Woodward-Clyde Consultants

STUDY OF EARTHQUAKE RECURRENCE INTERVALS ON THE WASATCH FAULT, UTAH

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By
Kathryn L. Hanson, F. H. Swan, III, David P. Schwartz

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INTRODUCTION

Detailed geologic mapping, topographic profiling, and trenching are being conducted at selected sites along the Wasatch fault zone to measure the cumulative fault displacements in Quaternary strata of various ages and to obtain data regarding the amount of displacement per surface faulting event and the number and recurrence of faulting events that produced the cumulative displacement. These data are used to estimate the frequency of occurrence and magnitude of earthquakes associated with surface faulting along individual segments of the Wasatch fault zone. Investigations have been completed at four sites, the Kaysville, Hobble Creek, Little Cottonwood Canyon, and North Creek sites (Figure 1). The results of the investigations at the Kaysville, Hobble Creek, and Little Cottonwood Canyon sites are discussed in our previous reports, which are listed in Appendix A. Detailed geologic investigations were conducted at the North Creek site during September and October, 1980. The location of the North Creek site is shown on Figures 1, 2, and 3. This report presents our findings, interpretations, and conclusions based on our field investigations at the North Creek site.

METHODS OF STUDY

Geologic investigations at the North Creek site included:

1. Photointerpretation - Analysis of 1970, 1:12000, low-sun-angle (morning) black and white aerial photographs of the site was made to identify fault traces and to aid in selecting trench locations.

2. Topographic Profiling - Longitudinal topographic profiles across the main fault scarp, antithetic fault scarps, and adjacent geomorphic surfaces were measured using an Abney

level, Brunton compass, and tape. The profiles, in conjunction with trench and map data, are used to assess cumulative displacement across the fault zone, examine the amount and extent of back-tilting and graben formation, and examine the relationship between faulting and scarp morphology. Locations of topographic profiles are shown on Figure 4.

3. Trenching - Three trenches, totaling 43 m in length, were excavated and logged at a scale of 1:20 to assess the structural and stratigraphic relationships across the fault scarp (Figures 7, 8, and 9). A fourth trench, 23 m long, was excavated 15 m west of and subparallel to the fault scarp to examine the stratigraphic relationships between fan deposits on the downthrown block. Two test pits, each approximately 4 to 4.5 m deep, were also excavated on the downthrown side of the fault. Locations of the trenches and test pits are shown on Figure 4.

4. Radiocarbon Dating - Four samples of detrital charcoal and organic-rich soil were collected from colluvial and graben fill deposits and submitted for age-dating by conventional (beta-counting) techniques. Six additional samples, which are too small to be dated by conventional techniques, will be submitted to Dr. A.B. Tucker (San Jose State University) to be dated at Stanford University or the Swiss Federal Institute of Technology using high energy mass spectometry (accelerator) techniques. Results of these analyses are expected later this summer.

LOCATION AND SETTING OF THE NORTH CREEK SITE

The North Creek site is located along the eastern side of Juab Valley at the mouth of North Creek Canyon 16 km north-northeast of Nephi, Utah (NE 1/4 SE 1/4 Sec 15, T11S, R1E,

Santaquin 15' quadrangle (Figure 3). The Wasatch Range in this area rises steeply eastward to an elevation of 3621 m in a horizontal distance of 4.5 km. Rocks in the range consist of quartzite of the Cambrian Tintic Formation, undifferentiated Cambrian rocks, and limestone of Mississippian and Pennsylvanian-Permian age. The site is located near the northern end of the longest (24 km) fault trace along the southern portion of the Wasatch fault that has nearly continuous evidence of late Holocene faulting (Figure 2). The most recent faulting in the site area is generally confined to a narrow zone only a few tens of meters wide at the base of the range front that consists of a fresh-looking, steep, west-facing scarp and associated graben (Figures 4 and 5). Post-faulting alluvial fan deposition on the downthrown block has partly buried and obscured antithetic faults that form the western boundaries of the graben.

Late Quaternary sediments at the site consist of coarse, poorly sorted alluvial fan deposits. The younger fan deposits grade to and below Bonneville-level shoreline deposits that occur at elevations of less than 1580 m west of the site.

Alluvial fan deposition along the eastern side of Juab valley has been interrupted by repeated slip along the Wasatch fault. At least three episodes of fan development are represented by alluvial fan sediment at the North Creek site. The oldest fan material is preserved in a terrace remnant east of the fault at an elevation of 1780 m, approximately 50 m above the present channel of North Creek (Figures 5 and 6). The age of these deposits is uncertain, but the height of the terrace remnant and surface weathering characteristics, which include a thick calcic soil and ventifacts on the surface, imply that the deposits are at least pre-Wisconsinan. Younger fan deposits of early to middle Holocene age extend up North Creek Canyon as a narrow valley-fill deposit (North Creek terrace)

that is inset into the older alluvial fan deposits. Remnants of an intermediate-aged alluvial fan surface are also preserved on the upthrown side of the fault at the mouth of a steeper drainage to the south, which is informally referred to as "South Creek" in this report (Figure 6). This fan is topographically lower than the pre-Wisconsinan terrace remnants and its surface appears to grade to an elevation higher than the North Creek terrace. The youngest fan deposits at the site include channel fillings on the fan surface that extend up the canyons along the present drainage lines. These deposits are not displaced across the Wasatch fault.

STRATIGRAPHY

Trenches NC-1 and NC-1A

Trench NC-1 (Figure 7) was excavated into the face of the fault scarp where the North Creek terrace has been displaced by the fault (Figures 4 and 5). Trench NC-1A was excavated perpendicular to this trench on the downthrown side of the fault. The oldest deposits exposed in these trenches consist of alluvium derived from North Creek (unit 1), which was exposed in the footwall of trench NC-1. Unit 1 was also exposed 2 m below the surface in trench NC-1A; 2.3 to 2.8 m below the surface in test pit 1 and at the ground surface in test pit 2. In trench NC-1 the deposits consist of moderately to well sorted, interbedded sandy gravel, gravelly sand, and open-work gravel. The gravel clasts consist of limestone and quartzite and are generally subrounded to subangular. The North Creek alluvial deposits exposed in test pits 1 and 2 and in natural exposures along North Creek are less well sorted and stratified and generally have a siltier matrix. Detrital charcoal from a burn layer 1.5 m below the surface of the North Creek terrace exposed in a stream cut along North Creek on the upthrown side of the fault has been radiocarbon dated

at 4580 ^{14}C years old (Bucknam, 1978). A weak soil having a cambic B horizon and Stage I carbonate accumulation in a C_{CA} horizon has formed on these deposits (Table 1). The soil was observed in relict positions on the upthrown side of the fault and in test pit 2 approximately 40 m west of the main fault scarp on the downthrown block. Within approximately 30 m of the main fault on the western downthrown block the North Creek alluvial fan surface has been affected by graben formation, and the downfaulted fan deposits and soil are buried by younger scarp-derived colluvium and alluvial fan deposits. A sample from the organic-rich A horizon of this soil collected in trench NC-1A yielded a radiocarbon age of 2180 $\pm$ 80 ^{14}C yr B.P. (Sample WC-12-80-3, Table 2). This date is younger than radiocarbon dates from stratigraphically younger deposits exposed in trench NC-3. The age of the soil sample probably represents an average of older organic material and younger contaminents.

In trench NC-1A the soil formed on unit 1 is overlain by alluvial deposits that consist of loose, moderately to well sorted, sandy gravel, gravelly silty sand, and some open-work gravel. In trench NC-1, these deposits (unit 2b) overlie a scarp-derived colluvium or mudflow deposit (unit 2a) adjacent to the main fault scarp. An organic-rich A horizon of a soil (unit 2s) that varies in thickness from 10 to 50 cm is formed on both the colluvium (unit 2a) and alluvium (unit 2b). The contact between this soil and the overlying deposits is very abrupt except adjacent to the main fault where it is less distinct.

The unit 2s soil is overlain by poorly sorted, massive gravelly sandy silt (unit 3). The origin of this deposit, which is restricted to a very localized area adjacent to the main fault in the south wall of the trench, is unclear. Its similarity in appearance and texture to mudflow deposits

(unit 4) within the alluvial fan deposits that also overlie the unit 2s soil suggest it may have been deposited in a similar environment. The different structural relations of units 3 and 4 to faulting that occurred during the most recent surface faulting event suggest they are probably separate deposits. On the south wall of trench NC-1 the geometry of unit 3 and its location adjacent to the main fault scarp suggest that it may be a scarp-derived colluvium. However, similar relationships were not present on the north wall of this trench. In this wall, a soil similar in appearance to unit 2s is draped up against the main fault and unit 3 is absent. Scarp-derived colluvial units equivalent to unit 3 in trench NC-1 are not present in trench NC-3 or test pit 1, and no alluvial fan deposits of equivalent age overlie the unit 2s soil in trench NC-1. For these reasons, it seems unlikely that unit 3 is a scarp-derived colluvium representing a separate surface faulting event.

The most recent surface faulting event is represented by scarp-derived colluvium (units 5a and 5b) in trench NC-1. Rapid deposition of the colluvium following this surface faulting event has resulted in the preservation of the steeply dipping free-face of the fault scarp. The colluvium, which is subdivided into a slightly coarser basal facies (unit 5a) and finer upper facies (unit 5b), generally consists of massive, loose sandy gravel. A weak fabric having an apparent dip of 30 to 33° W is developed in the lower unit. A very weak A soil horizon (unit 5s) is developed on the upper 10 to 30 cm of these deposits. The scarp-derived colluvium is overlain by a mudflow deposit (unit 5c) and alluvium (unit 5d) derived from "South Creek".

An historical mudflow (unit 6b) and slopewash (unit 6a) on the fault scarp bury the most recent fault scarp colluvium and associated alluvial fan deposits. Nails and pieces of metal occur in a burn layer at the base of the mudflow deposit.

Trench NC-2

Trench NC-2 (Figure 8) was excavated into the main fault scarp where the fault truncates older fan deposits that lie between the North Creek and "South Creek" fans on the upthrown block (Figures 4 and 6). The oldest deposits exposed in this trench consist of a weakly stratified sandy gravel (unit 1a) and massive, poorly sorted, clayey silty sand having less than 5 percent gravel clasts (unit 1b). The gravel clasts are subangular and consist primarily of limestone. These deposits are moderately to strongly indurated by calcium carbonate that occurs both as continuous coatings up to 4 mm thick on gravel clasts and as dissiminated lime throughout the matrix. These deposits are in fault contact with deposits similar to unit 1b, which are interpreted to be colluvium derived from an older fault scarp that has been buried by younger deposits. A Stage II carbonate soil (unit 2s) is developed on the colluvium; carbonate coats (generally less than 1 to 2 mm) occur on the bottoms of clasts throughout the deposit.

Unit 2 was deeply incised during subsequent erosion along the base of the fault scarp and channel fill deposits (unit 3) are in depositional contact with it. The channel margin is steeply dipping to overhanging in the upper part. Unit 3 consists of interbedded sandy gravel and gravelly coarse sand. A dip of 14 degrees to the northwest was measured on the base of a small channel gravel lense within these deposits. The channel deposits may correlate to alluvial fan deposits exposed in the footwall of trench NC-3.

