# INTERIM MAP SHOWING SHEAR-WAVE-VELOCITY CHARACTERISTICS OF ENGINEERING GEOLOGIC UNITS IN THE SALT LAKE CITY, UTAH, METROPOLITAN AREA

by

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## ABSTRACT

Site-class effects, important in understanding earthquake site response, are the amplification or de-amplification of earthquake ground motion attributable to the engineering properties of the near-surface soil or rock at a site. Empirical correlation between earthquake ground-motion amplification and the average shear-wave velocity in the upper 30 meters below the ground surface (Vs30) provides the basis of the site classes in the International Building Code (IBC). We characterized Vs30 for previously mapped engineering geologic units in the Salt Lake City metropolitan area, allowing engineers to estimate site-class effects based on mean Vs30 as well as the distribution of and variation in Vs30. Shear-wave-velocity profiles currently exist in only three Quaternary units. In each of these units, IBC site-class boundaries fall within the range of Vs30 for the unit. We estimated shear-wave-velocity characteristics for two of the Quaternary and three bedrock units. Our analysis indicates shear-wave velocity increases with grain size and thus dominant facies within Quaternary units provide constraints on Vs30.

## INTRODUCTION

### Background

In 2002, Utah formally adopted the International Building Code (IBC) (International Code Council, 2000) including its seismic provisions. The seismic provisions (IBC section 1615) describe the general design procedures for estimating earthquake ground motions, and include national-scale maps (IBC figures 1615[1] and 1615[2]) showing maximum considered earthquake spectral response accelerations at short periods and at a 1-second period. Engineers adjust the maximum considered earthquake spectral response accelerations provided by the maps based on site-class effects. Site-class effects, important in understanding earthquake site response, are the amplification or de-amplification of earthquake ground motion attributable to the engineering properties of the near-surface soil or rock at a site.

The IBC defines six site classes (A through F). Five of the site classes (table 1) can be determined based on the average shear-wave velocity (Vs) in the upper 100 feet (approximately 30 meters; equivalent to Vs30 of Wills and Silva, 1998). Site class F is defined on the basis of certain engineering properties or the potential for failure or collapse during earthquake ground shaking. The use of Vs30 to determine site class is based on the results of empirical ground motion and analytical studies which show a consistent relationship between site response and shear-wave velocity (Vs) (see summary in Wills and Silva, 1998).

***Table 1.***
*Ranges of Vs30 for IBC site classes A through E.*

| IBC Site Class | Soil Profile Name | Shear-Wave Velocity (Vs30) m/sec |
|---|---|---|
| A | Hard rock | Vs30 > 1,500 |
| B | Rock | 760 < Vs30 ≤ 1,500 |
| C | Very dense soil and soft rock | 360 < Vs30 ≤ 760 |
| D[1] | Stiff soil profile | 180 ≤ Vs30 ≤ 360 |
| E[1] | Soft soil profile | Vs30 < 180 |

[1]See IBC table 1615.1.1 for complete definition of site class E conditions. Certain soil-profile characteristics may define IBC site class E where Vs30 exceeds or equals 180 meters per second.

## Purpose and Scope

The purpose of this study is to map and characterize shear-wave velocities of engineering geologic units in the Salt Lake City metropolitan area for use in estimating IBC site classes. Mapped units are distinct in terms of a combination of Vs30 characteristics including the mean, distribution, and variability. We characterize each unit using the available local Vs30 data or published Vs and Vs30 data for similar units elsewhere. The scope of this study included compilation of a Vs30 database, statistical analysis of the data to define map units (Ashland, 2001; this study) (map units modified from Ashland and Rollins, 1999), and the creation of Vs profiles for three units and IBC site class maps. We added 27 Vs30 measurements using the profiles of Schuster and Sun (1993) to a modified version of the database of Ashland and Rollins (1999).

## Setting and Physiography

The study area is Salt Lake Valley and parts of the bounding mountain ranges (see plate 1). Salt Lake Valley is one of a series of valleys at the foot of the western slope of the Wasatch Range. These valleys are deep, north-trending, sediment-filled structural basins formed by extensional block faulting. Salt Lake Valley is bounded on the west by the Oquirrh Mountains, on the east by the Wasatch Range, on the south by the Traverse Mountains, and on the north by Great Salt Lake and the Salt Lake salient. The Jordan River flows north along the valley bottom.

## Land Use

Land use in the study area has changed significantly in response to recent economic and population growth. Agricultural land in Salt Lake Valley is rapidly being replaced by residential, commercial, and light industrial development. New construction in most of the valley consists primarily of one- to two-story, wood-framed residential housing; retail strip malls; and one- to five-story office buildings. High-rise construction is generally limited to downtown Salt Lake City.

Most of Salt Lake County's population, which in 1999 exceeded 840,000 people, lives in Salt Lake Valley. The valley contains three cities with populations in excess of 100,000 people: Salt Lake City, West Valley City, and Sandy. Salt Lake City, Utah's state capital and largest city, is located in the northern part of the valley.

## PREVIOUS INVESTIGATIONS

Ashland and Rollins (1999) compiled shear-wave-velocity data for Salt Lake Valley and mapped preliminary engineering geologic units based on engineering geology criteria. The shear-wave-velocity data consisted of downhole measurements by Tinsley and others (1991) (see also analysis of this shear-wave-velocity data in Williams and others, 1993) and published and unpublished data provided by the Utah Department of Transportation and local geotechnical consultants. Ashland (2001) added shear-wave-velocity profiles of Schuster and Sun (1993) to the Salt Lake Valley database and used the statistical test methods of Park and Elrick (1998) to assess the distinctiveness of the five units and two sub-units of Ashland and Rollins (1999). Based on the results of these statistical tests, Ashland (2001) grouped one Quaternary unit with two sub-units and remapped Salt Lake Valley engineering geologic units. Solomon and others (2002) extended the updated Salt Lake Valley engineering geologic units of Ashland (2001) into the remainder of the Wasatch Front urban corridor. Ashland (2001) included an earlier and slightly modified version of the Solomon and others (2002) mapping.

## GEOLOGY

The near-surface geology of the study area consists of thick unconsolidated Quaternary sediments in Salt Lake Valley and Tertiary and older rock in the surrounding mountains. Pleistocene glacial deposits exist locally in the Wasatch Range and along the valley margin at the mouths of glaciated canyons in the eastern part of the study area.

### Salt Lake Valley

Salt Lake Valley contains a combined thickness of unconsolidated Quaternary and semi-consolidated Tertiary basin-fill deposits that locally exceeds 3,300 feet (1,000 m) (Mabey, 1992). Using water-well logs and geological and geophysical data, Arnow and others (1970) determined that the thickness of unconsolidated Quaternary basin-fill deposits exceeds 2,200 feet (670 meters) in the northern part of the valley. However, unconsolidated Quaternary basin-fill deposits are less than 820 feet (250 m) thick in most of the valley (Wong and others, 2002).

Quaternary basin-fill deposits are dominated by lacustrine sediments deposited by repeated cycles of deep-water lakes during the Pleistocene (Lund and others, 1990; Hylland and others, 1997). The most recent lake cycle, known as the Bonneville lake cycle, occurred between 30,000 and 10,000 years ago. Coarse-grained Lake Bonneville shore facies, consisting primarily of sand and gravel, are present along the margins of the valley up to an elevation of about 5,180 feet (1,580 m), whereas deep-water facies consisting of clay, silt, and fine sand predominate toward the center of the valley. Post-Bonneville sediments consist mostly of marsh, alluvial, and deltaic deposits associated with the Jordan River and its tributaries. These deposits are relatively thin, generally less than 16 feet (5 m) thick (Personius and Scott, 1992). Glacial and pre-Bonneville alluvial-fan deposits as well as bedrock exist locally along the margins of Salt Lake Valley.

### Mountains

The mountains abutting Salt Lake Valley are comprised of a variety of rock types (Davis, 1983a, 1983b; Personius and Scott, 1992). In the Wasatch Range, rock units include Precambrian metamorphic rocks, Paleozoic and Mesozoic sedimentary rocks, and Tertiary intrusive igneous rocks. In the Oquirrh Mountains, rock units include Paleozoic and Tertiary sedimentary rocks, and Tertiary intrusive and volcanic igneous rocks. The Traverse Mountains consist of Paleozoic sedimentary rocks and Tertiary sedimentary and volcanic rocks. Tertiary sedimentary and volcanic rocks predominate in the Salt Lake salient, but Paleozoic rocks are present along its western edge.

Relatively thin Quaternary surficial deposits locally overlie rock units on mountain slopes and in canyons. These deposits consist of glacial soils, colluvium, alluvium, and landslides, and thicknesses locally exceed 10 feet (3 m). Glacial deposits consisting of till and outwash are only in the eastern part of the study area in the Wasatch Range.

## SHEAR-WAVE-VELOCITY CHARACTERISTICS OF ENGINEERING GEOLOGIC UNITS

We mapped five Quaternary and three bedrock engineering geologic units in the study area. Ashland (2001) used statistical tests to show that the three Quaternary units (Q01 through Q03) for which Vs30 data exist are distinct in terms of their means and distribution of Vs30. No Vs30 data currently exist for the two remaining Quaternary units Q04 and Q05 and the three bedrock units (T, M, and P). However, Ashland (2001) estimated mean Vs30 for three of these units (Q04, Q05, and P) based on comparison of regional shear-wave-velocity data for similar soils and rock. We used shear-wave-velocity data from probable buried rock encountered in Vs profiles at valley margin sites to estimate Vs30 in bedrock units T and M. In this section, we discuss the Vs30 characteristics of Quaternary units Q01 through Q03 and the basis of mean Vs30 estimates for the other soil (Q04 and Q05) and bedrock (T, M, and P) units.

## Quaternary Units

### Unit Q01

Unit Q01 consists primarily of lacustrine and alluvial clay, silt, and fine sand (L-Amcs). Most of the soils in the upper 100 feet (30 m) in this unit are lacustrine deposits. We calculated Vs30 for 67 profiles in the unit extending at least 100 feet (30 m) deep. The descriptive statistics for the Quaternary units are shown in table 2. Figure 1 shows the distribution of Vs30 for unit Q01 and figure 2 shows the composite shear-wave-velocity (Vs) profile to a depth of 295 feet (90 m).

The boundary between IBC site classes E and D falls within the range of Vs30 for unit Q01, but the distribution of Vs30 varies considerably within the unit. Table 3 shows the percentage of profiles in each site class for the entire unit and selected zones within it. The majority of profiles in site class E are located in Salt Lake City. Spatial analysis of the profiles indicates that an area between 300 South and North Temple is dominated by profiles in site class E. About 73 percent of the profiles in this area fall in site class E. In some cases profiles that fall in site class E are adjacent to profiles in site class D. The boundaries of this area, particularly the western and eastern boundaries, are not well constrained, due to clustering of profiles along the Interstate-15 corridor (see plate 1 and inset). Table 3 shows that the northwestern part of unit Q01 is dominated by site class D. However, because the small number of profiles is restricted to the southern part of the area, the summary of Vs30 in table 3 may not adequately characterize the entire area.

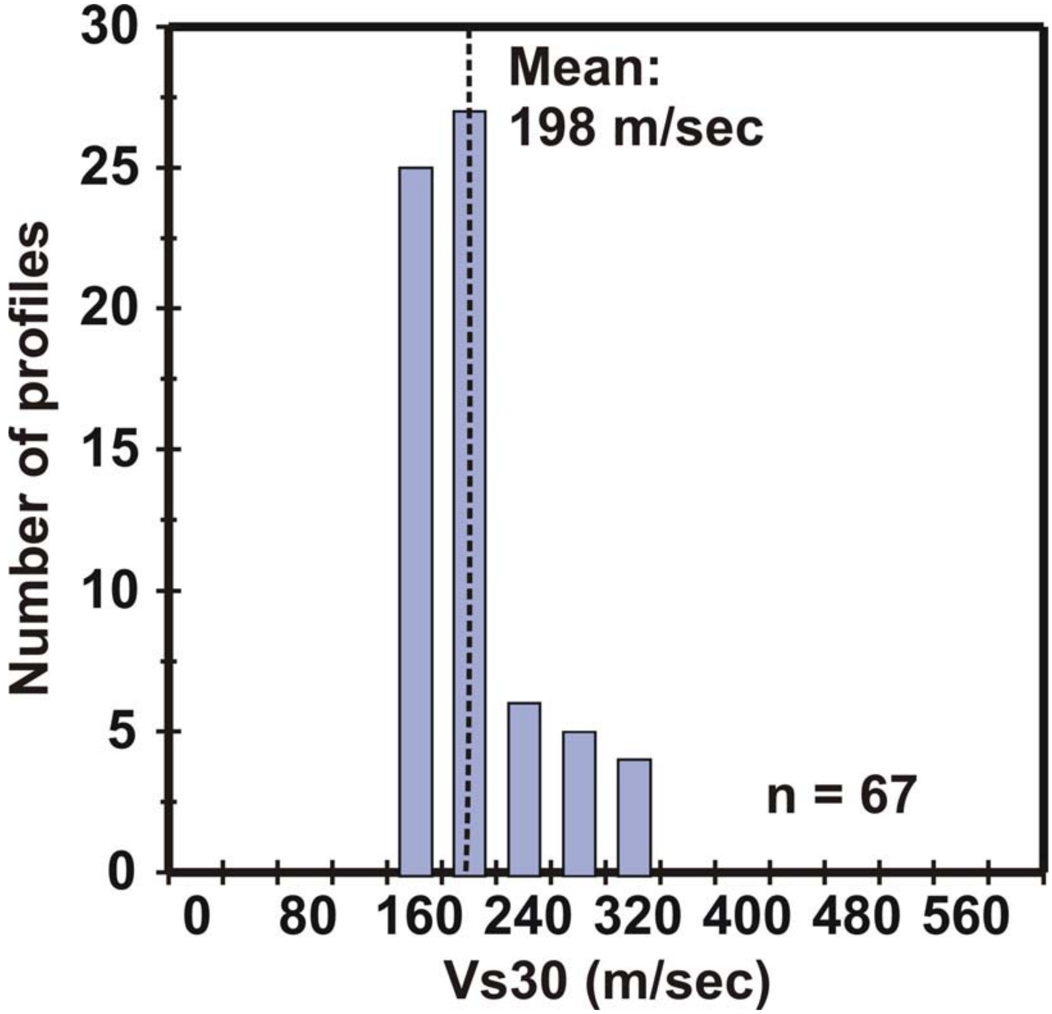


***Figure 1****. Histogram of Vs30 for unit Q01. Boundary between IBC site class E and site class D (180 m/sec) falls within range of Vs30. Class interval is 40 m/sec; for example, Vs30 for the class labeled 160 ranges from 140 to 179 m/sec. The total number of profiles (n) is shown.*

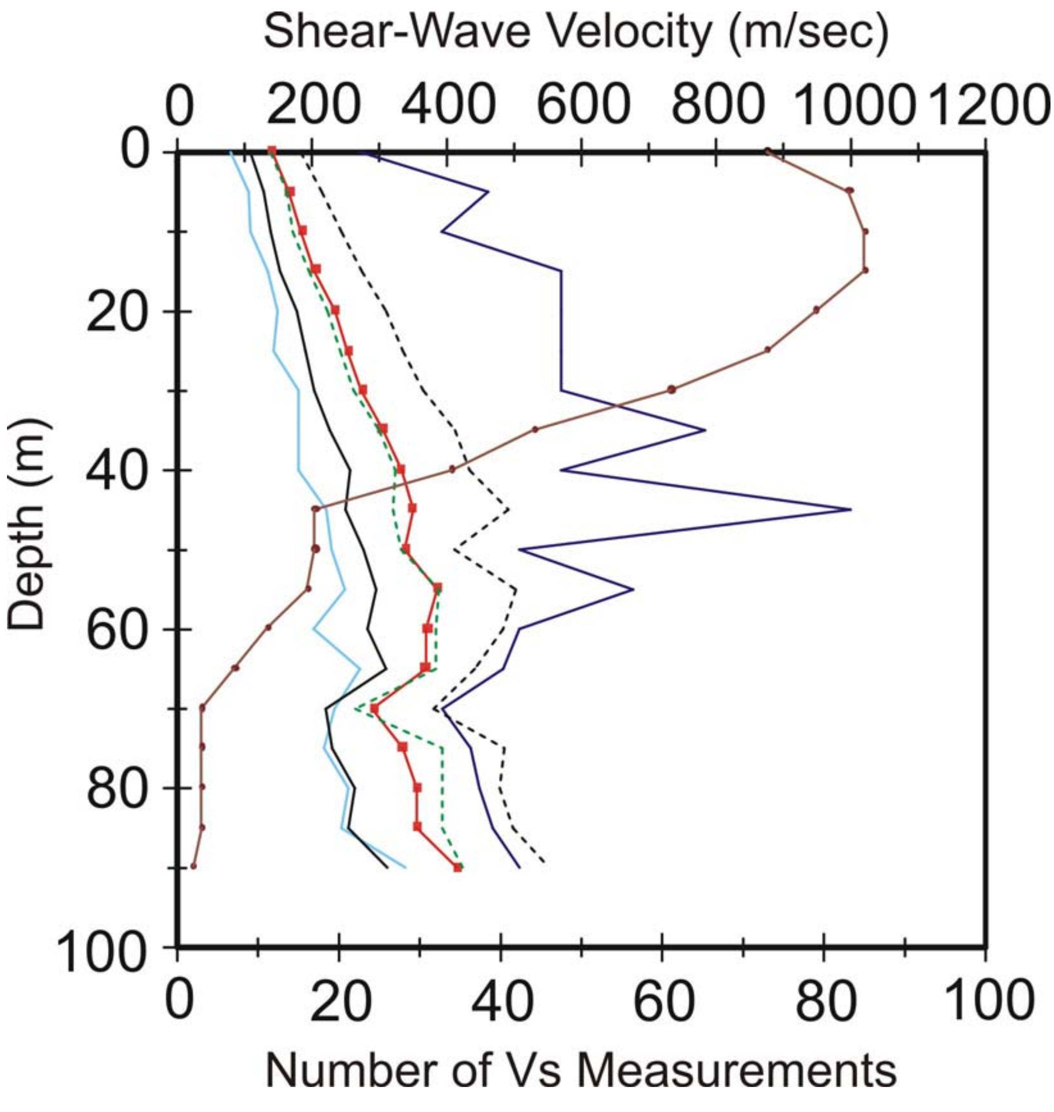


***Figure 2.*** *Composite Vs profile of unit Q01. Logarithmic mean Vs (red squares), maximum (dark blue), minimum (light blue), 16th percentile (solid black), 84th percentile (dashed black), and median (dashed green) shown. Maximum depth of Vs profiles used in composite is 92 meters. Eighty-nine profiles are used, but number of Vs measurements varies from two to eighty-five (circles).*

