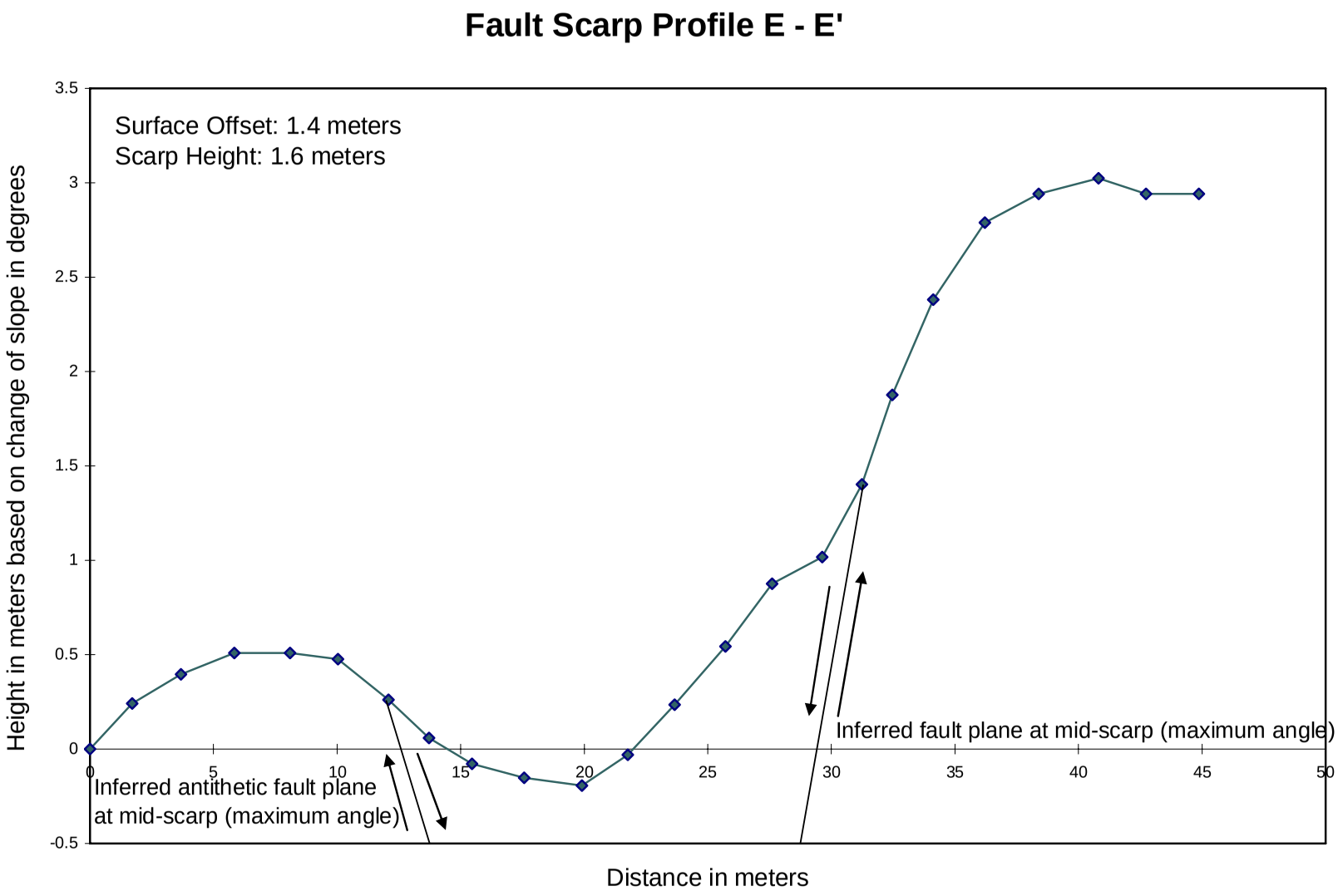
Starting location: 44°35’55” N, 112°09’36”W
Ending location: 44°35’53” N, 112°09’36”W

Station number	Slope in degrees	Distance (meters)
0-1	+8.0	6.60
1-2	+4.5	6.60
2-3	+3.0	6.42
3-4	+0.0	6.90
4-5	-1.0	6.60
5-6	-6.0	6.50
6-7	-7.0	6.65
7-8	-4.5	6.05
8-9	-2.0	6.65
9-10	-1.0	5.30
10-11	+5.0	4.85
11-12	+8.0	4.30
12-13	+8.5	4.02
13-14	+10.0	3.85
14-15	+4.0	3.26
15-16	+13.5	5.33
16-17	+21.0	4.45
17-18	+17.0	4.00
18-19	+11.0	3.63
19-20	+4.0	4.05
20-21	+2.0	4.46
21-22	-2.5	5.45
22-23	+0.0	6.10

Figure 24. Fault profile E – E', starting location: 44°35'55" N, 112°09'36"W; ending location: 44°35'53" N, 112°09'36"W, looking south.

Profile E – E' is located to the east of profile D – D'. This profile is for a fault scarp that offsets an inactive alluvial fan. The hanging wall far field toe of the profile starts relatively flat and then decreases in slope as the profile moves south. This decrease in slope is represented by an antithetic fault plane inferred at stations 6 – 7 where the slope is -7.0°. The profile continues through the graben until it starts to increase in slope again. The fault plane on the main fault is inferred at stations 16 – 17 where the slope is +21.0°. The fault scarp rounds at the top and then flattens as one moves south into the footwall of the profile.

This profile is rated: excellent


Fault Scarp Profile E - E'
Surface Offset: 1.4 meters
Scarp Height: 1.6 meters
Height in meters based on change of slope in degrees
Distance in meters
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
5
10
15
20
25
30
35
40
45
50
Inferred antithetic fault plane
at mid-scarp (maximum angle)
Inferred fault plane at mid-scarp (maximum angle)

Profile: F – F’

Starting location: 44°35’57” N, 112°09’16”W
Ending location: 44°35’31” N, 112°09’24”W

Station number	Slope in degrees	Distance (meters)
0-1	+0.5	7.13
1-2	-0.5	6.87
2-3	+2.0	7.56
3-4	+1.0	6.79
4-5	+1.0	7.60
5-6	-1.0	7.34
6-7	+0.0	6.95
7-8	+0.0	6.85
8-9	+0.0	7.40
9-10	+1.5	7.64
10-11	+1.0	7.48
11-12	+0.0	7.62
12-13	+1.0	7.65
13-14	+2.0	6.93
14-15	+4.0	7.48
15-16	+3.0	7.03
16-17	+4.0	6.30
17-18	+10.0	5.40
18-19	+16.5	3.63
19-20	+27.0	3.00
20-21	+24.5	3.53
21-22	+21.0	3.60
22-23	+12.5	4.25
23-24	+12.0	5.36
24-25	+13.0	5.20
25-26	+12.0	6.30
26-27	+10.0	6.70
27-28	+5.0	6.60
28-29	+14.0	3.50
29-30	+19.0	1.75
30-31	+25.0	2.30
31-32	+25.5	3.40
32-33	+22.5	4.00
33-34	+15.5	3.75
34-35	+15.0	3.80
35-36	+17.0	3.70
36-37	+20.0	4.40
37-38	+23.0	4.00
38-39	+20.0	5.23
39-40	+14.0	6.00

40-41	+10.0	5.90
41-42	+7.5	6.60
42-43	+8.0	8.30
43-44	+9.5	6.90
44-45	+11.0	7.80
45-46	+11.5	8.20
46-47	+10.5	6.62
47-48	+9.5	7.65
48-49	+8.5	6.45
49-50	+6.5	7.85
50-51	+0.0	7.00
51-52	+10.0	7.28
52-53	+9.0	6.80
53-54	+7.5	7.10
54-55	+8.0	7.30
55-56	+8.0	7.20
56-57	+7.5	8.00
57-58	+7.5	7.40
58-59	+6.5	8.41
59-60	+6.0	7.33
60-61	+9.0	6.75
61-62	+7.5	6.80
62-63	+11.0	7.25
63-64	+10.0	6.14
64-65	+4.5	7.75
65-66	+5.0	7.20
66-67	+7.0	7.90
67-68	+4.0	7.50
68-69	+4.5	6.63
69-70	+3.5	5.80
70-71	+4.5	7.89
71-72	+3.0	7.76
72-73	+5.0	7.90
73-74	+4.0	7.20
74-75	+5.0	6.95
75-76	+6.0	6.55
76-77	+2.0	7.05
77-78	+2.0	7.05
78-79	+3.0	6.64
79-80	+9.0	7.35
80-81	+18.0	5.06
81-82	+22.0	3.70
82-83	+22.0	4.50
83-84	+22.0	3.85
84-85	+24.0	4.50
85-86	+19.5	4.40

86-87	+20.0	4.85
87-88	+23.0	4.08
88-89	+15.0	6.50
89-90	+10.0	8.15
90-91	+8.0	7.95
91-92	+10.0	7.10
92-93	+8.0	7.65
93-94	+8.5	7.97
94-95	+6.5	8.18
95-96	+8.0	8.22
96-97	+7.0	8.05
97-98	+7.0	8.09
98-99	+6.0	8.20

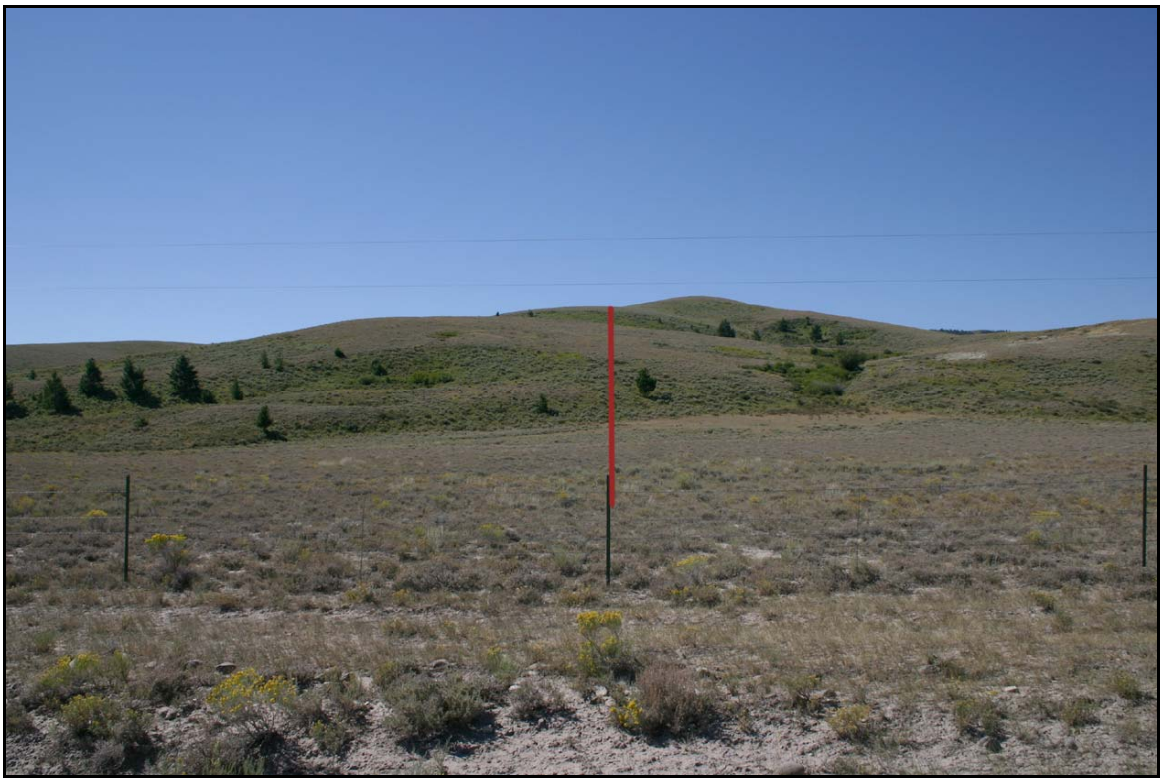
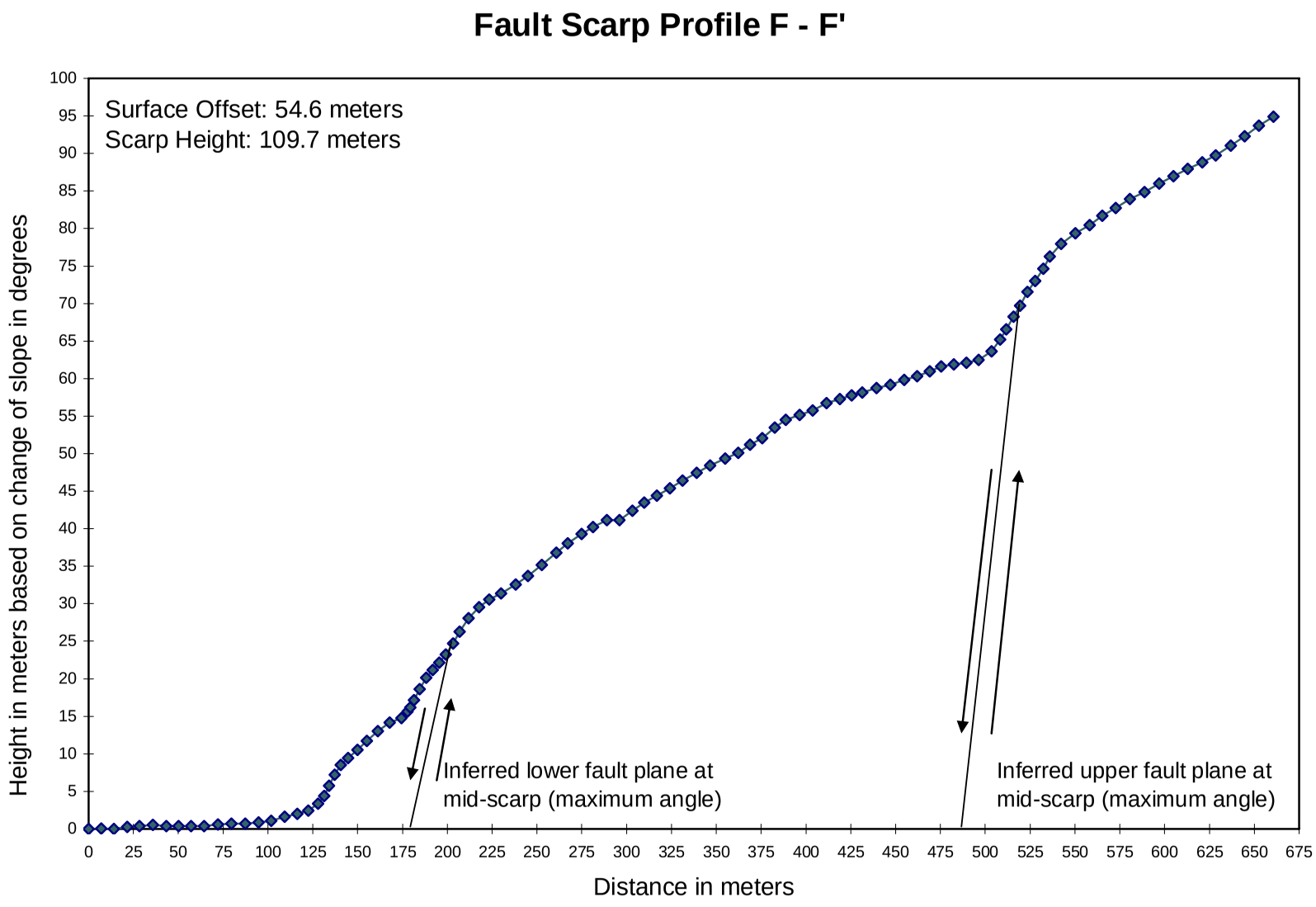


Figure 25. Fault profile F – F', starting location: 44°35'57" N, 112°09'16"W; ending location: 44°35'31" N, 112°09'24"W, looking south.

Profile F – F' is located approximately 0.8 kilometer east of profile C – C'. The lower part of the profile is covered by the edge of the earthflow. The main body of the earthflow starts just east of the profile. The profile runs upslope between the large tree to the west and the small tree to the east (trees located behind and to the left of field assistant). The profile starts out flat in the hanging wall until it moves up along the edge of the earthflow. The lower fault plane is inferred at stations 37 – 38 where the slope is +23.0°. The slope flattens at the top of the lower scarp and then starts to become steep

as it moves up the profile towards the upper scarp. The upper fault plane is inferred at stations 84 – 85 where the slope is +23.0°. The upper fault scarp rounds at the top of the hill and then flattens as one moves south into the footwall of the profile.

This profile is rated: fair


Fault Scarp Profile F - F'
Surface Offset: 54.6 meters
Scarp Height: 109.7 meters
Inferred lower fault plane at mid-scarp (maximum angle)
Inferred upper fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500
525
550
575
600
625
650
675

Profile: G – G’

Starting location: 44°35’51” N, 112°08’59”W
Ending location: 44°35’30” N, 112°09’03”W

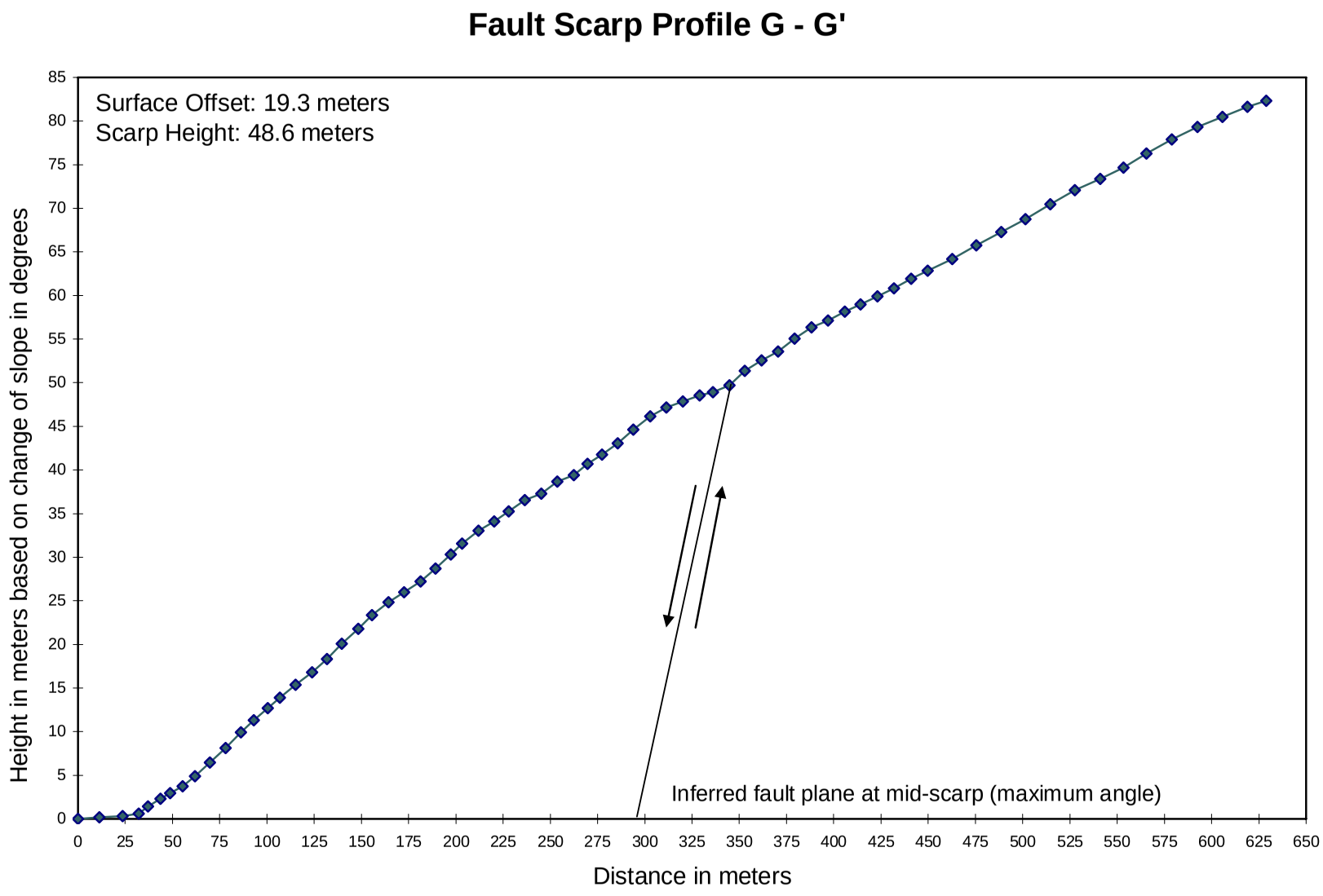
Station number	Slope in degrees	Distance (meters)
0-1	+1.0	11.30
1-2	+0.5	12.35
2-3	+2.0	8.60
3-4	+10.0	4.76
4-5	+7.5	6.75
5-6	+7.0	5.13
6-7	+7.0	6.70
7-8	+10.0	6.60
8-9	+11.0	8.12
9-10	+11.5	8.41
10-11	+12.5	8.36
11-12	+11.5	6.85
12-13	+10.5	7.71
13-14	+10.5	6.37
14-15	+10.0	8.54
15-16	+9.5	8.77
16-17	+11.0	8.00
17-18	+12.5	8.15
18-19	+11.0	8.80
19-20	+12.0	7.51
20-21	+10.0	8.75
21-22	+7.5	8.51
22-23	+8.5	8.68
23-24	+10.5	8.01
24-25	+11.5	8.20
25-26	+11.5	6.10
26-27	+9.5	8.88
27-28	+7.5	8.41
28-29	+8.5	7.70
29-30	+8.5	8.75
30-31	+5.0	8.65
31-32	+9.0	8.60
32-33	+5.0	8.82
33-34	+10.0	7.35
34-35	+8.0	7.75
35-36	+9.0	8.30
36-37	+10.5	8.61
37-38	+9.5	9.00
38-39	+7.0	8.50
39-40	+4.5	8.90

40-41	+4.5	8.97
41-42	+3.0	6.90
42-43	+5.0	8.85
43-44	+11.5	8.26
44-45	+8.0	8.91
45-46	+6.5	8.90
46-47	+9.5	8.81
47-48	+8.5	8.92
48-49	+5.0	8.85
49-50	+6.5	9.05
50-51	+5.5	8.38
51-52	+6.0	8.80
52-53	+6.0	8.96
53-54	+7.0	9.05
54-55	+6.0	8.78
55-56	+6.0	13.10
56-57	+7.0	12.90
57-58	+6.5	13.20
58-59	+6.5	12.93
59-60	+7.5	13.27
60-61	+7.0	13.19
61-62	+5.5	13.48
62-63	+6.0	12.25
63-64	+7.5	12.41
64-65	+7.0	13.41
65-66	+6.0	13.60
66-67	+5.0	13.40
67-68	+5.0	13.13
68-69	+4.0	10.10

Figure 26. Fault profile G – G', starting location: 44°35'51" N, 112°08'59"W; ending location: 44°35'30" N, 112°09'03"W, looking south.

Profile G – G' is located approximately 3 kilometer west of Price Peet Road. This profile runs directly upslope to the maximum elevation. The profile starts flat in the hanging wall and moves towards the break in slope. The lower fault scarp is covered by the small earthflow/alluvial fan located at the base of the slope. The profile continues up slope until it reaches the upper fault scarp. The upper fault plane is inferred at stations 43 – 44 where the slope is +11.5°. The profile continues until it reaches the top of the slope where it rounds off and flattens as it moves into the footwall of the profile.

This profile is rated: poor


Fault Scarp Profile G - G'
Surface Offset: 19.3 meters
Scarp Height: 48.6 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425
450
475
500
525
550
575
600
625
650

Profile: H – H'

Starting location: 44°35'43" N, 112°08'29"W
Ending location: 44°35'31" N, 112°08'29"W

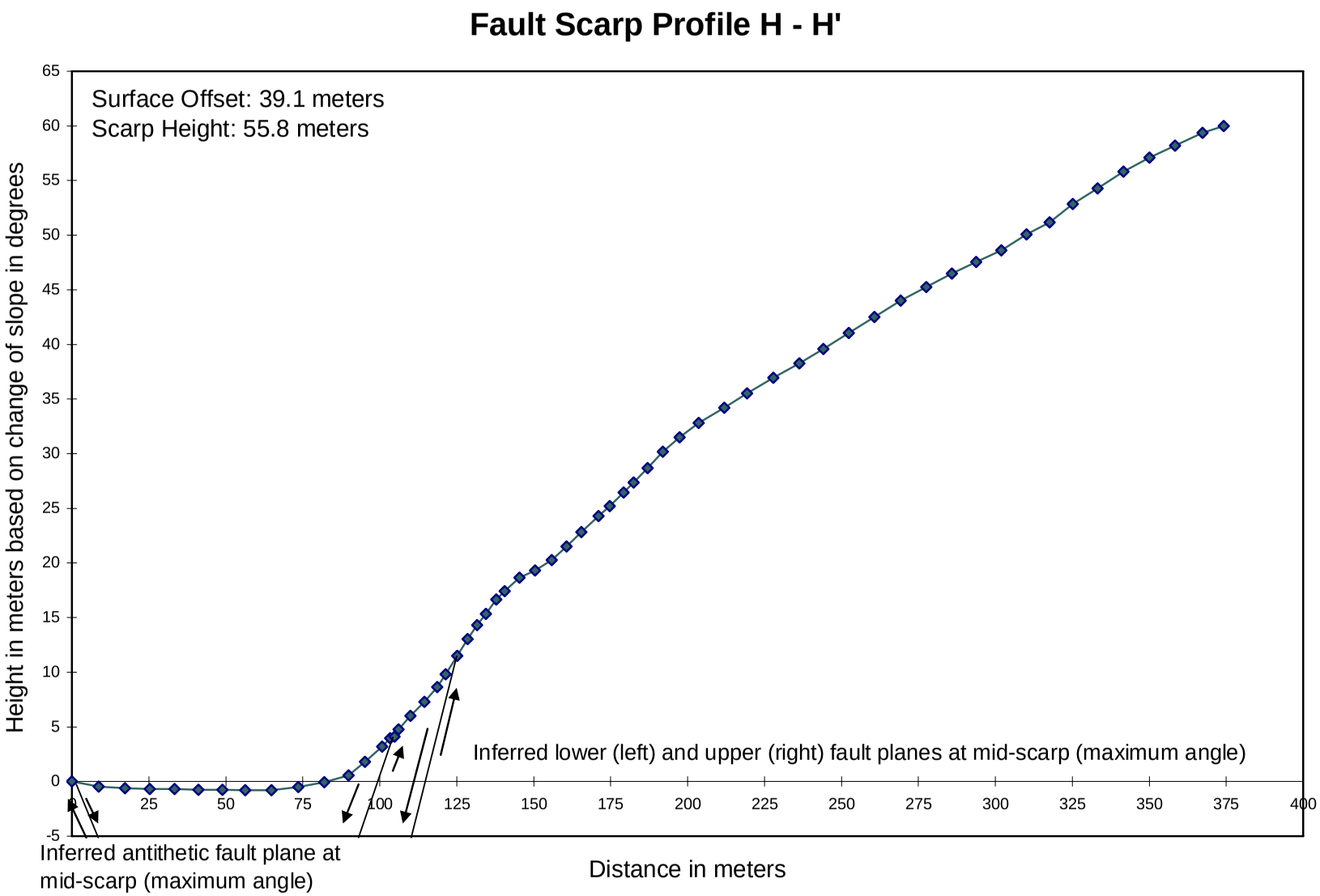
Station number	Slope in degrees	Distance (meters)
0-1	-3.0	8.70
1-2	-1.0	8.60
2-3	-0.5	8.00
3-4	+0.0	8.10
4-5	-0.5	7.70
5-6	+0.0	7.81
6-7	-0.5	7.44
7-8	+0.0	8.54
8-9	+2.0	8.66
9-10	+3.0	8.45
10-11	+4.5	7.92
11-12	+13.0	5.45
12-13	+14.0	5.77
13-14	+17.0	2.68
14-15	+5.0	1.43
15-16	+25.5	1.55
16-17	+18.0	4.00
17-18	+16.0	4.75
18-19	+18.0	4.32
19-20	+23.0	3.00
20-21	+24.0	4.15
21-22	+25.0	3.66
22-23	+21.5	3.44
23-24	+20.0	3.00
24-25	+21.0	3.64
25-26	+16.0	2.80
26-27	+14.5	5.00
27-28	+7.5	5.06
28-29	+10.0	5.56
29-30	+14.5	4.90
30-31	+15.0	5.04
31-32	+15.0	5.72
32-33	+14.5	3.70
33-34	+15.0	4.80
34-35	+15.5	3.33
35-36	+16.5	4.70
36-37	+17.0	5.13
37-38	+13.5	5.57
38-39	+12.0	6.37
39-40	+9.5	8.52

40-41	+10.0	7.45
41-42	+9.5	8.75
42-43	+9.0	8.43
43-44	+9.5	8.00
44-45	+10.0	8.40
45-46	+10.0	8.43
46-47	+10.0	8.60
47-48	+8.5	8.43
48-49	+8.5	8.43
49-50	+7.5	7.95
50-51	+7.5	8.20
51-52	+10.0	8.40
52-53	+8.5	7.52
53-54	+12.5	7.80
54-55	+10.0	8.05
55-56	+10.5	8.60
56-57	+8.5	8.50
57-58	+7.5	8.40
58-59	+7.5	9.08
59-60	+5.0	6.90

Figure 27. Fault profile H – H', starting location: 44°35'43" N, 112°08'29"W; ending location: 44°35'31" N, 112°08'29"W, looking south.

Profile H – H' starts approximately 170 meters to the east of Price Peet Road. There is a visible antithetic fault scarp in the hanging wall of the profile. The profile starts just to the north of the antithetic fault plane which is inferred at stations 0 – 1 where the slope is -3.0°. The profile goes through the graben and continues to move up slope. The lower fault plane is inferred at stations 15 – 16 where the slope is +25.5°. The lower fault scarp may be slightly slumped. The profile continues up slope until it reaches the upper fault scarp. The upper fault plane is inferred at stations 21 – 22 where the slope is +25.0°. The fault scarp rounds at the top of the hill and flattens as one moves south into the footwall of the profile. The upper fault scarp may be either tectonic or gravity induced.

This profile is rated: fair


Fault Scarp Profile H - H'
Surface Offset: 39.1 meters
Scarp Height: 55.8 meters
Height in meters based on change of slope in degrees
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
Distance in meters
Inferred lower (left) and upper (right) fault planes at mid-scarp (maximum angle)
Inferred antithetic fault plane at
mid-scarp (maximum angle)

Profile: I – I’

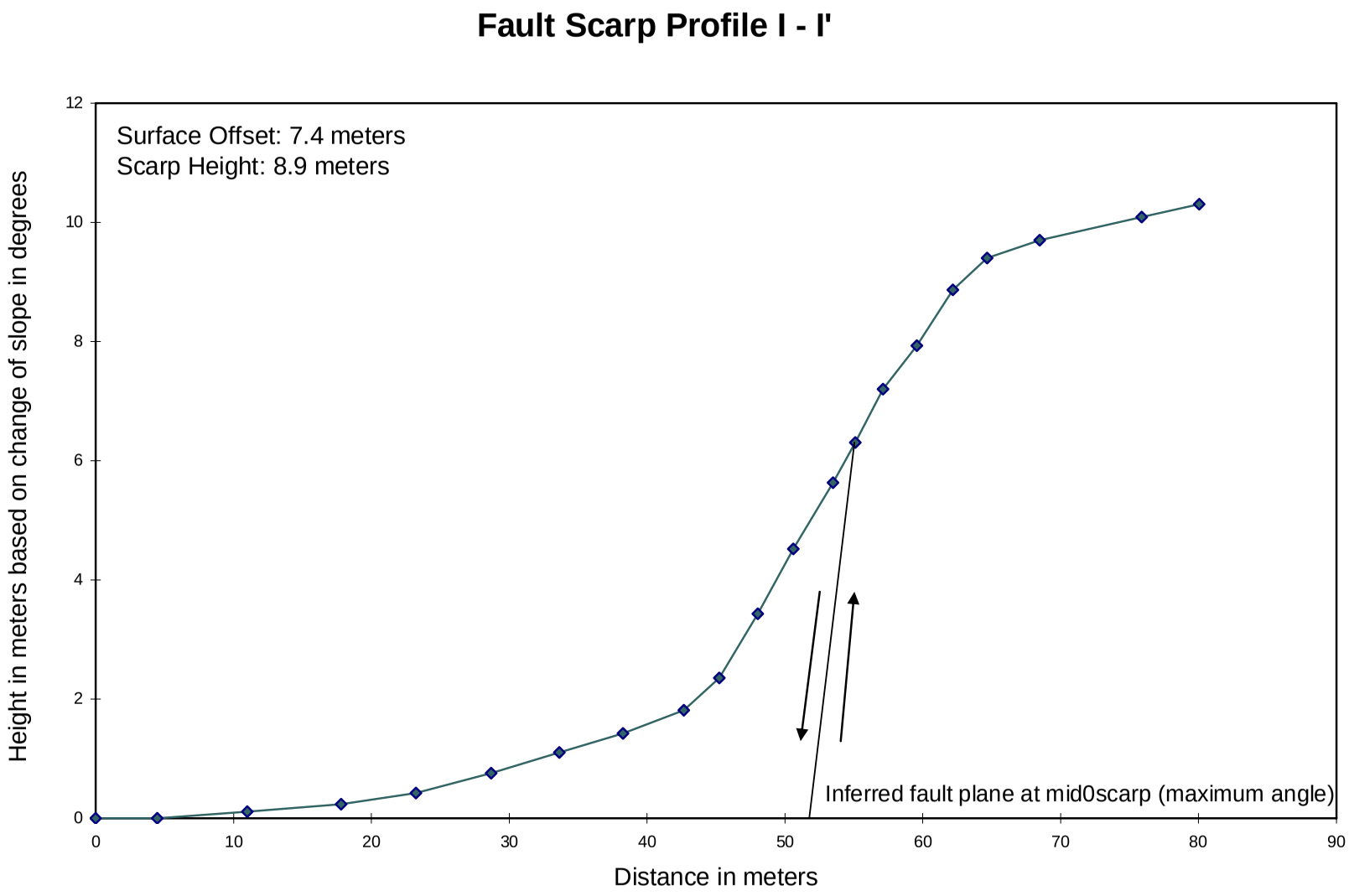
Starting location: 44°35’41” N, 112°07’51”W
Ending location: 44°35’38” N, 112°07’52”W

Station number	Slope in degrees	Distance (meters)
0-1	+0.0	4.47
1-2	+1.0	6.53
2-3	+1.0	6.81
3-4	+2.0	5.42
4-5	+3.5	5.49
5-6	+4.0	4.94
6-7	+4.0	4.64
7-8	+5.0	4.42
8-9	+12.0	2.63
9-10	+21.0	3.00
10-11	+23.0	2.79
11-12	+21.0	3.10
12-13	+22.5	1.75
13-14	+24.0	2.21
14-15	+16.5	2.55
15-16	+20.0	2.76
16-17	+12.0	2.55
17-18	+4.5	3.84
18-19	+3.0	7.39
19-20	+3.0	4.18

Figure 28. Fault profile I – I', starting location: 44°35'41" N, 112°07'51"W; ending location: 44°35'38" N, 112°07'52"W, looking south.

Profile I – I' is located directly west of Price Creek and Price Creek Road. This profile is for a fault scarp that offsets an inactive alluvial fan. The hanging wall far field toe of the profile starts relatively flat and then increases in slope as the profile moves south. The profile continues up slope until it reaches the faults plane inferred at stations 13 – 14 where the slope is +24.0°. The fault scarp rounds at the top of the slope and flattens as one moves south into the footwall of the profile.

This profile is rated: excellent


Fault Scarp Profile I - I'
Surface Offset: 7.4 meters
Scarp Height: 8.9 meters
Inferred fault plane at mid0scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
2
4
6
8
10
12
0
10
20
30
40
50
60
70
80
90

Profile: J – J'

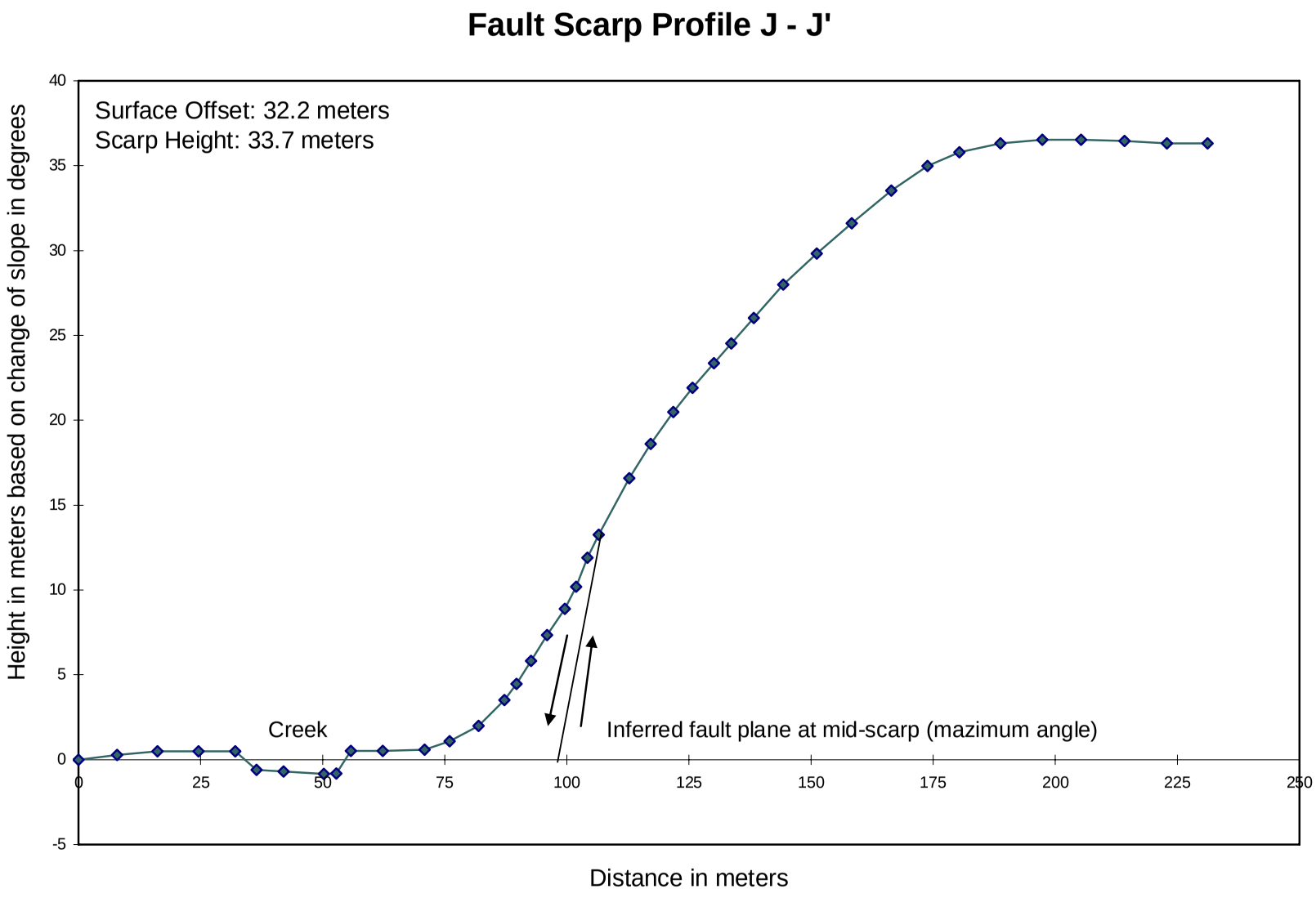
Starting location: 44°35'41" N, 112°07'43"W
Ending location: 44°35'27" N, 112°07'41"W

Station number	Slope in degrees	Distance (meters)	
0-1	+2.0	7.93	
1-2	+1.5	8.25	
2-3	+0.0	8.40	
3-4	+0.0	7.50	
4-5	-14.0	4.55	creek bed
5-6	-1.0	5.50	creek bed
6-7	-1.0	8.30	creek bed
7-8	+1.0	2.55	creek bed
8-9	+24.5	3.20	creek bed
9-10	+0.0	6.55	
10-11	+0.5	8.55	
11-12	+5.5	5.20	
12-13	+8.5	6.00	
13-14	+16.0	5.50	
14-15	+22.0	2.60	
15-16	+24.0	3.30	
16-17	+24.5	3.65	
17-18	+23.5	3.90	
18-19	+29.5	2.65	
19-20	+36.0	2.90	
20-21	+31.0	2.65	
21-22	+28.0	7.10	
22-23	+24.5	4.85	
23-24	+22.0	5.00	
24-25	+20.0	4.20	
25-26	+18.5	4.60	
26-27	+18.0	3.75	
27-28	+18.0	4.80	
28-29	+18.0	6.40	
29-30	+15.0	7.10	
30-31	+14.0	7.40	
31-32	+13.5	8.25	
32-33	+11.0	7.60	
33-34	+7.0	6.58	
34-35	+3.5	8.38	
35-36	+1.5	8.60	
36-37	+0.0	7.95	
37-38	-0.5	8.88	
38-39	-1.0	8.65	
39-40	+0.0	8.40	

Figure 29. Fault profile J – J', starting location: 44°35'41" N, 112°07'43"W; ending location: 44°35'27" N, 112°07'41"W, looking south-southwest. Picture is taken from an oblique view.