The older fan deposits (unit 1), scarp colluvium (units 2 and 2s), and channel deposits (unit 3) are older than the oldest deposits exposed in trenches NC-1 and NC-1A. These units are overlain by scarp-derived colluvium (unit 4) that truncates and buries the eastern-most fault exposed in trench NC-2 and is displaced across the main zone of recent faulting (Figure 8, stations 5 to 7). Unit 5 is similar in appearance to unit 4 and may be a scarp colluvium that was derived primarily from unit 4. Unit 5 is overlain by a more organic-rich deposit (unit 6) that is clearly scarp-derived colluvium that was deposited following the second-most-recent surface faulting event. Unit 6 exhibits a weak fabric subparallel to the present ground surface. Unit 5 may be a basal facies of the unit 6 colluvium or it may represent an earlier faulting event. Deposits similar to unit 6 could not be distinguished on the upthrown side of the fault zone; they may be included in deposits mapped as unit 7a-b.

Subsequent to the second most-recent surface faulting event and deposition of unit 6 a sequence of well-bedded alluvial fan sediments that onlap the fault scarp was deposited. These deposits were displaced across the main fault zone during the most recent surface faulting event. The basal facies of these fan deposits is a mudflow unit (unit 7a) on which an organic-rich A horizon of a soil (unit 7b) has formed. This unit is overlain by moderately well sorted, finer-grained alluvial deposits (units 7c and 7d) and an upper mudflow unit (7e). Detrital charcoal collected from unit 7c yielded a radiocarbon age-date of 1350 ^{14}C yr B.P. (Sample WC-12-80-5, Table 2). An organic-rich A horizon of a soil (unit 7s) is developed on these deposits. On the upthrown block (Figure 8, stations 0 to 5) this unit may also include younger colluvium and slopewash.

Unit 8b consists of colluvium derived from the fault scarp following the most-recent surface faulting event. This unit grades to and overlies alluvial deposits (unit 8a) from South Creek. The youngest deposit in trench NC-2 is a mudflow unit (unit 9) that correlates to the historical mudflow (unit 6b) exposed in trench NC-1.

Trench NC-3

Trench NC-3 (Figure 9) was excavated into the main fault scarp where it crosses the apex of the "South Creek" fan (Figure 4). The deposits exposed in this trench consist of alluvial fan deposits from "South" Creek and scarp-derived colluvium. The oldest recognized alluvial fan deposits from "South" Creek (unit 1) are preserved as fan surface remnants on the upthrown side of the fault zone (Figures 6 and 9). These deposits may correlate, in part, to the channel fill (unit 3) exposed in the footwall of trench NC-2. Unit 1 consists of interbedded silty sandy gravel, gravelly sand, pebbly sand, and open-work gravel. Limestone and quartzite clasts within the deposits are angular and subangular. Calcium carbonate occurs as thin (less than 1 mm) coats on the bottoms of gravel clasts and in some horizons carbonate is disseminated throughout the matrix giving the deposits a whitish color. Carbonate cementation is most abundant in the lower bouldery sand adjacent to the westernmost main fault plane (Figure 9, station 4 to 5).

Units 2a, 2b, and 2c consist of colluvium derived from the fault scarp that was deposited against the free-face of the fault scarp following the second-most-recent surface faulting event. The colluvium consists of a sequence of silty sandy gravel (unit 2a), loose, open-work pebble- and cobble-gravel (unit 2b), and gravelly sandy silt (unit 2c). Radiocarbon age-dating of a sample of the organic-rich soil developed on

this colluvium yielded an age-date of 3640 ± 75 ^{14}C yr B.P. (Sample WC-12-80-7, Table 2).

This soil is overlain by a sequence of mudflow deposits (units 3a, 3b, and 3c) separated by weakly developed A soil horizons (entisols). A radiocarbon age-date of 1110 ± 60 ^{14}C yr B.P. (Sample WC-12-80-6, Table 2) was obtained from detrital charcoal from one of these buried entisols (unit 3as). These deposits were displaced across at least two antithetic faults (Figure 9, station 13.5 and 17) during the most recent surface faulting event. The soil (unit 3s) on the upper mudflow deposits grades into a soil developed on scarp colluvium (unit 2) and older fan (unit 1) deposits. This soil represents the ground surface prior to the most recent surface faulting event. This soil is undisturbed across the older fault at station 5.

The most recent displacement occurred high on the fault scarp (Figure 9, station 0) and on a secondary fault (station 2.5). The 2 meter-wide block between these two faults has been displaced down to the west and rotated backwards towards the fault scarp. Colluvium (unit 4a) from the fault scarp has filled the depression produced by this down dropped block, and the free face of the main fault scarp, which appears as a distinct plane has been buried. Unit 4a grades upwards into units 4c and 4d, which bury the fault scarp and overlie a mudflow deposit (unit 4d) that partly fills the graben produced during the most recent faulting event.

FAULTING AND DEFORMATION

Faulting Associated with the Main Fault

Exposures of the main fault zone at three different localities (trenches NC-1, NC-2, and NC-3) showed some variations in the

near surface expression of faulting. In trench NC-1, the main fault is oriented N9E, 65-75°W. It juxtaposes North Creek alluvium (unit 1) in the footwall against colluvium derived from the fault scarp or mudflow deposit (unit 2a) and a younger mudflow deposit (unit 3). Young scarp derived colluvium (units 5a, 5b, 5s) and historical slopewash (unit 6a) are in depositional contact with the fault scarp. Cumulative stratigraphic separation across the main fault zone is greater than the height of the fault scarp combined with the depth of trench NC-1 below the scarp (approximately 11 m). On the south wall of trench NC-1 (Figure 7) the fault zone consists of two closely spaced (30 to 80 cm apart) planar faults that bound a block of displaced North Creek alluvium. Minor splays forming a small graben occur within the down-dropped block. On the north wall of this trench the fault is a single, well defined fault plane associated with a 30 cm-wide zone in which the long axes of clasts are oriented sub-parallel to the fault. The free-face of the fault scarp formed along the main fault during the most recent surface faulting event is preserved as a distinct planar contact on both walls.

In trench NC-2, the displacements associated with the main fault during the most recent faulting event occur across a 4-meter wide zone that contains at least two major faults and several subparallel minor faults. The two major faults are oriented N25E, 50NW and N25E, 60NW. The easternmost of these faults forms the boundary of a 10 to 60 cm-wide shear zone produced by prior surface faulting events. Scarp-derived colluviums, alluvial fan deposits from "South Creek," and older alluvial fan deposits are juxtaposed by the main fault zone. An older fault plane that has not slipped during at least the two most recent faulting events is located 4 m east of the main fault zone (Figure 8, station 2). This fault is a well defined, planar contact, oriented N5W, 67SW, between

older alluvial fan deposits and scarp-derived colluvium. A 10- to 20-cm wide zone cemented by calcium carbonate occurs parallel to the fault in the upthrown block.

In trench NC-3, two surface faulting events are recognized and the primary displacement occurred along different fault planes during each of these events. During the most recent displacement occurred along a fault east of, and higher on the scarp than, the older existing trace. During this faulting event a coherent block of alluvial fan material (unit 1) was downdropped and rotated back towards the main fault. The buried free-face of the main fault (Figure 9, station 0), which forms the eastern boundary of the block, is oriented N23E, 50-60E; a secondary fault (station 2.5) across which only 10 to 15 cm of displacement occurred forms the western boundary. During the previous event, displacement occurred along a fault (station 5) closer to the base of the scarp. Scarp-derived colluvium from this event is in depositional contact with alluvial fan deposits along the free-face of the fault scarp, which is oriented N15E, 75N. The trench exposures are not deep enough to show if older scarp-derived colluvial units occur at depth. Displacement did not occur along the western fault during the most recent surface rupture event.

Antithetic Faulting

Graben are not well defined at the North Creek site, but minor antithetic faults were exposed in trenches NC-1 and NC-3. Antithetic faults were not observed in trench NC-2, but some of the breaks in slope within the alluvial fan surface west of the trench may represent antithetic fault scarps that have been partly buried by post-faulting alluvial fan deposits from "South" Creek.

In trench NC-1 two small faults were exposed in the western end of the trench. The eastern antithetic fault is an apparent high angle reverse fault with a down-to-the-east displacement of approximately 20 cm. Down-to-the-west displacement across the western fault is approximately 60 cm. The upper contact of unit 2s in the west wall of trench NC-1A is approximately 60 cm higher than the contact at the west end of trench NC-1; this appears to be the result of displacement across another antithetic fault that trends subparallel to and along the axis of trench NC-1A. Total down-to-the-east displacement across the antithetic faults exposed in trenches NC-1 and NC-1A is 0.2 m.

Trench NC-3 extends across the entire zone of faulting associated with the most recent surface faulting event. During this event two antithetic faults formed 13 m and 17 m west of the main fault. Down-to-the-east displacement across these faults is 27 and 20 cm, respectively. The faults strike N15E and N21E and dip 60 to 70 SE. The easternmost fault is the boundary of a small graben that was partly filled by a mudflow deposit (unit 4b). Surface expression of this antithetic fault is pronounced immediately north of trench NC-3. The western antithetic fault splays into several traces in the upper part of the trench and exhibits only subtle surface expression.

CUMULATIVE DISPLACEMENT

Figure 10 is a topographic profile across the fault zone 20 m north of trench NC-1. Based on the topographic profile and exposures in test pit 1, the vertical stratigraphic separation of the North Creek fan surface across the main fault zone is 12 m. Vertical stratigraphic separation of the North Creek fan surface across the main fault and scarp height relative to true tectonic displacement has been increased as a result of

antithetic faulting on the downthrown block. The cumulative net tectonic displacement of the North Creek fan surface, calculated by projecting the fan surface on both sides of the fault outside the deformed zone to the projected trace of the fault plane, is 7.0 ± 0.5 m (Figure 10).

DISPLACEMENT PER EVENT

Estimates of the amount of displacement during the most recent event at the North Creek site are based on the geometry of the main fault, scarp morphology, thickness of scarp-derived colluvial units, and topographic profiles of surfaces displaced across the fault. These estimates are summarized in Table 3. On the south wall of trench NC-1 (Figure 7) the point of intersection of the projected plane of the eastern trace of the main fault and the pre-faulting ground surface is 0.5 m above the base of the scarp-derived colluvium. Displacement across the western trace based on the height of the buried free face is at least 1.9 m, producing a total down-to-the-west displacement of at least 2.4 m. On the north wall, displacement occurred along a single fault plane. The height of the buried free-face of this fault, measured from the top of a soil similar to unit 2s to the intersection of the projection of the fault plane and the pre-faulting ground surface, is 2.2 m down-to-the-west. Total displacement across antithetic faults observed in trenches NC-1 and NC-1A is approximately 0.2 m down to the east. The cumulative down-to-the-east displacement (0.2 m) subtracted from the estimates of displacement across the main fault (2.4 and 2.2 m) suggests a value of 2.0 to 2.2 m for net vertical tectonic displacement across the zone.

In trench NC-2, the cumulative down-to-the-west displacement of a fine-grained alluvial deposit (unit 7c) across the series of faults formed during the most recent faulting event is

4.5 m. It is uncertain how much of this displacement is the result of graben formation on the downthrown block west of trench NC-2.

In trench NC-3, the sloping surface between the inflection in the scarp profile (Point A, Figure 11) and the crest of the fault scarp represents a remnant of the fault scarp that existed prior to the most recent event. The vertical distance (1.5 to 2.1 m) between the projections of the displaced ground surface on both sides of the main fault beyond the zone of slumping to the projection of the main fault plane represents the displacement across the main fault during the most recent event. Cumulative down-to-the-east displacement across the antithetic faults (0.47 m) is subtracted from the displacement measured across the main fault (1.5 to 2.1 m) to give a value of between 1.0 to 1.6 m for the net vertical tectonic displacement across the fault zone.

