STUDY OF EARTHQUAKE RECURRENCE INTERVALS ON THE WASATCH FAULT, UTAH

SEVENTH SEMI-ANNUAL TECHNICAL REPORT
May 12, 1982

By

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

Sponsored By The
U.S. Geological Survey
Contract No. 14-08-0001-19842

The views and discussions in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

TITLE PAGE

1. CONTRACT NO. 14-08-0001-19842

2. NAME OF CONTRACTOR: Woodward-Clyde Consultants

3. PRINCIPAL INVESTIGATORS: F. H. Swan, III
   David P. Schwartz

4. GOVERNMENT TECHNICAL OFFICER: Mr. Steven Wegener

5. SHORT TITLE OF WORK: Continuation of Studies of Earthquake Recurrence Intervals on the Wasatch Fault, Utah

6. EFFECTIVE DATE OF CONTRACT: March 1, 1981

7. CONTRACT EXPIRATION DATE: May 30, 1982

8. AMOUNT OF CONTRACT: $75,056

9. DATE REPORT SUBMITTED: May 12, 1982

TABLE OF CONTENTS

	Page
TITLE PAGE	i
TABLE OF CONTENTS	ii
LIST OF FIGURES	iii
LIST OF TABLES	iii
INTRODUCTION	1
RADIOCARBON AGE-DATING USING ACCELERATOR MASS SPECTROMETRY	1
AGE-DATING INVESTIGATIONS, WASATCH FAULT STUDY	3
Methods	3
Results	5
RECURRENCE OF SURFACE FAULTING EARTHQUAKES	6
North Creek Site	6
Little Cottonwood Canyon Site	8
CONCLUSION	9
REFERENCES	10
FIGURES	
TABLE 1	
ATTACHMENT: RADIOCARBON DATES BY ACCELERATOR MASS SPECTROMETRY OF SAMPLES FROM THE WASATCH FAULT STUDY (TUCKER, 1981)	

LIST OF FIGURES

No.	Description
1	REGIONAL LOCATION MAP OF WASATCH FAULT ZONE, UTAH
2	RADIOCARBON CALIBRATION CURVE AND RESULTS OF DATED SAMPLES, LITTLE COTTONWOOD CANYON SITE
3	LOG OF TRENCH NC-1, NORTH CREEK SITE
4	LOG OF TRENCH NC-2, NORTH CREEK SITE
5	LOG OF TRENCH NC-3, NORTH CREEK SITE
6	RELATIONSHIP AMONG MAPPED UNITS, RADIOCARBON DATES, AND TECTONIC EVENTS, NORTH CREEK SITE
7a	LOG OF TRENCH LC-1, LITTLE COTTONWOOD CANYON SITE
7b	UNIT DESCRIPTIONS, TRENCH LC-1, LITTLE COTTONWOOD CANYON SITE
8	LOG OF TRENCH LC-2, LITTLE COTTONWOOD CANYON SITE
9	LOG OF TRENCH LC-3, LITTLE COTTONWOOD CANYON SITE

LIST OF TABLES

No.	Description
1	SUMMARY OF AGE-DATING RESULTS

INTRODUCTION

Detailed geologic studies have been conducted at four sites along the Wasatch fault zone to assess the frequency of occurrence and magnitude of earthquakes associated with surface faulting along individual segments of the fault zone (Figure 1). A critical aspect of these studies is the assignment of ages to geologic units mapped in trenches and at the ground surface. A recently developed method of age-dating that uses accelerators as mass spectrometers to directly measure isotope concentrations has been used to obtain preliminary radiocarbon age-dates for fifteen samples collected at the Little Cottonwood Canyon and North Creek sites along the Wasatch fault zone. These age-dates, some of which were obtained for samples too small to be dated by conventional methods, provide additional data for assessing recency and recurrence of faulting at these sites.

At this time the accelerator mass spectrometry technique is still in its developmental stage. Comparison of age-dates obtained using this technique with conventional radiocarbon age-dates and ages estimated from stratigraphic relationships also provides a means of evaluating the reliability and accuracy of this new technique.

This report presents a summary of the age-dates obtained for samples from the North Creek and Little Cottonwood Canyon sites, and a discussion of recurrence of surface faulting at these sites based on the newly obtained age-dates.

RADIOCARBON AGE-DATING USING ACCELERATOR MASS SPECTROMETRY

The technique of high energy mass spectrometry has been developed primarily during the past five years. Recent descriptions of the accelerator dating techniques are given by

Muller (1979), Bennett (1981), and Gove and others (1979). Summaries of papers presented at a conference on this new method are presented in Gove (1978). Several groups have made measurements using virtually unmodified existing accelerators, both cyclotrons and Tandem Van de Graaff accelerators. Cyclotrons have been used by the Lawrence Berkeley Laboratory group and by an Orsay/Grenoble collaboration. Tandem Van de Graaff accelerators are being used by collaborations of the University of Rochester, the General Ionex Corporation, and the University of Toronto; Simon Frasers and McMasters University; a group at Oxford, and a group at the Chalk River Nuclear Laboratories, Ontario Canada. Construction of accelerators dedicated solely to radioisotope dating is being planned at Oxford University, the University of Toronto, and the University of Arizona, but these facilities are not yet completed.

The most widely used radioisotope dating involves the isotope ^{14}C and techniques developed by Libby and his coworkers (Libby, 1946). During the past three decades, radiocarbon dating using Libby's beta-decay methods has developed into a precise and well calibrated technique. Samples containing two grams or more of carbon are generally required for conventional beta-counting techniques. Ages up to 45,000 to 50,000 years can be obtained in many laboratories and, in some cases, ages up to 60,000 to 70,000 years have been achieved using enrichment techniques. The ^{14}C concentrations are generally measured to 1 percent corresponding to an error in age of ± 80 years. It is possible to determine radiocarbon ratios for large young samples with an accuracy of ± 2 parts per mil (± 16 years) or less (Stuiver, 1978). At present, the new accelerator mass spectrometer techniques have not achieved such precision. However, with the high sensitivity of the new technique, only milligrams rather than grams of carbon are needed. Also, with the increased sensitivity, it may

eventually be possible to extend the radiocarbon range to older samples. At this time because of contamination problems, due to both high levels of ^{14}C background in existing accelerators and modern carbon in the sample, the age range has not been extended beyond the range that can be obtained using the conventional beta-decay technique.

AGE-DATING INVESTIGATIONS FOR WASATCH FAULT STUDY

Geological investigations at the North Creek and Little Cottonwood Canyon sites included detailed geologic mapping, topographic profiling, and trenching. The results of these studies are discussed in detail in previous reports (Swan and others, 1980 and 1981; Hanson and others, 1981). At the North Creek site eleven samples of detrital charcoal and organic-rich soil were collected from faulted alluvial fan deposits and scarp-derived colluviums. Conventional radiocarbon age-dates were obtained for five of these samples. Sample locations are shown on Figures 3, 4, and 5.

At the Little Cottonwood Canyon site three samples of detrital charcoal were collected from scarp-derived colluvium and graben deposits (Figures 7a and 9). A fourth sample, consisting of carbonized wood or burned root, was collected from an organic-rich infilling that fills a fissure in the graben deposits (Figure 8). None of these samples were large enough to date using conventional beta-counting techniques.

Methods

The fifteen samples were analyzed by Dr. Allen B. Tucker, San Jose State Univeristy. The eleven North Creek samples were analyzed using an existing MP Tandem Van de Graaff accelerator at Chalk River Nuclear Laboratories, Ontario, Canada; the four samples from the Little Cottonwood Canyon site were analyzed

using an existing EN Tandem Van de Graaff accelerator at the Swiss Federal Institute of Technology, Zurich, Switzerland. These systems have been described in recent publications (Andrews and others, 1980; Brown and others, 1981; Suter and others, 1981). At both facilities direct measurement of the $^{14}C/^{12}C$ ratio in the samples of both known and unknown age was made using accelerator mass spectrometry. Measurement procedures used at the Chalk River facility are discussed in Tucker, 1981 (Attachment); the procedure used at the Swiss facility are discussed in Tucker and others, 1981 and Suter and others, 1981.

Radiocarbon age-dates were obtained by comparing measured $^{14}C/^{12}C$ ratios to $^{14}C/^{12}C$ ratios for known standards. A National Bureau of Standards oxalic acid standard calibrated at 1.05 times the "modern" $^{14}C/^{12}C$ ratio was used at the Chalk River facility. Age-dates calculated at the Chalk River facility are based on the revised half-life for ^{14}C of 5,730 years. At the Swiss facility calibration samples included four charcoal samples having known ages of between 250 and 10,000 years, as determined by beta counting at radiocarbon labs at the University of Bern, Switzerland, and the U.S. Geological Survey in Menlo Park. The four calibration standards fell on a straight line having a slope corresponding to a half-life of 5,568 years, the original value used by Libby in beta-decay counting (Figure 2).

Samples analyzed at the Chalk River facilities were pretreated using standard techniques to eliminate contamination by young carbon and secondary carbonates. Soil samples were inspected under a microscope and grains or flecks that appeared to be charcoal were picked out. The material was dried, burned to CO_2, then reduced onto a hot magnesium block. The resulting block was washed with acid and distilled water, mixed with an iron powder binder, and pressed into target cones for the

accelerator's ion source. A typical target contained 5 mg of carbon and 20 mg of iron.

Sample preparation at the Swiss facilities also involved dissolution of the carbon material into melted iron to form targets (Suter and others, 1981). Samples analyzed at the Swiss facilities were not pretreated to remove secondary carbonate or young carbon contaminants.