Profile J – J' is located on the east side directly off of Price Creek Road. The hanging wall far field toe of the profile is flat until it reaches the creek bed where the slope decreases and then increases as the profile crosses the creek bed. The toe continues to the south side of the creek and remains flat until it reaches the break in slope. As the profile moves up slope the fault plane is inferred at stations 21 – 22 where the slope is +28.0°. The fault scarp rounds at the top of the hill and flattens as one moves south into the footwall of the profile.

This profile is rated: good


Fault Scarp Profile J - J'
Surface Offset: 32.2 meters
Scarp Height: 33.7 meters
Creek
Inferred fault plane at mid-scarp (mazimum angle)
Height in meters based on change of slope in degrees
Distance in meters
40
35
30
25
20
15
10
5
0
-5
0
25
50
75
100
125
150
175
200
225
250

Profile: K – K’

Starting location: 44°35’43” N, 112°06’48”W
Ending location: 44°35’30” N, 112°06’49”W

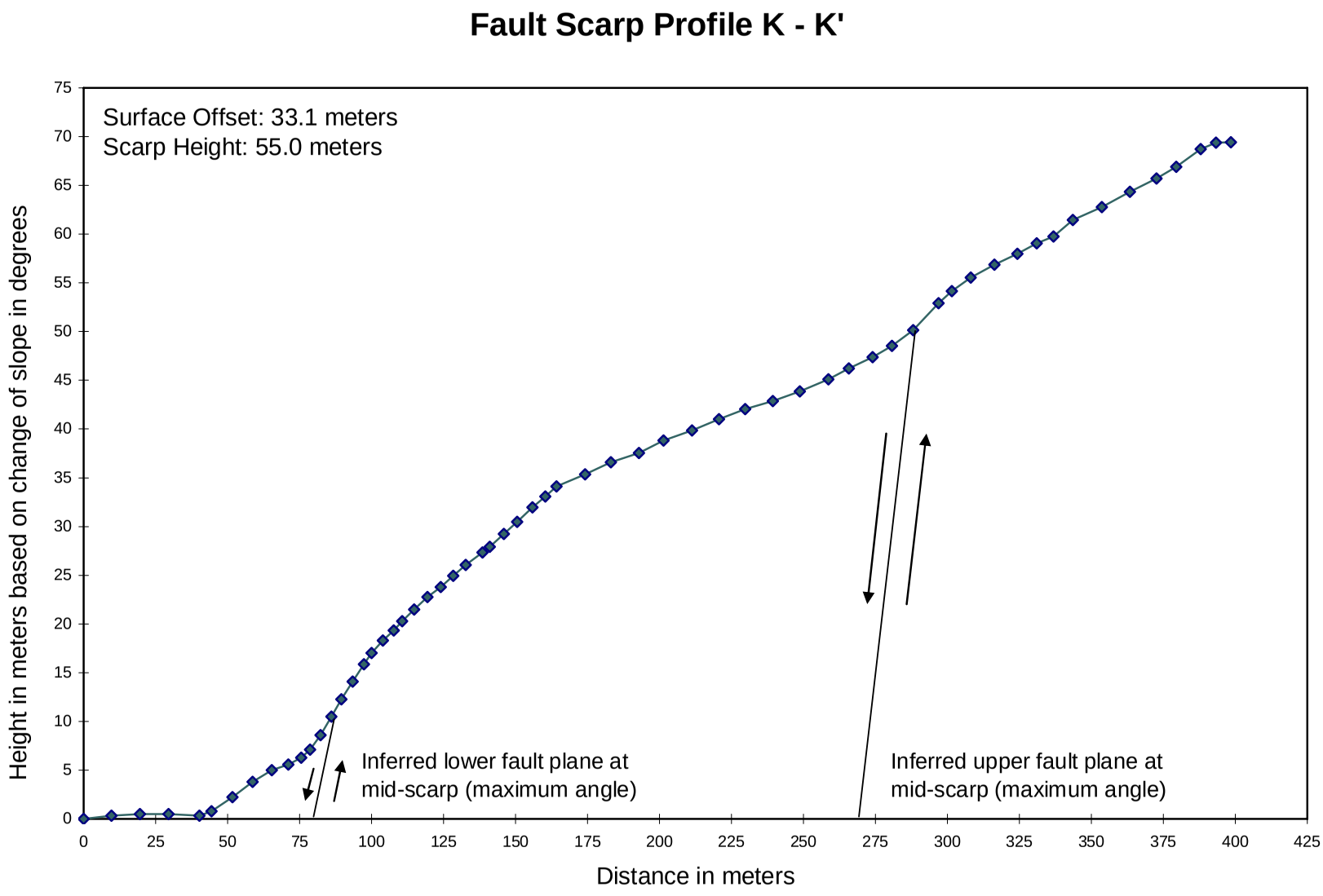
Station number	Slope in degrees	Distance (meters)
0-1	+2.0	9.60
1-2	+1.0	10.15
2-3	+0.0	9.85
3-4	-1.0	10.76
4-5	+6.0	4.28
5-6	+11.5	7.30
6-7	+12.5	7.27
7-8	+10.0	6.82
8-9	+6.0	5.66
9-10	+9.0	4.60
10-11	+15.0	3.07
11-12	+22.5	3.96
12-13	+26.0	4.28
13-14	+27.5	3.84
14-15	+25.0	4.30
15-16	+24.0	4.35
16-17	+24.0	2.90
17-18	+18.0	4.70
18-19	+15.5	3.92
19-20	+18.0	3.10
20-21	+16.0	4.40
21-22	+15.0	4.80
22-23	+13.0	4.70
23-24	+15.0	4.50
24-25	+14.0	4.50
25-26	+12.5	5.90
26-27	+13.5	2.63
27-28	+15.0	5.00
28-29	+15.0	4.86
29-30	+15.5	5.50
30-31	+14.0	4.65
31-32	+15.0	4.00
32-33	+7.0	10.00
33-34	+8.0	9.00
34-35	+5.5	9.75
35-36	+8.5	8.70
36-37	+6.0	9.90
37-38	+7.0	9.45
38-39	+6.5	9.16
39-40	+5.0	9.75

40-41	+6.0	9.38	
41-42	+7.0	10.00	
42-43	+9.0	7.20	
43-44	+8.0	8.24	
44-45	+10.0	6.80	
45-46	+12.0	7.62	
46-47	+17.5	9.25	
47-48	+15.5	4.69	
48-49	+12.0	6.76	
49-50	+9.0	8.30	
50-51	+8.0	8.05	
51-52	+9.0	6.80	drainage
52-53	+7.0	5.95	drainage
53-54	+14.0	6.95	
54-55	+7.5	10.15	
55-56	+9.0	9.90	
56-57	+8.5	9.30	
57-58	+10.0	6.90	
58-59	+12.0	8.70	
59-60	+7.0	5.38	
60-61	+0.5	5.10	

Figure 30. Fault profile K – K’, starting location: 44°35’43” N, 112°06’48”W; ending location: 44°35’30” N, 112°06’49”W, looking south.

Profile K – K' is located approximately 1.1 kilometers east of where Price Creek crosses the South Side Centennial Road. The hanging wall far field toe of the profile is relatively flat until it reaches a small slump that lies directly below the fault scarp. As the profile moves up slope the lower fault plane is inferred at stations 13 – 14 where the slope is +27.5°. The profile continues up slope until it reaches the upper scarp plane inferred at stations 46 – 47 where the slope is +17.5°. The profile continues up slope until it rounds at the top of the hill and flattens in the footwall of the profile. The upper scarp is of either tectonic or gravity origin. This profile just catches the westernmost edge of the upper scarp.

This profile is rated: fair


Fault Scarp Profile K - K'
Surface Offset: 33.1 meters
Scarp Height: 55.0 meters
Inferred lower fault plane at
mid-scarp (maximum angle)
Inferred upper fault plane at
mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Profile: L – L’

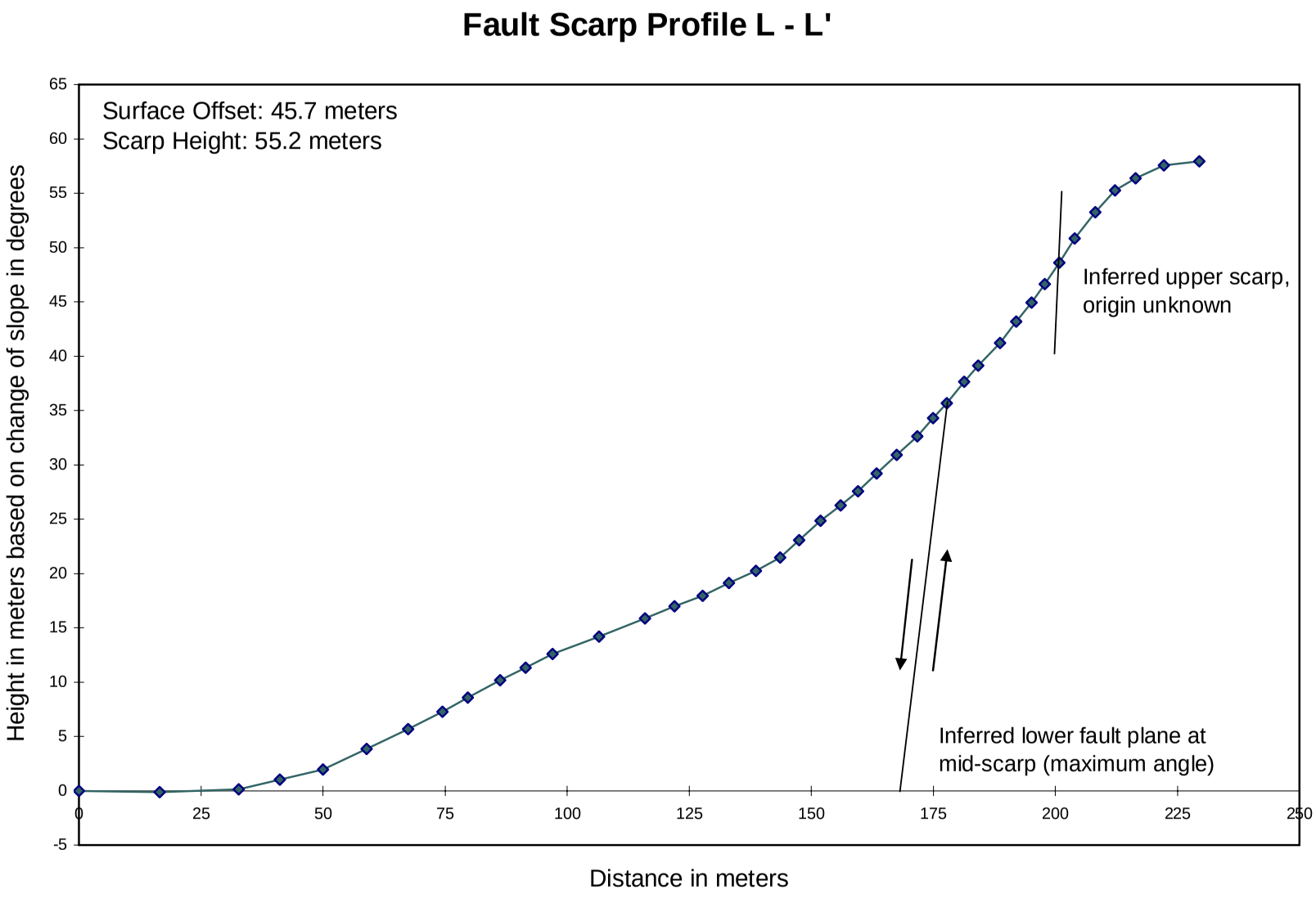
Starting location: 44°35’35” N, 112°06’13”W
Ending location: 44°35’28” N, 112°06’14”W

Station number	Slope in degrees	Distance (meters)
0-1	-0.5	16.55
1-2	+1.0	16.20
2-3	+6.0	8.45
3-4	+6.0	8.90
4-5	+12.0	9.10
5-6	+12.0	8.70
6-7	+13.0	7.25
7-8	+14.0	5.35
8-9	+13.5	6.81
9-10	+12.5	5.36
10-11	+13.0	5.65
11-12	+9.5	9.65
12-13	+10.0	9.55
13-14	+10.5	6.15
14-15	+9.5	5.86
15-16	+12.5	5.46
16-17	+11.5	5.65
17-18	+14.0	5.11
18-19	+22.0	4.20
19-20	+22.0	4.78
20-21	+19.0	4.30
21-22	+20.5	3.80
22-23	+23.0	4.20
23-24	+22.5	4.45
24-25	+22.0	4.55
25-26	+27.5	3.65
26-27	+26.0	3.12
27-28	+29.0	4.04
28-29	+27.5	3.25
29-30	+25.0	4.93
30-31	+31.0	3.83
31-32	+29.0	3.60
32-33	+32.0	3.21
33-34	+33.5	3.55
34-35	+35.0	3.89
35-36	+30.0	4.85
36-37	+26.0	4.55
37-38	+15.0	4.35
38-39	+11.5	5.90
39-40	+3.0	7.25

Figure 31. Fault profile L – L', starting location: 44°35'35" N, 112°06'13"W; ending location: 44°35'28" N, 112°06'14"W, looking south.

Profile L – L' is located to the east of profile K – K'. This profile has hummocky topography at the base of slope. There is evidence on either side of the profile for a lower or an upper fault scarp. The two best places: the lower fault plane is inferred at stations 27 – 28 where the slope is +29.0° and the upper scarp is at stations 34 – 35 where the slope is +35.0°. The upper scarp rounds at the top of the hill and flattens as the profile moves south into the footwall. The upper scarp is either of tectonic or gravity origin.

This profile is rated: poor


Fault Scarp Profile L - L'
Surface Offset: 45.7 meters
Scarp Height: 55.2 meters
Inferred upper scarp, origin unknown
Inferred lower fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
0
25
50
75
100
125
150
175
200
225
250

Profile: M – M'

Starting location: 44°35'25" N, 112°05'41"W
Ending location: 44°35'13" N, 112°05'47"W

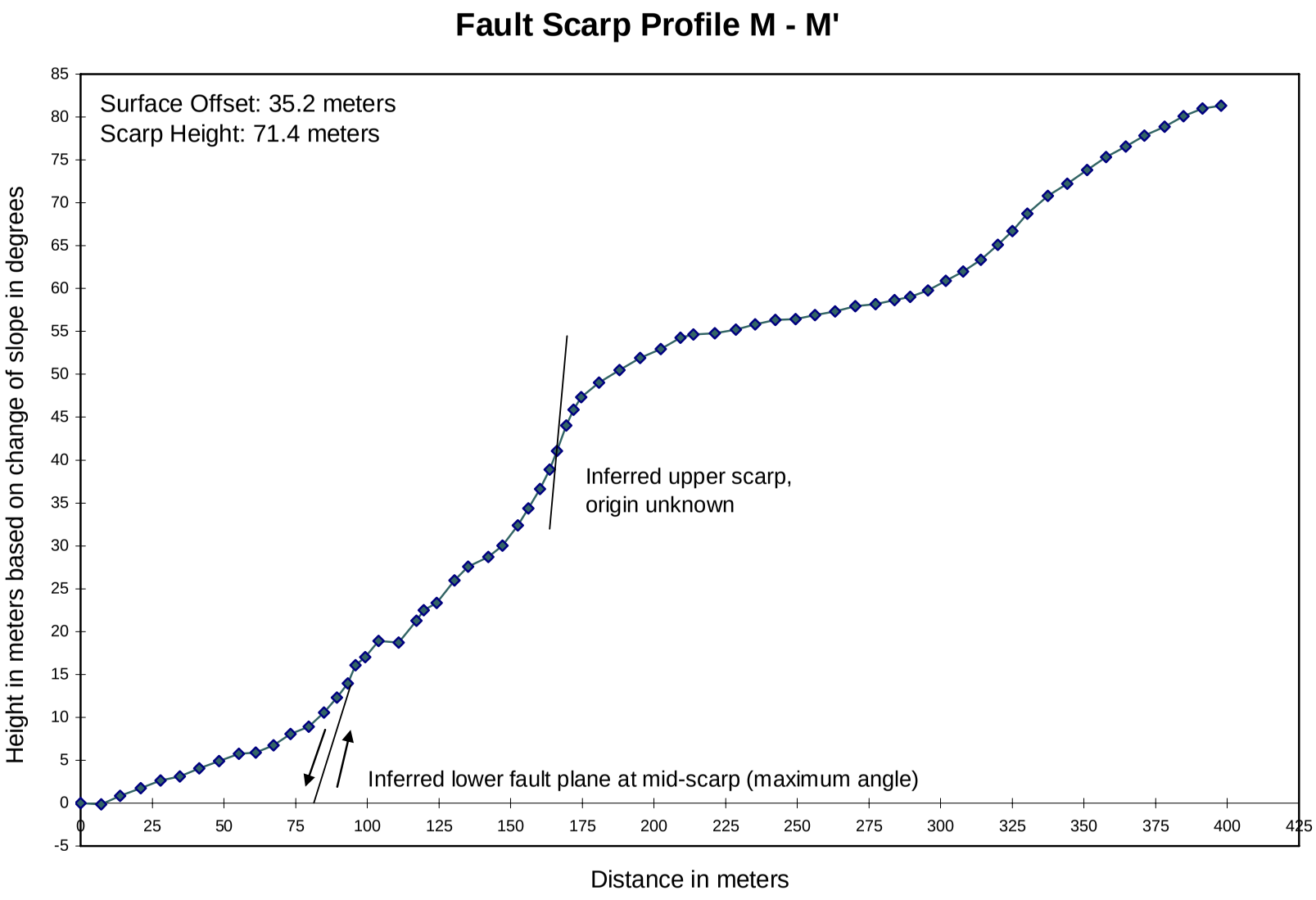
Station number	Slope in degrees	Distance (meters)
0-1	-1.0	7.20
1-2	+8.5	6.73
2-3	+7.0	7.20
3-4	+7.5	6.93
4-5	+4.0	6.85
5-6	+8.0	6.80
6-7	+7.0	6.90
7-8	+7.0	7.01
8-9	+1.0	5.82
9-10	+8.0	6.27
10-11	+12.5	6.17
11-12	+7.5	6.35
12-13	+17.0	5.58
13-14	+21.0	4.87
14-15	+24.5	4.05
15-16	+37.5	3.46
16-17	+16.0	3.51
17-18	+22.5	4.99
18-19	-1.5	7.10
19-20	+22.5	6.65
20-21	+25.5	2.87
21-22	+10.5	4.60
22-23	+23.0	6.70
23-24	+19.0	5.00
24-25	+9.0	7.10
25-26	+15.0	5.17
26-27	+24.0	5.81
27-28	+27.5	4.21
28-29	+29.5	4.63
29-30	+33.0	4.13
30-31	+41.0	3.34
31-32	+42.5	4.37
32-33	+37.0	3.11
33-34	+29.0	3.01
34-35	+15.0	6.51
35-36	+11.5	7.36
36-37	+11.0	7.25
37-38	+8.5	7.20
38-39	+10.5	7.10
39-40	+5.0	4.49

40-41	+1.0	7.47
41-42	+3.5	7.30
42-43	+5.0	6.81
43-44	+4.5	7.11
44-45	+0.5	7.07
45-46	+4.0	6.73
46-47	+3.5	7.00
47-48	+5.0	7.16
48-49	+2.0	7.06
49-50	+4.0	6.57
50-51	+4.0	5.50
51-52	+7.0	6.30
52-53	+10.0	6.30
53-54	+10.5	6.16
54-55	+12.5	6.27
55-56	+16.0	6.22
56-57	+18.0	5.26
57-58	+21.0	5.68
58-59	+16.0	7.43
59-60	+12.0	6.92
60-61	+13.0	7.01
61-62	+13.0	6.76
62-63	+10.0	7.11
63-64	+11.0	6.54
64-65	+8.5	7.20
65-66	+10.5	6.62
66-67	+8.0	6.67
67-68	+2.5	6.60

Figure 32. Fault profile M – M', starting location: 44°35'25" N, 112°05'41"W; ending location: 44°35'13" N, 112°05'47"W, looking south.

Profile M – M' is located to the east of profile L – L'. The profile starts at the fence and continues up slope. The profile goes over three distinctive slumps and encounters the lower fault scarp just above the first slump. The lower fault plane is inferred at stations 15 – 16 where the slope is +37.5°. The profile continues until it reaches the upper scarp inferred at stations 31 – 32 where the slope is +42.5°. The upper scarp rounds at the top of the hill and flattens as the profile moves south into the footwall. The upper scarp is either tectonic or gravity in origin.

This profile is rated: poor


Fault Scarp Profile M - M'
Surface Offset: 35.2 meters
Scarp Height: 71.4 meters
Inferred upper scarp,
origin unknown
Inferred lower fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Profile: N – N’

Starting location: 44°35’18” N, 112°05’28”W
Ending location: 44°35’11” N, 112°05’30”W

Station number	Slope in degrees	Distance (meters)
0-1	+0.5	6.70
1-2	+6.5	5.41
2-3	+11.5	3.43
3-4	+10.0	3.95
4-5	+0.5	3.24
5-6	+23.0	4.38
6-7	+20.0	5.21
7-8	+21.0	5.05
8-9	+16.0	3.28
9-10	+17.0	4.20
10-11	+24.5	5.12
11-12	+33.5	5.35
12-13	+33.0	5.70
13-14	+24.5	5.10
14-15	+35.5	6.84
15-16	+37.5	6.13
16-17	+37.0	5.10
17-18	+35.5	5.00
18-19	+26.0	4.63
19-20	+23.0	5.40
20-21	+24.5	3.00
21-22	+24.0	3.55
22-23	+23.0	4.30
23-24	+22.0	3.72
24-25	+22.0	4.13
25-26	+20.0	5.14
26-27	+22.5	5.30
27-28	+17.0	4.75
28-29	+15.0	5.56
29-30	+11.5	5.07
30-31	+9.0	6.72
31-32	+6.0	7.75
32-33	+6.0	7.73
33-34	+6.5	8.93
34-35	+3.0	7.97
35-36	+4.5	4.96

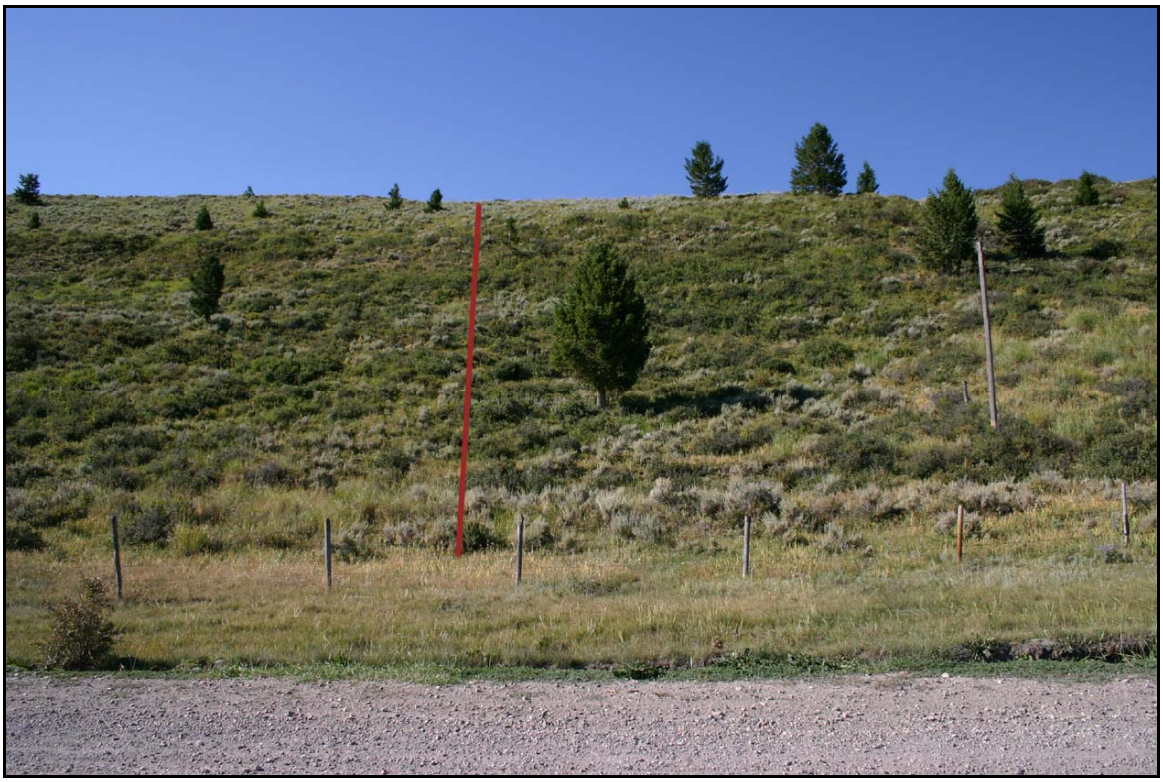
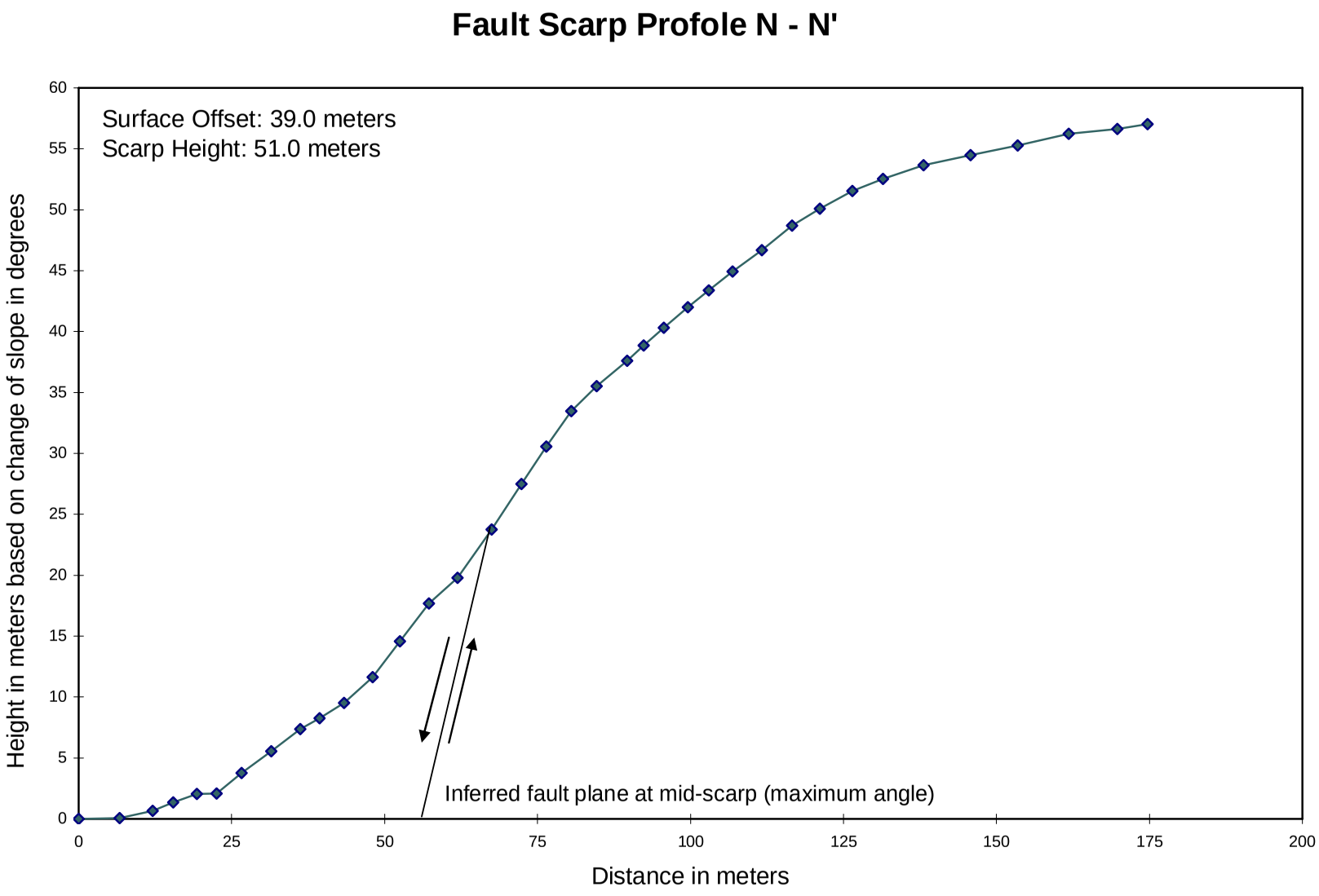


Figure 33. Fault profile N – N', starting location: 44°35'18" N, 112°05'28"W; ending location: 44°35'11" N, 112°05'30"W, looking south.

Profile N – N' is located approximately 2 kilometers to the west of Jones Ranch. The profile stats at the fence and encounters a slump at the base of the profile. The profile continues over the slump until it reaches the fault plane inferred at stations 15 – 16 where the slope is +37.5°. The profile continues up slope until it reaches the top of the hill where it rounds and flattens in the footwall of the profile. This location has lots of vegetation and a fair amount of moisture at the base of the profile. There is a grove of aspens located due west of this location.

This profile is rated: fair


Fault Scarp Profole N - N'
Surface Offset: 39.0 meters
Scarp Height: 51.0 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
30
35
40
45
50
55
60
0
25
50
75
100
125
150
175
200

Profile: O – O’

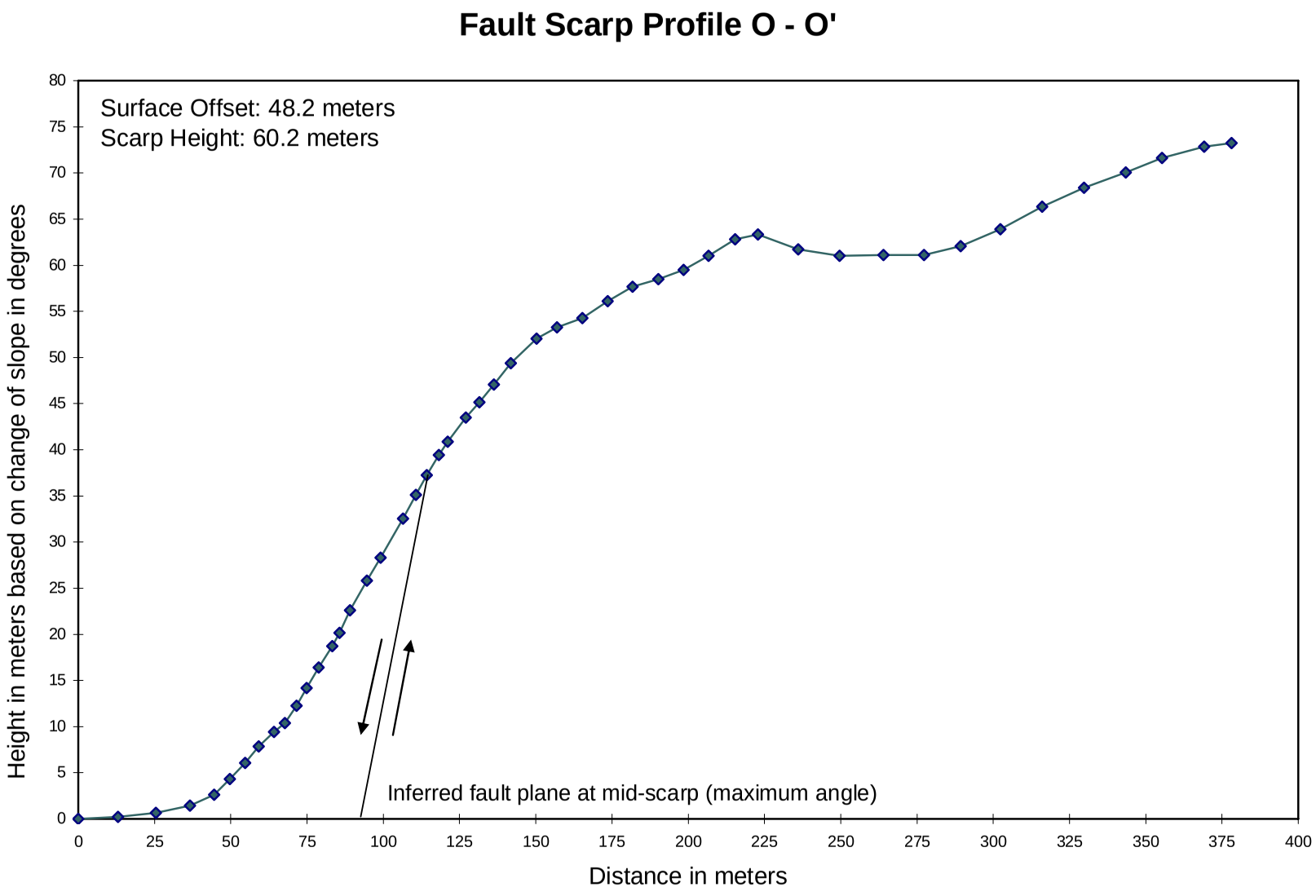
Starting location: 44°35’15” N, 112°05’06”W
Ending location: 44°35’03” N, 112°05’08”W

Station number	Slope in degrees	Distance (meters)
0-1	+1.0	13.11
1-2	+2.0	12.37
2-3	+4.0	11.14
3-4	+8.5	8.10
4-5	+18.0	5.40
5-6	+19.5	5.25
6-7	+22.0	4.80
7-8	+17.0	5.30
8-9	+15.5	3.69
9-10	+26.0	4.23
10-11	+30.0	3.85
11-12	+30.0	4.50
12-13	+27.0	5.08
13-14	+30.5	2.80
14-15	+36.5	4.12
15-16	+30.0	6.47
16-17	+29.0	5.15
17-18	+30.0	8.43
18-19	+31.5	4.96
19-20	+31.0	4.15
20-21	+28.5	4.55
21-22	+26.0	3.24
22-23	+24.0	6.50
23-24	+20.5	4.72
24-25	+21.5	5.18
25-26	+23.0	5.94
26-27	+17.5	8.91
27-28	+10.0	6.85
28-29	+7.0	8.35
29-30	+12.5	8.45
30-31	+11.0	8.30
31-32	+5.5	8.55
32-33	+7.0	8.30
33-34	+10.5	8.30
34-35	+11.5	8.90
35-36	+4.0	7.60
36-37	-7.0	13.20
37-38	-3.0	13.64
38-39	+0.5	14.32
39-40	+0.0	13.30

40-41	+4.5	12.10
41-42	+8.0	13.16
42-43	+10.0	13.94
43-44	+8.5	13.87
44-45	+7.0	13.71
45-46	+7.5	12.02
46-47	+5.0	13.86
47-48	+2.5	9.00

Figure 34. Fault profile O – O', starting location: 44°35'15" N, 112°05'06"W; ending location: 44°35'03" N, 112°05'08"W, looking south.

Profile O – O' is located to the east of profile N – N'. The profile starts close to the fence with a nice flat toe in the hanging wall. There is a small slump at the base of the slope. The profile continues up slope until it reaches the fault plane inferred at stations 20 – 21 where the slope is +28.5°. The scarp rounds at the top of the hill and flattens as it moves south into the footwall of the profile. There is lush vegetation covering the entire profile indicating a fair amount of moisture. The entire profile is covered by slight hummocky topography.
This profile is rated: fair


Fault Scarp Profile O - O'
Surface Offset: 48.2 meters
Scarp Height: 60.2 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400

Profile: P – P’

Starting location: 44°35’13” N, 112°04’44”W
Ending location: 44°35’00” N, 112°04’50”W

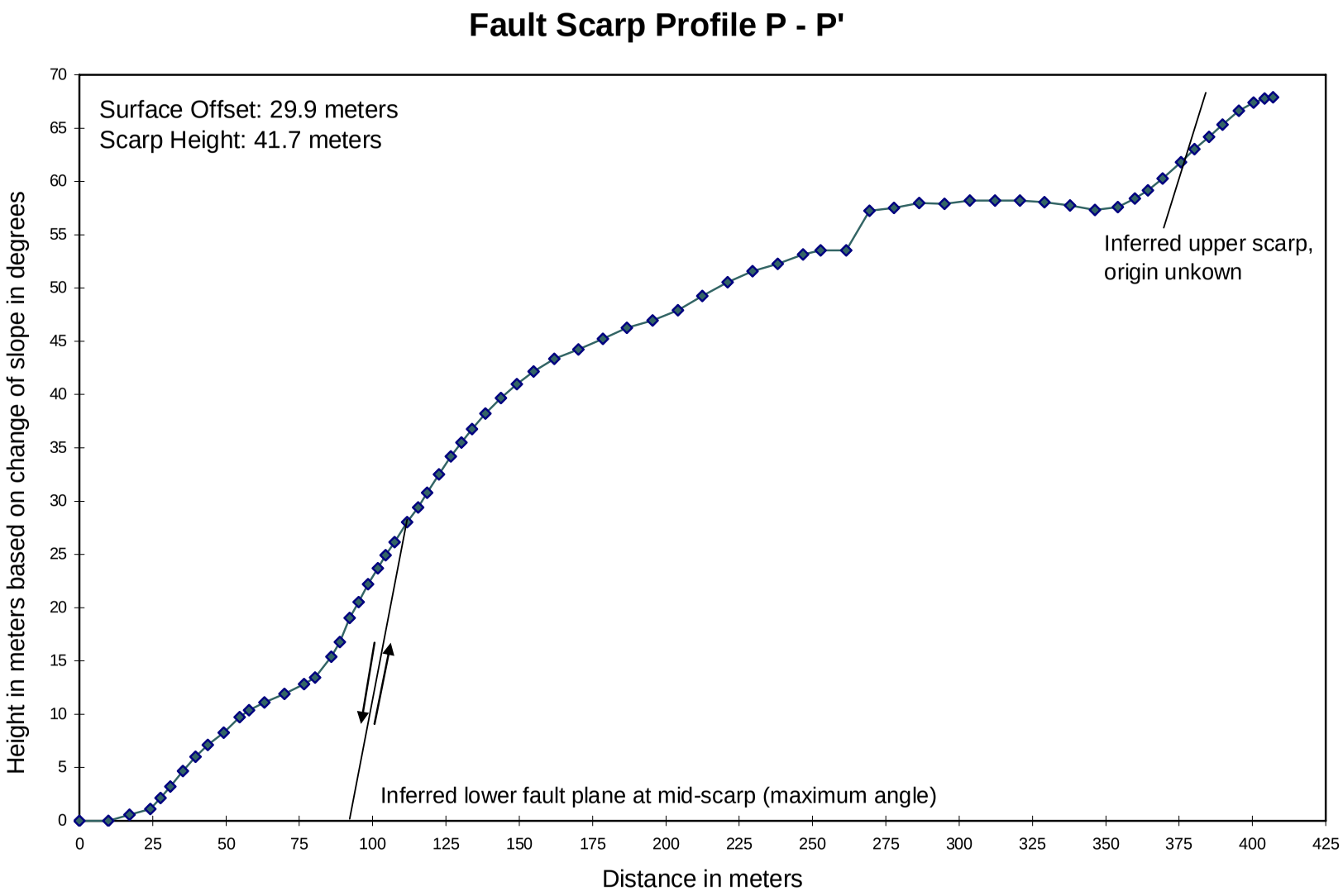
Station number	Slope in degrees	Distance (meters)
0-1	+0.0	9.90
1-2	+4.5	7.25
2-3	+4.5	7.15
3-4	+16.5	3.60
4-5	+17.5	3.55
5-6	+19.0	4.45
6-7	+17.5	4.49
7-8	+14.5	4.44
8-9	+12.0	5.45
9-10	+15.0	5.70
10-11	+11.5	3.14
11-12	+8.0	5.42
12-13	+6.5	6.87
13-14	+8.0	6.67
14-15	+9.5	3.80
15-16	+19.0	6.00
16-17	+26.0	3.10
17-18	+33.5	4.10
18-19	+26.5	3.35
19-20	+27.5	3.70
20-21	+24.0	3.65
21-22	+25.0	2.84
22-23	+22.0	3.32
23-24	+23.5	4.66
24-25	+20.5	4.00
25-26	+23.5	3.46
26-27	+23.0	4.35
27-28	+22.5	4.40
28-29	+20.0	3.82
29-30	+19.5	3.80
30-31	+18.0	4.75
31-32	+15.0	5.57
32-33	+13.5	5.58
33-34	+12.0	5.75
34-35	+9.5	7.22
35-36	+6.0	8.28
36-37	+7.0	8.40
37-38	+7.0	8.25
38-39	+4.5	8.72
39-40	+6.5	8.68

40-41	+9.0	8.55
41-42	+8.5	8.70
42-43	+7.0	8.57
43-44	+4.5	8.62
44-45	+6.0	8.66
45-46	+3.5	5.90
46-47	+0.0	8.82
47-48	+2.5	8.80
48-49	+2.0	8.25
49-50	+3.0	8.66
50-51	-0.5	8.62
51-52	+2.0	8.60
52-53	+0.0	8.63
53-54	+0.0	8.50
54-55	-1.0	8.40
55-56	-2.0	8.71
56-57	-3.0	8.55
57-58	+2.0	7.74
58-59	+8.0	5.85
59-60	+10.0	4.51
60-61	+12.0	5.20
61-62	+14.0	6.42
62-63	+15.0	4.77
63-64	+13.0	5.10
64-65	+14.0	4.70
65-66	+13.0	5.74
66-67	+8.5	5.10
67-68	+6.0	3.70
68-69	+2.5	3.00

Figure 35. Fault profile P – P', starting location: 44°35'13" N, 112°04'44"W; ending location: 44°35'00" N, 112°04'50"W, looking south.

