UTAH GEOLOGICAL SURVEY
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Utah Department of Natural Resources

Plate 1
Utah Geological Survey Special Study 125
Earthquake Site-Conditions Map for the Wasatch Front Urban Corridor, Utah

EARTHQUAKE SITE-CONDITIONS MAP FOR THE WASATCH FRONT URBAN CORRIDOR, UTAH

by
Greg N. McDonald and Francis X. Ashland
Utah Geological Survey

2008

Explanation

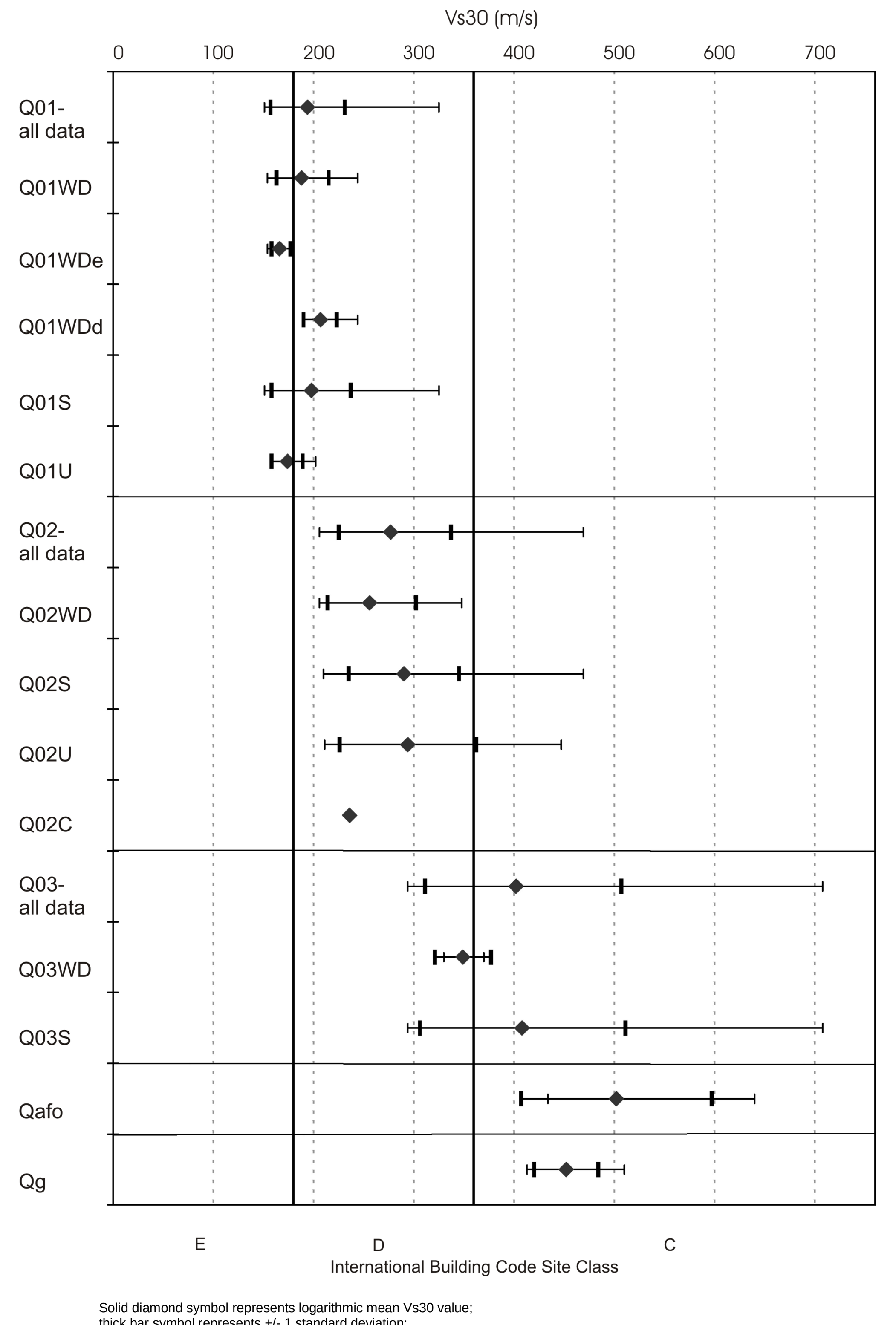
Symbols

- Vs30 (m/s) - Berry (2005)
- Vs30 (m/s) - Previous work
- Basin Boundary
- Wasatch Fault Zone
- Road

Site-Conditions-Unit Descriptions

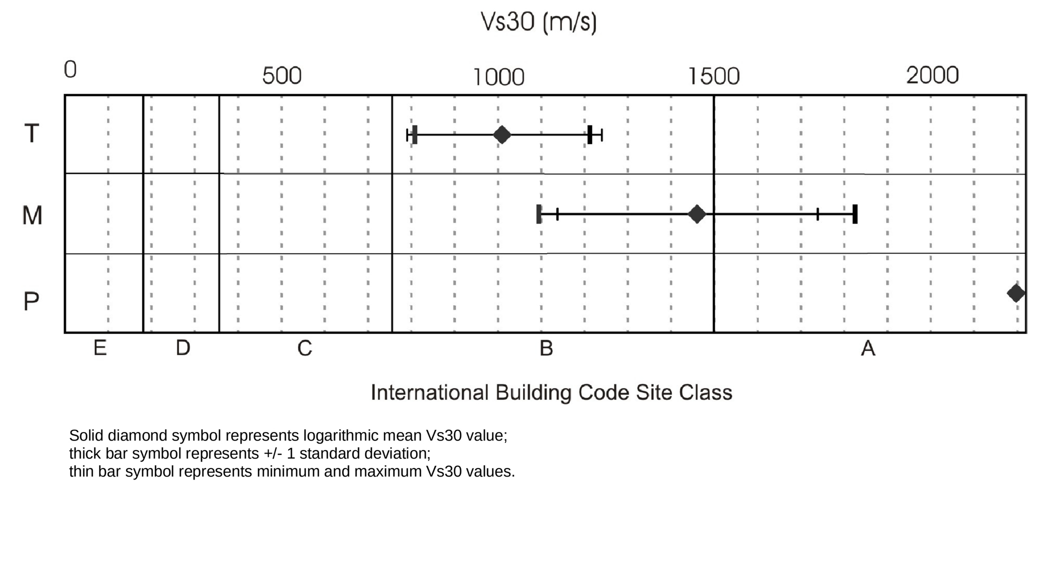
Unit		Vs30 (m/s) Minimum	Vs30 (m/s) Log Mean	Vs30 (m/s) Maximum	IBC Site Class Minimum	IBC Site Class Log Mean	IBC Site Class Maximum	Description
Q01	All data	151	**194**	325	E	**D**	D	Lacustrine and alluvial silt, clay, and fine sand; alluvial, lateral-spread, or marsh deposits typically overlie lacustrine deposits
	Q01WD	154	**188**	244	E	**D**	D	
	Q01WDe	154	**166**	179	E	**E**	E	
	Q01WDd	189	**207**	244	D	**D**	D	
	Q01S	151	**198**	325	E	**D**	D	
	Q01U	157	**174**	202	E	**E**	D	
Q02	All data	206	**281**	469	D	**D**	D	Lacustrine sand and gravel; interbedded lacustrine silt, clay, and sand; latest Pleistocene to Holocene alluvial-fan deposits
	Q02WD	206	**256**	348	D	**D**	D	
	Q02S	210	**290**	469	D	**D**	C	
	Q02U	211	**294**	447	D	**D**	C	
	Q02C	--	**236**	--	--	**D**	--	
Q03	All data	294	**402**	708	D	**C**	C	Lacustrine and alluvial gravel and sand; pre-Bonneville alluvial-fan deposits; primarily where they occur on the footwall of the Wasatch fault
	Q03WD	330	**349**	370	D	**D**	C	
	Q03S	294	**408**	708	D	**C**	C	
Qafo		434	**502**	640	C	**C**	C	Pre-Bonneville alluvial-fan gravel, sand, silt, and cobbles; includes large landslide complexes; locally indurated and/or overlain by thin lacustrine or younger alluvial-fan deposits
Qg		413	**452**	510	D	**C**	C	Glacial deposits including till and outwash
T		837	**1010**	1230	B	**B**	B	Tertiary bedrock
M		1009	**1460**	1782	B	**B**	A	Mesozoic bedrock
P		--	**2197**	--	--	**A**	--	Paleozoic and Precambrian bedrock; includes Tertiary intrusives

Quaternary Site-Conditions-Unit Vs30 Distributions



Solid diamond symbol represents logarithmic mean Vs30 value;
thick bar symbol represents +/- 1 standard deviation;
thin bar symbol represents minimum and maximum Vs30 values.

Bedrock Site-Conditions-Unit Vs30 Distributions



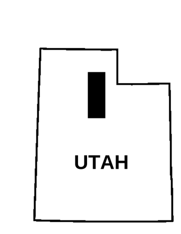
Solid diamond symbol represents logarithmic mean Vs30 value;
thick bar symbol represents +/- 1 standard deviation;
thin bar symbol represents minimum and maximum Vs30 values.

12°29'
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 2008

Scale 1:150,000

0 0.5 1 2 3 4 5 Kilometers

0 0.5 1 2 3 4 5 Miles



STUDY AREA

Shaded topography base generated from digital elevation data.
Basemap in NAD 1927

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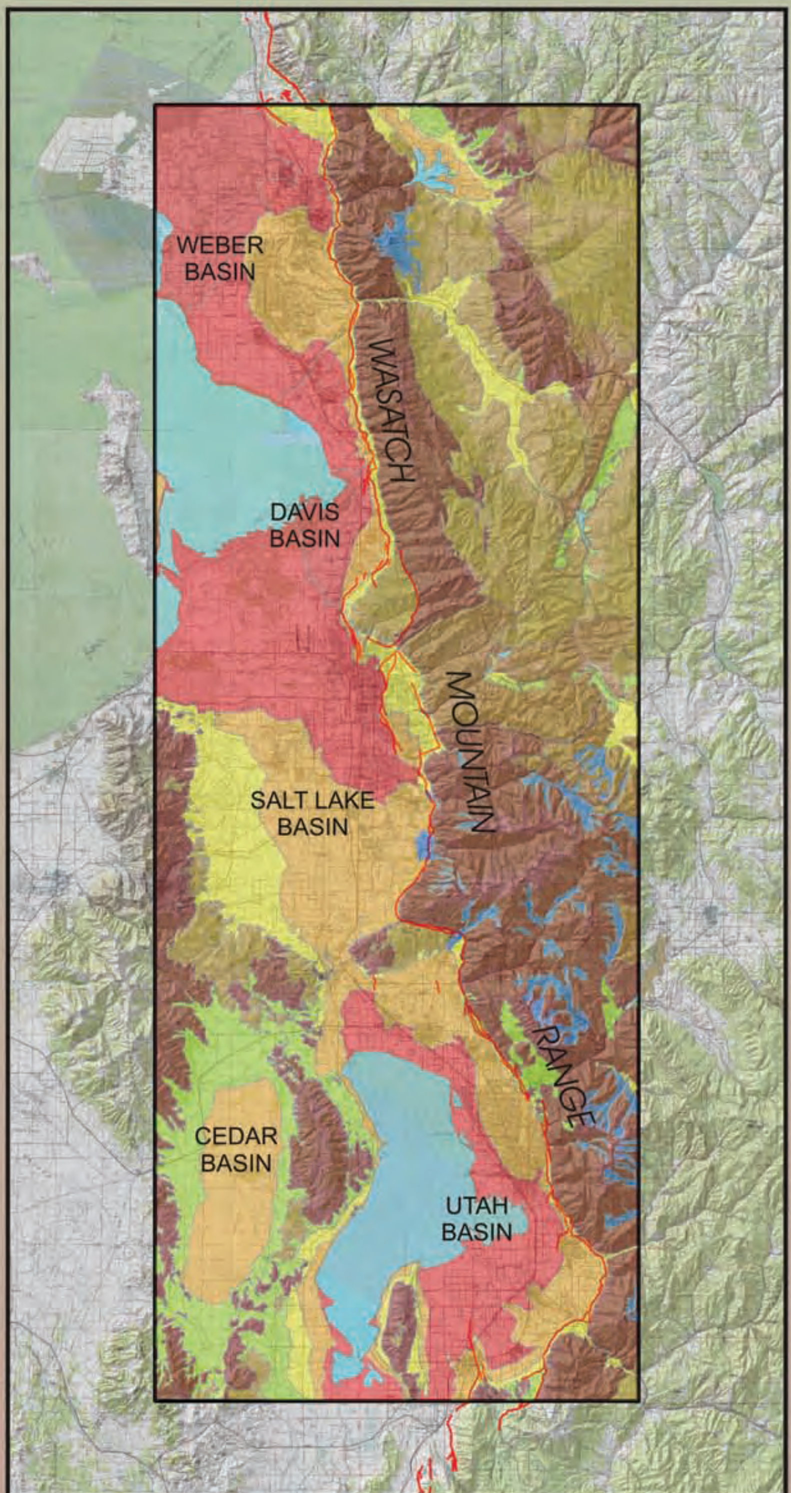

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Cover: Wasatch Front urban corridor site-conditions-map study area.

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EARTHQUAKE SITE CONDITIONS IN THE WASATCH FRONT URBAN CORRIDOR, UTAH

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ABSTRACT

We mapped and characterized Quaternary site conditions using shear-wave-velocity (Vs)-profile data for basins along the Wasatch Front urban corridor to provide a basis for estimating soil response during earthquake ground shaking. We map site conditions for each individual basin using surficial-geologic mapping as a foundation, taking into account local conditions and subsurface information to delineate units using mean Vs for the upper 30 meters (Vs30) that we relate to International Building Code (IBC) site classes.

Vs data for the Wasatch Front is derived from 204 sites in Weber, Davis, Salt Lake, Utah, and Cedar basins. Recent Vs-testing campaigns have added 87 Vs profiles to the Wasatch Front database for the total of 204 Vs30 sites. Salt Lake basin contains 139 sites, or 68% of the data, that are well distributed among the different site-conditions units. The remaining profiles consist of 24 in Weber basin, 16 in Davis basin, 20 in Utah basin, and five in Cedar basin. The present number and distribution of Vs30 data allow us to map and characterize site conditions on a preliminary basis for the basins individually, although most individual units do not contain enough data to be statistically robust. Conversely, characterizing site conditions by grouping units on a Wasatch Front-wide basis results in units with broad Vs30 ranges in each unit spanning several IBC site classes.

The Wasatch Front basins, Weber, Davis, Salt Lake, and Utah, are each effectively characterized by three site-conditions units: a low-velocity, silt-and-clay-dominated unit in their central parts, a sand-dominated alluviual and lacustrine unit near valley margins, and a gravel-dominated unit along the basin edges mostly on the footwall of the Wasatch fault zone. The Vs30 data allow us to group Weber and Davis basins into a composite basin. In addition, we are able to subdivide the Weber-Davis basin low-velocity silt and clay site-conditions unit into IBC site class D and E subunits. Cedar basin, west of Utah basin and off the Wasatch Front urban corridor, is characterized by two site-conditions units: a silt-dominated unit comprising the central part of the basin, and an older alluvial-fan unit around its margins. We characterize two site-conditions units, a glacial unit and an older alluvial-fan unit, on a Wasatch-Front-wide basis as they occur only locally and are widely spaced, are limited in extent, and have sparse Vs30 data.

Analyses of Wasatch Front Vs30 data indicate site conditions are best mapped and characterized using surficial geology and limited shallow subsurface well-log information to distinguish units that are characterized using Vs30. The number, spacing, and location of Vs30 data along the Wasatch Front are insufficient to attempt mapping IBC site class zones.

INTRODUCTION

We mapped site conditions for the Wasatch Front urban corridor to provide a basis for predicting soil behavior during a moderate- to large-magnitude earthquake affecting the Wasatch Front area. We characterized site-conditions units using mean shear-wave velocities (Vs) of the upper 30 m (Vs30) to relate the units to site classes defined by the International Building Code (IBC) (International Code Council, 2006a, 2006b). Previous researchers have recognized that certain soil types can amplify or deamplify seismic waves and that Vs30 provides a good measure of how soils at a particular site may behave during an earthquake (Wills and Silva, 1993). Better understanding of soil properties and earthquake site effects for the densely populated Wasatch Front allows for improved earthquake engineering and emergency planning and response.

We delineated site-conditions units using surficial geologic mapping and limited subsurface lithologic information to group and categorize soil types recognizing dominant grain size as an important geologic factor in site response effects. We characterized site conditions and refined map units using an iterative process involving descriptive statistics and Vs30 distributions.

Our study area extends from North Ogden City in Weber County to Payson in southern Utah County, and includes the densely populated Wasatch Front urban corridor along the seismically active Wasatch fault zone that defines the eastern edge of the Basin and Range Province (figure 1). We defined five basins in our study area for which Vs30 data exist based on geologic, physiographic, and county boundaries: Weber, Davis, Salt Lake, Utah, and Cedar basins. Delineating specific regional basins is problematic where geologic contacts or geographic features, such as topographic divides, are not present. For the Davis-Salt Lake, and Salt Lake-Utah basins, we define basin boundaries using county lines. Included in our study area are some Wasatch Front back valleys that presently lack Vs data, but are mapped using best available geologic mapping supplemented with limited well-log information and characterized using the Wasatch Front Vs30 data. For bedrock site-conditions units in our study area, we use mapping and characteristics from Ashland (2001) and Ashland and McDonald (2003). We adopt the term site conditions to describe our map units as used by Wills and others (2000) referring to properties of shallow (30 m or less) soils.

PREVIOUS WORK

Ashland and McDonald (2003) mapped site conditions in Salt Lake Valley by grouping engineering-geologic units based primarily on dominant grain size. Vs characteristics

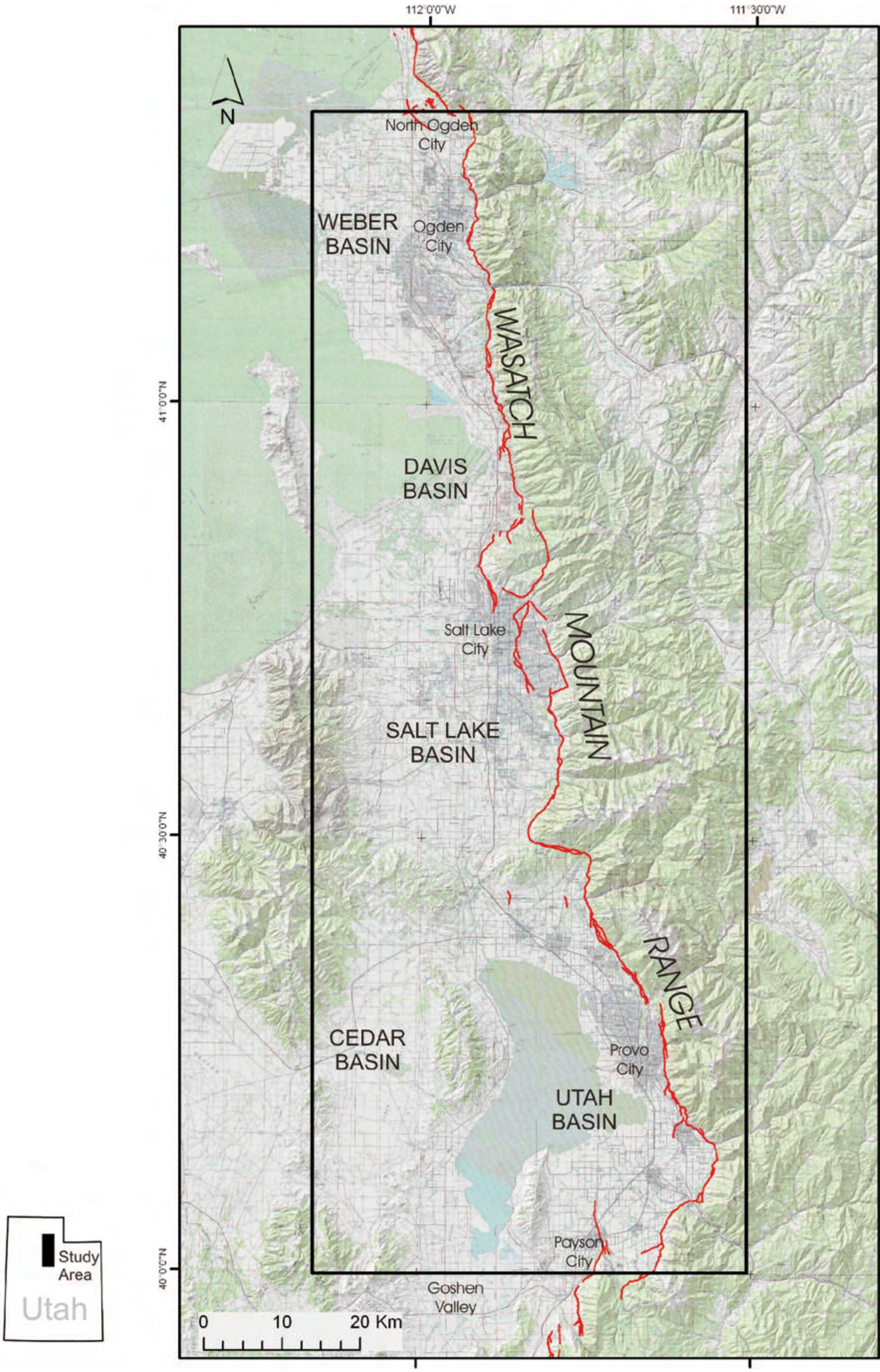

Figure 1. *Wasatch Front urban corridor site-conditions-map study area. Base from U.S. Geological Survey, Salt Lake City, Provo, Tooele, and Rush Valley 1:100,000-scale topographic maps.*