Results

Descriptions of the samples, sample location, and age-dates derived by accelerator and conventional methods are presented in Table 1. Most of the age-dates obtained for the suite of North Creek samples using the accelerator mass spectrometry techniques at the Chalk River Nuclear Laboratories are in agreement with age-dates measured using conventional techniques and with ages estimated based on the relative stratigraphic positions of the samples. The only samples that showed some discrepancies between the age-dates obtained by the two methods are samples WC-12-80-3, WC-12-80-7 and WC-12-80-9. The age-date of 4500 ± 300 ^{14}C yr B.P. obtained for soil sample WC-12-80-3 using accelerator mass spectrometry techinques, is in agreement with age-dates obtained for detrital charcoal within the underlying deposit (sample WC-12-80-11). The significantly younger conventional age-date of 2180 ± 80 ^{14}C yr B.P. probably reflects contamination of the soil by younger organic material. Samples WC-80-7 and WC-12-80-~~7~~9, a bulk soil sample and detrital charcoal from the same buried soil, yielded age-dates that fall into two separate age ranges (1350 ± 250 and 1700 ± 300; 3640 ± 75 and 3850 ± 400; Table 1). The younger age-dates, both measured using accelerator techniques, may represent younger material incorporated into the soil prior to burial. The older dates most likely represent a minimum age for the underlying scarp-

derived colluvium on which the soil is developed. Because the age of this deposit is crucial to estimating recurrence of surface faulting at this site (see following discussion), these samples have been resubmitted for analysis by both accelerator and conventional techniques.

Age-dating results for the Little Cottonwood Canyon samples are shown on Figure 2. The four samples from this site were too small to date by conventional techniques. Although there are no conventional dates for comparison, the age-dates are stratigraphically consistent within the assigned error values. Samples WC-5-81-1 and WC-5-81-2 have been resubmitted for analysis by accelerator mass spectrometry to test the reproducibility of these age-dates.

RECURRENCE OF SURFACE FAULTING EARTHQUAKES

North Creek Site

At least two, and probably three, surface faulting events have occurred along the segment of the Wasatch fault at North Creek since deposition of a burn layer in the North Creek alluvium approximately 5,200 years ago (4580 ^{14}C yr B.P.) and prior to settlement of the region approximately 135 years ago (Hanson and others, 1981). The two most recent events are represented by scarp-derived colluviums. An earlier surface faulting event is postulated on the basis of geomorphic evidence. At this site the actual intervals between successive events can be estimated based on radiocarbon dates 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 6.

Age-dates for samples of an organic-rich soil (Unit 2s, sample WC-12-80-7 and 7u) that formed on scarp-derived colluvium

deposited following the second-most recent surface faulting event, and detrital charcoal from the same soil, (WC-12-80-9) are critical for estimating the interval of time between faulting events at this site. These age-dates provide a minimum limiting date for surface faulting events that occurred prior to the most recent event. As discussed in the previous section, the older dates (3640 ± 75 and 3850 ± 400 ^{14}C yr B.P., Table 1) are more likely to represent the age for the soil than are the younger dates of 1350 ± 250 and 1700 ± 300 ^{14}C yr B.P. Assuming that the interval of time for deposition of the scarp-derived colluvium following the second-most recent faulting event and formation of the overlying soil was relatively short, on the order of a few hundred years, these age-dates (corrected to calendar years, Table 1) suggest that this faulting event occurred 4000 to 4500 years ago.

The age-dates of 1110 ± 70 and 700 ± 250 ^{14}C yr B.P. for sample WC-12-80-6 (Table 1) provide a maximum limiting age for the most recent event. These dates indicate that the most recent surface faulting event occurred less than 1000 to 1200 years ago.

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 is probably less than 1000 years.

Little Cottonwood Canyon Site

Data from trenches excavated across a graben at the Little Cottonwood Canyon site that displaces Holocene alluvial fan deposits indicate that the graben was produced by a minimum of two surface faulting events (Swan and others, 1981). Samples WC-5-81-1, WC-5-81-2, and LC-1-2 were collected from alluvium within the graben that grades to scarp-derived colluviums deposited in response to the oldest surface faulting event observed at this site (Figures 7a, 8, and 9). The age-dates for these samples, which range from 7800 (+400, -600) to 9000 (+400, -600) ^{14}C yr. B.P. (Table 1), provide a minimum limiting age for this event. At least one other surface faulting event has occurred since deposition of the charcoal-bearing alluvial deposits and prior to settlement of the region approximately 135 years ago. Based on these age-dates the maximum average recurrence interval is about 4600 (9265 years divided by 2 events. However, in addition to the fault scarp trenched, there are two other splays of the main fault scarp at this site for which there is no subsurface data. Additional surface faulting events may have occurred in which little or no slip occurred on fault trace that was trenched. If so, the estimate cited above for the average recurrence interval at this site is a maximum value. An alternative method of estimating the average recurrence interval is based on the slip rate and displacement per event using the following equation:

$$\text{Recurrence Interval} = \frac{\text{Displacement Per Event}}{\text{Slip Rate}}$$

Using the perferred values of 0.9 mm per year for the slip rate and 2 m for an average displacement per evetn, gives an average recurrence interval of 2200 years (Swan and others, 1981).

CONCLUSION

Using accelerator mass spectrometry to obtain radiocarbon age-dates for samples collected from trenches excavated across the Wasatch fault have provided useful new data for estimating earthquake recurrence intervals. The technique, which can used to date very small (a few milligrams) samples of organic carbon, greatly increases the number of age-dates that can be obtained. Although the technique is still in its developmental stages, the age-dates were generally consistent with age-dates obtained using conventional beta counting techniques and with the relative stratigraphic positions of the samples.

REFERENCES

Andrews, H. R., Ball, G. C., Brown, R. M., Davies, W. G., Imahori, Y., and Milton, J. C. D., 1980, Progress in radiocarbon dating with the Chalk River MP tandum accelerator: Radiocarbon, v. 22, no. 3, p. 822.

Bennett, C. L., 1981, Radiocarbon dating with accelerators, American Scientist, v. 67, no. 4, p. 450-457.

Brown, R. M., Andrews, H. R., Ball, G. C., Burn, N., Davies, W. G., Imahori, Y., and Milton, J. C. D., 1981, Radiocarbon measurement with the Chalk River MP tandem accelerator: IAEA Symposium on Methods of Low-Level Counting and Spectrometry, West Berlin.

Gove, H. E., (ed.), 1978, Proceedings of the first conference on radiocarbon dating with accelerators: April 20-21, 1978, Rochester, New York.

Gove, H. E., Fulton, B. R., Elmore, D., Litherland, A. E., Beukens, R. P., Purser, K. H., and Naylor, H., 1979, Radioisotope detection with tandem electrostatic accelerators, in Proceedings of the Conference on the Applications of Small Accelerators in Research and Industry, North Texas State University, Denton, Texas, November 6-8, 1978, p. 1414-1419: IEEE Transactions on Nuclear Science, v. NS-26, no. 1, part 2.

Hanson, K. L., Swan, F. H., III, and Schwartz, D. P., 1981, Study of earthquake recurrence intervals on the Wasatch fault, Utah: Sixth semi-annual technical report prepared for the U.S. Geological Survey under Contract No. 14-08-0001-19115 by Woodward-Clyde Consultants, San Francisco, California, 22 p.

Libby, W. F., 1946, Physical Review 69, p. 671.

Mast, T. S., and Muller, R. A., 1979, Radioisotope detection and dating with accelerators: Submitted to the Nuclear Science Applications, prepared for the U.S. Department of Energy, Contract No. W-7405-ENG-48, by Lawrence Berkeley Laboratory, University of California, 39 p.

Muller, R. A., 1979, Radioisotope dating with accelerators: Physics Today, v. 32, no. 2, p. 23-28.

Stuiver, M., 1978, Carbon-14 dating: A comparison of beta and ion counting: Science 202, p. 881.

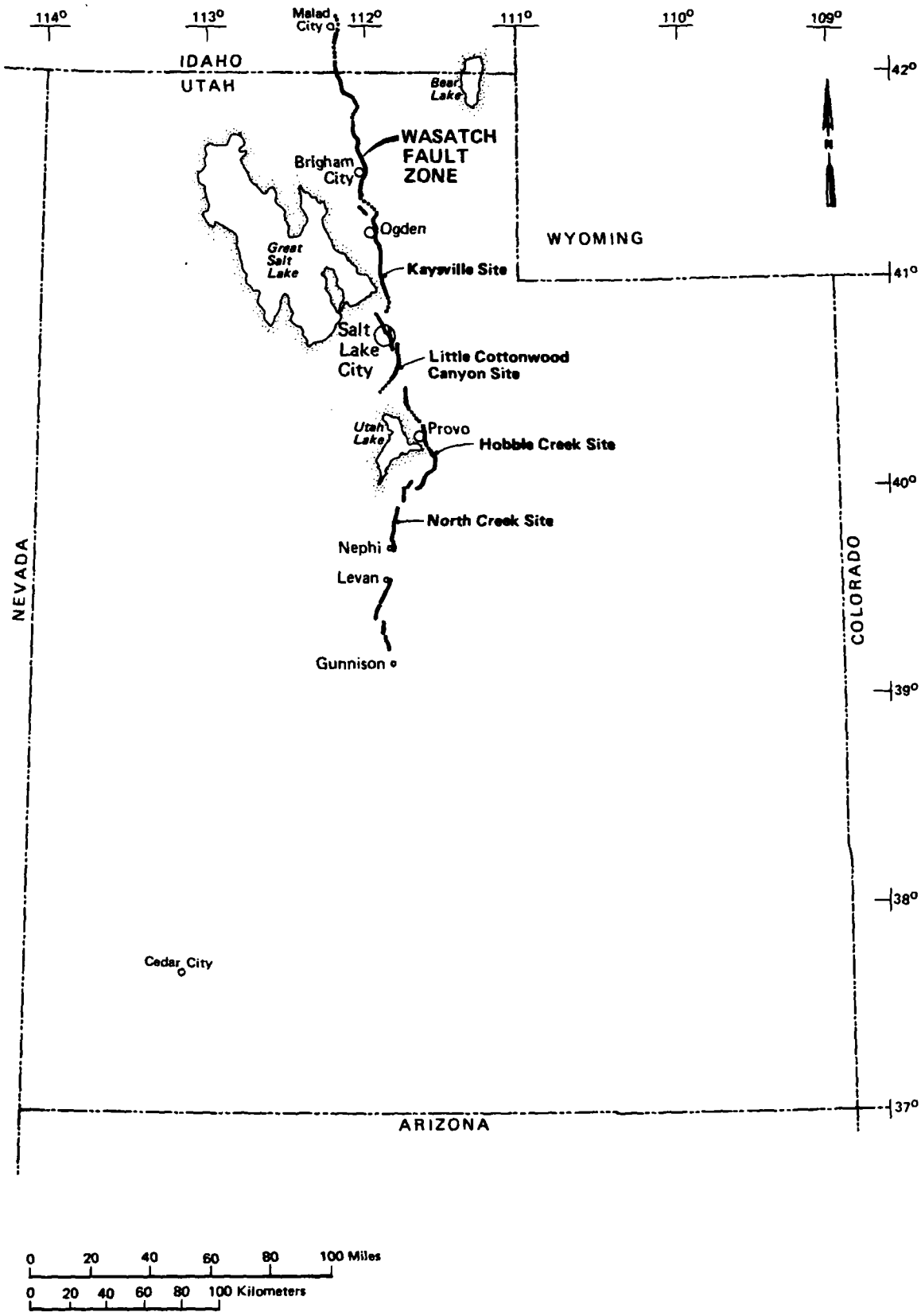
Suter, M., Balzer, R., Bonani, G., and Wolfli, W., 1981, Radioisotope dating using an EN-Tandem accelerator: Paper presented at the Sixth Conference on the Application of Accelerators, Denton, Texas, November 3-5, 1980, 3 p; to be published in Transactions on Nuclear Science, IEEE, April, 1981.