Profile P – P' is located approximately 1.1 kilometers to the west of Peet Creek Road. The profile starts at fence and goes up slope between two slumps. There is a small slump at the base of the slope. The profile continues up slope until it reaches the lower fault plane inferred at stations 25 – 26 where the slope is +23.5°. Towards the top, the profile goes to the west of the two trees until it reaches a small scarp (upper) inferred at stations 62 – 63 where the slope is +15.0°. The scarp rounds off and flattens in the footwall of the profile. The upper scarp is of tectonic or gravity origin.

This profile is rated: fair


Fault Scarp Profile P - P'
Surface Offset: 29.9 meters
Scarp Height: 41.7 meters
Inferred upper scarp, origin unkown
Inferred lower fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Profile: Q – Q’

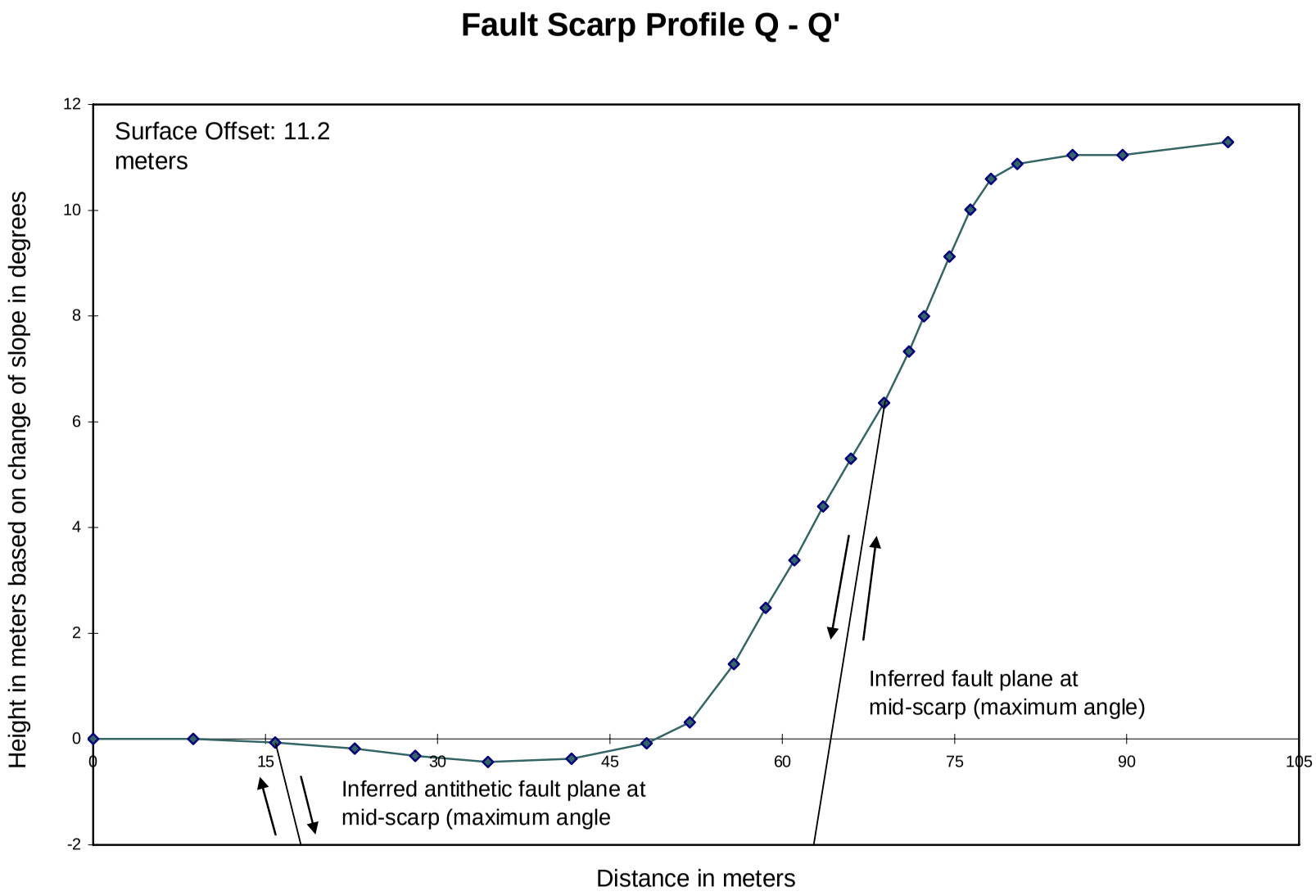
Starting location: 44°35’04” N, 112°03’52”W
Ending location: 44°35’01” N, 112°03’52”W

Station number	Slope in degrees	Distance (meters)
0-1	+0.0	8.72
1-2	-0.5	7.14
2-3	-1.0	6.39
3-4	-1.5	5.26
4-5	-1.0	6.32
5-6	+0.5	7.26
6-7	+2.5	6.55
7-8	+6.0	3.80
8-9	+16.0	3.99
9-10	+21.0	2.97
10-11	+20.0	2.64
11-12	+22.0	2.72
12-13	+20.5	2.57
13-14	+20.0	3.09
14-15	+24.0	2.39
15-16	+27.5	1.45
16-17	+27.0	2.49
17-18	+26.0	2.03
18-19	+18.0	1.88
19-20	+7.0	2.32
20-21	+2.0	4.81
21-22	+0.0	4.34
22-23	+1.5	9.18

Figure 36. Fault profile Q – Q', starting location: 44°35'04" N, 112°03'52"W; ending location: 44°35'01" N, 112°03'52"W, looking south.

Profile Q – Q' is located directly across from the Matador Ranch and to the east of profile P – P'. This profile is for a fault scarp that offsets an inactive alluvial fan. The hanging wall far field toe of the profile starts relatively flat and then decreases in slope as the profile moves south. This decrease in slope is represented by an antithetic fault plane inferred at stations 3 – 4 where the slope is -1.5°. The profile continues through the graben until it starts to increase in slope again. The fault plane on the main fault scarp is inferred at stations 15 – 16 where the slope is +27.5°. The fault scarp rounds at the top and flattens as one moves south into the footwall of the profile. The alluvial fan continues at the top of the profile and is cut by the present creek.

This profile is rated: excellent


Fault Scarp Profile Q - Q'
Surface Offset: 11.2 meters
Height in meters based on change of slope in degrees
Distance in meters
12
10
8
6
4
2
0
-2
0
15
30
45
60
75
90
105
Inferred antithetic fault plane at mid-scarp (maximum angle
Inferred fault plane at mid-scarp (maximum angle)

Profile: R – R’

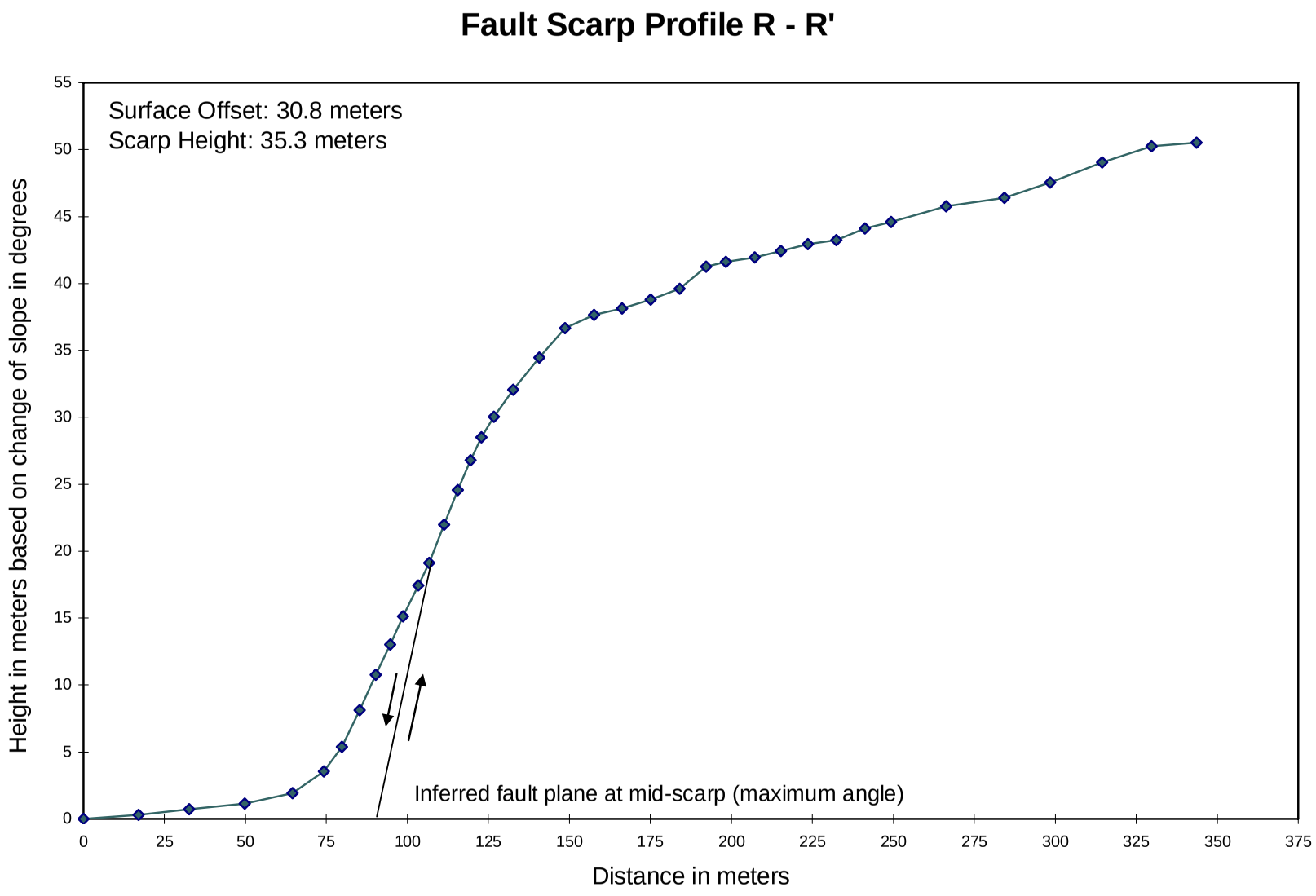
Starting location: 44°35’08” N, 112°03’43”W
Ending location: 44°34’42” N, 112°03’45”W

Station number	Slope in degrees	Distance (meters)
0-1	+1.0	17.02
1-2	+1.5	15.67
2-3	+1.5	17.07
3-4	+3.0	14.76
4-5	+9.5	9.82
5-6	+18.0	5.92
6-7	+27.0	6.06
7-8	+27.5	5.71
8-9	+27.0	4.98
9-10	+28.0	4.50
10-11	+26.0	5.25
11-12	+27.0	3.73
12-13	+31.5	5.45
13-14	+32.0	4.90
14-15	+29.5	4.52
15-16	+26.5	3.85
16-17	+22.0	4.06
17-18	+18.5	6.35
18-19	+16.5	8.45
19-20	+15.5	8.21
20-21	+16.5	9.01
21-22	+3.0	8.70
22-23	+4.5	8.76
23-24	+5.0	9.05
24-25	+11.5	8.35
25-26	+3.5	6.10
26-27	+2.0	8.86
27-28	+3.5	8.10
28-29	+3.5	8.36
29-30	+2.0	8.83
30-31	+5.5	8.86
31-32	+3.5	18.05
32-33	+4.0	17.06
33-34	+2.0	19.95
34-35	+4.5	14.28
35-36	+5.5	15.96
36-37	+4.5	15.33
37-38	+1.0	14.00

Figure 37. Fault profile R – R', starting location: 44°35'08" N, 112°03'43"W; ending location: 44°34'42" N, 112°03'45"W, looking south.

Profile R – R' is located approximately 0.3 kilometers east of Jones Ranch. The hanging wall toe of the profile is flat and continues until it reaches the break in slope. As it moves up slope the fault plane is inferred at stations 13 -14 where the slope is +32.0°. The fault scarp rounds at the top of the hill and then has a gentle increase in slope as one moves south into the footwall of the profile.

This profile is rated: good


Fault Scarp Profile R - R'
Surface Offset: 30.8 meters
Scarp Height: 35.3 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
30
35
40
45
50
55
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375

Profile: S – S’

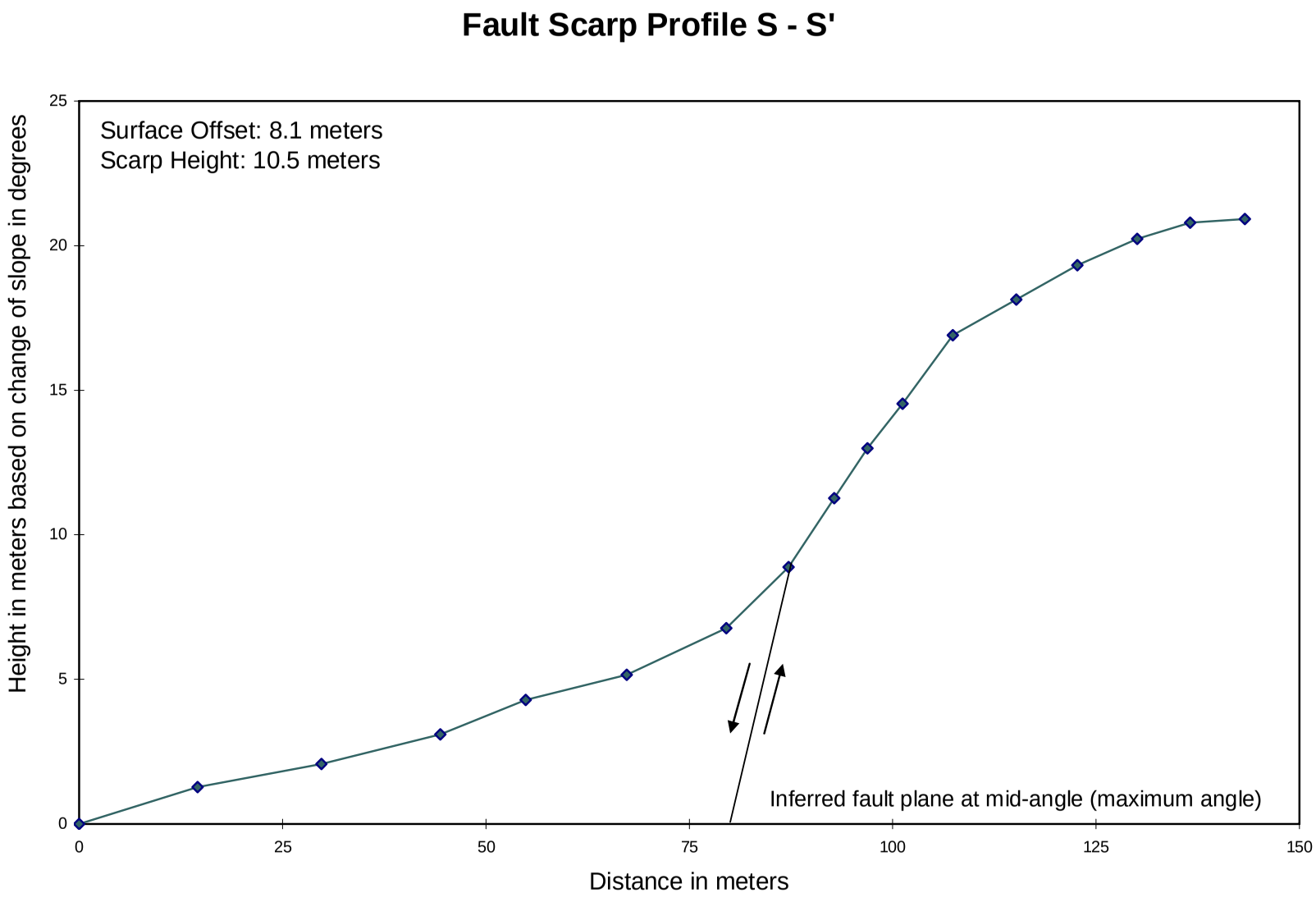
Starting location: 44°35’06” N, 112°02’51”W
Ending location: 44°35’02” N, 112°02’49”W

Station number	Slope in degrees	Distance (meters)
0-1	+5.0	14.62
1-2	+3.0	15.24
2-3	+4.0	14.67
3-4	+6.5	10.57
4-5	+4.0	12.45
5-6	+7.5	12.35
6-7	+15.5	7.91
7-8	+23.0	6.11
8-9	+23.0	4.41
9-10	+19.5	4.60
10-11	+21.0	6.62
11-12	+9.0	7.90
12-13	+9.0	7.60
13-14	+7.0	7.41
14-15	+5.0	6.53
15-16	+1.0	6.74

Figure 38. Fault profile S – S', starting location: 44°35'06" N, 112°02'51"W; ending location: 44°35'02" N, 112°02'49"W, looking south.

Profile S – S' is located approximately 1.4 kilometers to the west of Bean Creek. The hanging wall toe of the profile catches the very edge of the alluvial fan to the due east and is fairly flat. The profile continues up slope until it reaches the fault plane inferred at stations 8 – 9 where the slope is +23.0°. At the top, the profile goes between some trees; there is a single tree on west and lump of trees on east. The profile runs just west of the drainage and the alluvial fan.

This profile is rated: good


Fault Scarp Profile S - S'
Surface Offset: 8.1 meters
Scarp Height: 10.5 meters
Inferred fault plane at mid-angle (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
0
25
50
75
100
125
150

Profile: T – T’

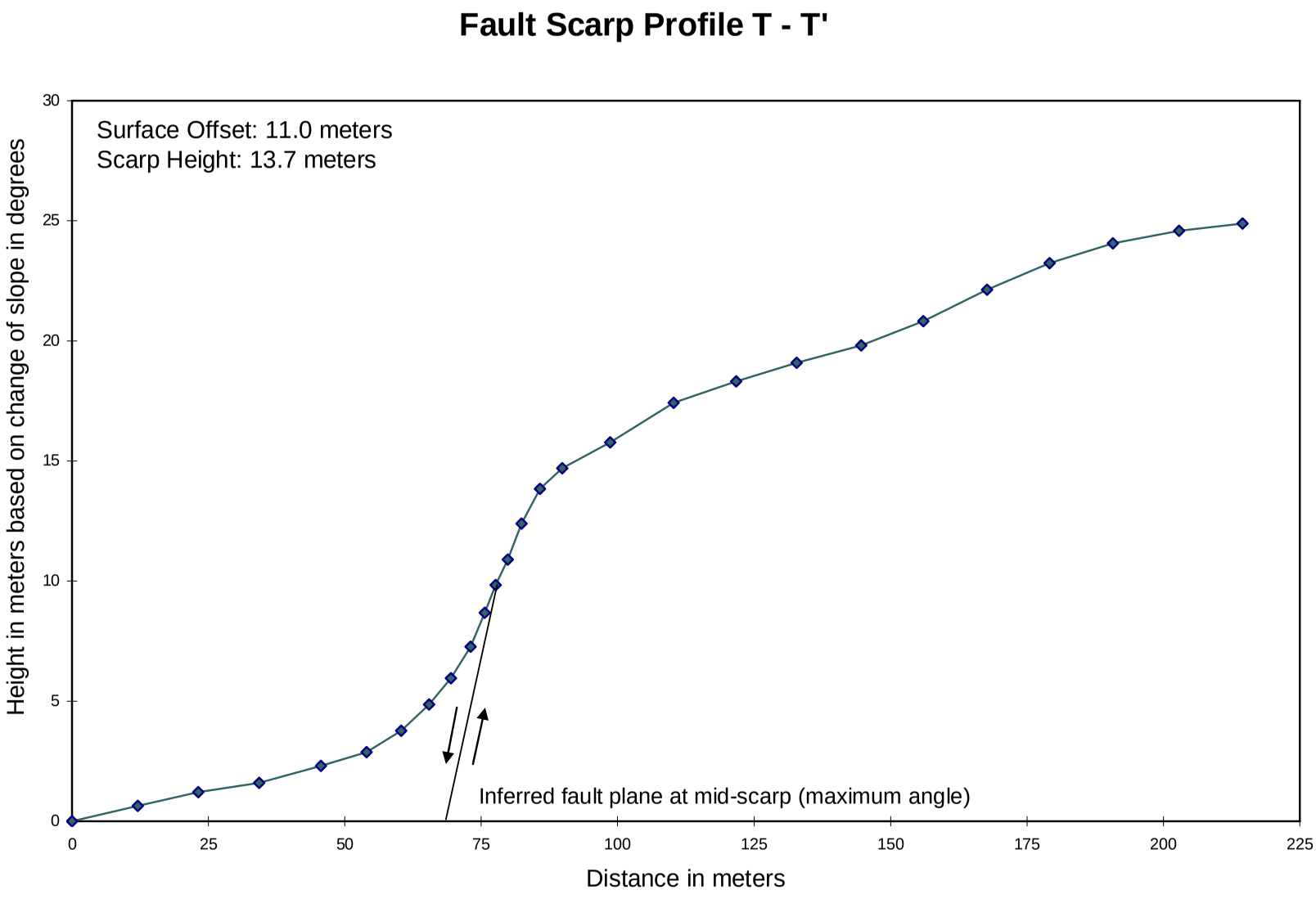
Starting location: 44°35’08” N, 112°02’46”W
Ending location: 44°34’57” N, 112°02’45”W

Station number	Slope in degrees	Distance (meters)
0-1	+3.0	12.06
1-2	+3.0	11.15
2-3	+2.0	11.15
3-4	+3.5	11.33
4-5	+4.0	8.38
5-6	+8.0	6.40
6-7	+12.0	5.25
7-8	+15.5	4.10
8-9	+20.0	3.84
9-10	+28.0	3.00
10-11	+30.0	2.30
11-12	+26.0	2.45
12-13	+30.5	2.93
13-14	+23.0	3.70
14-15	+12.0	4.15
15-16	+7.0	8.95
16-17	+8.0	11.75
17-18	+4.5	11.50
18-19	+4.0	11.10
19-20	+3.5	11.80
20-21	+5.0	11.50
21-22	+6.5	11.70
22-23	+5.5	11.54
23-24	+4.0	11.65
24-25	+2.5	12.10
25-26	+1.5	11.65

Figure 39. Fault profile T – T', starting location: 44°35'08" N, 112°02'46"W; ending location: 44°34'57" N, 112°02'45"W, looking south.

Profile T – T' is located approximately 1.6 kilometers to the east of Jones Ranch. The profile runs just east of the drainage and alluvial fan with a gentle hanging wall toe leading up the slope. The profile goes between the large group of tall trees to the east and small cluster of short trees to the west. As the profile moves up slope the fault plane is inferred at stations 12 – 13 where the slope is +30.5°. As the profile reaches the top of the hill it rounds off and flattens as it moves into the footwall of the profile.

This profile is rated: good


Fault Scarp Profile T - T'
Surface Offset: 11.0 meters
Scarp Height: 13.7 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
30
0
25
50
75
100
125
150
175
200
225

Profile: U – U’

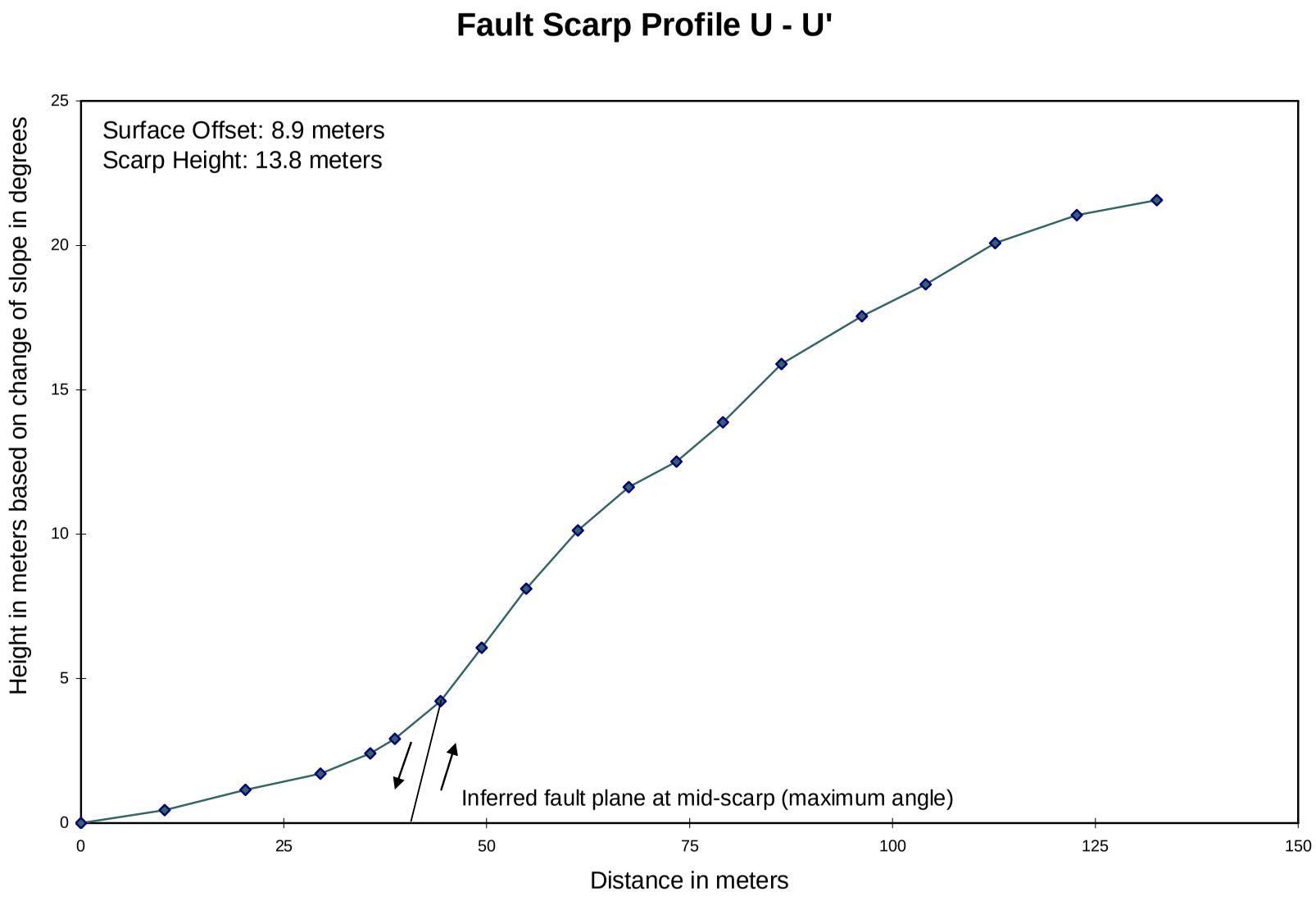
Starting location: 44°35’04” N, 112°02’04”W
Ending location: 44°34’59” N, 112°02’03”W

Station number	Slope in degrees	Distance (meters)
0-1	+2.5	10.30
1-2	+4.0	10.00
2-3	+3.5	9.25
3-4	+6.5	6.18
4-5	+9.5	6.09
5-6	+13.0	5.76
6-7	+20.0	5.42
7-8	+20.5	5.82
8-9	+17.5	6.96
9-10	+13.5	6.45
10-11	+8.5	5.95
11-12	+13.5	5.85
12-13	+15.5	7.52
13-14	+9.5	10.03
14-15	+8.0	7.94
15-16	+9.5	8.70
16-17	+5.5	10.10
17-18	+3.0	9.85

Figure 40. Fault profile U – U', starting location: 44°35'04" N, 112°02'04"W; ending location: 44°34'59" N, 112°02'03"W, looking south.

Profile U – U' is located approximately 0.4 kilometers to the west of Bean Creek. There is a very small alluvial fan at the base of the slope and as one moves up slope the fault plane is inferred at stations 7 – 8 where the slope is +23.0°. The profile rounds at the top of the hill and flattens as one moves south into the footwall of the profile. The profile runs parallel to the drainage at the start of the profile but at the top the profile is cut off by the drainage. After a year of cattle migration there has been extensive erosion to the profile.

This profile is rated: good


Fault Scarp Profile U - U'
Surface Offset: 8.9 meters
Scarp Height: 13.8 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
0
25
50
75
100
125
150

Profile: V – V’

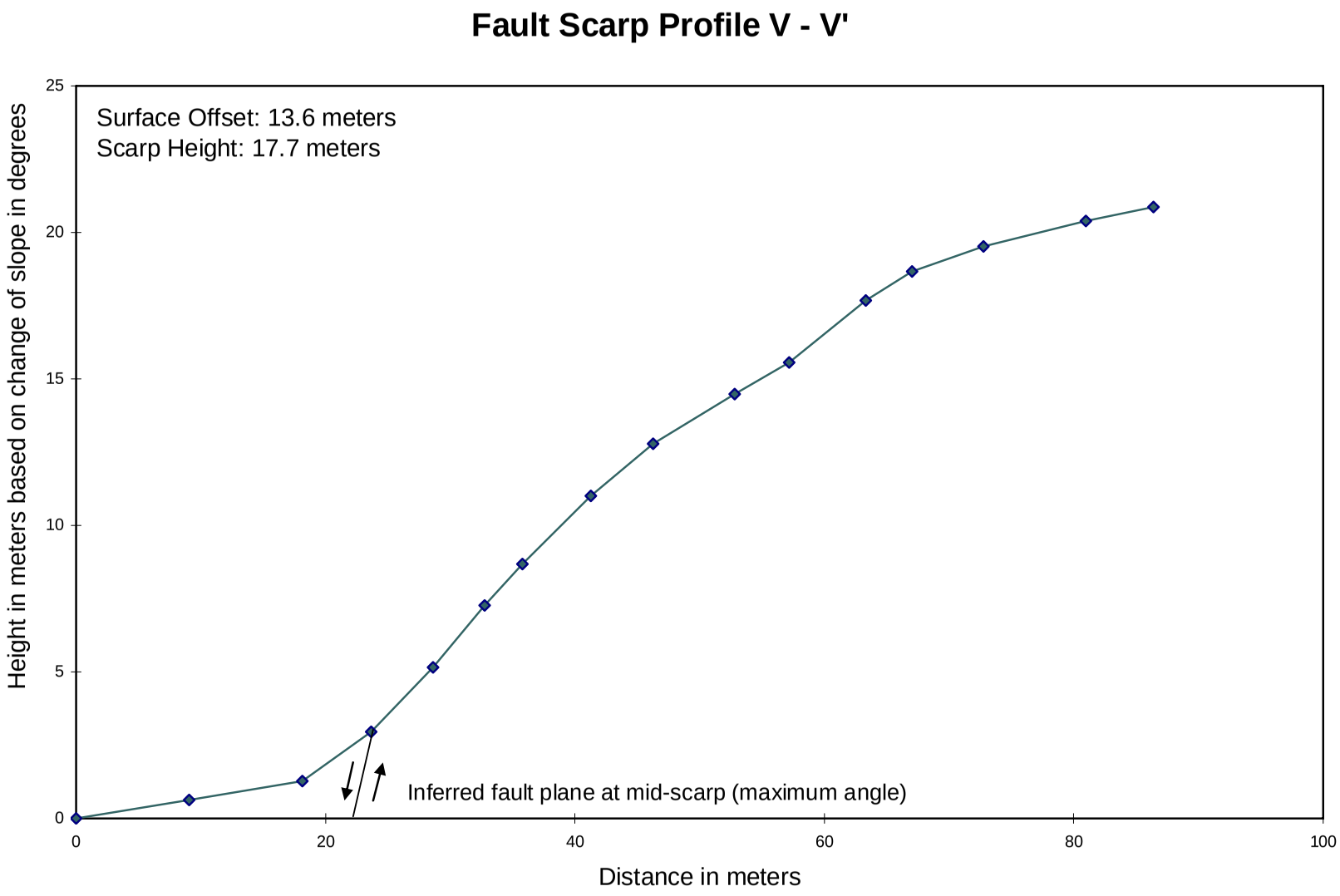
Starting location: 44°35’01” N, 112°01’42”W
Ending location: 44°34’59” N, 112°01’42”W

Station number	Slope in degrees	Distance (meters)
0-1	+4.0	9.10
1-2	+4.0	9.10
2-3	+17.0	5.75
3-4	+24.0	5.43
4-5	+27.0	4.65
5-6	+25.0	3.35
6-7	+23.0	5.96
7-8	+19.5	5.31
8-9	+14.5	6.74
9-10	+14.0	4.51
10-11	+19.0	6.48
11-12	+15.0	3.86
12-13	+8.5	5.77
13-14	+6.0	8.27
14-15	+5.0	5.44

Figure 41. Fault profile V – V', starting location: 44°35'01" N, 112°01'42"W; ending location: 44°34'59" N, 112°01'42"W, looking south.

Profile V – V' is located approximately 80 meters to the west of Bean Creek. The profile runs through trees that are rotated at the base of the roots. The hanging wall toe of the profile is flat and as it moves up slope the fault plane is inferred at stations 4 – 5 where the slope is +27.0°. The fault scarp rounds at the top of the hill and flattens as one moves south into the footwall of the profile.

This profile is rated: excellent


Fault Scarp Profile V - V'
Surface Offset: 13.6 meters
Scarp Height: 17.7 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
0
20
40
60
80
100

Profile: W – W’

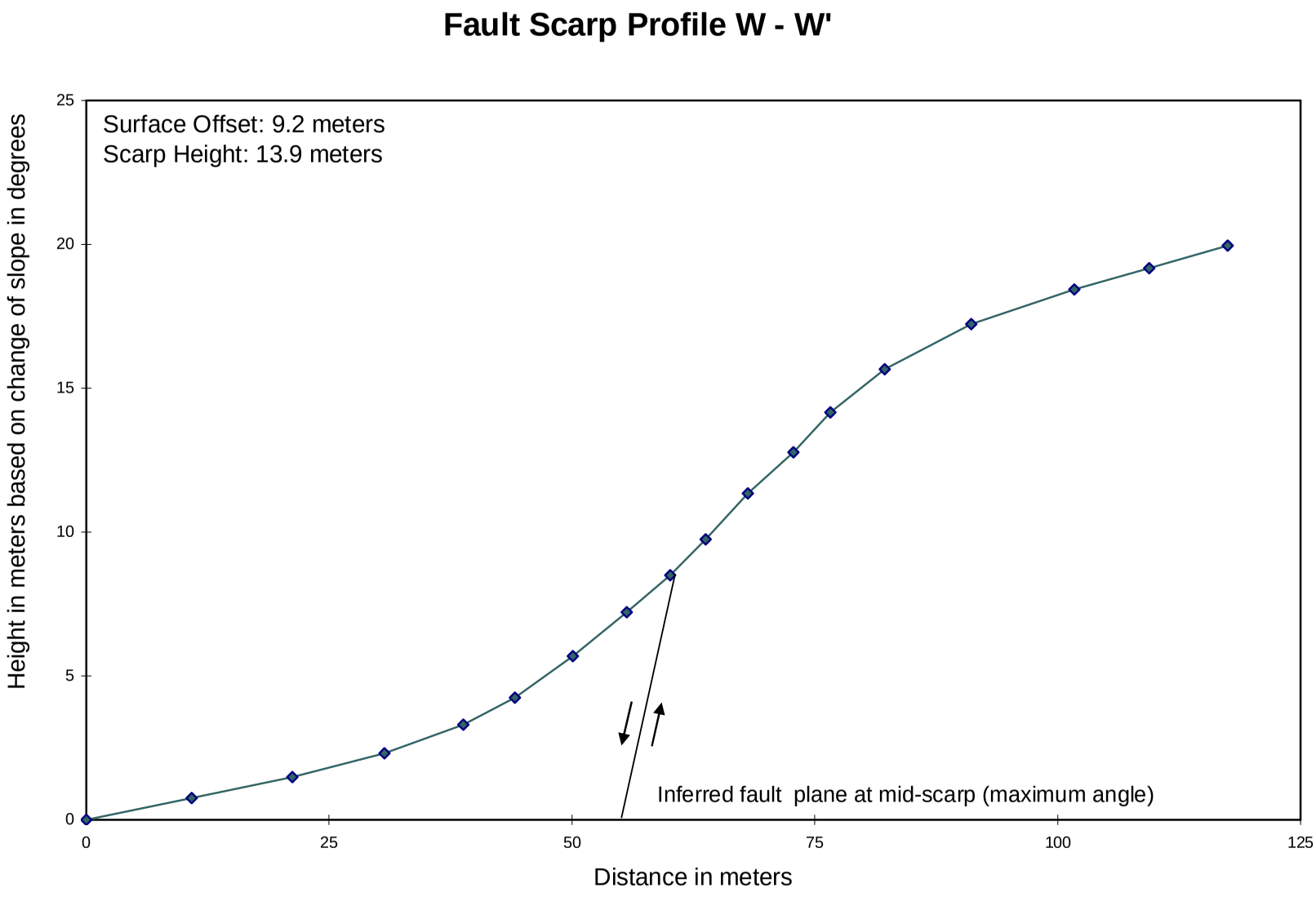
Starting location: 44°35’09” N, 112°00’53”W
Ending location: 44°35’05” N, 112°00’51”W

Station number	Slope in degrees	Distance (meters)
0-1	+4.0	10.90
1-2	+4.0	10.38
2-3	+5.0	9.50
3-4	+7.0	8.20
4-5	+10.0	5.38
5-6	+13.5	6.15
6-7	+15.5	5.75
7-8	+16.0	4.65
8-9	+19.0	3.85
9-10	+20.0	4.65
10-11	+17.0	4.90
11-12	+20.0	4.05
12-13	+15.0	5.76
13-14	+10.0	9.05
14-15	+6.5	10.70
15-16	+5.5	7.73
16-17	+5.5	8.13

Figure 42. Fault profile W – W', starting location: 44°35'09" N, 112°00'53"W; ending location: 44°35'05" N, 112°00'51"W, looking south.

Profile W – W' is located approximately 0.53 kilometers east of where Bean Creek crosses the South Side Centennial Road. The profile runs directly between the large grove of trees to the east and smaller grove of trees to the west. The hanging wall toe of the profile is relatively flat until it reaches the break in slope. As it moves up-slope the fault plane is inferred at stations 9 – 10 where the slope is +20.0°. The scarp rounds at the top of the hill and flattens as one moves south into the footwall of the profile.

This profile is rated: excellent


Fault Scarp Profile W - W'
Surface Offset: 9.2 meters
Scarp Height: 13.9 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
0
25
50
75
100
125

Profile: X – X’

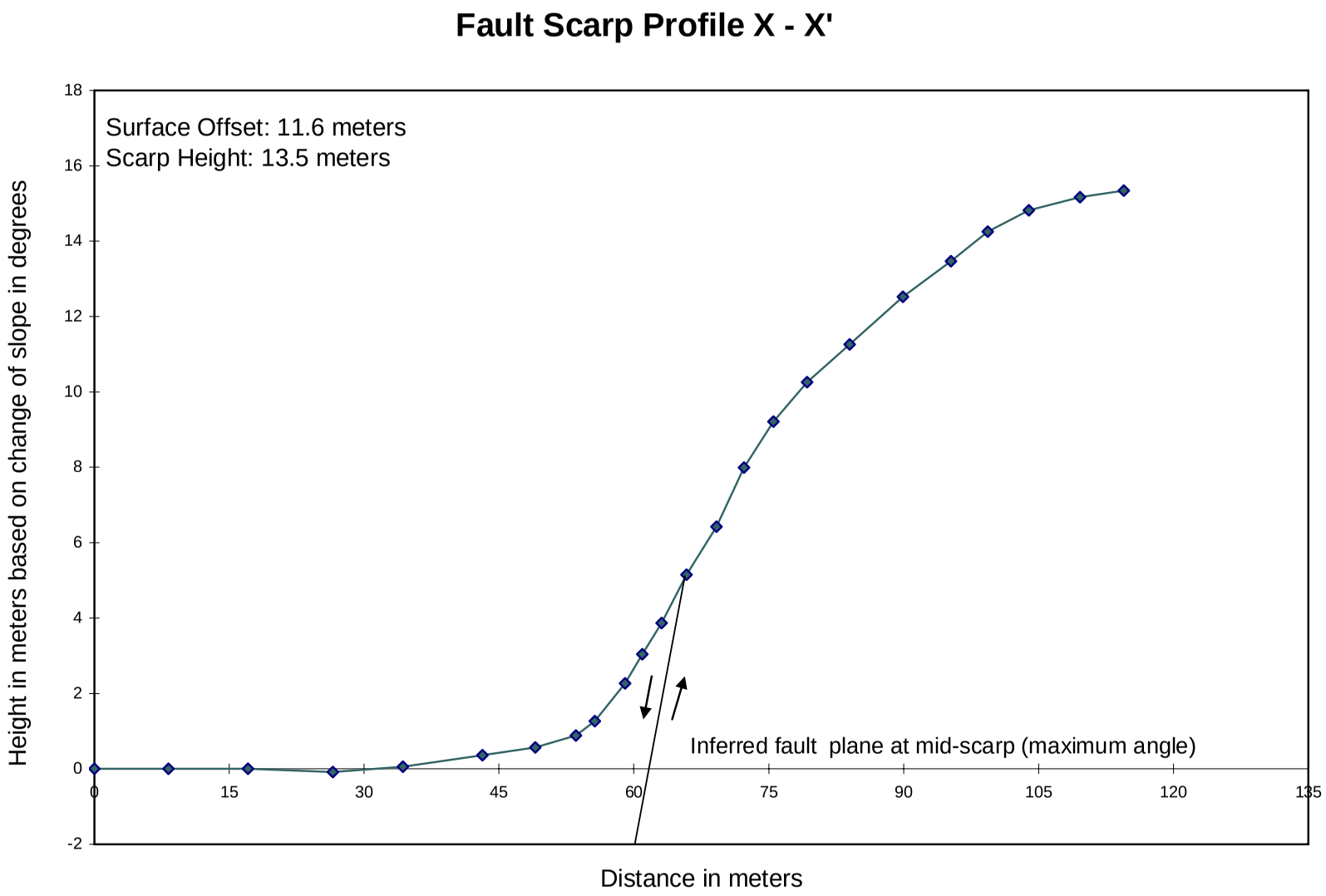
Starting location: 44°35’22” N, 111°59’27”W
Ending location: 44°35’18” N, 111°59’27”W

Station number	Slope in degrees	Distance (meters)
0-1	+0.0	8.26
1-2	+0.0	8.84
2-3	-0.5	9.42
3-4	+1.0	7.82
4-5	+2.0	8.84
5-6	+2.0	5.89
6-7	+4.0	4.52
7-8	+10.5	2.11
8-9	+16.5	3.53
9-10	+22.0	2.06
10-11	+21.0	2.31
11-12	+25.0	3.04
12-13	+21.0	3.57
13-14	+27.0	3.45
14-15	+20.5	3.48
15-16	+15.5	3.89
16-17	+12.0	4.85
17-18	+12.0	6.05
18-19	+10.0	5.44
19-20	+11.0	4.15
20-21	+7.0	4.62
21-22	+3.5	5.69
22-23	+2.0	4.88

Figure 43. Fault profile X – X', starting location: 44°35'22" N, 111°59'27"W; ending location: 44°35'18" N, 111°59'27"W, looking south.