Topographic profiles of the surfaces of mudflow deposits that are displaced across the fault at locations immediately north of, and approximately 750 m south of, trench NC-3 are shown on Figure 12. Displacement is calculated by projecting the surface of the mudflows on both sides of the fault to the projected trace of the fault. Estimates of the displacement of the two surfaces are 2.2 m and 2.1 to 3.1 m. This displacement appears to have occurred during the most recent surface faulting event.

Assessment of displacement per event for the oldest event(s) recognized at the North Creek site is more difficult because critical relationships lie below the bottoms of the trenches. The stratigraphy exposed in trenches NC-1, NC-2, and NC-3 record only two surface faulting events that post-date the North Creek alluvial fan surface. However, geomorphic relationships suggest there may have been a third

event. A strath terrace inset 2.6 m below the North Creek alluvial fan surface is preserved on the upthrown block of the fault. Trench NC-1 is excavated into the main fault scarp below this terrace. If this terrace formed in response to a surface faulting event, the height of the terrace scarp measured adjacent to the fault scarp (2.6 m) may approximate the displacement that occurred along the main fault during that faulting event. Because of channel erosion that would have occurred in the vicinity of trench NC-1, it is unlikely that scarp-derived colluvial units from this event would be deposited and/or preserved in this area. Alternatively, the terrace may have formed in response to a shift in the channel of North Creek that was not related to a tectonic event. In test pit 1, 20 m north of trench NC-1, the North Creek fan surface is preserved approximately 10 m from the base of the main fault scarp (Figure 8). There is stratigraphic evidence for only two faulting events exposed in this test pit. However, scarp-derived colluvium from an earlier event may be confined to within 10 m of the main fault and therefore, would not be exposed in the test pit.

If the tectonic displacement during the most recent event was between 1.0 and 4.5 m, and most likely about 2 m (Table 3), and if the cumulative net vertical tectonic displacement across the fault zone (7.0 $\pm$ 0.5) was produced by two events, then tectonic displacement associated with the event prior to the most recent event probably would have been about 4.5 to 5.5 m. An additional 4 to 5 m of displacement on the main fault resulting from backtilting and/or graben formation during this event would be required to account for the total vertical stratigraphic separation (12 m) of the North Creek fan surface across the main fault (Figure 10). However, if the 2.6 m-high terrace scarp on the upthrown block is representative of a third (oldest) event and displacement during the most recent event was about 2 m, tectonic displacement per

event during each of the past three surface faulting events has varied from about 2.0 to 3.0 m.

A comparison of available data on the amount of displacement present at different locations along the Wasatch fault zone is presented in Table 4.

RECURRENCE OF SURFACE FAULTING

The data on recurrence of surface faulting at the North Creek site, and from other sites along the Wasatch fault zone, are summarized on Table 5. At least two, and probably three, surface faulting events have occurred along the segment of the fault at North Creek since deposition of a burn layer in the North Creek alluvium approximately 5200 years ago (4580 ^{14}C yr B.P.) and prior to settlement of the region approximately 135 years ago. Data from the site allow estimation and comparison of average and actual recurrence intervals.

The average recurrence depends, in part, on when the first and last events occurred during this interval (Swan and others, 1980a). If an event occurred immediately before deposition of the burn layer in the North Creek alluvium and three events occurred subsequently, the average recurrence interval would be a minimum of 1300 years (5200 years divided by 4 events). The maximum value of 5200 years is calculated based on the assumption that only 2 events occurred during this interval and that the first identified event occurred immediately after deposition of the burn layer and the second event occurred shortly before settlement of the area. A median range of between 1700 and 2600 years can be calculated by dividing the interval (5200 years) by the number of faulting events (2 or 3).

At the North Creek site the actual intervals between successive events can be estimated based on radiocarbon dates (Table 2) for deposits exposed in the trenches. The relationship between the deposition of stratigraphic units that have been dated and the timing of tectonic events is shown on Figure 13. The radiocarbon dates used to calculate recurrence intervals have been corrected to calendar years using the calibration tables of Clark (1975). The radiocarbon dates are cited as ^{14}C yr B.P.; the reference year 1950 is used in the standard calculation of radiocarbon dates. The corrected ages are reported as dates on the Roman calendar. The corrected age range reflects the standard deviation (one-sigma), which incorporates both the analytical error and the error associated with the calibration curve. The corrected dates are rounded to the nearest 5 years.

In trench NC-3 a sample of an organic-rich soil (unit 2s) developed on scarp-derived colluvium that was deposited following the the second-most recent surface faulting event yielded a date of 2235 to 1940 B.C. (3640 $\pm$75 ^{14}C yr B.P.). This date provides a minimum limiting date for surface faulting events that occurred prior to the most recent event. The interval of time for deposition of the scarp derived colluvium and formation of the soil following this faulting event may have been relatively short, on the order of a few hundred years. This suggests that the second most recent surface faulting event probably occurred 4000 to 4500 years ago.

The most recent surface faulting event occurred after deposition of detrital charcoal between 770 to 965 AD (1110 $\pm$ 60 ^{14}C yr B.P.) in unit 3as exposed in trench NC-3 (Figure 9). Another date of 553 to 710 AD (1350 $\pm$ 70 ^{14}C yr B.P.) on detrital charcoal from unit 7c, trench NC-2, which was also deposited prior to this faulting event, is consistent with the

maximum limiting age given above. These dates indicate that the most recent surface faulting event occurred less than 1000 to 1200 years ago.

The timing of surface faulting events along the segment of the Wasatch fault at the North Creek site based on the available radiocarbon dates are summarized on Table 5. Based on the stratigraphic relationships of the dated units in trench NC-3, the interval between the two most recent surface faulting events was greater than 2900 years and probably less than 4500 years. If three surface rupture events have occurred since deposition of the North Creek fan, and two of these events occurred prior to burial of the Unit 2s soil in trench NC-3, the interval of time between the two older events would have been no longer than 1600 years and may have been significantly less. Although the actual intervals between successive events at the North Creek site fall within the range of values calculated for the average recurrence intervals, they vary from the median values by as much as a factor of two (Table 5).

SLIP RATE

The age of the charcoal layer in the North Creek alluvium, 3525 to 3270 BC (4580 ^{14}C yr B.P.) and cumulative net tectonic displacement of the alluvial fan (7.0 $\pm$ 0.5 m) from topographic profile (Figure 10) provide data to calculate a late Holocene slip rate for this segment of the Wasatch fault. Based on the corrected date, the late Holocene slip rate is 1.3 $\pm$ 0.1 mm/year. Table 6 summarizes the available slip rate data for the Wasatch fault.

SUMMARY AND CONCLUSIONS

1. The following observations and conclusions are based on geologic studies completed at the North Creek site:

   a. Cumulative net vertical displacement of an alluvial fan at the mouth of North Creek is 7.0 ± 0.5 m down to the west across the main fault scarp. Detrital charcoal from the upper section of the faulted alluvial fan has been dated by Bucknam (1978) at 3525 to 3270 BC (4,580 ^{14}C yr B.P.). Based on these data, the late Holocene slip rate at this location is 1.3 ± 0.1 mm/year.

   b. At least two, and probably three, surface faulting events have occurred along this trace of the fault since deposition of the dated fan deposits. The two most recent events are represented by scarp-derived colluviums. A 2.6 m-high strath terrace inset into the North Creek alluvial fan surface on the upthrown side of the fault may have formed in response to an earlier surface faulting event. The stratigraphic record of such an event is either buried below the trench exposures or was removed by channel erosion on the downthrown block prior to the second-most recent event.

   c. Estimates of the net vertical tectonic displacement along the main fault trace during the most recent surface faulting event range from 1.0 to less than 4.5 m, with a preferred value of about 2 m (Table 3). Assuming that the cumulative net vertical tectonic displacement across the fault zone (7.0 ± 0.5 m) was produced by two events, tectonic displacement associated with the older event would have been about

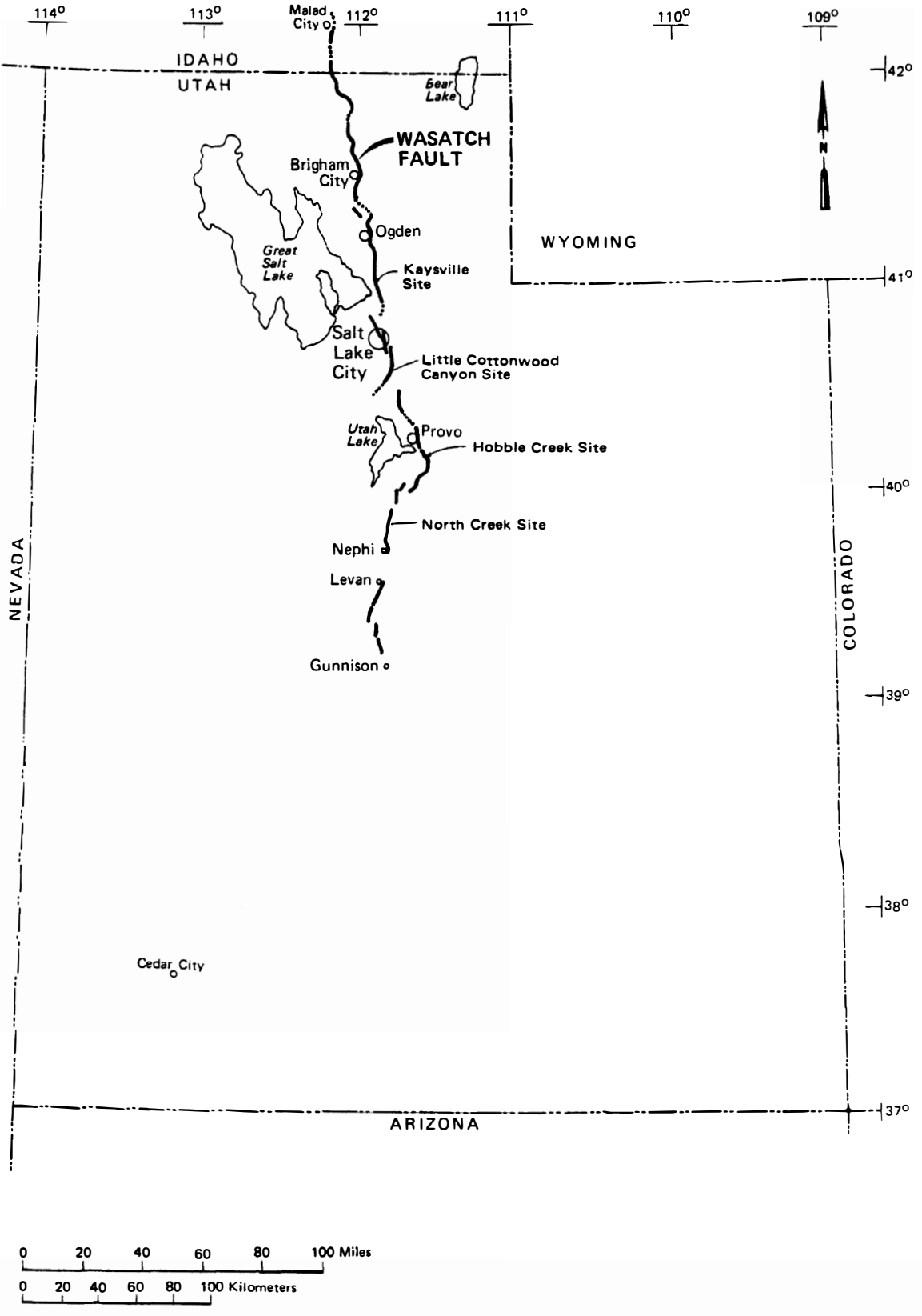
4.5 to 5.5 m. An additional 4 to 5 m of displacement on the main fault resulting from graben formation during this event would be required to account for the total vertical stratigraphic separation (12 m) of the North Creek fan surface across the main fault. If the 2.6 m-high strath terrace on the upthrown block is representative of a third (oldest) event, tectonic displacement per event during each of the past three surface faulting events has varied from about 2.0 to 3.0 m.

d. The average recurrence of surface faulting events during the late Holocene is between 1300 and 5200 years, with a median range of between 1700 and 2600 years. The actual intervals between events appear to have varied from these mean values by as much as a factor of two. Based on the stratigraphic and structural relationships of the dated deposits at the North Creek site the interval between the two most recent events was greater than 2900 years and probably less than 4500 years. If there have been three events post deposition of the North Creek fan, the interval between the second and third most recent events was less than 1600 years.