Swan, F. H., III, Hanson, K. L., Schwartz, D. P., and Knuepfer, P. L., 1980, Study of earthquake recurrence intervals on the Wasatch fault, Utah: Fourth semi-annual technical report prepared for the U.S. Geological Survey under Contract No. 14-08-0001-16827 by Woodward-Clyde Consultants, San Francisco, California, 30 p.

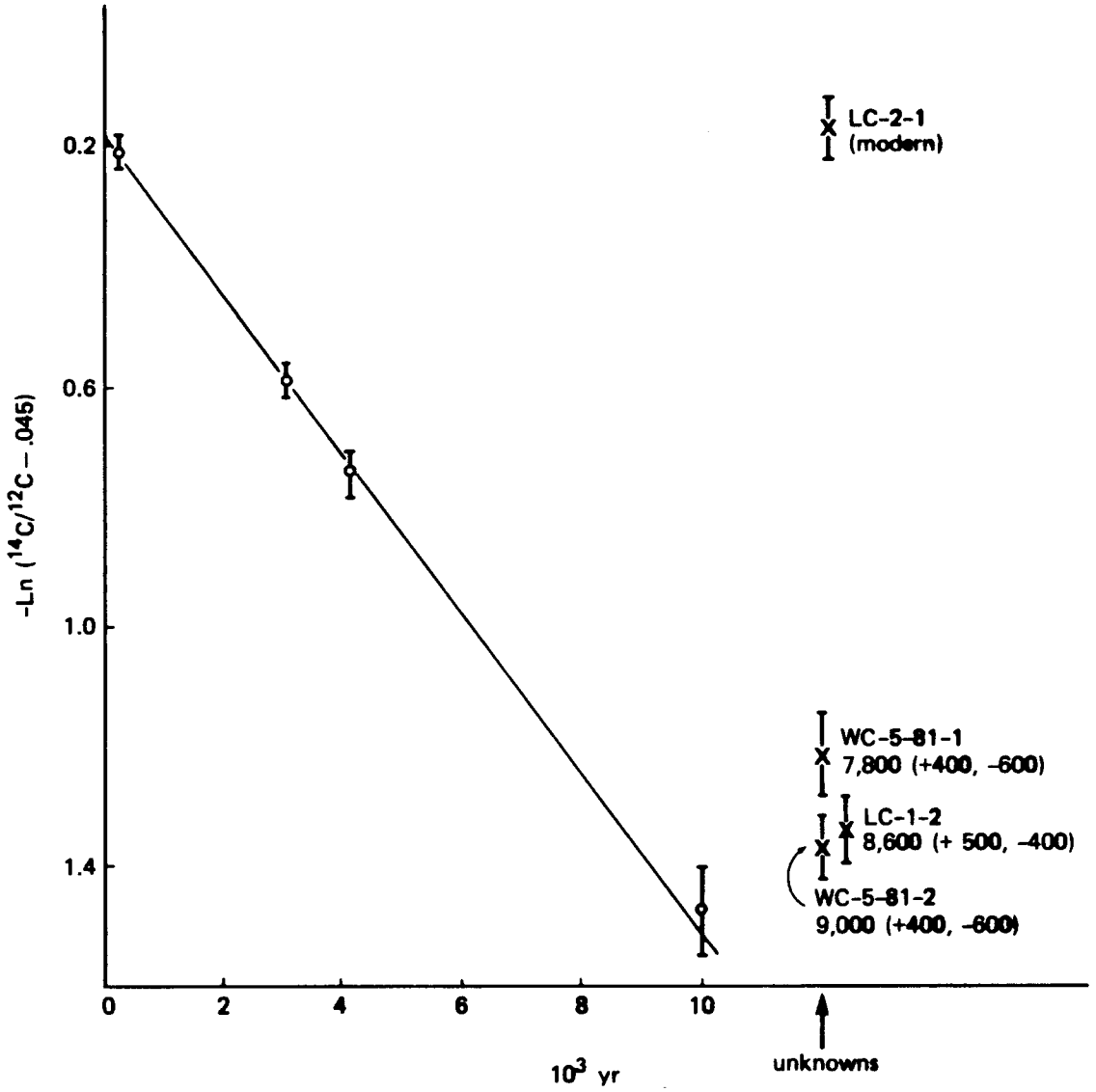
Swan, F. H., III, Hanson, K. L., Schwartz, D. P., and Knuepfer, P. L., 1981, Study of earthquake recurrence intervals on the Wasatch fault at the Little Cottonwood Canyon site, Utah: U.S. Geological Survey, Open-file Report No. 81-450, 30 p.

Tucker, A. B., 1981, Radiocarbon dates by accelerator mass spectrometry of samples from the Wasatch fault study: report submitted to Woodward-Clyde Consultants, San Francisco, California, 5 p.

Tucker, A. B., Bonani, G., Suter, M., and Wolfli, W., 1981, Earthquake dating by ^{14}C atom counting: in Proceedings of the Symposium on Accelerator Mass Spectrometry, Argonne National Laboratory, May, 1981.



Project No. 14093D	USGS Contract No. 14-08-0001-19842	REGIONAL LOCATION MAP OF WASATCH FAULT ZONE, UTAH	Figure 1
Woodward-Clyde Consultants			



The $^{14}C/^{12}C$ ratios are given in units of modern carbon ($1.2 \cdot 10^{-12}$). The carbon age of the calibrated samples (circles) was determined by beta counting techniques to better than ±80 years using $t_{1/2}$ = 5568y. The measured $^{14}C/^{12}C$ ratios of the calibrated samples (crosses) show the expected exponential relation. (modified from Suter and others, 1981).

Project No. 14093D	USGS Contract No. 14-08-0001-19842	RADIOCARBON CALIBRATION CURVE AND RESULTS OF DATED SAMPLES	Figure 2
Woodward-Clyde Consultants		Little Cottonwood Canyon Site	