Profile X – X' is located just west of Jones Cemetery and profile Y – Y'. The toe of the profile is flat and continues until it reaches the break in slope. As the profile moves up slope the fault plane is inferred at stations 13 – 14 w where the slope is +27.0°. The scarp rounds at the top of the hill and flattens as one moves south into the footwall of the profile.

This profile is rated: excellent


Fault Scarp Profile X - X'
Surface Offset: 11.6 meters
Scarp Height: 13.5 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
18
16
14
12
10
8
6
4
2
0
-2
0
15
30
45
60
75
90
105
120
135

Profile: Y – Y’

Starting location: 44°35’22” N, 111°59’23”W
Ending location: 44°35’15” N, 111°59’21”W

Station number	Slope in degrees	Distance (meters)
0-1	+1.0	11.51
1-2	+3.5	11.70
2-3	+8.0	9.90
3-4	+16.0	5.14
4-5	+20.0	5.20
5-6	+16.5	2.85
6-7	+19.0	6.05
7-8	+14.0	6.15
8-9	+21.5	3.55
9-10	+20.0	2.35
10-11	+8.5	5.60
11-12	+9.0	7.02
12-13	+9.5	6.90
13-14	+8.0	7.13
14-15	+12.5	3.71
15-16	+24.0	4.68
16-17	+22.0	4.00
17-18	+24.0	4.50
18-19	+30.5	1.87
19-20	+31.5	2.57
20-21	+9.5	6.61
21-22	+7.5	6.70
22-23	+6.0	6.76
23-24	+2.0	7.15
24-25	+3.0	7.33

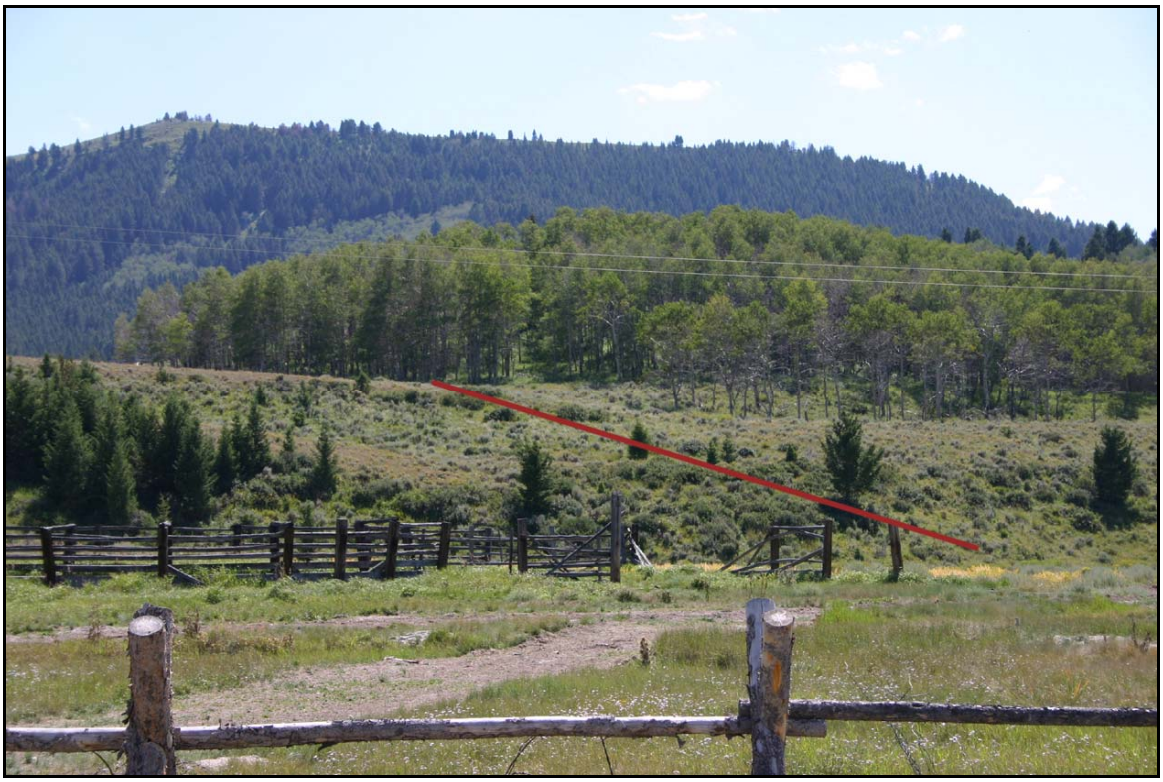
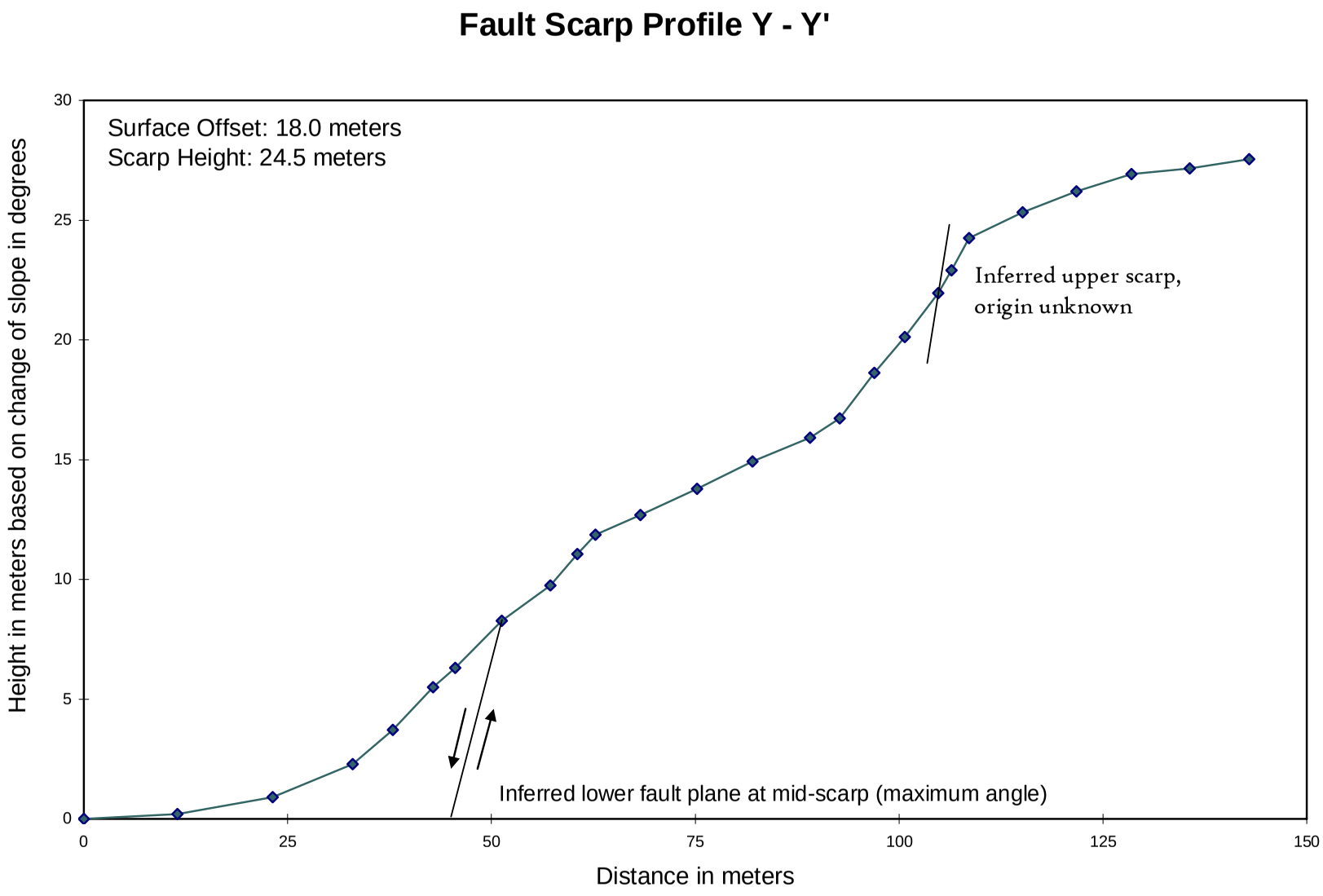


Figure 44. Fault profile Y – Y', starting location: 44°35'22" N, 111°59'23"W; ending location: 44°35'15" N, 111°59'21"W, looking south. Picture is taken from an oblique view.

Profile Y – Y' is located directly west of Jones Cemetery. The profile slope is highly vegetated with large grove of aspens to the south and west. The toe of the profile is relatively flat as the profile moves up slope the lower fault plane is inferred at stations 8 – 9 where the slope is +21.5°. The profile continues up slope until the upper scarp inferred at stations 19 – 20 where the slope is +31.5°. The upper scarp rounds at the top of the hill and flattens as one moves south into the footwall of the profile. The upper scarp is either tectonic or gravity in origin. At the top of the profile there is a slump from the drainage and a large earthflow directly to the east.

This profile is rated: fair


Fault Scarp Profile Y - Y'
Surface Offset: 18.0 meters
Scarp Height: 24.5 meters
Inferred upper scarp, origin unknown
Inferred lower fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
30
0
25
50
75
100
125
150

Profile: Z – Z'

Starting location: 44°35'50" N, 111°57'38"W
Ending location: 44°35'45" N, 111°57'29"W

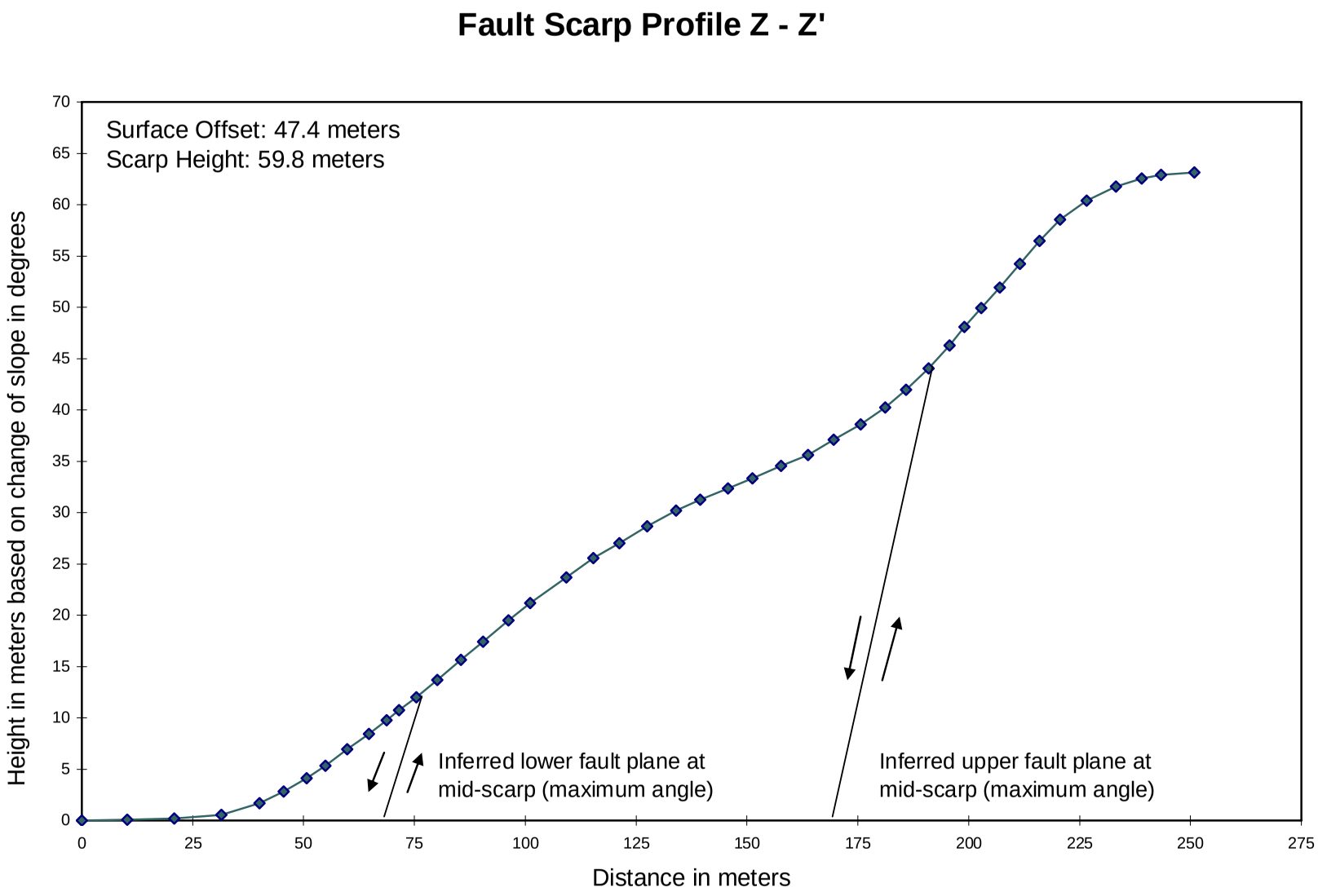
Station number	Slope in degrees	Distance (meters)
0-1	+0.5	10.25
1-2	+0.5	10.65
2-3	+2.0	10.61
3-4	+7.5	8.68
4-5	+12.0	5.50
5-6	+14.0	5.40
6-7	+16.0	4.36
7-8	+18.0	5.19
8-9	+17.0	5.12
9-10	+18.5	4.22
10-11	+19.0	2.95
11-12	+18.0	4.07
12-13	+19.5	5.07
13-14	+20.5	5.65
14-15	+19.5	5.30
15-16	+20.0	6.07
16-17	+19.0	5.18
17-18	+17.0	8.57
18-19	+17.0	6.35
19-20	+14.0	6.10
20-21	+14.5	6.47
21-22	+13.5	6.70
22-23	+11.0	5.55
23-24	+10.0	6.30
24-25	+10.0	5.62
25-26	+10.5	6.60
26-27	+10.0	6.15
27-28	+14.5	5.97
28-29	+13.5	6.26
29-30	+17.0	5.76
30-31	+20.0	5.00
31-32	+22.0	5.53
32-33	+25.5	5.20
33-34	+28.0	3.85
34-35	+26.0	4.23
35-36	+25.5	4.60
36-37	+27.0	5.10
37-38	+27.0	4.95
38-39	+24.0	5.10
39-40	+17.0	6.25

40-41	+12.0	6.75
41-42	+7.5	5.88
42-43	+4.5	4.38
43-44	+2.0	7.50

Figure 45. Fault profile Z – Z', starting location: 44°35'50" N, 111°57'38"W; ending location: 44°35'45" N, 111°57'29"W, looking south.

Profile Z – Z' is located approximately 6 to 9 meters to the east of Tipton Creek. The toe of the profile starts out flat until it reaches the slope. As the profile moves up slope the lower fault plane is inferred at stations 13 – 14 where the slope is +20.5°. At the top of the lower fault scarp the topography becomes gentle in slope until it reaches the upper scarp inferred at stations 33 – 34 where the slope is +28.0°. The upper scarp rounds at the top of the hill and flattens as one moves south into the footwall of the profile. The upper scarp is either tectonic or gravity in origin.

This profile is rated: fair


Fault Scarp Profile Z - Z'
Surface Offset: 47.4 meters
Scarp Height: 59.8 meters
Inferred lower fault plane at
mid-scarp (maximum angle)
Inferred upper fault plane at
mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
0
25
50
75
100
125
150
175
200
225
250
275

Profile: AA – AA’

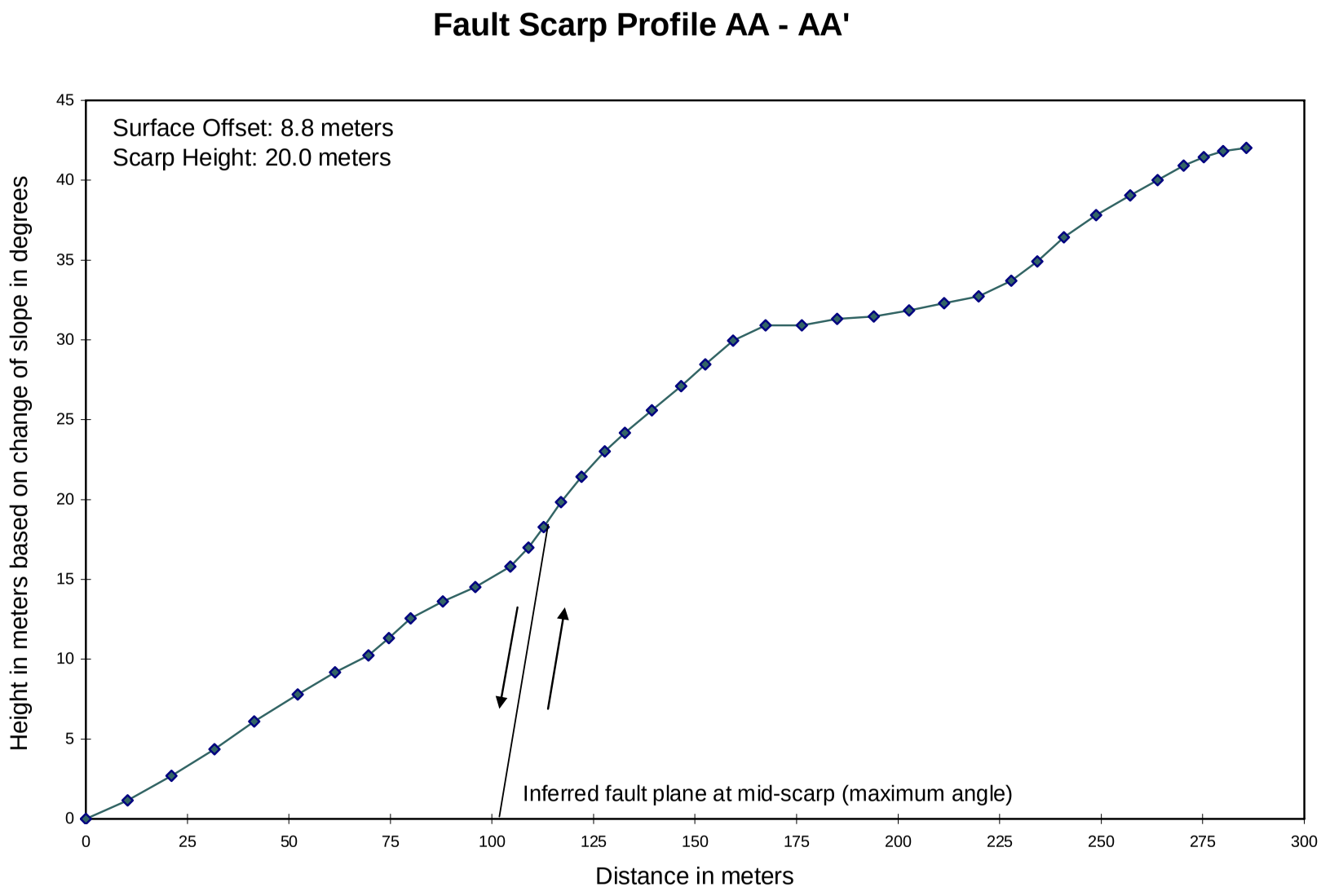
Starting location: 44°36’28” N, 111°53’39”W
Ending location: 44°36’19” N, 111°53’38”W

Station number	Slope in degrees	Distance (meters)
0-1	+6.5	10.32
1-2	+8.0	10.93
2-3	+9.0	10.74
3-4	+10.0	9.96
4-5	+9.0	10.76
5-6	+8.5	9.35
6-7	+7.5	8.25
7-8	+12.0	5.17
8-9	+13.0	5.55
9-10	+7.5	7.95
10-11	+6.5	8.08
11-12	+8.5	8.67
12-13	+15.0	4.63
13-14	+19.0	3.97
14-15	+20.0	4.50
15-16	+17.5	5.33
16-17	+15.5	5.94
17-18	+13.0	5.11
18-19	+12.0	6.82
19-20	+12.0	7.32
20-21	+13.0	6.07
21-22	+12.0	7.04
22-23	+7.0	8.05
23-24	+0.0	8.94
24-25	+2.5	8.72
25-26	+1.0	9.00
26-27	+2.5	8.70
27-28	+3.0	8.67
28-29	+3.0	8.50
29-30	+7.0	8.07
30-31	+10.5	6.55
31-32	+13.0	6.70
32-33	+10.0	8.04
33-34	+8.5	8.45
34-35	+8.0	6.86
35-36	+8.0	6.50
36-37	+6.0	4.92
37-38	+4.5	4.80
38-39	+2.0	5.73

Figure 46. Fault profile AA – AA', starting location: 44°36'28" N, 111°53'39"W; ending location: 44°36'19" N, 111°53'38"W, looking south.

Profile AA – AA' is located approximately 0.4 kilometers to the east of Lakeview Cemetery. The profile is of an earthflow that has been offset by the fault. The hanging wall toe of the profile gently increases along the earthflow until it reaches the fault plane inferred at stations 14 – 15 where the slope is +20.0°. The profile continues along the earthflow until it reaches the top where it rounds off and flattens as one moves south into the footwall of the profile.

This profile is rated: fair


Fault Scarp Profile AA - AA'
Surface Offset: 8.8 meters
Scarp Height: 20.0 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
30
35
40
45
0
25
50
75
100
125
150
175
200
225
250
275
300

Profile: AB – AB’

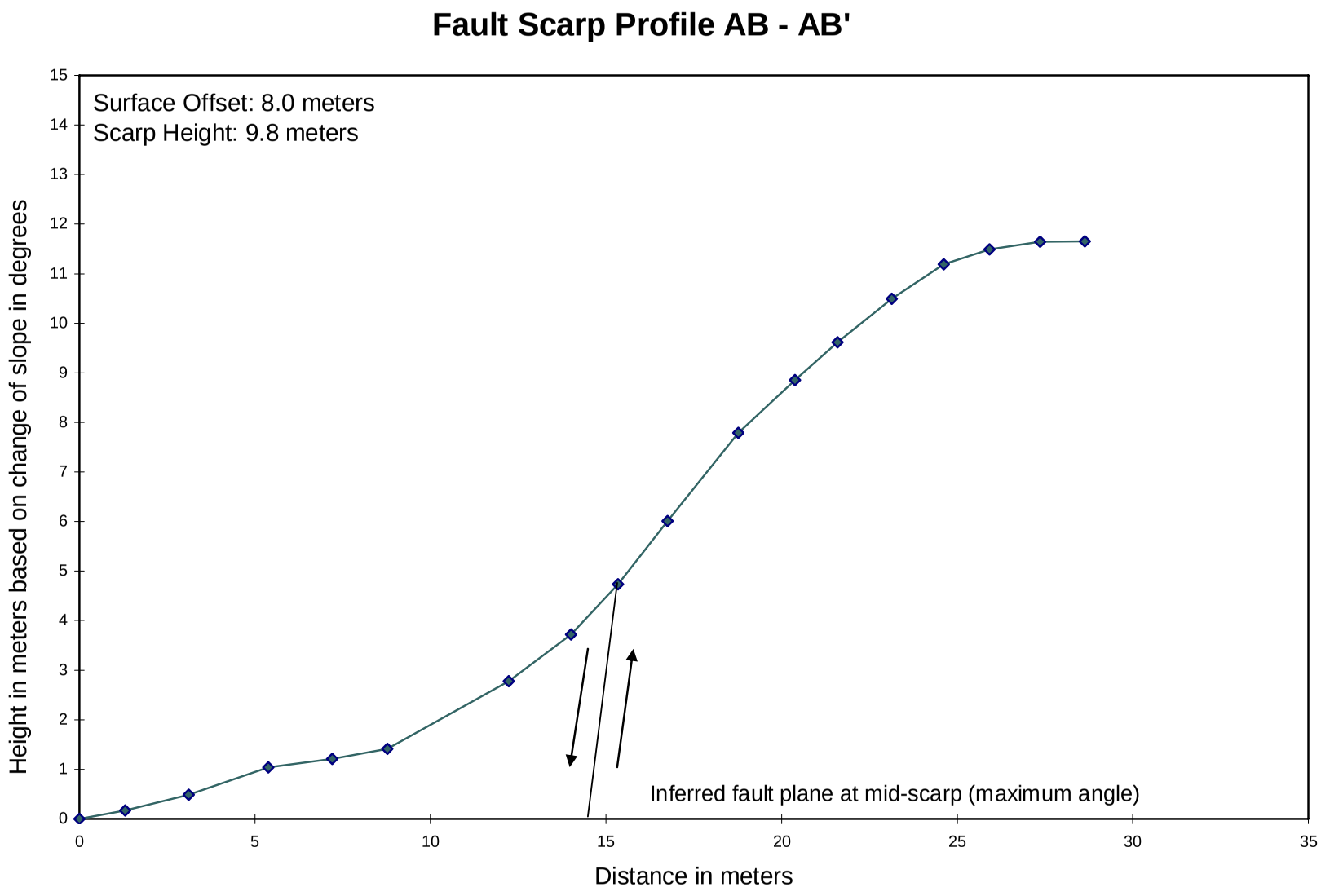
Starting location: 44°35’41” N, 111°47’11”W
Ending location: 44°34’41” N, 111°47’12”W

Station number	Slope in degrees	Distance (meters)
0-1	+7.5	1.32
1-2	+10.0	1.83
2-3	+13.5	2.34
3-4	+5.5	1.83
4-5	+7.5	1.57
5-6	+21.5	3.72
6-7	+28.0	2.01
7-8	+37.0	1.68
8-9	+42.0	1.91
9-10	+41.5	2.69
10-11	+33.5	1.93
11-12	+32.0	1.44
12-13	+29.5	1.78
13-14	+25.5	1.63
14-15	+13.0	1.35
15-16	+6.0	1.45
16-17	+0.5	1.27

Figure 47. Fault profile AB – AB', starting location: 44°35'41" N, 111°47'11"W; ending location: 44°34'41" N, 111°47'12"W, looking west southwest (Photograph courtesy of Ashley Yearous).

Profile AB – AB' is located approximately 0.32 kilometers to the southwest of the Taft Ranch. The hanging wall toe of the profile is flat and gently gains elevation as it moves up slope to the fault plane that is inferred at stations 8 – 9 where the slope is +42.0°. The fault scarp rounds at the top of the hill and flattens as one moves west into the footwall of the profile.

This profile is rated: good


Fault Scarp Profile AB - AB'
Surface Offset: 8.0 meters
Scarp Height: 9.8 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0
5
10
15
20
25
30
35

Profile: AC – AC’

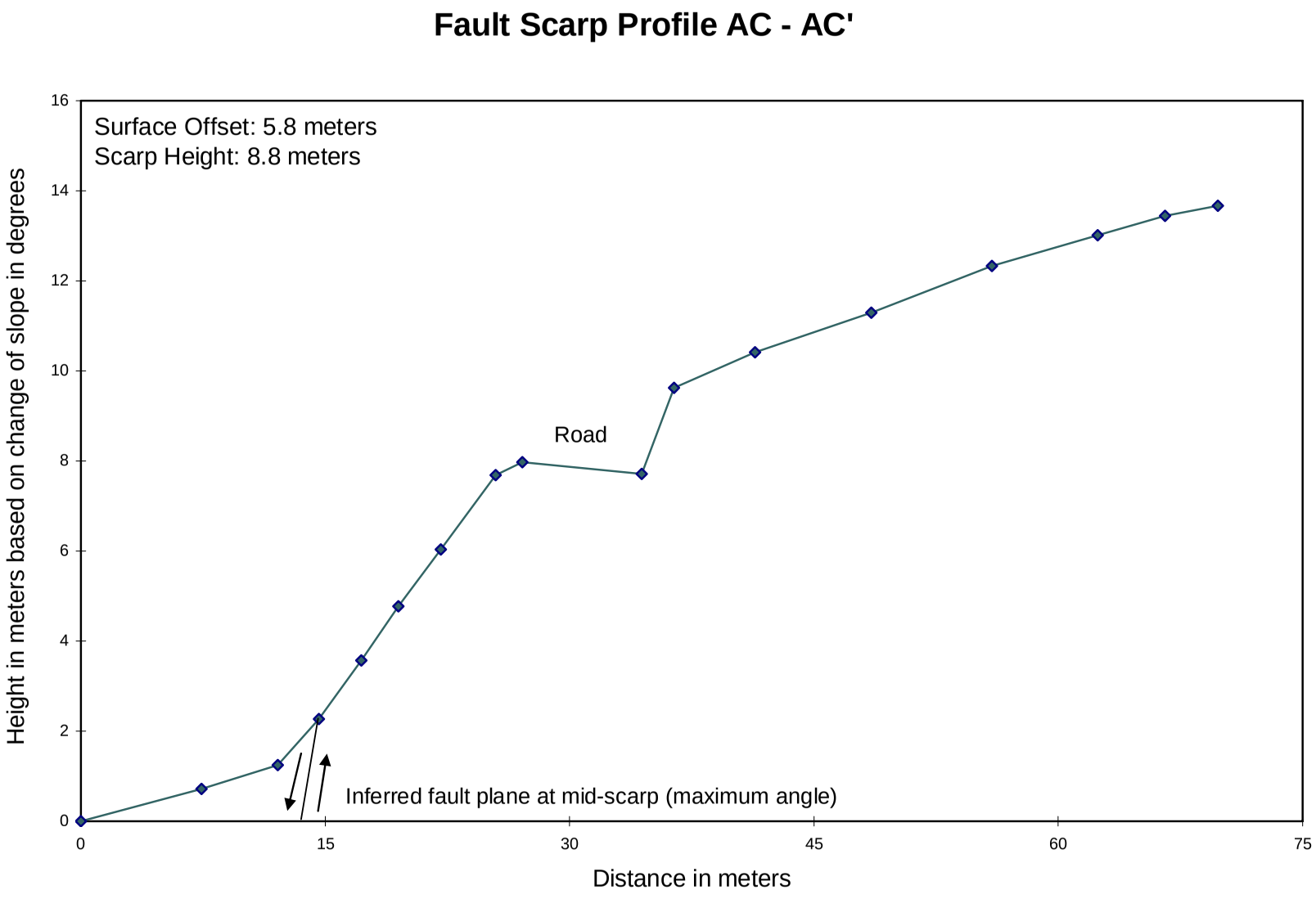
Starting location: 44°35’35” N, 111°43’45”W
Ending location: 44°35’33” N, 111°43’45”W

Station number	Slope in degrees	Distance (meters)	
0-1	+5.5	7.45	
1-2	+6.5	4.70	
2-3	+22.0	2.74	
3-4	+26.5	2.90	
4-5	+28.0	2.56	
5-6	+26.0	2.90	
6-7	+26.0	3.75	
7-8	+10.0	1.66	road
8-9	-2.0	7.35	road
9-10	+44.0	2.75	roadcut
10-11	+9.0	5.03	
11-12	+7.0	7.20	
12-13	+8.0	7.46	
13-14	+6.0	6.54	
14-15	+6.0	4.15	
15-16	+4.0	3.25	

Figure 48. Fault profile AC – AC', starting location: 44°35'35" N, 111°43'45"W; ending location: 44°35'33" N, 111°43'45"W, looking south.

Profile AC – AC' is located in the Upper Red Rock Lake campground. The hanging wall toe of the profile is gentle and slowly increases until the fault plane inferred at stations 4 – 5 where the slope is +28.0°. The profile continues up slope until it crosses the road and road cut where it continues to rise gradually into the footwall.

This profile is rated: poor


Fault Scarp Profile AC - AC'
Surface Offset: 5.8 meters
Scarp Height: 8.8 meters
Road
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
2
4
6
8
10
12
14
16
0
15
30
45
60
75

Profile: AD – AD’

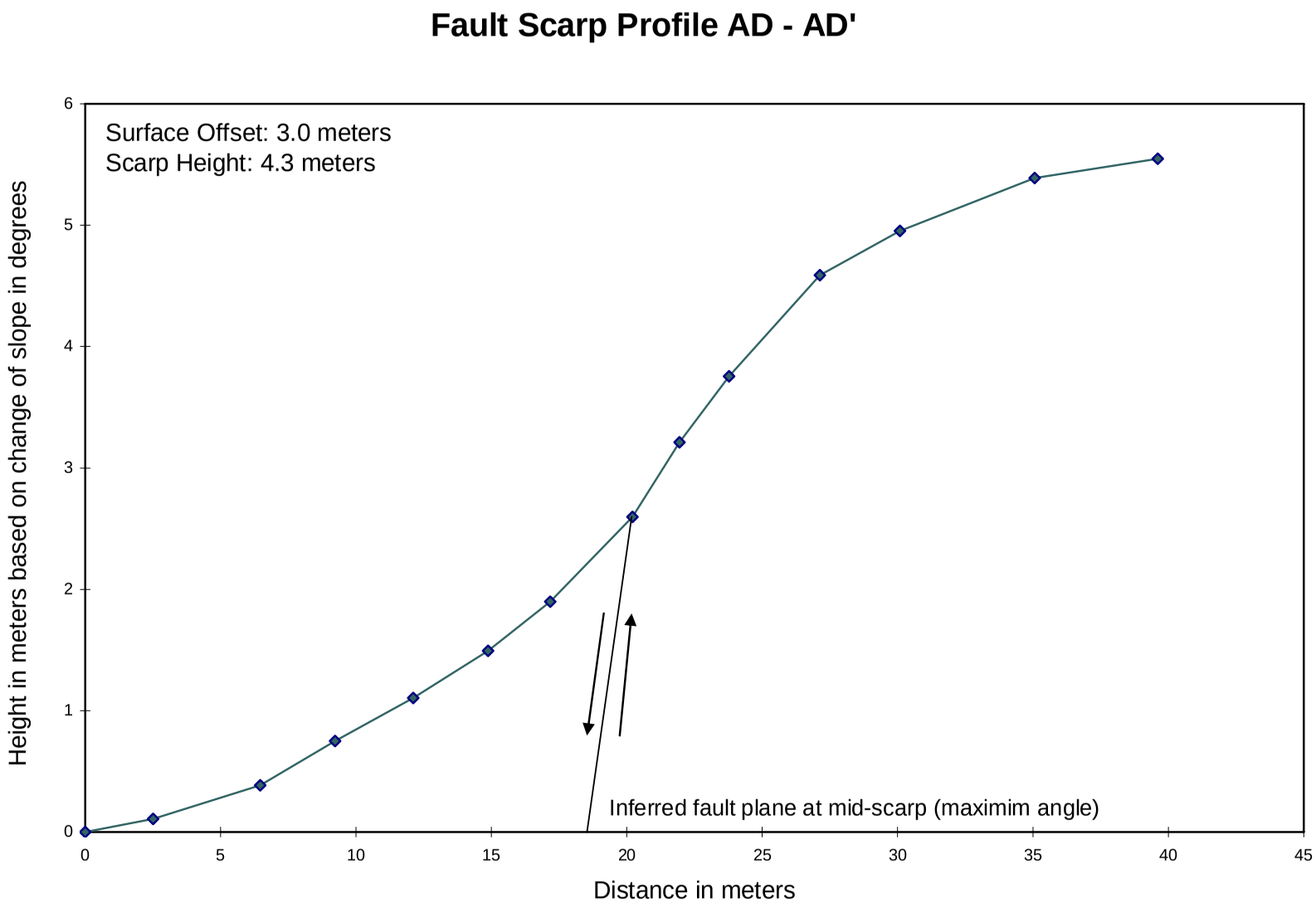
Starting location: 44°35’04” N, 111°41’23”W
Ending location: 44°35’03” N, 111°41’23”W

Station number	Slope in degrees	Distance (meters)
0-1	+2.5	2.51
1-2	+4.0	3.96
2-3	+7.5	2.78
3-4	+7.0	2.92
4-5	+8.0	2.78
5-6	+10.0	2.34
6-7	+13.0	3.11
7-8	+19.5	1.84
8-9	+16.5	1.91
9-10	+14.0	3.45
10-11	+7.0	3.00
11-12	+5.0	4.98
12-13	+2.0	4.55

Figure 49. Fault profile AD – AD', starting location: 44°35'04" N, 111°41'23"W; ending location: 44°35'03" N, 111°41'23"W, looking south.

Profile AD – AD' is located approximately 2.25 kilometers to the corner of the Walsh Ranch which is located to the east of the profile location. The hanging wall far field toe of the profile is flat and moves towards the break in slope until it reaches the fault scarp. The fault plane is inferred at stations 7 – 8 where the slope is +19.5°. The profile continues until it reaches the top of the slope where it rounds off and flattens as it moves into the footwall of the profile.

This profile is rated: excellent


Fault Scarp Profile AD - AD'
Surface Offset: 3.0 meters
Scarp Height: 4.3 meters
Inferred fault plane at mid-scarp (maximim angle)
Height in meters based on change of slope in degrees
Distance in meters
0
1
2
3
4
5
6
0
5
10
15
20
25
30
35
40
45

Profile: AE – AE'

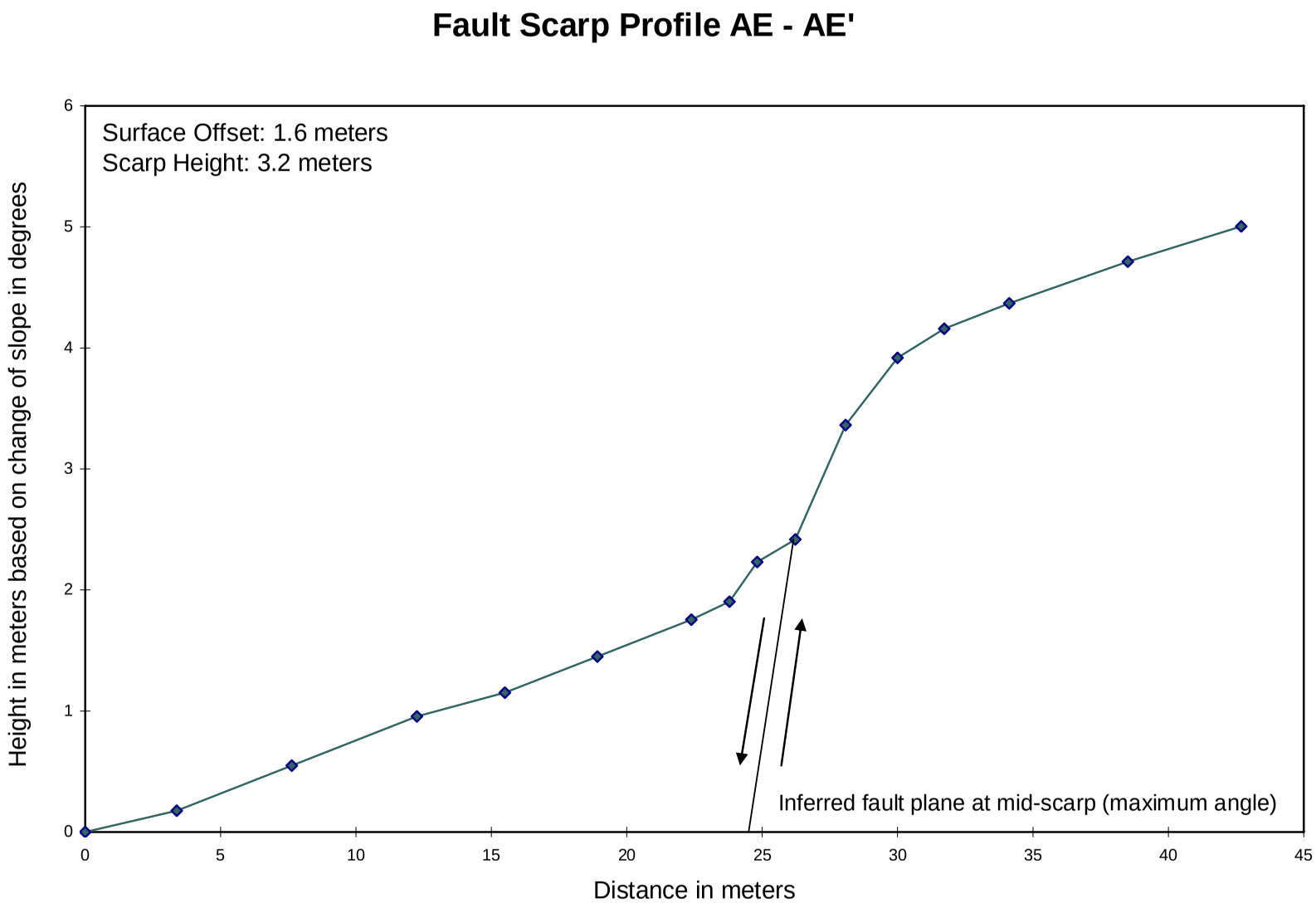
Starting location: 44°35'03" N, 111°41'15"W
Ending location: 44°35'02" N, 111°41'16"W

Station number	Slope in degrees	Distance (meters)
0-1	+3.0	3.39
1-2	+5.0	4.25
2-3	+5.0	4.65
3-4	+3.5	3.25
4-5	+5.0	3.43
5-6	+5.0	3.48
6-7	+6.0	1.42
7-8	+18.0	1.07
8-9	+7.5	1.42
9-10	+27.0	2.08
10-11	+16.0	2.01
11-12	+8.0	1.73
12-13	+5.0	2.41
13-14	+4.5	4.39
14-15	+4.0	4.20

Figure 50. Fault profile AE – AE', starting location: 44°35'03" N, 111°41'15"W; ending location: 44°35'02" N, 111°41'16"W, looking south.

