EARTHQUAKE HAZARD MAPS OF THE VISTA AND STEAMBOAT 7½-MINUTE QUADRANGLES, NEVADA

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USGS CONTRACT NO. 14-08-0001-19116
Supported by the EARTHQUAKE HAZARDS REDUCTION PROGRAM

OPEN-FILE NO. 81-945

U.S. Geological Survey
OPEN FILE REPORT

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INTRODUCTION

Development of earthquake hazards maps for the Vista and Steamboat 7 1/2-minute quadrangles provides information to planners and other public officials about the suspected or probable response of the geologic units to seismic loading. The maps also indicate the spatial distribution and recency of movement of faults within the quadrangles. Previous geologic mapping by Trexler and McKinny, 1980; and Trexler and Pease, 1980, provide the base from which the earthquake hazard maps are produced. Trenching of suspected young faults along the west side of the Truckee Meadows during the previous geologic mapping program provides information on the recency of movement along two faults, which displace alluvial material.

To develop earthquake hazard maps more specific information is needed in the following areas: 1) details of the physical properties of the geologic units such as grain size, degree of sorting, weathering and induration; 2) geotechnical data on bulk density and bearing strength; 3) depth to groundwater and degree of saturation and 4) seismic velocities in the geologic units.

These data are needed to determine the probable response of the geologic units to earthquake induced stresses. Geologic units can be categorized as to their probable response during seismic shaking by their seismic velocities and bulk densities. Medvedev (1965) first recognized that there is a relationship between degree of structural damage resulting from an earthquake and the geologic material on which the structure was located. He classified geologic units into preliminary shaking intensity categories based on what he termed "seismic rigidity", which is the product of the rate of propagation of longitudinal (P) waves and the bulk density.

In this study we will follow the procedures initiated by Bingler, 1974 and modified by Trexler and Bell, 1980. These include the determination of the suspected response of the geologic units based upon the product of the shear-wave (SH) velocity and the bulk density (ρ). The product of the values has been termed the "rigidity product". The classification derived from this technique are modified by the presence of groundwater; saturated unconsolidated sediments are placed in the next higher classification if they are within 10 m (30 ft) of the surface. For a detailed discussion of the methodology involved, the previous report on earthquake hazard maps of Carson City, New Empire, and South Lake Tahoe quadrangles (Trexler and Bell, 1979) should be consulted.

The recency of faulting is an important aspect in the preparation of the earthquake hazard maps. By using USDA Soil Conservation Service soil maps and applying the technique developed by Trexler and Bell, 1979 and Bell and Pease, 1979, faults that are Pleistocene or younger are divided into age groups based on soil development. Faults of Holocene age (<12,000 years B.P.) displace entisol soils which are characterized by an AC profile. Late Pleistocene faults (approximately 12,000 - 35,000 B.P.) displace soils identified as Haplargids and Argixerolls. These soil types are equivalent to the Churchill soil of the western Great Basin. Faults of Early to mid-Pleistocene age (approximately 100,000 - 1.8 m.y. B.P.) displace Durargid, Paleargid and Durargixeroll soils or equivalents and correspond to development similar to the Cocoon soil.

SEISMIC VELOCITY MEASUREMENTS

The seismic velocities (Vp and Vs) were measured using a Nimbus 12-channel enhancement seismograph. A series of measurements including: 1) P-wave forward direction; 2) P-wave, reverse (source at opposite end of geophone string); 3) SH-wave, right and 4) SH-wave, left. This sequence of measurements provides data on the attitude of boundary layer (if present) and provides a reversal in the SH-wave first arrival when opposite ends of the plank are struck. This reversal in first arrival aids in discerning the SH-wave component and that shear wave arrivals are being picked and not some other surface wave form, Figure 1.

A typical travel time plot of the SH-wave data is shown in Figure 2. This plot is from seismic measurement V-18 which was located on alluvial fan deposits in the Vista 7 1/2-minute quadrangle. The average velocity for the line is computed in this case between the triangles.

A total of 39 sites were occupied in the Steamboat and Vista 7 1/2-minute quadrangles. Fifteen sites representing eight distinct geologic units were measured in the Steamboat 7 1/2-minute quadrangle while the remaining 24 measurements were obtained on ten geologic units in the Vista 7 1/2-minute quadrangle. The location of the measurement sites are shown in Figures 3 and 4.

The selection of sites for seismic velocity measurements was based on accessibility to the vehicle, areal extent and competency of the unit based on prior knowledge. Multiple measurements were made on units having large areal extent and low competency, whenever possible. Therefore, those units which have low SH-wave velocities and large areal extent receive more attention than other units, due to their incipient propensity for greater shaking potential.

