to the east, the valley is bounded by the East Cache fault zone along the base of the uplifted Bear River Range. The mountains surrounding Cache Valley are comprised mainly of Precambrian to Permian sedimentary rocks, including limestone, dolomite, quartzite, sandstone, mudstone, siltstone, and shale. These rocks have provided detrital material to form the younger deposits that fill Cache Valley. Younger deposits in the valley include the Tertiary Salt Lake Formation, a conglomerate and tuffaceous sandstone that overlies the Precambrian and Permian rocks and crops out in a nearly continuous belt in the foothills around the valley, and unconsolidated Quaternary deposits which are several hundred feet thick in the valley center (Williams, 1962; Kariya and others, 1994).

Cache Valley is also a geomorphic subbasin of the Bonneville basin, an area of internal drainage for much of the past 15 million years. Several successive lakes occupied the Bonneville basin during this time, but deposits of Pleistocene Lake Bonneville dominate the Quaternary geology of the West Cache fault zone (Solomon, 1997). The Bonneville lacustral cycle is coincident with the last global ice age of marine isotope stage 2 and lasted from about 34,800 to 13,900 years ago (Currey and Oviatt, 1985; Oviatt and others, 1992). Between about 25,000 and 15,000 years ago, the lake occupied Cache Valley and deposited a thick sequence of sediments and formed two shoreline complexes (Solomon, 1997). The shorelines are useful datums for evaluating Holocene and late Pleistocene structure and stratigraphy.

Lake Bonneville began gradually rising from levels close to modern-day Great Salt Lake about 34,800 years ago (Oviatt and others, 1992). The transgression from low to moderate lake levels apparently was very rapid, and by 30,700 years ago the lake had transgressed to an elevation of 1,323 meters (4,341 ft) (Oviatt and others, 1992). Beginning about 25,500 years ago, the lake underwent a climatically induced still-stand and oscillation that produced the Stansbury shoreline (Oviatt and others, 1992). Brummer and McCalpin (1990) found no evidence of this shoreline in Cache Valley. Lake Bonneville continued rising during the Stansbury oscillation(s) and entered Cache Valley around 25,000 years ago (Solomon, 1997).

The lake rise eventually slowed as water levels approached an external basin threshold in northern Cache Valley at Red Rock Pass (elevation of 1,552 meters [5,092 ft]) near Zenda, Idaho. Lake Bonneville reached the Red Rock Pass threshold and occupied its highest shoreline, named the Bonneville beach by Gilbert (1890), after 18,000 years ago. The lake remained at this level until 17,400 to 16,800 years ago, when headward erosion of the Snake River-Bonneville basin drainage divide caused a catastrophic incision of the threshold and the lake level lowered by 108 meters (354 ft) in fewer than two months (Jarrett and Malde, 1987; O'Conner, 1993). Immediately after the Bonneville flood, the lake stabilized and formed the Provo shoreline (elevation of 1,444 meters [4,738 ft]). Oviatt (1986) found evidence that during the Bonneville flood, all of the water in the main body of Lake Bonneville between the Bonneville and Provo shorelines discharged through three small passes in the Junction Hills into Cache Valley, and then out through Red Rock Pass into the Snake River. The rapid drawdown of the lake reduced the water-column weight on the earth's crust, which resulted in crustal rebound from isostatic compensation (Crittenden, 1963). In western Cache Valley, isostatic rebound and regional

tectonics have uplifted the highest Bonneville shoreline as much as 27 meters (89 ft) to elevations of 1,567 to 1,579 meters (5,141-5,181 ft) (Currey, 1982; Solomon, 1997). Similarly, the Provo shoreline has been uplifted as much as 22 meters (72 ft) to elevations of 1,452 to 1,466 meters (4,764-4,810 ft) (Currey, 1982; Solomon, 1997).

After about 16,200 years ago, the Bonneville basin once again became hydrologically closed and discharge ceased at the new Red Rock Pass threshold near Zenda. Climatic factors caused Lake Bonneville to regress rapidly from the Provo shoreline, and the lake retreated from Cache Valley about 15,000 years ago. By about 13,900 years ago, the lake had dropped below the present elevation of Great Salt Lake. Oviatt and others (1992) consider this low stage as the end of the Bonneville lake cycle. A subsequent transgression of Great Salt Lake occurred between 13,900 and 11,600 years ago and formed the Gilbert shoreline, but the lake did not rise high enough to reenter Cache Valley.

Quaternary geology of the West Cache fault zone is also characterized by deposition of alluvium in alluvial fans along the front of the Malad Range and the Wellsville Mountains. Alluvial-fan deposits older than the Bonneville lake cycle are preserved on remnants of extensive, dissected pediment surfaces cut into Tertiary deposits in the range-front foothills (Solomon, 1997). McCalpin (1989) estimates the age of similar deposits in eastern Cache Valley as 100,000 to 200,000 years old based on the amount of surface erosion and soil development. When Lake Bonneville transgressed into Cache Valley, the fan deposits were truncated by the highest shoreline (Bonneville) and covered by lake deposits at lower elevations. After the lake regressed, rapid and extensive downcutting eroded the lake shorelines, lake deposits, and old alluvial fans at canyon mouths. Much of this material was deposited in younger alluvial fans along the range front (Solomon, 1997). Upper Holocene debris-flow deposits constitute some of the alluvial-fan sediments, and may have been deposited during a major fan-building episode from about 4,000 to 5,000 years ago (Machette and others, 1992). Stream alluvium was deposited in mountain drainages concurrently with the fan alluvium (Solomon, 1997).