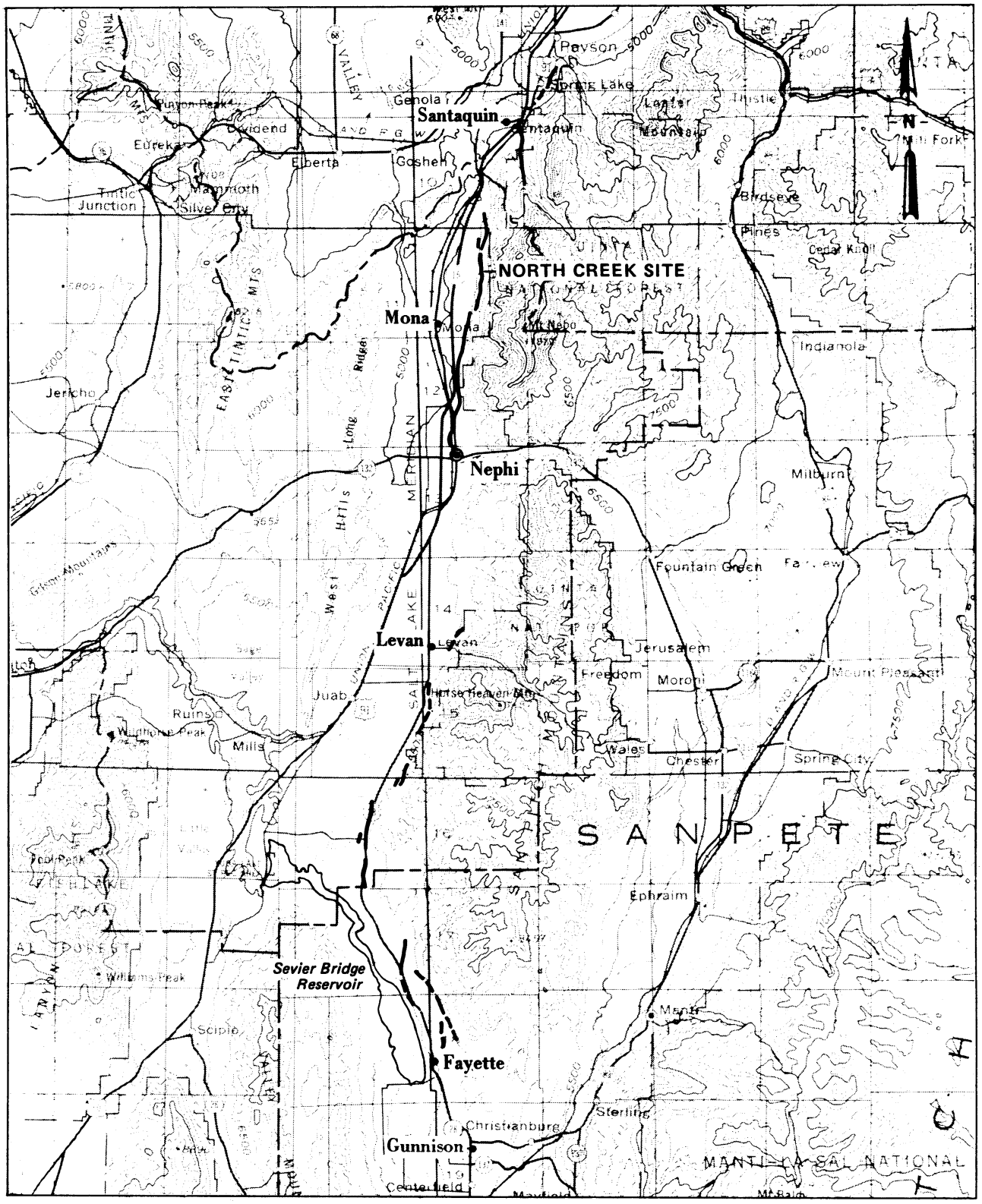
REFERENCES

Bucknam, R.C., 1978, Northwestern Utah seismotectonic studies: U.S. Geologic Survey, National Earthquake Hazards Reduction Program, Summaries of Technical Reports, v. VII, p. 64.

Clark, R.M., 1975, A calibration curve for radiocarbon dates: Antiguity, v. XLIX, p. 251-266.



Project No. 14093	USGS Contract No. 14-08-0001-19115	REGIONAL LOCATION MAP	Figure 1
Woodward-Clyde Consultants			



Scale 1:500,000 Base from USGS State Map of Utah

EXPLANATION

Holocene fault

0 10 mi

0 10 km

Project No. 14093	USGS Contract No. 14-08-0001-19115	MAP SHOWING SOUTHERN PORTION OF WASATCH FAULT ZONE	Figure 2
Woodward-Clyde Consultants			

QUADRANGLE LOCATION

Area of detailed map of Wasatch fault, North Creek Site (Figure 4)

Base map — Santaquin 15-minute quadrangle

0 1 mi

0 1 km

Project No. 14093	USGS Contract No. 14-08-0001-19115	LOCATION MAP North Creek Site	Figure 3
Woodward-Clyde Consultants			

EXPLANATION

Fault scarp; solid where clearly defined, dashed where less distinct, dotted where buried or concealed; bar and ball on downthrown side

A A′ Topographic profile

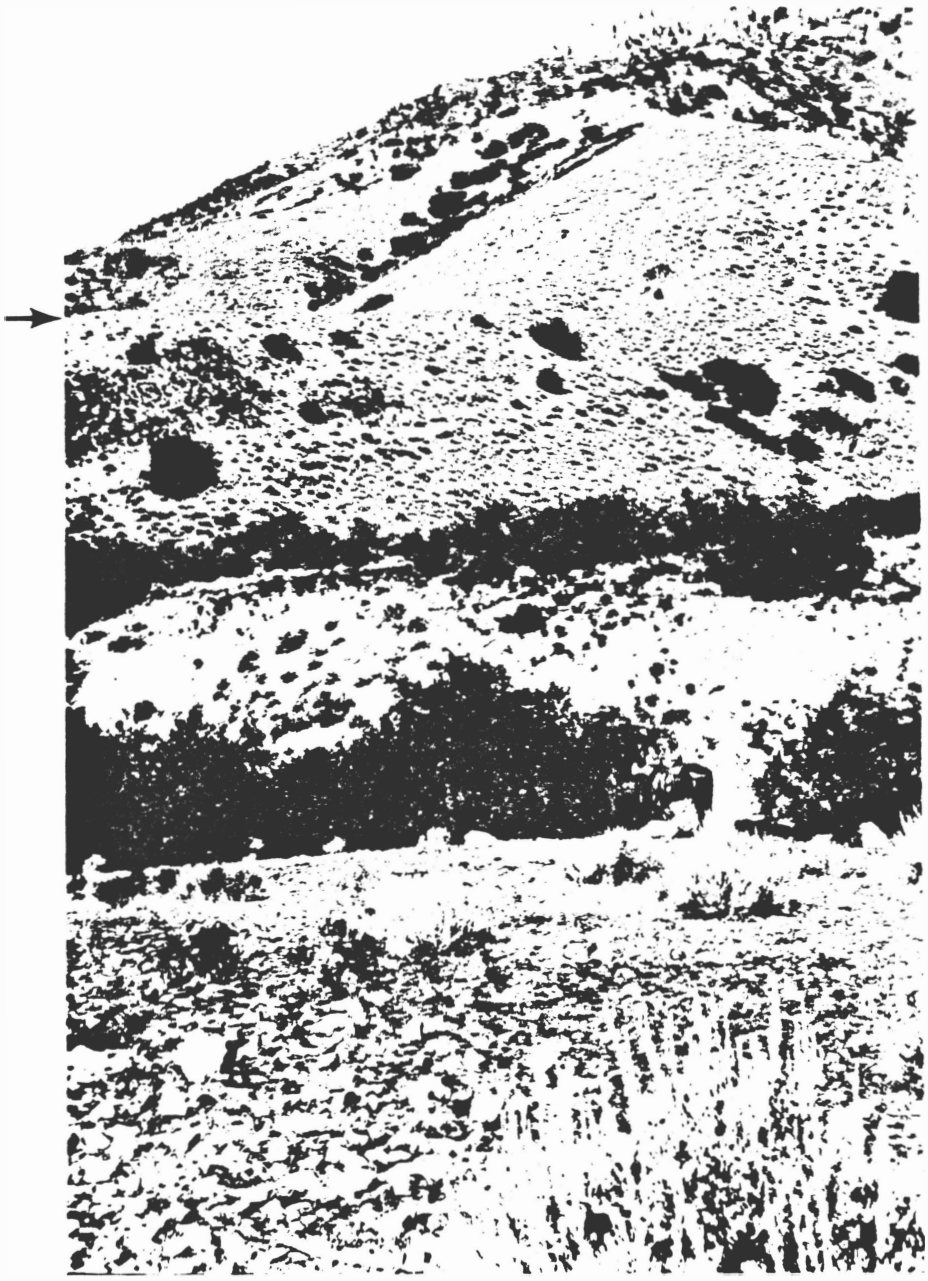
NC-1 Exploration trench

TP-1 Test pit

0 500

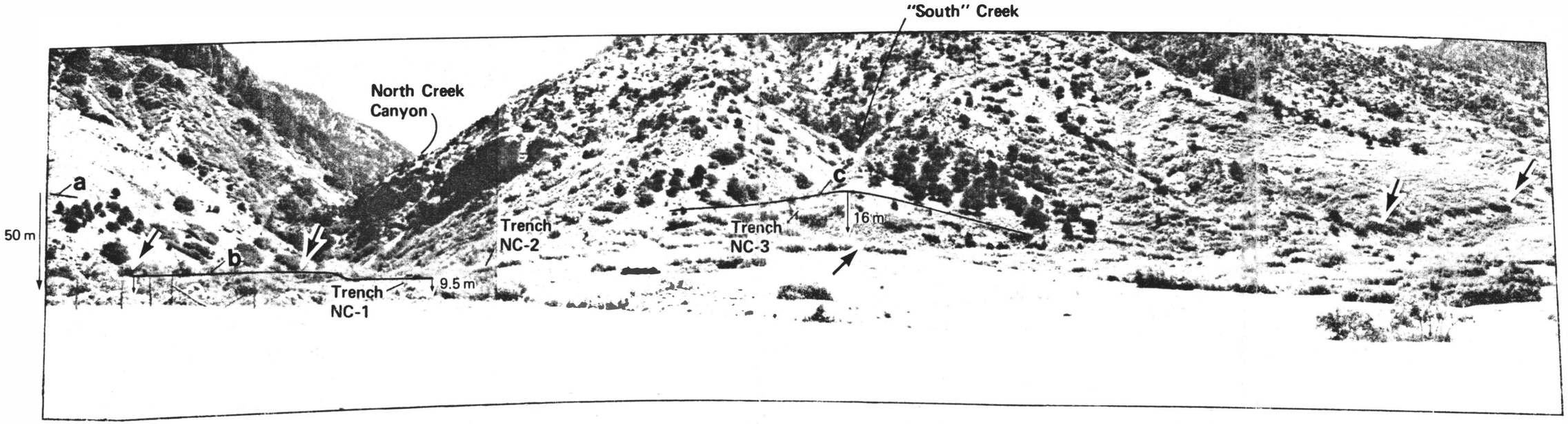
0 150

Project No. 14093	USGS Contract No. 14-08-0001-19115	MAP OF FAULT TRACES North Creek Site	Figure 4
Woodward-Clyde Consultants			



The Wasatch fault displaces middle Holocene-age alluvium deposited by North Creek forming a 9.5 meter high scarp. Older Pleistocene fan deposits (arrow) are displaced more than 50 m. Trench NC-1 was excavated into the fault scarp behind the horse. Photograph was taken in 1903 by F. B. Weeks. View is towards the east.