***Table 2.***

*Summary of Vs30 for Quaternary units.*

| Unit | UEGM Unit | Mean Vs30[1,2] (m/sec) | Stdev[3] | Max (m/sec) | Min (m/sec) | Median (m/sec) | 1st Quartile[4] (m/sec) | 3rd Quartile[4] (m/sec) | No. of Vs Profiles | IBC Site Class (based on mean) | Range in IBC Site Class |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Q01 | L-Amcs | 198 | 22% | 325 | 151 | 188 | 171 | 216 | 67 | D | E to D |
| Q02 | Ls-Lmc-Ag composite | 297 | 21% | 469 | 212 | 287 | 254 | 348 | 21 | D | D to C |
| Q03 | Lg and L-Ag | 389 | 31% | 590 | 260 | 363 | --- | --- | 9 | C | D to C |
| Q04 | cAg | 437 | --- | --- | --- | --- | --- | --- | None | C | na |
| Q05 | Gg | 486 | --- | --- | --- | --- | --- | --- | None | C | na |

[1]Logarithmic mean.
[2]Vs30 for units Q04 and Q05 estimated from published Vs values for similar soils.
[3]Determined from the natural log (velocity).
[4]Descriptive statistics calculated using web-based statistical software of the Physics Department of the College of Saint Benedict/Saint John’s University, Minnesota.
Abbreviations: IBC = International Building Code (International Code Council, 2000); UEGM = Unified Engineering Geology Mapping system (Keaton and DeGraff, 1996)

***Table 3.***
*Variability in Vs30 in unit Q01.*

| Sample area | Site Class E (percentage) | Site Class D (percentage) | Mean Vs30 (m/sec) | Number of profiles |
|---|---|---|---|---|
| Unit Q01 – entire | 37 | 63 | 198 | 67 |
| Northwestern Q01 | 14 | 86 | 192 | 7 |
| I-15 corridor – 2nd N. to 4th S. | 73 | 27 | 175 | 11 |
| I-15 corridor – I-80 to 33th S. | 0 | 100 | 200 | 7 |

**Unit Q02**

Unit Q02 is a composite unit consisting primarily of lacustrine sand (Ls); interbedded lacustrine clay, silt, and sand (Lmc); and alluvial-fan deposits (Ag). Ashland (2001) showed that Vs30 in these three surficial units is not statistically distinct and grouped them into a single unit. We calculated Vs30 for 21 profiles in the unit at least 100 feet (30 m) deep. The descriptive statistics for the unit are included in table 2. Figure 3 shows the distribution of Vs30 for unit Q02 and figure 4 shows the composite Vs profile to a depth of 197 feet (60 m).

The boundary between IBC site classes D and C falls within the range of Vs30 for unit Q02. Figure 5 shows the relative distribution of Vs30 of the three surficial units in unit Q02. The maximum difference in mean Vs30 between these three units is 17 meters/second (table 4). The highest Vs30 value occurs at a site underlain by sub-unit Lmc where rock or rock-like material with a shear-wave velocity of 800 meters/second (Vsi; Vs of an individual layer) exists at a depth of 92 feet (28 m) (Schuster and Sun, 1993).

***Table 4.***
*Comparison of mean Vs30 in sub-units of unit Q02.*

| Unit or sub-unit | Mean Vs30 (m/sec) | No. of profiles |
|---|---|---|
| Unit Q02 | 297 | 21 |
| Ls sub-unit | 290 | 7 |
| Lmc sub-unit | 303 | 10 |
| Ag sub-unit | 292 | 4 |

**Unit Q03**

Lacustrine gravel predominates in unit Q03, but the unit also contains alluvium, alluvial-fan deposits, and deltaic sand, gravel, and silt (Lg and L-Ag). We calculated Vs30 for nine profiles in the unit at least 100 feet (30 m) deep and included profiles for which borehole logs indicated the upper 100 feet (30 m) consists of predominantly lacustrine gravel. The descriptive statistics for the unit are shown in table 2. Figure 6

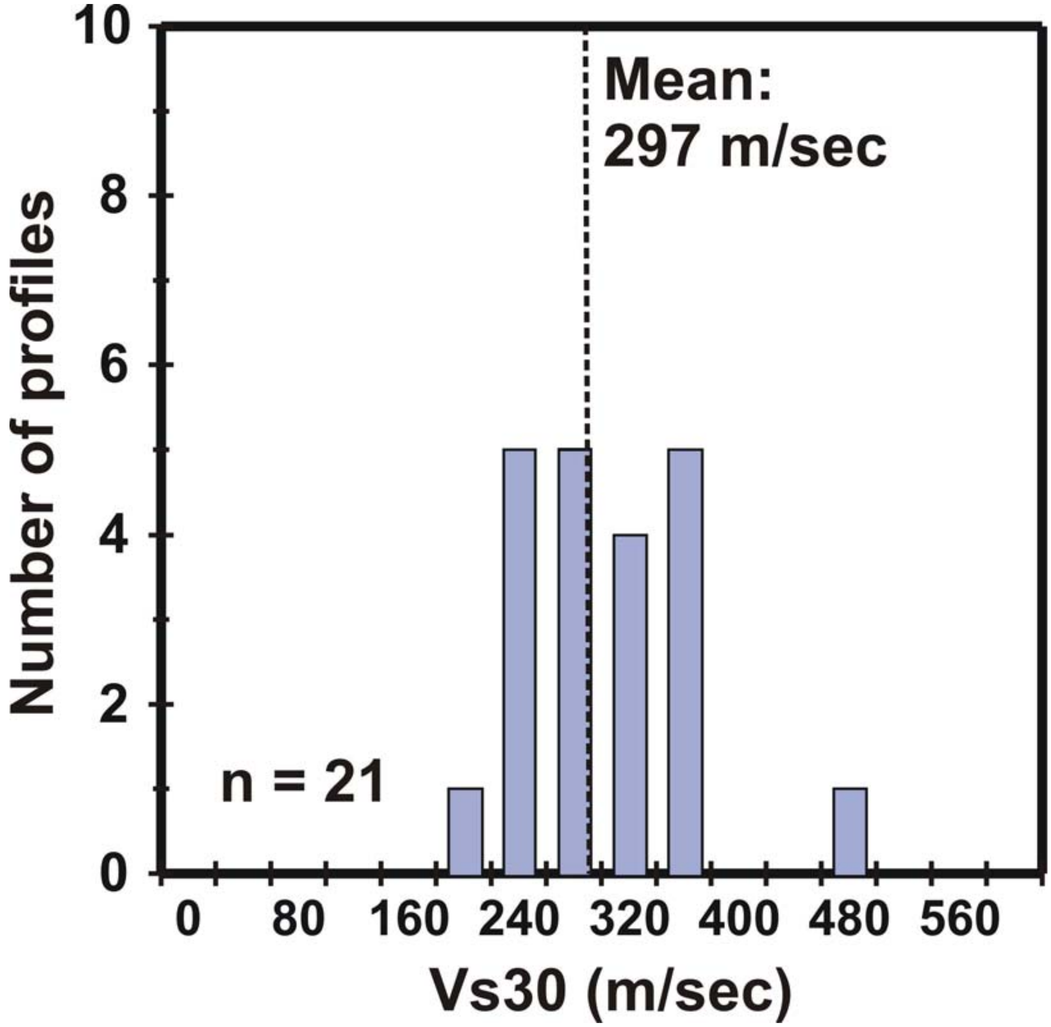


***Figure 3.*** *Histogram of Vs30 for unit Q02. Boundary between IBC site class D and site class C (360 m/sec) falls within range of Vs30. The high Vs30 value of 469 m/sec is due to the presence of rock or rock-like material (semi-consolidated sediments). Class interval is 40 m/sec. The total number of profiles (n) is shown.*

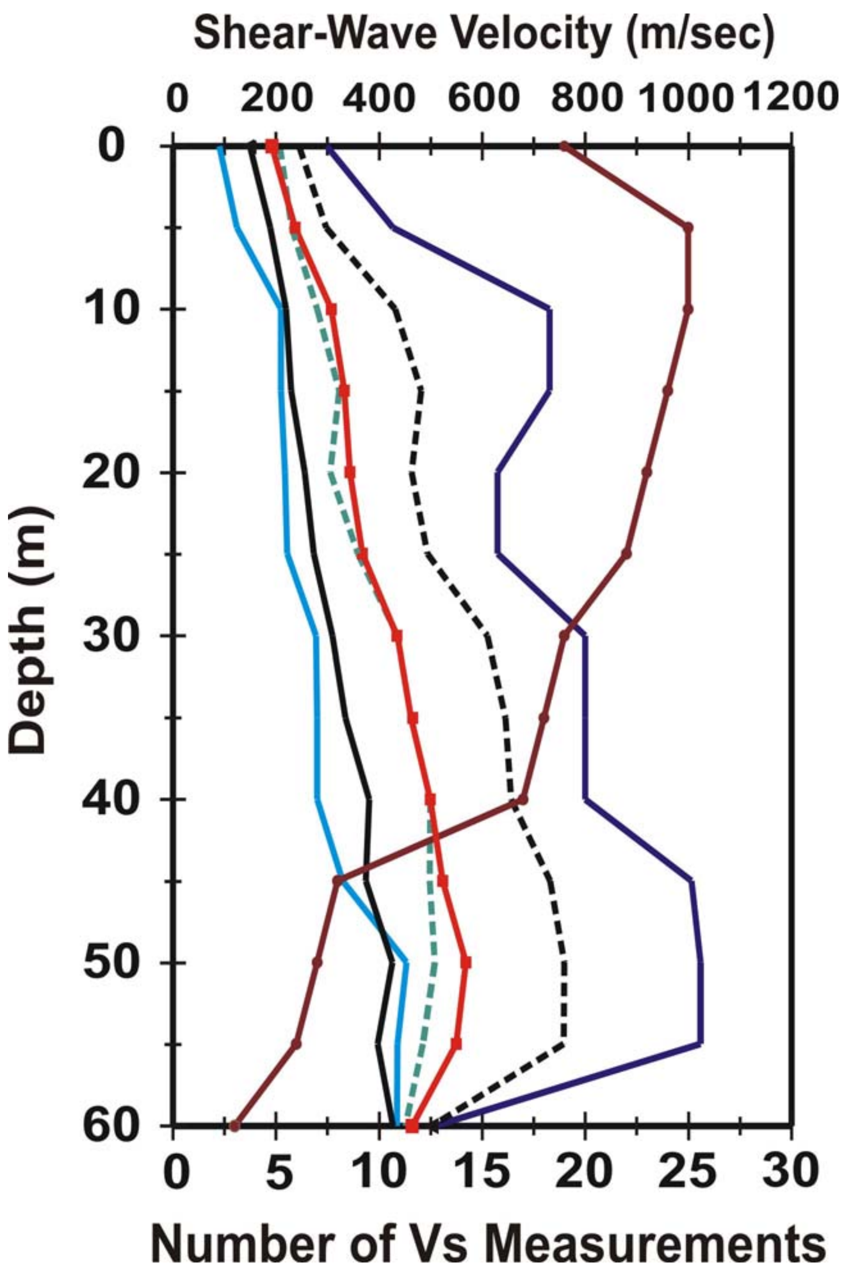


***Figure 4.*** *Composite Vs profile of unit Q02. Logarithmic mean Vs (squares), maximum (dark blue), minimum (light blue), 16th percentile (black), 84th percentile (dashed black), and median (dashed green) shown. Maximum depth of Vs profiles used in composite is 61 meters. Twenty-five profiles used, but number of Vs measurements varies from three to twenty-five (circles).*

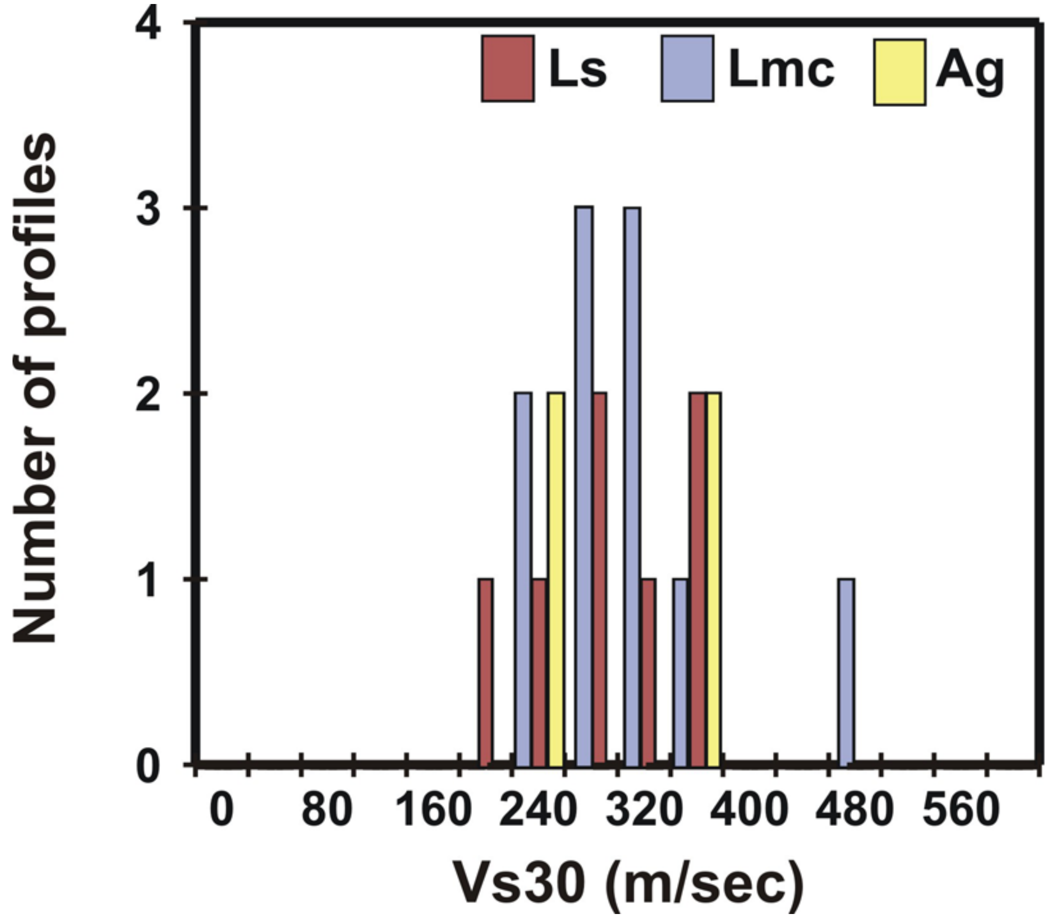


***Figure 5.*** *Histogram showing relative distribution of Vs30 for surficial units in unit Q02. Highest Vs30 is in unit Lmc (Schuster and Sun, 1993) at site where rock or rock-like material (semi-consolidated sediments) exists at a depth of 28 meters. At most sites (86 percent), Vs30 falls between 220 and 360 meters/second (IBC site class D). Class interval is 40 m/sec.*

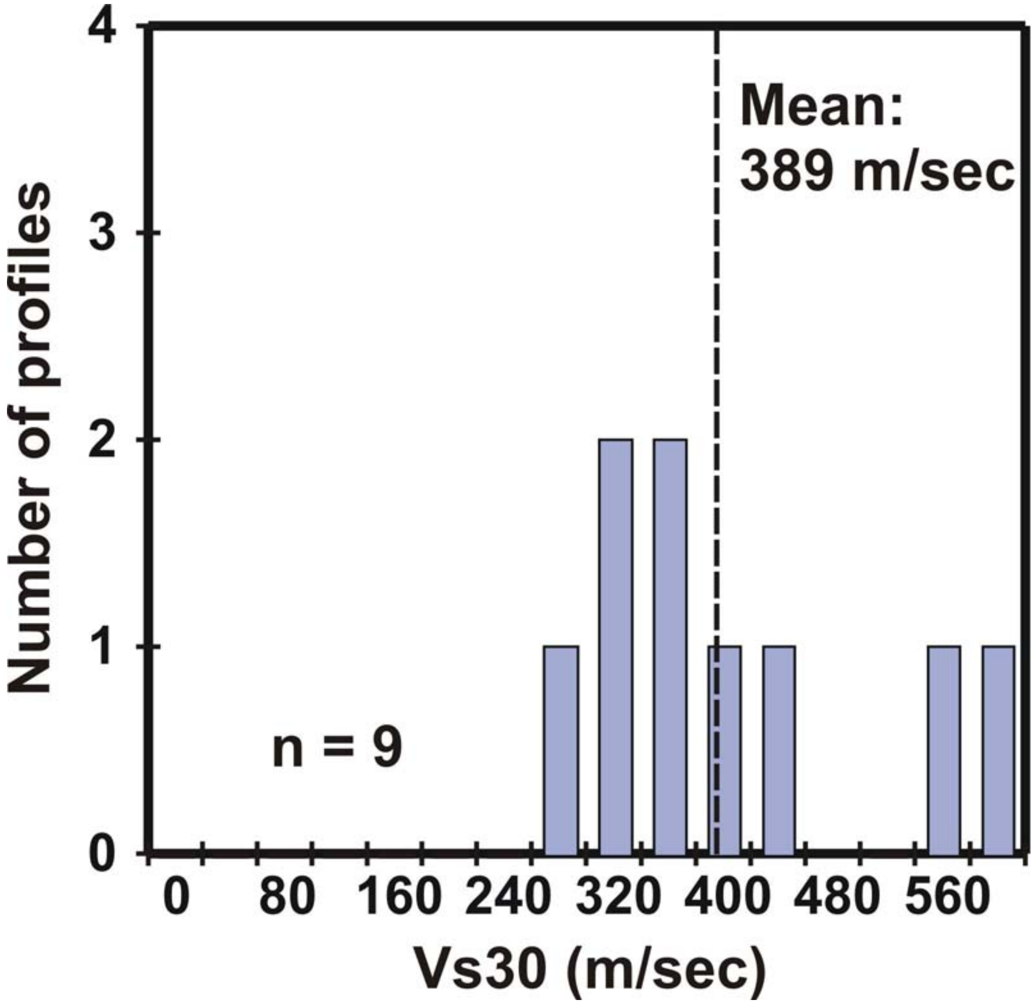


***Figure 6.*** *Histogram of Vs30 for unit Q03. Boundary between IBC site class D and site class C (360 m/sec) falls within range of Vs30. Higher Vs30 values are due to shallow tufa cementation and/or the presence of rock or rock-like material (semi-consolidated sediments). Class interval is 40 m/sec. The total number of profiles (n) is shown.*

shows the distribution of Vs30 for unit Q03 and figure 7 shows the composite Vs profile to a depth of 180 feet (55 m).