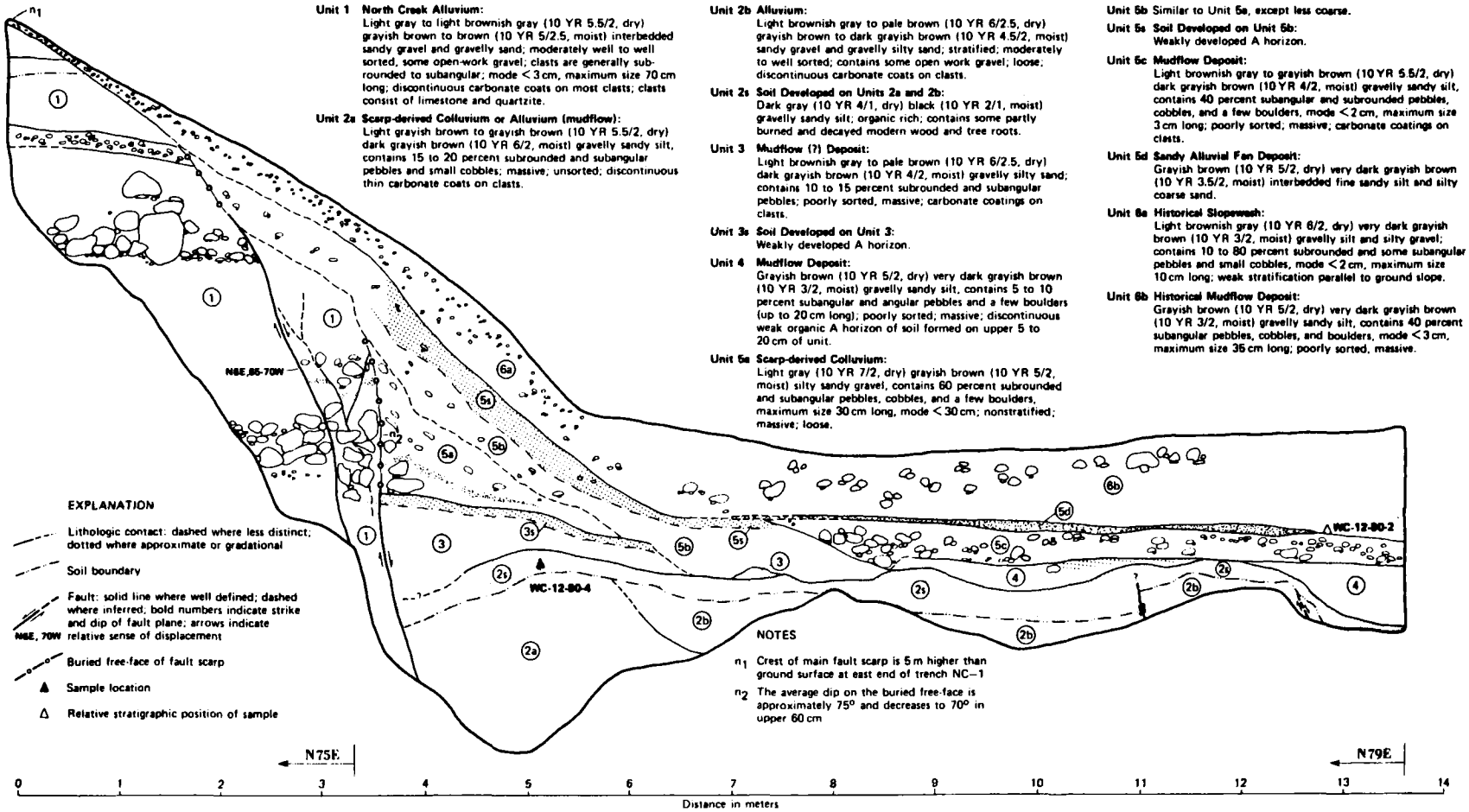
Project No. 14093D

USGS Contract No. 14-08-0001-19842

Woodward-Clyde Consultants

LOG OF TRENCH NC-1
North Creek Site

Figure 3



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 (10 YR 5.5/2, dry) dark grayish brown (10 YR 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.

Unit 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.

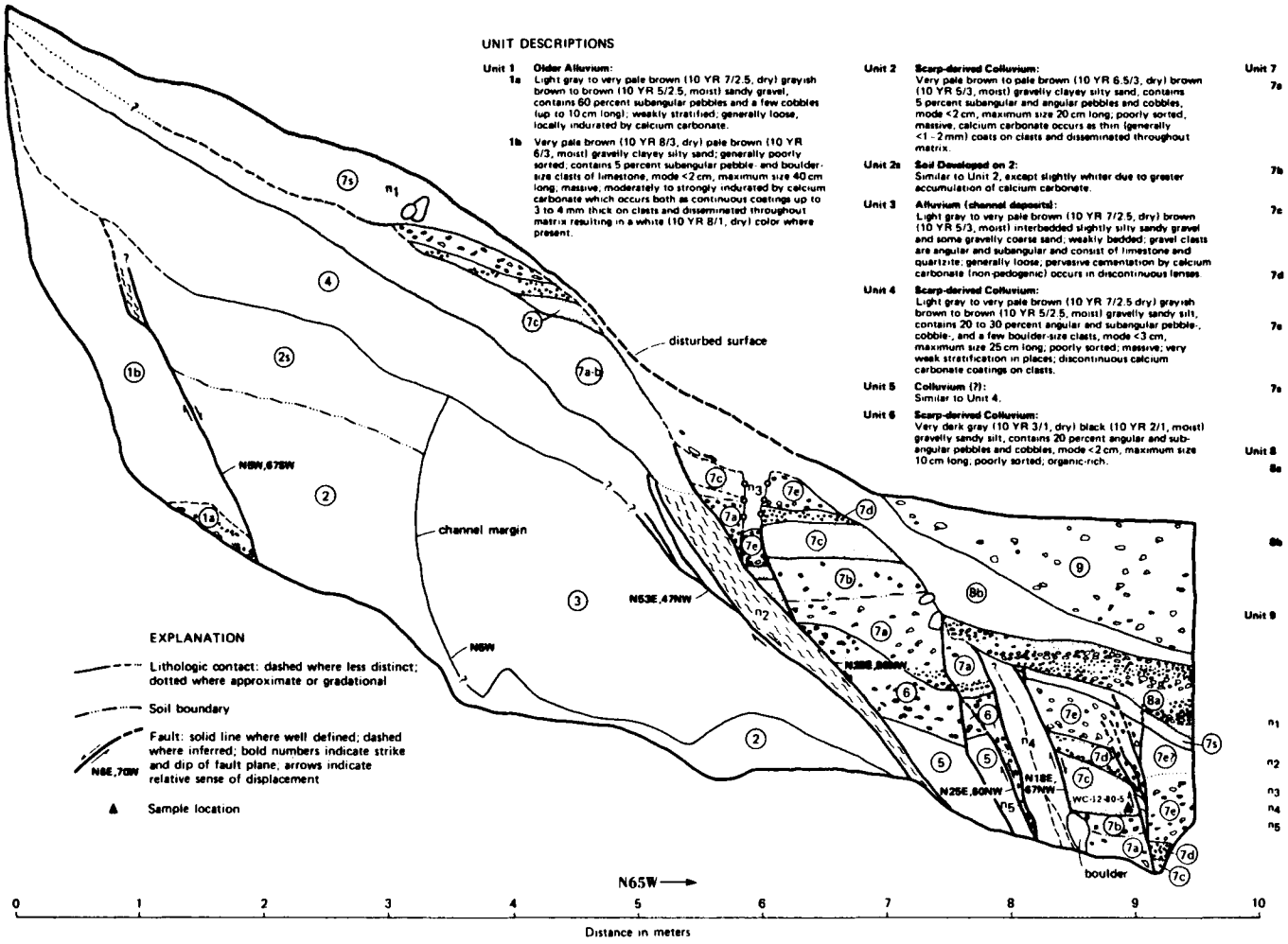
EXPLANATION

- 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 (N86E, 70W)
- Buried free-face of fault scarp
- ▲ Sample location
- Δ Relative stratigraphic position of sample

NOTES

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



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 2a **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.

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 (N8E,70W)
- Sample location

NOTES

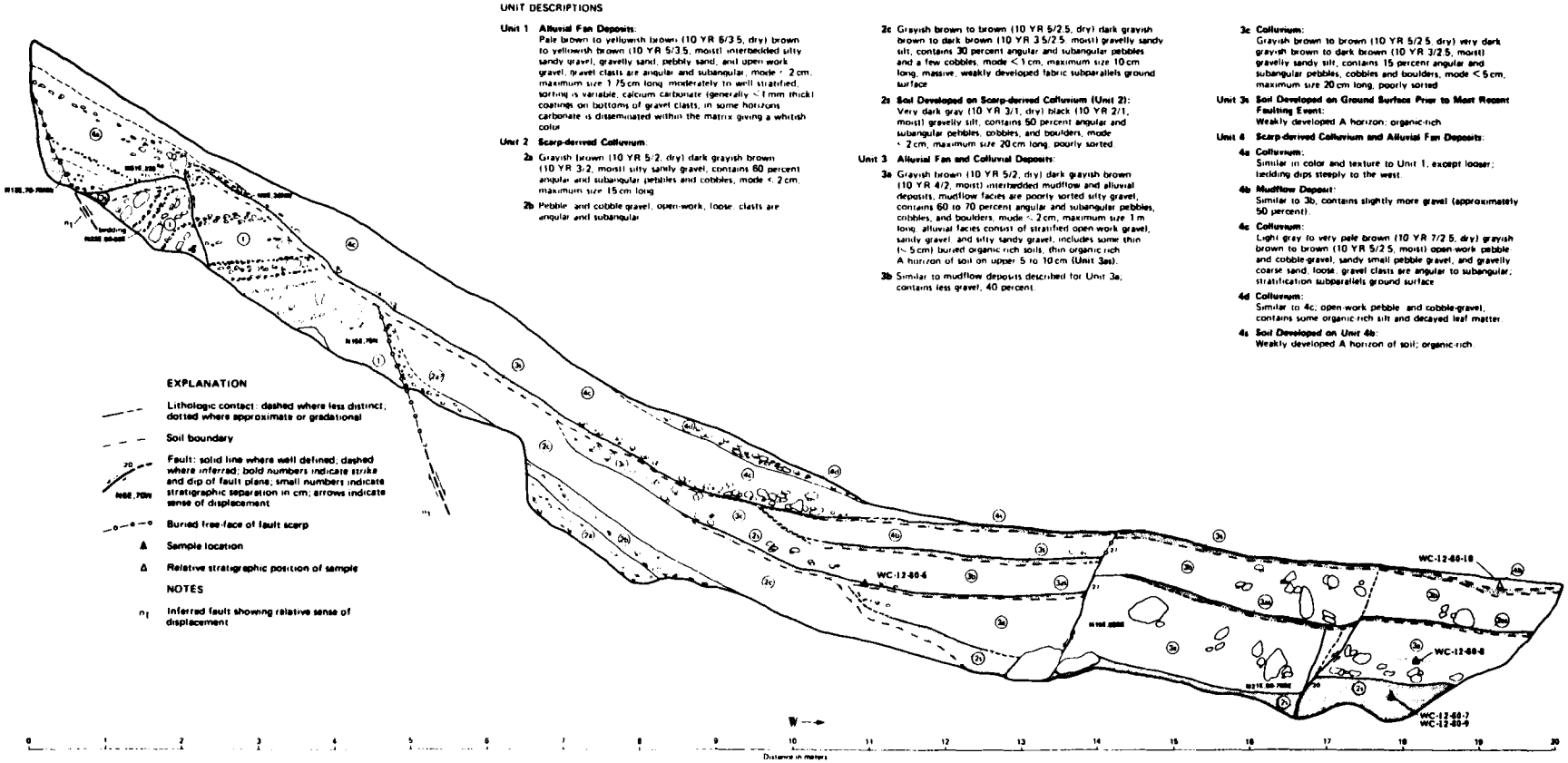
- n_1 On the fault scarp this unit may also include younger material comparable in age to units 8a, 8b, and 9
- n_2 Wide zone of sheared material similar to unit 4
- n_3 Infilled zone of loose, organic-rich material
- n_4 Zone of sheared material similar to unit 7a
- n_5 May represent either unit 6 or infill of fine organics derived from unit 6