Table 1. *Summary of descriptive statistics for site-conditions units.*

		All Data	Salt Lake Basin	Weber Basin			Davis Basin			Weber-Davis Composite Basin			Utah Basin	Cedar Basin
		Vs30 (m/s)	Vs30 (m/s)	Vs30 (m/s)	IBC E subunit	IBC D subunit	Vs30 (m/s)	IBC E subunit	IBC D subunit	Vs30 (m/s)	IBC E subunit	IBC D subunit	Vs30 (m/s)	Vs30 (m/s)
Q01	n[1]	95	70	12	4	8	7	4	3	19	8	11	6	---
	log mean[2]	194	198	193	165	209	181	167	203	189	166	207	174	---
	log stddev[3]	1.19	1.20	1.14	1.05	1.08	1.13	1.06	1.08	1.14	1.05	1.08	1.09	---
	mean	197	201	195	166	210	183	167	203	190	166	208	174	---
	stddev[4]	38	41	26	8	17	22	10	16	25	9	16	16	---
	max	325	325	244	173	244	221	179	221	244	179	244	202	---
	min	151	151	154	154	189	157	157	192	154	154	189	157	---
	3rd quartile[5]	211	216	207	169	217	194	175	209	203	173	218	179	---
Q02	n[1]	76	43	10	---	---	9	---	---	19	---	---	13	1
	log mean[2]	281	290	247	---	---	271	---	---	258	---	---	294	---
	log stddev[3]	1.20	1.19	1.20	---	---	1.11	---	---	1.17	---	---	1.23	---
	mean	286	294	251	---	---	273	---	---	261	---	---	300	236
	stddev[4]	54	55	49	---	---	29	---	---	41	---	---	64	---
	max	469	469	348	---	---	317	---	---	348	---	---	447	---
	min	206	210	206	---	---	231	---	---	206	---	---	211	---
	3rd quartile[5]	324	327	260	---	---	292	---	---	285	---	---	339	---
Q03	n[1]	24	20	2	---	---	---	---	---	2	---	---	---	---
	log mean[2]	409	408	349	---	---	---	---	---	349	---	---	---	---
	log stddev[3]	1.24	1.25	1.08	---	---	---	---	---	1.08	---	---	---	---
	mean	418	419	350	---	---	---	---	---	350	---	---	---	---
	stddev[4]	98	103	28	---	---	---	---	---	28	---	---	---	---
	max	708	708	370	---	---	---	---	---	370	---	---	---	---
	min	294	294	330	---	---	---	---	---	330	---	---	---	---
	3rd quartile[5]	460	457	360	---	---	---	---	---	360	---	---	---	---
Qafo	n[1]	4	---	---	---	---	---	---	---	---	---	---	---	4
	log mean[2]	502	---	---	---	---	---	---	---	---	---	---	---	502
	log stddev[3]	1.19	---	---	---	---	---	---	---	---	---	---	---	1.19
	mean	508	---	---	---	---	---	---	---	---	---	---	---	508
	stddev[4]	92	---	---	---	---	---	---	---	---	---	---	---	92
	max	640	---	---	---	---	---	---	---	---	---	---	---	640
	min	434	---	---	---	---	---	---	---	---	---	---	---	434
	3rd quartile[5]	536	---	---	---	---	---	---	---	---	---	---	---	536
Qg	n[1]	7	6	---	---	---	---	---	---	---	---	---	1	---
	log mean[2]	452	456	---	---	---	---	---	---	---	---	---	---	---
	log stddev[3]	1.07	1.08	---	---	---	---	---	---	---	---	---	---	---
	mean	453	457	---	---	---	---	---	---	---	---	---	431	---
	stddev[4]	33	34	---	---	---	---	---	---	---	---	---	---	---
	max	510	510	---	---	---	---	---	---	---	---	---	---	---
	min	413	413	---	---	---	---	---	---	---	---	---	---	---
	3rd quartile[5]	469	470	---	---	---	---	---	---	---	---	---	---	---

[1]Number of samples, [2]Logarithmic mean, [3]Multiplicative standard deviation, [4]Standard deviation, [5]Value 75% of data is less than.

were determined from compiled profiles limited to only three of the mapped units. Surficial and bedrock units lacking Vs data were characterized using data from the literature. Where possible, bedrock Vs measurements at depth were used when they could be inferred to be in a particular bedrock unit. Probabilistic and scenario earthquake ground-shaking maps for the Salt Lake City metropolitan area (Wong and others, 2002) relied on the earliest, unpublished version of the Salt Lake Valley site-conditions map.

Preliminary site-conditions mapping beyond Salt Lake Valley, including the Wasatch Front urban corridor from North Ogden City to southern Utah County, was conducted for implementing *SHAKEMAP* in northern Utah (Ashland, 2001) and was later used by Solomon and others (2004) in developing hazard maps for an earthquake scenario along the Wasatch fault zone. The preliminary site-conditions units for the Wasatch Front urban corridor were mapped at 1:250,000-scale using best available surficial geologic mapping and limited subsurface information consisting mostly of water-well drilling logs. Wasatch Front site conditions were estimated using the Salt Lake Valley Vs30 data.

Ashland and others (2005) revised the Salt Lake Valley site-conditions map of Ashland and McDonald (2003) using Vs profiles from the first of two Vs-testing campaigns by Utah State University (Gilbert, 2004) that improved the number and distribution of Vs30 data along the Wasatch Front with a focus on filling data gaps in Salt Lake Valley. The new data allowed for statistical analysis of Salt Lake Valley site-conditions units and resulted in a simpler map having fewer map units. Significant changes to the previous map included combining sand- and gravel-dominated units in the southeast part of the valley with unit Q02 and incorporating a previously distinct older alluvial-fan unit (Q04) along the western margin of Salt Lake Valley into an alluvial/lacustrine unit dominated by younger sand and gravel deposits (Q03).

DATA FOR THIS STUDY

Newly acquired Vs data and recent geologic mapping of several 7½-minute quadrangles allow for evaluation and revision of the preliminary site-conditions-unit mapping and characterization for the Wasatch Front urban corridor. Recently, an effort has been made to collect data in poorly characterized units along the Wasatch Front urban corridor (Gilbert, 2004; Berry, 2006). The second of two recent spectral-analysis-of-surface-waves (SASW) -testing campaigns by Berry (2006) focused on achieving better spatial distribution and site-conditions-unit characterization for Weber, Davis, and Utah basins where little data existed previously. Site selection was limited by logistical constraints including site access and property-ownership restrictions.

During the summer of 2005, Berry (2006) tested 45 new sites, greatly expanding the distribution of Vs30 data along the Wasatch Front urban corridor outside Salt Lake Valley. Tested sites included 17 in Weber basin, 10 in Davis basin, three in Salt Lake basin, 14 in Utah basin, and one in Cedar basin. While this SASW-testing campaign adds a substantial number of sites to the Wasatch Front Vs database, many site-conditions units within the individual basins contain ten or fewer Vs profiles and are thus not statistically robust.

Vs30 data for the Wasatch Front urban corridor presently consist of 204 profiles in five basins. The two recent SASW-testing campaigns (Gilbert, 2004; Berry, 2006) contributed 87 sites to the database. Of the 204 Vs30 sites, 139 (68%) are in Salt Lake Valley and are well distributed among the mapped site-conditions units. The remaining 65 profiles consist of 24 in Weber basin, 16 in Davis basin, 20 in Utah basin, and five in Cedar basin.

Our site-conditions map for the Wasatch Front is largely based on simplified surficial geology using mainly grain-size characteristics of units of significant thickness based on limited subsurface information, mostly well logs. While this method provides the best means of mapping site conditions along the Wasatch Front using the available data, inherent uncertainties exist when using surficial geology to characterize the upper 30 meters of a basin, including vertical and lateral heterogeneities and anisotropies of deposits, the gradational nature of many surficial geologic contacts, facies changes within a unit, age/consolidation differences, and variable deposit characteristics with depth. Our map is a working version that will likely change as additional Vs data become available. However, as no immediate large-scale Vs testing campaigns are anticipated, this map will likely not change in the near term.

INDIVIDUAL BASIN SITE-CONDITIONS MAPPING

Our site-conditions units are based on surficial deposits consisting mostly of late Pleistocene lacustrine shoreline, deltaic, and deep-water deposits; early Pleistocene to Holocene alluvial deposits; glacial deposits; and large landslides (including lateral spreads) associated with various deposits. We characterize site-conditions units associated with older alluvial fans and glacial deposits on a Wasatch-Front-wide basis given their widely spaced yet localized occurrences, relatively limited distribution, and paucity of Vs data that precludes distinguishing them for the individual basins.

We distinguish five major basins in our study area: Weber, Davis, Salt Lake, Utah, and Cedar basins (figure 1). We include the northern part of Goshen Valley with Utah basin. Several small Wasatch Range back valleys are included in our study area, which we characterized using mean Vs30 values from Wasatch Front data.

Following the methods of earlier studies (Park and Elrick, 1998; Ashland and McDonald, 2003), we assumed log-normal distributions for the Vs30 data. In addition, we performed statistical tests for units having larger datasets that confirmed they are consistent with log-normal distributions. Thus, we derive composite Vs profiles, Vs30 histograms, and descriptive statistics using natural-log functions. We produced composite Vs profiles for the site-conditions units by calculating logarithmic means and standard deviations of shear-wave velocities at one-meter depth intervals through the depth of deepest measurements. Table 1 summarizes descriptive statistics for the Wasatch Front site-conditions units.

We label Wasatch Front site-conditions units using the approach of Ashland and others (2005) that denotes Quaternary units with a "Q" prefix followed by numbers beginning with "01" through "03" that sequentially represent softest to stiffest units, respectively. We distinguish equivalent units for each basin using a one-letter suffix to denote a particular basin (e.g., Q03W designates the gravel-dominated unit for Weber basin). Because we map a Quaternary unit (older alluvial fan) not mapped in Salt Lake basin by Ashland and others (2005) that is sequentially between their units Q03 and Q04, we designate the older alluvial-fan unit as Qafo, and the glacial site-conditions unit, designated Q04 by Ashland and others (2005), as Qg.

Salt Lake Basin

We use site-conditions-unit mapping and characterization from Ashland and others (2005) for the Salt Lake basin that makes up the central portion of our map (figure 2). Salt Lake basin contains the greatest number of Vs profiles along the Wasatch Front and is the best characterized basin in our study area. Ashland and McDonald's (2003) initial mapping was based on compiled Vs30 data for Salt Lake basin as well as data from the first of two SASW-testing campaigns by Utah State University (Gilbert, 2004) that focused on improving the spatial and site-conditions-unit distributions of Vs30 data in Salt Lake basin. Subsequent Vs30 data for Salt Lake basin consist of a few additional sites that do not statistically affect site-conditions-unit characteristics and preclude a need to revise Salt Lake basin site-conditions units.

Figures 3 and 4 show composite Vs profiles and histograms, respectively, of Salt Lake basin site-conditions units. The recent SASW-testing campaign by Berry (2006) tested three sites in Salt Lake County where the University of Utah Seismograph Stations (UUSS) maintains Advanced National Seismic System (ANSS) stations. Two SASW-tests were done at "bedrock" sites (UUSS sites NOQ and CTU) that did not attain Vs profiles to depths of 30 m and are thus not included in our Vs30 database. One SASW test, performed near the northwest margin of Salt Lake basin, reoccupied a site tested during the 2003 SASW campaign and where the USGS performed seismic testing in 2003 (UUSS site FTT). Site NOQ is located in the northeastern part of the Oquirrh Mountains near the mouth of Coon Canyon and bedrock site CTU is located up Millcreek Canyon in the Wasatch Range east of Salt Lake Valley (figure 2). Both sites are characterized by a thin layer of alluvium/colluvium overlying Paleozoic bedrock and their Vs profiles are poorly resolved below a few meters. The third Salt Lake basin site tested by Berry (2006), FTT, reoccupied a site Gilbert (2004) tested in 2003 and where the USGS performed deep S-wave refraction soundings in 2003 and 2005.

The revised Salt Lake basin site-conditions map of Ashland and others (2005) contains four Quaternary site-conditions units:

- Q01 – Lacustrine and alluvial clay, silt, and fine sand.
- Q02 – Lacustrine sand, silt, and fine gravel, and younger alluvial-fan deposits.
- Q03 – Gravel-dominated lacustrine and alluvial valley-margin deposits; alluvial-fan and channel deposits; alluvium; deltaic sand, gravel and silt; and older alluvial-fan deposits.
- Q04 – Gravel-dominated glacial till and outwash.

We designate Ashland and others' (2005) Salt Lake basin site-conditions units Q01, Q02, Q03, and Q04 as Q01S, Q02S, Q03S, and QgS, respectively, following our site-conditions-unit labeling approach. Our Salt Lake basin site-conditions unit parameters (table 1) and composite profiles (figure 3) and histograms (figure 4) incorporate Vs30 data obtained subsequent to Ashland and others (2005) and thus may differ slightly; mean Vs30 for Salt Lake basin site-conditions units changed 1% or less.

Weber Basin

Weber County covers the northern part of our study area and includes the city of Ogden in addition to several large and rapidly growing suburban communities. The eastern part of the Weber/Davis county line is the Weber River where it bisects the Weber River delta into northern and southern parts (figure 5). The Weber delta is a prominent geologic landform built as the Weber River entered Pleistocene Lake Bonneville and is best represented within a single site-conditions unit. We therefore include the entire Weber delta in Weber basin, and use the Hobbs Creek drainage in Davis County to delineate the southern edge of the Weber delta and thus the Weber/Davis basin boundary (figure 5).

We mapped the Weber basin site-conditions units based mostly on Vs30 data acquired by Berry (2006), who performed 17 SASW tests in Weber basin, for a total of 24 points, including three in Davis County that fall within Weber basin using the Hobbs Creek boundary (figure 5). We subdivided the silt- and clay-dominated unit, Q01, into two subunits, a western subunit where Vs30 falls in IBC site class E and a discontinuous eastern subunit where Vs30 falls in IBC site class D, including a low-velocity portion of the Ogden River delta. The majority of the composite late Pleistocene Ogden and Weber River deltas and shoreline deposits in the hanging wall of the Wasatch fault zone (WFZ) are mapped as unit Q02 where Vs30 falls in IBC site class D. Our mapping shows the gravel-dominated unit Q03 to be of limited extent, occurring in a narrow north-trending belt in the eastern foothills and in a broader area in the northern foothills. Only two Vs profiles exist in unit Q03W in the northern part of Weber basin. Figures 6 and 7 show composite Vs profiles and Vs30 histograms, respectively, of Weber basin site-conditions units.

Unit Q01W (Q01We, Q01Wd)

Site-conditions unit Q01W is dominated by late Pleistocene lacustrine silt and clay deposits of Lake Bonneville. The southern part of the Ogden River delta contains four closely spaced Vs profiles that define an area of relatively low Vs30 ranging from 189 to 202 meters per second (m/s), more typical of silt- and clay-dominated site-conditions units, within an area of higher velocity unit Q02W. We therefore map and characterize the Ogden River delta as site-conditions unit Q01W (subunit Q01Wd). Doing so results in better Vs30 distributions for both site-conditions units Q01W and Q02W (figure 8).

Vs30 in unit Q01W has a mean of 193 m/s and ranges from 154 to 244 m/s with a distribution that spans the IBC site class D-E boundary (figure 7). The clustering of these data into similar IBC site classes allows for subdividing unit

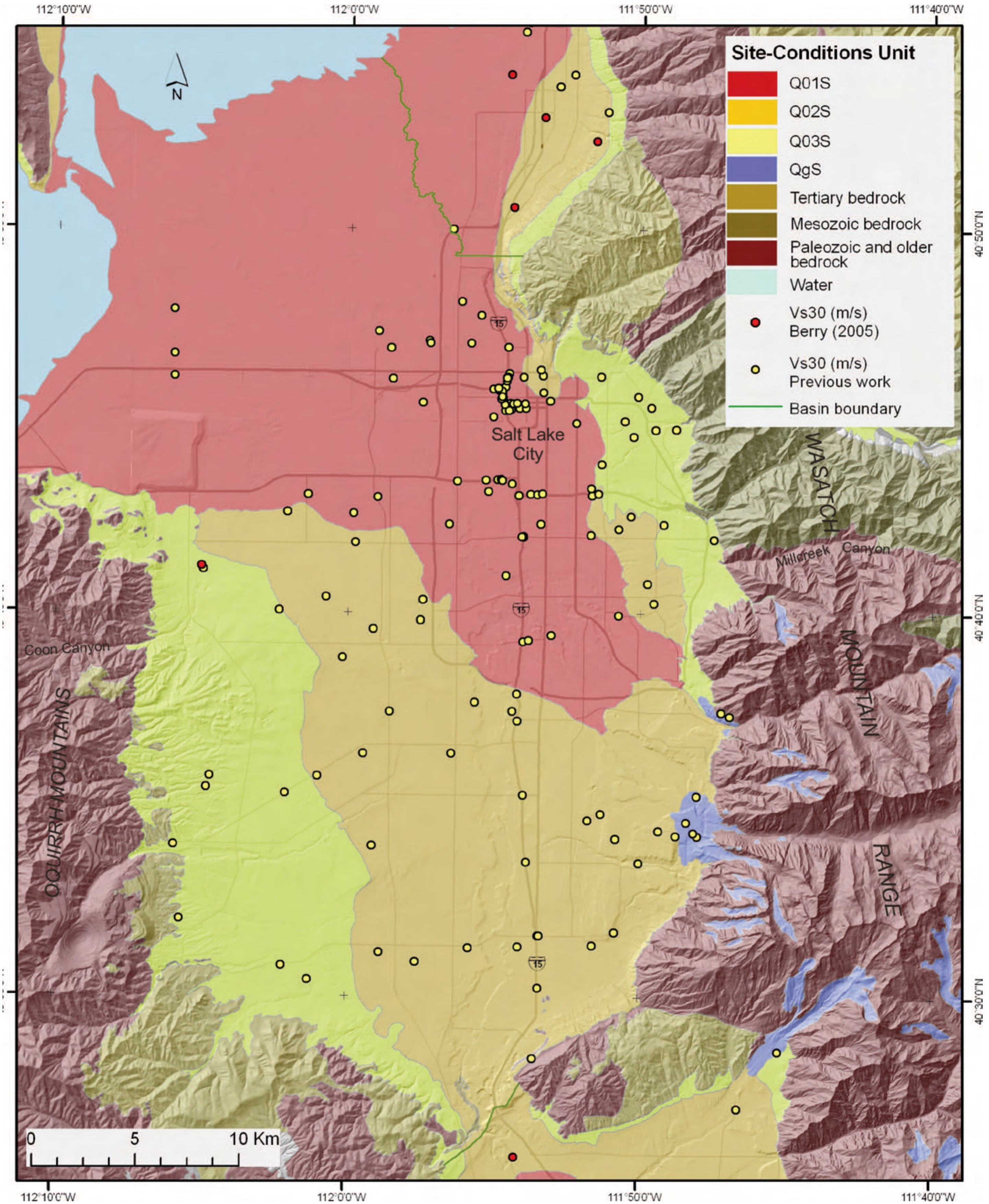

Figure 2. *Salt Lake basin site-conditions map from Ashland and others (2005). See plate 1 for detailed unit descriptions and Vs30 values.*

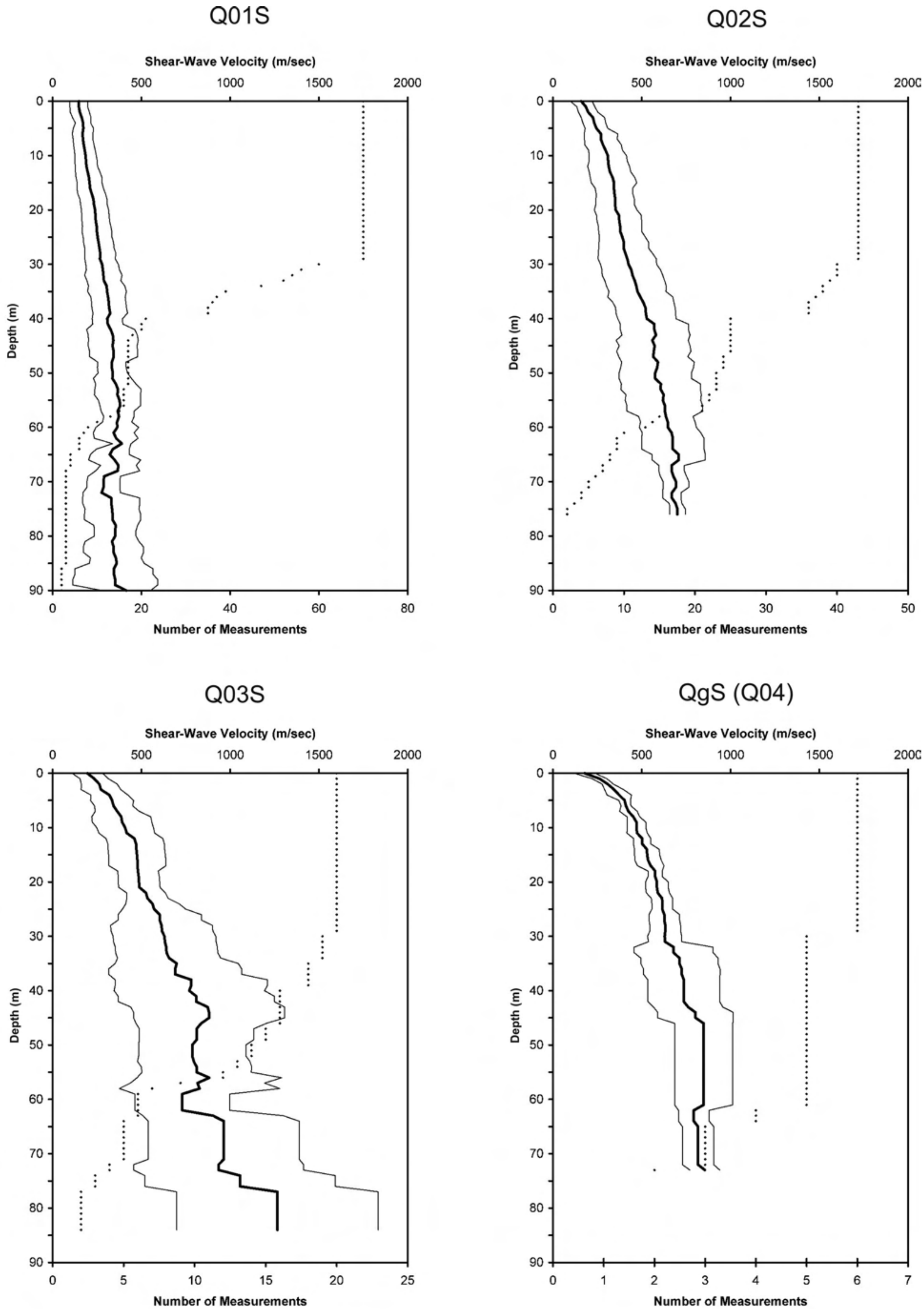

Figure 3. *Composite Vs profiles for Salt Lake basin site-conditions units. Thick solid line represents Vs logarithmic mean; thin lines are +/- 1 standard deviation. Dotted line represents number of Vs measurements per 1-meter interval.*