The boundary between IBC site classes D and C falls within the range of Vs30 for unit Q03. In five of the nine profiles (56 percent), Vs30 falls in site class C; in the remainder, Vs30 falls in site class D. The two highest Vs30 values are at sites with rock or rock-like material in the upper 100 feet (30 m). The highest Vs30 value is at Tinsley and others' (1991) borehole SLCLAI. Wong and Silva (1993) attributed a shallow layer with rock-like shear-wave velocity (Vs = 944 m/sec) in this borehole as tufa-cemented soils. Tufa cementation is inferred based on the presence of an underlying lower shear-wave-velocity layer. Wong and Silva (1993) interpreted high shear-wave-velocity soils in the lowermost part of the SLCLAI borehole as semi-consolidated sediments.

Based mostly on geologic conditions, we have mapped a possible sub-unit in the northeast part of Salt Lake Valley that we refer to as the Parleys-City Creek Canyons (PCCC) sub-unit Q03a. The sub-unit consists of complexly interfingered lacustrine gravel, lacustrine fine-grained deposits, alluvium, and alluvial-fan deposits, and thus, is more heterogeneous than unit Q03. Mean Vs30 for this unit (table 5) is slightly less than for unit Q03 and falls closer to the boundary between IBC site classes D and C (360 m/sec; table 1). The unit is also characterized by the presence of local, shallow tufa-cemented layers with shear-wave velocities within the range of site class B (Wong and Silva, 1993). In addition, the sub-unit contains local areas of shallow semi-consolidated deposits or rock (Tinsley and others, 1991; Wong and Silva, 1993). The possible presence of shallow buried rock is consistent with the location of the sub-unit to the east and in the footwall of the East Bench section of the Salt Lake City segment of the Wasatch fault zone. Figure 8 shows the distribution of Vs30 in sub-unit Q03a and figure 9 shows the composite Vs profile to a depth of 180 feet (55 m). Figure 10 compares the Vs profiles for sub-unit Q03a with a composite Vs profile using only the four profiles in unit Q03 outside or exclusive of the sub-unit. The two Vs profiles in figure 10 begin to diverge at a depth of about 66 feet (20 m); below this depth mean shear-wave velocity in the sub-unit remains higher than in unit Q03.

***Table 5.***
*Comparison of lacustrine-gravel-dominated units.*

| Unit | Mean Vs30 (m/sec) | Site Class D (percent) | Site Class C (percent) | No. of Profiles |
|---|---|---|---|---|
| Q03 | 389 | 44 | 56 | 9 |
| Q03a (PCCC) | 377 | 50 | 50 | 8 |

Ashland and Rollins (1999) mapped other possible sub-units of unit Q03 based on estimated variations in geologic characteristics and engineering properties of the sediments (figure 11). Currently, only four Vs30 measurements exist in these sub-units, too few to support further subdivision of unit Q03, so we do not show these other

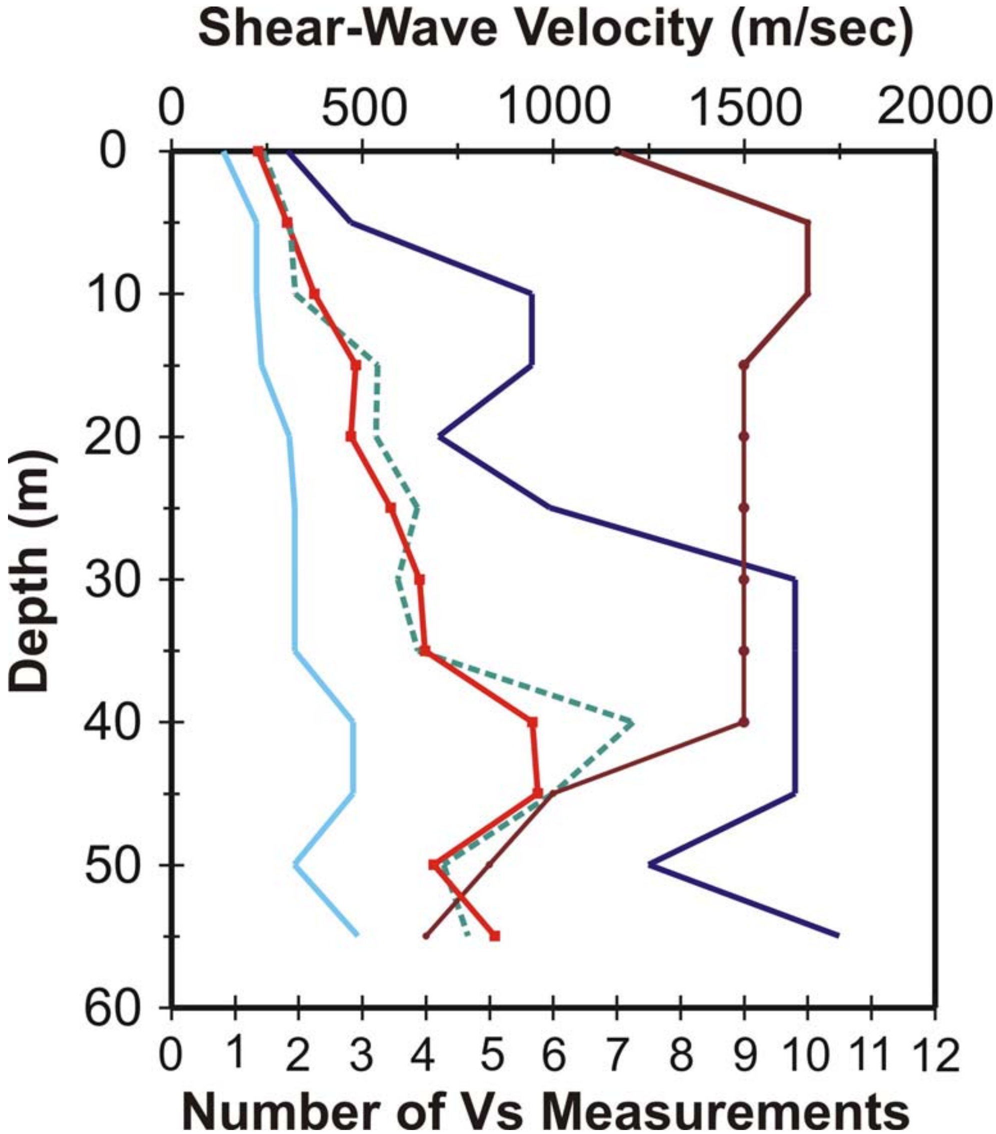


***Figure 7.*** *Composite Vs profile of unit Q03. Logarithmic mean Vs (red squares), maximum (dark blue), minimum (light blue), and median (dashed green) shown. Maximum depth of Vs profiles used in composite is 59 meters. Ten profiles used, but number of Vs measurements varies from four to ten (circles).*

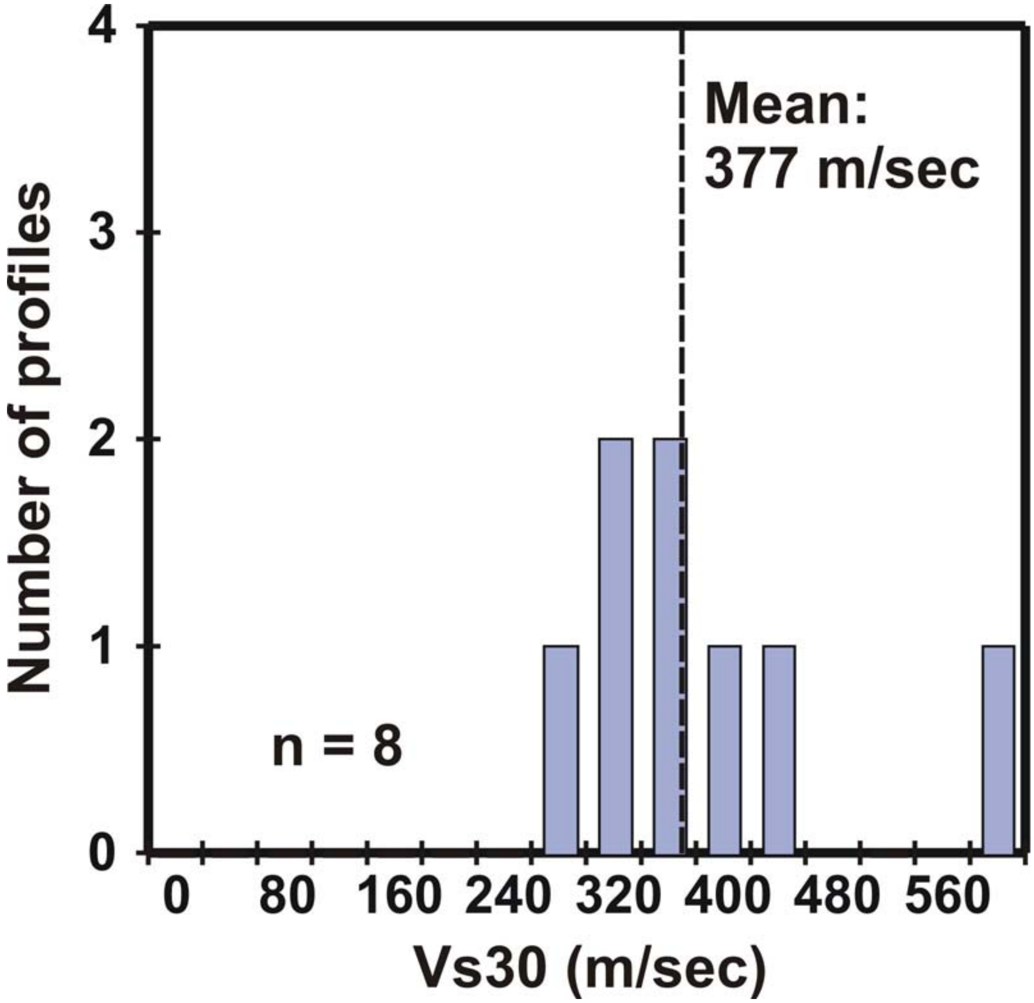


***Figure 8****. Histogram of Vs30 for sub-unit Q03a. The boundary between site class D and site class C (360 m/sec) falls within the range of Vs30 and is close to mean Vs30 for the sub-unit. The Vs30 value of 590 m/sec is probably a result of shallow tufa-cementation and the presence of rock or rock-like material (semi-consolidated sediments). Class interval is 40 m/sec. The total number of profiles (n) is shown.*

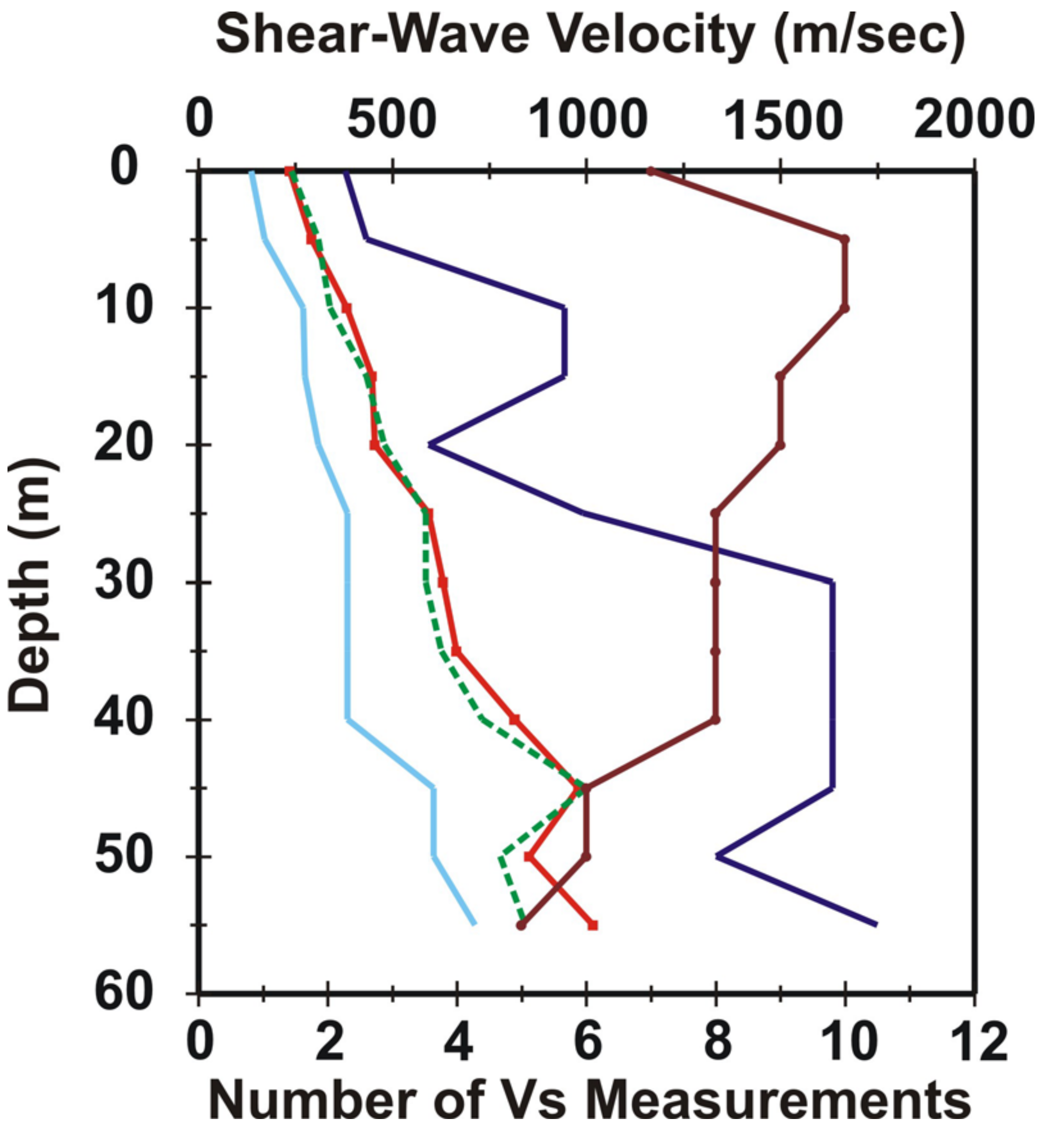


***Figure 9.*** *Composite Vs profile of sub-unit Q03a. Logarithmic mean Vs (red squares), maximum (dark blue), minimum (light blue), and median (dashed green) shown. Maximum depth of Vs profiles used in composite is 59 meters. Ten profiles used, but number of Vs measurements varies from five to ten (circles).*