LOG OF TRENCH NC-2
North Creek Site

Figure 4

Project No. 14093D	USGS Contract No. 14-08-0001-19842

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

Project No. 14093D	USGS Contract No. 14-08-0001-19842
Woodward-Clyde Consultants	

LOG OF TRENCH NC-3
North Creek Site

Figure 5

AGE[1]			COMPOSITE STRATIGRAPHIC SECTION	TECTONIC EVENTS	CORRELATION OF MAPPED UNITS		
Accelerator ^{14}C YR b.p.	Conventional ^{14}C YR b.p.	Calibrated[2] Date			Trench NC-1 (figure 7)	Trench NC-2 (figure 8)	Trench NC-3 (figure 9)
0 ± 300			Historical mudflow		Unit 6 △WC-12-80-4	Unit 9	△WC-12-80-10
250 ± 300			Scarp-derived colluvium and graben fill		Unit 5	Unit 8	Unit 4
					Unit 4?		
700 ± 250	1110 ± 60	770 to 965 A.D.	"South" Creek alluvium	faulting	Unit 3		▲WC-12-80-6
1550 ± 300	1350 ± 70	553 to 710 A.D.			Unit 2b	Unit 7 ▲WC-12-80-5	Unit 3
1200 ± 300							△ WC-12-80-8
1700 ± 300; 3850 ± 400; 1350 ± 70	3640 ± 75	2235 to 1940 B.C.	Scarp-derived colluvium		Unit 2a?	Unit 6	▲ WC-12-80-7&9 Unit 2
				faulting		—?———?—	
			Section not exposed			Unit 5	
				faulting?			
4500 ± 300					△WC-12-80-3		
4000 ± 400	4580	3525 to 3270 B.C.	(3) ▲ WC-12-80-11 North Creek alluvium		Unit 1	—?———?—	
						Unit 4?	—?———?—
			Pre-North Creek fan deposits			Unit 3	Unit 1
						Unit 2	
						Unit 1	

(1) Table 1

(2) Calibrated dates are calculated from conventional age-dates using calibration tables presented by Clark, 1975. 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.

(3) The sample that was age-dated by conventional techniques was collected by R. Bucknam, U.S. Geological Survey. A separate sample from the same burn layer was collected to age-date using the accelerator technique.

EXPLANATION

▲ Sample analyzed using both conventional and acclerator mass spectrometry techniques

△ Sample analyzed using only accelerator mass spectrometry technique

Project No. 14093	USGS Contract No. 14-08-0001-19842	RELATIONSHIP AMONG MAPPED UNITS, RADIOCARBON DATES AND TECTONIC EVENTS NORTH CREEK SITE	Figure 6
Woodward-Clyde Consultants			

EXPLANATION:

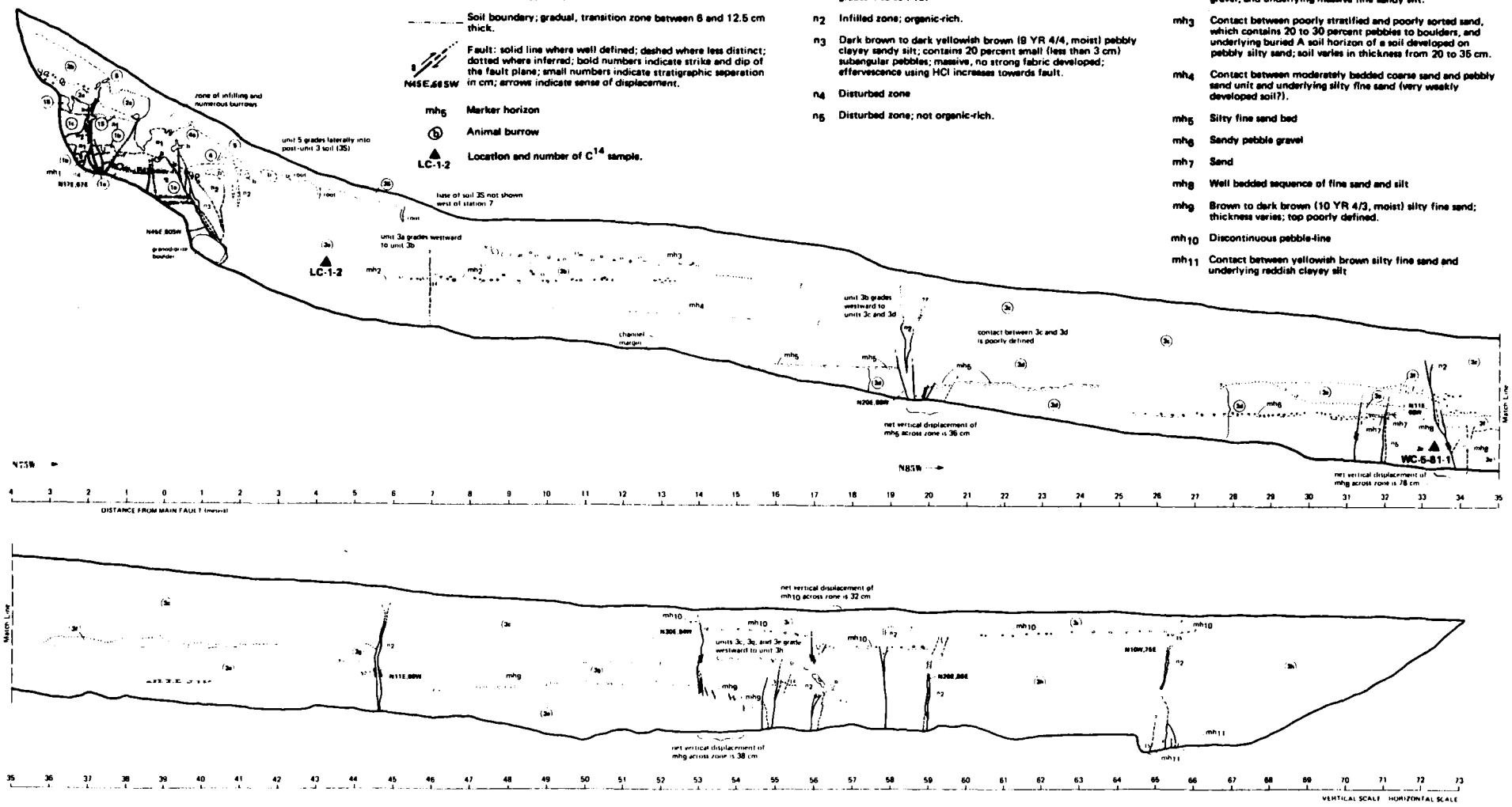
- Lithologic contacts; dashed where less distinct; dotted where approximate or gradational.
- Soil boundary; clear, transition zone between 2.5 and 6 cm thick.
- Soil boundary; gradual, transition zone between 6 and 12.5 cm thick.
- Fault: solid line where well defined; dashed where less distinct; dotted where inferred; bold numbers indicate strike and dip of the fault plane; small numbers indicate stratigraphic separation in cm; arrows indicate sense of displacement. (N45E,65SW)
- mh_5 Marker horizon
- Animal burrow
- LC-1-2 Location and number of C^{14} sample.

NOTES:

- n_1 Disturbed zone; fine sandy silt to silty sand; contains small (generally less than 1 cm, some up to 7 cm) randomly oriented fragments of laminated lake sediments (unit 1); calcareous, grades into soil 1S.
- n_2 Infilled zone; organic-rich.
- n_3 Dark brown to dark yellowish brown (9 YR 4/4, moist) pebbly clayey sandy silt; contains 20 percent small (less than 3 cm) subangular pebbles; massive, no strong fabric developed; effervescence using HCl increases towards fault.
- n_4 Disturbed zone
- n_5 Disturbed zone; not organic-rich.

MARKER HORIZONS:

- mh_1 Fine sandy silt; well stratified; iron-oxide stained; 5 cm thick.
- mh_2 Contact between pebble to cobble gravelly sand and sandy gravel, and underlying massive fine sandy silt.
- mh_3 Contact between poorly stratified and poorly sorted sand, which contains 20 to 30 percent pebbles to boulders, and underlying buried A soil horizon of a soil developed on pebbly silty sand; soil varies in thickness from 20 to 35 cm.
- mh_4 Contact between moderately bedded coarse sand and pebbly sand unit and underlying silty fine sand (very weakly developed soil?).
- mh_5 Silty fine sand bed
- mh_6 Sandy pebble gravel
- mh_7 Sand
- mh_8 Well bedded sequence of fine sand and silt
- mh_9 Brown to dark brown (10 YR 4/3, moist) silty fine sand; thickness varies; top poorly defined.
- mh_{10} Discontinuous pebble-line
- mh_{11} Contact between yellowish brown silty fine sand and underlying reddish clayey silt



Project No. 14093D

USGS Contract No. 14-08-0001-19842

Woodward-Clyde Consultants

LOG OF TRENCH LC-1

Little Cottonwood Canyon Site

Figure 7a

UNIT DESCRIPTIONS:

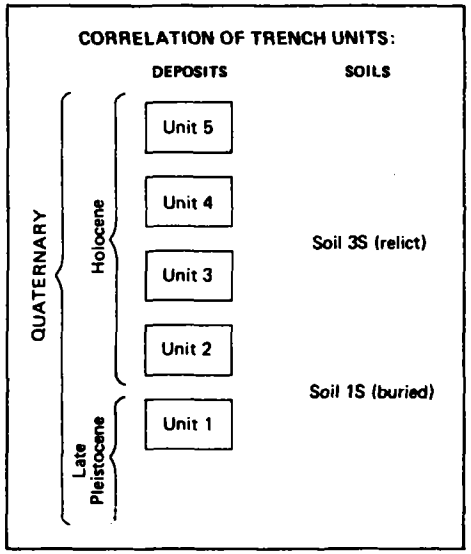
Unit 1 BONNEVILLE LAKE DEPOSITS

(1S) **Post-Bonneville soil** – light brownish gray to light yellowish brown (2.5 YR 6/3, moist) silt; massive; calcareous.