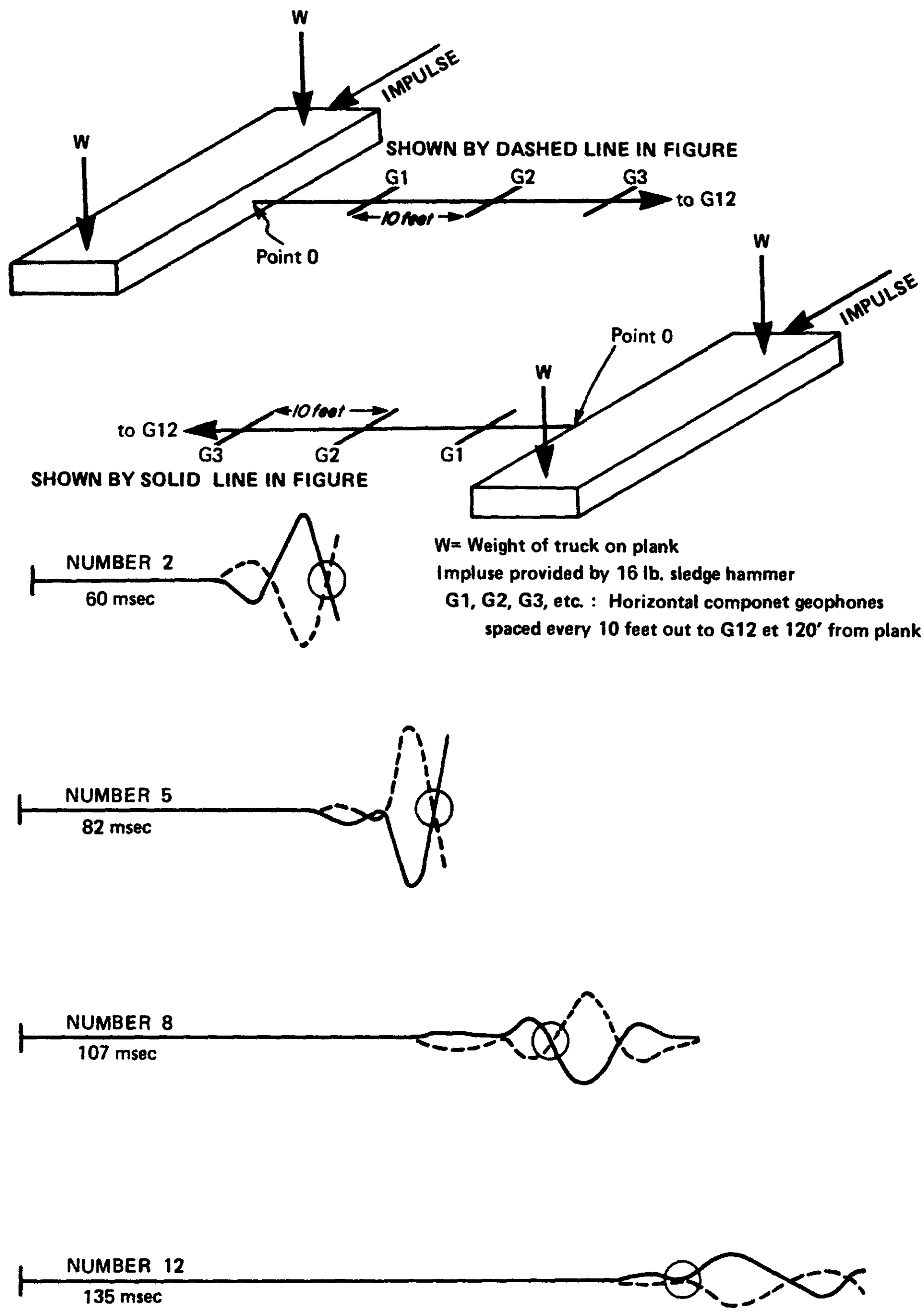


Figure 1. SH - wave source orientations and first arrivals.

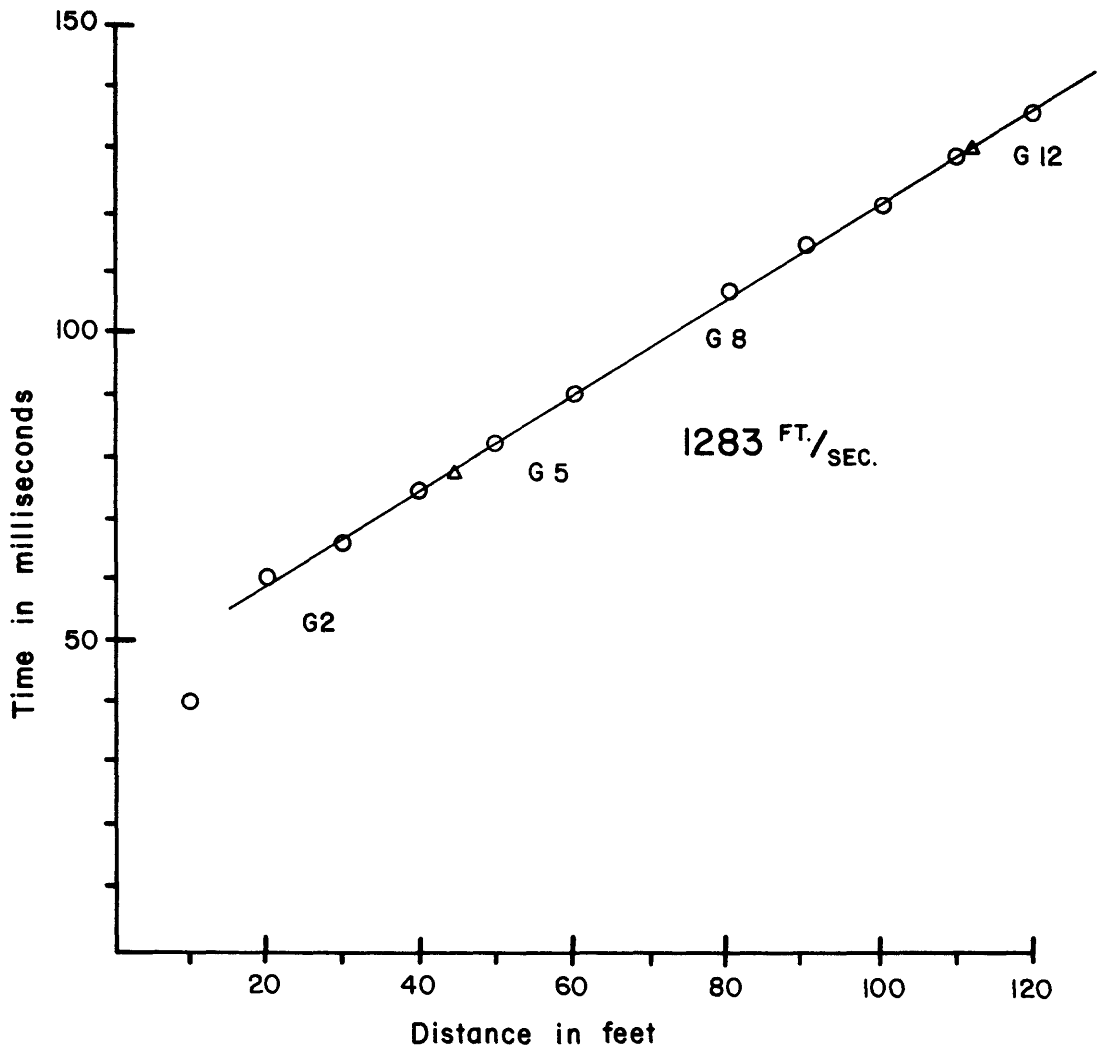
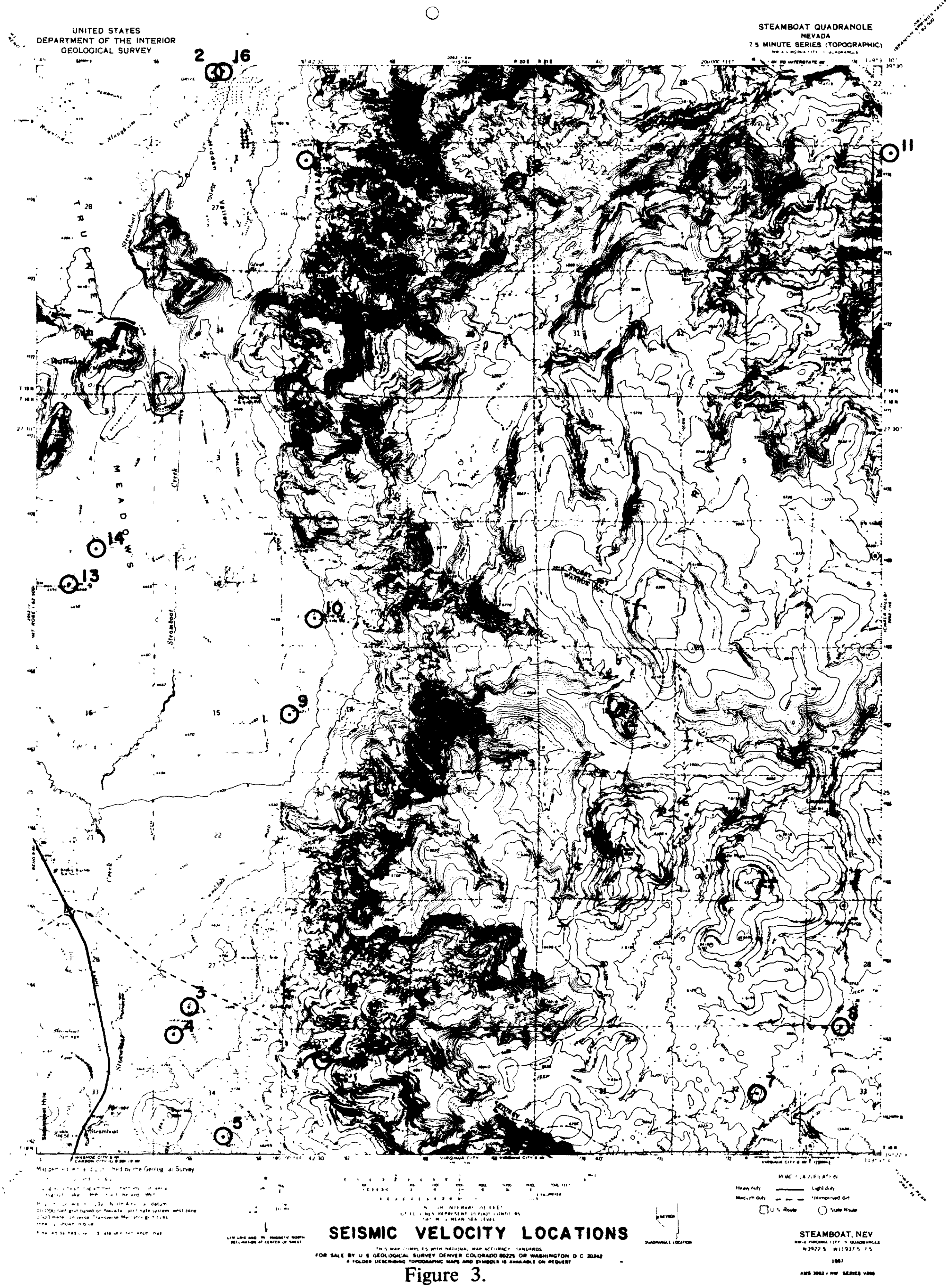