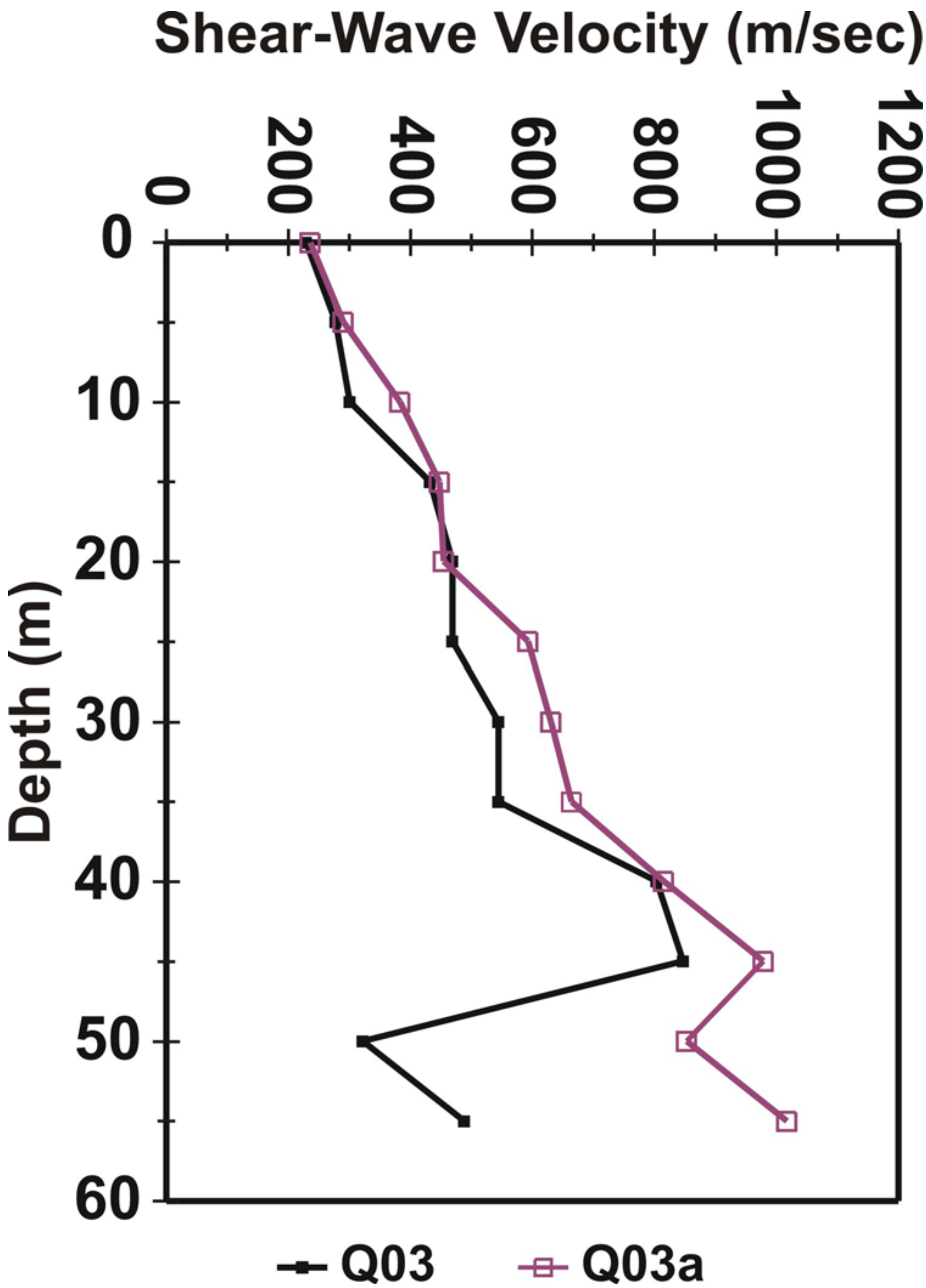


***Figure 10***. *Comparison of composite Vs profiles of unit Q03 and sub-unit Q03a. Vs profile shown for unit Q03 based only on four profiles outside or exclusive of the sub-unit. Vs profiles vary only slightly in the upper 20 meters, but diverge at depth. Convergence of profiles at a depth of 40 meters due, in part, to the presence of rock or rock-like material in the bottom part of two of the profiles used in Vs profile for unit Q03.*

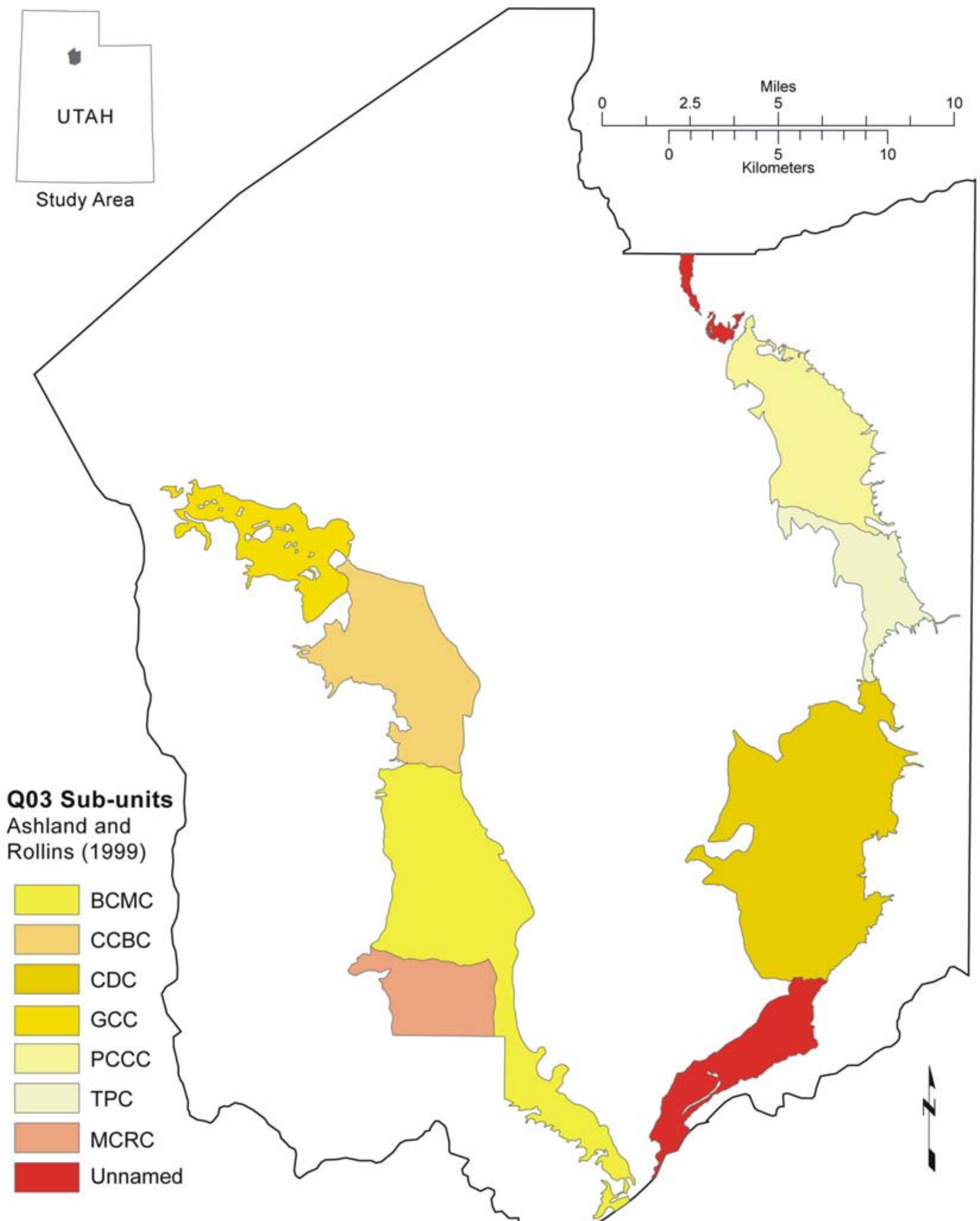


***Figure 11.*** *Map showing possible sub-units of unit Q03 of Ashland and Rollins (1999). Sub-units on the west side of Salt Lake Valley are Garfield-Coon Canyons (GCC), Coon Canyon-Barneys Creek (CCBC), Barneys Creek-Midas Creek (BCMC), and Midas Creek-Rose Canyon (MCRC). East side sub-units are Parleys-City Creek Canyons (PCCC; our unit Q03a), Tolcats-Parleys Canyons (TPC), Cottonwood delta complex (CDC), and two separate unnamed sub-units in the northern and southern part of Salt Lake Valley.*

possible sub-units on the map. No Vs30 measurements exist in four of these possible sub-units in southern and western Salt Lake Valley.

Ashland and Rollins (1999) mapped three other sub-units for which at least one Vs30 measurement exists in each unit. The Tolcats-Parleys Canyon sub-unit directly south of the Parleys-City Creek Canyons sub-unit Q03a consists mostly of near shore lacustrine and some alluvial gravels. The only Vs30 measurement in this possible sub-unit (363 m/sec) is close to the mean value for the Parleys-City Creek Canyons sub-unit Q03a (table 5). A single Vs30 measurement (561 m/sec) in the Coon Canyon-Barneys Creek sub-unit mapped by Ashland and Rollins (1999) in western Salt Lake Valley is in the upper half of the range in Vs30 for site class C. The high Vs30 value partly reflects the presence of rock or rock-like material (Vs = 1,210 m/sec) at a depth of 89 feet (27 m). Ashland and Rollins (1999) mapped this sub-unit based on the potential that the lacustrine gravels were underlain by high shear-wave velocity pre-Bonneville alluvial-fan gravels (equivalent of unit Q04).

Ashland and Rollins (1999) also mapped the large complex of Lake Bonneville deltaic gravels at the mouths of Little and Big Cottonwood Canyons and Bells Canyon as a possible sub-unit, referred to as the Cottonwood Delta Complex. The two Vs30 measurements in this possible sub-unit (260 and 306 m/sec) are within IBC site class D and are the lower bound of the Vs30 data for unit Q03. The two profiles in this possible sub-unit are located in the distal and central parts of the delta. In addition, soils in the upper 100 feet (30 m) of the profile with the lowest Vs30 value are predominately sand rather than gravel. Ashland and Rollins (1999) speculated that Vs30 in the sub-unit likely increases toward the mountain front and the mouths of the canyons. They also speculated that the boundary between site classes D and C exists within the possible sub-unit, but additional Vs30 measurements are needed to define the boundary.

### Units Q04 and Q05

Ashland and Rollins (1999) mapped two gravel-dominated valley-margin units for which no Vs30 measurements exist: pre-Bonneville alluvial-fan gravel (Q04) and glacial deposits (till and outwash) (Q05). Ashland (2001) used shear-wave-velocity data from Pacific Northwest glacial deposits to estimate mean Vs30 for glacial till and outwash in northern Utah. Lacking published shear-wave-velocity data for older alluvial-fan gravels, Ashland (2001) used the median value of the mean Vs30 for lacustrine gravels and the estimated Vs30 for glacial deposits as an estimate of mean Vs30 for pre-Bonneville alluvial-fan gravel. The estimated mean Vs30 values for units Q04 and Q05 are included in table 1.

## Bedrock Units

Ashland and Rollins (1999) mapped three bedrock units in the study area: Tertiary sedimentary and volcanic rocks (T), Mesozoic sedimentary rocks (M), and Paleozoic and older rocks including Tertiary intrusives (P). Currently, no shear-wave-velocity profiles exist in areas mapped as bedrock. Therefore, Ashland and Rollins (1999) estimated the probable range in Vs30 for each unit. Ashland (2001) estimated meanVs30 for bedrock units T and M (table 6) using limited shear-wave-velocity measurements from Vs profiles within the study area that encountered buried rock or rock-like material (semi-consolidated sediments). Ashland (2001) estimated mean Vs30 for bedrock unit P (table 6) based on a review of published shear-wave-velocity data for rock types similar to those comprising the unit.

***Table 6.***
*Summary of Vs30 for bedrock units.*

| Unit | Mean Vs30[1] (m/sec) | Stdev[2] | Max (m/sec) | Min (m/sec) | Median (m/sec) | No. of Profiles | IBC[3] Site Class |
|---|---|---|---|---|---|---|---|
| T[4] | 1010 | 20% | 1230 | 837 | 1058 | 5 | B |
| M[4] | 1460 | 25% | 1782 | 1009 | 1553 | 7 | B |
| P[5] | 2197 | -- | -- | -- | -- | na | A |

[1]Logarithmic mean. [2]Determined from the natural log (velocity). [3]IBC equals International Building Code (International Code Council, 2000). [4]Mean Vs30, standard deviation, and median slightly modified from Ashland (2001). [5]Includes older basement rocks and Tertiary intrusives. See text for unit abbreviations.

## Buried Rock or Rock-Like Material

Buried rock or rock-like material exists at 11 shear-wave-velocity profile sites in Salt Lake Valley (Tinsley and others, 1991; Schuster and Sun, 1993). At two sites, geologic logs accompanying the profiles identify rock at the bottom of the profiles (Adan and Rollins, 1993; Wong and Silva, 1993). At one of the two sites, the specific bedrock unit can be inferred with reasonable confidence. At all 11 sites, unconsolidated Quaternary basin-fill sediments overlie the rock or rock-like material. Therefore, some uncertainty exists regarding the geology of the rock or rock-like material encountered in the bottom of the profiles. Ashland (2001) used published geologic maps (Davis, 1983a,b; Van Horn and Crittenden, 1987) to infer geologic units and corresponding bedrock units (T, M, or P). The possibility exists that the rock-like material at the bottom of the profiles is semi-consolidated Quaternary or Tertiary basin-fill sediments rather than actual rock (Wong and Silva, 1993). However, based on the range in shear-wave velocities of this material, we interpret it to be buried Tertiary and older rock.

At only one site are more than 100 feet (30 m) of rock or rock-like material identified at the bottom of a profile. Ashland (2001) used the shear-wave-velocity data from this borehole (SLCLAI of Tinsley and others, 1991) to calculate an average shear-wave-velocity gradient and calculate Vs30 for the "buried rock" part of the profile. Figure 12 shows the shear-wave-velocity profile, average shear-wave-velocity gradient, and interval for which Vs30 was calculated at borehole SLCLAI. The possible variation in the results is summarized in table 7. Note that our Vs30 value is slightly modified from Ashland (2001).

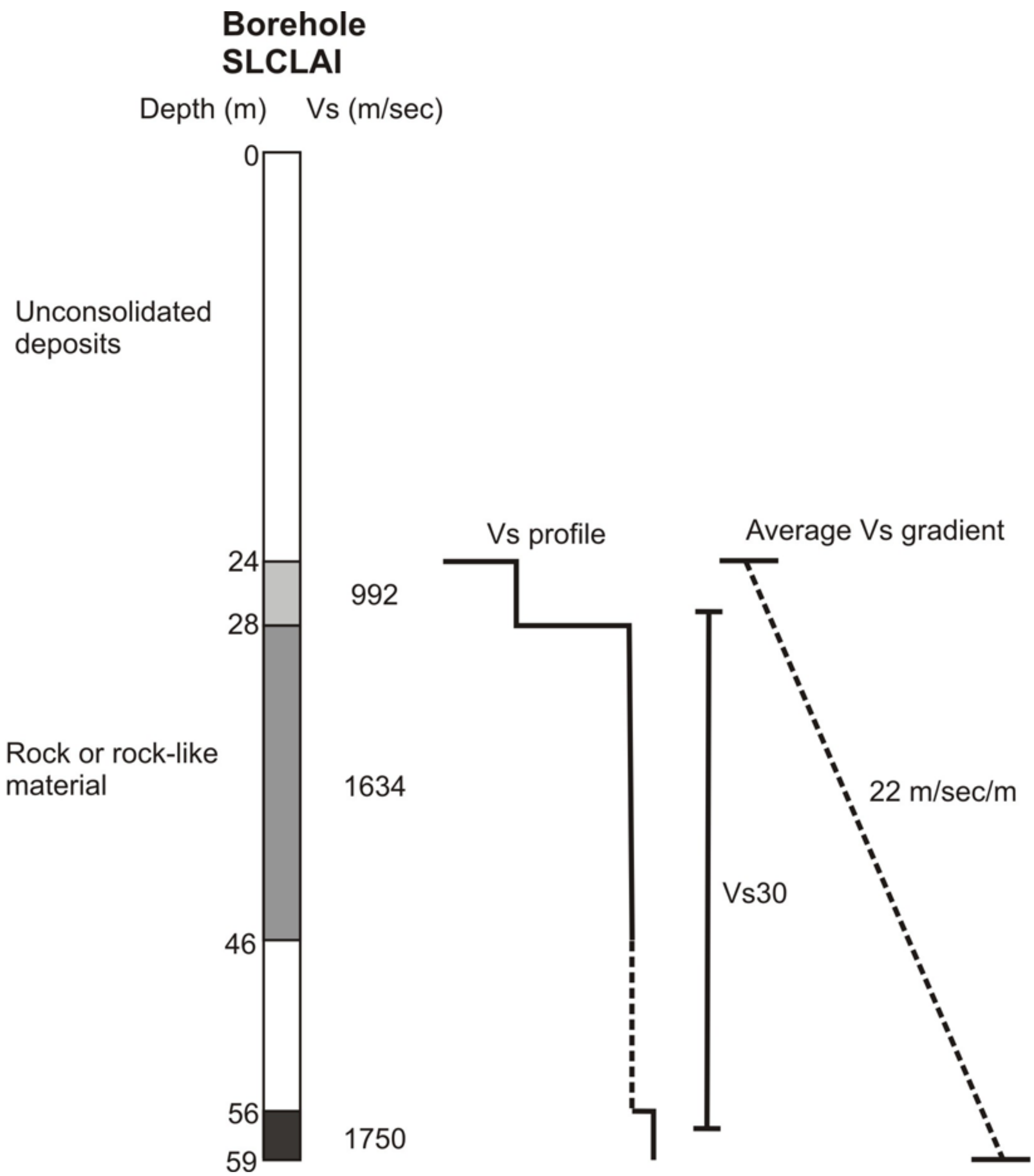


***Figure 12.*** *Schematic diagram showing interval in borehole SLCLAI with rock or rock-like material. Rock Vs30 was calculated over a 30-meter-thick interval overlapping the three distinct rock-like layers. Average gradient was determined over the entire interval of rock-like material. Borehole SLCLAI data from Tinsley and others (1991) except between 46 and 56 meters (dashed part of Vs profile) where Vs profile of Adan and Rollins (1993) used.*

***Table 7.***
*Summary of Vs30 and shear-wave-velocity-gradient results from borehole SLCLAI.*

| | Vs30 (m/sec) | Average Vs Gradient (m/sec/m) | Notes |
|---|---|---|---|
| This study (modified from Ashland [2001]) | 1603 | 22 | Vs30 depth interval: 27-57 m; gradient interval: 24-59 m |
| Maximum | 1645 | 58 | Vs30 depth interval: 29-59 m; gradient interval: 27-38 |
| Minimum | 1504 | 4 | Vs30 depth interval: 24-54 m; gradient interval: 30-59 m |

The selected Vs30 depth interval incorporates all three “buried” rock velocity layers. The selected gradient interval spans the entire “buried” rock interval of the Vs profile in figure 12. Other intervals selected to obtain the maximum and minimum values.

At the remaining ten profile sites where “buried rock” is inferred, the thickness of rock or rock-like material ranges from 3 to 14 meters and is therefore inadequate to calculate a Vs30 for rock. Ashland (2001) created synthetic shear-wave-velocity profiles for the uppermost 100 feet (30 m) of rock or rock-like material at these ten profile sites. The synthetic Vs profiles are a combination of the measured shear-wave velocity in the uppermost rock layer and the estimated shear-wave velocities of artificial layers extrapolated to a depth of 100 feet (30 m) below the top of rock or rock-like material using the average gradient of 22 meters per second per meter from SLCLAI (table 7). Table 8 lists the measured shear-wave velocities, estimated Vs30 using synthetic Vs profiles, and inferred units at these sites. Table 9 summarizes the descriptive statistics for the measured shear-wave velocities and estimated Vs30.