Project No. 14093	USGS Contract No. 14-08-0001-19115	PHOTOGRAPH OF MAIN FAULT SCARP North Creek Site	Figure 5
Woodward-Clyde Consultants			



Repeated Quaternary displacements on the Wasatch fault (arrows mark location) are indicated by progressively lower scarp heights in successively younger deposits. Pleistocene fan deposits (a) that have a well developed calcic soil are displaced vertically more than 50 m; the scarp across the middle Holocene alluvium (b) at the mouth of North Creek Canyon is only 9.5 m high. The scarp across an intermediate age fan (c) at "South" Creek is 16 m high. View is eastward.

Project No. 14093	USGS Contract No. 14-08-0001-19115	PHOTOGRAPH OF FAULT SCARP North Creek Site	Figure 6
Woodward-Clyde Consultants			

UNIT DESCRIPTIONS

Unit 1 North Creek Alluvium:
Light gray to light brownish gray (10 YR 5.5/2, dry) grayish brown to brown (10 YR 5/2.5, moist) interbedded sandy gravel and gravelly sand; moderately well to well sorted, some open-work gravel; clasts are generally subrounded to subangular; mode <3 cm, maximum size 70 cm long; discontinuous carbonate coats on most clasts; clasts consist of limestone and quartzite.

Unit 2a Scarp-derived Colluvium or Alluvium (mudflow):
Light grayish brown to grayish brown (10 YR 5.5/2, dry) dark grayish brown (10 YR 6/2, moist) gravelly sandy silt, contains 15 to 20 percent subrounded and subangular pebbles and small cobbles; massive; unsorted; discontinuous thin carbonate coats on clasts.

Unit 2b Alluvium:
Light brownish gray to pale brown (10 YR 6/2.5, dry) grayish brown to dark grayish brown (10 YR 4.5/2, moist) sandy gravel and gravelly silty sand; stratified; moderately to well sorted; contains some open work gravel; loose; discontinuous carbonate coats on clasts.

Unit 2s Soil Developed on Units 2a and 2b:
Dark gray (10 YR 4/1, dry) black (10 YR 2/1, moist) gravelly sandy silt; organic rich; contains some partly burned and decayed modern wood and tree roots.

Unit 3 Mudflow (?) Deposit:
Light brownish gray to pale brown (10 YR 6/2.5, dry) dark grayish brown (10 YR 4/2, moist) gravelly silty sand; contains 10 to 15 percent subrounded and subangular pebbles; poorly sorted, massive; carbonate coatings on clasts.

Unit 3s Soil Developed on Unit 3:
Weakly developed A horizon.

Unit 4 Mudflow Deposit:
Grayish brown (10 YR 5/2, dry) very dark grayish brown (10 YR 3/2, moist) gravelly sandy silt, contains 5 to 10 percent subangular and angular pebbles and a few boulders (up to 20 cm long); poorly sorted; massive; discontinuous weak organic A horizon of soil formed on upper 5 to 20 cm of unit.

Unit 5a Scarp-derived Colluvium:
Light gray (10 YR 7/2, dry) grayish brown (10 YR 5/2, moist) silty sandy gravel, contains 60 percent subrounded and subangular pebbles, cobbles, and a few boulders, maximum size 30 cm long, mode <30 cm; nonstratified; massive; loose.

Unit 5b Similar to Unit 5a, except less coarse.

Unit 5s Soil Developed on Unit 5b:
Weakly developed A horizon.

Unit 5c Mudflow Deposit:
Light brownish gray to grayish brown (10YR 5.5/2, dry) dark grayish brown (10YR 4/2, moist) gravelly sandy silt, contains 40 percent subangular and subrounded pebbles, cobbles, and a few boulders, mode <2 cm, maximum size 3 cm long; poorly sorted; massive; carbonate coatings on clasts.

Unit 5d Sandy Alluvial Fan Deposit:
Grayish brown (10 YR 5/2, dry) very dark grayish brown (10 YR 3.5/2, moist) interbedded fine sandy silt and silty coarse sand.

Unit 6a Historical Slopewash:
Light brownish gray (10 YR 6/2, dry) very dark grayish brown (10 YR 3/2, moist) gravelly silt and silty gravel; contains 10 to 80 percent subrounded and some subangular pebbles and small cobbles, mode <2 cm, maximum size 10 cm long; weak stratification parallel to ground slope.

6b Historical Mudflow Deposit:
Grayish brown (10 YR 5/2, dry) very dark grayish brown (10 YR 3/2, moist) gravelly sandy silt, contains 40 percent subangular pebbles, cobbles, and boulders, mode <3 cm, maximum size 35 cm long; poorly sorted, massive.

EXPLANATION

Lithologic contact: dashed where less distinct; dotted where approximate or gradational

Soil boundary

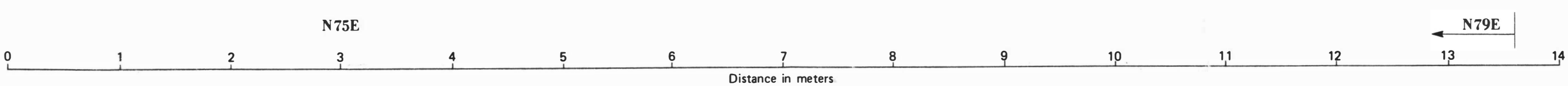
Fault: solid line where well defined; dashed where inferred; bold numbers indicate strike and dip of fault plane; arrows indicate relative sense of displacement

N6E, 70W

Buried free-face of fault scarp

n_1 Crest of main fault scarp is 5 m higher than ground surface at east end of trench NC–1

n_2 The average dip on the buried free-face is approximately 75° and decreases to 70° in upper 60 cm



Project No. 14093C	USGS Contract No. 14-08-0001-19115	LOG OF TRENCH NC-1 North Creek Site	Figure 7
Woodward-Clyde Consultants			

UNIT DESCRIPTIONS

Unit 1 **Older Alluvium:**

1a Light gray to very pale brown (10 YR 7/2.5, dry) grayish brown to brown (10 YR 5/2.5, moist) sandy gravel, contains 60 percent subangular pebbles and a few cobbles (up to 10 cm long); weakly stratified; generally loose, locally indurated by calcium carbonate.

1b Very pale brown (10 YR 8/3, dry) pale brown (10 YR 6/3, moist) gravelly clayey silty sand; generally poorly sorted; contains 5 percent subangular pebble- and boulder-size clasts of limestone, mode <2 cm, maximum size 40 cm long; massive; moderately to strongly indurated by calcium carbonate which occurs both as continuous coatings up to 3 to 4 mm thick on clasts and disseminated throughout matrix resulting in a white (10 YR 8/1, dry) color where present.

Unit 2 **Scarp-derived Colluvium:**
Very pale brown to pale brown (10 YR 6.5/3, dry) brown (10 YR 5/3, moist) gravelly clayey silty sand, contains 5 percent subangular and angular pebbles and cobbles, mode <2 cm, maximum size 20 cm long; poorly sorted, massive; calcium carbonate occurs as thin (generally <1–2 mm) coats on clasts and disseminated throughout matrix.

Unit 2s **Soil Developed on 2:**
Similar to Unit 2, except slightly whiter due to greater accumulation of calcium carbonate.

Unit 3 **Alluvium (channel deposits):**
Light gray to very pale brown (10 YR 7/2.5, dry) brown (10 YR 5/3, moist) interbedded slightly silty sandy gravel and some gravelly coarse sand; weakly bedded; gravel clasts are angular and subangular and consist of limestone and quartzite; generally loose; pervasive cementation by calcium carbonate (non-pedogenic) occurs in discontinuous lenses.

Unit 4 **Scarp-derived Colluvium:**
Light gray to very pale brown (10 YR 7/2.5 dry) grayish brown to brown (10 YR 5/2.5, moist) gravelly sandy silt, contains 20 to 30 percent angular and subangular pebble-, cobble-, and a few boulder-size clasts, mode <3 cm, maximum size 25 cm long; poorly sorted; massive; very weak stratification in places; discontinuous calcium carbonate coatings on clasts.

Unit 5 **Colluvium (?):**
Similar to Unit 4.

Unit 6 **Scarp-derived Colluvium:**
Very dark gray (10 YR 3/1, dry) black (10 YR 2/1, moist) gravelly sandy silt, contains 20 percent angular and subangular pebbles and cobbles, mode <2 cm, maximum size 10 cm long; poorly sorted; organic-rich.

Unit 7 **Alluvial Fan Deposits**

7a **Mudflow Deposit:**
Grayish brown to brown (10 YR 5/2.5, dry) dark grayish brown (10 YR 4/2, moist) silty sandy gravel, contains 50 to 60 percent angular and subangular pebbles and a few cobbles, mode <1 cm, maximum size 15 cm long; poorly sorted, loose; thin discontinuous coats of calcium carbonate on bottoms of some clasts.

7b **Soil Developed on Unit 7a:**
Similar to Unit 7a except darker (very dark gray 10 YR 3/1, dry), organic-rich.

7c **Sandy Silt Alluvium:**
Brown (7.5 YR 5/2, dry) brown to dark brown (7.5 YR 4/2, moist) coarse sandy silt, contains a few small (<5 mm) pebbles; upper 5 to 10 cm is grayer; locally, contains detrital charcoal.

7d **Coarse Sandy Alluvium:**
Grayish brown (10 YR 5/2, dry) very dark grayish brown (10 YR 3/2, moist) interbedded coarse sand and fine sandy silt.

7e **Mudflow Deposit:**
Light brownish gray (10 YR 6/2, dry) dark grayish brown (10 YR 4/2, moist) silty sandy gravel, contains 60 percent angular and subangular pebbles and a few cobbles, mode <2 cm, maximum size 10 cm; poorly sorted; massive; loose.

7s **Soil Developed on Unit 7:**
Dark gray (10 YR 4/1, dry) black (10 YR 2/1, moist) gravelly silt, contains 30 percent angular pebbles and cobbles, mode 1–2 cm, maximum size 10 cm long; organic-rich; loose.

Unit 8 **Colluvium and Associated Fan Deposits:**

8a **Alluvial Fan Deposits:**
Light brownish gray (10 YR 6/2, dry) dark grayish brown (10 YR 4/2, moist) silty sandy gravel and minor pebbly silt lenses, contains 40 to 60 percent angular to subrounded pebble- and cobble-size clasts; very weakly stratified.