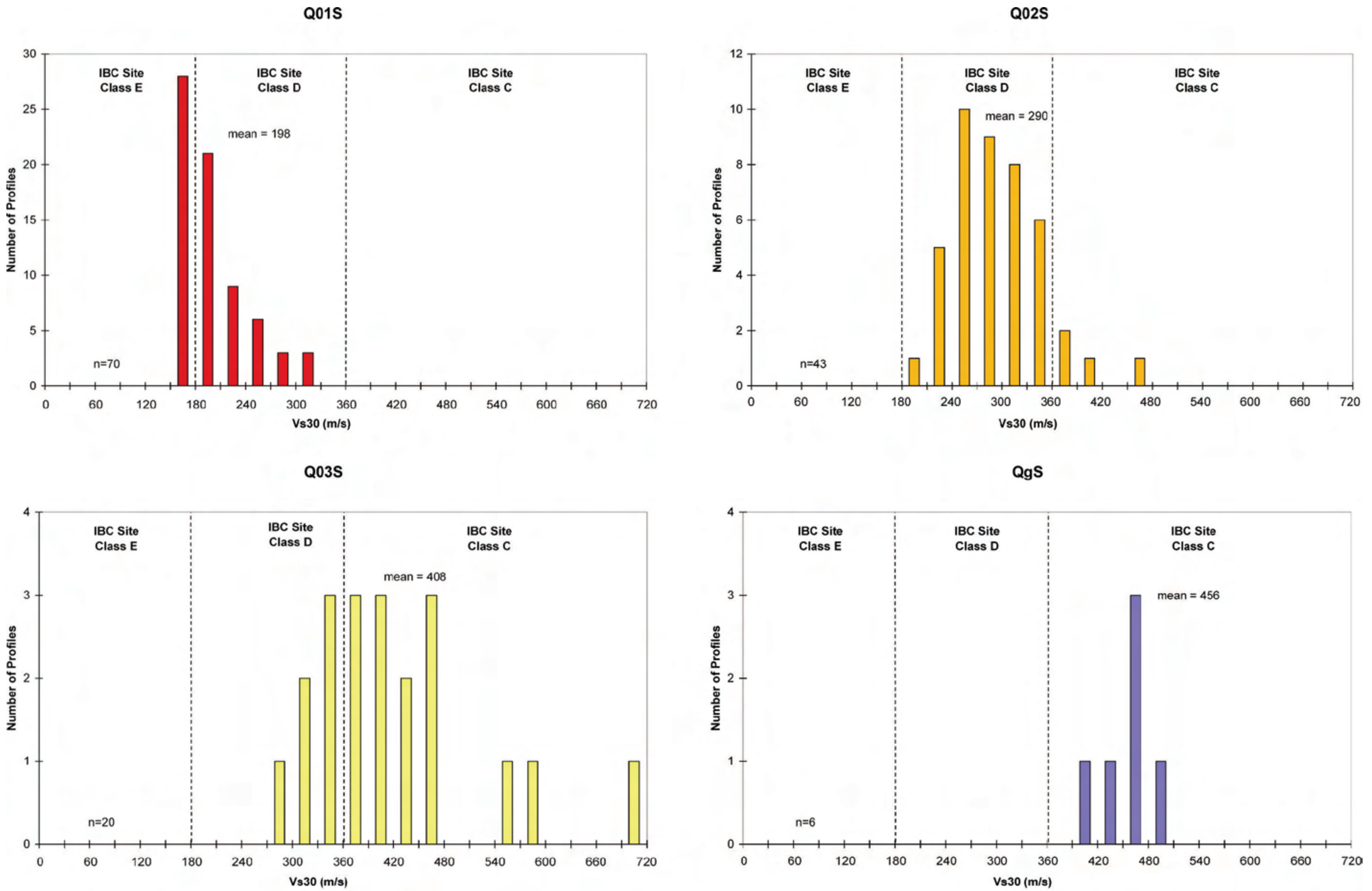

Figure 4. *Vs30 histograms of Salt Lake basin site-conditions units.*

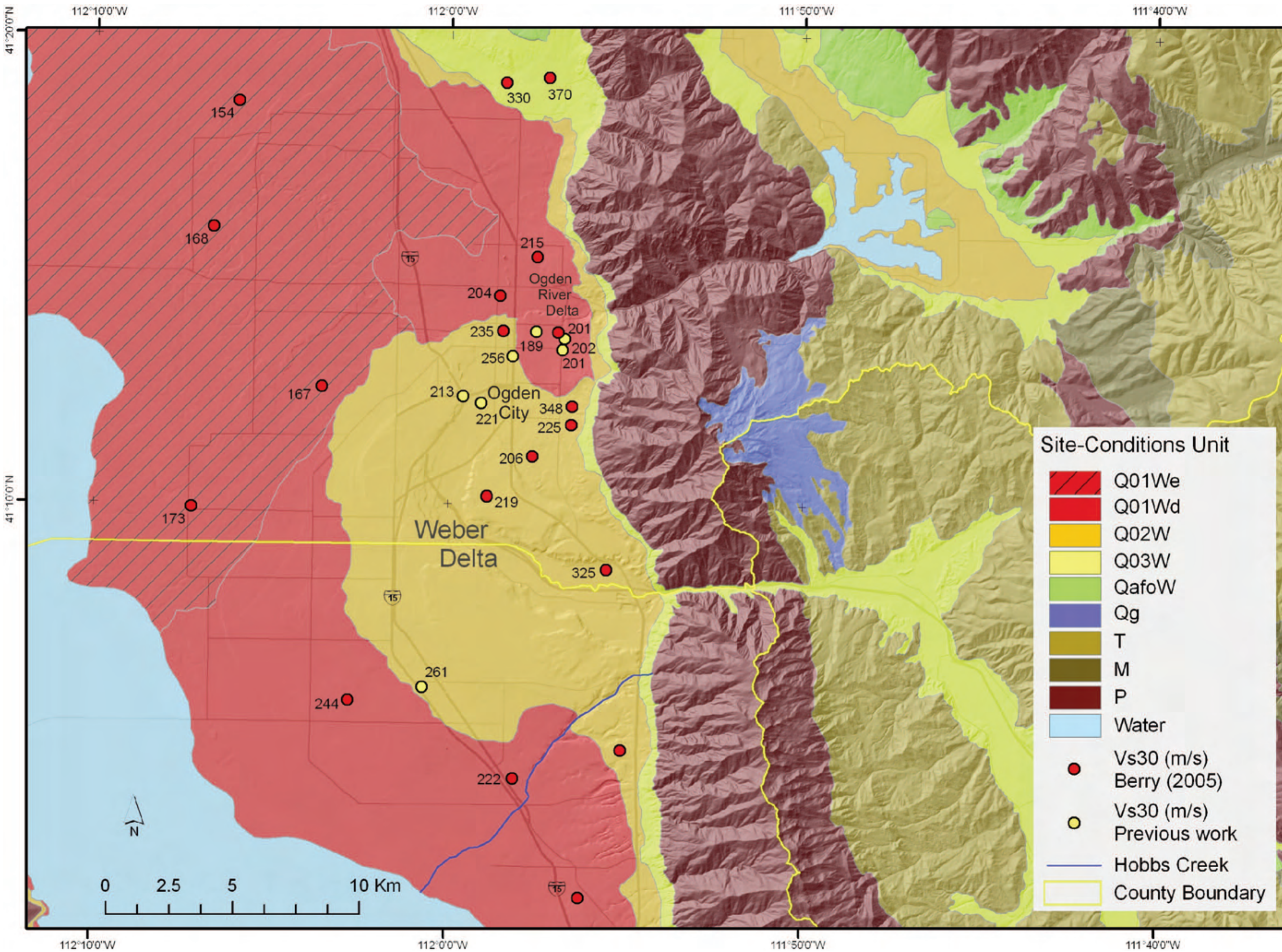

Figure 5. *Weber basin site-conditions units (see plate 1 for unit descriptions).*

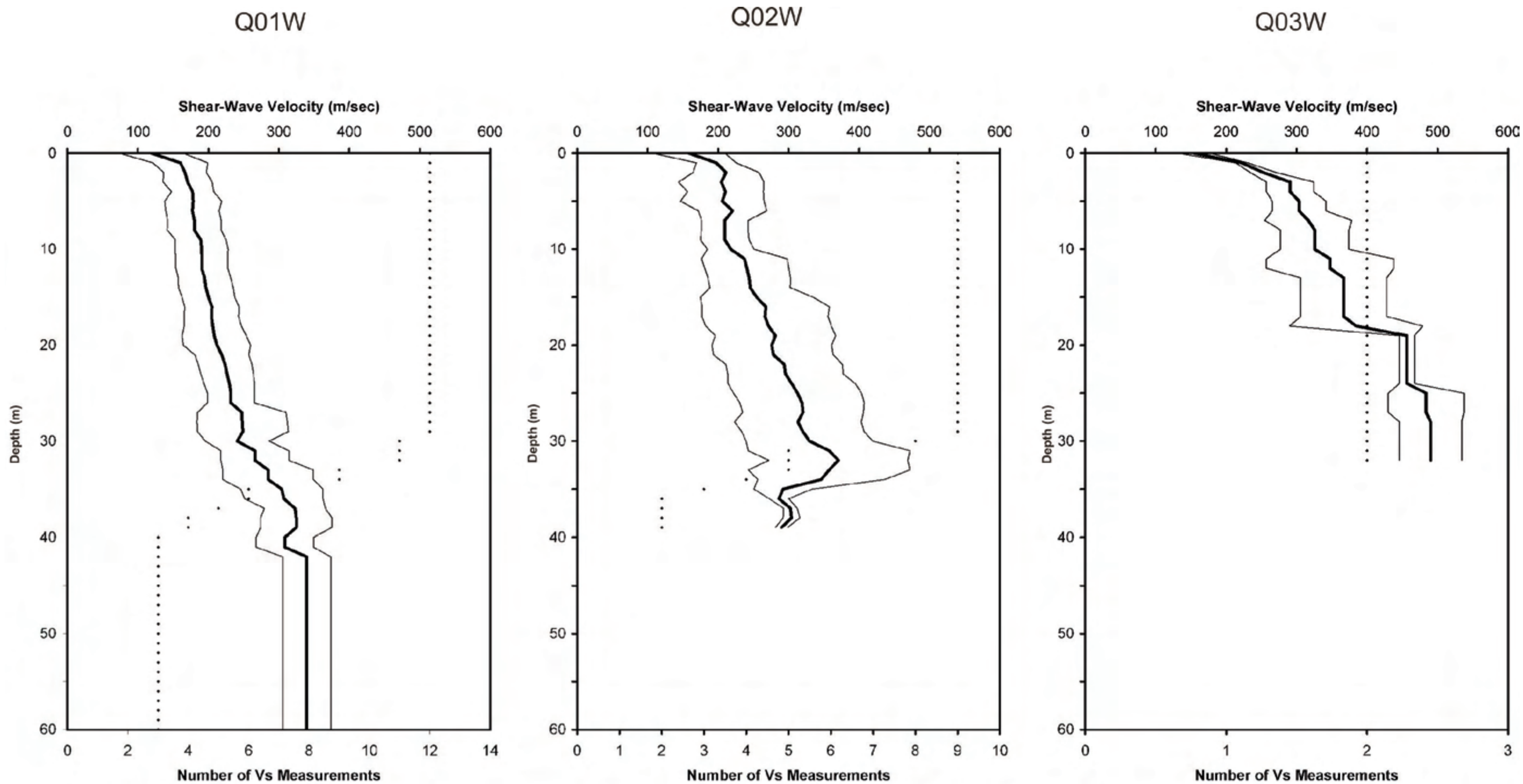

Figure 6. *Composite Vs profiles for Weber basin site-conditions units. Thick solid line represents Vs logarithmic means; thin lines +/- 1 standard deviation. Dotted line represents number of Vs measurements per 1-meter interval.*

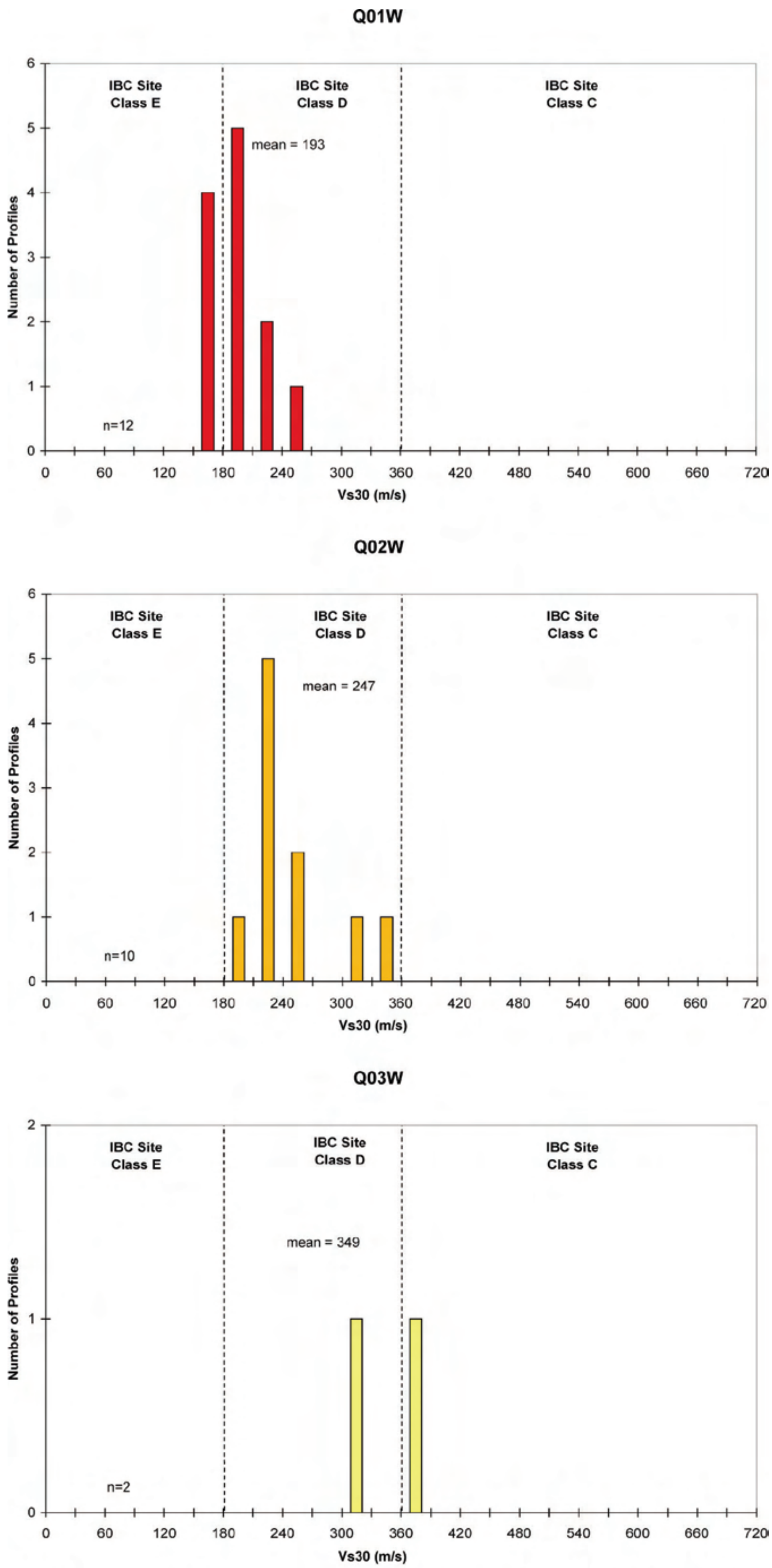

Figure 7. *Histograms of Weber basin site-conditions units.*

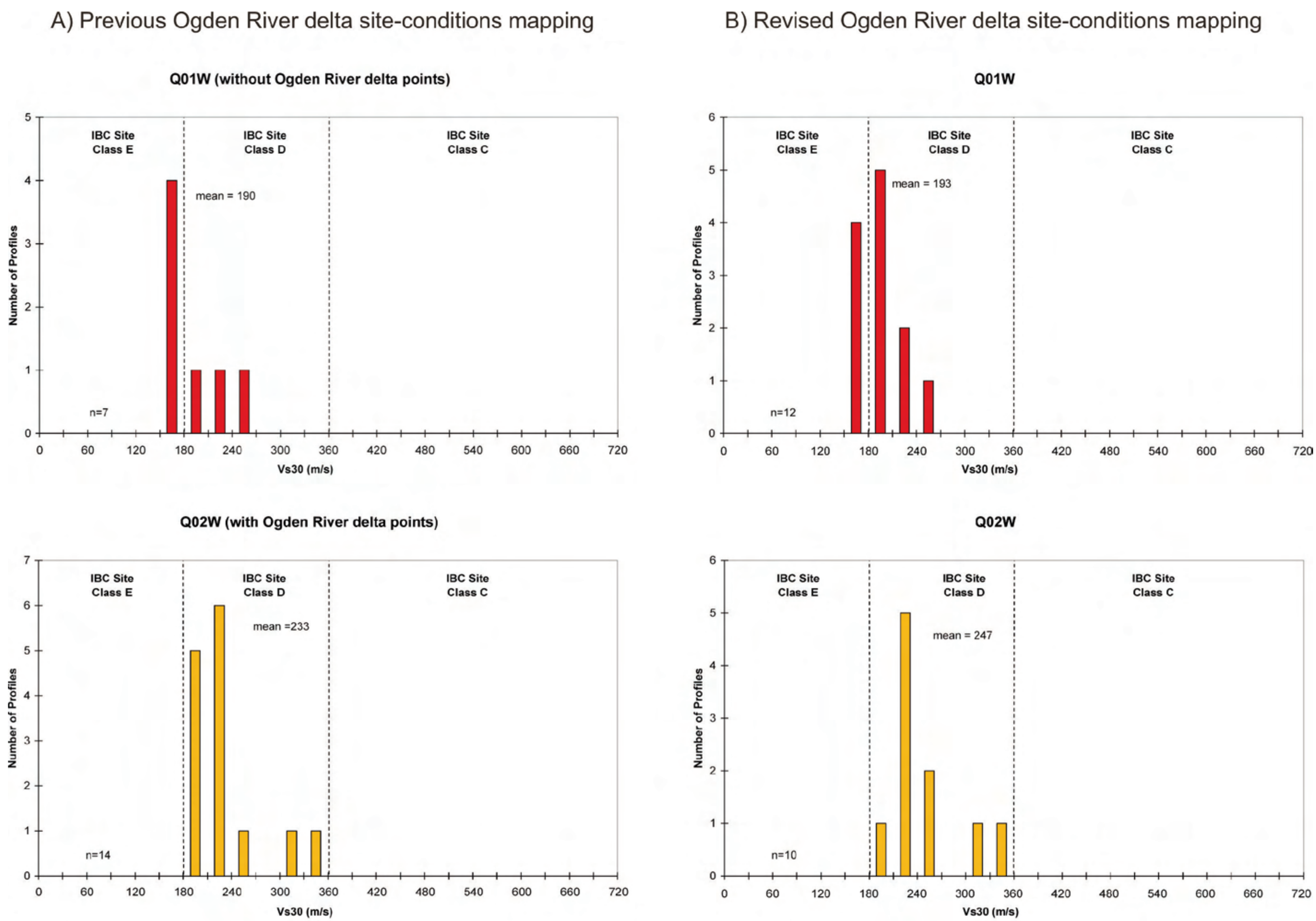

Figure 8. *Histograms of site-conditions units Q01W and Q02W. (A) before and (B) after extraction of the Ogden River delta Q01W unit from unit Q02W.*

Q01W into a northwestern subunit, Q01We, with a Vs30 distribution that falls within IBC site class E with a mean Vs30 of 165 m/s, and a eastern IBC site class D subunit, Q01Wd, with a mean Vs30 of 233 m/s. Figures 9 and 10, respectively, show composite Vs profiles and histograms of Weber basin site-conditions unit Q01W and subunits Q01We and Q01Wd.

Unit Q02W

We mapped unit Q02W as extending between the WFZ and the western edge of the Weber River delta complex (figure 5). We based the western Q02W boundary along the Weber River delta on new geologic mapping (Harty and Lowe, 2006; Solomon, 2006; Sack, 2005a, 2005b) showing the western extent of sand-dominated, regressive Lake Bonneville deltaic deposits.

Unit Q03W

We limit site-conditions unit Q03W along the eastern edge of Weber basin to a narrow band of gravel-dominated lacustrine and alluvial-fan deposits along the base of the Wasatch Range, mostly on the footwall of the WFZ. In the northeast part of Weber basin near the northern end of the Weber segment of the WFZ and Pleasant View salient, we map coarse alluvial-fan and lacustrine gravel deposits mantling the south-southwest-facing slopes at the northeast end of Weber basin as site-conditions unit Q03W (figure 5). Currently, only two Vs profiles exist in unit Q03W in this part of Weber basin with Vs30 values of 330 and 370 m/s and a resultant mean Vs30 of 349 m/s, near the IBC site class D-C boundary.

Unit QafoW

Older alluvial-fan deposits exist in northern Weber basin and Weber County back valleys as isolated, local remnants, but lack Vs30 data. We estimate a mean Vs30 of 502 m/s based on limited data collected from Cedar basin pre-Lake Bonneville alluvial-fan deposits (see unit QafoC described below).

Davis Basin

Our Davis basin extends from the Hobbs Creek drainage, as discussed above, to the Davis-Salt Lake County line at the Salt Lake salient, which is a well-defined geologic basin boundary (figure 11). The portion of Davis basin not covered by Great Salt Lake is relatively narrow, bounded by the lake on the west and the Wasatch Range on the east, and is less than 3.5 km wide near Farmington Bay. Surficial deposits in Davis basin are dominated by Lake Bonneville lacustrine deposits, mostly derived from nearby drainages in the Wasatch Range. Unlike Weber basin, Davis basin lacks any major rivers, and does not derive sediments from any back-valley areas. Davis basin surficial deposits consist of lacustrine shoreline and nearshore sand and gravel locally overlain by alluvial-fan deposits in the foothills that, in general, transition to more fine-grained facies westward. Along the edge of Great Salt Lake, lacustrine deposits consist of latest Pleistocene to Holocene interbedded silt and clay.