Figure 2. Travel - time plot of SH - wave first arrivals for site V- 18, alluvial fan material.


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
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SEISMIC VELOCITY LOCATIONS
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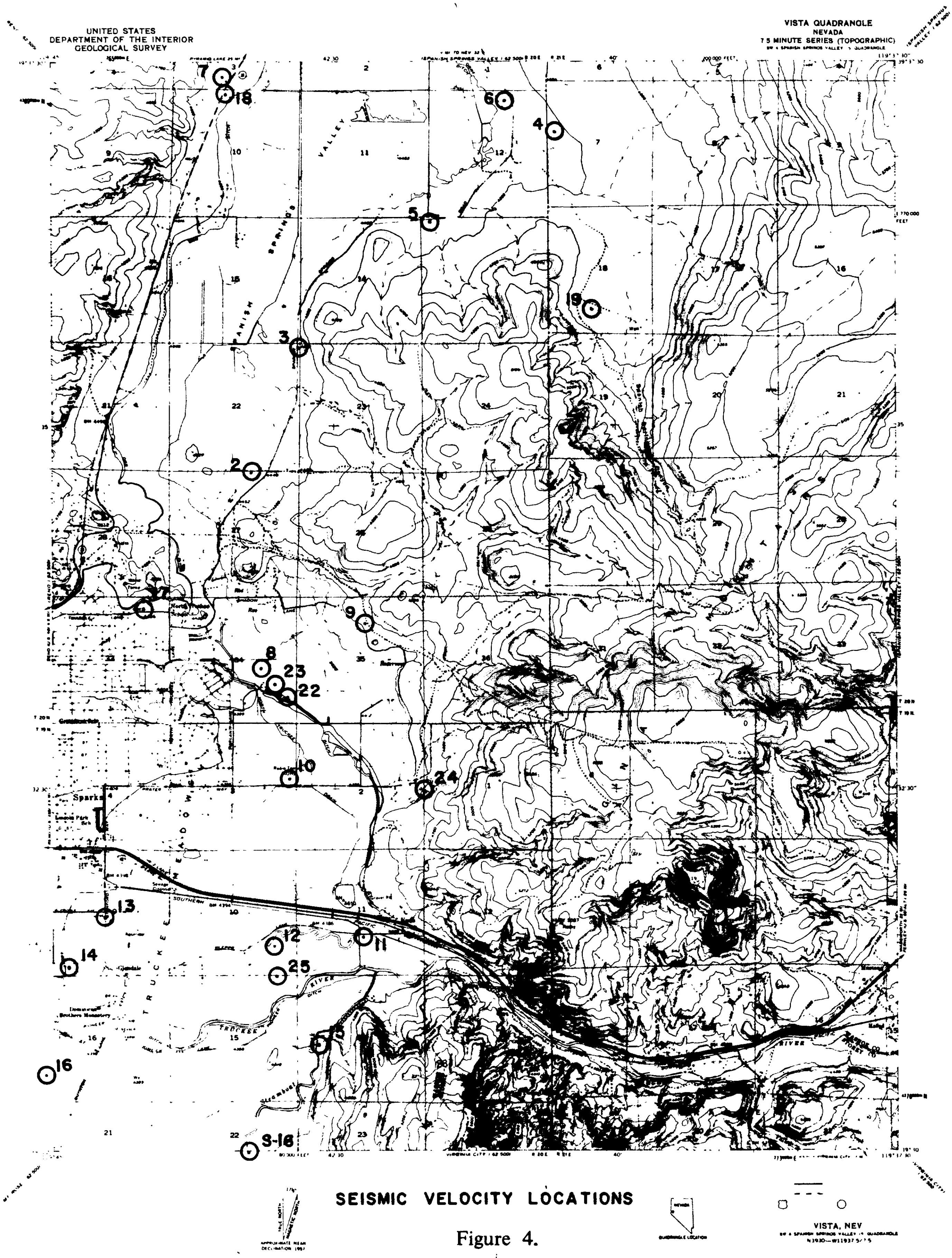
Figure 3.