Profile AE – AE' is located just east of profile AD – AD'. The hanging wall far field toe of the profile is flat and moves towards the break in slope until it reaches the fault scarp. The fault plane is inferred at stations 9 – 10 where the slope is +27.0°. The profile continues until it reaches the top of the slope where it rounds off and flattens as it moves into the footwall of the profile.

This profile is rated: good


Fault Scarp Profile AE - AE'
Surface Offset: 1.6 meters
Scarp Height: 3.2 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
1
2
3
4
5
6
0
5
10
15
20
25
30
35
40
45

Profile: AF – AF’

Starting location: 44°37’11” N, 111°37’34”W
Ending location: 44°37’17” N, 111°37’24”W

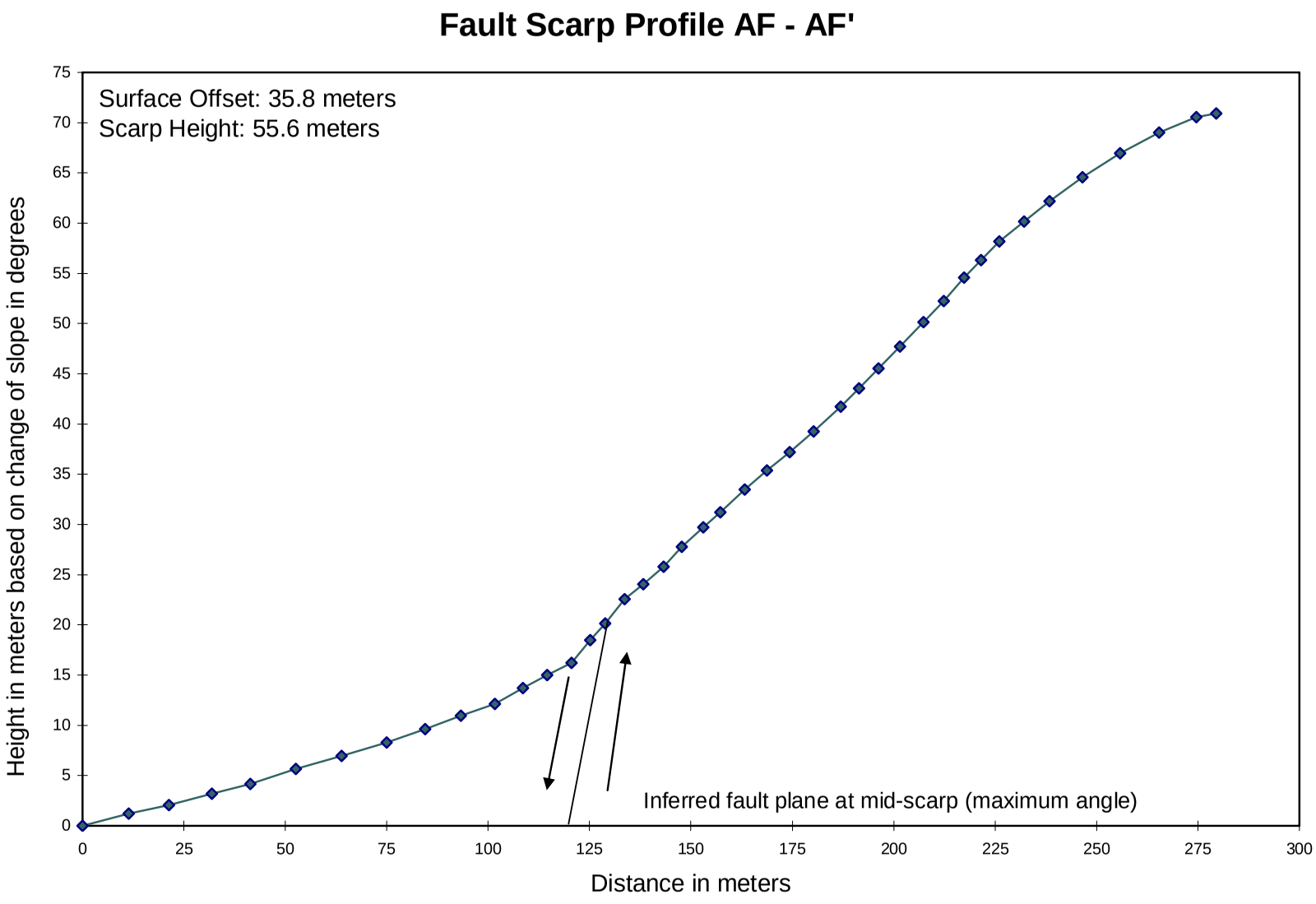
Station number	Slope in degrees	Distance (meters)
0-1	+6.0	11.50
1-2	+5.0	9.85
2-3	+6.0	10.67
3-4	+6.0	9.61
4-5	+7.5	11.22
5-6	+6.5	11.40
6-7	+7.0	11.20
7-8	+8.0	9.57
8-9	+8.5	8.95
9-10	+8.0	8.40
10-11	+13.0	7.10
11-12	+12.0	6.10
12-13	+11.5	6.21
13-14	+26.0	5.10
14-15	+24.5	4.05
15-16	+27.0	5.32
16-17	+18.0	4.87
17-18	+19.0	5.30
18-19	+24.0	4.90
19-20	+20.0	5.61
20-21	+20.0	4.48
21-22	+20.5	6.40
22-23	+19.0	5.85
23-24	+18.0	5.88
24-25	+19.0	6.30
25-26	+20.5	7.10
26-27	+22.0	4.88
27-28	+22.5	5.16
28-29	+22.5	5.70
29-30	+22.5	6.36
30-31	+23.0	5.35
31-32	+25.0	5.50
32-33	+22.5	4.62
33-34	+22.5	4.87
34-35	+18.0	6.41
35-36	+17.5	6.62
36-37	+16.5	8.40
37-38	+14.5	9.60
38-39	+12.0	9.87
39-40	+9.5	9.27

40-41	+4.5	4.90

Figure 51. Fault profile AF – AF', starting location: 44°37'11" N, 111°37'34"W; ending location: 44°37'17" N, 111°37'24"W, looking north to northeast.

Profile AF – AF' is located approximately 1.04 kilometers from the intersection of South Side Centennial Road and Elk Lake Road. The hanging wall far field toe of the profile is moderately flat and moves towards the break in slope until it reaches the fault scarp. The fault plane is inferred at stations 15 – 16 where the slope is +27.0°. The profile continues until it reaches the top of the slope where it starts to round off and flattens as it moves into the footwall of the profile.

This profile is rated: fair


Fault Scarp Profile AF - AF'
Surface Offset: 35.8 meters
Scarp Height: 55.6 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
0
25
50
75
100
125
150
175
200
225
250
275
300

Profile: AG – AG’

Starting location: 44°37’09” N, 111°37’24”W
Ending location: 44°37’16” N, 111°37’19”W

Station number	Slope in degrees	Distance (meters)
0-1	+12.0	8.90
1-2	+12.0	6.15
2-3	+11.0	7.12
3-4	+11.5	8.35
4-5	+15.0	6.95
5-6	+13.0	7.70
6-7	+15.5	6.55
7-8	+16.0	7.50
8-9	+16.5	5.23
9-10	+17.5	7.42
10-11	+26.0	6.60
11-12	+22.0	6.60
12-13	+22.0	6.20
13-14	+23.0	7.05
14-15	+20.0	8.00
15-16	+19.0	7.27
16-17	+19.0	8.41
17-18	+17.0	9.15
18-19	+15.5	10.41
19-20	+14.5	10.06
20-21	+13.5	10.50
21-22	+13.5	5.78
22-23	+23.0	4.55
23-24	+31.0	3.70
24-25	+22.5	6.13
25-26	+22.5	7.85
26-27	+17.0	7.50
27-28	+20.0	7.53
28-29	+20.5	6.40
29-30	+16.0	9.26
30-31	+8.5	10.80
31-32	+2.0	8.90

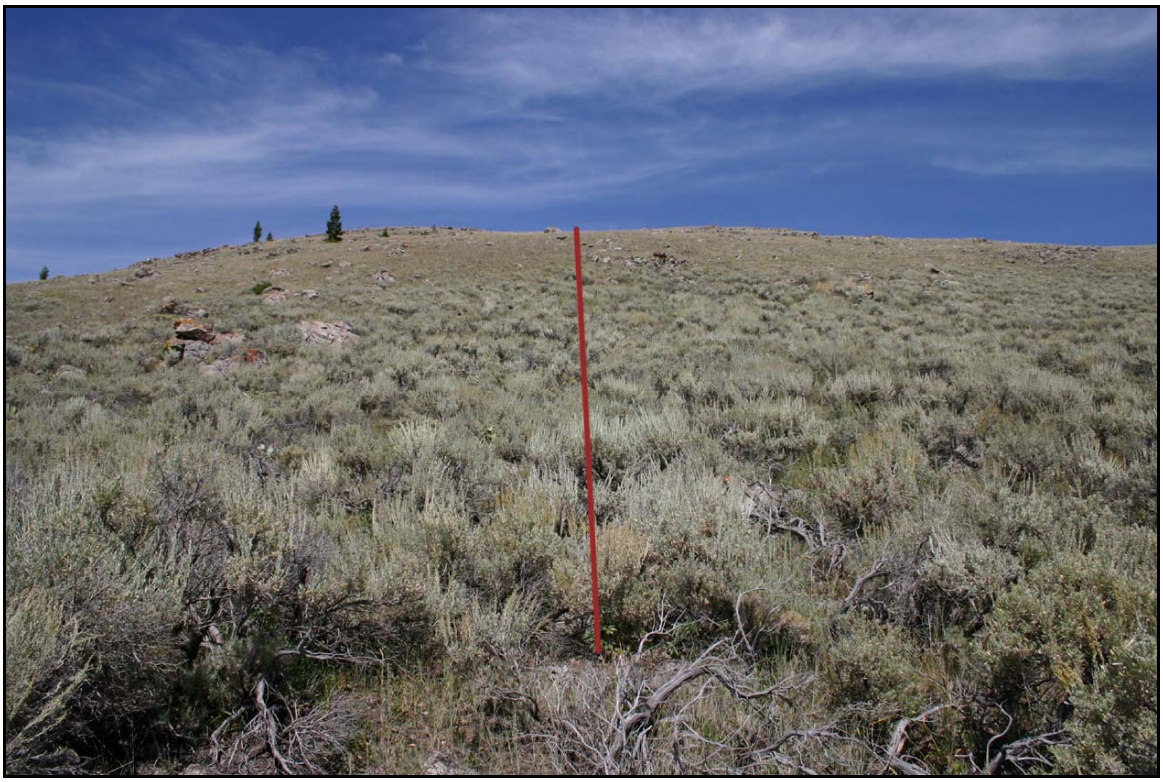
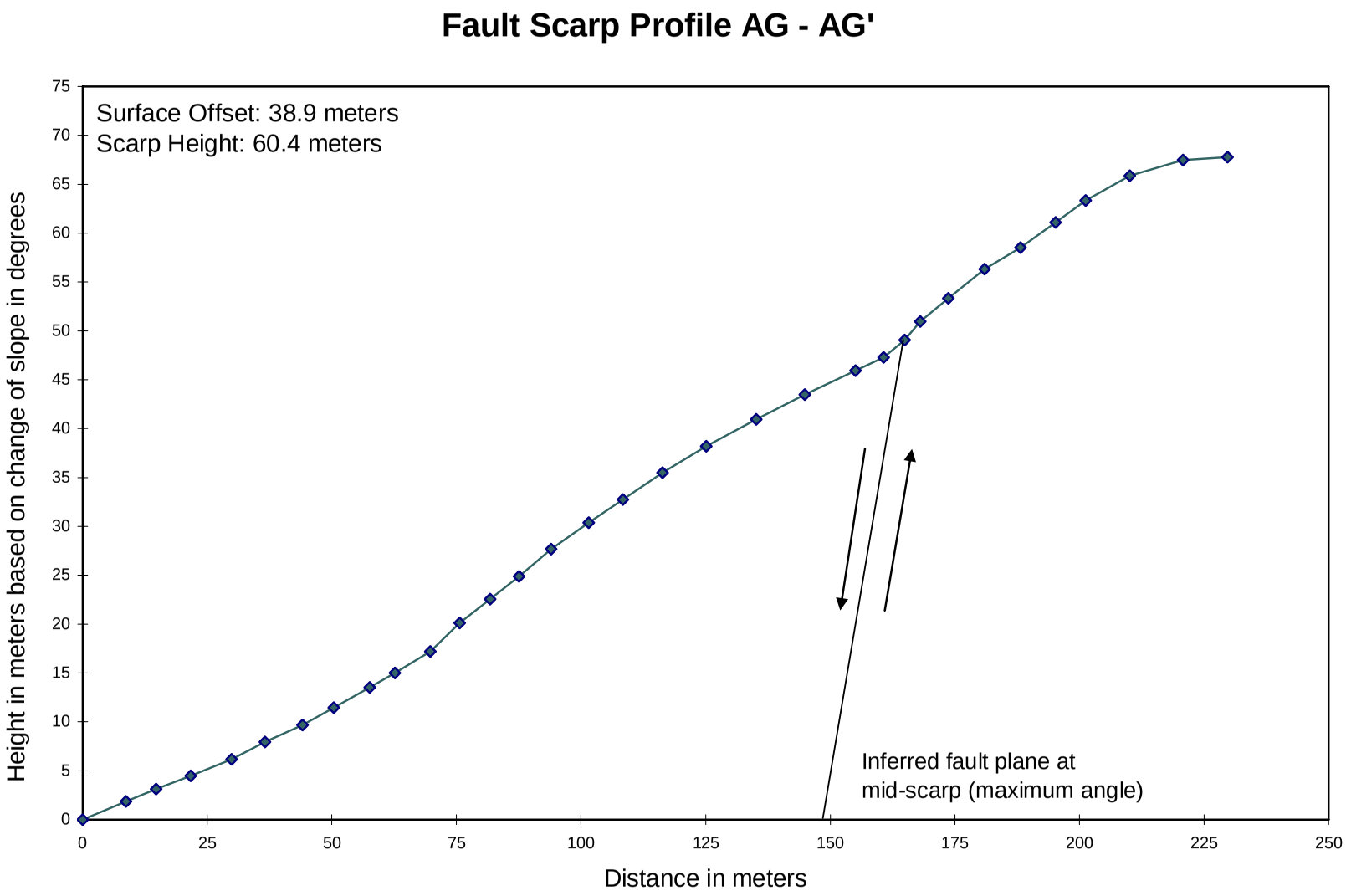


Figure 52. Fault profile AG – AG', starting location: 44°37'09" N, 111°37'24"W; ending location: 44°37'16" N, 111°37'19"W, looking north to northeast.

Profile AG – AG' is approximately 0.16 kilometers to the east southeast of profile AF – AF'. The hanging wall far field toe of the profile is moderately flat and moves towards the break in slope until it reaches the fault scarp. The fault plane is inferred at stations 23 – 24 where the slope is +31.0°. The profile continues until it reaches the top of the slope where it starts to round off and flattens as it moves into the footwall of the profile.

This profile is rated: fair


Fault Scarp Profile AG - AG'
Surface Offset: 38.9 meters
Scarp Height: 60.4 meters
Inferred fault plane at
mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
0
25
50
75
100
125
150
175
200
225
250

Profile: AH – AH’

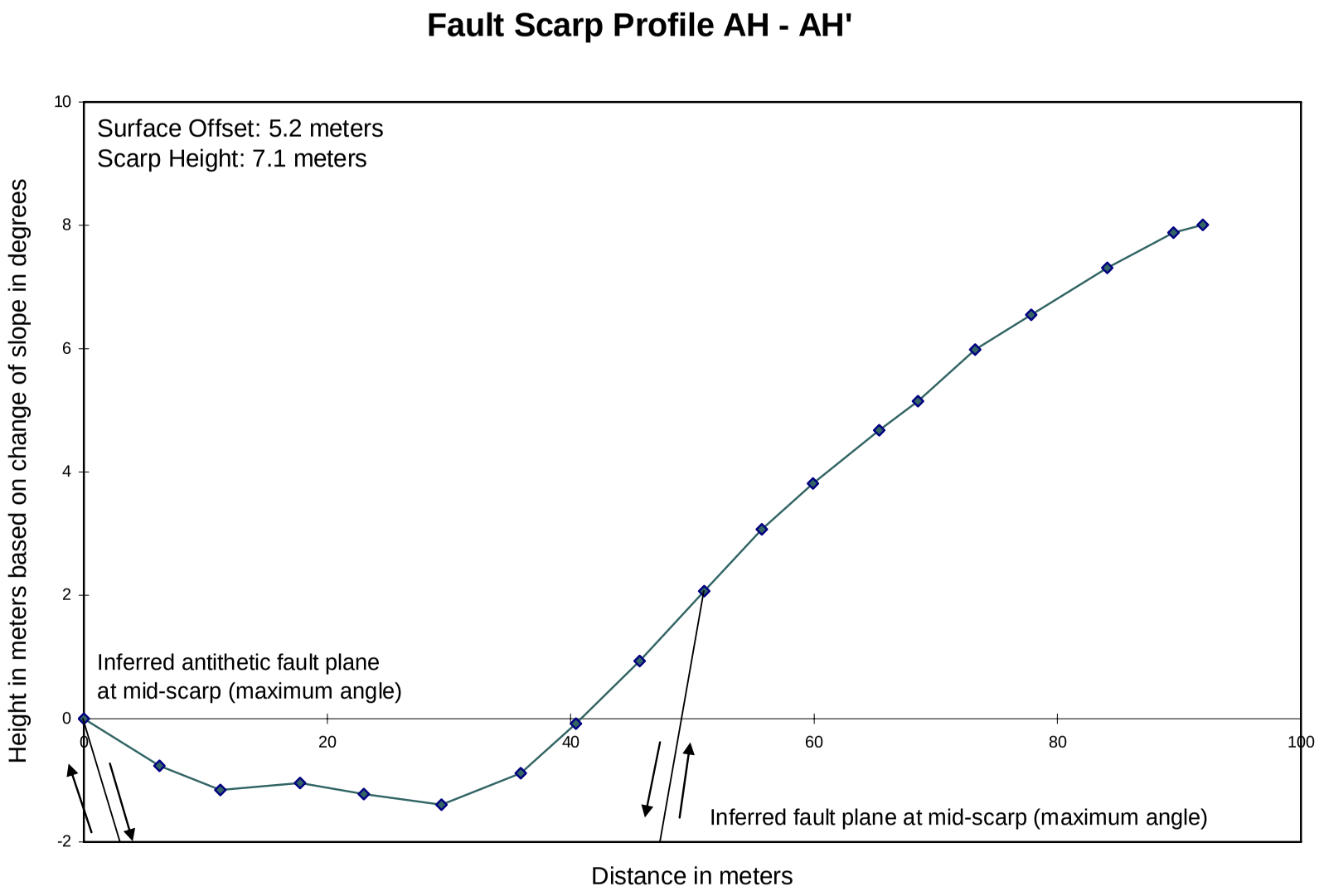
Starting location: 44°35’56” N, 111°31’55”W
Ending location: 44°35’54” N, 111°31’57”W

Station number	Slope in degrees	Distance (meters)
0-1	-7.0	6.27
1-2	-4.5	5.02
2-3	+1.0	6.55
3-4	-2.0	5.23
4-5	-1.5	6.38
5-6	+4.5	6.52
6-7	+10.0	4.62
7-8	+11.0	5.32
8-9	+12.0	5.45
9-10	+12.0	4.82
10-11	+10.0	4.27
11-12	+9.0	5.52
12-13	+8.5	3.20
13-14	+10.0	4.80
14-15	+7.0	4.62
15-16	+7.0	6.28
16-17	+6.0	5.47
17-18	+3.0	2.43

Figure 53. Fault profile AH – AH', starting location: 44°35'56" N, 111°31'55"W; ending location: 44°35'54" N, 111°31'57"W, looking north to northeast.

Profile AH – AH' is located approximately 0.06 kilometers to Southside Centennial Road. The hanging wall far field toe of the profile starts at the antithetic fault plate inferred at stations 0 – 1 where the slope is -7.0°. The profile continues through the graben until it starts to move up slope. The profile moves towards the break in slope until it reaches the fault scarp. The fault plane is inferred at stations 9 – 10 where the slope is +12.0°. The profile continues until it reaches the top of the slope where it starts to round off before it continues up slope into footwall of the profile.

This profile is rated: fair


Fault Scarp Profile AH - AH'
Surface Offset: 5.2 meters
Scarp Height: 7.1 meters
Inferred antithetic fault plane
at mid-scarp (maximum angle)
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
10
8
6
4
2
0
-2
0
20
40
60
80
100

Profile: AI– AI’

Starting location: 44°35’55” N, 111°31’54”W
Ending location: 44°35’56” N, 111°31’53”W

Station number	Slope in degrees	Distance (meters)
0-1	-5.0	2.61
1-2	-7.0	5.83
2-3	-8.5	5.06
3-4	+12.5	5.10
4-5	+15.5	4.77
5-6	+12.0	4.56
6-7	+8.5	6.24
7-8	+5.0	4.32
8-9	+4.5	3.75
9-10	+4.5	4.22

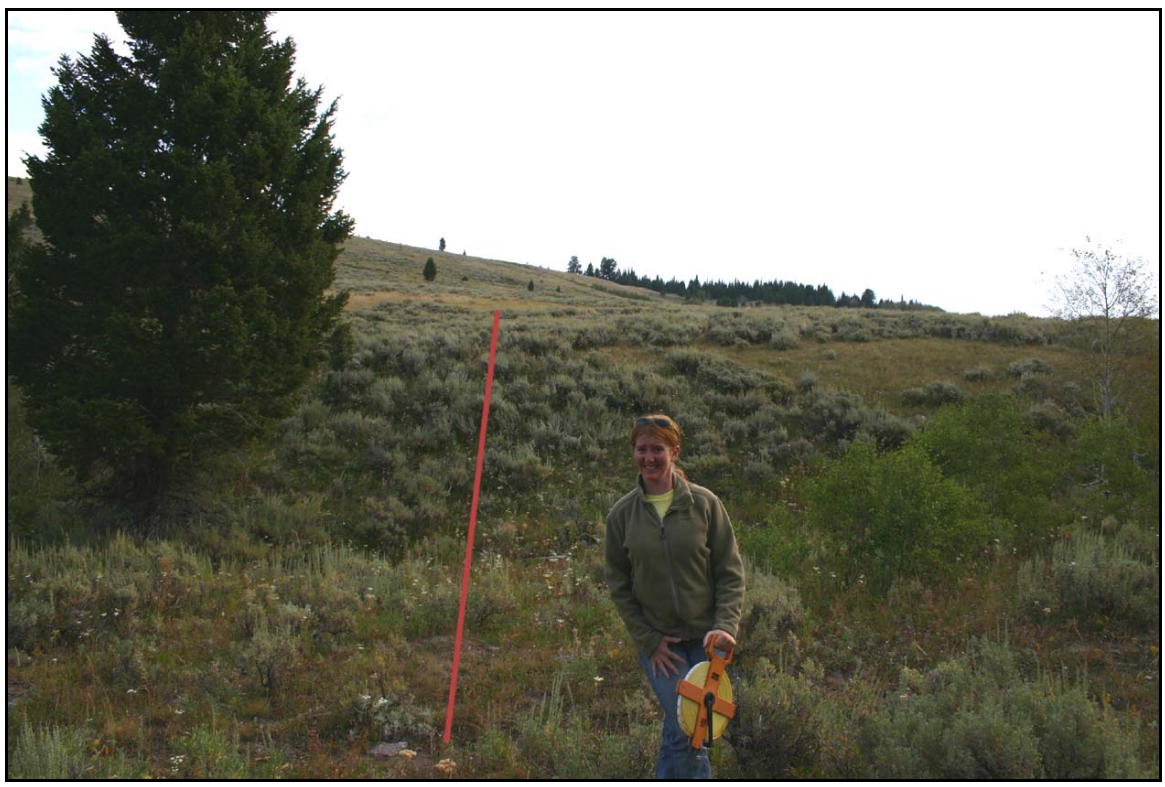
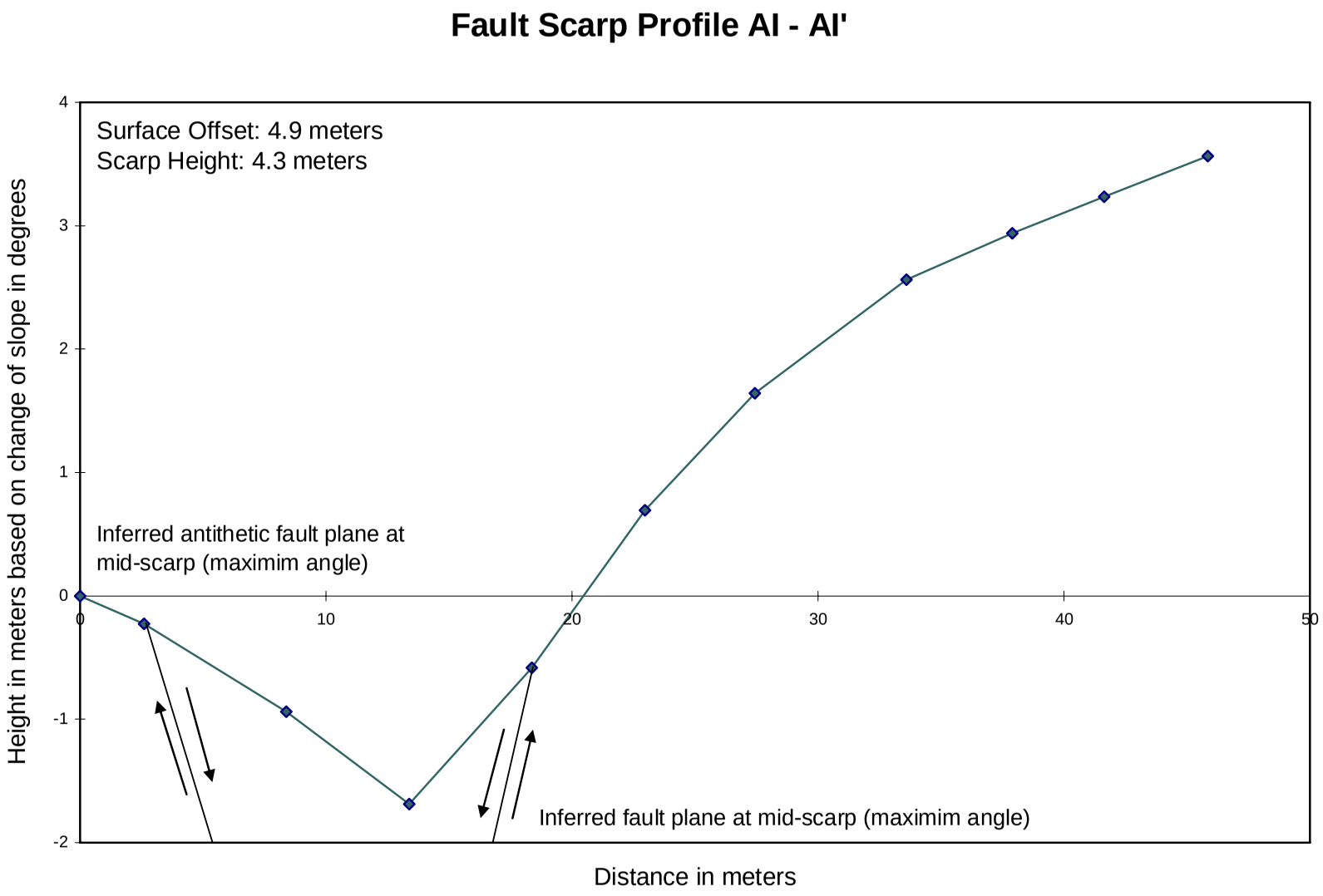


Figure 54. Fault profile AI – AI’, starting location: 44°35’55” N, 111°31’54”W; ending location: 44°35’56” N, 111°31’53”W, looking north to northeast.

Profile AI – AI’ is located approximately 0.19 kilometers to the east north east of profile AH – AH”. The hanging wall far field toe of the profile starts at the antithetic fault plate inferred at stations 1 – 2 where the slope is -7.0°. The profile continues through the graben until it starts to move up slope. The profile moves towards the break

in slope until it reaches the fault scarp. The fault plane is inferred at stations 4 – 5 where the slope is +15.5°. The profile continues until it reaches the top of the slope where it starts to round off and flatten as it continues into the footwall of the profile.

This profile is rated: fair


Fault Scarp Profile AI - AI'
Surface Offset: 4.9 meters
Scarp Height: 4.3 meters
Inferred antithetic fault plane at
mid-scarp (maximim angle)
Inferred fault plane at mid-scarp (maximim angle)
Height in meters based on change of slope in degrees
Distance in meters
4
3
2
1
0
-1
-2
0
10
20
30
40
50

Profile: AJ – AJ'

Starting location: 44°35'56" N, 111°31'37"W
Ending location: 44°35'54" N, 111°31'37"W

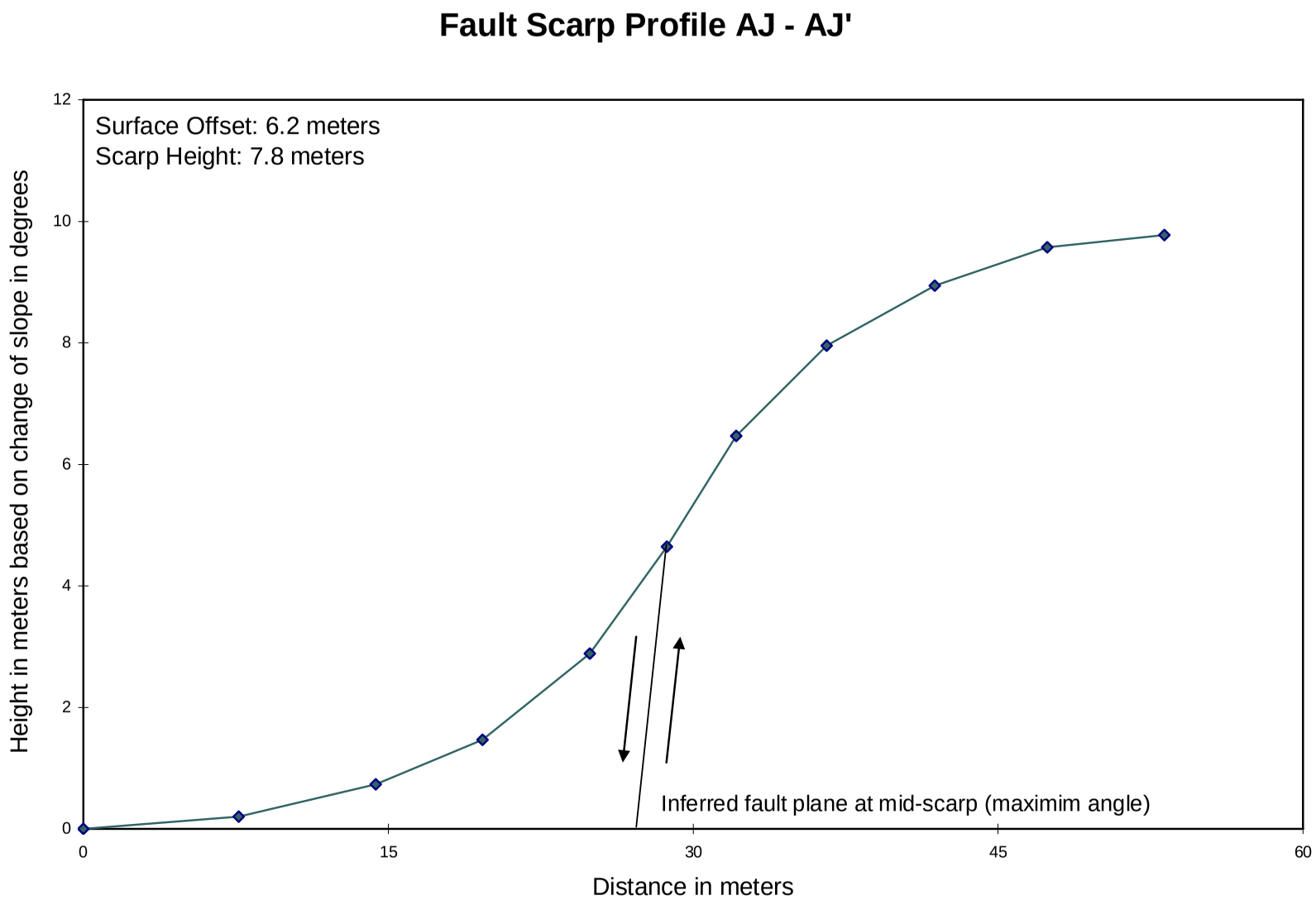
Station number	Slope in degrees	Distance (meters)
0-1	+1.5	7.65
1-2	+4.5	6.76
2-3	+8.0	5.30
3-4	+15.0	5.46
4-5	+25.0	4.18
5-6	+28.0	3.87
6-7	+18.5	4.70
7-8	+10.5	5.41
8-9	+6.5	5.57
9-10	+2.0	5.75

Figure 55. Fault profile AJ – AJ', starting location: 44°35'56" N, 111°31'37"W; ending location: 44°35'54" N, 111°31'37"W, looking south to southwest.

Profile AJ – AJ' is located approximately 0.37 kilometers to the east of profile AI – AI'. The hanging wall far field toe of the profile starts relatively flat and continues until it reaches the break in slope. As it moves up slope the fault plane is inferred at stations 5

– 6 where the slope is +28.0°. The profile continues until it reaches the top of the slope where it starts to round off and flatten as it continues into the footwall of the profile.

This profile is rated: excellent


Fault Scarp Profile AJ - AJ'
Surface Offset: 6.2 meters
Scarp Height: 7.8 meters
Inferred fault plane at mid-scarp (maximim angle)
Height in meters based on change of slope in degrees
Distance in meters
0
2
4
6
8
10
12
0
15
30
45
60

Profile: AK – AK’

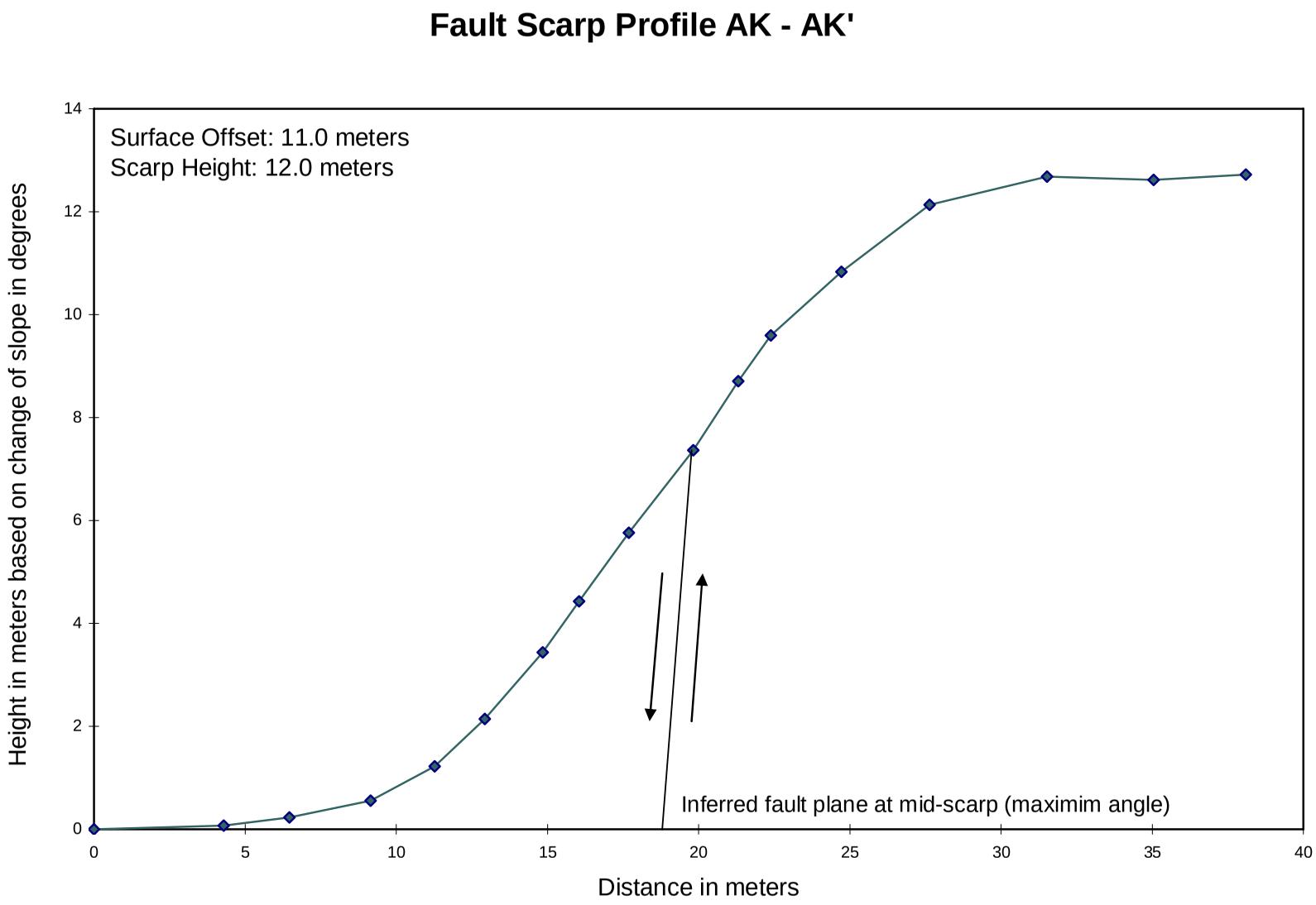
Starting location: 44°34’58” N, 111°31’16”W
Ending location: 44°34’57” N, 111°31’16”W

Station number	Slope in degrees	Distance (meters)
0-1	+1.0	4.29
1-2	+4.0	2.17
2-3	+7.0	2.72
3-4	+17.5	2.21
4-5	+29.0	1.91
5-6	+34.0	2.31
6-7	+39.5	1.56
7-8	+39.0	2.11
8-9	+37.0	2.67
9-10	+42.0	2.01
10-11	+39.5	1.40
11-12	+28.0	2.64
12-13	+24.0	3.20
13-14	+8.0	3.91
14-15	-1.0	3.53
15-16	+2.0	3.05

Figure 56. Fault profile AK – AK', starting location: 44°34'58" N, 111°31'16"W; ending location: 44°34'57" N, 111°31'16"W, looking south.

Profile AK – AK' is located approximately 0.18 kilometers to the east northeast of Cole Creek. This profile offsets the Red Rock Pass glacial moraine. The hanging wall far field toe of the profile starts relatively flat and continues until it reaches the break in slope. As it moves up slope the fault plane is inferred at stations 9 – 10 where the slope is +42.0°. The profile continues until it reaches the top of the slope where it starts to round off and flatten as it continues into the footwall of the profile.