Ten SASW tests in Davis basin performed by Berry (2006) expanded the number of Vs30 measurement sites to 16 and provided a basis for site-conditions mapping. We map three site-conditions units in Davis basin (figure 11). Figures 12 and 13 show composite Vs profiles and histograms, respectively, of Davis basin site-conditions units.

Unit Q01D (Q01De, Q01Dd)

Unit Q01D is dominated by Lake Bonneville silt and clay deposits as well as two large, liquefaction-induced lateral spreads in the northwest and southwest parts of the basin (figure 11). Clustering of the limited Vs30 data by IBC site class in Davis basin allows for subdividing unit Q01D into northern and southern subunits with Vs30 values within IBC classes D and E, respectively (figure 11). Site-conditions unit Q01Dd, the northern subunit, has a mean Vs30 of 203 m/s based on three sites, and subunit Q01De has a mean Vs30 of 167 m/s based on four sites. A single Vs profile from a site within the Farmington Siding lateral-spread complex has a Vs30 of 192 m/s, within 7% of the Davis basin Q01D mean of 181 m/s derived from seven sites in lacustrine fine-grained deposits, suggesting Vs for lateral spreads may not differ significantly from their source deposits. Figures 14 and 15 show composite Vs profiles and histograms, respectively, of Davis basin site-conditions unit Q01D and subunits Q01De and Q01Dd.

Unit Q02D

Site-conditions unit Q02D consists of mostly sand-dominated, lacustrine and young alluvial-fan deposits along the base of the Wasatch Range (in the foothills) mainly on the hanging wall of the WFZ (figure 11). Vs30 at nine sites falls within IBC site class D, with a mean Vs30 of 271 m/s (figure 13).

Included in unit Q02D in the southern part of Davis basin is an area underlying much of Bountiful and the I-15 corridor through southern Davis County that is mapped by Nelson and Personius (1993) as lacustrine silt and clay. Well logs indicate the silt and clay deposits form a thin veneer overlying coarser alluvium and transgressive lacustrine deposits. Subsequent Vs testing at three sites with Vs30 ranging from 268 to 317 m/s supports this interpretation. A narrow, transitional zone in unit Q01D of IBC site class D soils may exist in this area between units Q01De and Q02D, but no data were recovered to demonstrate its existence.

Unit Q03D

Site-conditions unit Q03D consists of a narrow band of gravel-dominated lacustrine and alluvial-fan deposits along the base of the Wasatch Range mostly on the footwall of the WFZ (figure 11). We mapped unit Q03D solely on the WFZ footwall because of probable differences in thickness and subsurface geology between the similar deposit (Q02D) on the hanging wall side of the fault zone. Three SASW test sites on the hanging wall side of the fault zone had Vs30 values of 238, 292, and 307 m/s, consistent with unit Q02D. Currently, unit Q03D lacks Vs30 data; thus, we assign it a mean Vs30 of 349 m/s using Weber basin data.

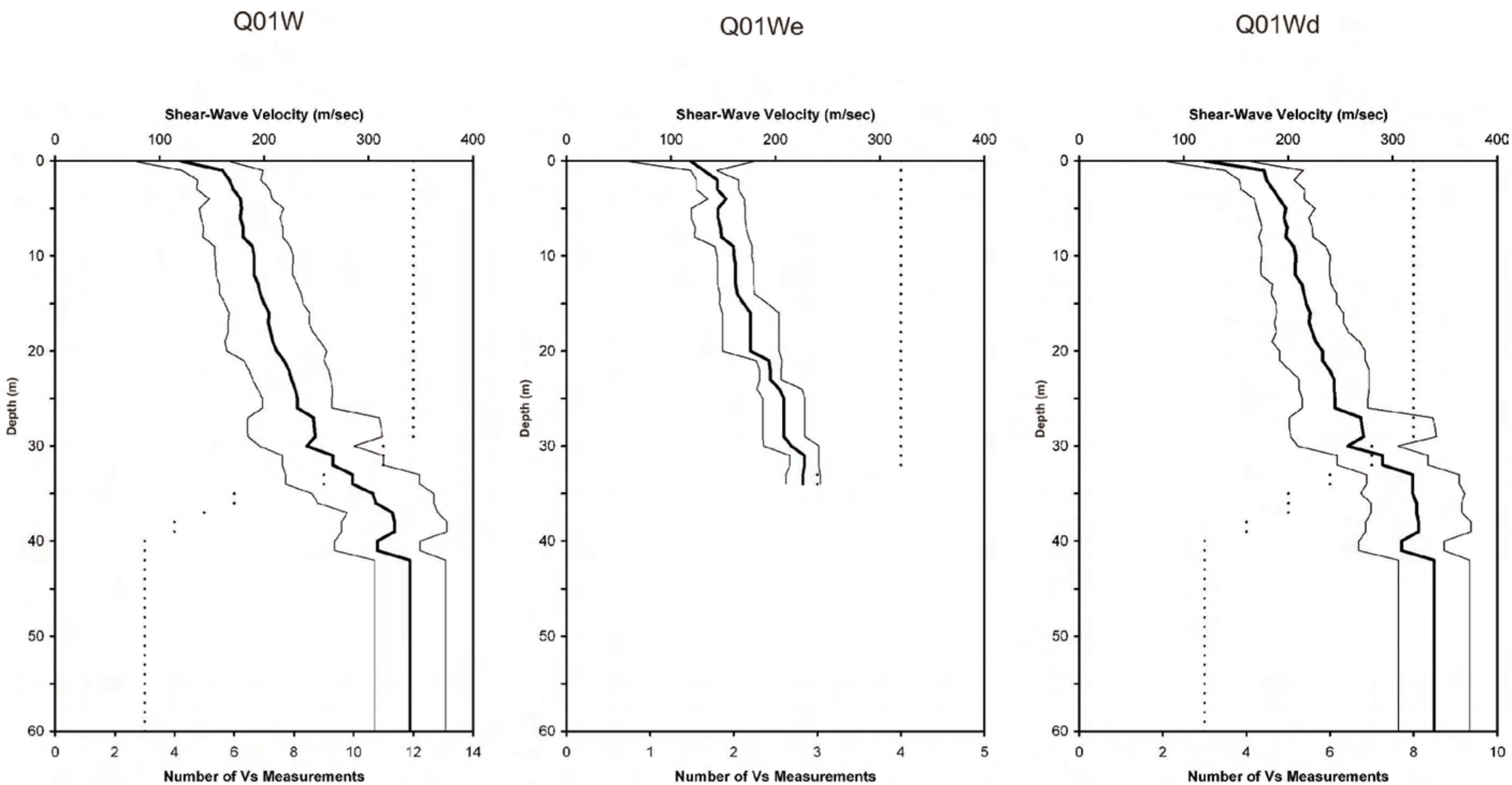

Figure 9. *Composite Vs profiles for Weber basin site-conditions unit Q01W and subunits Q01We and Q01Wd. Thick solid line represents Vs logarithmic mean; thin lines +/- 1 standard deviation. Dotted line represents number of Vs measurements per 1-meter interval.*

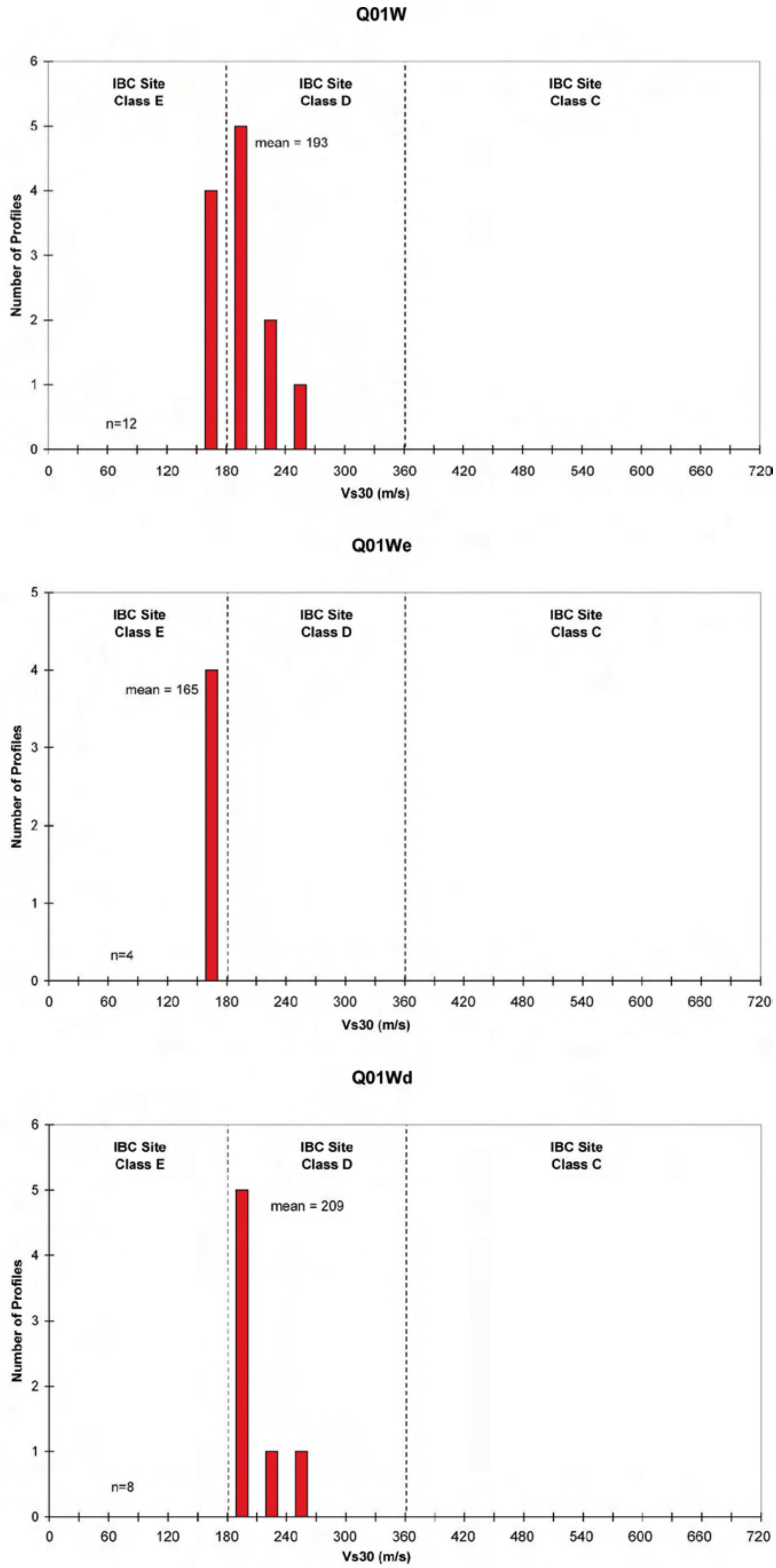

Figure 10. *Historgrams for Weber basin site-conditions unit Q01W and subunits Q01We and Q01Wd.*

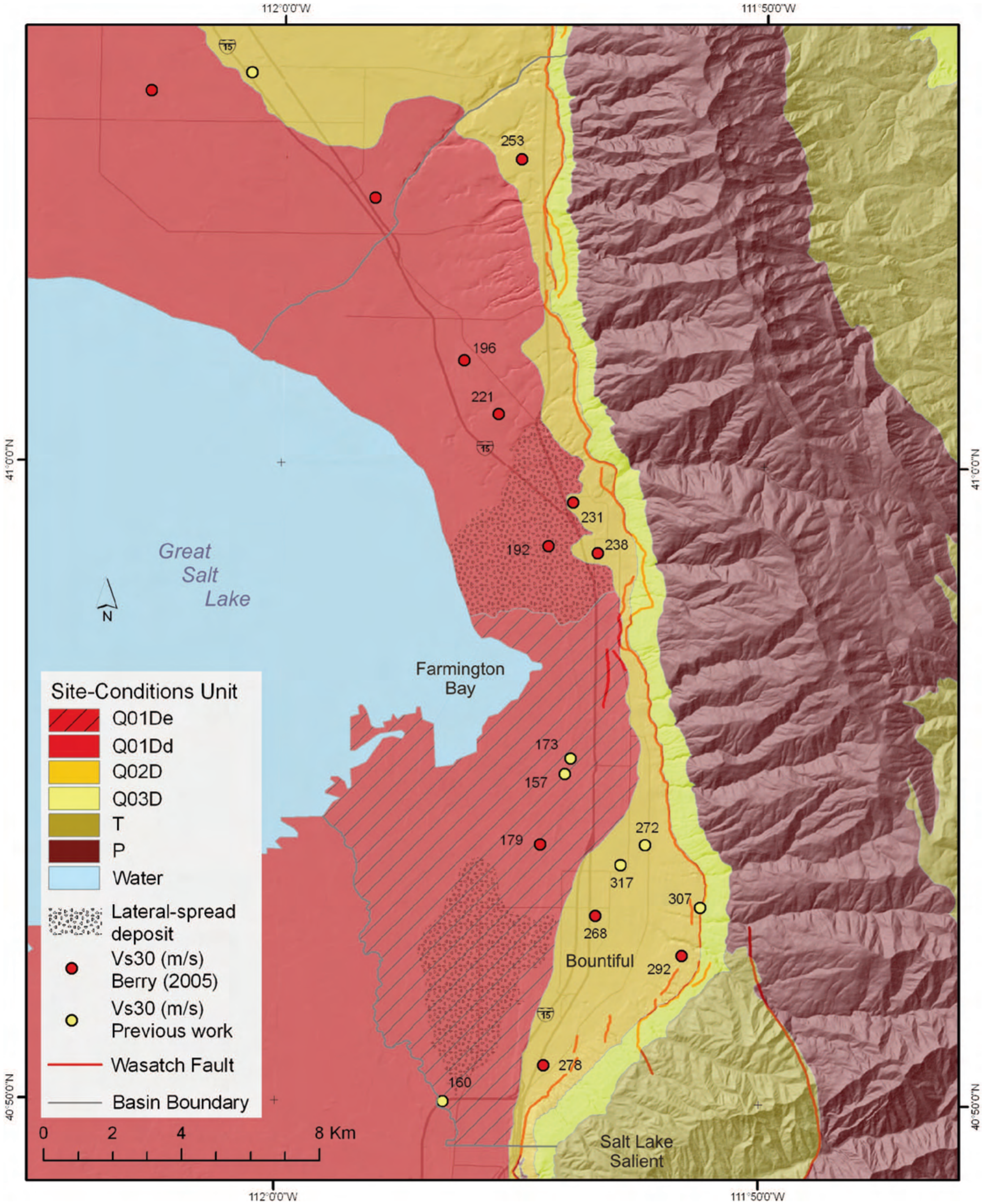

***Figure 11.** Davis basin site-conditions units (see plate 1 for unit descriptions).*

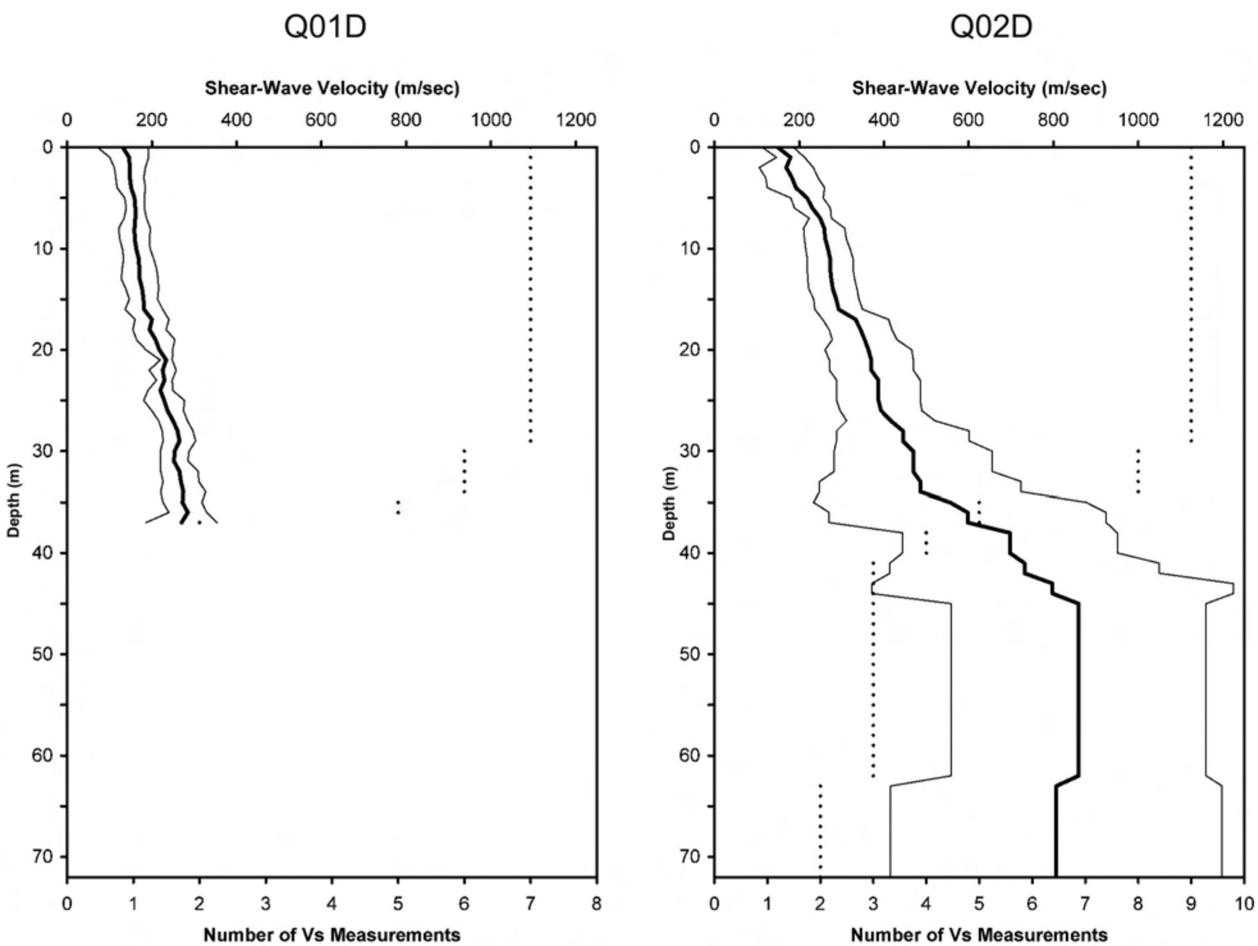

Figure 12. *Composite Vs profiles for Davis basin site-conditions units. Thick solid line represents Vs logarithmic mean; thin lines +/- 1 standard deviation. Dotted line represents number of Vs measurements per 1-meter interval.*