SEISMIC VELOCITY LOCATIONS

Figure 4.

Seismic velocity measurements in the Vista 7 1/2-minute quadrangle (Appendix I) have SH-wave velocity values ranging from 594 to 867 ft/sec for the fluvial-lacustrine deposits (Qfl) to a maximum of 4,320 ft/sec for competent unaltered Kate Peak andesite (Tk). The low mean SH-wave values of 714 ft/sec for Qfl deposits are not unusual for this deposit and reflect the unconsolidated nature of the unit.

Intermediate SH-wave velocities ranging between 912 and 1411 ft/sec were measured in alluvium, Tahoe outwash and older alluvium. Mean P-wave velocities for the same units range from 1506 to 3125 ft/sec.

Seismic velocities for the bedrock units were taken from measurements in the Steamboat quadrangle. However, the Washington Hill rhyolite was measured in sec. 8, T19N, R21E; velocities for the P-wave were 2012 ft/sec and the SH-wave was 1741 ft/sec. The highly fractured nature of the outcrop may cause the low P-wave velocity for this extrusive dome.

In the Steamboat 7 1/2-minute quadrangle the geologic unit with the lowest SH-wave velocity is the fluvial-lacustrine deposit which has a slightly lower mean velocity (555 ft/sec) than the same unit in the Vista quadrangle (Appendix I). The variation in velocity from a range of 461-648 ft/sec in the Steamboat 7 1/2-minute quadrangle to 594-867 ft/sec in the Vista 7 1/2-minute quadrangle is undoubtedly due to the increased presence of peat and intercalated organic material in the southern part of the unit. Apparently the lowest portion of the Truckee Meadows during the time of deposition of the fluvial-lacustrine deposits was in the northern portion of the Steamboat 7 1/2-minute quadrangle.

Intermediate SH-wave velocities in the Steamboat 7 1/2-minute quadrangle range from 1263 to 1507 ft/sec. Units represented by this range in velocities are main stream gravels (Qmg), alluvium in closed basins in the Virginia Range (Qal), Donner Lake outwash (Qdm), alluvial fan deposits (Qf) and alluvial deposits (Qa). The P-wave velocities also exhibit a close grouping ranging from 1957 to 2742 ft/sec.

Three seismic velocity measurements were made on Kate Peak andesite, one measurement was made on unaltered andesite and two were made on bleached and altered andesite. SH-wave velocities for the bleached andesite ranged from 1533-2044 ft/sec and averaged 1789 ft/sec. The mean SH-wave velocity for unaltered andesite was 4320 ft/sec or 2.5 times greater than the bleached and altered andesite. The P-wave velocities have similar large variations between altered and unaltered andesite, 3260 and 6590 ft/sec, respectively.

RIGIDITY PRODUCT

To categorize geologic units into probable (suspected) response groups the rigidity product is computed. The rigidity product is the product of the near-surface shear-wave (SH) velocity and the bulk density of the unit. The values used in calculation of the rigidity products for the Steamboat and Vista 7 1/2-minute quadrangles are presented in Tables 1 and 2.

The geologic unit having the lowest rigidity product values in both quadrangles is the fluvial-lacustrine deposits (Qfl). The values ranged from 599 to 1,214 using the range of SH-wave velocities and the mean density. Values determined using the mean velocity and mean density were 722 for the Steamboat quadrangle and 1,000 for the Vista quadrangle.

The next lowest calculated value for the rigidity product was for a unit common to both quadrangles, the mainstream gravels (Qmg). Only one seismic velocity measurement site was occupied in the Steamboat quadrangle due to accessibility problems. The mean rigidity product for this unit is 1768. This value is comparable to mean values for young alluvium and alluvial fan deposits in the Vista quadrangle, but due to the degree of saturation of these deposits, they are considered to be less stable than the alluvial deposits.

Mean rigidity product values for young alluvium (Qa) range from 1,459 to 2,562. This large range in mean values for similar deposits in the two quadrangles result from the combined effect of higher mean velocities and densities in the Steamboat quadrangle. This disparity in rigidity products for similar geologic materials is not surprising over such a wide area. The number of determinations used in calculating the respective values of velocity and density effect the calculated rigidity products. It is readily apparent the mean of 101 density measurements is a more realistic

TABLE 1. Rigidity product calculations for the Steamboat 7 1/2-minute quadrangle.