This profile is rated: excellent


Fault Scarp Profile AK - AK'
Surface Offset: 11.0 meters
Scarp Height: 12.0 meters
Inferred fault plane at mid-scarp (maximim angle)
Height in meters based on change of slope in degrees
Distance in meters
0
2
4
6
8
10
12
14
0
5
10
15
20
25
30
35
40

Profile: AL – AL’

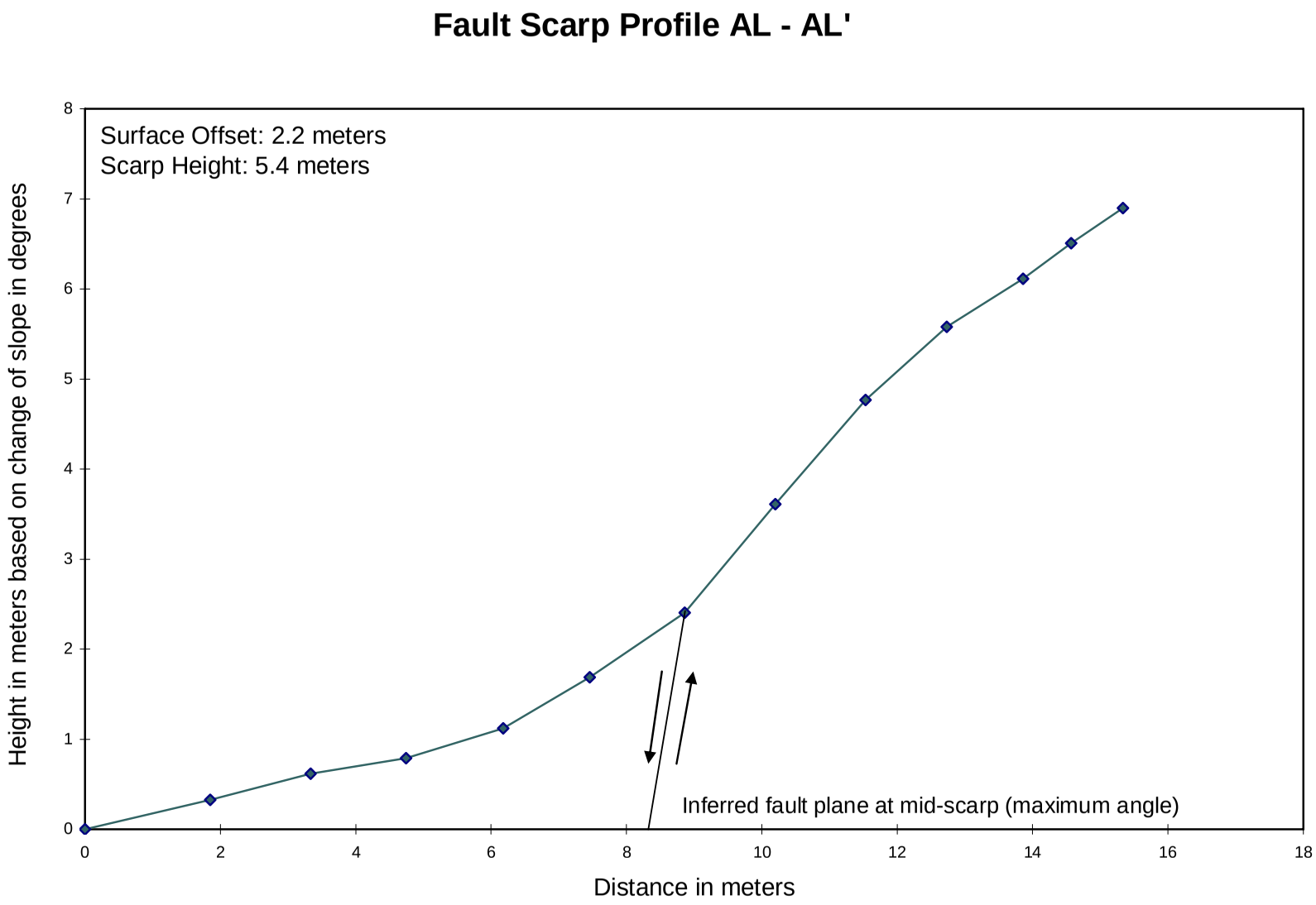
Starting location: 44°35’31” N, 111°26’22”W
Ending location: 44°35’30” N, 111°26’22”W

Station number	Slope in degrees	Distance (meters)
0-1	+10.0	1.88
1-2	+11.0	1.51
2-3	+7.0	1.42
3-4	+13.0	1.47
4-5	+24.0	1.40
5-6	+37.0	1.57
6-7	+42.0	1.80
7-8	+41.0	1.77
8-9	+34.0	1.45
9-10	+25.5	1.24
10-11	+29.0	0.81
11-12	+27.0	0.86

Figure 57. Fault profile AL – AL’, starting location: 44°35’31” N, 111°26’22”W; ending location: 44°35’30” N, 111°26’22”W, looking south to southwest.

Profile AL – AL' is located approximately 0.51 kilometers to the east northeast of Hope Creek. The profile is of offset Rock Creek glacial moraine. The fault scarp has lots of marsh and springs to the east of the location of the profile. The hanging wall far field toe of the profile starts relatively flat and continues until it reaches the break in slope. As it moves up slope the fault plane is inferred at stations 6 – 7 where the slope is +42.0°. The profile continues until it reaches the top of the slope where the topography flattens enough to end the profile. In general the slope continues to rise into the footwall of the profile.

This profile is rated: good


Fault Scarp Profile AL - AL'
Surface Offset: 2.2 meters
Scarp Height: 5.4 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18

Profile: AM – AM’

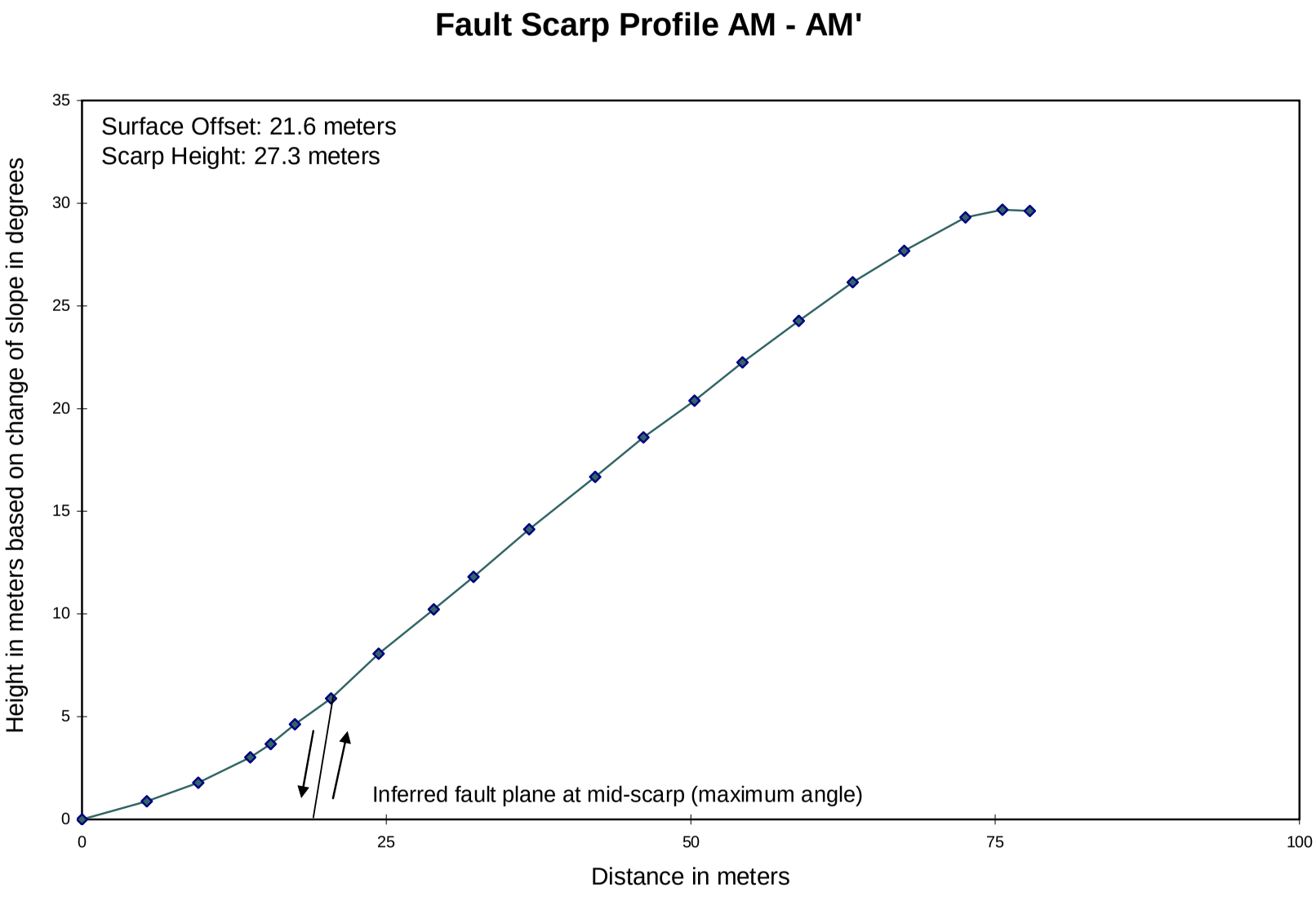
Starting location: 44°35’43” N, 111°24’26”W
Ending location: 44°35’45” N, 111°24’27”W

Station number	Slope in degrees	Distance (meters)
0-1	+9.5	5.40
1-2	+12.0	4.31
2-3	+16.0	4.45
3-4	+21.0	1.81
4-5	+26.0	2.21
5-6	+23.0	3.22
6-7	+29.0	4.47
7-8	+25.5	5.01
8-9	+26.0	3.66
9-10	+27.0	5.10
10-11	+25.0	6.00
11-12	+26.0	4.41
12-13	+23.0	4.55
13-14	+25.5	4.34
14-15	+23.5	5.08
15-16	+23.0	4.79
16-17	+20.0	4.52
17-18	+18.0	5.26
18-19	+7.0	3.07
19-20	-1.5	2.25

Figure 58. Fault profile AM – AM', starting location: 44°35'43" N, 111°24'26"W; ending location: 44°35'45" N, 111°24'27"W, looking south to southwest.

Profile AM – AM' is located approximately 0.16 kilometers from the Jeep Trail of Bootjack Pass. The hanging wall far field toe of the profile starts relatively flat and continues until it reaches the break in slope. As it moves up slope the fault plane is inferred at stations 6 – 7 where the slope is +29.0°. The profile continues until it reaches the top of the slope where it starts to round off and flatten as it continues into the footwall of the profile.

This profile is rated: good


Fault Scarp Profile AM - AM'
Surface Offset: 21.6 meters
Scarp Height: 27.3 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
30
35
0
25
50
75
100

Profile: AN – AN’

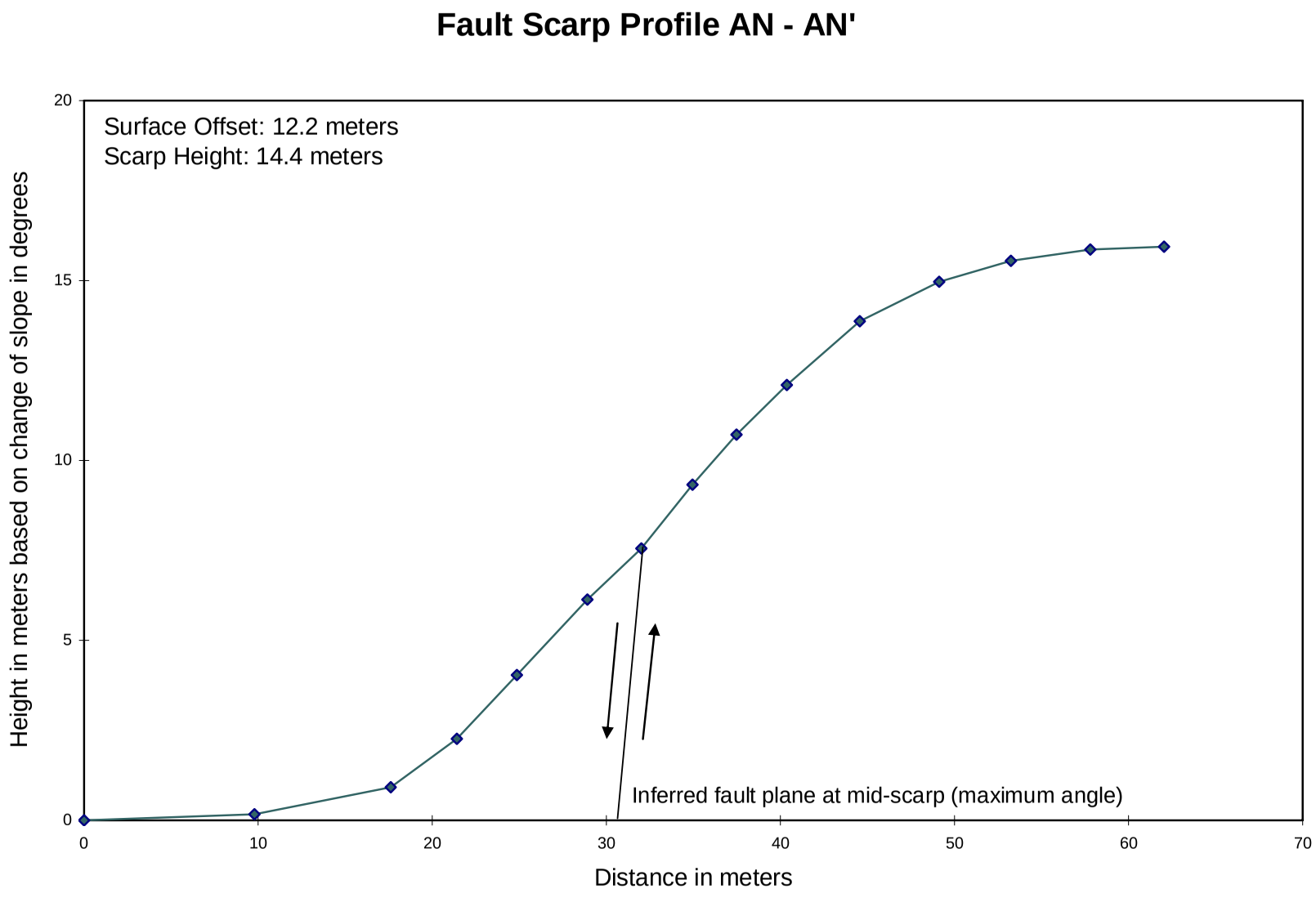
Starting location: 44°35’42” N, 111°24’15”W
Ending location: 44°35’41” N, 111°24’17”W

Station number	Slope in degrees	Distance (meters)
0-1	+1.0	9.79
1-2	+5.5	7.86
2-3	+19.5	4.02
3-4	+27.0	3.89
4-5	+27.5	4.55
5-6	+24.5	3.43
6-7	+31.0	3.43
7-8	+29.0	2.87
8-9	+25.5	3.20
9-10	+23.0	4.55
10-11	+13.5	4.70
11-12	+8.0	4.17
12-13	+4.0	4.55
13-14	+1.0	4.25

Figure 59. Fault profile AN – AN’, starting location: 44°35’42” N, 111°24’15”W; ending location: 44°35’41” N, 111°24’17”W, looking south to southwest.

Profile AN – AN' is located approximately 0.21 kilometers to the east of profile AM – AM'. The hanging wall far field toe of the profile starts relatively flat and continues until it reaches the break in slope. As it moves up slope the fault plane is inferred at stations 6 – 7 where the slope is +31.0°. The profile continues until it reaches the top of the slope where it starts to round off and flatten as it continues into the footwall of the profile.

This profile is rated: excellent


Fault Scarp Profile AN - AN'
Surface Offset: 12.2 meters
Scarp Height: 14.4 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
0
10
20
30
40
50
60
70

Profile: AO – AO’

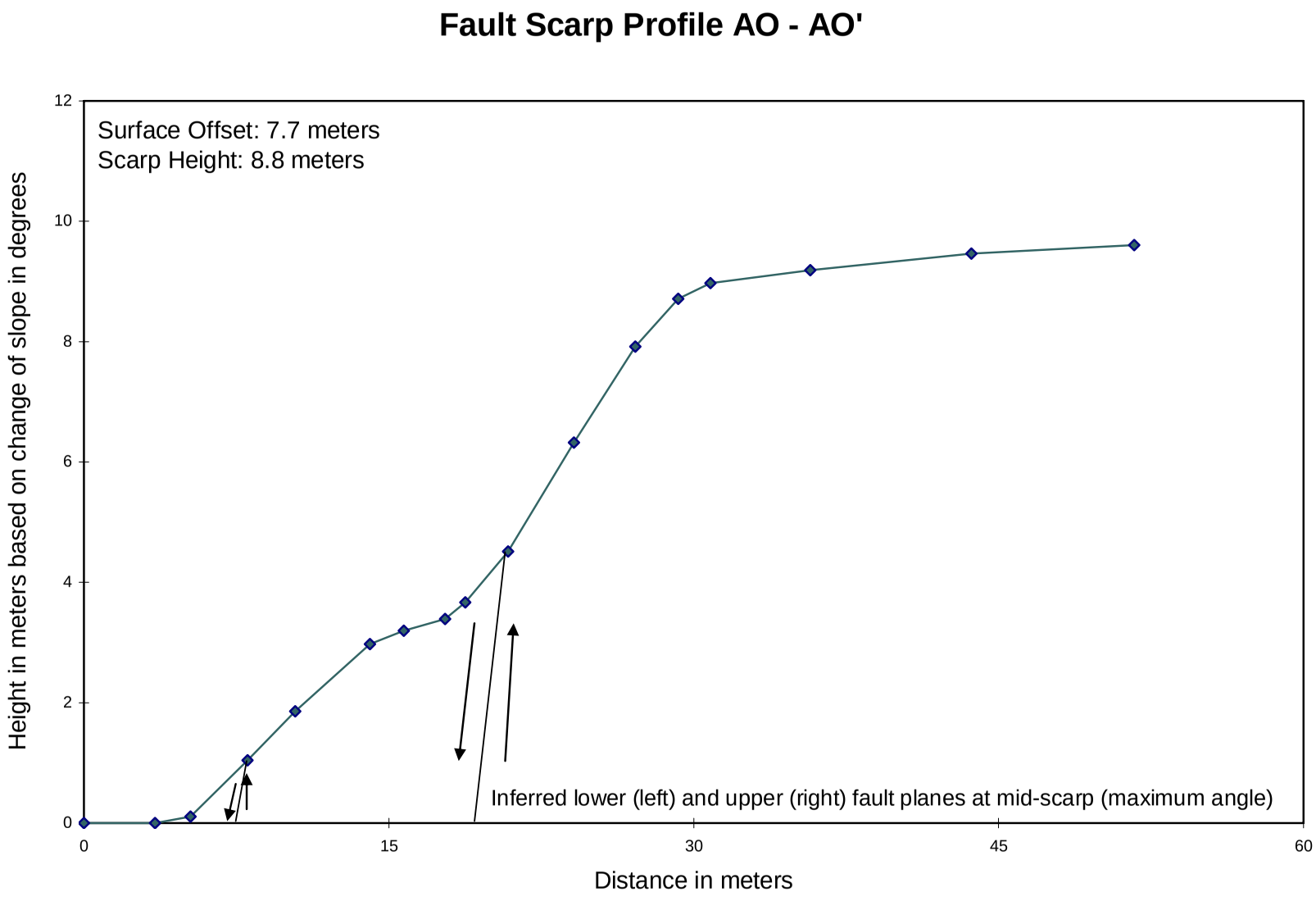
Starting location: 44°37’09” N, 111°21’56”W
Ending location: 44°37’07” N, 111°21’56”W

Station number	Slope in degrees	Distance (meters)
0-1	+0.0	3.49
1-2	+3.5	1.75
2-3	+18.5	2.95
3-4	+19.0	2.49
4-5	+17.0	3.84
5-6	+7.5	1.68
6-7	+5.5	2.04
7-8	+15.5	1.04
8-9	+22.0	2.26
9-10	+29.0	3.72
10-11	+28.0	3.40
11-12	+20.5	2.26
12-13	+9.5	1.60
13-14	+2.5	4.91
14-15	+2.0	7.95
15-16	+1.0	8.00

Figure 60. Fault profile AO – AO', starting location: 44°37'09" N, 111°21'56"W; ending location: 44°37'07" N, 111°21'56"W, looking south.

Profile AO – AO' is located approximately 0.03 kilometers to the north of Henrys Lake State Park Road. The hanging wall far field toe of the profile starts relatively flat and continues until it reaches the break in slope. As it moves up slope the lower fault plane is inferred at stations 3 – 4 where the slope is +19.0°. At the top of the lower fault scarp the topography flattens before the start of the upper fault scarp. The upper fault plane is inferred at stations 9 – 10 where the slope is +29.0°. The profile continues until it reaches the top of the slope where it starts to round off and flatten as it continues into the footwall of the profile.

This profile is rated: excellent


Fault Scarp Profile AO - AO'
Surface Offset: 7.7 meters
Scarp Height: 8.8 meters
Inferred lower (left) and upper (right) fault planes at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
2
4
6
8
10
12
0
15
30
45
60

Profile: AP – AP’

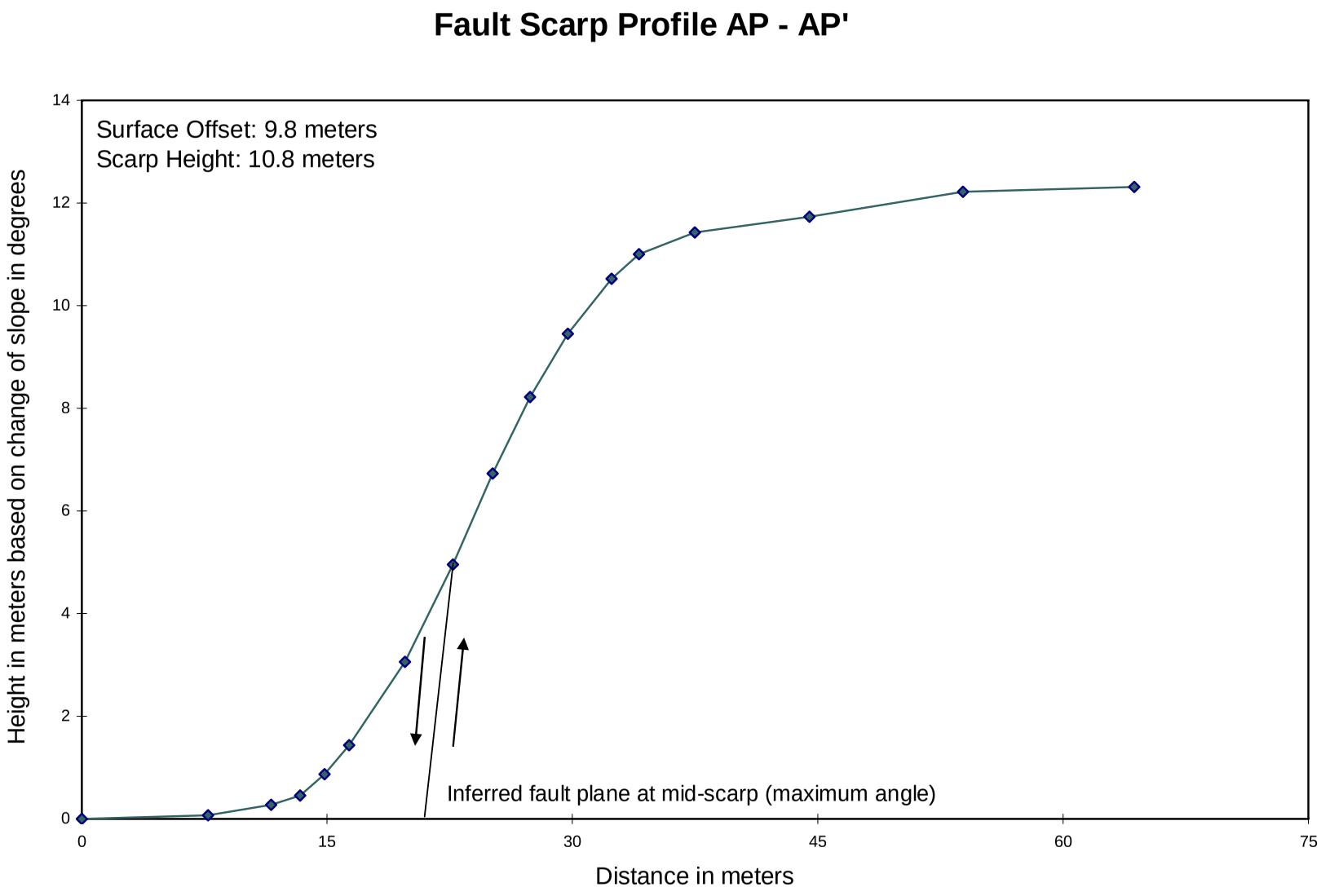
Starting location: 44°37’13” N, 111°21’40”W
Ending location: 44°37’11” N, 111°21’41”W

Station number	Slope in degrees	Distance (meters)
0-1	+0.5	7.71
1-2	+3.0	3.89
2-3	+6.0	1.77
3-4	+15.5	1.56
4-5	+20.5	1.60
5-6	+25.5	3.78
6-7	+33.0	3.48
7-8	+36.0	3.01
8-9	+33.0	2.74
9-10	+28.0	2.62
10-11	+22.0	2.87
11-12	+16.0	1.74
12-13	+7.0	3.45
13-14	+2.5	7.01
14-15	+3.0	9.40
15-16	+0.5	10.46

Figure 61. Fault profile AP – AP', starting location: 44°37'13" N, 111°21'40"W; ending location: 44°37'11" N, 111°21'4124'17"W, looking south.

Profile AP – AP' is located approximately 0.26 kilometers to the north of Henrys Lake State Park Road. The hanging wall far field toe of the profile starts relatively flat and continues until it reaches the break in slope. As it moves up slope the fault plane is inferred at stations 7 – 8 where the slope is +36.0°. The profile continues until it reaches the top of the slope where it starts to round off and flatten as it continues into the footwall of the profile.

This profile is rated: excellent


Fault Scarp Profile AP - AP'
Surface Offset: 9.8 meters
Scarp Height: 10.8 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
2
4
6
8
10
12
14
0
15
30
45
60
75

Profile: AQ – AQ'

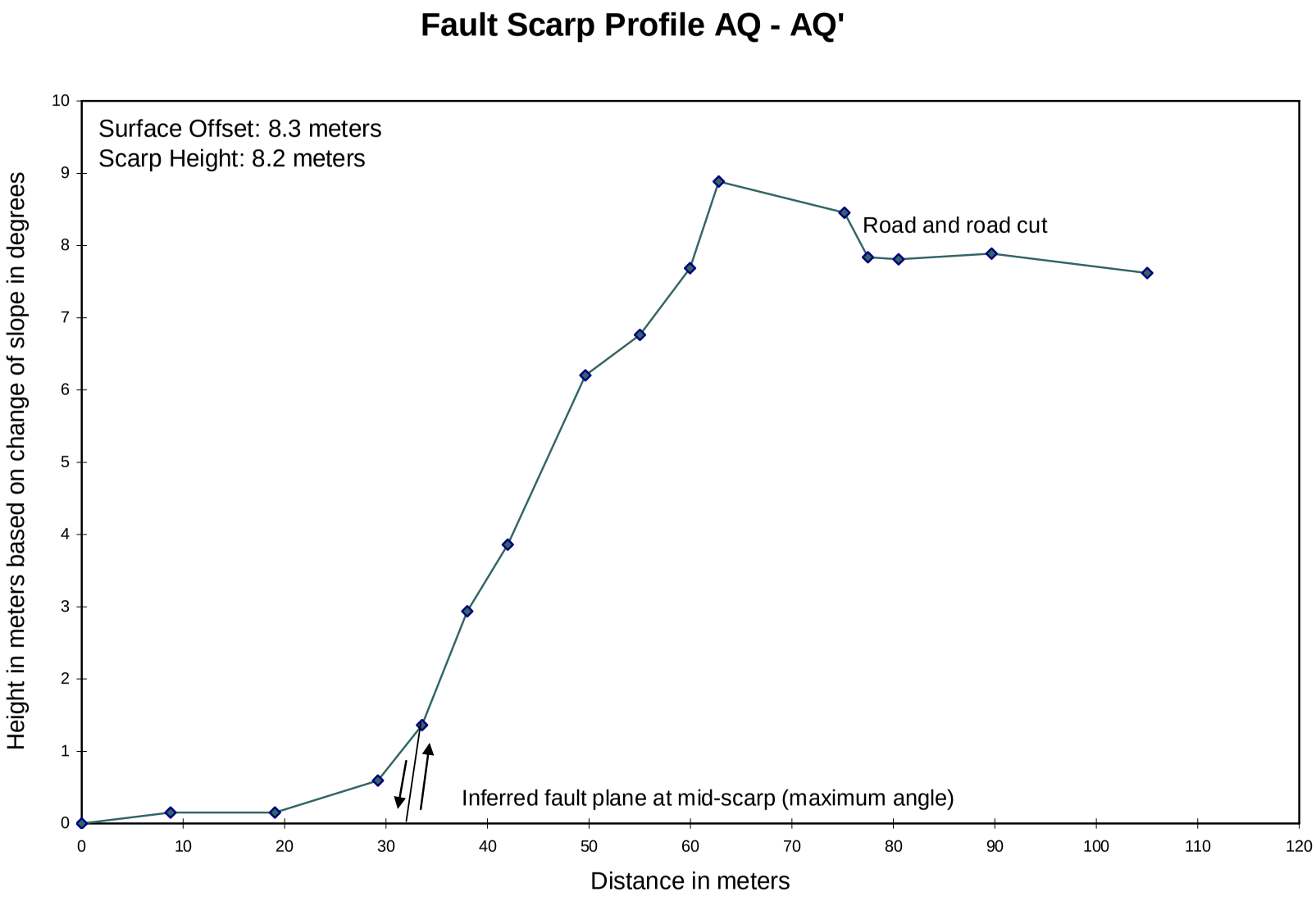
Starting location: 44°37'07" N, 111°21'26"W
Ending location: 44°37'04" N, 111°21'25"W

Station number	Slope in degrees	Distance (meters)	
0-1	+1.0	8.78	
1-2	+0.0	10.27	
2-3	+2.5	10.17	
3-4	+10.0	4.42	
4-5	+19.5	4.71	
5-6	+13.0	4.11	
6-7	+17.0	8.00	
7-8	+6.0	5.38	
8-9	+10.5	5.05	
9-10	+23.0	3.07	road cut
10-11	-2.0	12.37	road
11-12	-15.0	2.39	road cut
12-13	-0.5	3.05	
13-14	+0.5	9.17	
14-15	-1.0	15.34	

Figure 62. Fault profile AQ – AQ', starting location: 44°37'07" N, 111°21'26"W; ending location: 44°37'04" N, 111°21'25"W, looking south.

Profile AQ – AQ' is located approximately 0.08 kilometers to the north of Henrys Lake State Park Road and approximately 0.40 kilometers to the southwest of the start of profile AP – AP'. The hanging wall far field toe of the profile starts relatively flat and continues until it reaches the break in slope. As it moves up slope the fault plane is inferred at stations 4 – 5 where the slope is +19.5°. The profile continues until it reaches the top of the slope where it encounters the road and road cut. At this location there is a negative change in slope. After the profile crosses the road cut it starts to round off and flatten as it continues into the footwall of the profile.

This profile is rated: fair


Fault Scarp Profile AQ - AQ'
Surface Offset: 8.3 meters
Scarp Height: 8.2 meters
Road and road cut
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50
60
70
80
90
100
110
120

Profile: AR – AR’

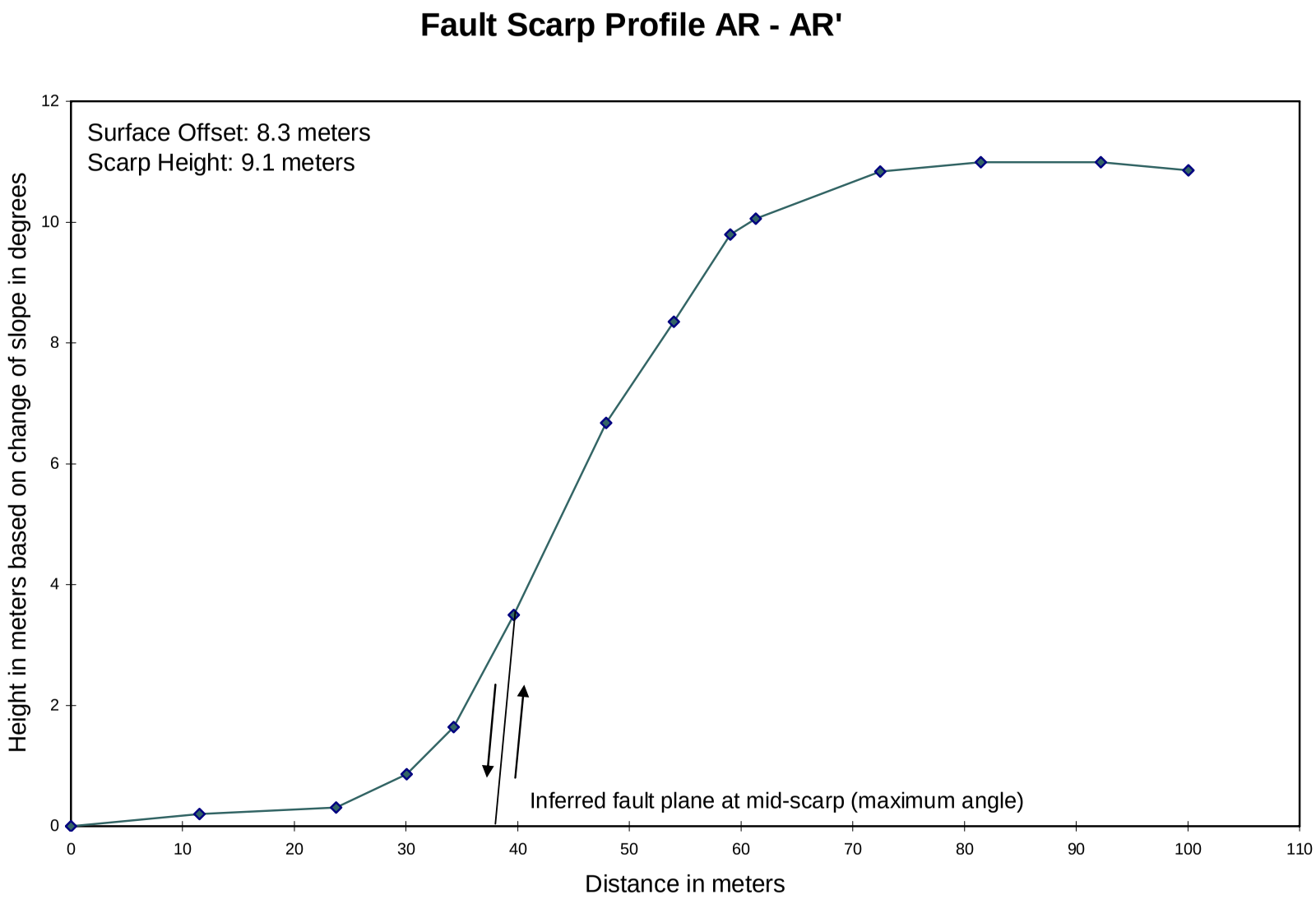
Starting location: 44°37’09” N, 111°21’22”W
Ending location: 44°37’06” N, 111°21’22”W

Station number	Slope in degrees	Distance (meters)
0-1	+1.0	11.51
1-2	+0.5	12.24
2-3	+5.0	6.34
3-4	+10.5	4.28
4-5	+19.0	5.70
5-6	+21.0	8.86
6-7	+15.5	6.27
7-8	+16.0	5.25
8-9	+6.5	2.29
9-10	+4.0	11.18
10-11	+1.0	9.02
11-12	+0.0	10.74
12-13	-1.0	7.85

Figure 63. Fault profile AR – AR’, starting location: 44°37’09” N, 111°21’22”W; ending location: 44°37’06” N, 111°21’22’17”W, looking south.

Profile AR – AR' is located approximately 0.11 kilometers to the north of Henrys Lake State Park Road. The hanging wall far field toe of the profile starts relatively flat and continues until it reaches the break in slope. As it moves up slope the fault plane is inferred at stations 5 – 6 where the slope is +21.0°. The profile continues until it reaches the top of the slope where it starts to round off and flatten as it continues into the footwall of the profile.

This profile is rated: excellent


Fault Scarp Profile AR - AR'
Surface Offset: 8.3 meters
Scarp Height: 9.1 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
2
4
6
8
10
12
0
10
20
30
40
50
60
70
80
90
100
110

Profile: AS – AS’

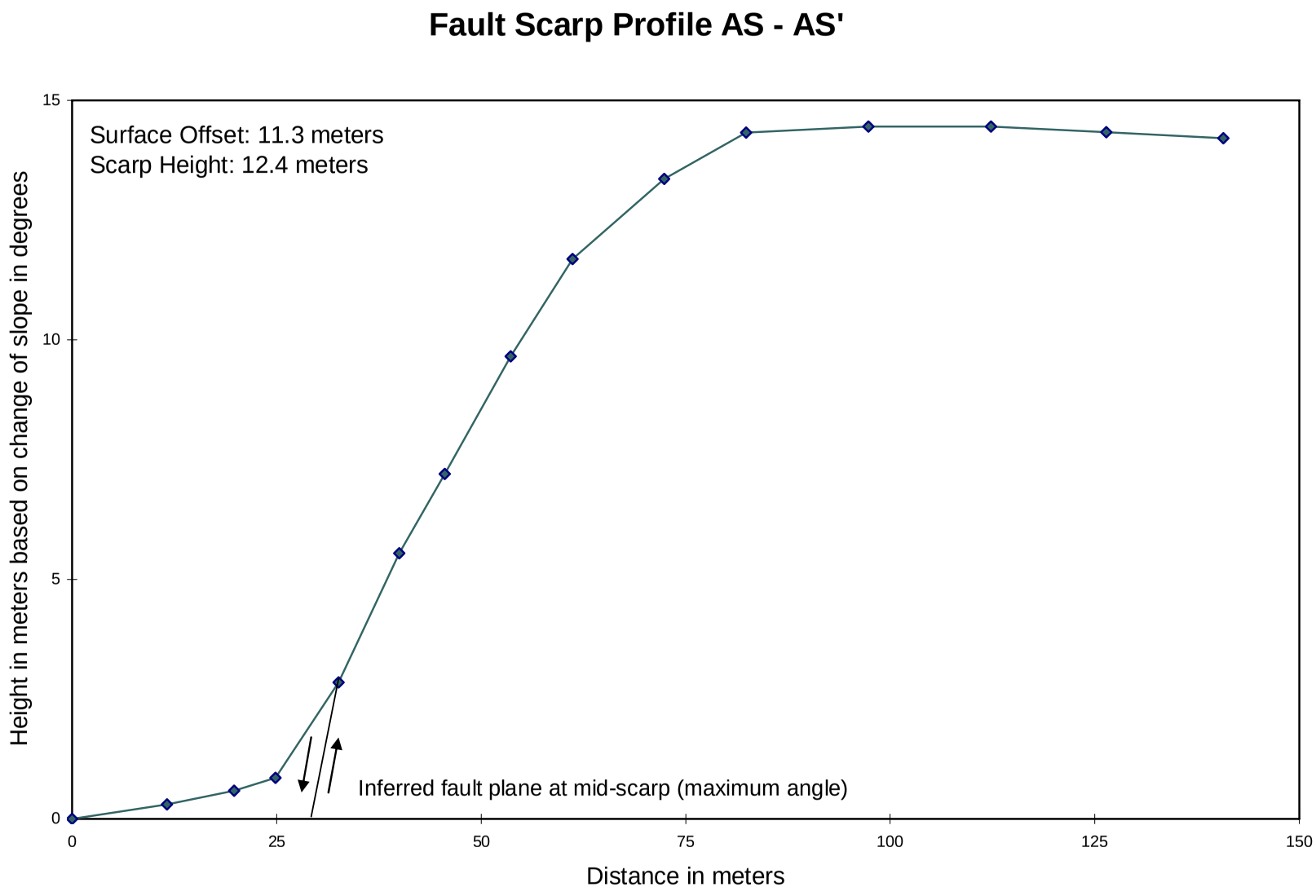
Starting location: 44°37’10” N, 111°21’17”W
Ending location: 44°37’07” N, 111°21’16”W

Station number	Slope in degrees	Distance (meters)
0-1	+1.5	11.61
1-2	+2.0	8.18
2-3	+3.0	5.09
3-4	+14.5	7.95
4-5	+20.0	7.90
5-6	+16.5	5.81
6-7	+17.0	8.39
7-8	+15.0	7.87
8-9	+8.5	11.30
9-10	+5.5	10.06
10-11	+0.5	14.94
11-12	+0.0	15.01
12-13	-0.5	14.10
13-14	-0.5	14.27

Figure 64. Fault profile AS – AS’, starting location: 44°37’10” N, 111°21’17”W; ending location: 44°37’07” N, 111°21’16”W, looking south.

Profile AS – AS' is located approximately 0.13 kilometers to the north of Henrys Lake State Park Road. The hanging wall far field toe of the profile starts relatively flat and continues until it reaches the break in slope. As it moves up slope the fault plane is inferred at stations 4 – 5 where the slope is +20.0°. The profile continues until it reaches the top of the slope where it starts to round off and flatten as it continues into the footwall of the profile.