(1a) Interbedded fine to coarse sand, gravelly sand and sandy gravel; light gray to light brownish gray (10 YR 6.5/2, dry) brown and dark grayish brown (10 YR 5/3 and 10 YR 4/2, moist); well stratified and bedded; beds range in thickness from less than 1 cm to 10 cm; gravel clasts are subrounded and rounded; gravel clasts are generally less than 2 cm, pebbles up to 3 to 4 cm common; fine-grained horizons are weakly cemented by calcium carbonate; gravel horizons are generally loose.

(1b) Grayish brown (2.5 YR 5/2, moist) and light olive brown (2.5 YR 5/4, moist) silt; finely laminated, individual lamina are generally less than 1 mm thick.

(1c) Silty clay; finely laminated; bedding disrupted, in places, and tilted 5 degrees to the west; calcareous.



Unit 2 ALLUVIAL FAN DEPOSITS

(2a) Yellowish brown to dark yellowish brown (10 YR 4.5/4, moist) silty fine sand and minor clay; upper 10 to 20 cm contains approximately 10 percent pebbles and cobbles, maximum size 10 cm; massive; upper 15 cm contains some organic material and is dark brown (10 YR 3.5/3, moist) in color.

(2b) Dark brown (10 YR 3/3, moist) gravelly sand; poorly sorted, unstratified; contains 5 to 20 percent subangular and some subrounded pebbles and cobbles, mode less than 2 cm, maximum size 20 cm; massive.

Unit 3 GRABEN-FILL DEPOSITS

Interbedded sequence of sandy silt, gravelly sandy silt, and silty sand; contains minor discontinuous lenses of pebbly sand and gravel. These deposits are subdivided into the following units:

A horizon of soil developed on unit 3 (formed on upper 50 to 100 cm of unit 3, not shown everywhere) –

(3S) Very dark gray (10 YR 3/1, moist) pebbly sandy silt; massive to weakly developed coarse blocky structure; numerous fine roots: upper 20 to 30 cm may be disturbed by plowing; gradational lower soil boundary.

(3a) Dark brown (10 YR 3/3, moist) pebbly fine sandy silt, silty fine sand, coarse sand, and pebble to cobble sand; massive; unstratified, lenticular bedding poorly developed in places. Upper 1.5 m contains 5 to 10 percent subangular pebble- to cobble-size clasts; mode less than 2 cm, maximum size 10 cm; gravel content decreases to less than 2 percent towards bottom of unit. Minor disseminated charcoal fragments occur in the lower part of the unit.

(3b) Interbedded sequence of brown to dark yellowish brown (10 YR 4/3.5, moist) silty fine sand, pebbly medium to coarse sand, and pebble to cobble gravel; gravel clasts are generally subrounded to subangular; bedding is poorly to well developed. In places poorly developed buried A horizons of soils are preserved; some of which can be followed laterally for several meters (see markers mh_3 and mh_4).

(3c) Dark brown (10 YR 3/3, moist) gravelly sandy silt; contains 5 to 10 percent subangular and a few subrounded pebbles, maximum size 10 cm, mode less than 1 cm, 2 to 3 cm clasts common; some fine rootlets in upper part of unit.

(3d) Dark brown (10 YR 3/3, moist) interbedded sandy silt, silty sand, pebbly sand, and pebble-cobble gravel; generally coarsens to east; lenticular bedding, moderate to well bedded bedded; beds vary in thickness from 2 to 20 cm.

(3e) Dark yellowish brown (10 YR 4/4, moist) clayey silt and minor coarse sand; locally contains discontinuous sandy silt lenses; massive.

(3f) Interbedded silty fine sand, pebbly sand, and sandy fine gravel; beds are generally discontinuous and less than 5 cm thick.

(3g) Similar to 3c, except contains less pebbles (approximately 1 to 2 percent) and less organic material; pebble content increases slightly to the east.

(3h) Dark brown (10 YR 3/3, moist) fine sandy silt; minor small pebbles, coarse sand, and discontinuous pebbly sand lenses; pebbles generally less than 2 to 5 mm in diameter; less than 1 percent $CaCO_3$ occurs along root tubules; some fine rootlets.

(3i) Very dark gray (10 YR 3/1, moist) pebbly sandy silt; contains 5 to 10 percent subangular to subrounded pebbles; maximum size 1 cm; mode less than 3 mm; micaceous; massive; organic staining; fine rootlets, some animal burrows.

Unit 4 SCARP-DERIVED COLLUVIUM

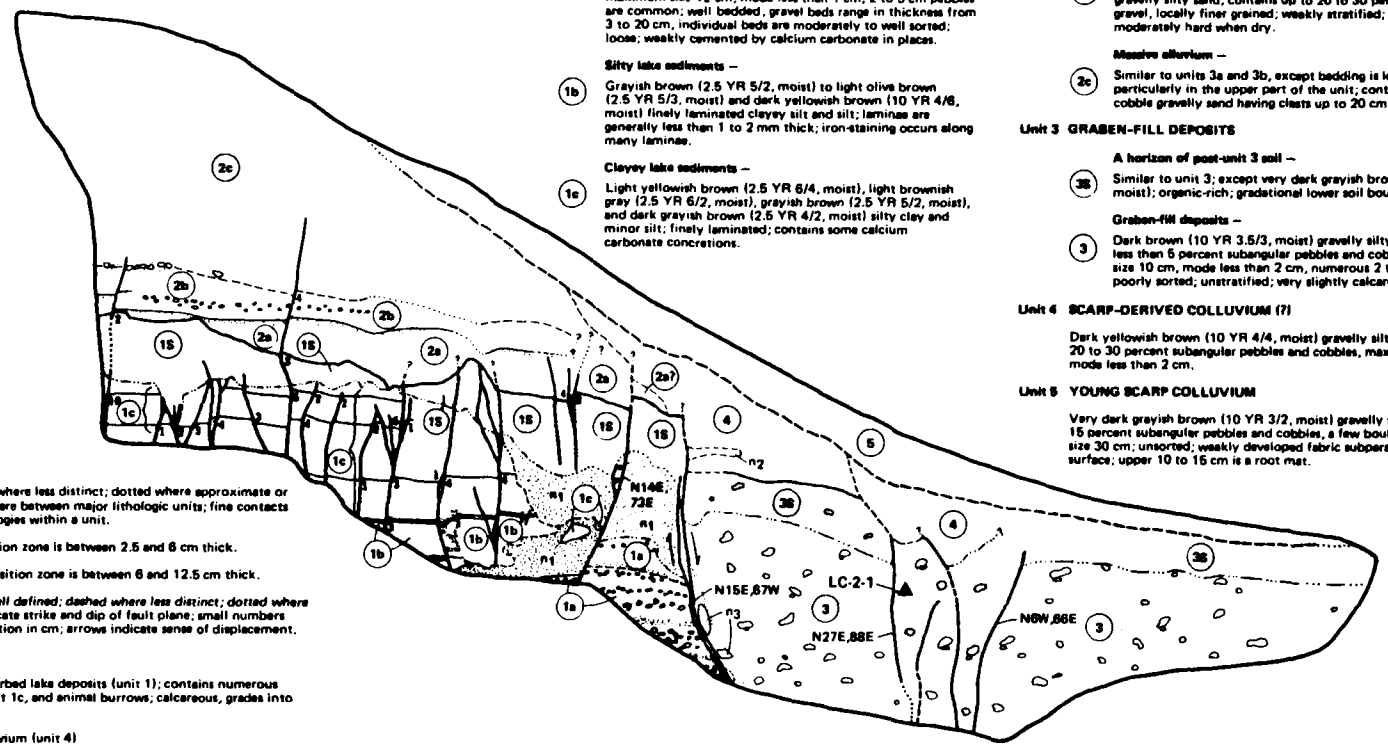
Dark brown to dark yellowish brown (10 YR 4/3.5, moist) pebbly silty sand derived primarily from units 2a and 2b; contains 15 to 20 percent small (less than 1 cm) subangular to angular clasts and a few pebbles up to 4 cm; massive, poorly sorted.

(4a) **Disturbed zone between units 4 and 5** – zone of mixing; consists primarily of unit 4; numerous burrows; organic material in upper part.

Unit 5 YOUNG SCARP COLLUVIUM

Very dark gray (10 YR 3/1, moist) and very dark grayish brown (10 YR 3/2, moist) pebbly sandy silt; contains 5 percent angular to subangular pebbles; very weakly defined stratification, subparallel to slope where developed; disturbed by numerous animal burrows; some roots and rootlets.

Project No. 14093D	USGS Contract No. 14-08-0001-19842	Figure 7b
Woodward-Clyde Consultants	UNIT DESCRIPTIONS TRENCH LC-1 Little Cottonwood Canyon Site	



UNIT DESCRIPTIONS:

Unit 1 BONNEVILLE LAKE DEPOSITS

Post-Bonneville soil –

(1S) Brown (10 YR 5/3, moist) and grayish brown (10 YR 5/2, moist) silty fine sand; vesicular; weakly cemented by calcium carbonate; locally, upper 10 to 15 cm is noncalcareous and darker (10 YR 4.5/4, moist).

Coarse-grained lake sediments –

(1a) Interbedded coarse sand, pebble to cobble gravel, and minor fine to medium sand; gravel clasts are subrounded to rounded, maximum size 12 cm, mode less than 1 cm, 2 to 5 cm pebbles are common; well bedded, gravel beds range in thickness from 3 to 20 cm, individual beds are moderately to well sorted; loose; weakly cemented by calcium carbonate in places.