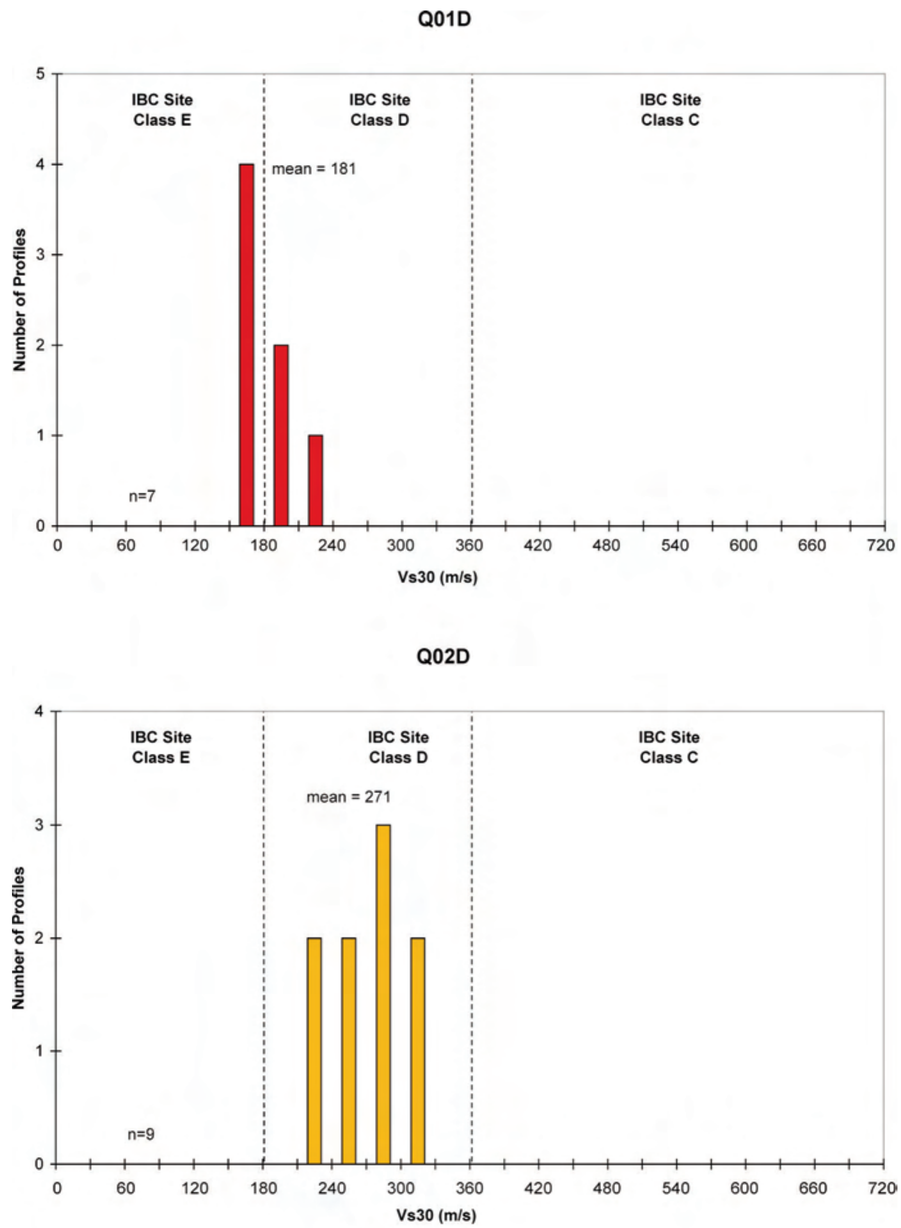

Figure 13. *Histograms of Davis basin site-conditions units.*

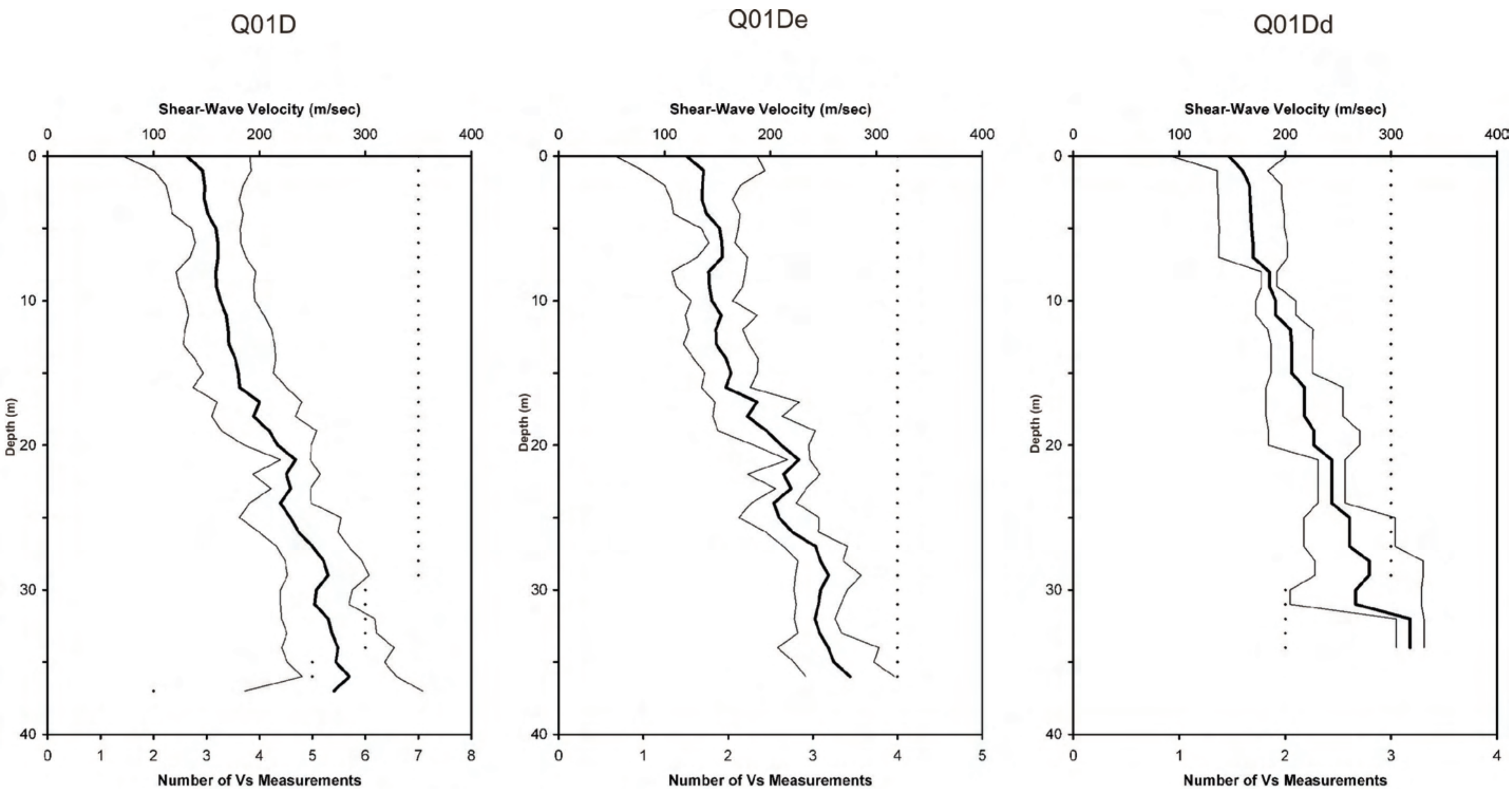

Figure 14. *Composite Vs profiles for Davis basin site-conditions unit Q01D and subunits Q01De and Q01Dd. Thick solid line represents Vs logarithmic mean; thin lines +/- 1 standard deviation. Dotted line represents numer of Vs measurements per 1-meter interval.*

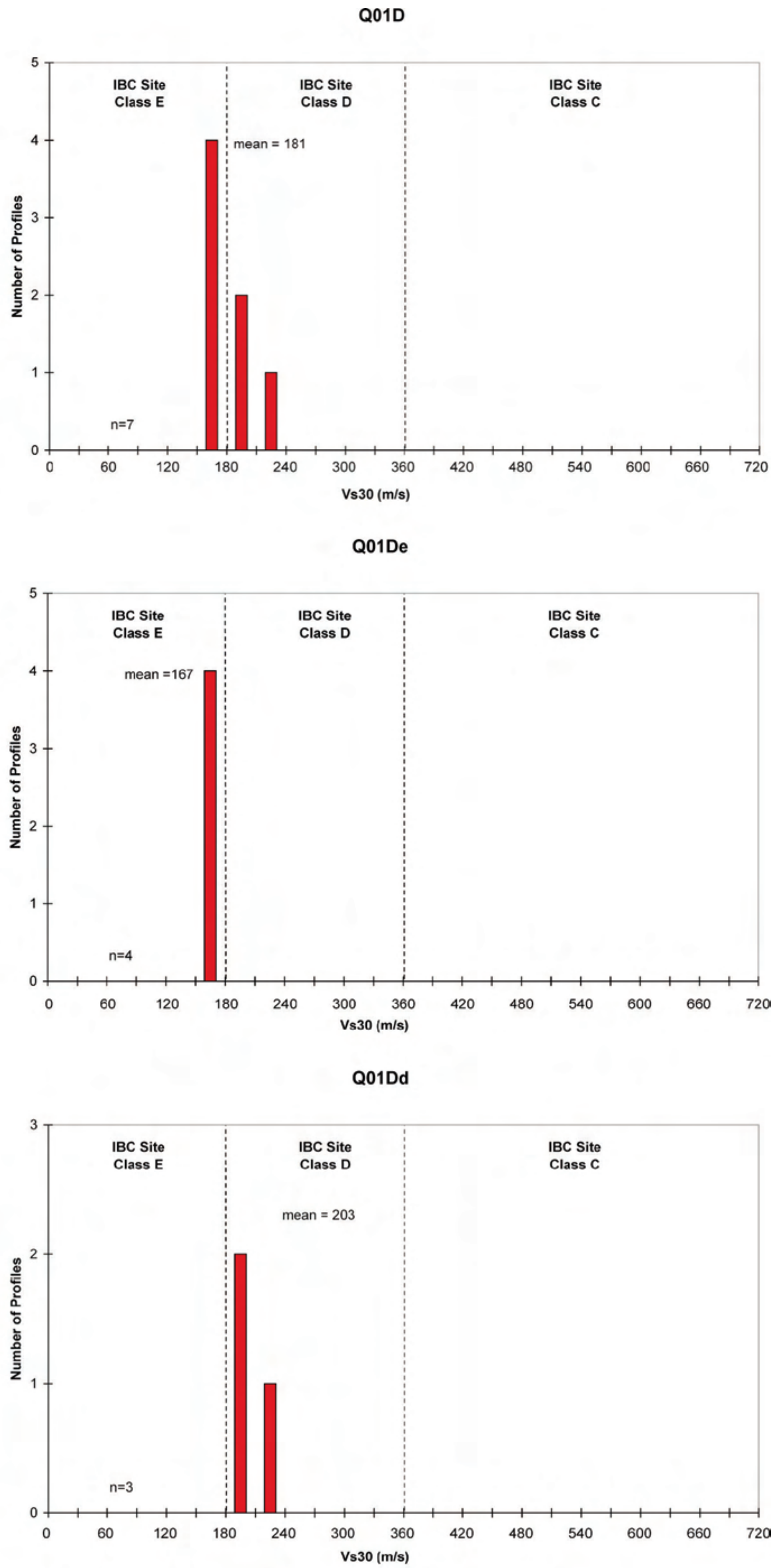

Figure 15. *Histograms for Davis basin site-conditions unit Q01D and subunits Q01De and Q01Dd.*

Utah Basin

Two Utah County basins (Utah and Cedar) make up the southern third of our study area. Utah and Cedar Valleys are geologically distinct basins separated by the Lake Mountains west of Utah Lake. Utah basin, on the east, is part of the Wasatch Front urban corridor and contains the cities of Provo and Orem as well as several rapidly growing neighboring communities (figure 16). Surficial geology in Utah basin is a complex assemblage of alluvial, deltaic, and lacustrine deposits. Sediment sources include the Provo River, American Fork, and Spanish Fork, and several perennial creeks including Dry Creek, Battle Creek, and Hobble Creek. Sediment from both the Provo River and Spanish Fork comes from large watersheds that include several Wasatch Range back valleys.

Berry (2006) tested 14 sites bringing the total number of Utah basin Vs30 measurements to 20: six are in site-conditions unit Q01U; thirteen in Q02U; and one in QgU. These new data, in addition to recent geologic mapping for much of Utah Valley (Biek, 2004a, 2004b, 2005a, 2005b, and 2005c), were the basis of site-conditions mapping for Utah basin (figure 16).

We map five site-conditions units in Utah basin. Figures 17 and 18 show composite Vs profiles and histograms, respectively, of Utah basin site-conditions units.

Unit Q01U

Site-conditions unit Q01U is dominated by Lake Bonneville silt and clay deposits and local young lacustrine and marsh deposits near the eastern margin of Utah Lake. Unit Q01U contains six Vs profiles with a mean Vs30 of 174 m/s and a Vs30 distribution that spans the IBC site class D-E boundary of 180 m/s. All but one Vs30 are less than 180 m/s (IBC site class E). Three SASW sites along a roughly 9-kilometer, north-northwest transect in southern Utah Valley all had Vs30s within IBC site class E, ranging from 157 to 175 m/s, but showed no progressive basinward decrease in Vs30.

Unit Q02U

Site-conditions unit Q02U is a geologically diverse unit consisting of sand-dominated Lake Bonneville nearshore, transgressive, and deltaic deposits and latest Pleistocene to Holocene alluvial deposits. Unit Q02U has a mean Vs30 of 294 m/s based on 13 sites and is within 8% of the Salt Lake basin unit Q02S Vs30 of 290 m/s based on 43 sites. Statistical testing suggests mean Vs30 in unit Q02 are similar in both basins; however, the limited Utah basin data preclude combining the units at this time (see Interbasin Site-Conditions Unit Comparisons section below).

Unit Q03U

Site-conditions unit Q03U consists of primarily gravel-dominated lacustrine deposits and latest Pleistocene to Holocene alluvial deposits. As with unit Q03 in Weber and Davis basins, we mapped the unit along the eastern margin of the valley as a narrow band of gravel-dominated deposits along the base of the Wasatch Range, mostly on the footwall of the WFZ.

Unit QafoU

We mapped an older alluvial-fan site-conditions unit locally at the southern end of Utah basin near the mouth of Payson Canyon and along the eastern flank of the Lake Mountains. Within the older alluvial-fan site-conditions unit, we included large landslide complexes associated with a shale bedrock unit along the northeast margin of Utah basin (figure 16). No Vs data exist in Utah basin for either the older alluvial-fan or landslide deposits. As in the Weber Basin, we assigned a Vs30 of 502 m/s to unit QafoU based on limited data collected from Cedar basin pre-Lake Bonneville alluvial-fan deposits.

Unit QgU

Site-conditions unit QgU consists of local glacial deposits limited to the Dry Creek drainage in the northeast corner of Utah basin and to some high-elevation, mostly east- to northeast-trending mountain valleys in the Wasatch Range. Utah basin site-conditions unit QgU contains one Vs profile collected in late Pleistocene glacial outwash near the mouth of Dry Creek Canyon northeast of Alpine City. This site has a Vs30 of 431 m/s, within 6% of the mean of 456 m/s for the Salt Lake basin glacial site-conditions unit (Q04 in Ashland and others, 2005) based on six profiles. Given the limited extent and localized nature of glacial deposits in the Wasatch Front, and lack of development in areas underlain by such deposits, we characterize Qg as a Wasatch Front site-conditions unit with a mean Vs30 of 452 m/s based on the seven Vs profiles.

Cedar Basin

Cedar Valley, west of Utah Valley and off the Wasatch Front urban corridor, is a sparsely populated but rapidly growing area that includes the communities of Eagle Mountain and Cedar Fort, which serve as suburban communities to both Utah and Salt Lake basins (figure 19). Geologically, Cedar basin differs from other Wasatch Front basins in that it is not along the Wasatch fault zone and therefore is not as tectonically or depositionally active. Thus, Cedar basin lacks thick deposits of younger (Quaternary) basin fill. Cedar basin contains no perennial drainages and is a hydrologically closed basin except for the very northern part that drains eastward through Cedar Pass to Utah Lake. Local deposits of Quaternary alluvial fans, stream alluvium, and stream-reworked lacustrine sediments are present around the basin. Lake Bonneville occupied Cedar basin only during the Bonneville highstand level and associated deposits consist of thin, discontiguous shoreline remnants around the valley margins and silt, clay, and fine sand in most of the central part of the basin. Early to middle Pleistocene and possibly older alluvial-fan deposits are common around the valley margins and are locally overlain by younger thin surficial deposits.

Cedar basin Vs30 data are limited to five sites from three surficial-geologic units: two in Holocene alluvial-fan deposits, two in pre-Lake Bonneville alluvial-fan deposits, and one in silt-dominated Lake Bonneville lacustrine sediments (figure 19).

Although limited, the Vs30 data suggest Cedar basin

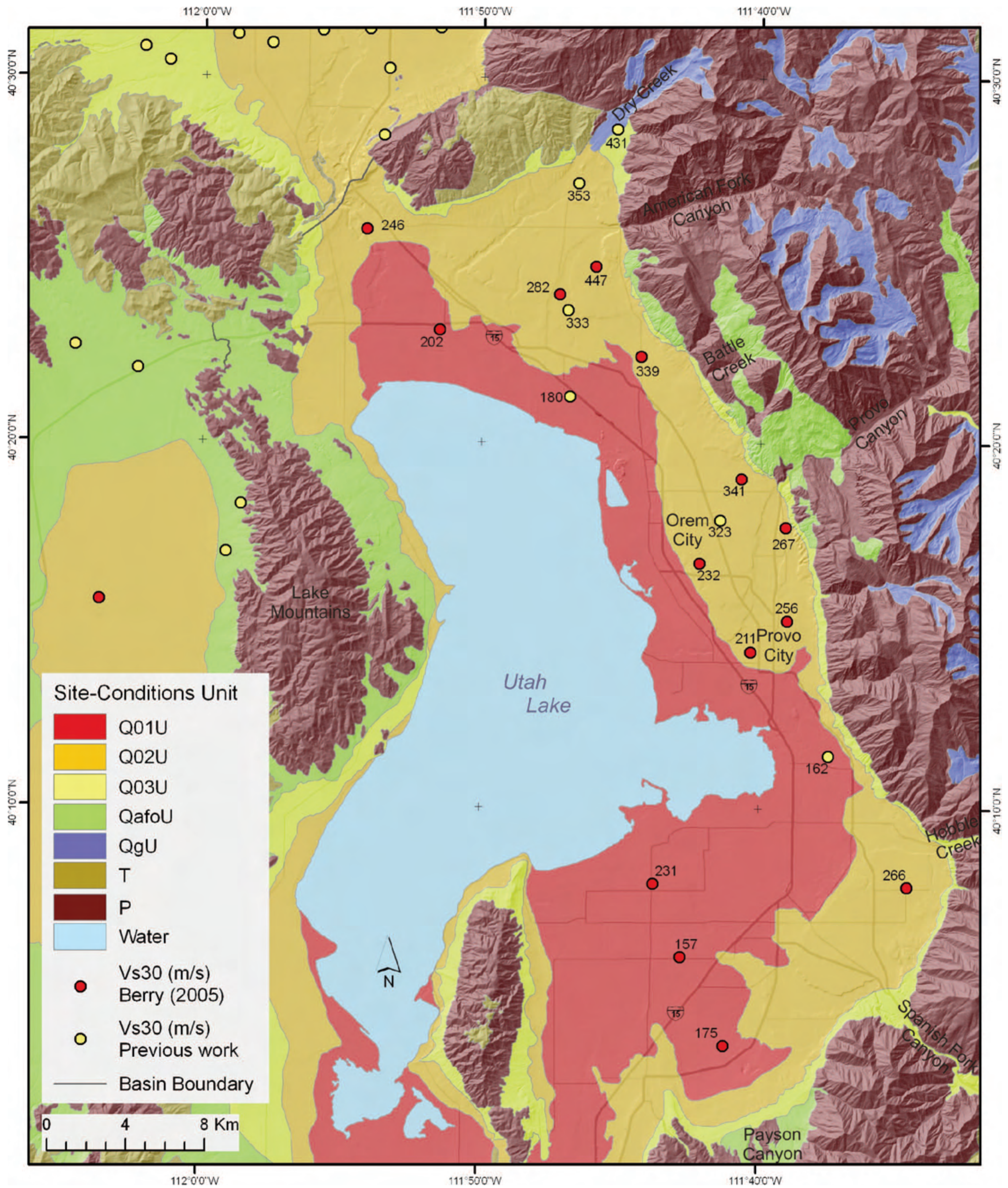

Figure 16. *Utah basin site-conditions units (see plate 1 for unit descriptions).*

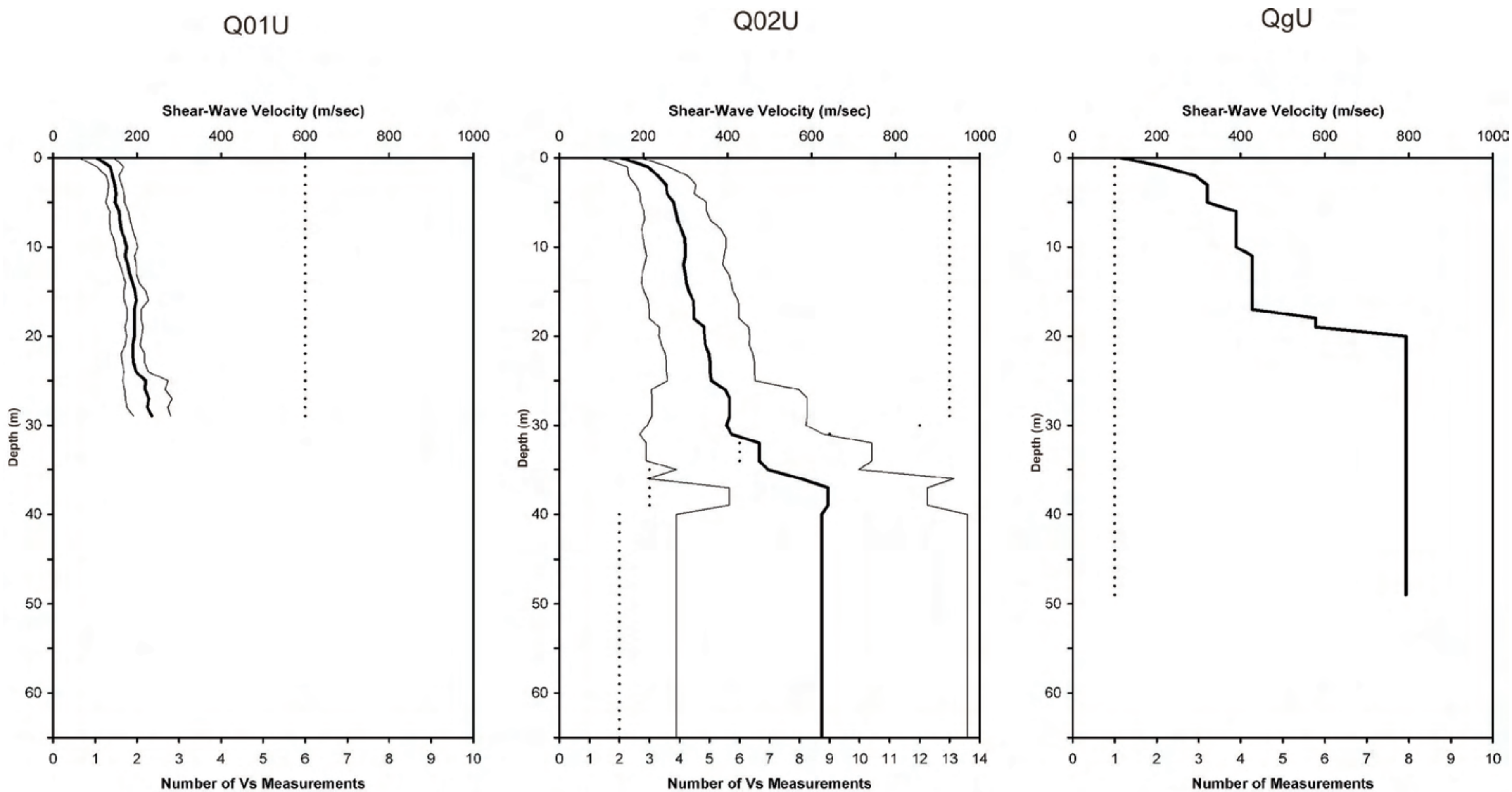

Figure 17. *Compostie Vs profiles for Utah basin site-conditions units QW01U, Q02U, and QgU. Thick solid line represents Vs logarithmic mean; thin lines +/- 1 standard deviation. Dotted line represents number of Vs measurements per 1-meter interval.*