This profile is rated: excellent


Fault Scarp Profile AS - AS'
Surface Offset: 11.3 meters
Scarp Height: 12.4 meters
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
0
25
50
75
100
125
150

Profile: AT – AT’

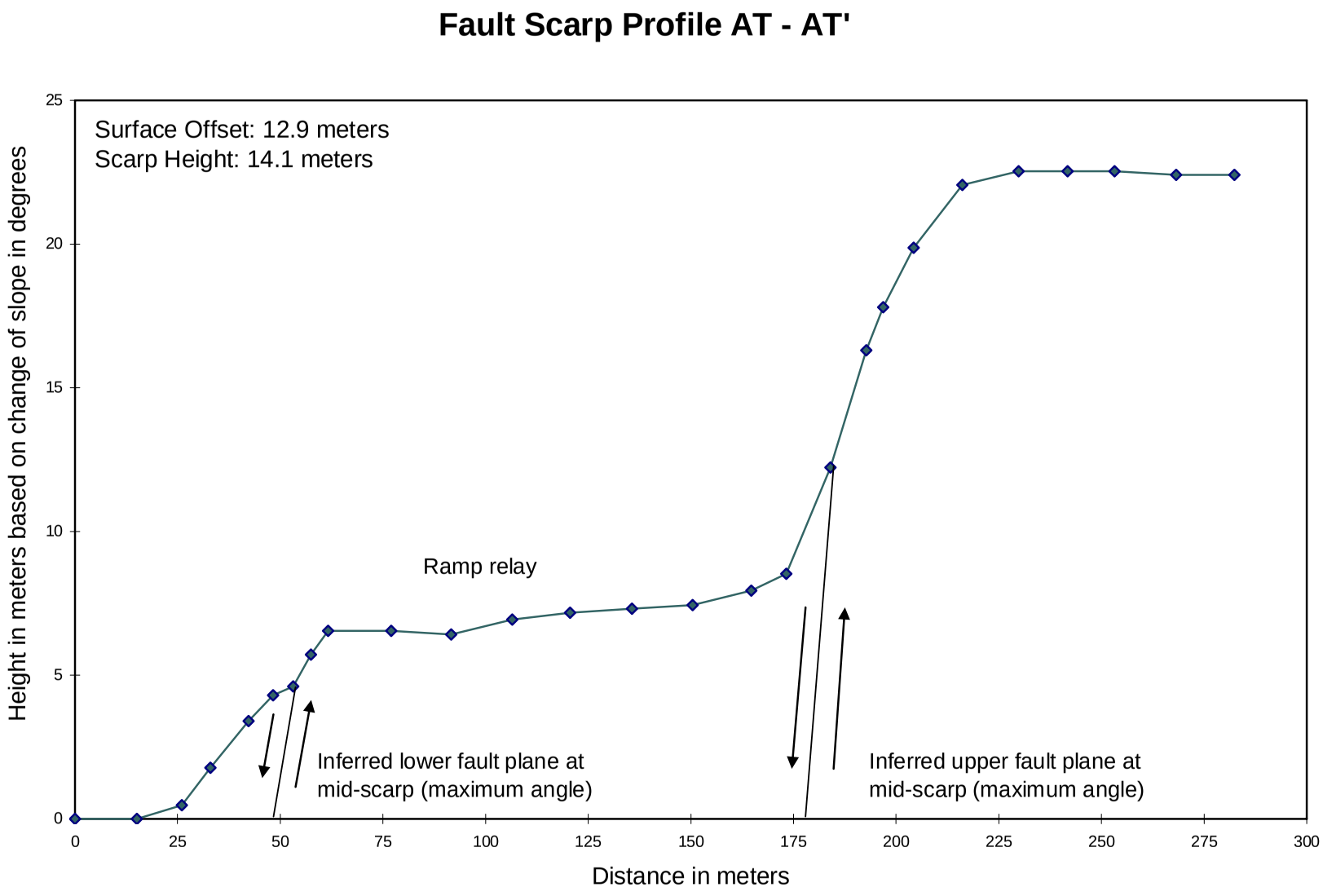
Starting location: 44°37’16” N, 111°21’16”W
Ending location: 44°37’08” N, 111°21’14”W

Station number	Slope in degrees	Distance (meters)
0-1	+0.0	15.06
1-2	+2.5	10.95
2-3	+10.5	7.14
3-4	+10.0	9.40
4-5	+8.5	6.05
5-6	+3.5	4.95
6-7	+14.5	4.42
7-8	+11.0	4.32
8-9	+0.0	15.32
9-10	-0.5	14.55
10-11	+2.0	14.94
11-12	+1.0	14.07
12-13	+0.5	15.11
13-14	+0.5	14.76
14-15	+2.0	14.30
15-16	+4.0	8.53
16-17	+19.0	11.35
17-18	+25.0	9.63
18-19	+20.0	4.39
19-20	+15.5	7.75
20-21	+10.5	11.99
21-22	+2.0	13.72
22-23	+0.0	11.99
23-24	+0.0	11.43
24-25	-0.5	14.97
25-26	+0.0	14.17

Figure 65. Fault profile AT – AT', starting location: 44°37'16" N, 111°21'16"W; ending location: 44°37'08" N, 111°21'14"W, looking south.

Profile AT – AT' is located approximately 0.32 kilometers to the north of Henrys Lake State Park Road. The hanging wall far field toe of the profile starts relatively flat and continues until it reaches the break in slope. As it moves up slope the lower fault plane is inferred at stations 6 – 7 where the slope is +14.5°. At the top of the lower fault scarp the topography flattens as it crosses the ramp relay before the start of the upper fault scarp. The upper fault plane is inferred at stations 17 – 18 where the slope is +25.0°. The profile continues until it reaches the top of the slope where it starts to round off and flatten as it continues into the footwall of the profile.

This profile is rated: good


Fault Scarp Profile AT - AT'
Surface Offset: 12.9 meters
Scarp Height: 14.1 meters
Ramp relay
Inferred lower fault plane at
mid-scarp (maximum angle)
Inferred upper fault plane at
mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
0
5
10
15
20
25
0
25
50
75
100
125
150
175
200
225
250
275
300

Profile: AU – AU’

Starting location: 44°37’22” N, 111°21’03”W
Ending location: 44°37’12” N, 111°20’56”W

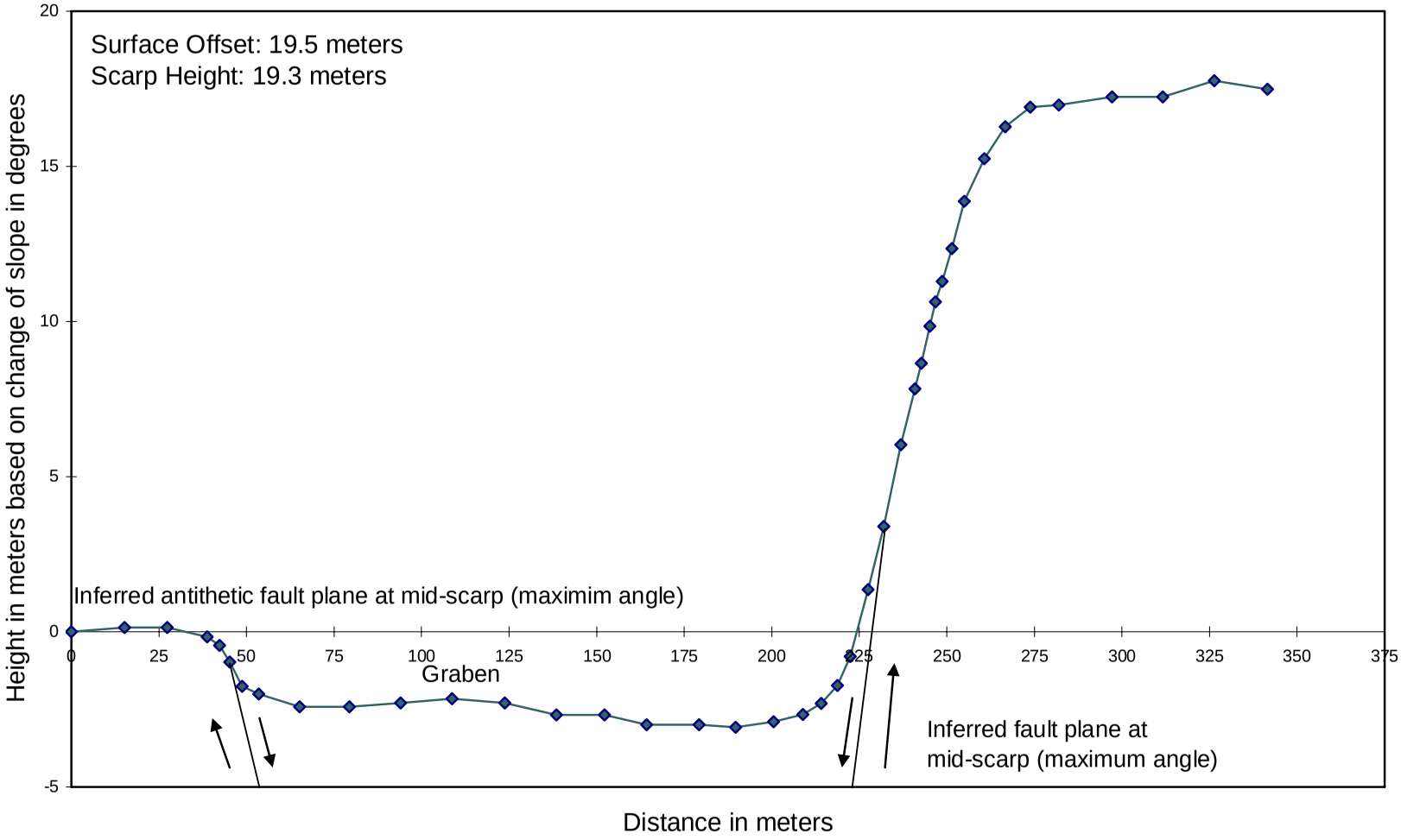
Station number	Slope in degrees	Distance (meters)
0-1	+0.5	15.20
1-2	+0.0	12.14
2-3	-1.5	11.48
3-4	-4.5	3.54
4-5	-10.5	2.93
5-6	-12.5	3.61
6-7	-3.0	4.79
7-8	-2.0	11.62
8-9	+0.0	14.26
9-10	+0.5	14.61
10-11	+0.5	14.73
11-12	-0.5	15.04
12-13	-1.5	14.67
13-14	+0.0	13.78
14-15	-1.5	12.04
15-16	+0.0	15.01
16-17	-0.5	10.36
17-18	+1.0	10.85
18-19	+1.5	8.45
19-20	+4.0	5.19
20-21	+7.0	4.72
21-22	+14.5	3.72
22-23	+23.0	5.55
23-24	+24.5	4.89
24-25	+28.0	5.61
25-26	+24.5	4.33
26-27	+23.5	2.07
27-28	+27.0	2.64
28-29	+25.5	1.80
29-30	+19.5	2.01
30-31	+20.5	3.00
31-32	+23.0	3.90
32-33	+13.5	5.89
33-34	+10.0	5.94
34-35	+5.0	7.21
35-36	+0.5	8.20
36-37	+1.0	15.14
37-38	+0.0	14.49
38-39	+2.0	14.72
39-40	-1.0	15.29

Figure 66. Fault profile AU – AU', starting location: 44°37'22" N, 111°21'03"W; ending location: 44°37'12" N, 111°20'56"W, looking south southwest.

Profile AU – AU' is located approximately 0.53 kilometers to the north of Henrys Lake State Park Road. The hanging wall far field toe of the profile starts relatively flat and then decreases in slope as the profile moves south. This decrease in slope is represented by an antithetic fault plane inferred at stations 5 – 6 where the slope is -12.5°. The profile continues through the graben until it starts to increase in slope again. The fault plane on the main fault is inferred at stations 24 – 25 where the slope is +28.0°. The fault scarp rounds at the top and then flattens as one moves south into the footwall of the profile.

This profile is rated: excellent

Fault Scarp Profile AU - AU'



Profile: AV – AV’

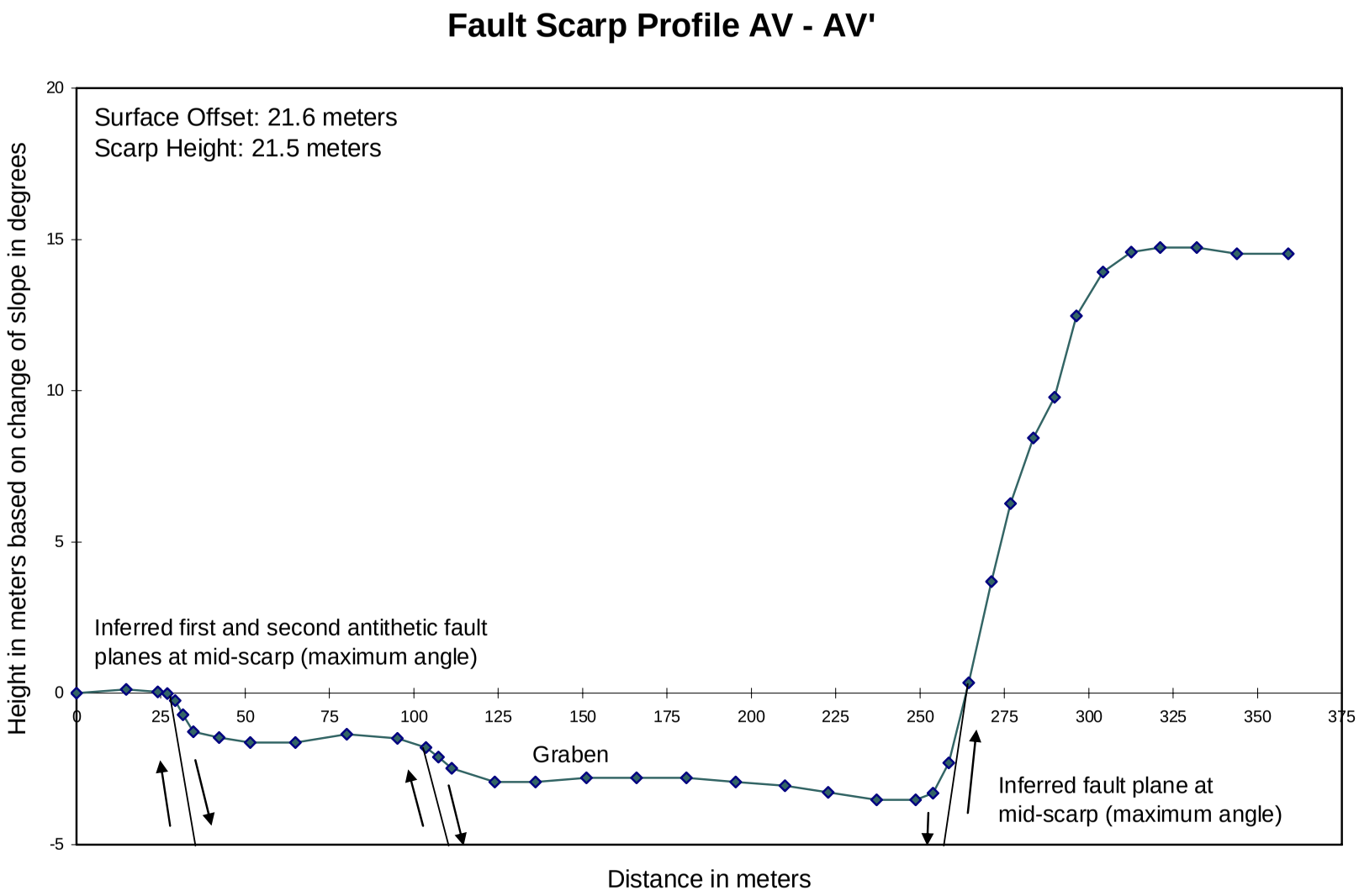
Starting location: 44°37’27” N, 111°20’54”W
Ending location: 44°37’18” N, 111°20’45”W

Station number	Slope in degrees	Distance (meters)
0-1	+0.5	14.77
1-2	-0.5	9.33
2-3	-1.0	2.82
3-4	-6.0	2.29
4-5	-11.0	2.41
5-6	-10.5	3.09
6-7	-1.5	7.62
7-8	-1.0	9.21
8-9	+0.0	13.46
9-10	+1.0	15.20
10-11	-0.5	15.04
11-12	-2.0	8.51
12-13	-5.0	3.62
13-14	-5.5	3.96
14-15	-2.0	12.81
15-16	+0.0	12.04
16-17	+0.5	15.10
17-18	+0.0	14.87
18-19	+0.0	14.77
19-20	-0.5	14.54
20-21	-0.5	14.73
21-22	-1.0	12.69
22-23	-1.0	14.38
23-24	+0.0	11.62
24-25	+2.5	5.14
25-26	+12.0	4.79
26-27	+24.5	6.40
27-28	+26.0	7.62
28-29	+24.5	6.24
29-30	+18.0	6.99
30-31	+12.0	6.49
31-32	+22.5	7.01
32-33	+10.5	7.99
33-34	+4.5	8.38
34-35	+1.0	8.62
35-36	+0.0	10.86
36-37	-1.0	11.89
37-38	+0.0	15.24

Figure 67. Fault profile AV – AV', starting location: 44°37'27" N, 111°20'54"W; ending location: 44°37'18" N, 111°20'45"W, looking south southwest.

Profile AV – AV' is located approximately 0.64 kilometers to the north of Henrys Lake State Park Road. The hanging wall far field toe of the profile starts relatively flat and then decreases in slope as the profile moves south. This decrease in slope is represented by the first antithetic fault plane inferred at stations 4 – 5 where the slope is -11.0°. The profile continues to decrease in slope where the second antithetic fault plane is inferred at stations 12 – 13 where the slope is -5.0°. The profile continues through the graben until it starts to increase in slope again. The fault plane on the main fault is inferred at stations 27 – 28 where the slope is +26.0°. The fault scarp rounds at the top and then flattens as one moves south into the footwall of the profile.

This profile is rated: excellent


Fault Scarp Profile AV - AV'
Surface Offset: 21.6 meters
Scarp Height: 21.5 meters
Inferred first and second antithetic fault planes at mid-scarp (maximum angle)
Graben
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
20
15
10
5
0
-5
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375

Profile: AW – AW

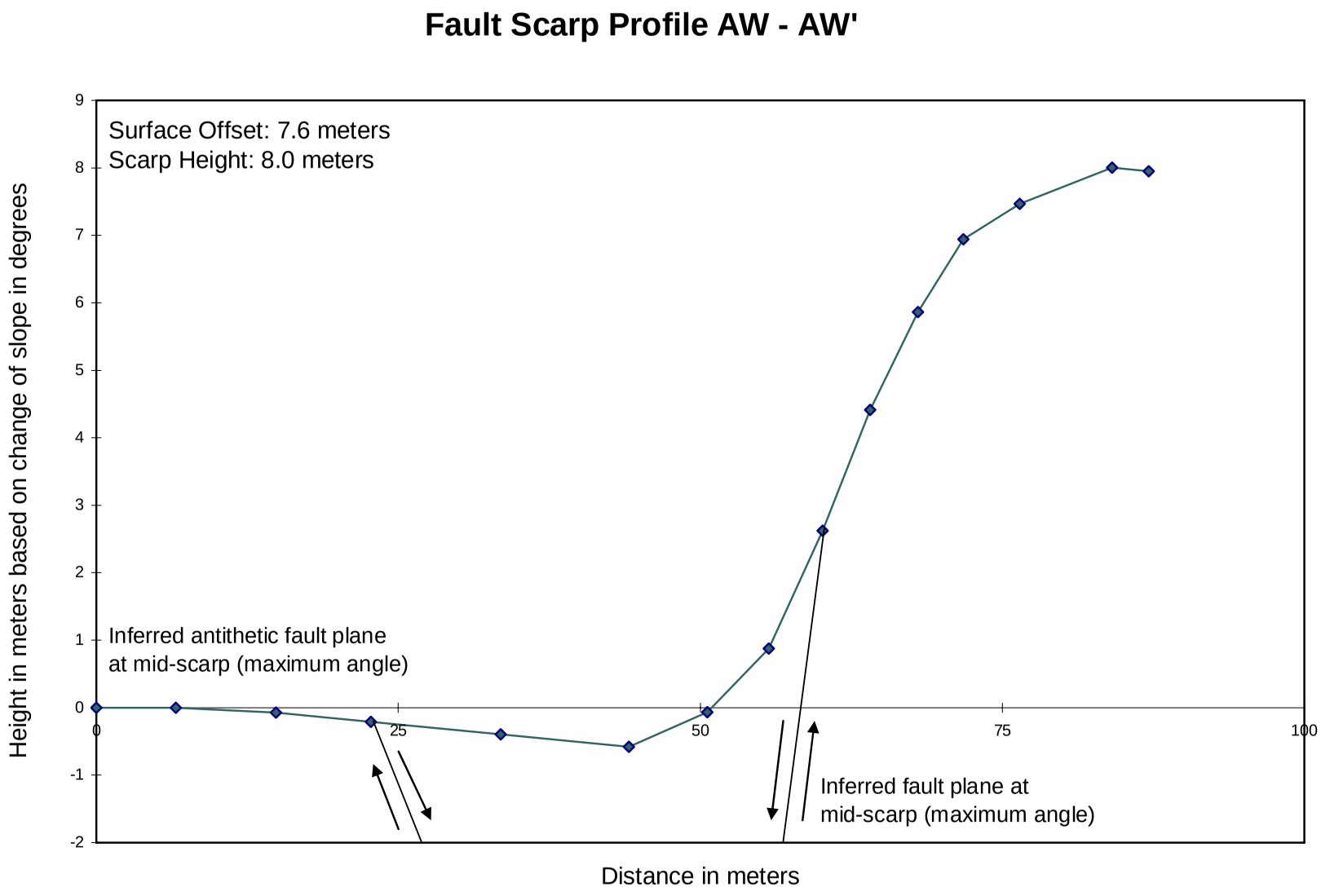
Starting location: 44°37’32” N, 111°20’26”W
Ending location: 44°37’29” N, 111°20’25”W

Station number	Slope in degrees	Distance (meters)
0-1	+0.0	6.58
1-2	-0.5	8.28
2-3	-1.0	7.86
3-4	-1.0	10.74
4-5	-1.0	10.62
5-6	+4.5	6.53
6-7	+10.5	5.18
7-8	+21.5	4.78
8-9	+24.5	4.32
9-10	+20.0	4.23
10-11	+16.0	3.91
11-12	+6.5	4.67
12-13	+4.0	7.70
13-14	-1.0	3.01

Figure 68. Fault profile AW – AW’, starting location: 44°37’32” N, 111°20’26”W; ending location: 44°37’29” N, 111°20’25”W, looking south southwest.

Profile AW – AW' is located approximately 0.80 kilometers to the north of Henrys Lake State Park Road. The hanging wall far field toe of the profile starts relatively flat and then decreases in slope as the profile moves south. This decrease in slope is represented by an antithetic fault plane inferred at stations 3 – 4 where the slope is -1.0°. The profile continues through the graben until it starts to increase in slope again. The fault plane on the main fault is inferred at stations 8 – 9 where the slope is +24.5°. The fault scarp rounds at the top and then flattens as one moves south into the footwall of the profile.

This profile is rated: excellent


Fault Scarp Profile AW - AW'
Surface Offset: 7.6 meters
Scarp Height: 8.0 meters
Inferred antithetic fault plane
at mid-scarp (maximum angle)
Inferred fault plane at
mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
9
8
7
6
5
4
3
2
1
0
-1
-2
0
25
50
75
100

Profile: AX – AX'

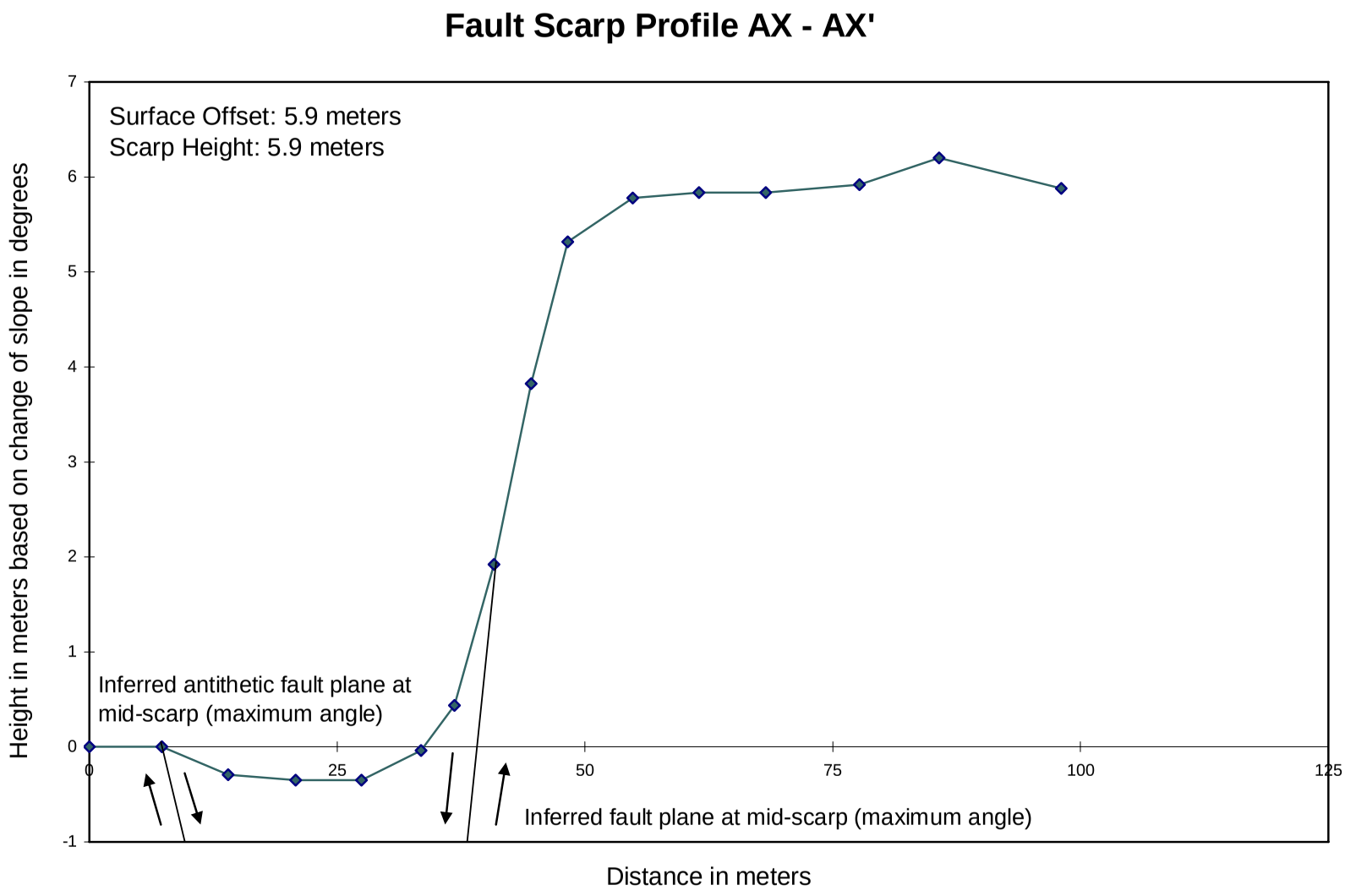
Starting location: 44°37'40" N, 111°20'25"W
Ending location: 44°37'38" N, 111°20'25"W

Station number	Slope in degrees	Distance (meters)
0-1	+0.0	7.32
1-2	-2.5	6.71
2-3	-0.5	6.78
3-4	+0.0	6.67
4-5	+3.0	6.02
5-6	+8.0	3.40
6-7	+20.5	4.24
7-8	+27.0	4.19
8-9	+22.0	3.99
9-10	+4.0	6.58
10-11	+0.5	6.71
11-12	+0.0	6.71
12-13	+0.5	9.47
13-14	+2.0	8.05
14-15	-1.5	12.29

Figure 69. Fault profile AX – AX', starting location: 44°37'40" N, 111°20'25"W; ending location: 44°37'38" N, 111°20'25"W, looking south.

Profile AX – AX' is located approximately 0.80 kilometers to the north of Henrys Lake State Park Road. The hanging wall far field toe of the profile starts relatively flat and then decreases in slope as the profile moves south. This decrease in slope is represented by an antithetic fault plane inferred at stations 1 – 2 where the slope is -2.5°. The profile continues through the graben until it starts to increase in slope again. The fault plane on the main fault is inferred at stations 7 – 8 where the slope is +27.0°. The fault scarp rounds at the top and then flattens as one moves south into the footwall of the profile.

This profile is rated: good


Fault Scarp Profile AX - AX'
Surface Offset: 5.9 meters
Scarp Height: 5.9 meters
Inferred antithetic fault plane at mid-scarp (maximum angle)
Inferred fault plane at mid-scarp (maximum angle)
Height in meters based on change of slope in degrees
Distance in meters
7
6
5
4
3
2
1
0
-1
0
25
50
75
100
125

APPENDIX B:

THE CENTENNIAL MOUNTAINS MAP UNIT DESCRIPTIONS

Qal **Alluvium and fluvial channel deposits (Holocene to present)** – Unconsolidated fluvial deposits of sand, silt, clay, and pebble to cobble gravel in narrow stream channels and on broad alluvial slopes at base of low hills and mountain fronts. Locally includes thin colluvial deposits. Generally less than 5 m thick (Witkind, 1975b; O'Neill and Christiansen, 2004).

Qss **Scarp slump (Holocene)** – Lobate sometimes hummocky deposit of unconsolidated to semi-consolidated unsorted debris from the scarp that lies higher topographically; usually contains the material that offset by the scarp.

Qssf **Scarp slump/fan (Holocene)** – Fan shape deposit of unconsolidated to semi-consolidated unsorted debris from the scarp that lies higher topographically; usually contains the material that offset by the scarp.

Qls **Earthflow and landslide deposits (Holocene)** – Coarse, unsorted and unstratified deposits of locally derived, angular pebbles, cobbles, and boulders associated with fine-grained matrix of silt and sand that have been moved down slope by gravity. Topography is characterized by irregular hummocky deposits of unconsolidated to semi-consolidated debris (Witkind, 1975b; Lonn et al., 2000; O'Neill and Christiansen, 2004).

Qe **Eolian deposits (Holocene)** – Translucent tan to brown, well-sorted, moderately frosted quartz sand grains; forms sand dune field in northern Centennial Valley. Maximum thickness (dune height) about 10 m (O'Neill and Christiansen, 2004).

Qc **Colluvium (Holocene and Pleistocene)** – Unconsolidated deposits of silt, sand, and angular pebbles and cobbles formed by mass movement down slope. Rubble chiefly at base of steep slopes; includes talus and slope wash. Thickness generally less than 2 m (Witkind, 1975b; Lonn et al., 2000; O'Neill and Christiansen, 2004).

Qf **Alluvial Fan, undivided (Holocene)** – Poorly to moderately sorted deposits of locally-derived, sub-angular to sub-rounded, silt- to boulder-sized clasts deposited in debris flow and fluvial environments as alluvial fans along valley margins, in tributary valleys, and around hills and mountains (Lonn et al., 2000; O'Neill and Christiansen, 2004).

Qaf1 **Young alluvial fan (Holocene)** – Active, small to large alluvial fans along valley margins. West of 112° 00': chiefly small steep cone-shaped deposits of silt and fine sand that partly bury scarp; formed where small north-flowing streams empty onto the broad lowland and deposit their sediment load downstream from or across the scarp. East of 112° 00': chiefly broad lobate deposits of unconsolidated moderately well-sorted silt, sand, gravel, and cobbles; formed at mouths of high-gradient streams debouching from nearby mountains. Maximum thickness unknown (Witkind, 1975b; O'Neill and

Christiansen, 2004).

Qcfy **Young coalesced alluvial fan (Holocene)** – Low lobate deposit resulting from the coalescence of several young alluvial fans; composed mostly of fine sand and silt (Witkind, 1975b).

Qaf2 **Old alluvial fan (Holocene to Pleistocene)** – Inactive, generally large alluvial fans with broad conical deposit of low slope composed of fluvial silt, sand, gravel, cobbles, and boulders; coarser material near apex of fan grades into finer grained materials, such as silt and sand, near distal edges of fan. Fans are weakly dissected and locally cut by Holocene fault scarps. Maximum thickness unknown (Witkind, 1975b; O'Neill and Christiansen, 2004).

Qta **Talus deposits (Holocene)** – Unsorted, unstratified angular clasts and slabs as much as 2 m across that accumulate at base of cliffs and very steep slopes (O'Neill and Christiansen, 2004).

Qbo **Boulder field (Holocene)** – Unsorted accumulation of angular bounders on steep slopes (O'Neill and Christiansen, 2004).

Qat **Alluvium of alluvial terrace deposits, undivided (Holocene)** – Pebble- to boulder-size gravel and sand on low terraces adjacent to major streams. Maximum exposed thickness about 5 m (O'Neill and Christiansen, 2004).

Qlk **Lacustrine deposits (Holocene to Pleistocene)** – Light-brown to brown, well-sorted, unconsolidated sand, silt, and clay veneer on undissected surfaces underlain mainly by basin fill deposits. Marked, in part, by multiple strand lines that outline limit of dwindling glacial lake. Thickness unknown, probably less than 2 m (O'Neill and Christiansen, 2004).

Qle **Lake deposits and overlying eolian deposits (Holocene and Pleistocene?)** – Active sand dunes in the Centennial Basin; carried by prevailing winds from the southwest. Dunes are underlain by lake deposits of pale yellowish-brown to light brown, unconsolidated sand, silt, and clay that locally contain small pebbles about 3mm in diameter (Lonn et al., 2000).

Qgr **Gravel deposit (Holocene and Pleistocene)** – Unconsolidated to poorly consolidated sand, gravel, and cobbles that form low mounds or cap small hills; origin uncertain, but may represent remnants of a former continuous alluvial cover (Witkind, 1975b; Lonn et al., 2000).

Qgo **Glacial outwash deposits (Pleistocene)** – Generally poorly sorted, pebble to boulder, layered sand and gravel deposited by glacial melt water (O'Neill and Christiansen, 2004).

Qgt **Glacial till and related deposits (Pleistocene)** – Poorly sorted, unconsolidated deposits of silt, sand, gravel, and boulders in, commonly adjacent to, and locally at mouths of major alpine valleys. Deposits are both Pinedale and Bull Lake in age; cirque moraines and pre-talus ramparts are Holocene in age. Maximum thickness unknown (O'Neill and Christiansen, 2004).

QTgr **Gravel (Holocene through Miocene)** – Unconsolidated to poorly consolidated gravels of uncertain affinity (Lonn et al., 2000).

QTtg **Alluvium , undivided (Pleistocene to Miocene)** – Isolated sand and pebble- to boulder-size gravel deposits at high elevations in the Centennial Range (O'Neill and Christiansen, 2004).

IGNEOUS ROCKS

Qlc **Lava Creek Tuff (Pleistocene)**

Qlcu **Upper member** – Light-gray, locally pale red, fine-grained to aphanitic, densely welded ash-flow tuff; phenocrysts compose as much as 20 percent of rock. Thickness east of map area ranges from 180 to 300 m (O'Neill and Christiansen, 2004).

QTba **Basaltic volcanic rocks (Quaternary and Tertiary)** – Dark gray, fine grained, vesicular; in thin flows overlying boulder gravels in the south part of the Snowcrest Range. May include lavas related to the Tertiary Sage Creek and Blacktail Deer Creek flows, and younger flows contemporaneous with Snake River Plain volcanics 3 to 4 Ma (Lonn et al., 2000).

Thr **Huckleberry Ridge Tuff, undivided (Pliocene)**

Thru **Upper member** – Pinkish-gray, gray, to brown welded tuff containing abundant phenocrysts of sanidine and quartz (25 to 10 percent, respectively); uppermost part is locally nonwelded and light pink on weathered surfaces, and contains noncompacted pumice fragments (O'Neill and Christiansen, 2004).

Thrl **Lower member** – Medium- to dark-gray welded tuff containing sparse (less than 5 percent) phenocrysts; base of unit is a vitrophyre overlain by densely welded tuff that becomes only partly welded at top (O'Neill and Christiansen, 2004).

Tba **Basalt (Pliocene and/or Miocene)** – Extrusive mafic igneous rock. Includes two units, possibly representing two different flows: (1) dark-gray to black dense porphyritic basalt containing large abundant phenocrysts; (2) dark-gray to black dense nonporphyritic fine- and even-grained basalt containing abundant subhedral grains scattered throughout the groundmass. Both units

are medium bedded to thick bedded, locally massive, and moderately jointed (Witkind, 1975b).

Ta **Andesite (Pliocene and/or Miocene)** –

Tr **Rhyolite (Pliocene and/or Miocene)** – Extrusive felsic igneous rock. Light-gray, locally pale-red or purple, dense lithoidal porphyritic rhyolitic ash-flow tuff; contains angular to rounded phenocrysts scattered throughout a fine-grained ground mass; thin to medium bedded, locally platy; moderately jointed (Witkind, 1975b).

Tmv **Mafic volcanic rocks (Miocene to Oligocene)** – Dark-gray to black, dense, fine-grained flow rock; commonly vesicular or columnar jointed; sparse olivine phenocrysts. In Eastern Centennial Mountains, divided into two similar mafic flow sequences separated by rhyolitic flows (Tfv). Upper sequence is sparsely porphyritic basalt to basaltic andesite flows inter-layered with thin, discontinuous beds of mudflow breccia. Lower sequence consists of lava flows and flow breccias of dark-gray to brownish-black basalt, basaltic andesite, and gray, brown, and yellowish brown andesite; mafic flows diminish lowermost in sequence. All rocks are porphyritic; basaltic rocks contain plagioclase and olivine phenocrysts whereas andesite contains sparse to abundant phenocrysts of plagioclase and at least one mafic mineral in a glassy to aphanitic groundmass. Total thickness about 870 m (O'Neill and Christiansen, 2004).

Tfv **Felsic volcanic rocks (Miocene to Oligocene)** – In Eastern Centennial Mountains, consists of two units. Upper sequence is light-gray, yellowish-gray, and brown porphyritic dacite and rhyodacite flows and flow breccias inter-layered with thin, discontinuous beds of mudflow breccia; maximum thickness about 350 m. Lower sequence is light- to brownish-gray mudflow breccia and mudstone containing poorly sorted volcanic rock fragments in an ash-rich matrix; thickness 0 – 60 m (O'Neill and Christiansen, 2004).

Tav **Absaroka Volcanic Supergroup, undivided (Eocene)** – In Eastern Centennial Mountains consists of dark-gray to black, fine-grained to aphanitic pyroxene trachyte porphyry; augite, olivine, and andesine phenocrysts common. Correlative volcanic rocks present in Henry Mountains. Thickness unknown (O'Neill and Christiansen, 2004).

SEDIMENTARY ROCKS

Tgr **Gravel (Miocene)** – Chiefly unconsolidated, locally cemented, rounded to sub-rounded, quartzite boulder gravel (Lonn et al., 2000).

Tsc **Sixmile Creek Formation (Miocene)** – Weakly consolidated, tan to light-orange-brown, laminated, tuffaceous mudstone, siltstone, sandstone, and lithic

pebble conglomerate (O'Neill and Christiansen, 2004).

Kbm **Mondia sandstone (Upper Cretaceous)** – Clean, calcareous quartz sandstone (Wilson, 1970; Ryder and Scholten, 1973).

Kf **Frontier Formation (Upper Cretaceous)** – Interbedded sandstone, siltstone, mudstone, carbonaceous shale and coal seams, and minor limestone. Sandstone is predominantly medium grained, and commonly calcareous. Coarse-grained varieties include subangular lithic sand grains of chert, feldspar, and biotite; locally conglomeratic, containing well-rounded pebbles of quartzite and chert. Sandstone beds generally less than 1 m, but occurs in layered units as much as 7 m thick. Siltstone and mudstone are olive gray to medium to dark gray, bentonitic and porcellanitic. Limestone is thin bedded to nodular, light to medium gray, and micritic (Lonn et al., 2000; O'Neill and Christiansen, 2004).

Kt **Thermopolis Shale (Lower Cretaceous)** – Dark-gray to black, fissle, organic-rich shale overlying light- to dark-brown-weathering, thin- to medium-bedded, fine- to medium-grained sandstone. Thickness ranges from about 50 to 75 m (O'Neill and Christiansen, 2004).

Kk **Kootenai Formation (Lower Cretaceous)** – Upper 15 m consists of conspicuous, ledge-forming, medium- to thick-bedded, light-gray fresh-water limestone that contains abundant gastropods. Middle part is a slope-forming gray, maroon, yellow, red, and purple mudstone with siltstone, sandstone, and in it lowers part, minor limestone. Lower part is thick-bedded, cherty, crossbedded, quartz-rich sandstone and minor, well-rounded chert-pebble conglomerate. Thickness about 125 m (O'Neill and Christiansen, 2004).

Jme **Morrison Formation (Upper Jurassic) and Ellis Group (Upper and Middle Jurassic), undivided**

Jm **Morrison Formation (Upper Jurassic)** – Interbedded red, green, gray, and yellowish-gray siltstone, mudstone, and shale locally inter-layered with thin beds of dense, fine-grained limestone. Generally poorly exposed and forms reddish-colored slopes. Maximum thickness about 100 m (O'Neill and Christiansen, 2004).

Je **Ellis Group (Upper and Middle Jurassic)**

Swift Formation (Upper Jurassic) – Thin- to medium-bedded, medium- to coarse-grained, calcareous, locally chert bearing quartz sandstone; contains abundant ooids and shell fragments. Lowermost part is olive-green shale and claystone. The Swift is the only formation of the Ellis Group exposed in western part of map area. Thickness ranges from about 1 to 30 m (O'Neill and Christiansen, 2004).