8b **Colluvium:**
Dark gray to dark grayish brown (10 YR 4/1.5, dry) very dark gray (10 YR 3/1, moist) gravelly sandy silt, contains 10 percent angular and subangular pebbles and cobbles, mode <2 cm, maximum size 6 cm long; massive, unsorted; organic-rich.

Unit 9 **Historical Mudflow Deposit:**
Light brownish gray to grayish brown (10 YR 5.5/2, dry) very dark grayish brown (10 YR 3/2, moist) gravelly sandy silt, contains 30 to 50 percent angular and subangular pebbles and cobbles, mode <1 cm, maximum size 25 cm long; poorly sorted; massive.

channel margin

EXPLANATION

Lithologic contact: dashed where less distinct; dotted where approximate or gradational

Soil boundary

N6E,70W — Fault: solid line where well defined; dashed where inferred; bold numbers indicate strike and dip of fault plane; arrows indicate relative sense of displacement

1350 ± 70 — Location and age (^{14}C yr.b.p.) of ^{14}C sample; refer to Table 2 for corrected ages in calendar years.

NOTES

n1 On the fault scarp this unit may also include younger material comparable in age to units 8a, 8b, and 9

n2 Wide zone of sheared material similar to unit 4

n3 Infilled zone of loose, organic-rich material

n4 Zone of sheared material similar to unit 7a

n5 May represent either unit 6 or infill of fine organics derived from unit 6

N65W →

0 1 2 3 4 5 6 7 8 9 10

Distance in meters

Project No. 14093C	USGS Contract No. 14-08-0001-19115	LOG OF TRENCH NC-2 North Creek Site	Figure 8
Woodward-Clyde Consultants			

UNIT DESCRIPTIONS

Unit 1 Alluvial Fan Deposits:
Pale brown to yellowish brown (10 YR 6/3.5, dry) brown to yellowish brown (10 YR 5/3.5, moist) interbedded silty sandy gravel, gravelly sand, pebbly sand, and open-work gravel; gravel clasts are angular and subangular, mode < 2 cm; maximum size 1.75 cm long; moderately to well stratified; sorting is variable; calcium carbonate (generally <1 mm thick) coatings on bottoms of gravel clasts; in some horizons carbonate is disseminated within the matrix giving a whitish color.

Unit 2 Scarp-derived Colluvium:

2a Grayish brown (10 YR 5/2, dry) dark grayish brown (10 YR 3/2, moist) silty sandy gravel, contains 60 percent angular and subangular pebbles and cobbles, mode < 2 cm, maximum size 15 cm long.

2b Pebble- and cobble-gravel; open-work, loose; clasts are angular and subangular.

2c Grayish brown to brown (10 YR 5/2.5, dry) dark grayish brown to dark brown (10 YR 3.5/2.5, moist) gravelly sandy silt, contains 30 percent angular and subangular pebbles and a few cobbles, mode < 1 cm, maximum size 10 cm long; massive; weakly developed fabric subparallels ground surface.

2s Soil Developed on Scarp-derived Colluvium (Unit 2):
Very dark gray (10 YR 3/1, dry) black (10 YR 2/1, moist) gravelly silt, contains 50 percent angular and subangular pebbles, cobbles, and boulders, mode < 2 cm, maximum size 20 cm long; poorly sorted.

Unit 3 Alluvial Fan and Colluvial Deposits:

3a Grayish brown (10 YR 5/2, dry) dark grayish brown (10 YR 4/2, moist) interbedded mudflow and alluvial deposits; mudflow facies are poorly sorted silty gravel, contains 60 to 70 percent angular and subangular pebbles, cobbles, and boulders, mode < 2 cm, maximum size 1 m long; alluvial facies consist of stratified open-work gravel, sandy gravel, and silty sandy gravel; includes some thin (5 cm) buried organic-rich soils, thin organic-rich A horizon of soil on upper 5 to 10 cm **(Unit 3as).**

3b Similar to mudflow deposits described for Unit 3a; contains less gravel, 40 percent.

3c Colluvium:
Grayish brown to brown (10 YR 5/2.5, dry) very dark grayish brown to dark brown (10 YR 3/2.5, moist) gravelly sandy silt, contains 15 percent angular and subangular pebbles, cobbles and boulders, mode < 5 cm, maximum size 20 cm long; poorly sorted.

Unit 3s Soil Developed on Ground Surface Prior to Most Recent Faulting Event:
Weakly developed A horizon; organic-rich.

Unit 4 Scarp-derived Colluvium and Alluvial Fan Deposits:

4a Colluvium:
Similar in color and texture to Unit 1, except looser, bedding dips steeply to the west.

4b Mudflow Deposit:
Similar to 3b, contains slightly more gravel (approximately 50 percent).

4c Colluvium:
Light gray to very pale brown (10 YR 7/2.5, dry) grayish brown to brown (10 YR 5/2.5, moist) open-work pebble- and cobble-gravel, sandy small pebble gravel, and gravelly coarse sand; loose; gravel clasts are angular to subangular; stratification subparallels ground surface.

4d Colluvium:
Similar to 4c; open-work pebble- and cobble-gravel; contains some organic-rich silt and decayed leaf matter.

4s Soil Developed on Unit 4b:
Weakly developed A horizon of soil, organic-rich.

EXPLANATION

Lithologic contact: dashed where less distinct; dotted where approximate or gradational

Soil boundary

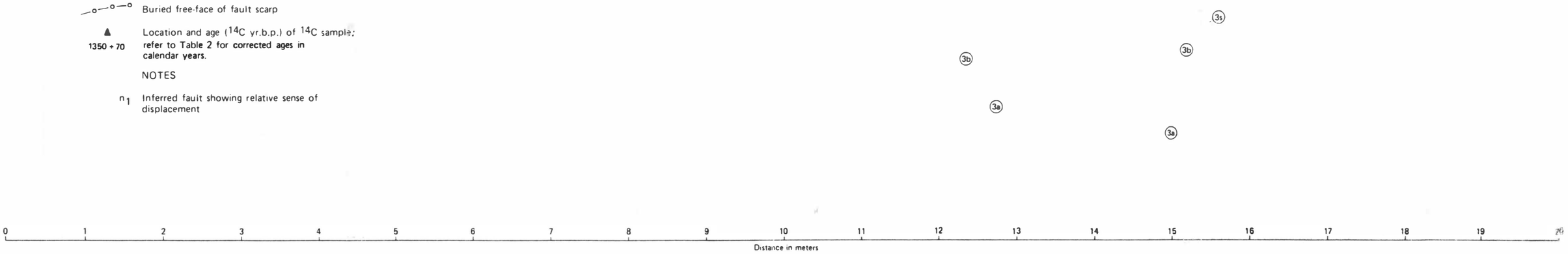
20 — N6E,70W — Fault: solid line where well defined; dashed where inferred; bold numbers indicate strike and dip of fault plane; small numbers indicate stratigraphic separation in cm; arrows indicate sense of displacement.

Buried free-face of fault scarp

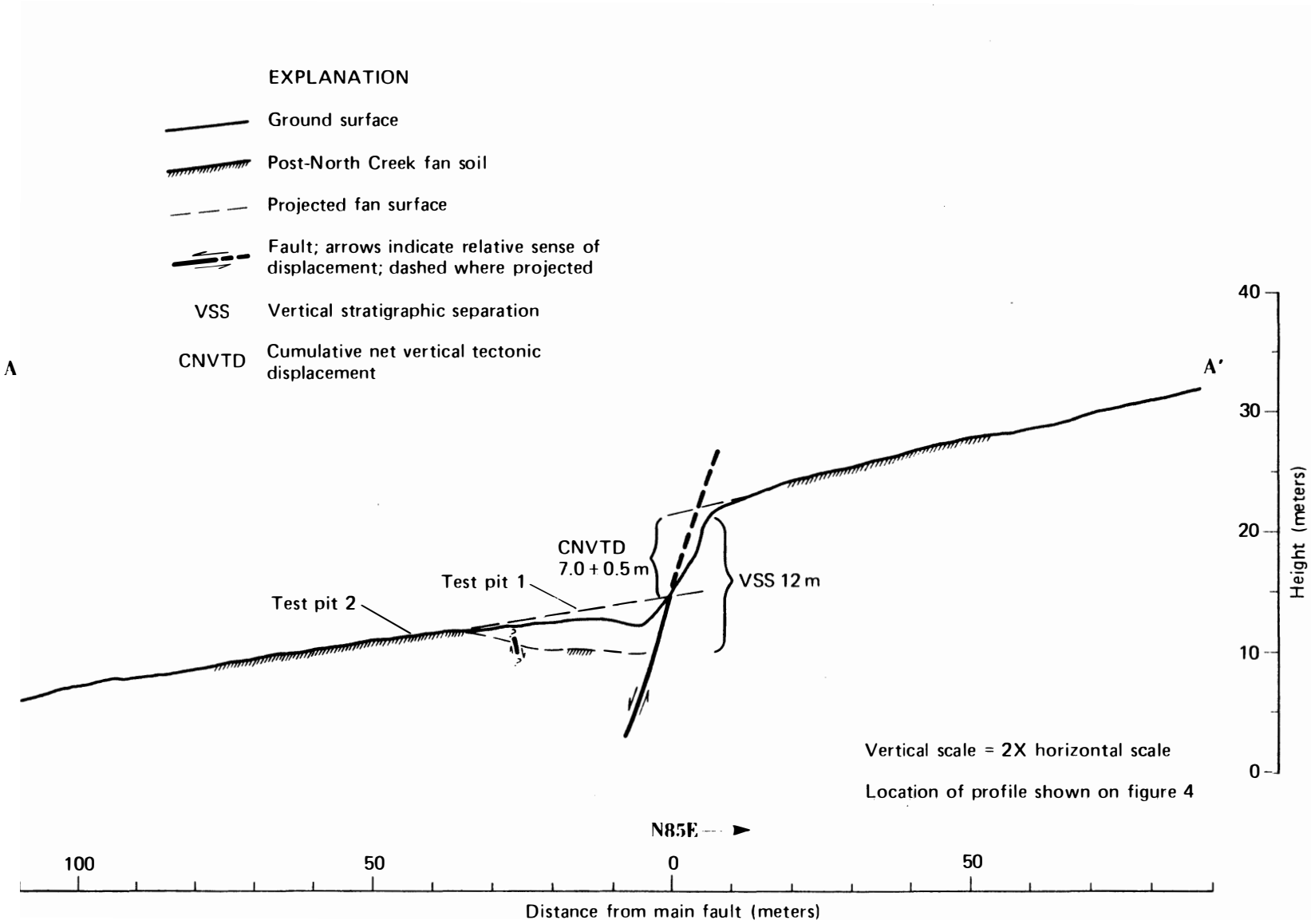
▲ 1350 ± 70 — Location and age (^{14}C yr.b.p.) of ^{14}C sample; refer to Table 2 for corrected ages in calendar years.