Silty lake sediments –

(1b) Grayish brown (2.5 YR 5/2, moist) to light olive brown (2.5 YR 5/3, moist) and dark yellowish brown (10 YR 4/6, moist) finely laminated clayey silt and silt; laminae are generally less than 1 to 2 mm thick; iron-staining occurs along many laminae.

Clayey lake sediments –

(1c) Light yellowish brown (2.5 YR 6/4, moist), light brownish gray (2.5 YR 6/2, moist), grayish brown (2.5 YR 5/2, moist), and dark grayish brown (2.5 YR 4/2, moist) silty clay and minor silt; finely laminated; contains some calcium carbonate concretions.

Unit 2 ALLUVIAL FAN DEPOSITS

Basal alluvium –

(2a) Dark yellowish brown (10 YR 4/4, moist) and dark brown (10 YR 4/3, moist) interbedded silty sand and gravelly sand to sandy gravel; contains subangular pebble-size clasts ranging in size from less than 1 cm to approximately 5 cm; moderately to well bedded; weakly cemented by calcium carbonate.

Stratified alluvium –

(2b) Dark brown to dark yellowish brown (10 YR 4/3.5, moist) gravelly silty sand; contains up to 20 to 30 percent pebble gravel, locally finer grained; weakly stratified; poorly sorted; moderately hard when dry.

Massive alluvium –

(2c) Similar to units 3a and 3b, except bedding is less well defined, particularly in the upper part of the unit; contains some coarse cobble gravelly sand having clasts up to 20 cm.

Unit 3 GRABEN-FILL DEPOSITS

A horizon of post-unit 3 soil –

(3S) Similar to unit 3; except very dark grayish brown (10 YR 3/2, moist); organic-rich; gradational lower soil boundary.

Graben-fill deposits –

(3) Dark brown (10 YR 3.5/3, moist) gravelly silty sand, contains less than 5 percent subangular pebbles and cobbles; maximum size 10 cm, mode less than 2 cm, numerous 2 to 7 mm clasts; poorly sorted; unstratified; very slightly calcareous.

Unit 4 SCARP-DERIVED COLLUVIUM (?)

Dark yellowish brown (10 YR 4/4, moist) gravelly silty sand; contains 20 to 30 percent subangular pebbles and cobbles, maximum size 10 cm; mode less than 2 cm.

Unit 5 YOUNG SCARP COLLUVIUM

Very dark grayish brown (10 YR 3/2, moist) gravelly silty sand, contains 15 percent subangular pebbles and cobbles, a few boulders; maximum size 30 cm; unsorted; weakly developed fabric subparallels ground surface; upper 10 to 15 cm is a root mat.

EXPLANATION:

Lithologic contact; dashed where less distinct; dotted where approximate or gradational; heavy contacts are between major lithologic units; fine contacts are between different lithologies within a unit.

Soil boundary; clear, transition zone is between 2.5 and 6 cm thick.

Soil boundary; gradual, transition zone is between 6 and 12.5 cm thick.

N14E,73E — FAULT: *solid line where well defined; dashed where less distinct; dotted where inferred*; bold numbers indicate strike and dip of fault plane; small numbers indicate stratigraphic separation in cm; arrows indicate sense of displacement.

NOTES:

n_1 Zone of deformed and disturbed lake deposits (unit 1); contains numerous shears, rotated blocks of unit 1c, and animal burrows; calcareous, grades into soil 1S.

n_2 Fragment of soil 1S in colluvium (unit 4)

n_3 Pods of calcium-carbonate cemented fan deposits along fault.

▲ LC-2-1 Location and number of C^{14} sample

N78W → | N88W → | N50W → | N74W →

5 4 3 2 1 0 1 2 3 4 5 6

DISTANCE FROM MAIN FAULT (meters)

VERTICAL SCALE = HORIZONTAL SCALE

LOG OF TRENCH LC-2

Little Cottonwood Canyon Site

Figure 8

Project No. 14093D

USGS Contract No. 14-08-0001-19842

Woodward-Clyde Consultants

Project No. 14093D

USGS Contract No. 14-08-0001-19842

Woodward-Clyde Consultants

LOG OF TRENCH LC-3

Little Cottonwood Canyon Site

Figure 9

EXPLANATION:

Lithologic contacts; dashed where less distinct.

Soil boundary; clear, transition zone is between 2.5 and 6 cm thick.

Soil boundary; gradual to diffuse; transition zone is greater than 6 cm thick.

Fault: solid line where well defined; dashed where less distinct; numbers indicate strike and dip of the fault plane; arrows indicate sense of displacement.

N29E,90

WC-5-81-2 Location and number of C^{14} sample.

UNIT DESCRIPTIONS:

Unit 1 BELLS CANYON TILL

(1) Yellowish brown (10 YR 5/5, moist) poorly sorted, compact mixture of sand, gravel, and some silt; contains 10 to 30 percent subangular and subrounded pebbles, cobbles, and boulders, maximum size 1 m; contains some thin (1 to 6 cm) sand beds; very weakly developed subhorizontal bedding; numerous quartz monzonite clasts are partly grussified (easily broken with pick); some roots in upper 1 to 2 m.

Unit 2 GRABEN-FILL DEPOSITS (OLDER)

(2) Dark yellowish brown (10 YR 3.5/4, moist) slightly clayey gravelly silty sand; contains 10 to 20 percent angular and subangular pebbles, cobbles, and boulders, boulders up to 30 cm common, mode less than 10 cm; poorly sorted, nonstratified; massive.

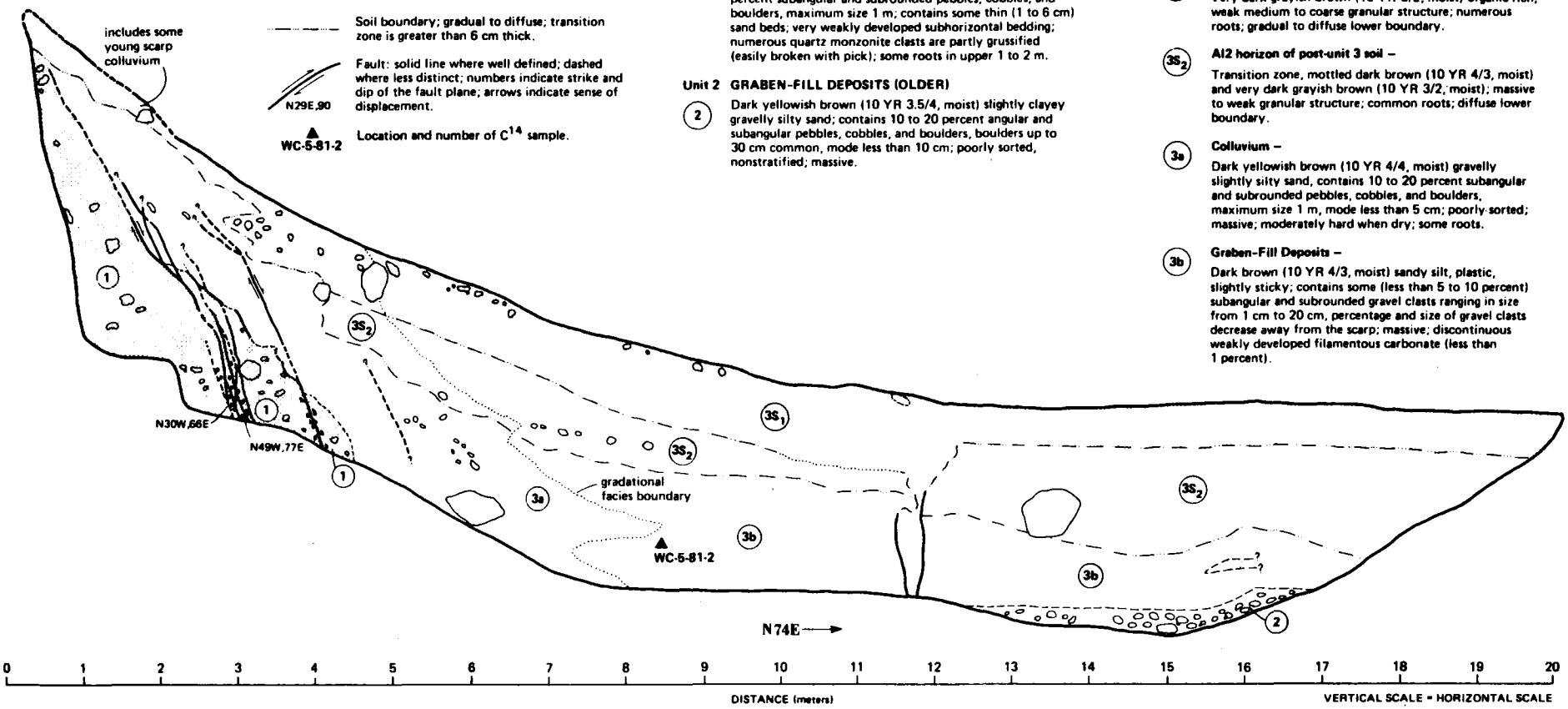
Unit 3 COLLUVIUM AND GRABEN-FILL DEPOSITS

($3S_1$) **A1 horizon of post-unit 3 soil –** Very dark grayish brown (10 YR 3/2, moist) organic-rich, weak medium to coarse granular structure; numerous roots; gradual to diffuse lower boundary.

($3S_2$) **A12 horizon of post-unit 3 soil –** Transition zone, mottled dark brown (10 YR 4/3, moist) and very dark grayish brown (10 YR 3/2, moist); massive to weak granular structure; common roots; diffuse lower boundary.

(3a) **Colluvium –** Dark yellowish brown (10 YR 4/4, moist) gravelly slightly silty sand, contains 10 to 20 percent subangular and subrounded pebbles, cobbles, and boulders, maximum size 1 m, mode less than 5 cm; poorly sorted; massive; moderately hard when dry; some roots.