Rierdon Limestone (Middle Jurassic) – Light-gray to pale-brown, thin-to thick-bedded, dense, oolitic limestone; locally contains sparse chert pebbles. Absent in western part of map area. Maximum thickness about 30 m (O'Neill and Christiansen, 2004).

Sawtooth Formation (Middle Jurassic) – Thin-bedded, light- to dark-gray limestone; local shaly to silty limestone interbeds; locally fossiliferous and oolitic. Absent in western part of map area. Maximum thickness about 55 m (O'Neill and Christiansen, 2004).

$T_R$wd **Woodside and Dinwoody Formations, undivided (Lower Triassic)**

T_Rw **Woodside Formation (Lower Triassic)** – Brick-red to orange-red, thin-bedded siltstone and mudstone interbedded with gypsum and thin, discontinuous limestone beds; uppermost strata are silty and locally crossbedded. Thickness ranges from 0 to about 220 m (O'Neill and Christiansen, 2004).

T_Rd **Dinwoody Formation (Lower Triassic)** – Tan- to pale-brown weathering, finely laminated, calcareous siltstone in upper part; grades downward into chocolate-brown-weathering gray to tan limestone, silty limestone, and siltstone. Thickness variable, ranging from about 20 to 80 m (O'Neill and Christiansen, 2004).

Psh **Shedhorn Sandstone (Lower Permian)** – Uppermost part is medium-bedded, fine- to coarse-grained sandstone; minor chert lenses grade downward into yellowish- to dark-brown, thin-bedded chert with silty, locally phosphatic partings. Lower part is brown to gray, thin- to medium-bedded sandstone that grades downward into yellowish-gray, medium-bedded dolomite and sandy dolomite locally containing abundant chert fragments. Equivalent in part to the Phosphoria Formation. Thickness variable, ranging from about 35 to 70 m (O'Neill and Christiansen, 2004).

IPq **Quadrant Sandstone (Pennsylvanian)** – White to tan, medium- to thick-bedded, clean, well-sorted quartz sandstone. Lower part contains thin interbeds of pale-brown dolomite and gray limestone. Thickness 60 – 100 m (O'Neill and Christiansen, 2004).

IPMa **Amsden Formation (Middle Pennsylvanian to Upper Mississippian)** – Dark-red, gray-red, and pinkish-red, thin-bedded, calcareous siltstone, silty shale, and shale. Upper part contains interbeds of medium- to coarse-grained calcareous sandstone whereas lower part is interbedded with thin-bedded limestone, limestone-pebble conglomerate, and dolomite. Thickness ranges from about 10 to 50 m (O'Neill and Christiansen, 2004).

Mm **Madison Group, undivided (Upper and Lower Mississippian)** – Thickness ranges from about 400 to 700 m.

Mission Canyon Limestone (Upper and Lower Mississippian) – Commonly cliff forming, thick-bedded, light-gray-weathering, cherty, fine-grained limestone and minor dolomite. Uppermost few meters of formation contain prominent orangish-gray-weathering solution breccia (O'Neill and Christiansen, 2004).

Lodgepole Limestone (Lower Mississippian) – Slope- to ledge-forming, thin- to medium-bedded, light-gray, finely crystalline, fossiliferous limestone brownish-gray silty limestone partings (O'Neill and Christiansen, 2004).

MDt **Three Forks Formation (Lower Mississippian and Upper Devonian)** – Consists of three members, from top to bottom: yellowish-tan calcareous siltstone and silty limestone (Sappington Member, maximum thickness 25m); gray-green, fissle, micaceous shale (Trident Member, maximum thickness 6 m); and yellowish-gray vuggy limestone and dolomite underlain by olive-green micaceous shale (Logan Gulch Member, maximum thickness 12 m) (O'Neill and Christiansen, 2004).

Dj **Jefferson Dolomite (Upper Devonian)** – Light-gray, tan, yellowish-brown, and dark-gray, finely crystalline to sucrosic dolomite locally interbedded with 1-m-thick silty, shaly, laminated dolomite. Maximum thickness about 100 m (O'Neill and Christiansen, 2004).

O€s **Bighorn (?) Dolomite (Upper Ordovician) and Snowy Range Formation and Pilgrim Limestone (Upper Cambrian), undivided**

Bighorn (?) Dolomite – Light-gray, thin-bedded, dense cryptocrystalline dolomite. About 11 m thick (O'Neill and Christiansen, 2004).

Snowy Range Formation – Tan, thin-bedded limestone with reddish mottles underlain by greenish, thin-bedded dolomite and dolomitic mudstone grades downward into red calcareous siltstone and green sandy shale. About 300 m thick (O'Neill and Christiansen, 2004).

Pilgrim Limestone – Light-gray and yellowish-brown to gray-brown, thin-to medium-bedded, glauconitic dolomitic limestone; mudchip conglomerate and oolitic beds locally common. Thickness approximately 60 m (O'Neill and Christiansen, 2004).

€p **Park Shale (Middle Cambrian)** – Greenish-gray to reddish-gray, fissile, locally waxy looking shale interbedded with minor limestone, limestone-pebble conglomerate, and oolitic limestone. Locally included with the underlying Meagher Limestone where too thin to show on map. Thickness 0 –

30 m (O'Neill and Christiansen, 2004).

Єm **Meagher Limestone (Middle Cambrian)** – Light-gray to brownish-gray, thin- to medium bedded, finely crystalline limestone; thin partings of calcareous shale in upper and lower parts; characteristically contains irregular orange-yellow silty mottles; locally interbedded with centimeter-thick oolitic limestone. Maximum thickness about 150 m (O'Neill and Christiansen, 2004).

Єw **Wolsey Shale (Middle Cambrian)** – Gray-green to dark-gray, fissile, micaceous shale interbedded with minor, thin limestone beds similar to mottled limestone of the overlying Meagher Limestone as well as thin, glauconitic, quartzose sandstone similar to the underlying Flathead Sandstone. Locally missing in Centennial Range. Thickness 0 – 60m (O'Neill and Christiansen, 2004).

Єf **Flathead Sandstone (Middle Cambrian)** – White, tan to reddish-brown, hematitic, thin- to medium-bedded, fine- to medium-grained quartz to feldspathic sandstone; inter-layered with greenish shale in upper part; glauconitic locally. Where unmapped in Centennial Range, formation may be missing or so thin that it is included in the overlying Meagher Limestone. Thickness 0 – 30 m (O'Neill and Christiansen, 2004).

EARLY PALEOPROTEROZOIC (?) AND LATE ARCHEAN SUPRACRUSTAL METASEDIMENTARY AND META-IGNEOUS ROCKS

[Amphibolite-grade metasedimentary rocks are strongly deformed and show abundant evidence of internal thickening and thinning; original thickness of metamorphic units is not known. These supracrustal rocks, called the Cherry Creek Metamorphic Suite for exposures in Gravelly Range along Cherry Creek directly north of map area (Heinrich, 1960), have traditionally been accepted as being late Archean in age. Erslev and Sutter (1990) obtained latest Archean (2.53 Ga) cooling ages from gneissic rocks inter-layered with metasedimentary rocks directly west of Henrys Lake; however, it is not clear how the gneissic rocks are related to the enclosing metasedimentary rocks. Given the strongly folded and thrust-faulted nature of these rocks, the likely imbricate stacking of Archean crustal rocks with overlying, younger supracrustal rocks in a fold-and-thrust belt, and the fact that supracrustal rocks are virtually unknown from Archean basement rocks of North America, we tentatively suggest the possibility of an early Paleoproterozoic age for these metasedimentary rocks (O'Neill and Christiansen, 2004).]

XAam **Amphibolite** – In Eastern Centennial Range the amphibolite is green to greenish brown, schistose to massive, generally fine grained, and locally porphyroblastic; actinolite makes up as much as 50 – 90 percent of rock (O'Neill and Christiansen, 2004).

XAm **Marble** – Massive, light-gray to cream-colored dolomitic marble inter-layered with thin quartzite bands; schistosity defined by aligned chlorite and

phlogopite, and flattened dolomite grains. In thin section, dolomite dominates the marble; calcite is associated with quartzite layers only; quartz is present generally as granular bands within marble (O'Neill and Christiansen, 2004).

XAq **Quartzite** – Light-green, poorly banded quartzite; inter-fingers with adjacent rock units; quartzite has been completely recrystallized and does not show clastic textures or graded bedding (O'Neill and Christiansen, 2004).

XAms **Mica schist** – Inter-layered rusty-yellow-weathering, quartz-rich muscovite schist and thin quartzite; locally contains abundant magnetite, chlorite, biotite, and poikiloblastic garnet (O'Neill and Christiansen, 2004).

MIDDLE ARCHEAN ROCKS

[Middle Archean amphibolite- to granulite-grade metamorphic tectonites and associated igneous rocks; relative ages uncertain. Middle Archean (>3.1 Ga) age has been confirmed by U-Pb zircon ages from crystalline rocks collected from southern Madison Range (Shuster et al., 1987; O'Neill and Christiansen, 2004).]

Ag **Granite and granitic gneiss** – Pink, foliated granitic rocks having weakly to strongly discordant contacts with adjacent rocks. Rock composition and texture variable, ranging from medium grained and equigranular with faint layering defined by aligned biotite, to highly folded and contorted leucogranite enclosing granodioritic xenoliths, to mafic folded granite and granite gneiss (O'Neill and Christiansen, 2004).

Adi **Dioritic gneiss** – White- and green-spotted, well-foliated plagioclase-hornblende-quartz rock as thin sills and small stocks. Sills typically consist of 60 – 80 percent plagioclase and hornblende, and minor quartz; stocks are more felsic and include biotite and as much as 30 percent quartz (O'Neill and Christiansen, 2004).

At **Tonalitic gneiss** – Tonalitic migmatite gneiss and tonalitic biotite gneiss; highly variable both texturally and compositionally; gneiss includes amphibolitic migmatite breccia, leucotonalite gneiss, and dark-gray tonalitic biotite gneiss with moderate migmatite banding. Locally, tonalite gneiss is interlayered with a mixed gneiss composed of green quartzite, biotite-garnet gneiss, amphibolite and garnet amphibolite, and gedrite-cordierite-bearing gneiss. All tonalitic rocks consist of essential plagioclase, quartz, hornblende, and biotite with a granoblastic texture. Also included with these rocks is migmatitc granite gneiss characterized by granite leucosomes containing abundant microcline between thin layers enriched in plagioclase, biotite, and, locally, hornblende (O'Neill and Christiansen, 2004).

APPENDIX C:

ESTIMATED CALCULATED AGES FOR FAULT SCARP PROFILES

Table 14. Comparison of the eastern Centennial profile surface offset to the calculated ages for late Pleistocene age deposits. These ages are the amount of time since the last surface rupturing earthquake event. NA values represent the profiles that had an initial slope angle too large as defined by McCalpin (1996, p. 135-137). The 0.46 m^2/1000 yr and 0.52 m^2/1000 yr values represent the upper and lower K_0 values from the linear-plus-cubic diffusion model. The estimated number of earthquakes is based on a maximum surface offset of 3.0 m per event. The rock type and estimated age (ka) from rock type help to constrain the amount of time possible for offset to occur.

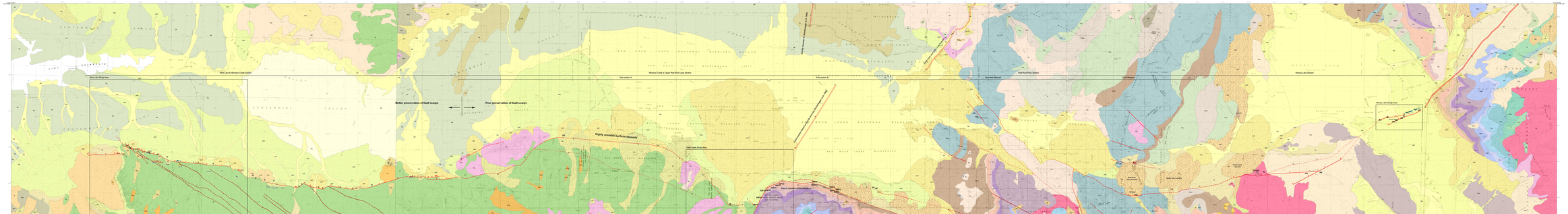
Profile	Surface Offset (m)	Calculated Age (yrs)		Estimated Number of Earthquakes	Rock Type offset	Estimated age (ka) from rock type
		0.46 m^2/1000 yr	0.52 m^2/1000 yr			
AE	1.60	600	500	1	Late Pleistocene	12,000-14,000
AD	3.00	13,400	12,000	1	Late Pleistocene	12,000-14,000
AC	5.80	5500	4900	2	Late Pleistocene	12,000-14,000
AX	5.90	4700	4200	2	Late Pleistocene	12,000-14,000
AW	7.60	14,000	13,000	3	Late Pleistocene	12,000-14,000
AO	7.70	4500	4000	3	Late Pleistocene	12,000-14,000
AQ	8.30	24,000	21,000	3	Late Pleistocene	12,000-14,000
AR	8.30	41,000	36,000	3	Late Pleistocene	12,000-14,000
AP	9.80	NA	NA	4	Late Pleistocene	12,000-14,000
AK	11.00	NA	NA	4	Late Pleistocene	12,000-14,000
AS	11.30	172,000	152,000	4	Late Pleistocene	12,000-14,000
AT	12.90	55,000	49,000	5	Late Pleistocene	12,000-14,000
AV	21.10	84,000	74,000	7	Late Pleistocene	12,000-14,000
AU	21.30	51,000	45,000	7	Late Pleistocene	12,000-14,000

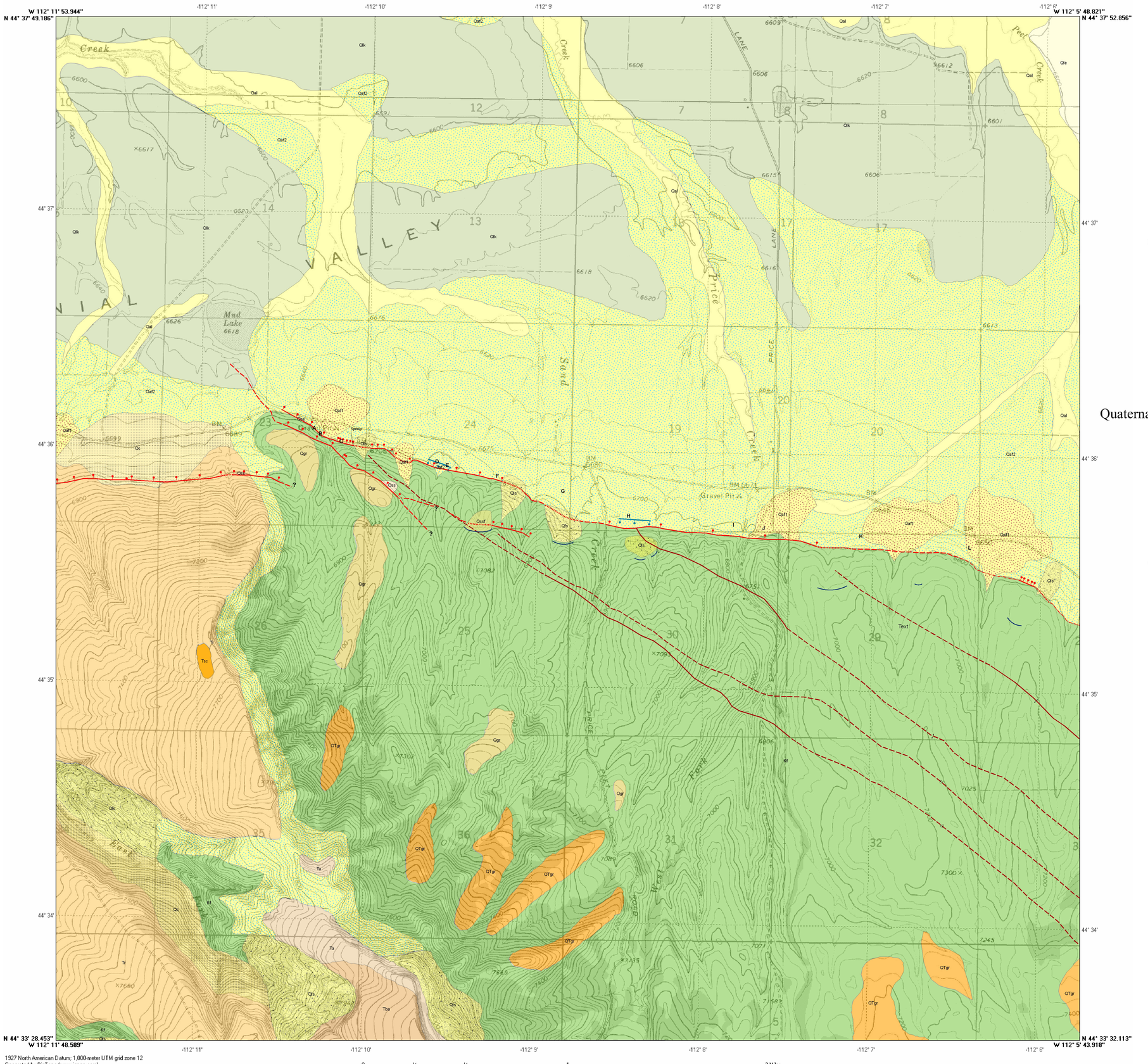
Table 15. Comparison of the eastern Centennial profile surface offset to the calculated ages for Bull Lake age deposits. These ages are the amount of time since the last surface rupturing earthquake event. NA values represent the profiles that had an initial slope angle too large as defined by McCalpin (1996, p. 135-137). The 0.46 m^2/1000 yr and 0.52 m^2/1000 yr values represent the upper and lower K_0 values from the linear-plus-cubic diffusion model. The estimated number of earthquakes is based on a maximum surface offset of 3.0 m per event. The rock type and estimated age (ka) from rock type help to constrain the amount of time possible for offset to occur.

Profile	Surface Offset (m)	Calculated Age (yrs)		Estimated Number of Earthquakes	Rock Type offset	Estimated age (ka) from rock type
		0.46 m^2/1000 yr	0.52 m^2/1000 yr			
AX	5.90	4700	4200	2	Bull Lake	130,000-140,000
AW	7.60	14,000	13,000	3	Bull Lake	130,000-140,000
AO	7.70	4500	4000	3	Bull Lake	130,000-140,000
AQ	8.30	24,000	21,000	3	Bull Lake	130,000-140,000
AR	8.30	41,000	36,000	3	Bull Lake	130,000-140,000
AP	9.80	NA	NA	4	Bull Lake	130,000-140,000
AK	11.00	NA	NA	4	Bull Lake	130,000-140,000
AS	11.30	172,000	152,000	4	Bull Lake	130,000-140,000
AT	12.90	55,000	49,000	5	Bull Lake	130,000-140,000
AV	21.10	84,000	74,000	7	Bull Lake	130,000-140,000
AU	21.30	51,000	45,000	7	Bull Lake	130,000-140,000

Table 16. Comparison of the western Centennial profile surface offset to the calculated ages. These ages are the amount of time since the last surface rupturing earthquake event. NA values represent the profiles that had an initial slope angle too large as defined by McCalpin (1996, p. 135-137). The 0.46 m^2/1000 yr and 0.52 m^2/1000 yr values represent the upper and lower K_0 values from the linear-plus-cubic diffusion model. The estimated number of earthquakes is based on a maximum surface offset of 3.0 m per event. The rock type and estimated age (ka) from rock type help to constrain the amount of time possible for offset to occur.

Profile	Surface Offset (m)	Calculated Age (yrs)		Estimated Number of Earthquake	Rock Type offset	Estimated age (ka) from rock type
		0.46 m^2/1000 yr	0.52 m^2/1000 yr			
D	0.80	1000	900	1	Late Pleistocene	12,000-14,000
E	1.40	2000	1800	1	Late Pleistocene	12,000-14,000
I	7.40	15,000	13,000	3	Late Pleistocene	12,000-14,000
AB	8.00	NA	NA	3	Late Pleistocene	12,000-14,000
S	8.10	25,000	22,000	3	Late Pleistocene	12,000-14,000
AA	8.80	76,000	67,000	3	Pinedale	12,000-14,000
U	8.90	90,000	80,000	3	Late Pleistocene	12,000-14,000
W	9.20	97,000	85,000	4	Late Pleistocene	12,000-14,000
Q	11.20	19,000	16,000	4	Late Pleistocene	12,000-14,000
X	11.60	29,000	26,000	4	Late Pleistocene	12,000-14,000
T	11.90	7700	6800	4	Late Pleistocene	12,000-14,000
V	13.60	33,000	29,000	5	Late Pleistocene	12,000-14,000
Y	18.00	NA	NA	6	Late Pleistocene	12,000-14,000


Mud Lake to Winslow Creek Section
Sub-section A
Winslow Creek to Upper Red Rock Lake Section
Sub-section B
Poverty Flat Section
Red Rock Pass Section
Henrys Lake Section
Mud Lake Study Area
Henrys Lake Study Area
Better preservation of fault scarps
Poor preservation of fault scarps
Highly variable surficial deposits
Centennial Normal Fault Zone
Red Rock Fault Zone
Hebgen Lake Fault Zone
Hebgen Lake Fault Zone
Red Rock Fault Zone
Red Rock Pass
Lima
Dillon
Monida
Lakes
Centennial Valley
Tendoy
Red Rock Lakes National Wildlife Refuge
Beaverhead National Forest
Gallatin National Forest
Caribou National Forest
Targhee National Forest
Sawtooth National Forest
Salmon National Forest
Bitterroot National Forest
Lolo National Forest
Deer Lodge National Forest
Helena National Forest
Lewis and Clark National Forest
Gallatin National Forest
Custer National Forest
Bridger National Forest
Shoshone National Forest
Medicine Bow National Forest
Arapaho National Forest
Pike National Forest
Pike National Forest
Pike



1927 North American Datum; 1,000-meter UTM grid zone 12
Generated by BigTopo (www.igage.com)
Map compiled from USGS Quads: Wolverine Creek, MT Antelope Peak, MT Corral Creek, MT,ID Big Table Mountain, ID,MT

0 ¼ ½ 1 2 Miles
1000 0 1000 2000 3000 4000 5000 6000 7000 8000 10,000 Feet
1,000 Meters 500 0 ½ 1 2 Kilometers

Scale 1:12,000
Contour interval 200 Ft

N W E S

Mud Lake study area geologic map units from:

Lonn, J.D., Skipp, E., Ruppel, E.T., Janecke, S.U., Perry Jr., W.J., Sears, J.W., Bartholomew, M.J., Stickney, M.C., Fritz, W.J., Hurlow, H.A., Thomas, R.C., 2000, Geologic map of the Lima 30' x 60' quadrangle, southwest Montana, Montana Bureau of Mines and Geology: Open File Report 408, 12 p., 1 sheet(s), 1:100,000.

Geologic Map Units and Symbols

Quaternary

- **Qal - Alluvium and fluvial channel deposits**
- **Qss - Scarp slump**
- **Qssf - Scarp slump/fan**
- **Qls - Earthflow and landslide deposits**
- **Qc - Colluvium deposits**
- **Qaf1 - Young alluvial fan**
- **Qaf2 - Old alluvial fan**
- **Qlk - Lacustrine deposits**
- **Qle - Lake deposits and overlying eolian deposits**
- **Qgr - Gravel deposits**

Quaternary-Tertiary

- **QTgr - Gravel deposits**

Tertiary

- **Tba - Basalt**
- **Ta - Andesite**
- **Tr - Rhyolite**
- **Tsc - Sixmile Creek Formation**

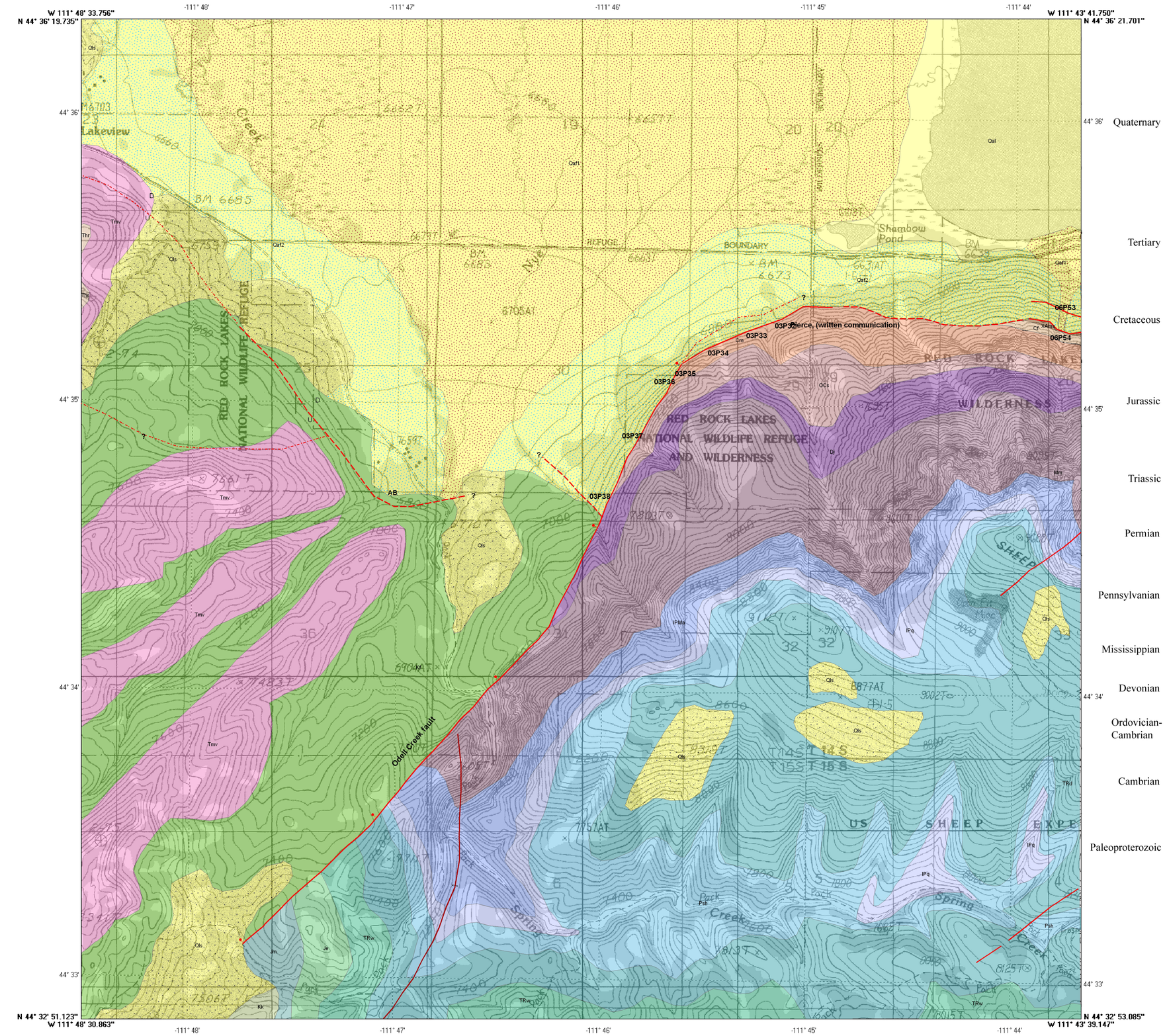
Cretaceous

- **Kf - Frontier Formation**

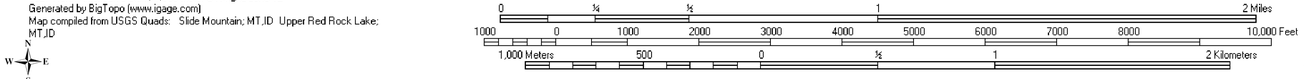
- **Centennial Normal Fault with sense of motion**
- **Centennial Normal Fault**
- **Inferred fault**
- **Inferred/Concealed fault**
- **Concealed fault**
- **Antithetic fault**
- **Scarp of Unknown origin**
- **Location of actual fold**
- **Location of approximate fold**
- **Anticline - actual location**
- **Anticline - approximate location**
- **Syncline - actual location**
- **Syncline - approximate location**
- **Overturned anticline - approximate location**
- **Overturned syncline - approximate location**

Alphabetical value: fault scarp profile label and location
Refer to Appendix A for fault scarp profile data
Refer to Appendix B for geologic unit descriptions

Plate 2: Compiled geologic map of the Mud Lake study area with updated Centennial Normal Fault location and fault scarp profile locations from this study, Beaverhead County, Montana.
By: Falene Petrik
2006



1927 North American Datum; 1,000-meter UTM grid zone 12
Generated by BigTopo (www.igage.com)
Map compiled from USGS Quads: Slide Mountain; MT,ID Upper Red Rock Lake; MT,ID



Scale 1:12,000
Contour lines 200 Ft

Odell Creek study area geologic map units from:

O'Neill, J.M., Christiansen, R.L., 2002, Geologic map of the Hebgen Lake quadrangle, Montana Bureau of Mines and Geology: Open File Report 464, 21 p., 1 sheet(s), 1:100,000.

Geologic Map Units and Symbols

Quaternary	Qal - Alluvium and fluvial channel deposits
	Qls - Earthflow and landslide deposits
	Qaf1 - Young alluvial fan
	Qaf2 - Old alluvial fan
Tertiary	Thr - Huckleberry Ride Tuff, undivided
	Tmv - Mafic volcanic rocks
Cretaceous	Kf - Frontier Formation
	Kk - Kootenai Formation
Jurassic	Jm - Moorison Formation
	Je - Ellis Group
Triassic	TRw - Woodside Formation
	TRd - Dinwoody Formation
Permian	Psh - Shedhorn sandstone
Pennsylvanian	IPq - Quadrant sandstone
	IPMa - Amsden Formation
Mississippian	Mm - Madison Group, undivided
Devonian	Dj - Jefferson dolomite
Ordovician-Cambrian	OCs - Bighorn dolomite, Snowy Range Formation and Pilgrim limestone, undivided
Cambrian	Cm - Meagher limestone
	Cf - Flathead sandstone
Paleoproterozoic	XAms - Mica schist

Centennial Normal Fault with sense of motion

Centennial Normal Fault

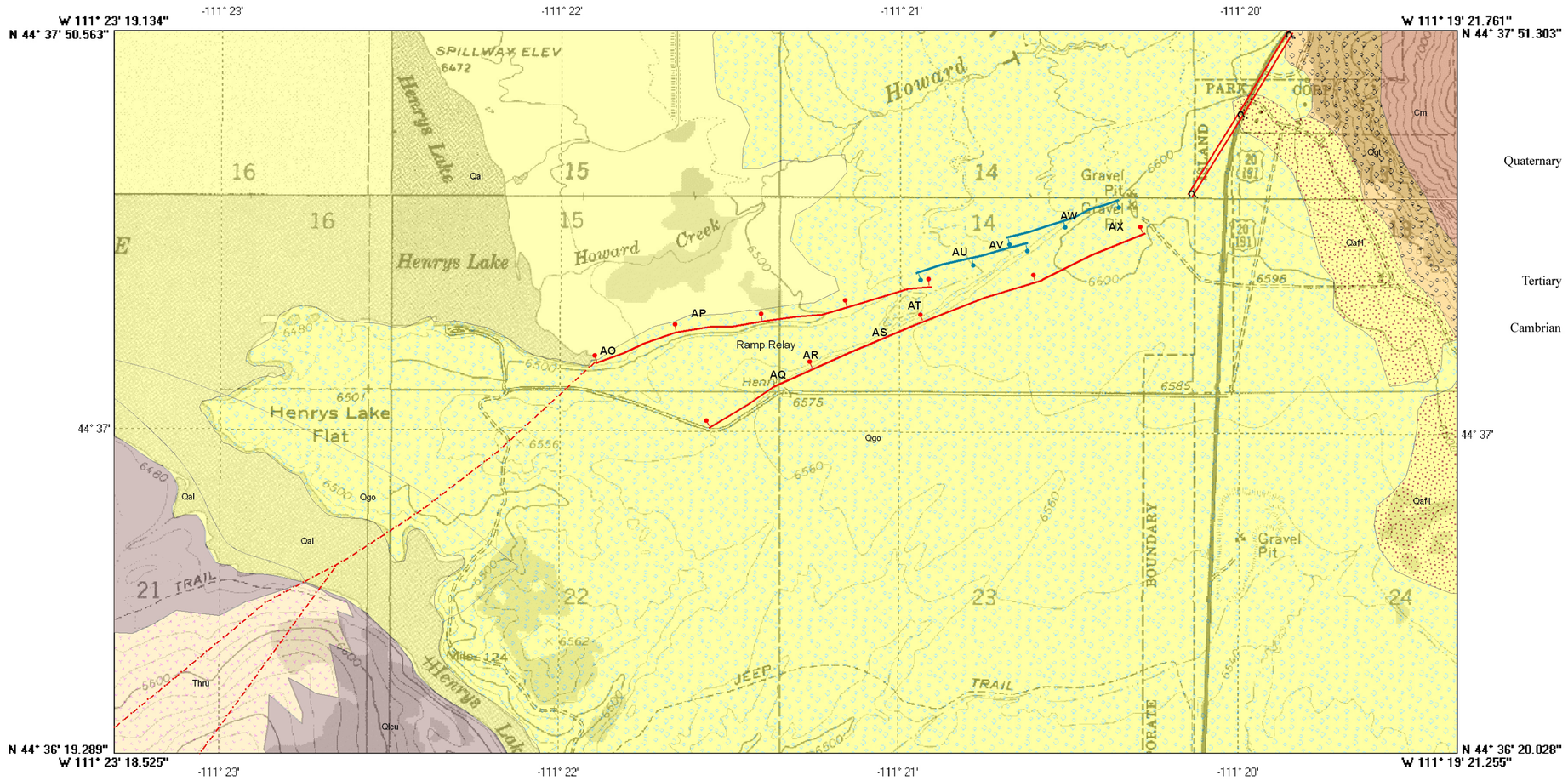
Inferred fault

Inferred/Concealed fault

Anticline - actual location

Alphabetical value: fault scarp profile label and location
Refer to Appendix A for fault scarp profile data
Refer to Appendix B for geologic unit descriptions

Plate 3: Compiled geologic map of the Odell Creek study area with updated Centennial Normal Fault location and fault scarp profile location from this study, Beaverhead County, Montana.
By: Falene Petrik
2006



1927 North American Datum; 1,000-meter UTM grid zone 12
Generated by BigTopo (www.igage.com)
Map compiled from USGS Quads: Targhee Peak; ID,MT Targhee Pass; ID, MT Sawtell Peak; ID,MT Big Springs; ID

0 ¼ ½ 1 2 Miles

1000 0 1000 2000 3000 4000 5000 6000 7000 8000 10,000 Feet

Scale 1:12,000
Contour intervals 200 Ft

1,000 Meters 500 0 ½ 1 2 Kilometers

N W E S

Geologic Map Units and Symbols

Quaternary

- **Qal - Alluvium and fluvial channel deposits**
- **Qaf1 - Young alluvial fan**
- **Qgo - Glacial outwash deposits**
- **Qgt - Glacial til and related deposits**
- **Qlcu - Lava Creek Tuff - upper member**

Tertiary

- **Thru - Huckleberry Ridge Tuff - upper member**

Cambrian

- **Cm - Meagher Limestone**

Centennial Normal Fault with sense of motion

Inferred/Concealed fault

Antithetic fault with sense of motion

Extrapolated projection of fault - not physically mapped

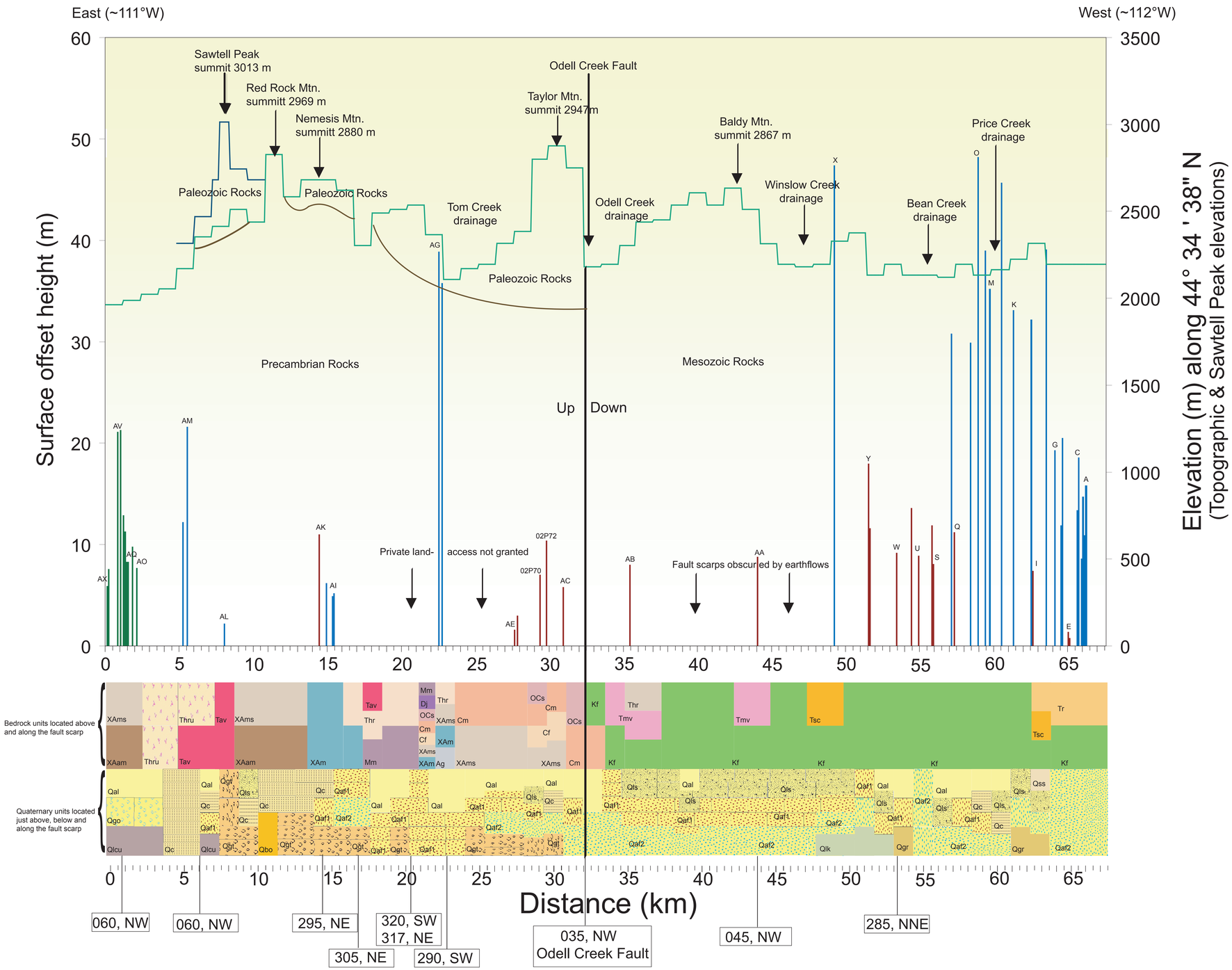
Alphabetical value: fault scarp profile label and location
Refer to Appendix A for fault scarp profile data
Refer to Appendix B for geologic unit descriptions

Henrys Lake study area geologic map units from:

O'Neill, J.M., Christiansen, R.L., 2002, Geologic map of the Hebgen Lake quadrangle, Montana Bureau of Mines and Geology: Open File Report 464, 21 p., 1 sheet(s), 1:100,000.

Plate 4: Compiled geologic map of the Henrys Lake study area with updated Centennial Normal Fault location and fault scarp profile locaitons from this study, Fremont County, Idaho
By: Falene Petrik
2006

Topographic elevation vs. fault scarp surface offset along the Centennial normal fault, MT-ID



Legend

Strike, dip directions — Location & orientation of faults

- Pinedale Moraines and Alluvial Fans
- Bull Lake Alluvial Fans
- Bedrock (Footwall Only, min. value represented)
- Topographic Elevation
- Sawtell Peak Elevation
- Qal-Alluvium and fluvial channel deposits
- Qss-Scarp slump
- Qls-Earthflow and landslide deposits
- Qc-Colluvium
- Qaf1-Young alluvial fan
- Qaf2-Old alluvial fan
- Qbo-Boulder field
- Qlk-Lacustrine deposits
- Qgr-Gravel deposits
- Qgo-Glacial outwash deposits
- Qgt-Glacial till and related deposits
- Qlcu-Lava Creek Tuff (upper member)
- Thr-Huckleberry Ridge tuff
- Thru-Huckleberry Ridge tuff (upper member)
- Tr-Rhyolite
- Tmv-Mafic volcanic rocks
- Tsc-Sixmile Creek Formation
- Tav-Absaroka Volcanic Supergroup
- Kf-Frontier Formation
- Mm-Madison Group, undivided
- Dj-Jefferson Dolomite
- OCs-Bighorn Dolomite, Snowy Range Formation and Pilgrim Limestone, undivided
- Cm-Meagher Limestone
- Cf-Flathead Sandstone
- XAam-Amphibolite
- XAm-Marble
- XAms-Mica schist
- Ag-Granite and granitic gneiss

See Plate 1 and Appendix B for rock unit descriptions and references