Geol. Unit		Seismic velocities ft/sec				Density g/cc			Rigidity Product		
	No. of Measurements	Vp Range	Vp Mean	Vs Range	Vs Mean	No. of Measurements	ρ Range	ρ Mean	Mean Vs x Range ρ	Mean Vs x Mean ρ	Range Vs x Mean ρ
Qmg	1		1957		1263	**	1.3-1.5	1.4	1642-1895	1768	
Qfl	2	1170-1178	1174	461-648	555	25	0.8-1.5	1.3	444-833	722	599-842
Qa	2	2154-3231	2693	1446-1568	1507	3	1.5-2.0	1.7	2261-3014	2562	2458-2666
Qf	3	1826-2955	2742	1402-1564	1463	23	1.3-1.8	1.6	1902-2633	2341	2243-2502
Qal	1		1619		1344	2	1.5-1.7	1.6	2016-2285	2150	
Qdm	3	1959-2938	2498	1320-1491	1426	32	1.5-2.0	1.8	2139-2852	2567	2376-2684
Tk bleached	2	3081-3438	3260	1533-2044	1789	*		2.0		3578	3066-4088
Tk	1		6590		4320	*	2.7-3.0	2.8	11,664-12,960	12,096	

*Clark, S. P., 1966, in "Handbook of Physical Constants", rev. ed., Geol. Soc. Am. Mem. 97.

**Data from Vista 7 1/2-minute quadrangle.

TABLE 2. Rigidity product calculations for the Vista 7 1/2-minute quadrangle.

Geol. Unit		Seismic veolcities ft/sec				Density g/cc				Rigidity Product	
	No. of Measurements	Vp Range	Vp Mean	Vs Range	Vs Mean	No. of Measurements	ρ Range	ρ Mean	Mean Vs x Range ρ	Mean Vs x Mean ρ	Range Vs x Mean ρ
Qmg						2	1.3-1.5	1.4			
Qfl	5	1141-1355	1203	594-867	714	111	0.9-2.1	1.4	642-1499	1000	832-1214
Qa	5	1086-2250	1506	667-1020	912	101	1.2-2.0	1.6	1094-1824	1459	1067-1632
Qf	3	2154-2414	2301	1280-1508	1357	*	1.3-1.8	1.6	1764-2442	2171	2048-2413
Qto	3	1144-1824	1371	736-1267	955	68	1.2-2.3	1.7	1146-2197	1624	1251-2154
Qdo	0					1		1.7			
Qfo	5	1662-2274	1993	1108-1548	1411	8	1.3-1.8	1.6	1834-2540	2258	1773-2477
Qao	2	2211-4039	3125	1247-1333	1290	2	1.8	1.8	2322	2322	2245-2399
Tk	0					**	2.7-3.0	2.8			
Tw	1		2012		1741	***	2.0-2.3	2.2	3482-4004	3830	

*Data from Steamboat quad.

**Clark, S. P., 1966, in "Handbook of Physical Constants," rev. ed., Geol. Soc. Am. Mem. 97.

***Oral comm., Dennis Bryan, Metchem Engineering, Reno.

value than the average of 3 density determinations. Similarly the mean of 5 seismic velocity measurements from one quadrangle is a more realistic value than the average of 2 measurements in the other.

The rigidity product values for young alluvial fan deposits in both quadrangles are similar with the mean values being 2,171 and 2,341. Other intermediate rigidity product values include those for basin fill alluvium (Qal) and Donner Lake age alluvium (Qdm) in the Steamboat quadrangle and Tahoe outwash material and older alluvium and fan deposits.

The major bedrock units exhibited a wide range in rigidity product values. The Washington Hill rhyolite (Tw) had low rigidity product values due to slow SH-wave velocities which are probably the result of the highly fractured nature of the rock in the near surface and the low density because of its pumaceous texture. Altered Kate Peak andesite (Tk bleached) has a lower rigidity product value than the Washington Hill rhyolite. The bleached and hydrothermally brecciated andesite has many more characteristics of instability that are characterized by a range of rigidity product values from intermediate rigidity to the lower part of the most stable bedrock units.

The unaltered andesites (Tk) have mean rigidity products in excess of 12,000. This value is greater than 3 times the nearest value for other measured bedrock units. This value compares favorably with the rigidity product values derived from Quaternary basalts in the New Empire quadrangle which had a value of 12,480 (Trexler and Bell, 1979).

EARTHQUAKE HAZARDS MAPS

The shaking characteristics for the individual geologic units are computed from the SH-wave velocity and the bulk density. This value has been termed the "rigidity product" by Trexler and Bell (1979). The geologic units within the Steamboat 7 1/2-minute quadrangle are grouped into five categories based on suspected seismic response. The rigidity product values and shaking categories for geologic units in the Steamboat quadrangle are presented in Table 3. The map is Plate I in the pocket.

Geologic units with low rigidity products and saturated within 10 m (30 ft) of the surface have the lowest ranking shaking category (low ranking = most severe shaking). These units include: fluvial-lacustrine deposits, mainstream gravels, eolian sand and siliceous sinter deposited by hot springs in the Steamboat Springs area. The rigidity product for the flucial-lacustrine deposits (Qfl), based on two seismic velocity measurements and 25 density determination, is 722. This is computed from SH-wave velocity of 555 ft/sec coupled with a mean density of 1.3 g/cc. Mainstream gravel deposits which are by their nature saturated in the near surface have higher rigidity product values based on measurements obtained in the Vista quadrangle. These deposits are generally thin and restricted to the present day drainage channels of the major streams. It is doubtful that development would occur in the floodplains due to potential flooding, they are however, included with those deposits being the most susceptible for seismic shaking.

The eolian sand unit (Qe) is a thin, areally restricted deposit for which seismic velocity values are unavailable. The unconsolidated nature of these deposits would require that they be excavated before construction. They have been included here as having a high potential for seismic shaking so that these

TABLE 3.