**Unit T**

Unit T consists of areas underlain by Tertiary sedimentary and volcanic rock. Lacking shear-wave-velocity profiles in this unit, Ashland (2001) used the estimated Vs30 data for “buried rock” sites inferred to be possible Tertiary rock (T?, table 8) to estimate Vs30. Since the Vs gradient used to create the synthetic profiles was from a site inferred to be bedrock unit M, Ashland (2001) corrected the estimated Vs30 values in table 8 by multiplying them by the ratio of estimated mean Vs30 for units T and M (table 10). The basis of the correction factor ($Vs30_T/Vs30_M = 0.83$) is the likely difference in the average Vs gradients of the two bedrock units T and M. The mean Vs30 value (tables 6 and 11) also incorporates the uncertainty in profile site geology. Table 6 summarizes the descriptive statistics for estimated Vs30 in unit T. Note that these values are slightly modified from Ashland (2001). The estimated range in Vs30 for unit T falls entirely within IBC site class B.

***Table 8.***
*Measured shear-wave velocities, estimated Vs30, and inferred units at "buried rock" sites.*

| Vs Profile | Measured Vs (m/sec) | Depth interval (m) | Geology | Estimated[1] Vs30 (m/sec) | Inferred unit[2] |
|---|---|---|---|---|---|
| **SLCLAI** | **992-1750** | **24-59** | **unknown** | **1603** | **M** |
| SLCSUN | 1250 | 37.5-50 | Jt | 1484 | M |
| SLCMAG | 1195 | 52-58 | Ss. | 1482 | T? or P? |
| SLCTMP | 1024 | 48-58 | unknown | 1275 | T? or P? |
| SLCWES | 1334 | 43-57 | unknown | 1553 | M? |
| SLCROS | 1510 | 48-57 | unknown | 1782 | M? |
| SLCBON | 843 | 46-58 | unknown | 1067 | M |
| SLCWAS | 778 | 54-57 | unknown | 1009 | P?, M?, or T? |
| SS07 | 1330 | 35-40 | unknown | 1625 | M |
| SS18 | 1210 | 27-40 | unknown | 1427 | T? |
| SS24 | 800 | 28-40 | unknown | 1022 | T? |

[1]Calculated from synthetic profiles of Ashland (2001), but excludes SLCLAI for which Vs30 was calculated using the depth interval of 27 to 57 meters. [2]Question marks indicate increased uncertainty regarding geology. Abbreviations: Jt – Jurassic Twin Creek Limestone, Ss. – sandstone; T, M, and P refer to bedrock units in table 5.

***Table 9.***
*Summary of measured shear-wave velocities and estimated Vs30 for "buried rock" sites.*

| | Mean[1] (m/sec) | Stnd Dev[2] (percent) | Max (m/sec) | Min (m/sec) | Median (m/sec) |
|---|---|---|---|---|---|
| Measured Vs | 1166 | 30 | 1750 | 778 | 1210 |
| Estimated Vs30 | 1369 | 22 | 1782 | 1009 | 1482 |

[1]Logarithmic mean. [2]Determined from the natural log (velocity).

***Table 10.***

*Corrected Vs30 estimates for "buried rock" sites.*

| Vs Profile | Estimated[1] Vs30 (m/sec) | Corrected Vs30 estimate (m/sec) | Inferred unit[2] |
|---|---|---|---|
| **SLCLAI** | **1603** | **Na** | **M** |
| SLCSUN | 1484 | Na | M |
| SLCMAG | 1482 | 1230 | T? or P? |
| SLCTMP | 1275 | 1058 | T? or P? |
| SLCWES | 1553 | Na | M? |
| SLCROS | 1782 | Na | M? |
| SLCBON | 1067 | Na | M |
| SLCWAS[3] | 1009 | 837 | P?, M?, or T? |
| SS07 | 1625 | Na | M |
| SS18 | 1427 | 1184 | T? |
| SS24 | 1022 | 848 | T? |

[1]Excludes SLCLAI for which Vs30 was calculated using the depth interval of 27 to 57 meters. [2]Question marks indicate increased uncertainty regarding geology. [3]Both corrected and uncorrected Vs30 estimates may apply at the SLCWAS Vs profile site because of unit uncertainty.

Our estimated Vs30 for unit T is higher than Vs30 reported for Tertiary rocks in the western United States. Table 11 compares our estimated Vs30 to literature values of Vs30 and shear-wave velocities for Tertiary rocks. The significant difference between our estimated mean Vs30 and mean Vs30 in the western states suggests that Salt Lake City area Tertiary rocks may be more lithified than Tertiary rocks in those states. In addition, a low mean Vs30 for Tertiary sedimentary rocks in California is attributed to the location of the majority of profiles at sites characterized by "younger, poorly lithified formations" (Wills and Silva, 1998). The lower bound of both the measured Vs at "buried Tertiary rock" sites and our estimated Vs30 overlaps with the upper part of the range in Vs30 in California. The mean shear-wave velocity for tufa-cemented sediments in the Salt Lake City area is near the lower bound in the range of estimated Vs30 for unit T, supporting the reasonableness of the estimates.

***Table 11.***
*Comparison of estimated Vs30 for unit T with literature values.*

| Description | Mean Vs30 (m/sec) | Range in Vs30 | Actual Vs measurements (m/sec) | Source(s) |
|---|---|---|---|---|
| Unit T (Tertiary sedimentary and volcanic rocks) | 1010 | 837-1230 | 778-1210 | This study; Tinsley and others (1991); Schuster and Sun (1993) |
| California Tertiary sedimentary rocks | 421 | 260-910 | --- | Wills and Silva (1998) |
| California Tertiary volcanic rocks | 685 | --- | --- | Wills and Silva (1998) |
| Washington Tertiary rocks | 433 | 240-595 | --- | Williams and others (1997) |
| Tufa-cemented sediments – Salt Lake City area | --- | --- | 828 | This study |

**Unit M**

Unit M consists of areas underlain by Mesozoic sedimentary rock. Lacking shear-wave-velocity profiles in this unit, Ashland (2001) used estimated Vs30 data for "buried rock" sites inferred to be possible Mesozoic rock, including borehole SLCLAI (Tinsley and others, 1991), to estimate Vs30 (table 8). Table 6 summarizes the descriptive statistics for estimated Vs30. Note that these values are slightly modified from Ashland (2001). We estimate that the boundary between IBC site classes A and B falls within the range of Vs30 for this unit.

Table 12 compares our estimated Vs30 to literature values of Vs30 and shear-wave velocities for sedimentary rocks. Our estimated mean Vs30 for unit M falls within the range of shear-wave velocities reported for sedimentary rocks excluding those identified as Tertiary. However, it is considerably higher than mean Vs30 values for Mesozoic sedimentary and undifferentiated rocks in California probably due to differences in rock types, and degrees of lithification, weathering, and fracturing of Mesozoic rocks in Utah and California.

***Table 12.***
*Comparison of estimated Vs30 for unit M with literature values.*

| Description | Mean Vs30 (m/sec) | Range in Vs30 (m/sec) | Actual Vs measurements[1] (m/sec) | Source |
|---|---|---|---|---|
| Unit M (Mesozoic sedimentary rocks) | 1460 | 1067-1782 | 778(?)-1750 | This study; Tinsley and others (1991); Schuster and Sun (1993) |
| Cretaceous sedimentary rocks - California | 864 | --- | --- | Wills and Silva (1998) |
| California Mesozoic rocks | 589 | --- | --- | Park and Elrick (1998) |
| Sedimentary rocks (non-Tertiary) | --- | --- | 1117-1739 | Compiled from literature for this study |

[1]Question mark (?) indicates uncertainty in site geology.

**Unit P**

Unit P consists of areas underlain by Paleozoic and older sedimentary and metamorphic rocks and Tertiary intrusive igneous rocks. In the absence of any shear-wave-velocity profiles in unit P, Ashland (2001) estimated Vs30 based on the mean of the composite of published shear-wave-velocity data for rock types similar to those in the unit and upper crustal shear-wave-velocity measurements (Christensen, 1989) in the northern Utah area (table 13). We estimate that mean Vs30 falls within IBC site class A.

***Table 13.***
*Explanation of mean Vs30 estimate for unit P.*

| Rock types | Max Vs (m/sec) | Min Vs (m/sec) | Mean Vs (m/sec) | Mean Upper Crustal Vs[1] (m/sec) | Vs30 estimate (m/sec) |
|---|---|---|---|---|---|
| Intrusive Igneous | 2701 | 2202 | | | |
| Carbonate | 3141 | 2715 | | | |
| Quartzite | 3678 | 1510 | | | |
| Metamorphic | 1803 | ----- | | | |
| Composite | **2831** | **2142** | **2487** | 1966 | **2227** |

[1]Mean from Christensen (1989).

## Variation in Shear-Wave Velocity with Depth and Grain Size

Variation in shear-wave velocity (Vs) with depth appears to be related in part to changes in dominant grain size. Whereas Vs generally increases with depth, a linear correlation between Vs and depth (figure 13) appears absent when variability in grain size is eliminated. However, mean Vs varies with dominant grain size (facies) and a positive correlation exists between mean Vs and grain size using data from Adan and Rollins (1993) (figure 14). Similar facies-dependent variation occurs within individual units (figure 15).

Despite the substantial observed variation in Vs30 in the units, it may be possible to constrain the probable range in Vs30 with some information on dominant facies in the subsurface at a site. Figure 15 shows for example that in unit Q01 at locations where the dominant facies is sand and gravel, Vs30 is more likely to be in the upper part of site class D. However, Vs30 is more likely to fall within the lower part of site class D at sites in unit Q01 dominated by clay and silt facies.

## Lateral Variation within Units

Lateral variation in shear-wave velocity in units in Salt Lake Valley is due, in part, to lateral changes in dominant grain size in the near-surface unit. Observed lateral variation in certain units is consistent with predicted changes in lateral facies (defined as part of a unit that exhibits characteristics, in this case dominant grain size, significantly different than in other parts of the unit). In most units, finer grained facies occur in more distal parts of the unit, generally toward the central part of the valley, although exceptions exist. Williams and others (1993) recognized a decrease in average shear-wave velocity in Salt Lake Valley with increasing distance from the Wasatch Range, which they attributed to both an overall reduction in grain size and a lesser degree of consolidation of near-surface deposits toward the central part of the valley.

Preliminary data suggest most gravel-dominated units exhibit a lateral decrease in grain size toward more distal parts of the unit. This is evident in the City Creek alluvial fan (unit Q02), where a gradual decrease in Vs30 is observed toward the distal part of the fan. Vs30 decreases by about 30 percent between the north-central part of the fan near the apex and distal edges (southern and western) of the fan. Although a lateral decrease in grain size toward the distal parts of the fan likely contributes to the decrease in Vs30 in the City Creek fan, decreasing thickness of the alluvial-fan deposit where it overlaps lacustrine silt and clay is also an important factor.

Ashland and Rollins (1999) showed that lateral variation in site class can occur across very short distances, including within a project site. The inset (see plate 1) showing the detail of the I-15/western downtown Salt Lake City area shows the proximity of profiles that fall in site classes D and E. For example, Vs profiles 158 and 159 are separated by less than 400 feet (120 m), but Vs30 at each site falls in separate site classes.

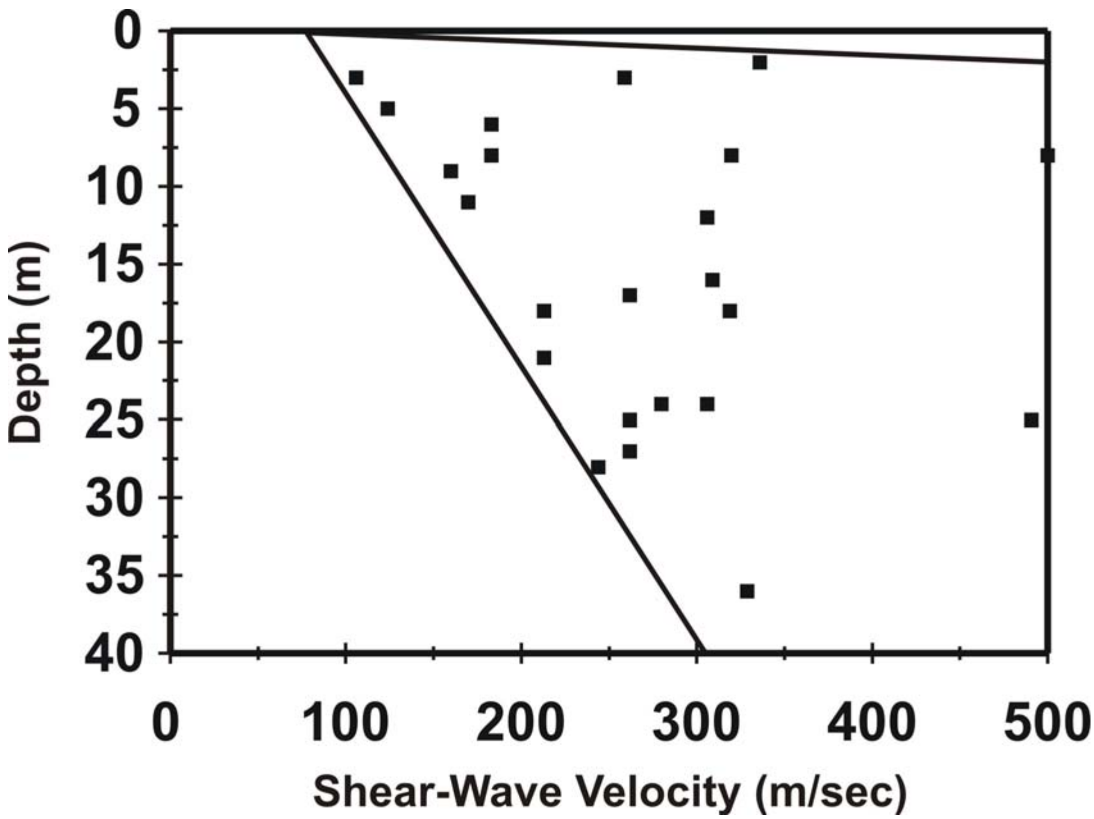


***Figure 13**. Variation of shear-wave velocity with depth for clay soils. Data from shear-wave-velocity profiles in a variety of units. Whereas shear-wave velocity generally increases with depth, no linear trend between these parameters is evident. Lines represent boundaries of envelope that contains all values. Shear-wave velocities and soil descriptions from Adan and Rollins (1993).*

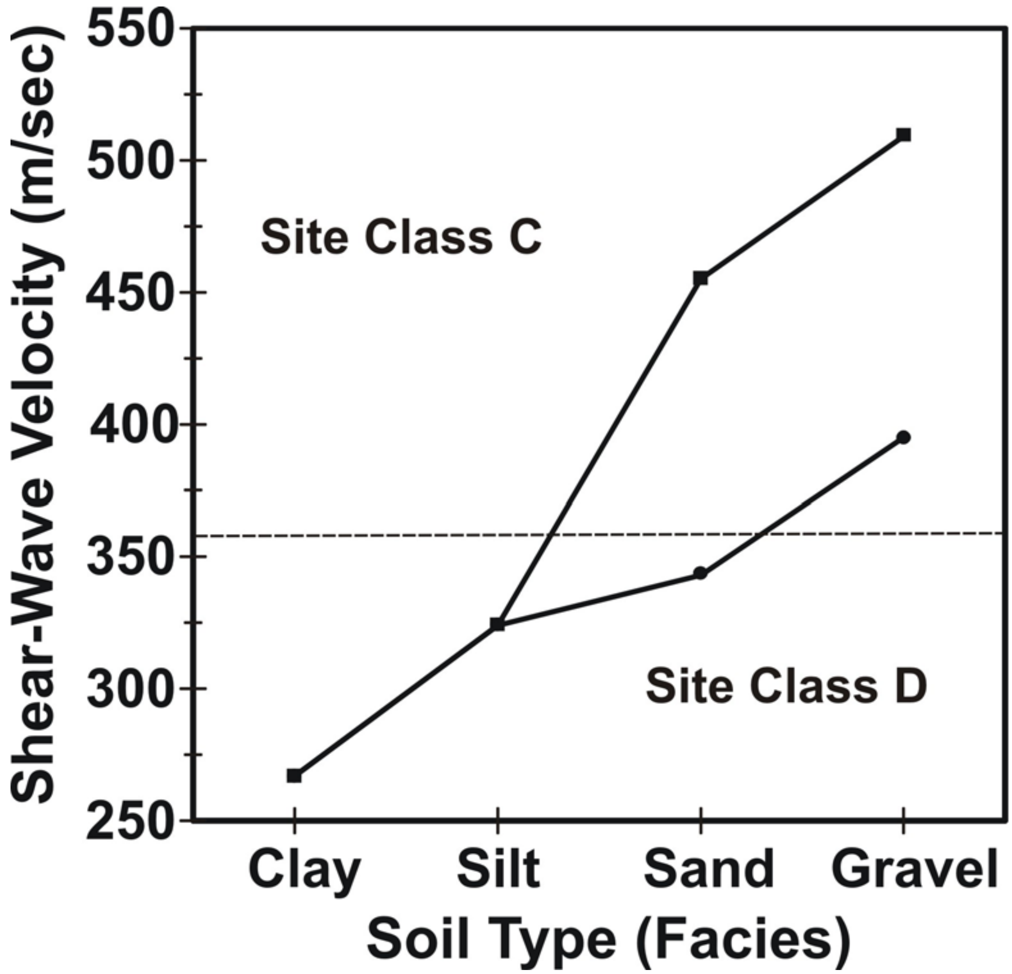


***Figure 14.*** *Variation in mean shear-wave velocity with soil type (facies). Plot indicates that mean shear-wave velocity increases with increasing grain size. Mean values are from boreholes in three Quaternary units. Depth of upper contacts of soil layers does not exceed 30 meters. Upper curve (squares) includes tufa-cemented or semi-consolidated soils (Wong and Silva, 1993). These soils have been removed from analysis in lower curve (circles). Shear-wave velocities and soil types from Adan and Rollins (1993). Plot shows arithmetic means from Ashland and Rollins (1999). Horizontal line is boundary (360 m/sec) between IBC site classes D and C.*