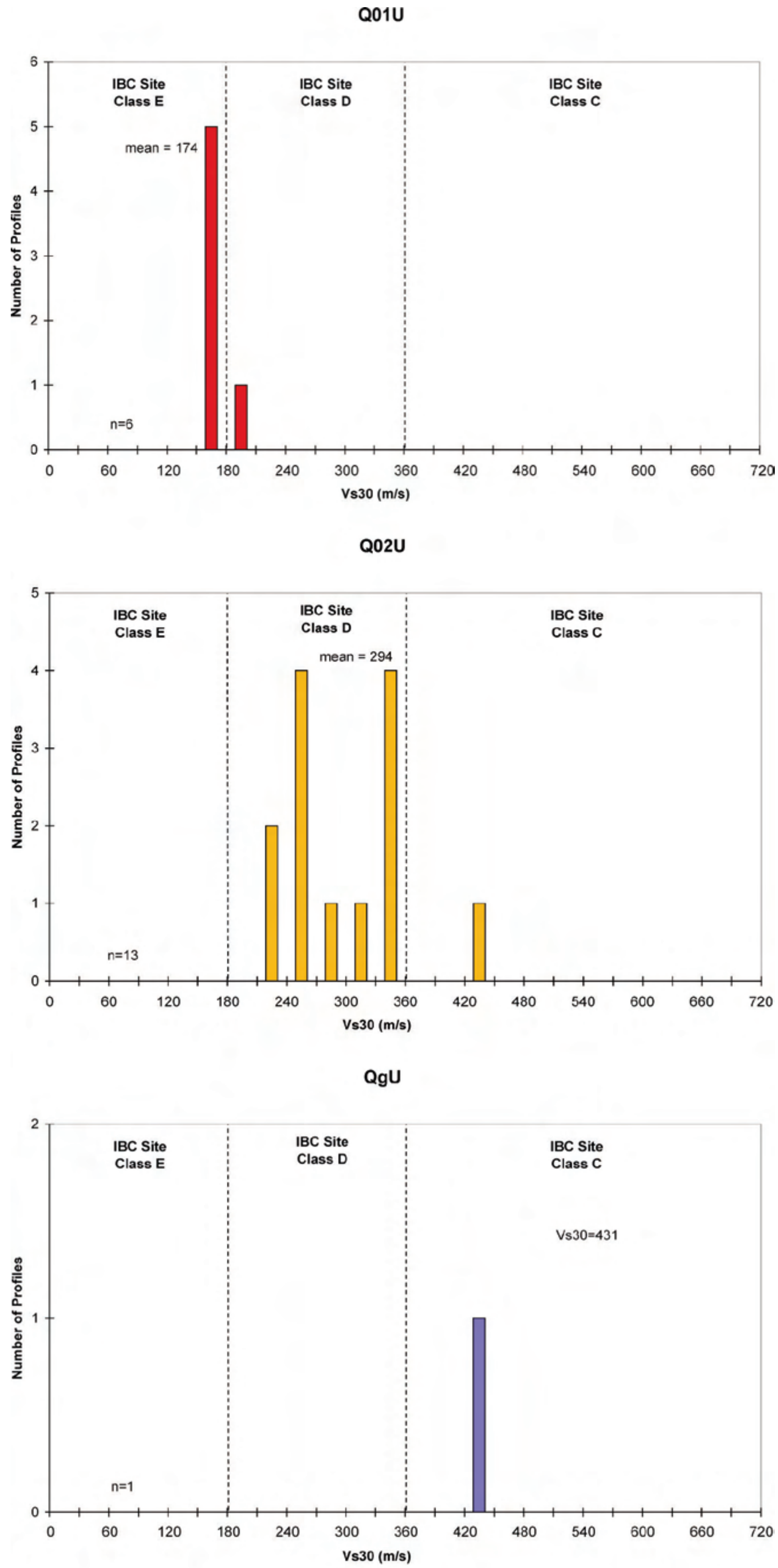

Figure 18. *Histograms of Utah basin site-conditions units.*

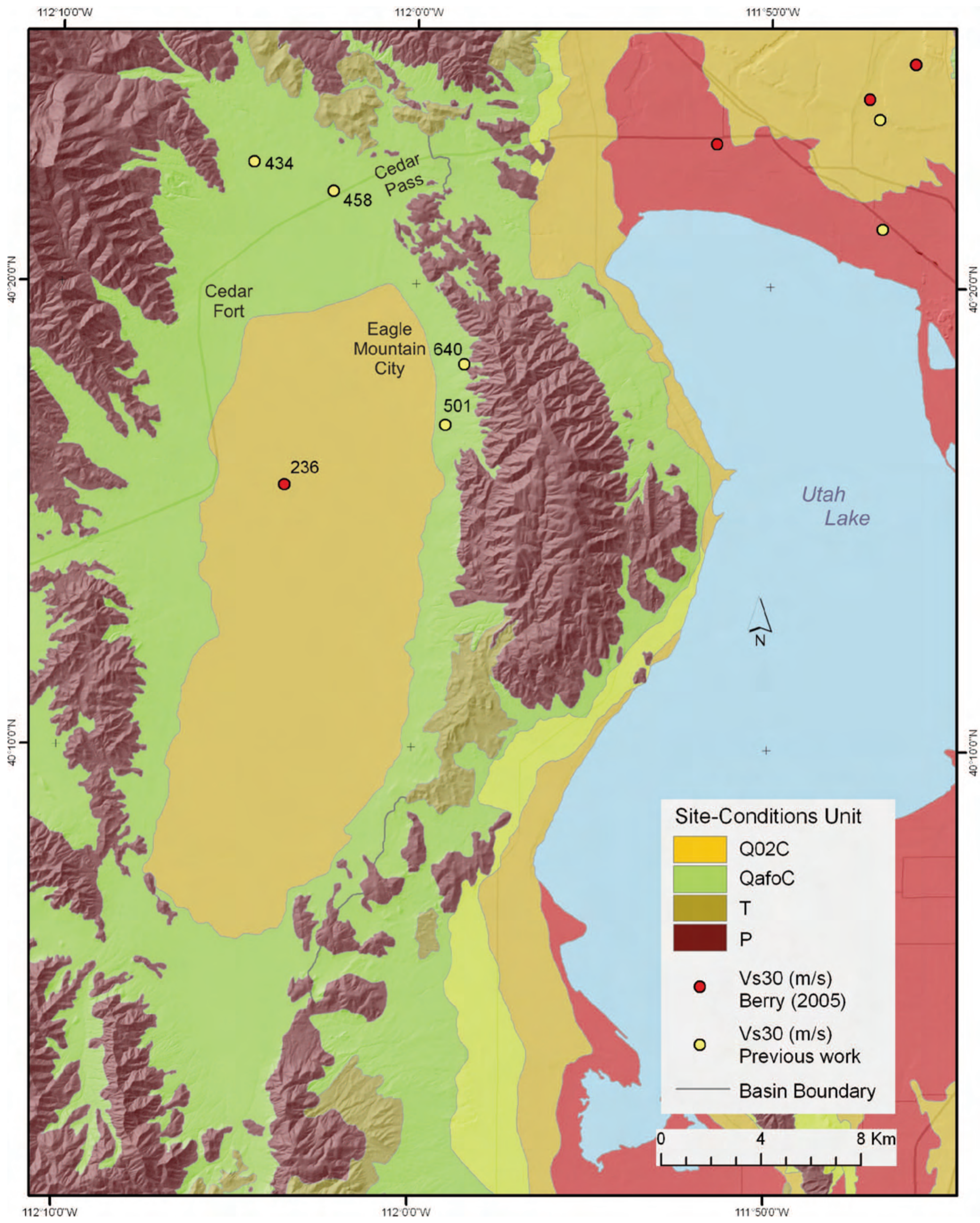

Figure 19. *Cedar basin site-conditions units (see plate 1 for unit descriptions).*

soils may exhibit different site-conditions characteristics than equivalent geologic units in the other basins. Two Vs profiles in Holocene alluvial-fan deposits fall in IBC site class C with Vs30 values of 458 and 501 m/s and are at the higher end of the Vs30 distribution for all young alluvial-fan profiles in our database that ranges from 202 to 708 m/s. Similarly, the single test performed in lacustrine fine-grained deposits, mapped by Biek (2004b) as lacustrine silt and clay, has a high Vs gradient to depth and a Vs30 of 236 m/s, 19% greater than the Salt Lake basin Q01 mean Vs30 of 198 m/s.

Recognizing the different surficial geology of Cedar basin, we mapped the lacustrine fine-grained deposits as site-conditions unit Q02 rather that Q01, and valley-margin Lake Bonneville nearshore and younger alluvial-fan deposits with older, pre-Lake Bonneville alluvial-fan deposits as site conditions unit QafoC. We refined the contacts of the site-conditions units in Cedar Valley from those used in Solomon and others (2004) using recent geologic mapping by Biek (2004a, 2004b, 2005a, and 2005c) and Hurlow (2004). Figures 20 and 21 show composite Vs profiles and Vs30 histograms, respectively, of the Cedar basin site-conditions units.

Unit Q02C

Site-conditions unit Q02C is mapped extensively in central Cedar basin and consists of lacustrine silt, clay, and fine sand locally reworked by stream and/or wind action. A single, centrally located Vs profile in this unit has a Vs30 of 236 m/s that is within IBC site class D.

Unit QafoC

Older (pre-Lake Bonneville) alluvial-fan deposits are mapped around the margins of Cedar basin, most extensively in the north-northwestern and southern parts. The alluvial fans consist of early to middle Pleistocene sand-, gravel-, and cobble-dominated deposits that may be locally semi-consolidated. Gilbert (2004) tested two QafoC sites in the north and east parts of Cedar Valley that yielded Vs30 values of 434 and 640 m/s. Both Vs profiles encountered Vs greater than 760 m/s at depths shallower than 30 m. Lacustrine nearshore and younger alluvial-fan deposits mapped by Solomon and others (2004) are included in unit QafoC as distinct, gravel-dominated site-conditions unit (Q03). Two SASW tests performed in younger alluvial-fan deposits encountered relatively stiff material with Vs30s of 458 and 501 m/s. Both profiles encountered Vs greater than 760 m/s at depths of 30 and 33 m, indicating a relatively shallow depth of either weathered rock or semi-consolidated basin fill. We therefore group this gravel-dominated site-conditions unit with the older alluvial-fan unit (QafoC). The resulting Cedar basin margin unit, QafoC, has a mean Vs30 of 502 m/s based on 4 Vs profiles (figure 21[B]). A Vs profile on the northeast margin of Cedar basin encountered high-velocity layers (greater than 760 m/s) below a depth of 12 m. Recalculating Vs30 using only Vs from the soil column (<760 m/s) results in a mean Vs30 of 453 m/s (figure 21[C]), and may be more representative of Vs for older alluvial-fan deposits.

Wasatch Range Back-Valley Basins

Our study area includes some relatively small back-valley basins of the Wasatch Range, most prominently Ogden and Morgan Valleys east of Ogden and Layton, respectively (plate 1). Both Ogden and Morgan Valleys are rapidly growing suburban communities of the Wasatch Front urban corridor and are subject to earthquake-related hazards from the

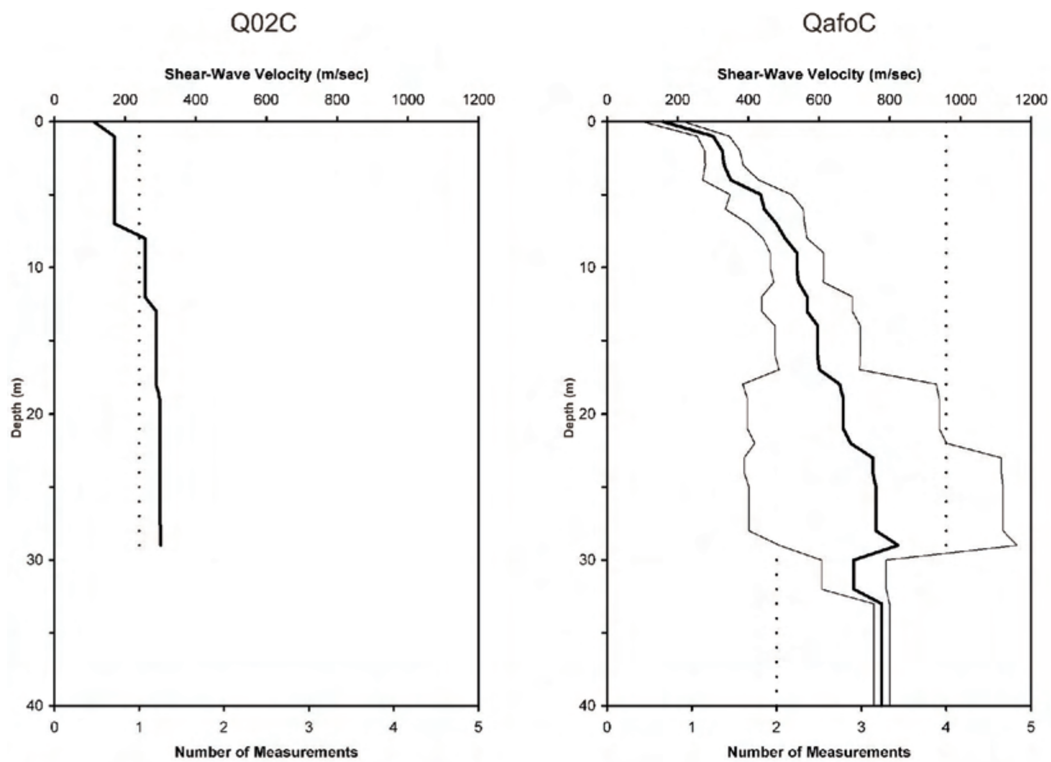

__Figure 20.__ Composite Vs profiles for Cedar basin site-conditions units. Thick solid line represents Vs logarithmic mean; thin lines +/- 1 standard deviation. Dotted line represents number of Vs measurements per 1-meter interval.

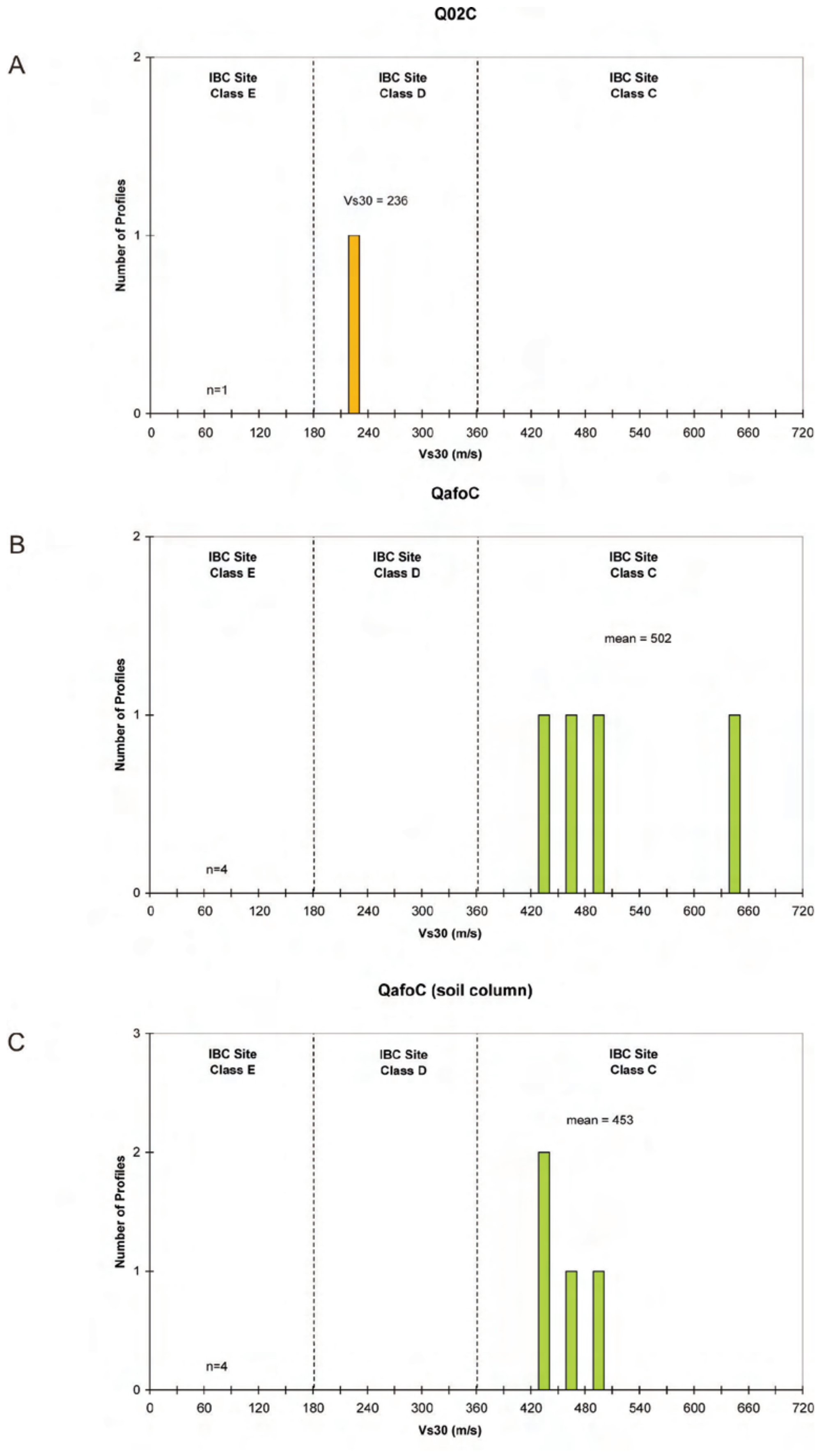

Figure 21. *Vs30 Histograms of Cedar basin site-conditions units. (A) Q02C, (B) QafoC including bedrock velocities, and (C) QafoC using Vs30 calculated using soil column values only.*

WFZ as well as from Quaternary faults along the margins of both back-valley basins.

We map site conditions for Wasatch Range back valleys using 1:24,000 or smaller-scale geologic mapping and group site-conditions units using the same methods as for the Wasatch Front basins. Given the scale of our site-conditions map (1:150,000), and the relative size of the back-valley basins in our study area, we group Quaternary site-conditions for the Wasatch Range back valleys into four units:

Q02 – Silt- and sand-dominated basin fill in Ogden Valley deposited during the Lake Bonneville highstand and/or stream-reworked Lake Bonneville deposits.

Q03 – Sand-, gravel-, and cobble-dominated lacustrine and alluvial deposits.

Qafo – Pre-Bonneville alluvial gravel, sand, silt, and cobbles that may be locally semi-consolidated. Includes larger landslide complexes.

Qg – Glacial deposits including till and outwash. Mapped mostly in several isolated high mountain valleys east of Salt Lake and Utah basins.

No Vs data exist for the Wasatch Range back-valley site-conditions units; we characterize them using mean Vs30 values from the Wasatch Front basins (table 1).

BEDROCK SITE-CONDITIONS UNITS

Our study shows generalized bedrock site-conditions units for the mountain ranges in our study area. Ashland (2001) and Solomon and others (2004) mapped site conditions for the greater Wasatch Front including bedrock units. Ashland and McDonald (2003) mapped and characterized bedrock site-conditions units for the Salt Lake basin using limited local Vs values from profiles that encountered rock at depth, supplemented with Vs data from the literature. We refined some bedrock site-conditions unit contacts using new geologic mapping (Biek, 2004a, 2004b, 2005a, 2005b, 2005c; Hurlow, 2004; Sack, 2005a, 2005b; Solomon, 2006) and characterize the units using Vs30 estimates and IBC site classes from Ashland and McDonald (2003). Bedrock site-conditions units are grouped into three age-defined categories: Tertiary sedimentary and volcanic rocks (T); Mesozoic sedimentary rocks (M); and Paleozoic and older rocks, including Tertiary intrusives (P). Table 2 summarizes Vs30 values and IBC site classes for Wasatch Front bedrock site-conditions units.

INTERBASIN SITE-CONDITIONS-UNIT COMPARISONS

We evaluated the site-conditions units by an iterative process involving comparison of descriptive statistics and statistical testing to evaluate the distinctiveness of site-conditions units. Interbasin comparisons were done using the well-characterized Salt Lake basin site-conditions map as a basis for the Wasatch Front map. Statistical tests were made in a few cases where sample sizes were sufficiently large, but many individual basin site-conditions units lack enough Vs30 data for statistical testing. Statistical t-tests and Kolmogorov-Smirnov (KS) tests were performed to compare units with at least seven and ten points, respectively, to determine whether the units are the same in each basin. T-tests compare sample means and were done assuming unequal variances and one-tailed distributions. KS tests compare two sample populations making no assumptions as to their distributions and can be used to assess the probability of the normalcy or log-normalcy of datasets. Significance values for positive t-tests and KS tests estimate the probabilities of equality of sample means and cumulative distributions, respectively, being due to chance, and are a function of sample size. Small sample sizes result in lower significance values, and therefore, while positive results cannot be precluded, tests having low significance are not considered conclusive.

Table 1 summarizes descriptive statistics for Wasatch Front site-conditions units. Table 3 shows statistical testing results. KS tests were done using web-based software developed by the College of Saint Benedict and Saint John's University, Minnesota (http://www.physics.csbsju.edu/stats/). T-tests and descriptive statistics were done with Microsoft Excel 2000 spreadsheet functions.

Our results indicate that Wasatch Front site conditions are better characterized for most basins individually rather than on a composite, Wasatch-Front-wide basis. Vs30-data statistics, sample distributions, site locations, and surficial geology support site-conditions characterization of individual basins with the available data at this time, with the exception of Weber and Davis basins that are best characterized as a composite basin.

A contributing factor in support of individually characterizing basins is that the present number and location of Vs30 sites for many site-conditions units preclude good statistical comparisons. Statistical comparisons with units having small datasets may indicate the two samples are from the same population, but with a low significance. Thus, combining the units is not warranted unless supported by additional factors such as geology or spatial clustering. In addition, combining small datasets may result in increased Vs30 variability of the resultant composite unit and Vs30 distributions having broader site class ranges.

Weber-Davis Composite Basin

The small differences in Vs30 for equivalent site-conditions units in the Weber and Davis basins suggest a possibility of combining each equivalent unit into a site-conditions unit for a composite Weber-Davis basin. Similarities in the Vs30 characteristics of the equivalent site-conditions units appear to exist despite differences in geography (basin shape and extent) and surficial geology related to sediment-source-area proximity and lithology. Figures 22 and 23 show that combining Weber and Davis basins site-conditions units (Q01W with Q01D and Q02W with Q02D) improves the log-normalcy of the Vs30 data and only nominally changes mean Vs30.