Mass-movement deposits are found locally in the West Cache fault zone, including landslides and hillslope colluvium. The landslides are late Tertiary to late Pleistocene in age, and are associated with failures of underlying Tertiary and Paleozoic sedimentary rocks and nearshore Lake Bonneville deposits (Solomon, 1997). Most landslides were caused either by wave erosion of the Bonneville shoreline, rapid dewatering of oversteepened slopes during the Bonneville flood, or earthquakes (Solomon, 1997). Colluvial deposits are commonly found on mountain slopes and above stream channels in canyons. Solomon (1997) mapped undifferentiated colluvium and alluvium where colluvium-mantled hillsides grade imperceptibly into alluvium-filled ephemeral stream channels.

PALEOSEISMIC INVESTIGATIONS AND DATA

To establish timing for past surface-faulting earthquakes on the Clarkston, Junction Hills,

and Wellsville faults, we investigated two trenches and a natural stream-cut exposure. One trench was excavated near the mouth of Winter Canyon west of Clarkston, Utah (figures 1 and 3). At this location, Solomon (1997) noted the Clarkston fault may displace upper Holocene alluvial-fan deposits. We also mapped a natural stream-cut exposure of the Junction Hills fault at Roundy Farm west of Cache Junction, Utah (figures 1 and 4), where Oviatt (1986) noted displacement in transgressive Lake Bonneville deposits. A second trench was excavated near the mouth of Deep Canyon west of Mendon, Utah (figures 1 and 5). At this location, Solomon (1997) indicated the Wellsville fault displaces upper to middle Pleistocene alluvial-fan deposits. The surficial geology at each site, sequence of deposition and faulting in the exposures, and results of our investigations are discussed below. Detailed logs of the fault zones in these exposures are shown on plates 1A through 1C.

Radiocarbon Dating

Radiocarbon age estimates from this study come from organic-rich material in paleosol A horizons and fault-scarp-derived colluvium, except for a sample in the Deep Canyon trench that was detrital charcoal entrained in a debris-flood deposit. The age from the detrital charcoal was obtained from accelerator-mass-spectrometer methods; the remaining ages were obtained from conventional gas-proportional methods. One sample from the Winter Canyon trench was not analyzed and was taken as a backup in case the first sample was contaminated by animal burrowing.

Table 1 shows radiocarbon laboratory results and calendar-calibrated age estimates for all

Figure 3. West view of the Winter Canyon trench.

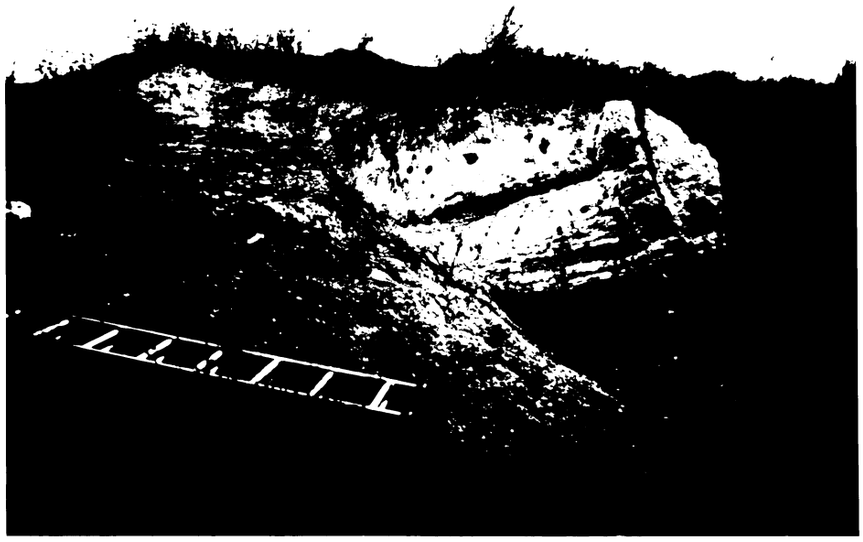

Figure 4. North view of the Roundy Farm stream cut.

samples taken from the Winter and Deep Canyon trenches, and the Roundy Farm stream cut. We calibrated the laboratory results using the computer program CALIB 3.0.3C (Stuiver and Reimer, 1993), which is based on studies of tree rings of known ages (Stuiver and Quay, 1979; Stuiver and Kra, 1986). We used an error multiplier of one and a uniform carbon age span (CAS) of 200 years for all the samples. CAS is used by the calibration program to smooth fluctuations in the calibration curve (Machette and others, 1992; Stuiver and Reimer, 1993).

Radiocarbon ages obtained from soil organics and organic-rich colluvium are termed apparent-mean-residence-time (AMRT) ages, and are a measure of total ^{14}C carbon activity. Although we used the calibration procedure to improve accuracy of the AMRT ages, the corrected ages are not accurate enough to be termed dates and thus represent intervals of time. Machette and others (1992) indicate soils serve as a "carbon bank," accumulating a range of carbon of different ages having a distribution dependent on the carbon turnover rate in the soil. Modern soils thus typically yield AMRT ages of a few tens to a few hundreds of years. Careful sampling of the uppermost 5-10 centimeters (2-4 in) typically yields ages with the least variation, best reflecting the time of soil burial (Machette and others, 1992). The AMRT age of a soil before burial is termed the mean residence correction (MRC); we estimated MRC for the samples using methods in Machette and others (1992). The MRC was subtracted from the radiocarbon age prior to calibration (Minze Stuiver, University of Washington, personal communication to W.R. Lund, 1992); table 1 shows modified radiocarbon ages. Because of the uncertainties in