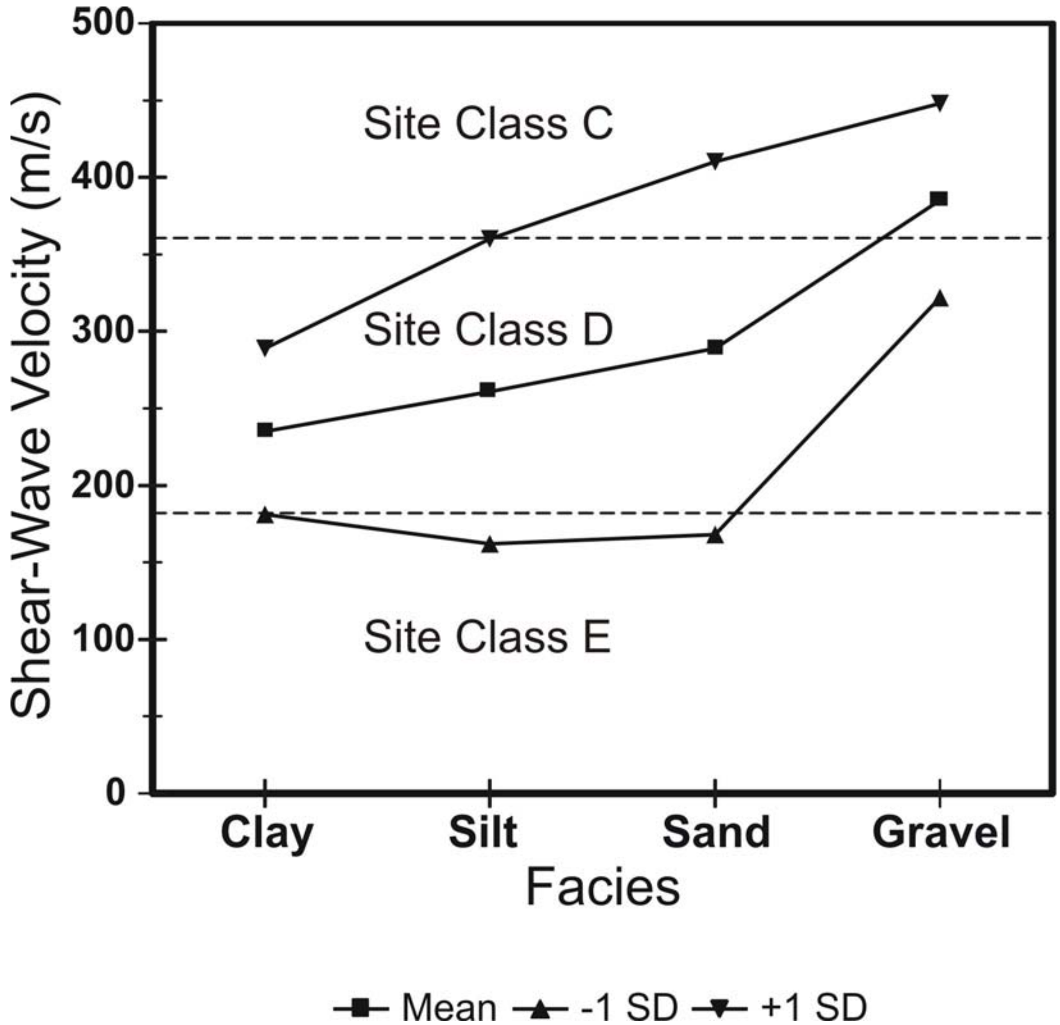


***Figure 15.*** *Variation in shear-wave velocity (Vs) with facies in Quaternary units Q01 and Q02. Plot shows arithmetic mean (squares) and one standard deviation boundary (triangles) from Ashland and Rollins (1999). Horizontal lines are IBC site class boundaries.*

## METHODS

### Database Sources and Measurement Techniques

Ashland and Rollins (1999) compiled a database of shear-wave-velocity profiles for Salt Lake Valley. We have separated out those profiles that extend to a depth of at least 29.6 meters in creating the Vs30 database in the appendix. The Vs30 database uses profiles measured by numerous investigators employing several methods. Most shear-wave-velocity measurements were obtained from seismic Cone Penetration Tests (CPT) or downhole techniques (figure 16). Schuster and Sun (1993) used surface-wave-dispersion techniques to obtain 27 of the Vs profiles. From these, we used only the profiles generated from the dispersion of Rayleigh waves to calculate Vs30. We used equation 16-22 in the International Building Code (International Code Conference, 2000) to calculate Vs30:

$$Vs30 = \sum_{i=1}^{n} d_i \Big/ \sum_{i=1}^{n} d_i / v_{si}$$

where $d_i$ equals the thickness of any layer between 0 and 30 meters (0-100 ft) and $v_{si}$ equals the shear-wave velocity of that layer in meters per second.

### Logarithmic versus Arithmetic Distributions

Following the methods of Park and Elrick (1998) and recommendations from Walter Silva (Pacific Engineering and Analysis, verbal communication, 2000) we assumed that the shear-wave-velocity distributions for each unit are lognormal and calculated the logarithmic mean and the standard deviation using the natural log of the velocity. The use of the lower logarithmic mean, as compared to the arithmetic mean, decreases the gap between the median and the mean value of each distribution. Thus, the use of the logarithmic mean reduces the influence of outlier (higher) shear-wave-velocity values on the mean. We used a web-based statistical package to determine the normalcy of the shear-wave-velocity distributions. In general, the distributions are consistent with both lognormal and normal distribution, but in cases where outlier values exist, the distribution is not consistent with a normal distribution. Figure 17 compares our logarithmic mean with a geometric mean (commonly used to describe the mean of a lognormal distribution) using the Vs profile for unit Q02. Our logarithmic mean deviates only slightly from the geometric mean.

### Surface-Wave versus Downhole Measurements

We compared Vs30 obtained from both surface-wave and downhole measurements to test whether the two types of Vs profiles could be combined into a single data set. Schuster and Sun (1993) used three surface-wave techniques to generate Vs profiles: (1) refraction analysis, (2) Rayleigh wave inversion, and (3) Love wave inversion. We compared the variation in Vs30 (table 14) at three sites where Vs profiles had been measured by both Tinsley and others (1991) using downhole techniques and Schuster and

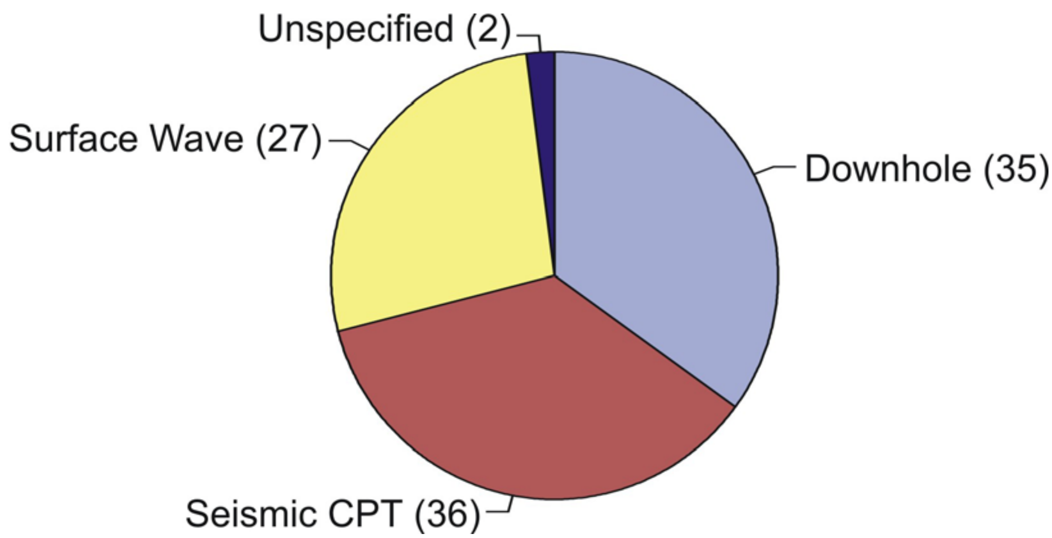


***Figure 16.*** *Measurement methods used for Vs profiles.*

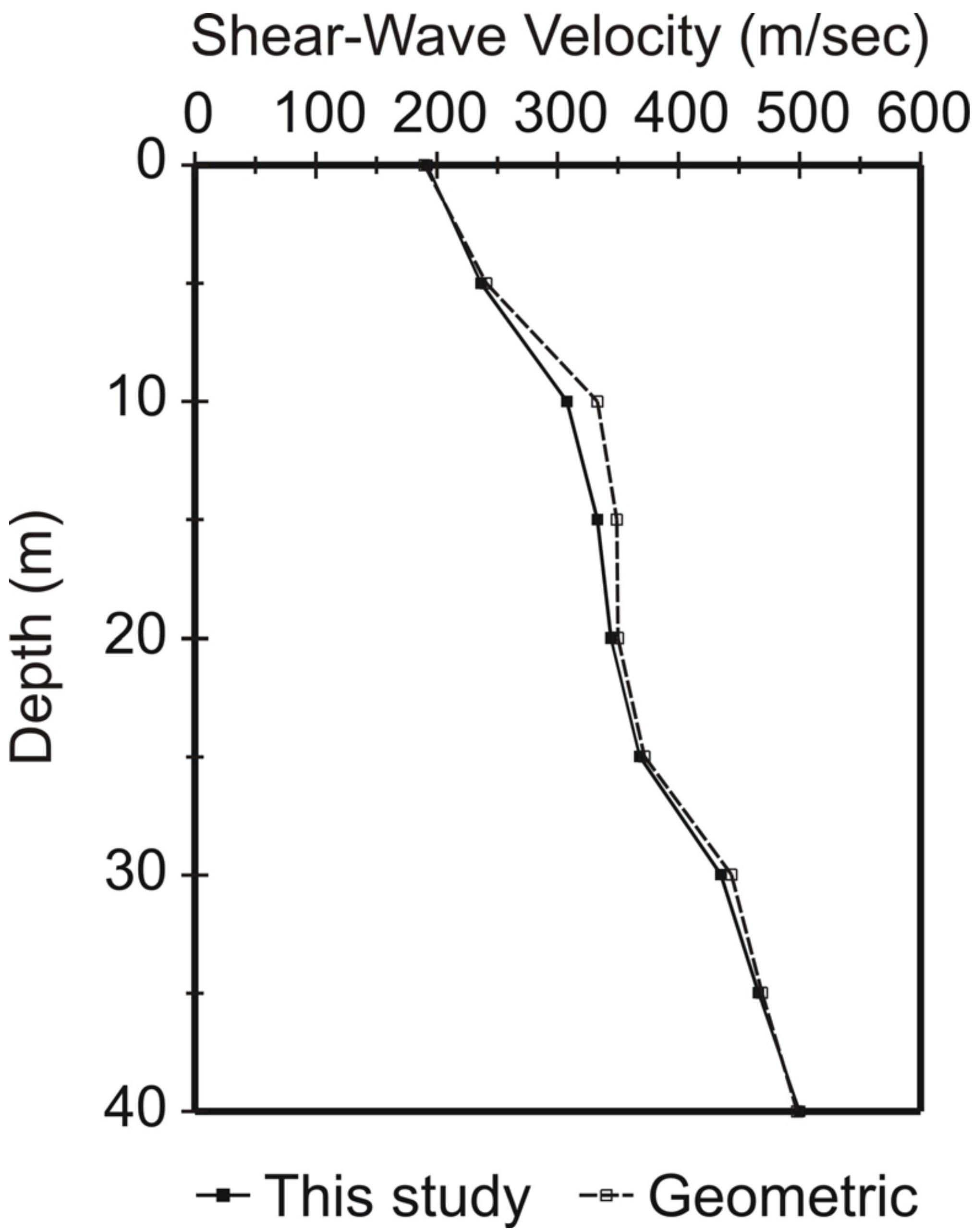


***Figure 17.*** *Comparison of logarithmic mean (this study) and geometric mean using Vs profile of unit Q02. Geometric mean calculated using web-based statistical software developed at the Physics Department of the College of Saint Benedict/Saint John's University, Minnesota. Variation between means ranges from 0 to 8 percent and averages 2 percent.*

Sun (1993) using surface-wave methods. The comparison indicates the lowest variation from Vs30 as determined using Vs profiles from downhole measurements occurs using Vs profiles from the Rayleigh wave inversion technique. We therefore used the Vs profiles derived from the Rayleigh wave inversion technique of Schuster and Sun (1993) to calculate Vs30.

## Sources of Variation

Many sources of variation exist in the Vs30 data presented herein. In our opinion, the most significant source of variation is the natural spatial variation in shear-wave velocity and other geotechnical properties of the soil types in each unit. This source of variation particularly affects Vs30 values for units with a small number of Vs profiles (less than 25).

We followed the methods of Wills and Silva (1998) in characterizing site-response units using Vs30 (in meters) rather than Vs100 (in feet). The differences between Vs30 and Vs100 are for all practical purposes negligible. Variation between Vs30 and Vs100 at five randomly selected profile sites ranged from 0.3 to 0.7 percent.

***Table 14.***
*Comparison of Vs30 based on surface-wave and downhole measurements.*

| **Borehole** | **Downhole Vs30[1] (m/sec)** | | **Surface-Wave Vs30[2] (m/sec)** | | **Mean** |
|---|---|---|---|---|---|
| | | **RA** | **RWI** | **LWI** | |
| SLCMAG | 212 | 187 | 248 | 408 | 281 |
| SLCBAT | 278 | 226 | 273 | 237 | 245 |
| SLCFOR | 298 | NA | 285 | 344 | 315 |
| | | **Variation** | **from (percent)** | **downhole** | **Vs30** |
| SLCMAG | --- | -12 | 17 | 92 | 33 |
| SLCBAT | --- | -19 | -2 | -15 | -12 |
| SLCFOR | --- | NA | -4 | 15 | 6 |
| Absolute mean | | 15 | **8** | 41 | 17 |

[1]Vs30 derived from Vs profile in Tinsley and others (1991). [2]Vs30 derived from Vs profiles in Schuster and Sun (1993). Abbreviations: RA – refraction analysis; RWI – Rayleigh wave inversion; LWI – Love wave inversion; NA – Vs profile not available.

We included average shear-wave velocities from five shear-wave-velocity profiles between 29.6 and 29.9 meters deep on the basis of significant digits equivalency without extrapolating the Vs profile to a 30-meter depth. We randomly selected three of these profiles and calculated no difference between Vs30 and the calculated average shear-wave velocity (for example Vs29.6) in two out of the three cases. In the third case, the variation was 0.5 percent and hence, negligible.

Many of the Vs profiles were obtained from seismic Cone Penetration Tests where shear-wave velocities were measured at a 1-meter spacing. Although using accompanying geologic information to define distinct geologic layers with a mean shear-wave velocity ($v_{si}$) and thickness ($d_i$) is possible, we chose to use the measurement spacing to define $d_i$. Ashland and Rollins (1999) demonstrated that Vs30 is not significantly affected by the method of selecting $d_i$. They demonstrated the variation in Vs30 was only a few percent regardless of the method used to select $d_{i.}$

## SUMMARY AND CONCLUSIONS

Our mapping and shear-wave-velocity characterization of the Salt Lake City metropolitan area indicates five distinct Quaternary and three bedrock units. Shear-wave-velocity profiles that extend to 30 meters depth and allow calculation of Vs30 exist in only three of the five Quaternary units (units Q01, Q02, and Q03). In these three units, IBC site-class boundaries fall within the range of Vs30. Vs30 in these units spans IBC site classes C through E. Shear-wave velocity increases with grain size allowing a better estimate of Vs30 in a unit using information on the dominant facies.

Limited data exist for rock (units T, M, and P) and two valley-margin Quaternary units (units Q04 and Q05). Mean Vs30 for bedrock unit P (Paleozoic rocks and Tertiary intrusives) and the two valley-margin Quaternary units was estimated based on published shear-wave-velocity data for similar geologic units. Vs30 for Tertiary (unit T) and Mesozoic (unit M) rocks was estimated based on shear-wave velocities of "buried" rock along the margins of Salt Lake Valley. Additional shear-wave velocity measurements are needed in these units.