Shaking Categories for the Steamboat Quadrangle Earthquake Hazard Map

Unit/Description	Rigidity Product	Shaking Category depth of groundwater		
		<3 m	<10 m	>10 m
Qfl - Fluvial-lacustrine deposits	722	I		
Qs - Siliceous sinter (hot spring)		I		
Qe - Eolian sand		I		
Qmg - Main stream gravels	1,768*	I		
Qa - Alluvium	2,562		II	III
Qf - Alluvial fan deposits	2,341		II	III
Qal - Alluvium	2,150		II	III
Qdm - Older alluvial fan deposits	2,567		II	III
Ql - Playa lake deposits			II	III
Qfo - Old alluvial fan deposits	2,258*		II	III
Qtg - Gravel			II	III
Tt - Truckee formation	1,800**		II	III
Qmp - McClellan Peak olivine basalt	12,480***			IV
Qbs - Basaltic andesite				IV
Qtr - Rhyolite intrusive	3,380*			IV
Tl - Lousetown formation				IV
Tw - Washington Hill rhyolite	3,830*			IV
Tk - Kate Peak formation	12,096			
Ta - Alta formation	6,900**			
Tst - Santiago Canyon tuff				IV
Kgd - Granodiorite	6,600**			IV
Trms - Metasedimentary rocks				IV
Hydrothermally altered andesites	3,580			V

*Data from adjoining Vista quadrangle
**Data from Reno quadrangle
***Data from Carson City-New Empire quadrangles

potential problems can be mitigated. The siliceous sinter deposits (Qs) are depicted on the earthquake hazards map as having a high potential for shaking during an earthquake. These deposits are restricted to past and present hot spring activity in the Steamboat Springs area located in the southwest part of the quadrangle. Construction at this site may be restricted to geothermal generating facilities and are therefore included in the category of highest shaking potential.

The next shaking category includes units which have rigidity products ranging from 1800 to 2567. The values calculated for the deposits in the Steamboat quadrangle ranged from 2150 for alluvial deposits (Qal) which occupy closed basins in the Virginia Range to 1800 for the Truckee formation (Tt) based on measurements from the Reno quadrangle. The seismic velocity measurements of SH-wave velocities in the Reno quadrangle were not performed in the same manner as the present measurements and provide uniformally low SH-wave velocities in unconsolidated deposits.

Alluvial fan deposits had the next highest rigidity product (2341) of the deposits comprising categories II and III. Calculated values for alluvium of the Truckee Meadows (Qa) and older alluvial fan deposits (Qdm) have almost identical rigidity product values of 2562 and 2567 repectively. Rigidity product values for units in the Steamboat quadrangle were derived from measurments of the same deposits in the Vista quadrangle for old alluvial fan deposits. This value of 2258 is intermediate in the range of values for this category.

The shaking category ranking of II and III are assigned to the units described above based upon the depth to groundwater. If saturation of the deposits occurs within 10 m (30 ft) of the surface, the lower (more severe) shaking category is used. A category III value is assigned to the units when the depth to groundwater exceeds 10 m (30 ft). The depth to saturated conditions is considered important in determining the potential for differential settlement in the unconsolidated deposits.

The remaining geologic units which comprise shaking categories IV and V are bedrock units consisting of intrusive and extrusive igneous rocks and metamorphosed sediments. Rigidity product values range from a low of 3830 for rhyolitic intrusive bodies to a value in excess of 12,000 for the Kate Peak formation and the McClellan Peak olivine basalts. Category V is made up of the Kate Peak formation and Alta formation, which have been hydrothermally altered. Rigidity product values calculated from SH-wave velocity measurements and bulk densities indicate that a value of approximately 3600 represents a lower value for the altered equivalents of these units. Multiple episodes of hydrothermal brecciation have left these rocks in a highly sheared, silicifiedcondition that resembles broken glass. Several degrees of alteration in the andesitic rocks are apparent ranging from degradation of the feldspars to silicification. Due to the range of physical characteristics of these bleached and altered deposits they are assigned to shaking category V, which has a range of potential shaking characteristics which cannot be definitely defined. This range of potential shaking characteristics ranges from responses suspected for indurated alluvium to the mid-range of unaltered extrusive volcanic rocks.

Unaltered Kate Peak formation had the highest calculated rigidity product within the quadrangle based on in situ SH-wave velocities and estimated bulk density values. Other volcanic rocks such as the McClellan Peak olivine basalt have had similar rigidity product values (12,480) determined from measurements by Trexler and Bell (1979) in the New Empire quadrangle.

Intermediate rigidity product values for bedrock units in the quadrangle were extrapolated from similar units in adjoining or nearby quadrangles. The rigidity product values for the rhyolite intrusive and Washington Hill rhyolite were based on measurements made in the adjoining quadrangle. Values of 6,600 and 6,900 are used for granodiorite and Alta formation based on seismic velocity measurements made in the Reno quadrangle. As mentioned previously, values derived by earlier investigators are consistantly lower than rigidity product values determined during studies in the Carson City - New Empire quadrangles and the present studies.

The shaking categories for geologic units in the Vista quadrangle are similar to those of the Steamboat quadrangle, except that an additional category has been added to reflect the lower values of rigidity product calculated for the alluvium and Tahoe outwash (table 4). The map is present as Plate II (in pocket). Seismic velocity measurements for these geologic units were medial between the fluvial-lacustrine deposits, excluding mainstream gravels which present a special case due to the degree of saturation, and the other alluvial, pediment and late Tertiary sedimentary deposits. The later units have rigidity products ranging from 2171 to 2700. This does not include the 1800 rigidity product value calculated for the Truckee formation in the Reno quadrangle based on seismic velocity measurements that were made with different instrumentation and techniques than those presented in this report and following procedures developed in the Carson City, New Empire and South Lake Tahoe quadrangles (Trexler and Bell, 1979).

Again the mainstream gravels (Qmg) are included in the most severe shaking category (I) because of the saturated conditions which are characteristic of their recency and environment of deposition. These deposits are confined to the active channel of the Truckee River, which traverses the quadrangle near the southern boundary and in Long Valley Creek at its confluence with the Truckee River near the southeastern corner of the quadrangle.

TABLE 4.