Combining Weber and Davis basins site-conditions units results in composite units Q01WD, Q02WD, and Q03WD. We are able to subdivide unit Q01WD into IBC site class E and D subunits (Q01WDe and Q01WDd) (figure 24). Sub-

Table 2. *Summary of Vs30 and IBC site class estimates.*

	Vs30 (m/s)			IBC Site Class		
	Minimum	**Mean***	**Maximum**	**Minimum**	**Mean**	**Maximum**
Q01 (all data)	151	**194**	325	E	**D**	D
Q01WD	154	**188**	244	E	**D**	D
Q01WDe	154	**166**	179	E	**E**	E
Q01WDd	189	**207**	244	D	**D**	D
Q01S	151	**198**	325	E	**D**	D
Q01U	157	**174**	202	E	**E**	D
Q02 (all data)	206	**277**	469	D	**D**	C
Q02WD	206	**258**	348	D	**D**	D
Q02S	210	**290**	469	D	**D**	C
Q02U	211	**294**	447	D	**D**	C
Q02C	--	**236**	--	--	**D**	--
Q03 (all data)	294	**409**	708	E	**D**	D
Q03WD	330	**349**	370	D	**D**	C
Q03S	294	**408**	708	D	**C**	C
Qafo	434	**502**	640	C	**C**	C
Qg	413	**452**	510	D	**C**	C
T	837	**1010**	1230	B	**B**	B
M	1009	**1460**	1782	B	**B**	A
P	--	**2197**	--	--	**A**	--

* Logarithmic mean

Table 3. *Summary of Vs30 test statistics.*

Site-conditions unit	n	Site-conditions unit	n	t-critical (1-tailed)	t-test statistic	significance (%)	KS-test statistic	significance (%)
Q01S	70	Q01W	12	1.73	0.48	31.8	0.24	53.3
Q01S	70	Q01D	7	1.83	1.69	6.3	---	---
Q01W	12	Q01D	7	1.76	1.07	15.1	---	---
Q01S	70	Q01WD	19	1.68	1.21	11.6	0.16	82.1
Q02S	43	Q02W	10	1.77	2.53	1.3	0.48	2.9
Q02S	43	Q02D	9	1.73	1.44	8.3	---	---
Q02D	9	Q02W	10	1.75	1.40	9.1	---	---
Q02U	13	Q02S	43	1.73	0.22	41.5	0.18	85.8
Q02U	13	Q02W	10	1.72	2.14	2.2	0.49	8.7
Q02U	13	Q02D	9	1.73	1.16	13.0	---	---
Q02S	43	Q02WD	19	1.68	2.58	0.7	0.30	14.1
Q02U	13	Q02WD	19	1.72	1.90	3.5	0.36	22.3

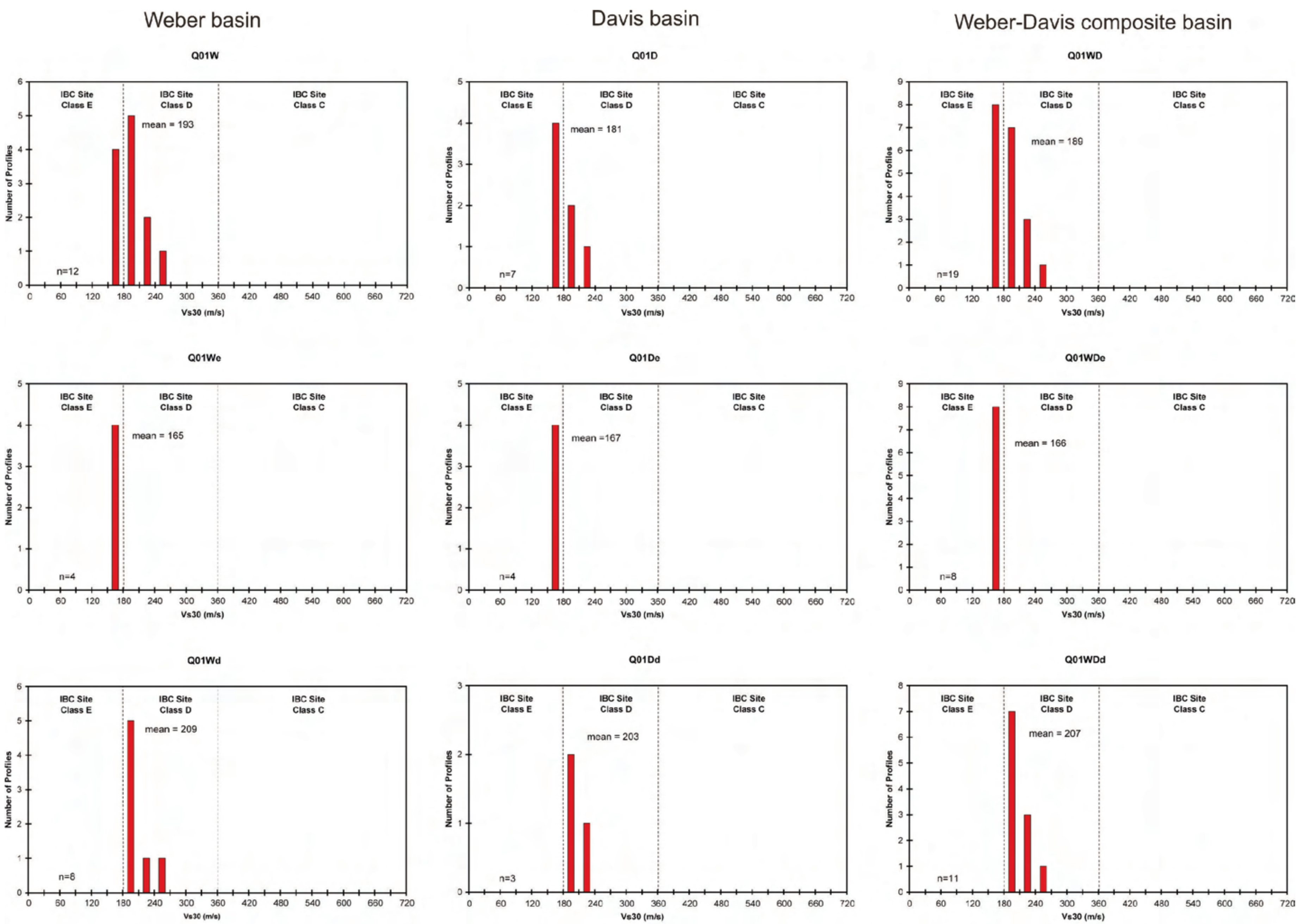

Figure 22. *Histograms of Weber and Davis basins individual and composite Q01 IBC site class E and D subunits.*

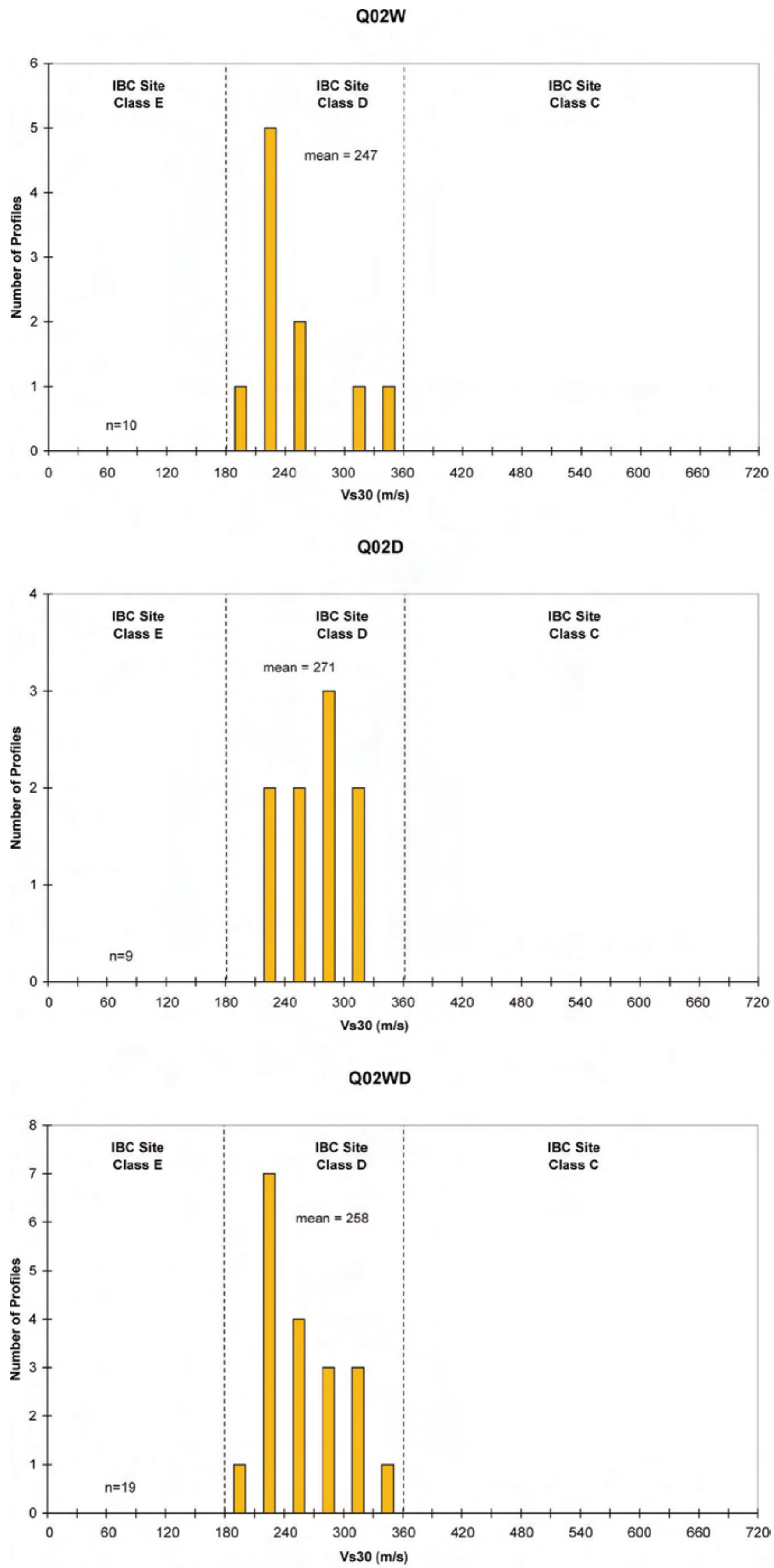

Figure 23. *Histograms of Weber and Davis basins individual and composite Q02 site-conditions units.*

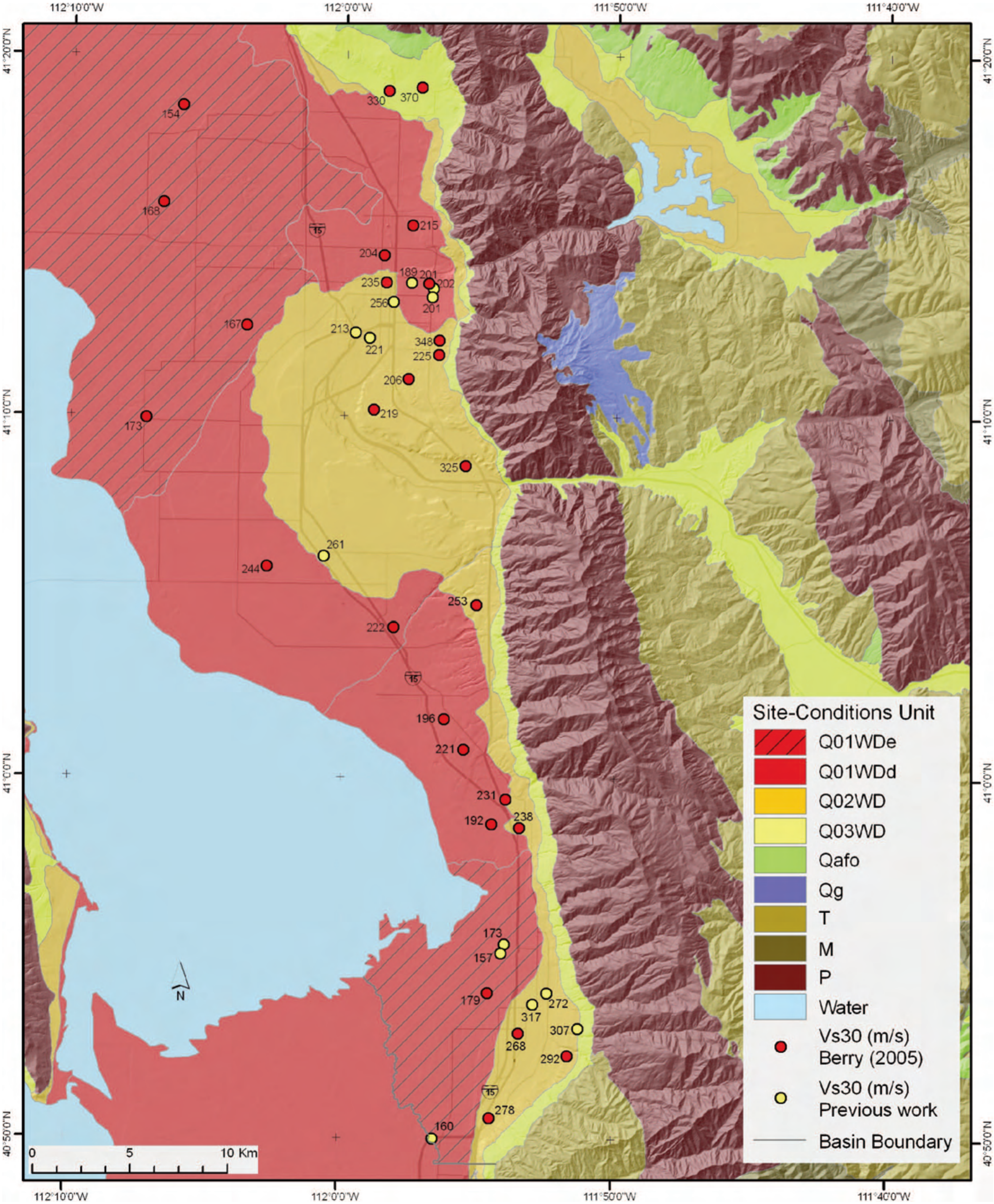

Figure 24. *Weber-Davis composite basin site-conditions units (see plate 1 for unit descriptions).*

unit Q01WDe is mapped in the northern and southern part of Weber-Davis basin. Subunit Q01WDd is mapped in the central part of Weber-Davis basin and includes the southern part of the Ogden River delta. Figures 25 through 28 show the Vs profiles for Weber-Davis composite units and sub-units. Site-conditions unit Q03WD is characterized only by Weber basin Vs data that consists of two SASW sites in the northeast part of the basin.

Weber-Davis Composite Basin-Salt Lake Basin Comparisons

Results of the statistical tests for silt- and clay-dominated site-conditions units (Q01S and Q01WD) in the composite Salt Lake and Weber-Davis basins indicate similar mean Vs30 and Vs30 distributions, but with significance values suggesting the results are not unequivocal (table 3). However, results from the sand-dominated units, Q02S and Q02WD, indicate that the mean and distribution of Vs30 are distinct. Therefore, no basis exists for combining the equivalent site-conditions units of Salt Lake and composite Weber-Davis basins. A sub-unit where Vs30 falls solely in IBC site class E is not apparent in Salt Lake basin as it is in Weber-Davis composite basin. Conversely, rather closely spaced Vs profiles in Salt Lake basin alternate between IBC site classes D and E. A sub-unit in Q01S where Vs30 falls solely in IBC site class D exists along the margins of the unit and in the transition zone abutting unit Q02S, but no geologic contact defines the boundary between the IBC site class D and E areas.

IBC SITE CLASS ZONATION FROM CONTOURED Vs30 DATA

Previous researchers demonstrated IBC site class mapping where sparse or variably spaced Vs data exist is best achieved using surficial-geologic unit-based maps that group units taking into account local geologic conditions and heterogeneities (Wills and Silva, 1993; Park and Elrick, 1998; Wills and others, 2000). In the Las Vegas basin, Scott and others (2006) extrapolated locally dense Vs data along a transect using a three-dimensional model based on water-well logs and surficial-geologic maps to produce IBC site class microzonation maps. However, they could not accurately extrapolate Vs30 using the detailed stratigraphic framework where data were sparse, and presently work is underway to increase the density and distribution of Vs30 data in the Las Vegas basin (Murvosh and others, 2006a, 2006b).

With the expanded Wasatch Front Vs30 database, we assessed the viability of delineating site conditions, and ultimately IBC site class zones, by contouring the Vs30 data. Mapping site classes by contouring Vs30 data provides a means of delineating IBC site class zones directly and does not use surficial-geologic contacts to delineate zones.

We used Surfer v. 8.05 (Golden Software, Inc., 2004) for gridding and contouring the Vs30 data. We contoured the Vs30 data by both kriging and natural-neighbor methods to account for the spatial variability of our Vs30 data. We assigned the Quaternary deposit/bedrock contacts a Vs30 value of 760 m/s to define the valley margin as the IBC site class B-C boundary.

Figure 29 shows IBC site classes produced by kriging and natural-neighbor contouring methods overlain on our plate 1 map. Given the relatively sparse and locally clustered Vs30 data for the Wasatch Front, contouring produces variable boundaries that are in large part a reflection of variable Vs sampling density. Contouring the Wasatch Front Vs30 data produces IBC site class zones that are only grossly reflective of basin-wide areas of dominant grain size and Vs, and produces zones that are likely not suitable for predicting site class effects on a basin-specific level. Gridding the data in areas having few data or anomalous values tends to bias or overly weight individual data points, creating "bulls-eyes" or highly irregular polygons driven by a few points. Basin-scale contouring is not accurate or effective in areas where Vs30 at closely spaced sites falls into both IBC site classes D and E, such as along the I-15 corridor in Salt Lake City. A physical constraint is also present along the Wasatch Front urban corridor where Utah and Great Salt Lakes cover significant parts of basins, creating large Vs data gaps. Gridding the Vs data assuming low-velocity material for the modern lake deposits results in IBC site class E and D zones that essentially mimic the lake boundaries and may not be reflective of actual site conditions. Figure 30 shows an example of contours produced using a lake/soil boundary of 150 m/s to reflect assumed low-velocity/IBC site class E site conditions for modern lake deposits.

In general, contouring data is more applicable to areas where Vs30 data are uniformly distributed and units are not geologically controlled. The method is ideally used where Vs data are collected in a systematic fashion with pre-determined site spacing suitable for the intended map scale. The method has limitations in the Wasatch Front urban corridor given the present number and location of Vs30 data, and geographical constraints.

CONCLUSIONS

We mapped site conditions using the approach used in Salt Lake Valley (Ashland and McDonald, 2003; Ashland and others, 2005) that maps site conditions using surficial geology and limited shallow subsurface information to distinguish units that are characterized using Vs30. Our Wasatch Front urban corridor site-conditions map provides a basis for predicting seismic site-response characteristics and site class effects. Table 2 summarizes Vs30 estimates and IBC site classes for the site-conditions units.

Recently acquired Vs data have significantly expanded the area of the Wasatch Front urban corridor having Vs30 measurements, providing a basis for site-conditions mapping and characterization. We used the new Vs30 data in conjunction with new, relatively detailed geologic mapping for much of the Wasatch Front to define site-conditions units in the Weber-Davis, Salt Lake, Utah, and Cedar basins.