NOTES

n_1 Inferred fault showing relative sense of displacement



Project No. 14093C	USGS Contract No. 14-08-0001-19115	LOG OF TRENCH NC-3 North Creek Site	Figure 9
Woodward-Clyde Consultants			



Project No. 14093

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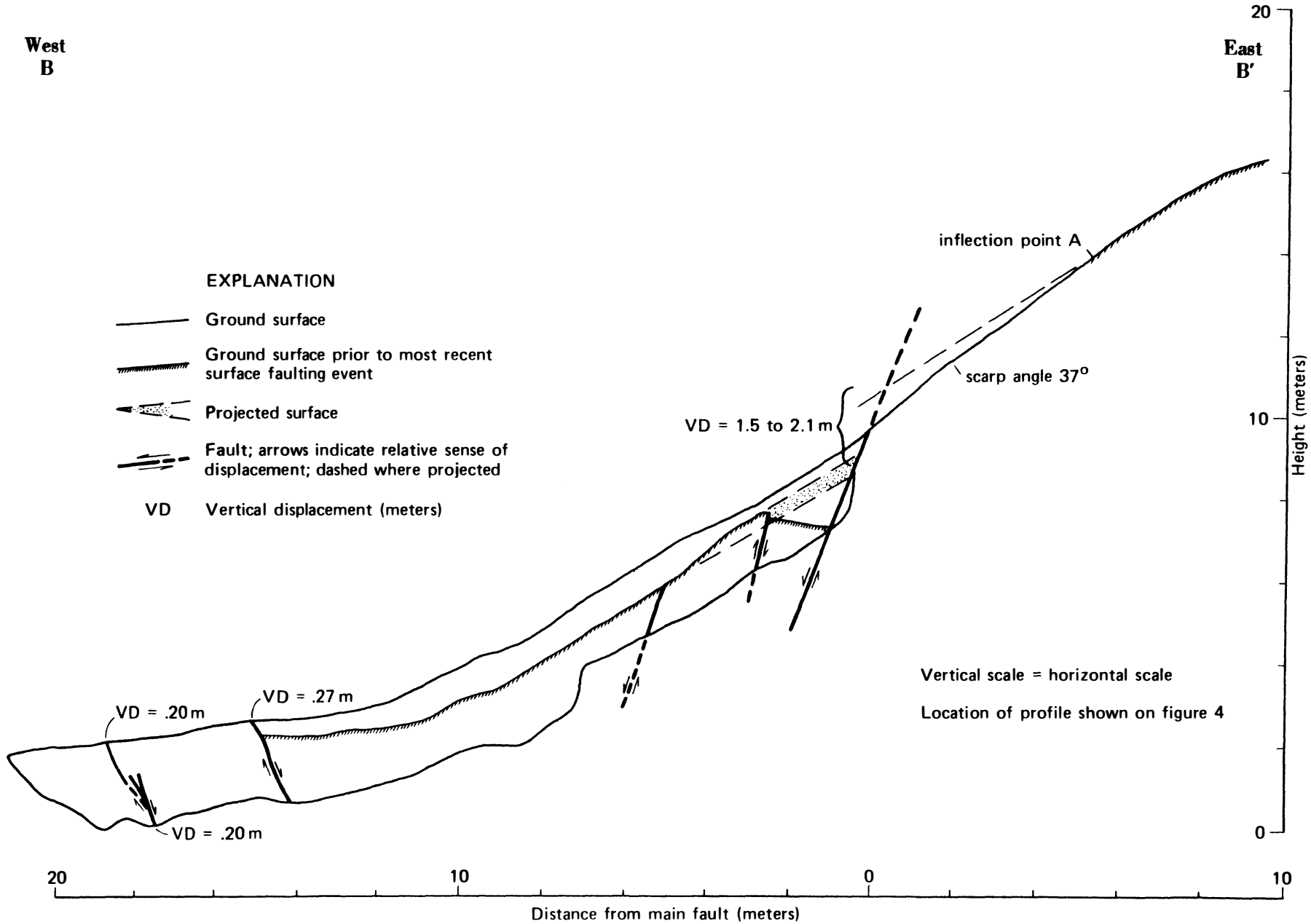
TOPOGRAPHIC PROFILE AA'
North Creek Site

Figure 10



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USGS Contract No. 14-08-0001-19115

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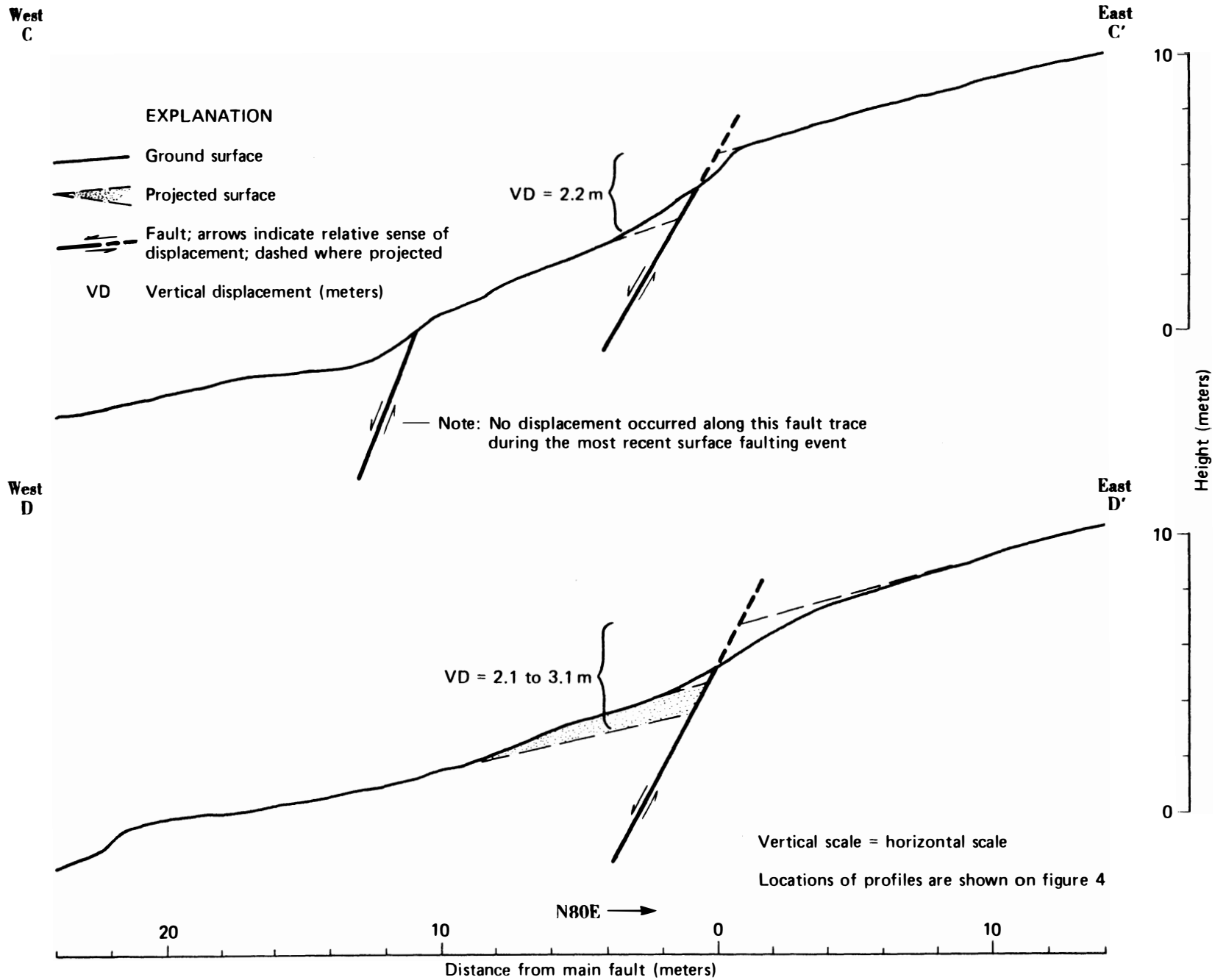
TOPOGRAPHIC PROFILE BB' OF FAULT SCARP AT TRENCH NC-3

North Creek Site

Figure 11



Project No. 14093

USGS Contract No. 14-08-0001-19115

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TOPOGRAPHIC PROFILES CC′ and DD′ OF FAULTED MUDFLOWS
North Creek Site

Figure 12

AGE[1]		COMPOSITE STRATIGRAPHIC SECTION	TECTONIC EVENTS	CORRELATION OF MAPPED UNITS		
^{14}C yr B.P.	Calibrated Date			Trench NC-1 (figure 7)	Trench NC-2 (figure 8)	Trench NC-3 (figure 9)
		Historical mudflow		Unit 6	Unit 9	Unit 4
		Scarp-derived colluvium and graben fill		Unit 5 Unit 4?	Unit 8	
			faulting			
1110±60	770 to 965 A.D.	"South" Creek alluvium		Unit 3	Unit 7 ▲	▲
1350±70	553 to 710 A.D.			Unit 2b		Unit 3
3640±75	2235 to 1940 B.C.					▲
		Scarp-derived colluvium		Unit 2a?	Unit 6	Unit 2
			faulting		—?— — —?—	
		Section not exposed			Unit 5	
			faulting?			
4580	3525 to 3270 B.C.	▲ North Creek alluvium		Unit 1	—?— — —?— Unit 4?	—?— — —?—
		Pre-North Creek fan deposits			Unit 3	Unit 1
					Unit 2	
					Unit 1	

(1) Table 2

Project No. 14093	USGS Contract No. 14-08-0001-19115	RELATIONSHIP AMONG MAPPED UNITS, RADIOCARBON DATES AND TECTONIC EVENTS North Creek Site	Figure 13
Woodward-Clyde Consultants			

Table 1

PROFILE DESCRIPTION OF RELICT SOIL DEVELOPED ON NORTH CREEK ALLUVIAL FAN, EXPOSED IN TEST PIT 2
North Creek Site

HORIZON	DEPTH (cm)	DESCRIPTION
A0	0-2	Root mat
A11	2-6	Dark grayish brown (10YR 4/2, dry), very dark grayish brown (10YR 3/2, moist), pebbly silt loam, contains 10 to 20 percent subangular clasts, mode 1.5 cm, max. 5 cm; slightly plastic, nonsticky; fine to medium crumb structure; loose, friable; numerous roots; clear smooth boundary.
A12	6-42	Dark grayish brown (10YR 4/2, dry), very dark grayish brown (10YR 3/2, moist), gravelly silt loam, contains 20 percent subangular and subrounded pebbles, cobbles, and boulders, mode 7 cm, max. 20 cm; plastic, slightly sticky; weak fine to medium angular blocky structure; friable to firm; numerous roots; clear wavy boundary.
B2	42-67	Grayish brown to brown (10YR 5/2.5, dry) dark grayish brown to dark brown (10YR 4/2.5, moist), gravelly silt loam, contains 20 percent subangular and subrounded pebbles, cobbles and boulders, mode 7 cm, max. 60 cm; plastic, slightly sticky, medium angular blocky structure; very few thin clay films; some roots; clear wavy boundary.
Cca	67-200	Very pale brown (10YR 7/3, dry), brown (10YR 5/3, moist), gravelly sandy loam, contains 30 to 40 percent pebbles, cobbles, and some boulders, mode 5 cm, max. 60 cm; nonplastic; nonsticky; massive; contains approximately less than 5 percent filamentous Stage I carbonate; thin (less than 1 to 2 mm) discontinuous carbonate coatings on bottoms of clasts; gradual to diffuse smooth lower boundary.
C	200-400	Gravelly sand and sandy gravel, weakly stratified, clasts are subangular and subrounded.
	400 cm	Base of exposure.

