corresponding event on the opposing basin-bounding fault, or one of the faults is antithetic to the opposing fault and ruptured co-seismically, or both. However, no such correlations are evident between the East Cache fault zone and the Clarkston and Junction Hills faults.

Table 2. *Comparison between ages of faulting and slip rates for the West Cache and East Cache fault zones.*

	Timing of most recent surface-faulting earthquake	*Timing of penultimate surface-faulting earthquake*	*Slip rate (time frame)*
WEST CACHE FAULT ZONE			
Clarkston fault	3,600-4,000 years ago	Post-Bonneville (<16,800 years ago)	0.54 millimeters/year (late Pleistocene)
Junction Hills fault	8,250-8,650 years ago	Pre-Bonneville (>16,800 years ago)	0.13 millimeters/year (late Pleistocene)
Wellsville fault	4,400-4,800 years ago	15,100-25,000 years ago	0.18-0.29 millimeters/year (late Pleistocene)
EAST CACHE FAULT ZONE[1]			
Northern segment	Pre-Bonneville (>16,800 years ago)		0.25-0.5 millimeters/year (early Pleistocene)
Central segment	4,300-4,800 years ago	15,100-18,000 years ago	0.28 millimeters/year (late Pleistocene)
Southern segment	Pre-Bonneville (>16,800 years ago)		0.01-0.07 millimeters/year (early Pleistocene)

[1] East Cache fault zone data are from McCalpin (1994). Ages reported in McCalpin (1994) are uncalibrated and are calibrated here for comparison only. We determined calibrated age of the most recent surface-faulting earthquake on the central segment using methods described in the Radiocarbon Dating section, based on a lab age of 4,240 ± 80 yr B.P., MRC of 200, and a CAS of 200. We estimated age of the penultimate surface-faulting earthquake on the central segment by multiplying by 1.16, as per the method used to calibrate lake-cycle ages.

Earthquake Magnitude

Various empirical relations have been developed to estimate paleoearthquake magnitudes from fault parameters. Table 3 compares magnitude estimates for the Clarkston, Junction Hills, and Wellsville faults based on surface-rupture length (L_S), displacement (D), and slip rate (S) (Bonilla and others, 1984; Mason, 1992; Mason and Smith, 1993; Wells and Coppersmith, 1994; Anderson and others, 1996). Moment magnitude (M_w) is generally considered to be a better estimate of earthquake magnitude than surface-wave magnitude (M_s) (Hanks and Kanamori, 1979; Machette, 1986). Based on the various rupture parameters, table 3 shows moment magnitudes for surface-faulting earthquakes on the Clarkston fault are M_w 6.9-7.1; surface-faulting earthquakes on the Junction Hills and Wellsville faults are M_w 6.8-7.1 and M_w 6.6-6.9, respectively.

Table 3 also shows magnitude estimates based on displacement are consistently higher than those based on surface-rupture length for all the faults. Zollweg (1998) indicates that regressions based solely on rupture length can underestimate paleoearthquake magnitudes,

Table 3. *Magnitude estimates for surface-faulting earthquakes on the Clarkston, Junction Hills, and Wellsville faults.*

FAULT PARAMETERS				
	Surface-trace distance (L_S, in kilometers)	*Displacement (D, in meters)*	*Aspect ratio (D/L_S)*	*Maximum slip rate (S, in millimeters/year)*
Clarkston fault	37	3.7	1.00×10^{-4}	0.54
Junction Hills fault	33	2.9	8.79×10^{-5}	0.13
Wellsville fault	20	2.2	1.1×10^{-4}	0.13
MAGNITUDE ESTIMATES				
	Moment Magnitude (M_W)		**Surface-Wave Magnitude (M_S)**	
	Wells and Coppersmith (1994)[1]	*Anderson and others (1996)*[2]	*Bonilla and others (1984)*[3]	*Mason (1992); Mason and Smith (1993)*[4]
Based on rupture length (L_S)				
Clarkston fault	6.9		7.1	
Junction Hills fault	6.8		7.0	
Wellsville fault	6.6		6.8	
Based on rupture length (L_S) and slip rate (S)				
Clarkston fault		7.0		
Junction Hills fault		7.1		
Wellsville fault		6.8		
Based on displacement (D)				
Clarkston fault	7.1		7.4	
Junction Hills fault	7.0		7.3	
Wellsville fault	6.9		7.2	
Based on rupture length (L_S) and displacement (D)				
Clarkston fault				7.1
Junction Hills fault				7.0
Wellsville fault				6.9

[1] *Regression for all types of slip;* $M_W = 5.08 + 1.16 \log L_S$; $M_W = 6.69 + 0.74 \log D$.
[2] $M_W = 5.12 + 1.16 \log L_S - 0.20 \log S$.
[3] *Ordinary least-squares relations for western North America;* $M_S = 5.17 + 1.237 \log L_S$, $M_S = 6.98 + 0.742 \log D$.
[4] $M_S = 6.1 + 0.47 \log(D \times L_S)$

probably from a failure to recognize all fault traces that ruptured in an event (such as small-displacement scarps removed by erosion, or incomplete surface ruptures). Faults having aspect ratios (displacement divided by surface-rupture length, D/L_S) around 10^{-4} or less may have a longer rupture length than is evident, and thus earthquake magnitudes may be underestimated

(Zollweg, 1998). All the faults in the West Cache fault zone have aspect ratios near 10^{-4} (table 2). Observations of historical surface-faulting earthquakes also show a discrepancy between predicted and observed values of M_w based on rupture length, and Anderson and others (1996) indicate inclusion of fault slip rate in relations based on rupture length can reduce this discrepancy and yield more accurate predictions of future earthquake magnitudes on active faults. Our estimates from displacement and rupture length-slip rate are similar, and indicate moment magnitude for surface-faulting earthquakes on the Clarkston and Junction Hills faults is M_w 7.0-7.1, and M_w 6.8-6.9 for the Wellsville fault.