Our analysis of Vs30 data indicates Wasatch Front site-conditions units are best characterized for the basins individually rather than on a Wasatch-Front-wide basis, with the exception of Weber and Davis basins where equivalent site-conditions units could be combined into composite units. This is not unreasonable given Wasatch Front surficial geologic units from which the Quaternary site-conditions units are derived may represent diverse sources, facies, thicknesses, and relative ages in each basin. In addition, two site-con-

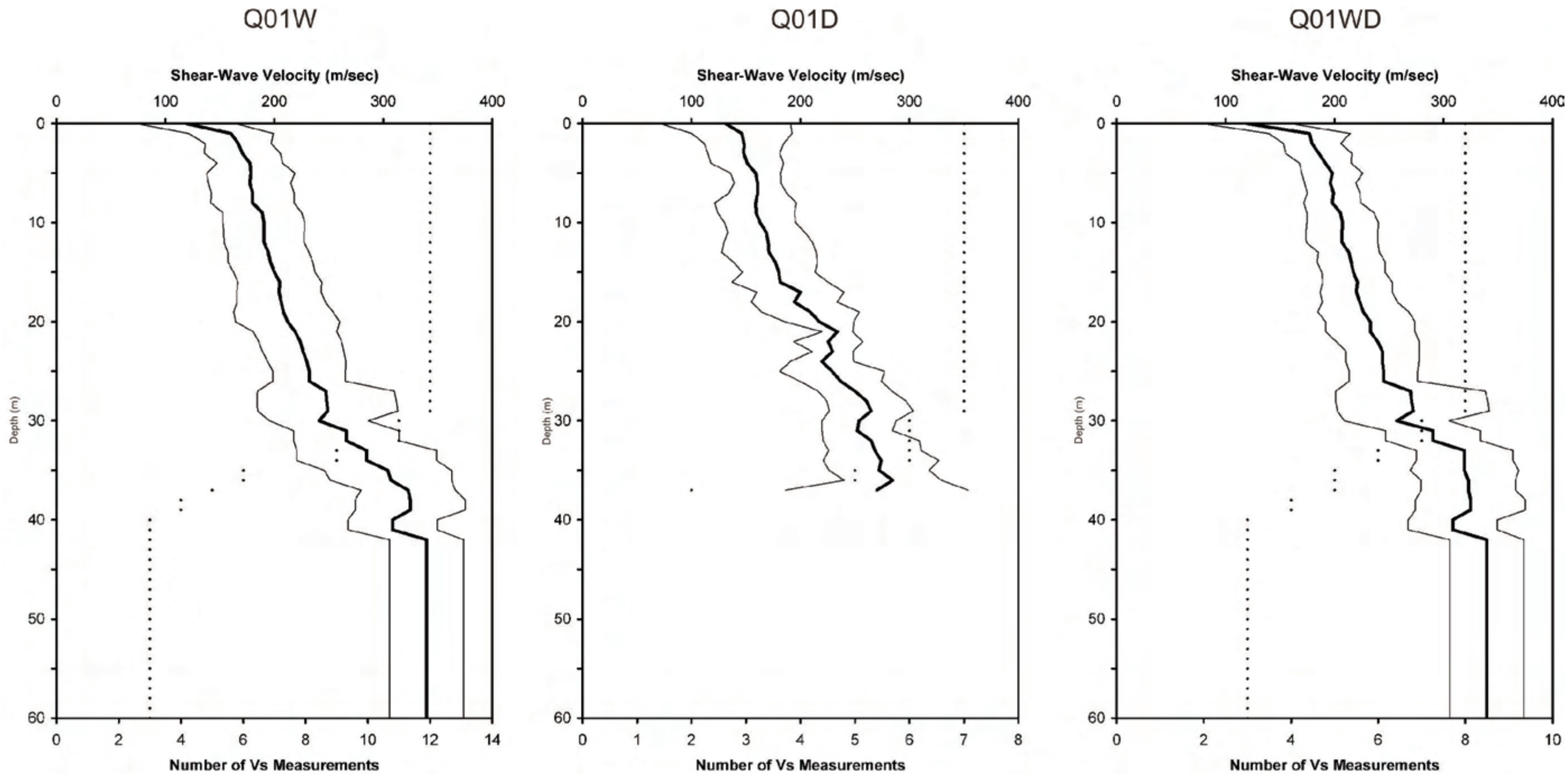

Figure 25. *Composite Vs profiles for individual and combined Weber and Davis basins Q01 site-conditions units. Thick solid line represents Vs logarithmic mean; thin lines +/- 1 standard deviation. Dotted line represents number of Vs measurements per 1-meter interval.*

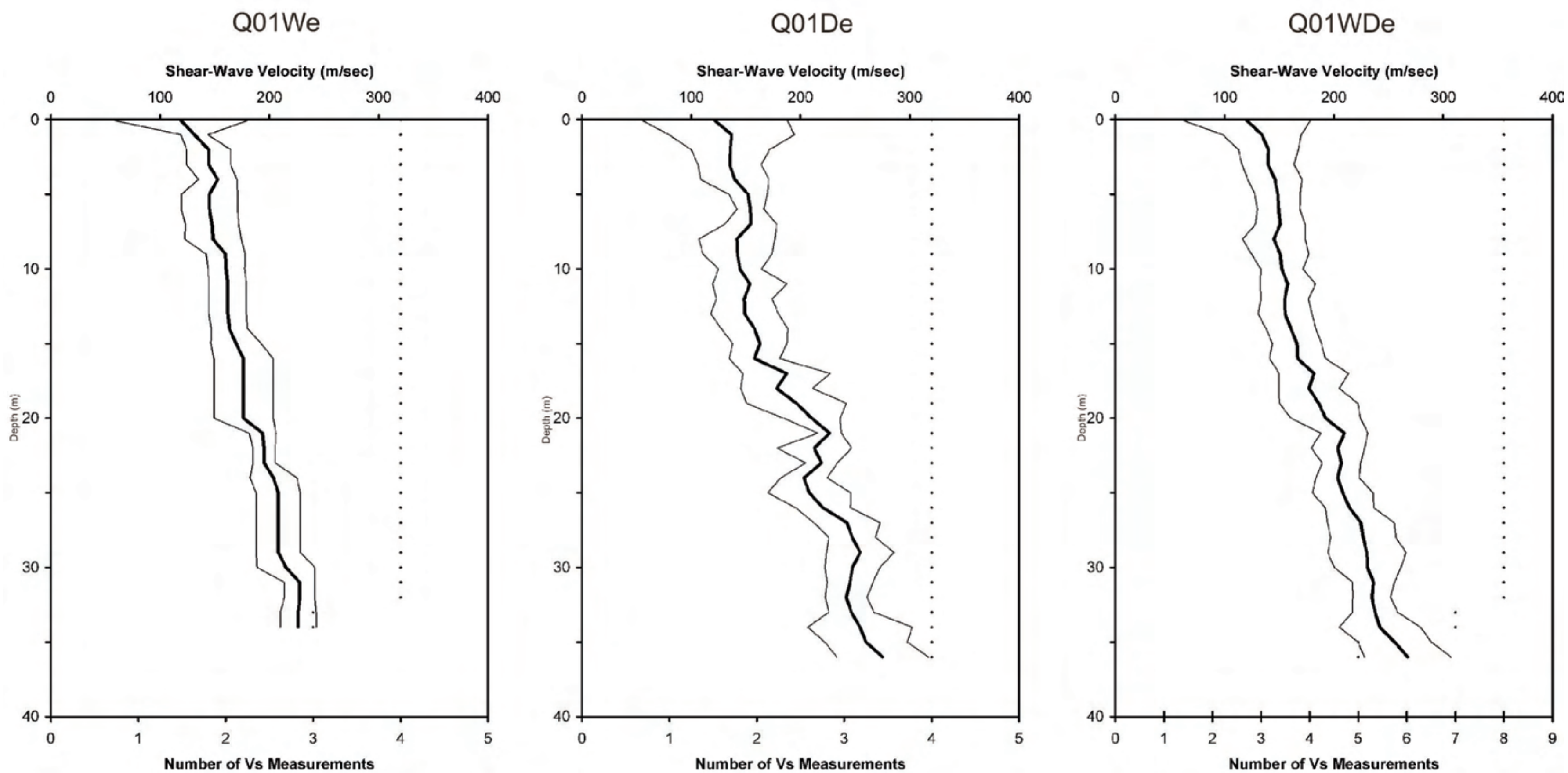

Figure 26. *Composite Vs profiles for individual and combined Weber and Davis basins IBC site class EQ0l site-conditions subunits. Thick solid line represents Vs logarithmic mean; thin lines +/- 1 standard deviation. Dotted line represents number of Vs measurements per 1-meter interval.*

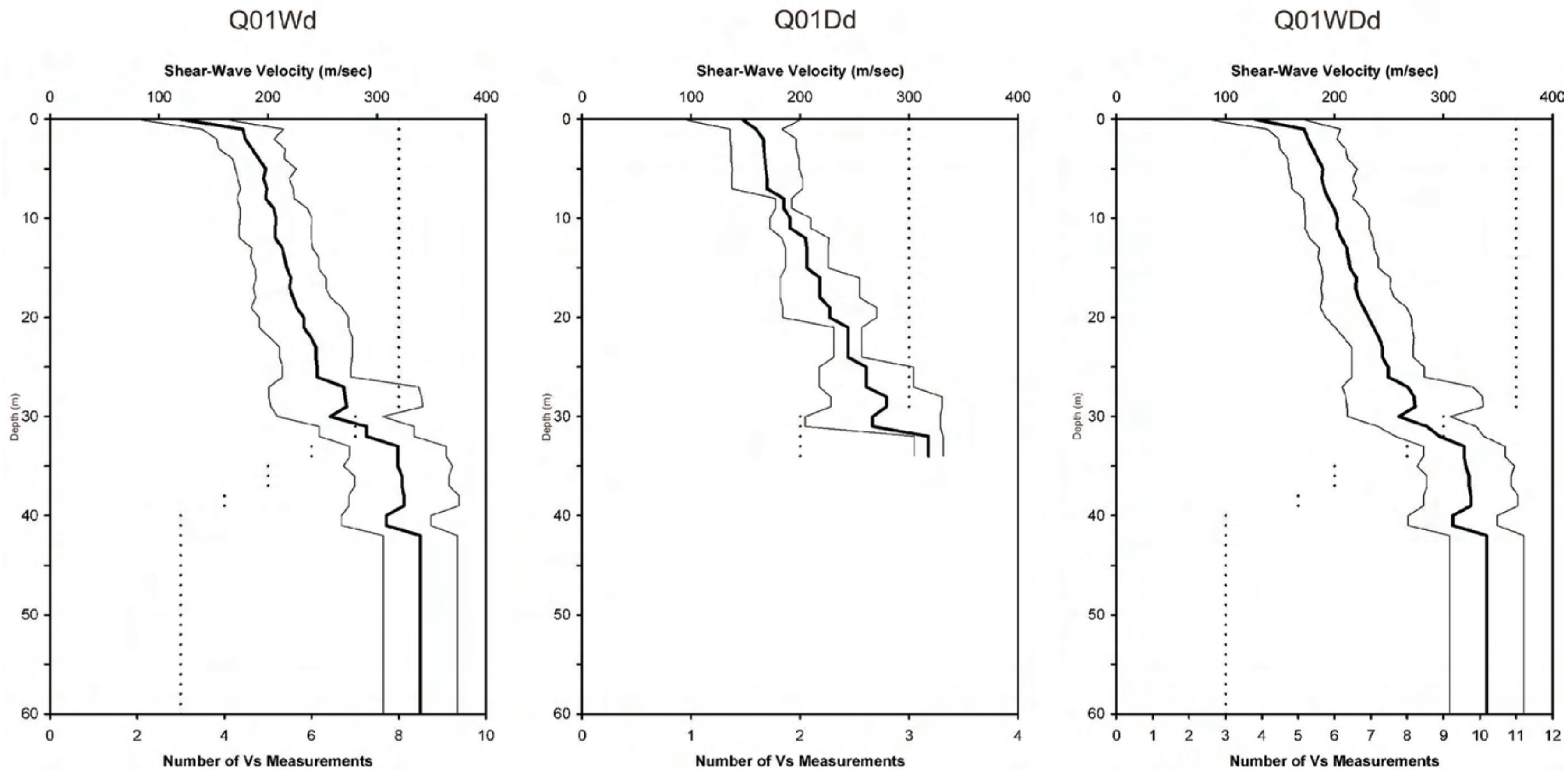

Figure 27. *Composite Vs profiles for individual and combined Weber and Davis basins IBC site class D Q01 site-conditions subunits. Thick solid line represents Vs logarithmic mean; thin lines +/- 1 standard deviation. Dotted line represents number of Vs measurements per 1-meter interval.*

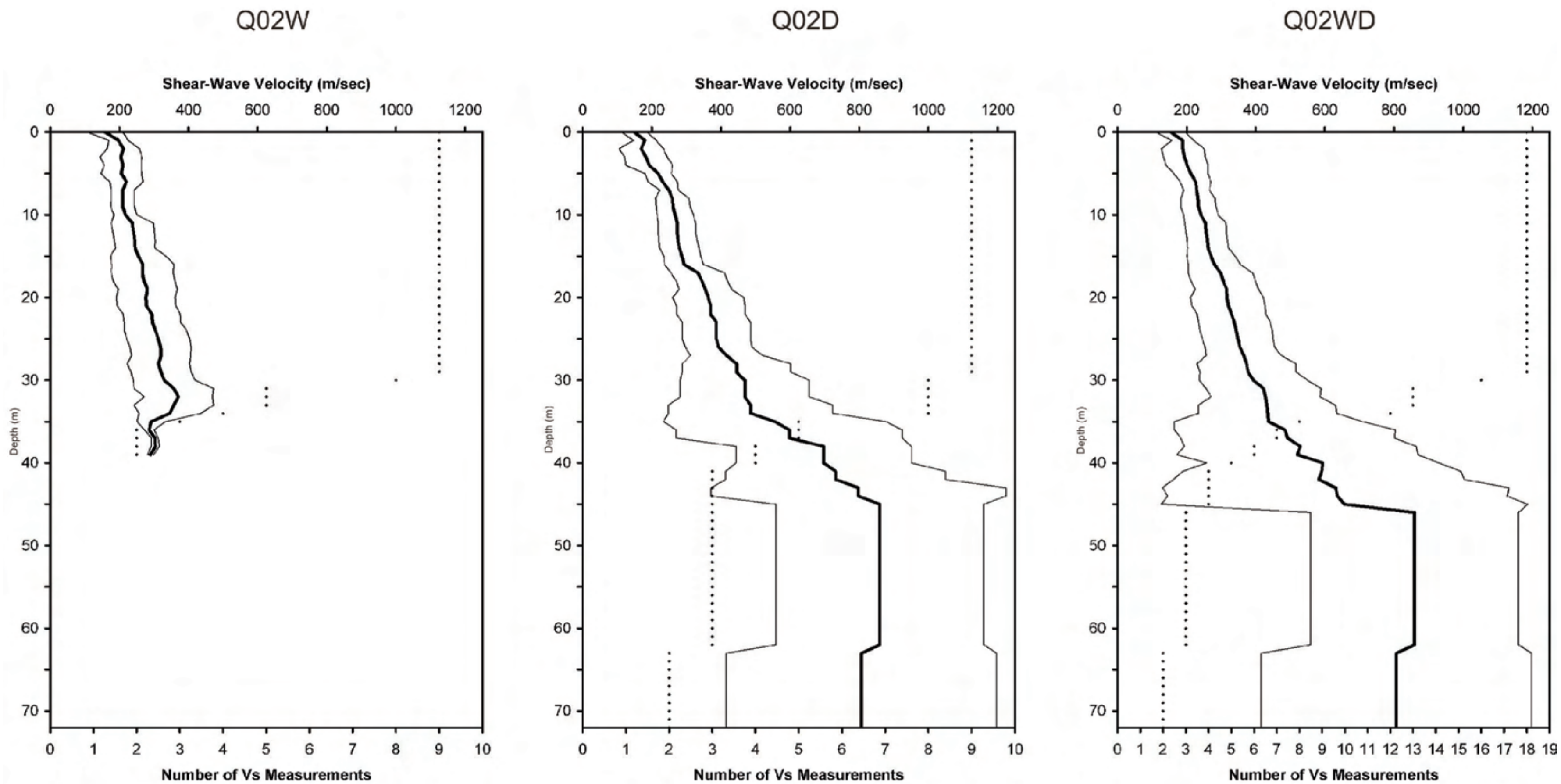

Figure 28. *Composite Vs profiles for individual and combined Weber and Davis basins Q02 site-conditions units. Thick solid line represents Vs logarithmic mean; thin lines +/- 1 standard deviation. Dotted line represents number of Vs measurements per 1-meter interval.*

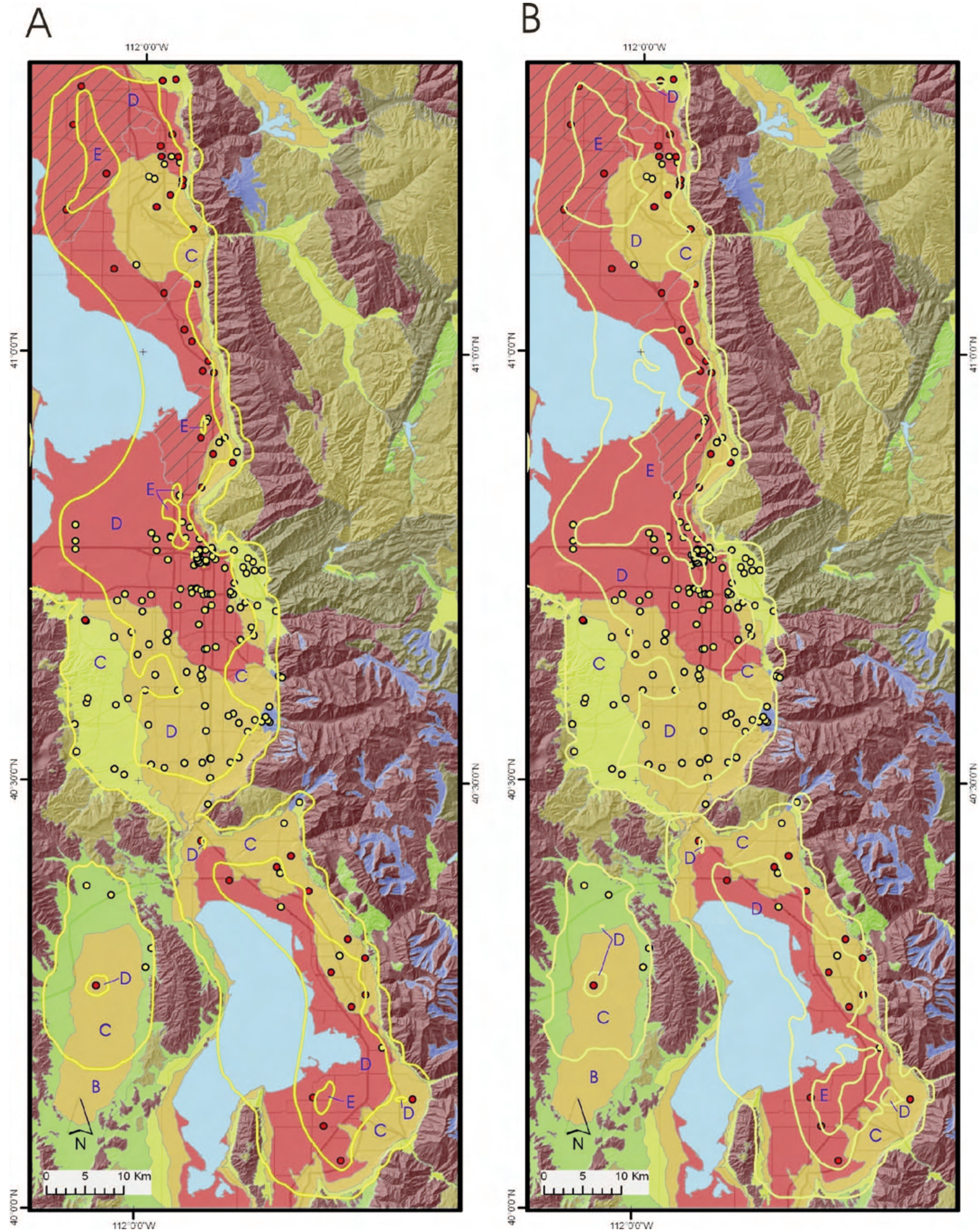

Figure 29. IBC site class zones from contouring of Vs30 data by: (A) natural-neighbor; and (B) kriging.

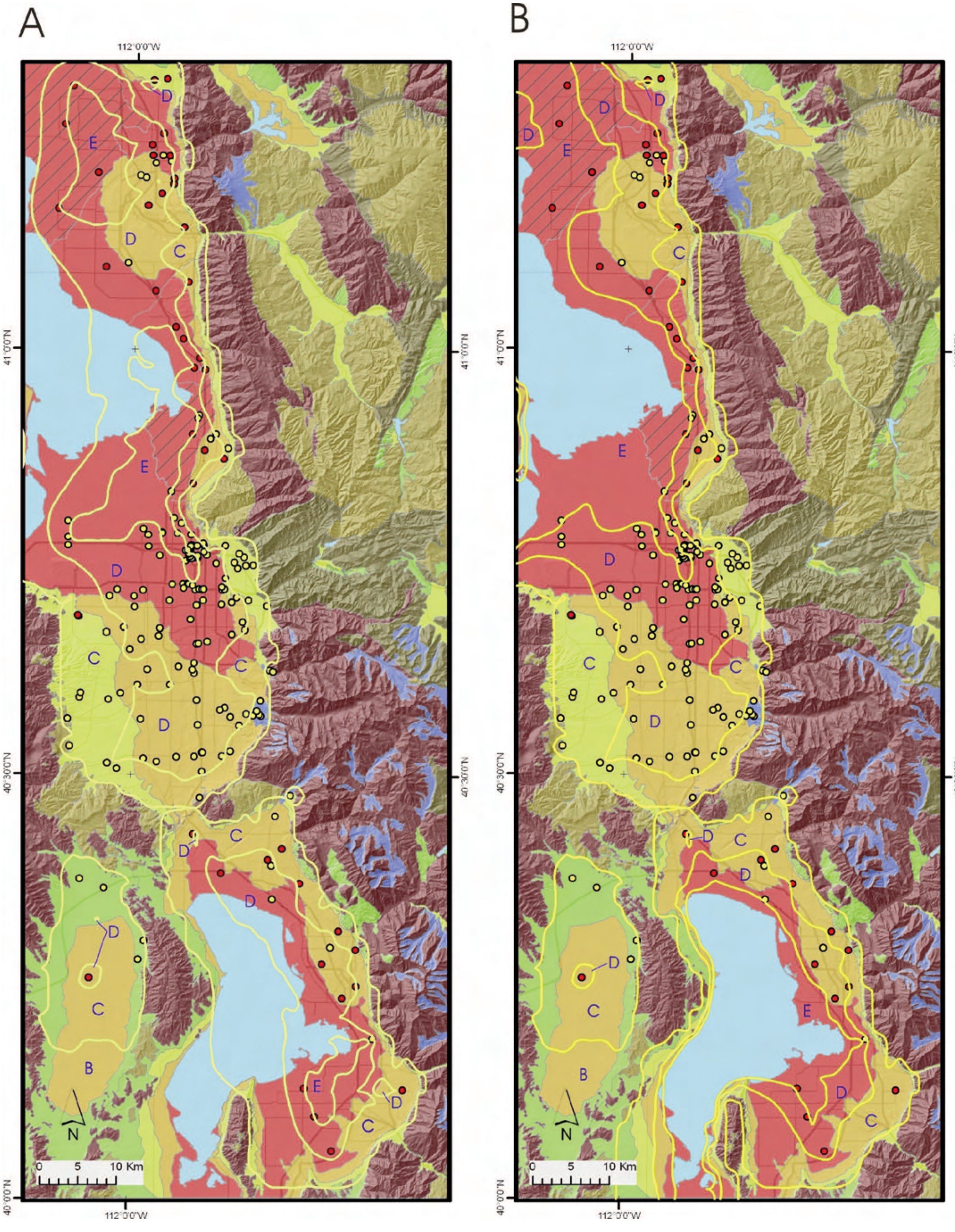

Figure 30. *IBC site class zones from krig contouring of: (A) Vs30 data only; and (B) including assumed lake bed Vs of 150 m/s.*

ditions units, the older alluvial-fan (Qafo) and glacial (Qg) units are characterized as single, Wasatch-Front-wide units, given their widely-spaced and limited extent, localized occurrences, lack of Vs30 data, and geographic setting that preclude characterizing the units in each basin. The number, spacing, and location of Vs30 data along the Wasatch Front do not allow for contouring the data to produce IBC site class zones.

LIMITATIONS

Our characterization of site conditions uses parameters, including mean Vs30, based on limited data and acquired using methods having inherent uncertainties. Our site-conditions-unit boundaries and characteristics will likely change as new Vs data become available. Given the scale of our mapping, site-conditions characterization is likely not representative at the site-specific scale. Delineating discrete unit contacts and basin boundaries is necessary but does not reflect the more likely gradational nature of the contacts.

ACKNOWLEDGMENTS

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