Table 2
RADIOCARBON DATES
North Creek Site

SAMPLE NUMBER		AGE		LOCATION	DESCRIPTION
WCC No.	Lab No.[1]	^{14}C yr B.P.[3]	Calibrated Date[4]		
WC-12-80-3	DIC-1937	2180 ± 80[5]	415 to 140 B.C.	Trench NC-1A; 2.0 to 2.5 m below ground surface	Bulk soil sample from buried organic-rich soil developed on North Creek alluvium
WC-12-80-5	DIC-1939	1350 ± 70	553 to 710 A.D.	Trench NC-2, station 9; unit 7c	Detrital charcoal from a burn layer in coarse sandy silt alluvium (unit 7c)
WC-12-80-6	DIC-1943	1110 ± 60	770 to 965 A.D.	Trench NC-3, station 11; unit 3as	Detrital charcoal from buried Entisol (unit 3as) developed on alluvial fan deposits (unit 3a)
WC-12-80-7	DIC-1938	3640 ± 75	2235 to 1940 B.C.	Trench NC-3, station 18; unit 2s	Buried organic-rich soil (unit 2s) developed on scarp-derived colluvium (unit 2c)
WC-12-80-11		4580[2]	3525 to 3270 B.C.	Natural exposure along southern bank of North Creek at mouth of North Creek Canyon	Detrital charcoal from burn layer in North Creek alluvium 1.5 m below terrace surface

Notes:

(1) Lab analyses by DICARB Radioisotope Co., Gainesville, Florida

(2) From Bucknam (1978)

(3) Radiocarbon dates are given in years before present relative to the reference year 1950

(4) Based on calibration tables presented by Clark, 1975; the corrected dates are given in calendar years; the corrected age range reflects the standard deviation (one-sigma) and incorporates both the analytical error and the error associated with the calibration curve; corrected dates are rounded to the nearest 5 years.

(5) Age not consistent with stratigraphy; probably too young due to contamination

Table 3

ESTIMATED DISPLACEMENT DURING THE MOST RECENT SURFACE FAULTING EVENT

Vertical Displacement (meters)	Trench NC-1		Trench NC-2	Trench NC-3 (Profile BB′)	Profile	
	North Wall	South Wall			CC′	DD′
Main fault	2.2	2.4	4.5	1.5-2.1	2.2	2.1-3.1
Antithetic faults (cumulative)	0.2	0.2	*	.47	*	*
Net across zone	2.0	2.2	<4.5	1.0-1.6	⩽2.2	⩽3.1

*data not available

Table 4

SUMMARY OF DATA ON DISPLACEMENT PER EVENT ON THE WASATCH FAULT ZONE

LOCATION	VERTICAL DISPLACEMENT PER EVENT ON MAIN FAULT SCARP (m)		NET VERTICAL TECTONIC DISPLACEMENT PER EVENT ACROSS FAULT ZONE		SOURCE
	Average	Measurement for Individual Events	Average	Measurement for Individual Events	
Kaysville Site	3.7 to 7.3	4[1] ≥3.4[2]	≤3.3 to ≤3.7	1.8[1] ≥1.7[2]	Swan and others, (1980a)
Hobble Creek Site	1.6 to 5.6	---	0.8 to 2.8	---	Swan and others, (1980a)
Little Cottonwood Canyon Site	4.3 to 6.5	0.4[3]	1.3 to 2.0	---	Swan and others, (1980b)
North Creek Site	4.0 to 6.0	1.5 to 4.5[4] (2.5) 2.6[5] 9.5[6]	2.2 to 3.8	1.0 to <4.5[4] (2.0) ≤2.6[5] 4.5 to 5.5[6]	this report

Notes:

(1) Most recent event.

(2) Second most recent event.

(3) Evidence for this event is equivocal.

(4) Most recent event (see Table 3); preferred value in parantheses.

(5) Displacement for possible third most recent event based on height of tectonic(?) terrace.

(6) Estimated displacement during second most recent event assuming there have been only 2 events and using the preferred values for most recent event.

Table 5

RECURRENCE INTERVALS AT SELECTED SITES ALONG THE WASATCH FAULT ZONE

LOCATION	RECURRENCE INTERVAL FOR SURFACE FAULTING EVENTS (years)		SOURCE
	Average	Interval Between Successive Events Constrained by ^{14}C Dates	
Kaysville Site	---	500-1000(2) (1000)	Swan and others (1980a)
Little Cottonwood Canyon Site	450-3300 (2200)	---	Swan and others (1980b)
Hobble Creek Site	1500-2600 (2000)	---	Swan and others (1980a)
North Creek Site	1300-5200 (1700-2600)	>2900 to <4500(2) (3500) <1600(3)	this report

Notes:

(1) Preferred values shown in parentheses

(2) Interval between two most recent events

(3) Interval between second most recent event and an inferred third event

Table 6

SUMMARY OF DATA ON SLIP RATES
ALONG THE WASATCH FAULT ZONE

LOCATION	SLIP RATE (mm/year)	INTERVAL	SOURCE
1) West flank of Wellsville Mountains	~0.2	post ~150,000	Scott (1980)
2) West flank of Wellsville Mountains	~0	post Bonneville	Scott (1980)
3) Bountiful to Ogden	0.4	post 10 m.y.	Naesser and others (1979)
4) Kaysville Site	1.8 (+1.0; -0.6)	late Holocene	Swan and others (1980a)
5) Big Cottonwood Canyon	>0.1	next to last major lake cycle (~150,000)	Scott (1980)
6) Big Cottonwood Canyon	>0.5	post Bonneville	Scott (1980)
7) Little Cottonwood Canyon Site	0.9 (+1.0; -0.3)	late Pleistocene-Holocene	Swan and others (1980b)
8) Hobble Creek Site	1.0 (±0.1)	Holocene (post Provo)	Swan and others (1980a)
9) North Creek Site	1.3 (±0.1)	late Holocene	this report

APPENDIX A

REPORTS AND PUBLICATIONS

APPENDIX A

REPORTS AND PUBLICATIONS

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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

SUMMARIES OF TECHNICAL REPORTS, VOLUME XII

Prepared by Participants in

NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

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OPEN-FILE REPORT 81-833

This report has not been reviewed for conformity with USGS editorial standards and stratigraphic nomenclature. Parts of it were prepared under contract to the U.S. Geological Survey and the opinions and conclusions expressed herein do not necessarily represent those of the USGS. Any use of trade names is for descriptive purposes only and does not imply endorsement by the USGS.

Menlo Park, California

1981

STUDY OF EARTHQUAKE RECURRENCE INTERVALS ON THE WASATCH FAULT ZONE, UTAH

14-08-0001-19115

F. H. Swan, Principal Investigator
Kathryn L. Hanson
David P. Schwartz

Woodward-Clyde Consultants
Three Embarcadero Center, Suite 700
San Francisco, California 94111
(415) 956-7070

Investigations

1. A research age-dating program is being conducted with Dr. Allen Tucker at San Jose State University, in conjunction with Stanford University, to evaluate the feasibility of using an accelerator to measure carbon radioisotope concentrations in very small (approximately 3 mg) samples of charcoal and other organic material.

2. Ground reconnaissance has been conducted along the northern and southern portions of the Wasatch fault zone to assess variations in fault behavior along different segments of the fault.

3. Detailed geologic studies, which include mapping of the late Quaternary deposits, topographic profiling of displaced geomorphic surfaces, and exploratory trenching across the main fault scarp, have been completed at a site located at the mouth of North Creek, 16 km north of Nephi, Utah.

Results

1. Preliminary age-dates for three samples of detrital charcoal from the scarp-derived colluvium and graben deposits at Little Cottonwood Canyon site (Swan and others, 1980b), which were not sufficiently large enough to date using conventional radiocarbon methods, have been obtained by Dr. Tucker using an accelerator at the Swiss Federal Institute of Technology in Zurich. The age-dates are 7,800 (+400, -600) for sample LC 1-1; 8,600 (+500, -400) for samples LC 1-2, and 9,000 (+400, -600) for samples LC 3-1. A fourth samples, LC 2-1, consisting of carbonized wood or burned root collected from an organic-rich infilling that fills a fissure in the graben deposits yielded a modern age. The preliminary dates, which were calibrated using samples of known age, appeared to be stratigraphically consistent within the assigned error values. Continued studies are being conducted to assess the reliability of these dates and to date additional small samples

collected at the North Creek site and other locations along the fault zone.

2.a. Observations along the 90-km long northern part of the Wasatch fault zone between the Kaysville site, which is 32 km north of Salt Lake City, and the northern part of the Wellsville Range suggest that there is a decrease in Holocene activity from south to north. 1) At the Kaysville site an alluvial fan surface, estimated to be 6,000 ± 2,000 years old, is displaced 10 to 11 m. Data from trenches excavated across the main fault and graben at this site indicate that the cumulative displacement was produced by at least three surface faulting events (Swan and others, 1979; 1980a). 2) From the Kaysville site north to North Ogden, a distance of approximately 35 km, the fault zone is generally characterized by a single, prominent, main fault scarp and associated local graben; geomorphic evidence indicates there have been repeated Holocene displacements along this part of the fault zone. 3) The fault scarps between North Ogden and Nerva, where a prominent embayment in the range front occurs, are more subdued and appear to be older, with the exception of a complex zone of scarps in the Pole Patch area. The patterns and complexity in this area suggest that landsliding and/or liquefaction may have played important roles in the origin of these scarps. 4) Evidence of repeated Holocene displacement is also apparent along the front east of Nerva and extending 10 km northward to Threemile Creek north of Willard. The geomorphic expression of faulting north of the Threemile Creek has been modified by shoreline erosion and is discontinuous. With the exception of a prominent 2 km-long fault scarp in the northeastern part of Brigham City that displaces Holocene alluvial fans, and scarps across older alluvial fans at Antimony and Dry canyons 6.5 km north of Brigham City, there is little evidence for Holocene activity. 5) The most northerly location where fault scarps are clearly recognizable is aproximately 16 km north of Brigham City near the mouth of Jim May canyon. Alluvial fan deposits displaced across these fault scarps are probably pre-Bonneville in age. Although Bonneville lake sediments may be faulted in places north of Brigham City, the faulting is less continuous, more subdued and commonly masked by shoreline features. The decrease in the amount of Holocene faulting along the Wasatch fault at about latitude 41.5°N appears to coincide with southern end of the Cache Valley fault to the east and of the Pocatello fault to the west.

b. Along a 45 km long portion of the fault south of Santaquin, the Wasatch fault zone has had late Quaternary displacement along at least six distinct traces. The recently active traces are defined by nearly continuous, fresh-looking scarps and they range in length from 1.5 to 24 km. These traces are separated by gaps up to 27 km long that do not appear to have experienced Holocene and/or late Pleistocene displacement.

3. The following observations are based on geologic studies at the North Creek site:

   a. Cumulative net vertical tectonic displacement of an alluvial fan at the mouth of North Creek is 7.0 ± 0.5 m down to the west across the main fault scarp. Detrital charcoal from the upper section of the faulted alluvial fan is dated by Buckman (1978) at 4,580 ^{14}C yr B.P. (3,525 to 3,270 B.C.; calibration based on Clark, 1975). The late Holocene slip rate at this location is approximately 1.3 ± 0.1 mm/year.

   b. Estimates of the amount of displacement during the most recent surface faulting event range from 1.0 m to less than 4.5 m, with a preferred value of approximately 2 m.

   c. Two or three surface faulting events have occurred along this trace of the fault since deposition of the dated fan deposits. At least one and possibly two events occurred post 4,580 ^{14}C yr B.P. (3,525 to 3,270 B.C.). The most recent surface faulting event occurred post 1,110 ± 60 ^{14}C yr B.P. (770 to 965 A.D.). The interval between the two most recent events was greater than 2,900 years and probably less than 4,500 years. If there have been three events post deposition of the North Creek fan, the interval between the second and third most recent events was less than 1,600 years.

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