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## ACKNOWLEDGMENTS

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# APPENDIX

## Vs30 Database
## Salt Lake City Metropolitan Area

### Explanation of Column Headings

Vs30 number: See map for Vs profile locations.
Vs30: See text for explanation.
Depth: Total depth of profile n meters below land surface.
IBC Site Class: International Building Code site class.
Unit: See text, map, and tables for explanation.
UEGM Unit: Unified Engineering Geology Mapping System unit.
Measurement Technique (Msmnt Tech):

| | |
|---|---|
| D | Downhole |
| S | Surface wave dispersion (Rayleigh waves) |
| C | Seismic Cone Penetration Test |
| U | Unspecified |

Method:

| | |
|---|---|
| 1 | Vs30 determined using distinct layers defined by Vsi and/or geology |
| 2 | Vs30 determined using layer thickness defined solely by sampling interval |
| 3 | Vs extrapolated upward through thick fill lacking Vsi |

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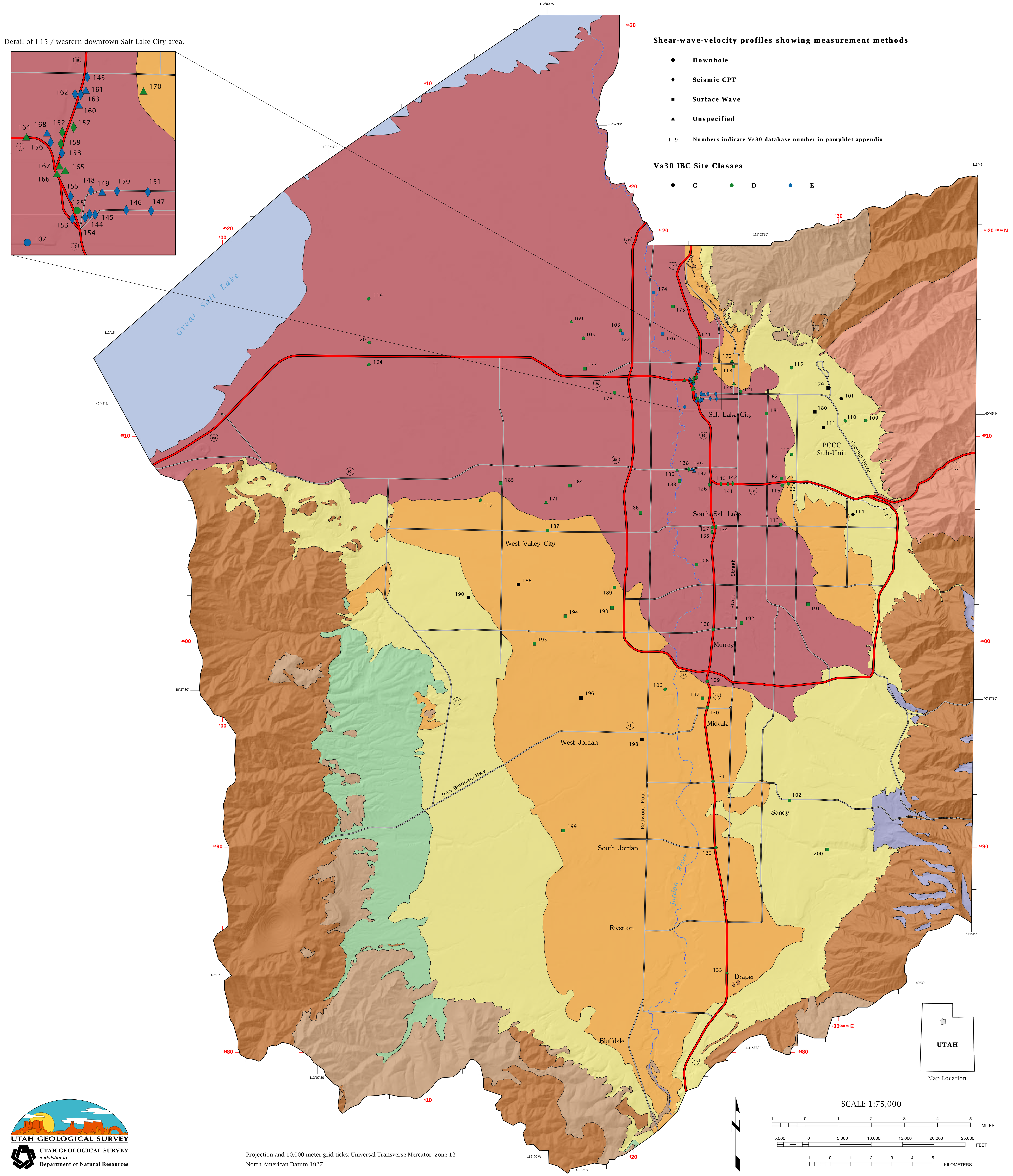
| Vs30 No. | Vs30 (m/sec) | Depth (m) | IBC Site Class | Unit | UEGM Unit | Location | Source | Msmnt Tech | Method |
|---|---|---|---|---|---|---|---|---|---|
| 101 | 401 | 58 | C | Q03a | Lg | 606 Blackhawk Way (former UGMS office) | Tinsley and others (1991) | D | 1 |
| 102 | 260 | 58 | D | Q03 | Lg | Sandy City Fire Station; Alta View Hospital | Tinsley and others (1991) | D | 1 |
| 103 | 205 | 59.4 | D | Q01 | L-Amcs | SLC Airport East – No. 1 | Tinsley and others (1991) | D | 1 |
| 104 | 196 | 57 | D | Q01 | L-Amcs | Saltair - Morton Salt Company | Tinsley and others (1991) | D | 1 |
| 105 | 198 | 59 | D | Q01 | L-Amcs | SLC Airport West (Fire Station) | Tinsley and others (1991) | D | 1 |
| 106 | 278 | 58 | D | Q02 | Ls | Bateman Dairy Farm | Tinsley and others (1991) | D | 1 |
| 107 | 177 | 65 | E | Q01 | L-Amcs | VIC. N. Jordan Pk. (Campos Drive-in) | Tinsley and others (1991) | D | 1 |
| 108 | 222 | 53 | D | Q01 | L-Amcs | 4060 South 725 West - on the Jordan River | Tinsley and others (1991) | D | 1 |
| 109 | 354 | 50 | D | Q03a | Lg | Sunnyside Training Center - 2675 Mich. Avenue | Tinsley and others (1991) | D | 1 |
| 110 | 327 | 58 | D | Q03a | Lg | Bonneville Golf Course | Tinsley and others (1991) | D | 1 |
| 111 | 590 | 59 | C | Q03a | Lg | Laird Park | Tinsley and others (1991) | D | 1 |
| 112 | 294 | 57 | D | Q03a | Ag | Westminster College Track | Tinsley and others (1991) | D | 1 |
| 113 | 269 | 44 | D | Q01 | L-Amcs | Roosevelt School | Tinsley and others (1991) | D | 1 |
| 114 | 363 | 47 | C | Q03 | Lg | Rosecrest Elementary School | Tinsley and others (1991) | D | 1 |
| 115 | 303 | 57 | D | Q03a | Ag | Wasatch School | Tinsley and others (1991) | D | 1 |
| 116 | 298 | 59 | D | Q01 | L-Amcs | Forest Dale Golf Course | Tinsley and others (1991) | D | 1 |
| 117 | 212 | 58 | D | Q02 | Ls | Magna Water District – Well field | Tinsley and others (1991) | D | 1 |
| 118 | 347 | 58 | D | Q02 | Ag | Temple Square – Utah Power and Light | Tinsley and others (1991) | D | 1 |
| 119 | 184 | 86 | D | Q01 | L-Amcs | Duck Club | Tinsley and others (1991) | D | 1 |
| 120 | 187 | 65 | D | Q01 | L-Amcs | KSL Radio Transmitter | Tinsley and others (1991) | D | 1 |
| 121 | 248 | 68 | D | Q01 | L-Amcs | City and County Building | Tinsley and others (1991) | D | 1 |
| 122 | 179 | 58 | E | Q01 | L-Amcs | SLC Airport East – No. 2 - 300 North 2265 West | Tinsley and others (1991) | D | 1 |
| 123 | 327 | 58 | D | Q02 | Lmc | 2420 to 2436 Highland Dr. (south of the Utah Power & Light Building) | Tinsley and others (1991) | D | 1 |
| 124 | 266 | 91.7 | D | Q01 | L-Amcs | 600 North & Interstate-15 | Dames & Moore (1996) | D | 2 |
| 125 | 180 | 61 | D | Q01 | L-Amcs | 600 South & Interstate-15 | Dames & Moore (1996) | D | 2 |
| 126 | 188 | 64.6 | D | Q01 | L-Amcs | 2300 South & Interstate-15 (I-80) | Dames & Moore (1996) | D | 2 |
| 127 | 216 | 91.5 | D | Q01 | L-Amcs | 3300 South & Interstate-15 | Dames & Moore (1996) | D | 2 |
| 128 | 291 | 61 | D | Q01 | L-Amcs | 5300 South & Interstate-15 | Dames & Moore (1996) | D | 2 |
| 129 | 325 | 61 | D | Q01 | L-Amcs | 6600 South & Interstate-15 | Dames & Moore (1996) | D | 2 |
| 130 | 316 | 61 | D | Q02 | Lmc | 7200 South & Interstate-15 | Dames & Moore (1996) | D | 2 |
| 131 | 265 | 61 | D | Q02 | Lmc | 9000 South & Interstate-15 (300 West) | Dames & Moore (1996) | D | 2 |
| 132 | 251 | 61 | D | Q02 | Lmc | 10600 South & Interstate-15 | Dames & Moore (1996) | D | 2 |
| 133 | 240 | 36.4 | D | Q02 | Lmc | Bangerter Highway - Final Section | Conetec/Kleinfelder (1996a) | C | 2 |
| 134 | 220 | 34.2 | D | Q01 | L-Amcs | I-15 Rebuild 3300 South | Conetec/Kleinfelder (1996b) | C | 3 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 135 | 215 | 32.1 | D | Q01 | L-Amcs | I-15 Rebuild 3300 South | Conetec/Kleinfelder (1996b) | C | 3 |
| 136 | 184 | 30 | D | Q01 | L-Amcs | I-15 Rebuild S.R. 201 & 900 West | Conetec/Kleinfelder (1996c) | C | 2 |
| 137 | 190 | 43 | D | Q01 | L-Amcs | I-15 Rebuild S.R. 201 & 900 West | Conetec/Kleinfelder (1996c) | C | 2 |
| 138 | 170 | 30.8 | E | Q01 | L-Amcs | I-15 Rebuild S.R. 201 & 900 West | Conetec/Kleinfelder (1996c) | C | 3 |
| 139 | 168 | 39.9 | E | Q01 | L-Amcs | I-15 Rebuild S.R. 201 & 900 West | Conetec/Kleinfelder (1996c) | C | 2 |
| 140 | 184 | 29.7 | D | Q01 | L-Amcs | I-15 Rebuild State Street & I-80 | Conetec/Kleinfelder (1996d) | C | 2 |
| 141 | 195 | 29.8 | D | Q01 | L-Amcs | I-15 Rebuild State Street & I-80 | Conetec/Kleinfelder (1996d) | C | 3 |
| 142 | 188 | 29.9 | D | Q01 | L-Amcs | I-15 Rebuild State Street & I-80 | Conetec/Kleinfelder (1996d) | C | 2 |
| 143 | 161 | 29.6 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | |
| 144 | 170 | 33.6 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 145 | 166 | 35.7 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 146 | 164 | 32 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 147 | 168 | 30.4 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 148 | 173 | 36.6 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 149 | 161 | 34.7 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 150 | 160 | 32.8 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 151 | 165 | 36 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 152 | 182 | 30.4 | D | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 153 | 162 | 33.5 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 154 | 163 | 34.5 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 155 | 175 | 32.7 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 156 | 169 | 35 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 157 | 194 | 35.0 | D | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 3 |
| 158 | 174 | 34.0 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 159 | 195 | 35.1 | D | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 160 | 168 | 30.0 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 161 | 175 | 29.7 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 162 | 161 | 34.0 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 163 | 176 | 29.9 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 164 | 181 | 34.5 | D | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 165 | 180 | 34.8 | D | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 166 | 211 | 41.1 | D | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 3 |
| 167 | 211 | 42.9 | D | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 3 |
| 168 | 178 | 34.7 | E | Q01 | L-Amcs | I-15 Rebuild 600 South to 600 North | Conetec/Kleinfelder (1996e) | C | 2 |
| 169 | 198 | 60.4 | D | Q01 | L-Amcs | Rollins Airport Pile Test | LGS Geophysics Inc. (1996) | D | 2 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 170 | **235** | 34.3 | D | Q02 | Ag | Proposed 43 Story Tower at 400 West South Temple | Chen and Associates, Inc. | U | 1 |
| 171 | 311 | 37.5 | D | Q01 | L-Amcs | 2800 S 4600W (Intermountain Health Care Site) | LGS Geophysics Inc. (1997) | D | 2 |
| 172 | 348 | 47.2 | D | Q02 | Ag | North Temple West Temple (LDS Assembly Hall - entire block) | AGEC (1997) | U | 1 |
| 173 | 257 | 30.2 | D | Q02 | Ag | Northeast corner of 300 South & Main (American Stores) | LGS Geophysics Inc. | D | 1 |
| 174 | 165 | 40 | E | Q01 | L-Amcs | Rose Park Golf Course, 1700 N Redwood Rd | Schuster and Sun (1993) | S | 1 |
| 175 | 251 | 40 | D | Q01 | L-Amcs | East Rose Park, 1200 West 1300 North | Schuster and Sun (1993) | S | 1 |
| 176 | 151 | 40 | E | Q01 | L-Amcs | Riverside Park, 1400 West 700 North | Schuster and Sun (1993) | S | 1 |
| 177 | 191 | 40 | D | Q01 | L-Amcs | Wingpointe Golf Course near SLC Airport | Schuster and Sun (1993) | S | 1 |
| 178 | 208 | 40 | D | Q01 | L-Amcs | 500 South 2800 West | Schuster and Sun (1993) | S | 1 |
| 179 | 364 | 40 | C | Q03a | Ag | University of Utah campus, SE | Schuster and Sun (1993) | S | 1 |
| 180 | 455 | 40 | C | Q03a | Lg | 1600 East Sunnyside Avenue | Schuster and Sun (1993) | S | 1 |
| 181 | 325 | 40 | D | Q01 | L-Amcs | 700 East 900 South | Schuster and Sun (1993) | S | 1 |
| 182 | 285 | 40 | D | Q01 | L-Amcs | Fairmont Park, 2300 South 900 East | Schuster and Sun (1993) | S | 1 |
| 183 | 198 | 40 | D | Q01 | L-Amcs | Jordan River Park, 2320 South | Schuster and Sun (1993) | S | 1 |
| 184 | 232 | 40 | D | Q01 | L-Amcs | 2400 South 3800 West | Schuster and Sun (1993) | S | 1 |
| 185 | 248 | 40 | D | Q01 | L-Amcs | 5600 South 2460 West | Schuster and Sun (1993) | S | 1 |
| 186 | 195 | 40 | D | Q01 | L-Amcs | Decker Lake Park, 3000 South 2000 West | Schuster and Sun (1993) | S | 1 |
| 187 | 271 | 40 | D | Q02 | Lmc | West Valley City Park, 3500 South 4400 West | Schuster and Sun (1993) | S | 1 |
| 188 | 377 | 40 | C | Q02 | Ls | 4500 South 5194 West, LDS church | Schuster and Sun (1993) | S | 1 |
| 189 | 307 | 40 | D | Q02 | Ls | 2700 West 4500 South | Schuster and Sun (1993) | S | 1 |
| 190 | 561 | 40 | C | Q03 | Lg | 4700 South 6300 West | Schuster and Sun (1993) | S | 1 |
| 191 | 313 | 40 | D | Q01 | L-Amcs | Creekside Park, 4750 South 1665 East | Schuster and Sun (1993) | S | 1 |
| 192 | 216 | 40 | D | Q01 | L-Amcs | Murray Park Race Track, 5000 South State Street | Schuster and Sun (1993) | S | 1 |
| 193 | 352 | 40 | D | Q02 | Ls | West Valley City Park, 2700 West 4900 South | Schuster and Sun (1993) | S | 1 |
| 194 | 253 | 40 | D | Q02 | Ls | South Ridge Park, 4000 West 5000 South | Schuster and Sun (1993) | S | 1 |
| 195 | 287 | 40 | D | Q02 | Ls | Kearns Recreation Center, 5800 South 4800 West | Schuster and Sun (1993) | S | 1 |
| 196 | 469 | 40 | C | Q02 | Lmc | 7000 South 3600 West | Schuster and Sun (1993) | S | 1 |
| 197 | 273 | 40 | D | Q02 | Lmc | 6980 South 580 West | Schuster and Sun (1993) | S | 1 |
| 198 | 375 | 40 | C | Q02 | Lmc | West Jordan City Park, 7900 South 1800 West | Schuster and Sun (1993) | S | 1 |
| 199 | 308 | 40 | D | Q02 | Lmc | 4000 West 10200 South | Schuster and Sun (1993) | S | 1 |
| 200 | 306 | 40 | D | Q03 | Lg | Dimple Dell trail head, 10600 South 2100 East | Schuster and Sun (1993) | S | 1 |

Detail of I-15 / western downtown Salt Lake City area.