Shaking Categories for the Vista Quadrangle Earthquake Hazard Map

Unit/Description	Rigidity Product	Shaking Category depth to groundwater	
		<3 m	>3 m
Qfl - Fluvial-lacustrine deposits	1000	I	
Qmg - Main stream gravels	1768	I	
Qe - Eolian sand		I	
Qle - Lake Lahontan dèltaic sediments		I	
Qa - Alluvium	1459	II	III
Qt - Tahoe outwash	1624	II	III
Qal - Thin alluvium in closed basins		III	IV
Qf - Alluvial fan deposits	2171	III	IV
Qfo - Older alluvial fan deposits	2258	III	IV
Qoa - Older alluvium	2322	III	IV
Qdo - Donner Lake outwash	2700**	III	IV
Qpf - Older fan deposits	2250*	III	IV
Qft - Alluvial fan deposits		III	IV
Qpo - Old pediment deposits		III	IV
Qtg - Gravel		III	IV
Tt - Truckee formation	1800**	III	IV
Qmp - McClellan Peak olivine basalt	12,480***		V
Qbi - Basalt dike rock			V
Tl - Lousetown formation			V
Tss - Basaltic andesite			V
Tw - Washington Hill rhyolite	3830		V
Tk - Kate Peak formation	12,096*		V
Ta - Alta formation	6900**		V
Kqm - Quartz monzonite			V
Kgd - Granodiorite	6600*		V
Trmv - Metavolcanic rocks	10,800**		V
Trms - Metasedimentary rocks			V
Hydrothermally altered Ta and Tk	3578*		VI

*Data from adjoining Steamboat quadrangle
**Data from adjoining Reno quadrangle
***Data from Carson City quadrangle

As mentioned above, the young alluvial deposits and Tahoe outwash deposits exhibit rigidity products intermediate with the lowest values and other alluvial deposits. These lower values necessitated an additional shaking category. Based upon the physical properties of these units it is not anticipated that they would react as violently to seismic loading as the finer grained fluvial-lacustrine deposits or the unconsolidated and saturated mainstream gravels. The alluvium and outwash units are identified as shaking category II when saturation due to groundwater is within 3 m (10 ft) of surface and are identified as category III when the depth to groundwater is greater than 3 m (10 ft).

Unconsolidated deposits and sediments of the Truckee formation with rigidity products in the range of 1800-2700 are included in shaking category III when the depth to groundwater is less than 3 m (10 ft). When conditions of saturation occur at depths greater than 3 m (10 ft) the units included in shaking category III are elevated to shaking category IV. It is anticipated that the response of the units to seismic loading in a dewatered condition in the near surface will be less severe than when conditions of saturation exist.

The bedrock units which are not altered comprise shaking category V. This category will have the least severity of shaking induced by an earthquake. The rigidity products range from 3,830 for the Washington Hill rhyolite to 12,480 for olivine basalt.

The hydrothermally altered andesites are not as extensive in the Vista quadrangle. The altered rocks are included in shaking category VI. Their response to earthquake stresses will vary over a wide range because their physical properties vary greatly. Silicification is locally common causing resistant ridges and knobs, whereas other altered rocks are loose and friable and will have more severe shaking characteristics than the silicified rock.

POTENTIAL FOR FAULT SURFACE RUPTURE

Delineation of Faults in the Steamboat 7 1/2-minute Quadrangle

The faults previously mapped by Trexler and McKinny (1980) form the basis for the potential for surface rupture in the Steamboat 7 1/2-minute quadrangle. Fault locations and their subtle topographic features were enhanced by the use of low sun-angle photography. For a complete description of this technique, see Slemmons, 1969 and Walker and Trexler, 1977. The interpretation of 1:12,000 scale low sun-angle photography was especially useful in delineating suspected fault scarps in the alluvial plain and alluvial fan areas of the southern Truckee Meadows.

Faulting in the Steamboat 7 1/2-minute quadrangle can be divided into three categories based on age. The youngest fault activity is characterized by faults which displace deposits which have soils that are older than 10,000 years and younger than 35,000 years. These soils are identified using the method described by Trexler and Bell, 1979 and Bell and Pease, 1979 as being those soils identified as Haplargids and Argixerolls. This degree of soil development is equivalent to the Churchill soil of the western Great Basin which has been assigned an age of 35,000 years (Trexler and Bell, 1979 and Bell and Pease, 1979). This age assignment is based on radiocarbon ages from the Wyemaha formation which range from 27,500 to 33,500 and a single pedogenic carbon date of 26,300 (Morrison and Frye, 1965). Later work by Davis (1979) using tephrochronology and radiocarbon dating place the date for the beginning of the development of the Churchill soil at approximately 35,000 years B.P.

The next age that can be assigned to fault activity in the Steamboat 7 1/2-minute quadrangle is that which displaces soils of Sangamon age, which are approximately 100,000 years old. These ages are based on correlations between the development of the Cocoon soil which is pre-Tahoe age (pre-80,000 years). Based on continental correlations a 100,000 year date for a major interpluvial is apparent, which would equate with development of a mature soil such as the Cocoon. Correlations between the Carson Sink and the Truckee Meadows is based on the work of Birkeland, 1968 and Mock, 1972 who describe the relationship between glacial outwash terraces and alluvial surfaces with similar units and surfaces in the Lahontan sequence.

Other faults in the Steamboat quadrangle are post-Tertiary in age. Based on slope morphology, none of the faults appear to be Pleistocene age or younger. Trenching of the most youthful appearing scarps in the Steamboat 7 1/2-minute quadrangle based on morphology, indicated that the last movement along these faults occurred during mid-Pleistocene time (Trexler and Pease, 1980). Specific areas of fault activity are discussed below and are indicated on the accompanying maps.

Area 1: Steamboat Springs

Faults in this area displace Haplargid and Argixeroll soils. These soil types are equivalent to the Churchill soil in the western Great Basin. This indicates that the surface is not more than 35,000 years old. The faults are all in bedrock and the most westerly of the faults has relative displacement with the westside down.

Area 2: Brown-Washoe School

Three faults in the immediate area either displace or bound Donner Lake age alluvium. A similar relationship occurs along the fault located approximately 1 mile south-southeast of Brown-Washoe School. Soils developed on the alluvium are Durargids. This type of soil development indicates the surface is older than 35,000 years and is probably equivalent to the Cocoon soil which is approximately 100,000 years old. Therefore, these faults are early to mid-Pleistocene in age.

Area 3:

The two faults in this area bound Donner Lake age alluvium and have a similar relationship as the faulting in Area 2. In each case the older alluvial material is up on the southeast side relative to the northwest. Soils developed on the surfaces are Durargids indicating an age of mid-Pleistocene for faulting.

Area 4: Virginia Foothills

The westernmost fault in this area juxtaposes alluvium and bedrock; the other faults displace Alta andesite and granodiorite. Soils developed on the basement rocks are Halargids, indicating that the surface on which they are developed is not older than 35,000 years. The alluvial-bedrock fault is also covered with Haplargid soils indicating a late Pleistocene age.