(3b) **Graben-Fill Deposits –** Dark brown (10 YR 4/3, moist) sandy silt, plastic, slightly sticky; contains some (less than 5 to 10 percent) subangular and subrounded gravel clasts ranging in size from 1 cm to 20 cm, percentage and size of gravel clasts decrease away from the scarp; massive; discontinuous weakly developed filamentous carbonate (less than 1 percent).



SAMPLE NO.	LOCATION	SAMPLE DESCRIPTION	PRETREATMENT (3)	CONVENTIONAL age-date (^{14}C YR b.p.)	ACCELERATOR (4) age-date (^{14}C YR b.p.)	COMMENTS
	NORTH CREEK SITE (1)					
WC-12-80-2	Trench NC-1	detrital charcoal– From buried organic-rich soil developed on scarp-derived colluvium or alluvium	yes		300±300	Decayed wood and the soil fraction from this deposit (unit 2a) yielded conventional radiocarbon dates of modern and 130±95 ^{14}C YR b.p., respectively. All the age-dates obtained for this deposit appear to be too young and probably reflect some contamination by younger material.
WC-12-80-3	Trench NC-1A	soil– Buried organic-rich soil developed on North Creek alluvium.	yes	2180±80	4500±300	The age-date obtained by the accelerator spectrometry techniques is in agreement with the age-date obtained for the North Creek alluvium (sample WC-12-80-11). The younger conventional age-date probably reflects contamination by younger carbonaceous material.
WC-12-80-4	Trench NC-1A	detrital charcoal– From burn layer at the base of an historical mudflow	yes		250±300	The historical age assigned to the mudflow is based on the presence of nails and pieces of metal associated with the burn layer at the base of the unit.
WC-12-80-5	Trench NC-2	detrital charcoal– From sandy silt alluvium	yes	1350±70	1550±300	
WC-12-80-6	Trench NC-3	detrital charcoal– From buried soil developed on faulted alluvium	yes	1110±60	700±250	
WC-12-80-7 7u	Trench NC-3	soil– Buried organic-rich soil developed on colluvium derived from the fault scarp subsequent to the second most recent surface faulting event	yes yes	3640±75	1700±300 (5) 3850±400 (6)	
WC-12-80-8	Trench NC-3	detrital charcoal– From buried soil within alluvium	yes		1200±300	The age-date obtained for this sample is consistent with age-dates from stratigraphically older and younger deposits.
WC-12-80-9	Trench NC-3	detrital charcoal– From same deposit as sample WC-12-80-7	yes		1350±250	
WC-12-80-10	Trench NC-3	detrital charcoal– From unfaulted mudflow deposit	yes		0±300	
WC-12-80-11	North Creek Site stream cut	detrital charcoal– From North Creek alluvial fan deposit	yes	4580 (7)	4000±400	
	LITTLE COTTONWOOD CANYON SITE (2)					
WC-5-81-1	Trench LC-1	detrital charcoal– From faulted alluvial fan deposits within graben	no		7800 (+400,-600)	
WC-5-81-2	Trench LC-3	detrital charcoal– From faulted alluvium within graben	no		9000 (+400,-600)	
LC-1-2	Trench LC-1	detrital charcoal– From faulted alluvial fan deposits within graben	no		8600 (+500,-400)	
LC-2-1	Trench LC-2	carbonized wood or burned root– From an organic-rich infilling that fills a fissure in the graben	no		modern	

NOTES: (1) Hanson and others, 1981

(2) Swan and others, 1981

(3) Sample pretreated using conventional methods to remove modern carbonaceous material and humic acids, and secondary carbonate.

(4) Samples from the North Creek Site were analyzed at Chalk River Nuclear Laboratories, Ontario, Canada; t½ = 5730 years. Samples from the Little Cottonwood Canyon Site were analyzed at Swiss Federal Institute of Technology; t½ = 5568 years.

(5) Age-date obtained during first run; sample pretreated by Dicarb Radioisotope Inc.

(6) Age-date obtained during second run; sample pretreated by Chalk River Nuclear Laboratories

(7) Bucknam, 1978

TABLE 1 SUMMARY OF AGE-DATING RESULTS

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

14-08-0001-19842

F. H. Swan, David P. Schwartz, Principal Investigators
Kathryn L. Hanson
John H. Black

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

Investigations

1. Eleven additional radiocarbon age-dates have been obtained for samples collected from trenches across the Wasatch fault at the North Creek site using accelerator mass spectrometry techniques. Sample analysis was conducted by Dr. A. B. Tucker (San Jose State University) using an existing MP Tandem Van de Graaff accelerator at Chalk River Nuclear Laboratories, Ontario, Canada.

2. Detailed geologic studies including mapping of the late Quaternary deposits, topographic profiling of displaced geomorphic surfaces, and excavation of test pits, have been conducted along the East Cache fault.

Results

1. Radiocarbon age-dates obtained for the suite of North Creek samples using the accelerator mass spectrometry technique are in general agreement with age-dates measured using conventional beta counting techniques and with ages estimated based on the relative stratigraphic positions of the samples (Table 1). These age-dates, some of which were obtained for samples too small to be dated by conventional methods, support previous estimates for recency and intervals of time between individual surface faulting earthquakes at this site (Hanson and others, 1981; Swan and others, 1981).

2. The East Cache fault lies parallel to the Wasatch fault zone. The fault extends in a north-south direction for a distance of about 70 km from the latitude of Brigham City, Utah, to Preston, Idaho, passing immediately east of Logan, Utah. At the golf course on the north side of the river near the mouth of Logan Canyon, there are two west facing scarps that are less than 2 m-high on a post-Provo strath terrace. Minor backtilting occurs on the downthrown side of the eastern scarp. On projection of these scarps to the north, two test pits were excavated across a subtle break in slope near the

base of a scarp immediately below the Bonneville shoreline. The test pits were located between Logan and Green Canyon in an area that has not been affected by landslides. The Bonneville age sediments exposed in both test pits are displaced by numerous small faults. To the south of the Logan River, the fault scarp crosses extensive landslides developed in Bonneville late deposits. The geologic mapping and data from the test pits provide evidence that there has been only one surface faulting event post recession below the Provo shoreline (approximately 12,000 years B.P.).

Reconnaissance along the northern Wasatch fault zone indicates that there is a significant decrease in Holocene fault activity from approximately the latitude of Brigham City north to the northern end of the Wellsville Range (Swan and others, 1981). There are a number of faults subparallel to the Wasatch fault zone north of the latitude of Brigham City, including the Hansel Valley fault, the East Cache fault, and the Bear Valley fault, that have experienced late Pleistocene and/or Holocene faulting. It appears that the Holocene deformation in north-central Utah is distributed across a wide zone that includes all of these faults.

References Cited

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

Hanson, K. L., Schwartz, D. P., and Swan, F. H., III, 1981, Recurrence of surface faulting along the Wasatch fault zone near Nephi, Utah: Geological Survey of America Abstracts with Programs, v. 13, no. 7, p. 469.

Swan, F. H., III, Hanson, K. L., and Schwartz, D. P., 1981, Study of earthquake recurrence intervals on the Wasatch fault zone, Utah, in Summaries of Technical Reports, v. XII, National Earthquake Hazards Reduction Program: U.S. Geological Survey Open-File Report 81-833, p. 106-109.

SAMPLE NO.	LOCATION	SAMPLE DESCRIPTION	AGE-DATE		COMMENTS
			Conventional (^{14}C yr B.P.)	Accelerator (^{14}C yr B.P.)	
	NORTH CREEK SITE				
WC-12-80-2	Trench NC-1	detrital charcoal–From buried organic-rich soil developed on scarp-derived colluvium or alluvium		300±300	Decayed wood and the soil fraction from this deposit yielded conventional radiocarbon dates of modern and 130±95 ^{14}C yr B.P., respectively. All the age-dates obtained for this deposit appear to be too young and probably reflect some contamination by younger material.
WC-12-80-3	Trench NC-1A	soil–Buried organic-rich soil developed on North Creek alluvium	2180±80	4500±300	The age-date obtained by accelerator mass spectrometry for this soil sample is in agreement with the age-date obtained for the underlying parent deposit (sample WC-12-80-11). The younger conventional age-date probably reflects contamination by younger carbonaceous material.
WC-12-80-4	Trench NC-1A	detrital charcoal–From burn layer at the base of an historical mudflow		250±300	The historical age assigned to the mudflow is based on the presence of nails and pieces of metal associated with the burn layer at the base of the unit.
WC-12-80-5	Trench NC-2	detrital charcoal–From sandy silt alluvium	1350±70	1550±300	
WC-12-80-6	Trench NC-3	detrital charcoal–From buried soil developed on faulted alluvium	1110±60	700±250	These age-dates provide a maximum limiting age for the most recent faulting event.
WC-12-80-7 7u	Trench NC-3	soil–Buried organic-rich soil developed on colluvium derived from the fault scarp subsequent to the second most recent surface faulting event	3640±75	1700±300 3850±400	Samples 7 and 7u were obtained from the same bulk soil sample; sample WC-12-80-9, which consists of detrital charcoal, is also from the same soil. The older dates obtained for this unit most likely represent a minimum age for the underlying scarp-derived colluvium on which the soil is developed.
WC-12-80-8	Trench NC-3	detrital charcoal–From buried soil within alluvium		1200±300	The age-date obtained for this sample is consistent with age-dates from stratigraphically older and younger deposits.
WC-12-80-9	Trench NC-3	detrital charcoal–From same deposit as sample WC-12-80-7		1350±250	
WC-12-80-10	Trench NC-3	detrital charcoal–From unfaulted mudflow deposit		0±300	
WC-12-80-11	North Creek Site stream cut	detrital charcoal–From North Creek alluvial fan deposit	4580 (1)	4000±400	

NOTE: (1) Bucknam, 1978

TABLE 1 SUMMARY OF AGE-DATING RESULTS