## EXPLANATION

| Unit | Description |
|---|---|
| Q01 | Lacustrine and alluvial silt, clay, and fine sand; alluvial or marsh deposits typically overlie lacustrine deposits |
| Q02 | Lacustrine sand, interbedded lacustrine silt, clay, and sand, latest Pleistocene to Holocene alluvial-fan deposits |
| Q03 | Lacustrine and alluvial gravel and sand; includes Parleys - City Creek Canyons (PCCC) sub-unit |
| Q04 | Pre-Bonneville alluvial-fan deposits |
| Q05 | Glacial deposits including till and outwash |
| T | Tertiary sedimentary and volcanic rocks; excludes Tertiary intrusive rocks |
| M | Mesozoic sedimentary rocks |
| P | Paleozoic and older sedimentary, igneous, and metamorphic rocks; and Tertiary intrusive (igneous) rocks |

SCALE 1:75,000

MILES · FEET · KILOMETERS

Projection and 10,000 meter grid ticks: Universal Transverse Mercator, zone 12
North American Datum 1927


UTAH GEOLOGICAL SURVEY
a division of
Department of Natural Resources

Plate 1
Utah Geological Survey Open-File Report 424

# INTERIM MAP SHOWING SHEAR-WAVE-VELOCITY CHARACTERISTICS OF ENGINEERING GEOLOGIC UNITS IN THE SALT LAKE CITY, UTAH METROPOLITAN AREA

By

Francis X. Ashland and Greg N. McDonald

Digital Compilation by Justin P. Johnson and Neil D. Storey

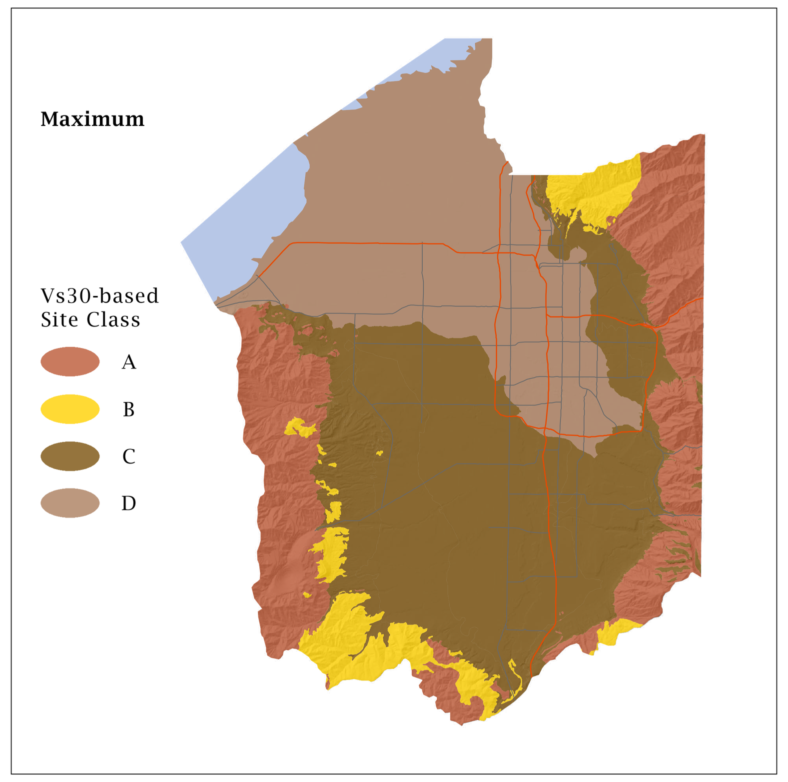
2003

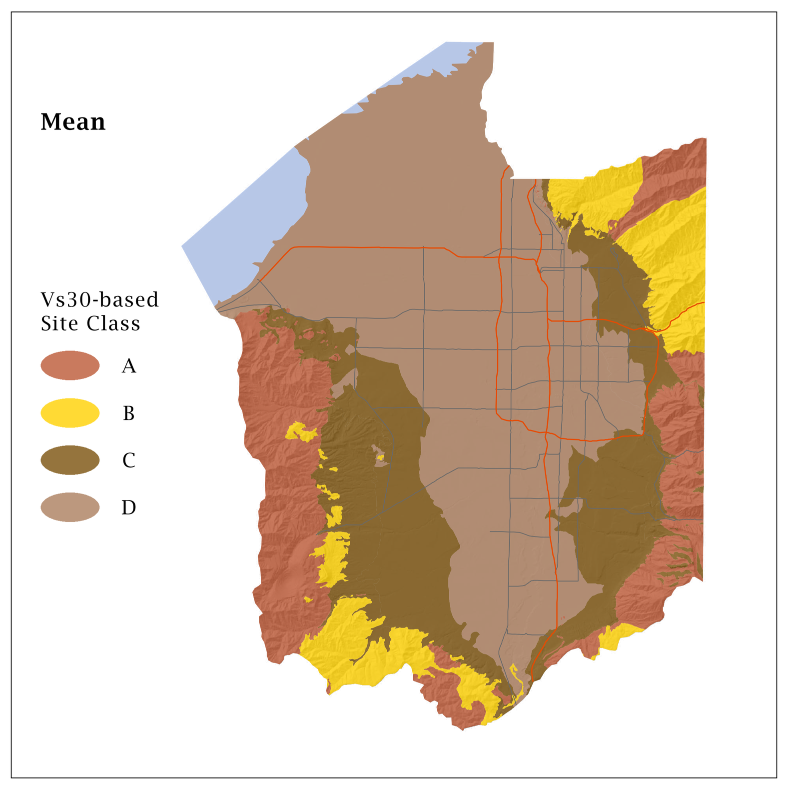
## Summary of Vs30 Estimates

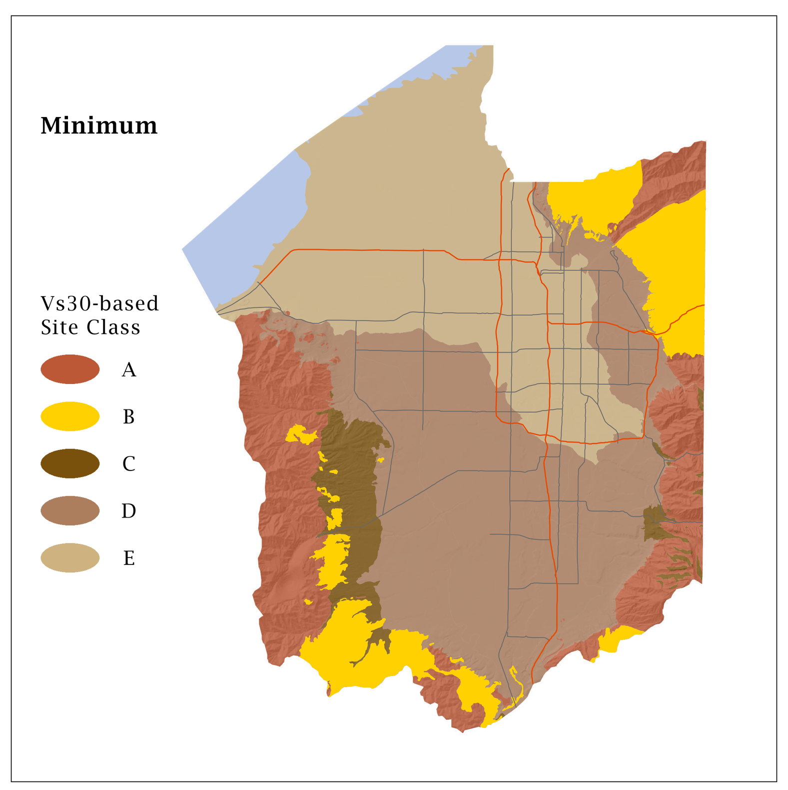
| Unit | Vs30[1,2,3] (m/sec) | | | IBC Site Class | | |
|---|---|---|---|---|---|---|
| | Mean | Maximum | Minimum | Mean | Maximum | Minimum |
| Q01 | 199 | 325 | 151 | D | D | E |
| Q02 | 298 | 469 | 212 | D | C | D |
| Q03 | 389 | 590 | 260 | C | C | D |
| Q04 | 437 | --- | --- | C | --- | --- |
| Q05 | 486 | --- | --- | C | --- | --- |
| T | 1010 | 1230 | 837 | B | B | B |
| M | 1459 | 1782 | 1067 | B | A | B |
| P[4] | 2197 | --- | --- | A | --- | --- |

[1] Logarithmic mean
[2] Vs30 for units Q04, Q05, and P estimated from published Vs values for similar soils or rocks
[3] Vs30 for units T and M estimated based on Vs measurements of "buried rock" in Salt Lake Valley
[4] Includes older basement rocks and Tertiary intrusives

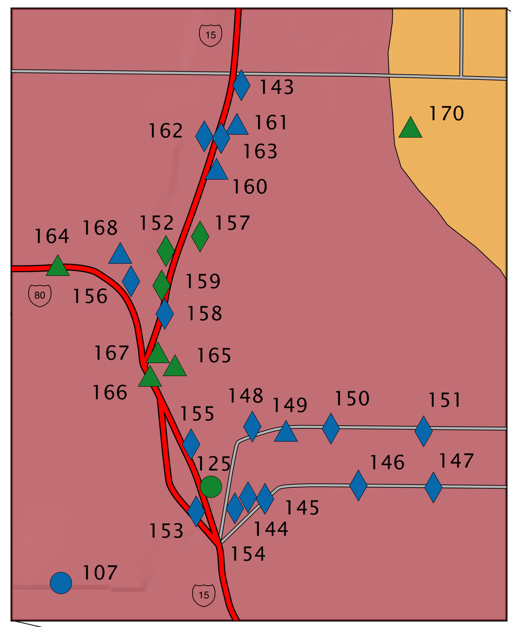
## IBC Site Class Maps

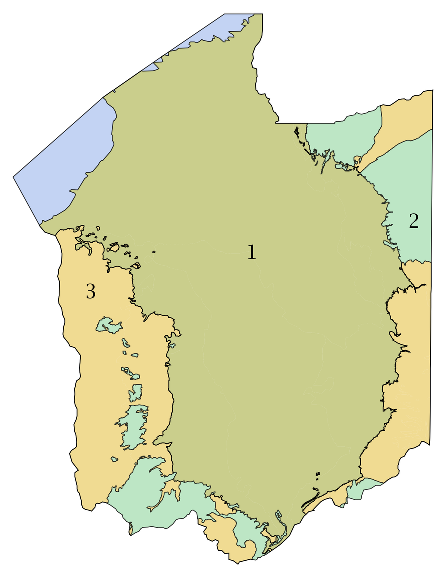


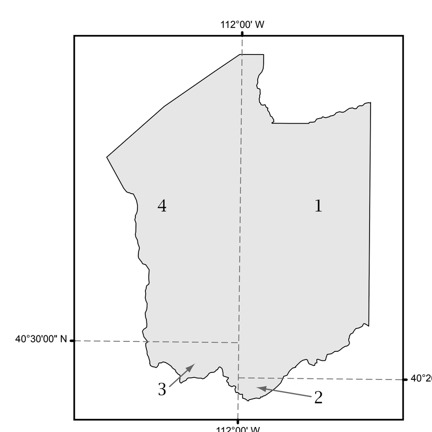

Detail of I-15 / western downtown Salt Lake City area.






## Basis of Vs30 Estimates

1. Q01 - Q03: Based on Vs measurements from 100 Vs profiles. See map for Vs profile location and spatial distribution.
2. T and M: Based on Vs measurements of "buried rock" at 11 sites in the Salt Lake Valley. Vs30 estimated using Vs gradient from single site, probably in unit M.
3. Q04, Q05, and P: Based on published Vs values for similar soils or rocks.




## Sources of Geologic Data

1. Soils and bedrock: Personius and Scott (1992); buried rock: Van Horn and Crittenden (1987)
2. Soils: Miller (1982); bedrock: Davis (1983b)
3. Soils: this study, Tooker and Roberts (1998); bedrock: Davis (1983a), Laes and others (1997), Tooker and Roberts (1998)
4. Soils and bedrock: Miller (1980); bedrock and buried rock: Davis (1983a), Laes and others (1997)

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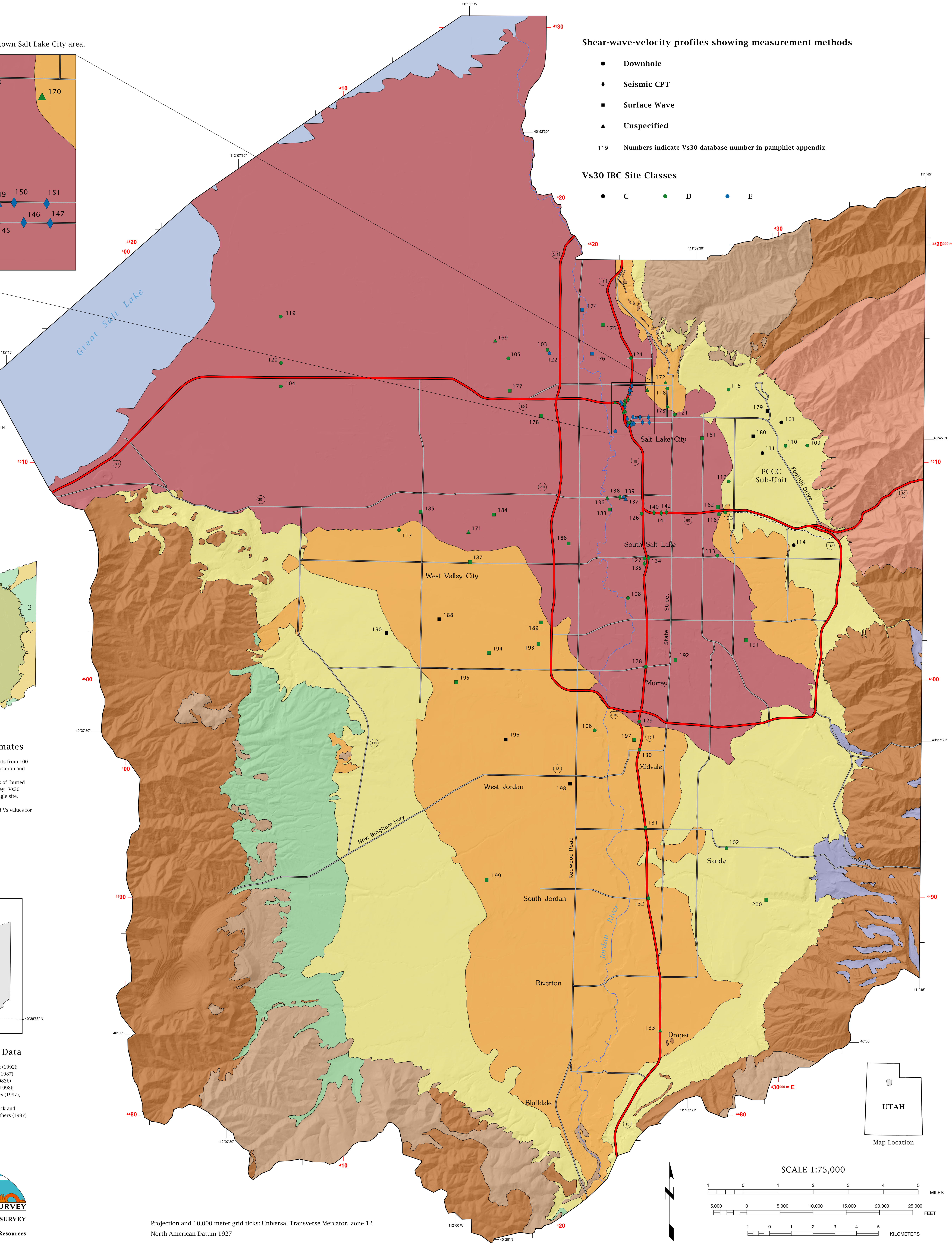


UTAH
Map Location

## EXPLANATION

| Unit | Description |
|---|---|
| Q01 | Lacustrine and alluvial silt, clay, and fine sand; alluvial or marsh deposits typically overlie lacustrine deposits |
| Q02 | Lacustrine sand, interbedded lacustrine silt, clay, and sand, latest Pleistocene to Holocene alluvial-fan deposits |
| Q03 | Lacustrine and alluvial gravel and sand; includes Parleys - City Creek Canyons (PCCC) sub-unit |
| Q04 | Pre-Bonneville alluvial-fan deposits |
| Q05 | Glacial deposits including till and outwash |
| T | Tertiary sedimentary and volcanic rocks; excludes Tertiary intrusive rocks |
| M | Mesozoic sedimentary rocks |
| P | Paleozoic and older sedimentary, igneous, and metamorphic rocks; and Tertiary intrusive (igneous) rocks |

## USE OF THIS MAP

This map shows the shear-wave-velocity characteristics of eight engineering geologic units in the Salt Lake City metropolitan area for use in estimating International Building Code (IBC) (International Code Council, 2000) soil or rock site classes. A detailed description of Vs30, the average shear-wave velocity to a depth of 30 meters, for each unit is included in the pamphlet. The maps at the left show the IBC site classes, excluding site class F, for the range in Vs30 of each unit. IBC site-class boundaries fall within the range of Vs30 for units Q01, Q02, and Q03. Site-specific investigations have demonstrated that the variability in Vs30 at a building site can span the boundary of IBC site classes (Ashland and Rollins, 1999). Thus, an individual shear-wave-velocity (Vs) profile at a site may be inadequate to completely characterize Vs30 and IBC site class. Our characterization of Vs30, particularly for units Q01 and Q02, may be useful for estimating the potential range in Vs30 and IBC site class at a site. The sole use of Vs30 to determine IBC site class may be inappropriate particularly where site class E conditions may exist.

This map provides some guidance in estimating Vs30 at sites where structures are proposed for which detailed subsurface explorations and characterization of soil conditions to determine IBC site class are not typically performed in Utah. The sole use of this map for engineering design is discouraged particularly for essential facilities (IBC Seismic Use Group III) or for structures for which failure would pose a substantial public hazard (IBC Seismic Use Group II).

The map is not intended for use at scales other than the published scale. Map boundaries are based on limited data available prior to the date of publication, are approximate, and are subject to change as the quantity and quality of available data improve. Users should review the spatial distribution of Vs profile sites used to create this map and their relation to project sites. In any mapped unit, uncertainties in IBC site class become larger with increased distance from the nearest Vs profile site. The site class at any particular site may differ from that shown on this map due to geologic variations within the unit or because of gradational and approximate map boundaries, and the regional scale of this map.

## DISCUSSION

This map was compiled using available Vs profiles extending to at least 30 meters in depth. Of the 97 Vs profiles used, 68 are in unit Q01 and no Vs measurements exist in units Q04 and Q05. The methods used to estimate mean Vs30 for units Q04, Q05, T, M, and P are discussed in the pamphlet. Unit boundaries generally coincide with mapped geologic contacts for surficial deposits (Miller, 1980, 1982; Personius and Scott, 1992) and rock units (Davis, 1983a, 1983b; Van Horn and Crittenden, 1987; Personius and Scott, 1992). Preliminary engineering geologic mapping of surficial deposits and rock units was performed by Ashland and Rollins (1999). Ashland (2001) used statistical analysis of Vs30 to re-map units using methods similar to Park and Elrick (1998). This map is slightly modified from Ashland (2001).

Soils having the characteristics defining IBC site class F are not shown on this map or maps at the left. IBC table 1615.1.1 (International Code Council, 2000) describes site class F soil characteristics. Potential site class F soils in the Salt Lake City metropolitan area include, but are not limited to, liquefiable soils, quick and highly sensitive clays, and collapsible, weakly cemented soils. Anderson and others (1986) mapped liquefaction potential of shallow surficial soils in the study area. Parry (1974) identified sensitive lacustrine clay soils in southern Davis County a short distance north of the study area. Similar sensitive clay soils may exist in the northern part of the study area. Personius and Scott (1992) mapped landslides and lateral spreads in the study area that may be vulnerable to potential failure under seismic loading.

## ACKNOWLEDGMENTS

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