SUMMARY

The West Cache fault zone extends 80 kilometers (50 mi) from northern Utah into southern Idaho, and consists of three normal faults: the Clarkston, Junction Hills, and Wellsville faults. The faults dip eastward beneath Cache Valley, and form the boundary between the valley to the east and the mountains to the west. Cache Valley is near the center of the Intermountain seismic belt, a north-south trending zone of historical seismicity that extends from northern Arizona to central Montana, and three major fault zones are in and adjacent to the valley that pose a significant seismic risk to citizens living nearby: the Wasatch, East Cache, and West Cache fault zones. All of these faults displace the surface and show evidence of large earthquakes in recent geologic time. Trenching to identify the size and timing of prehistoric earthquakes has been done for the Wasatch and East Cache fault zones, but no such studies have been previously conducted for the West Cache fault zone.

Cache Valley is an intermontane graben formed by movement on two high-angle normal faults, the East Cache and West Cache fault zones. The East Cache fault zone dips westward beneath the valley and forms the boundary between the eastern edge of the valley and the uplifted Bear River Range. The West Cache fault zone dips eastward beneath the valley and bounds the uplifted Malad Range and Wellsville Mountains. The Quaternary geology of Cache Valley is dominated by deposits of Pleistocene Lake Bonneville, which occupied the valley between about 25,000 to 15,000 years ago. Shorelines formed by the lake provide useful datums for evaluating Holocene and late Pleistocene structure and stratigraphy.

To determine the paleoseismic history of the West Cache fault zone, the Utah Geological Survey excavated and mapped two trenches at Winter and Deep Canyons across the Clarkston and Wellsville faults (respectively), and mapped a natural stream-cut exposure of the Junction Hills fault at Roundy Farm. Evidence from these exposures suggests the MRE on the faults occurred: 3,600 to 4,000 years ago on the Clarkston fault, 8,250 to 8,650 years ago on the Junction Hills fault, and 4,400 to 4,800 years ago on the Wellsville fault. Evidence for a PE was exposed in the Deep Canyon trench on the Wellsville fault, but timing for this event is uncertain and between 15,100 to 25,000 years ago. Indirect evidence for a PE on the Junction Hills fault was exposed in the Roundy Farm stream cut; although we could not determine timing for this event, younger undisplaced Lake Bonneville deposits in the exposure suggest this event occurred prior to the transgression of the lake across the site 22,500 years ago. No evidence for a PE was exposed in the Winter Canyon trench on the Clarkston fault, but a difference in shoreline elevations between the Junction Hills and Clarkston faults suggests two or three events occurred on the Clarkston fault since the Lake Bonneville highstand.

Trenching, scarp profiling, and geologic mapping from the Winter Canyon, Roundy Farm, and Deep Canyon sites also provide information on fault displacement and slip rate for the Clarkston, Junction Hills, and Wellsville faults. For the Clarkston fault, the data show 3.1 to 3.7 meters (10.2-12.1 ft) of displacement from the MRE and a maximum slip rate of 0.54 millimeters/year (0.021 in/yr) since late Pleistocene time. For the Junction Hills fault, the data show 2.9 meters (9.5 ft) of displacement from the MRE and a maximum slip rate during late Pleistocene time of 0.13 millimeters/year (0.005 in/yr). For the Wellsville fault, the data show 1.9 meters (6.2 ft) of displacement from the MRE, and 6.6 meters (21.7 ft) from probably the last three surface-faulting earthquakes; slip rate for the Wellsville fault since late Pleistocene time is 0.18-0.29 millimeters/year (0.007-0.11 in/yr). The data and paleoseismic history suggest that the faults in the West Cache fault zone behave independently. Earthquake timing and slip rates are similar for the Wellsville fault and central segment of the East Cache fault zone and suggest a possible correlation between these faults, but no correlation is evident between the East Cache fault zone and other faults in the West Cache fault zone. Empirical relations to estimate paleoearthquake magnitudes from fault parameters such as rupture length, displacement, and slip rate indicate a moment magnitude of M_w 7.0-7.1 for the Clarkston and Junction Hills faults, and M_w 6.8-6.9 for the Wellsville fault.

ACKNOWLEDGMENTS

The authors thank Thad Ericksen (Cache County Water Coordinator) for his assistance in contacting landowners, and each of the landowners (Wesley Hansen, Winter Canyon; the Roundy family, Roundy Farm; and Carolyn Barcus, Deep Canyon) for giving permission for our investigation. We also thank Gary Christenson, Francis Ashland, Barry Solomon, and Bill Lund for their assistance in logging and interpretation of the trenches.

REFERENCES

Anderson, J.G., Wesnousky, S.G., and Stirling, M.W., 1996, Earthquake size as a function of fault slip rate: Bulletin of the Seismological Society of America, v. 86, no. 3, p. 683-690.

Black, B.D., Lund, W.R., Schwartz, D.P., Gill, H.E., and Mayes, B.H., 1996, Paleoseismic investigation on the Salt Lake City segment of the Wasatch fault zone at the South Fork Dry Creek and Dry Gulch sites, Salt Lake County, Utah, *in* Lund, W.R., editor, Paleoseismology of Utah, Volume 7: Utah Geological Survey Special Study 92, 22 p.