Area 5:

Faults in this area displace alluvial fan deposits that have Haplargid soils. Scarp morphology of the faults is similar to those faults which were trenched three miles to the north. Based on soil development and scarp morphology, the faults are late Pleistocene in age.

Area 6:

The fault along Miraloma Road was trenched during the previous contract period. The fault is pre-soil and since the soil is a Durargid the fault is early to mid-Pleistocene in age. The range bounding faults in this area have Haplargid soil over the scarps indicating a late Pleistocene age for faulting. The bedrock alluvium faults in this area and to the south are apparently late Pleistocene in age, while faults further to the north have Durargid soils covering the scarps. This would indicate that the faults to the north are older. Trenching at two locations along a fault segment that cuts alluvial fan deposits in the SW¼ of section 23, T19N, R20E shows that the fault is pre-soil and that the soil being a Durargid indicates that faulting is early to mid-Pleistocene in age.

Delineation of Faults in the Vista 7 1/2-minute Quadrangle

The faults previously mapped by Trexler and Pease (1980) form the basis for the potential for surface rupture in the Vista 7 1/2-minute quadrangle. Low sun-angle photography was flown over the northern portion of the quadrangle at a scale of 1:12,000. Based on scarp morphology, the faults in the major bedrock units appear to be older than 12,000 years.

The northeast trending faults in the east-central portion of the quadrangle are subparallel to the Olinghouse fault located 16 miles to the northeast. Scarp morphology indicates movement along this segment of the fault occurred in 1869 (Sanders and Slemmons, 1979). They indicate that maximum fault length and maximum fault displacement to earthquake magnitude relations correspond to an earthquake of about magnitude 7. Based on interpretation of low sun-angle photography and field mapping, evidence of recent movement along any of the northeast trending faults in the Vista quadrangle was not found.

Area 1:

The fault which bounds the bedrock of the Virginia Range in the southern portion of the quadrangle displaces older alluvial fan material in section 14 which has a Durargid soil developed on the surface. This relationship indicates that the age of last movement is probably mid-Pleistocene.

Area 2:

The northwest trending fault at this location bounds deposits of Donner Lake outwash. The soils developed on these surfaces are a Durargid and a Haplargid. As indicated previously, the age of the surfaces are approximately 100,000 and 35,000 years old, respectively.

Area 3:

The alluvial fans along the west side of Spanish Spring Valley are younger than the fans on the east side of the valley. The difference in age is the result of faulting along the west side. Faulting and uplift of the range provide renewed deposition and fan development. The age of the fan surfaces based on soil development range from Holocene to Sangamonian (12,000 to 35,000 years B.P.), since the oldest soils developed on the fan surfaces are Haplargid and Argixeroll types.

Area 4:

Air photo interpretation indicated that the fault trending north-northwest-south-southeast in Spanish Springs Canyon displaces older fan deposits in sec. 19, T20N, R21E. These deposits have a Durargid soil developed on the surface, which indicates the surface is early to mid-Pleistocene in age. The scarp morphology tends to confirm this age of last movement.

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APPENDIX

SEISMIC VELOCITY DATA
FOR THE VISTA 7 1/2-MINUTE QUADRANGLE

Geol. Unit	ID No	$V_{p_{for}} - V_{p_{rev}}$	$V_{p_{for}}$	$V_{p_{rev}}$	$V_{p_{Aug.}}$	Comments	V_s	V_s/V_p
Qfl	V-11	20	1176	1196	1186		867	.73
	V-12	143	1083	1226	1155			
	V-15	33	1158	1125	1141		594	.52
	V-25	238	1233	1471	1355	Surface mudcracked	745	.55
	S-16	89	1222	1133	1178		648	.55
Qa	V- 2	36	1100	1136	1118	May overlie Qfo	667	.60
	V- 8	113	1030	1143	1086		1020	.94
	V-10	15	1122	1106	1114		838	.75
	V-22	146	2035	1889	1962	May overlie Qdo	978	.50
	V-23	388	2444	2056	2250		1058	.47
Qf	V- 7	28	2428	2400	2414		1508	.62
	V-17	581	2444	1863	2154	May overlie Ta	1280	.59
	V-18	99	2286	2385	2335	Underlying Qa	1283	.55
Qto	V-13	11	1150	1139	1824		1267	.69
	V-14	25	1133	1158	1146		863	.75
	V-16	47	1167	1120	1144		736	.64
Qfo	V- 3	454	1435	1889	1662	Overlying Ta	1108	.67
	V- 5	702	2625	1923	2274		1548	.68
	V- 9	158	2158	2000	2079	Overlying Ta		
	V-19	500	2000	2500	2250		1433	.64
	V-24	526	1964	1438	1701		1520	.87
Qao	V- 4	22	2222	2200	2211		1333	.60
	V- 6	650	4364	3714	4039	Close to Qa	1247	.31
Tw	V-20	198	1913	2111	2012		1741	.85

SEISMIC VELOCITY DATA
FOR THE STEAMBOAT 7 1/2-MINUTE QUADRANGLE

Geol. Unit.	ID No	$V_{p_{for}} - V_{p_{rev}}$	$V_{p_{for}}$	$V_{p_{rev}}$	$V_{p_{Aug.}}$	Comments	V_s	V_s/V_p
Qmg	S-11	87	2000	1913	1957		1263	.65
Qfl	S- 2	53	1196	1143	1170		461	.39
	S-16	89	1222	1133	1178		648	.55
Qa	S- 9	297	2154	1857	2005	May overlie Qf	1446	.72
	S-13	19	3250	3231	3241	May overlie Qdm	1568	.48
Qf	S- 1	91	3000	2909	2955		1564	.53
	S- 3	2797	4100	1303	2702	Dipping beds	1440	.53
	S-10	15	1818	1833	1826		1402	.77
Qal	S- 8	96	1667	1571	1619	May overlie Ta	1344	.83
Qdm	S- 4	557	2875	2318	2597		1467	.56
	S- 5	83	2000	1917	1959		1320	.67
	S-14	125	3000	2875	2938		1491	.51
Tk	S- 6	1625	3500	3375	3438		2044	.59
Bleached	S-12	384	2889	3273	3081		1533	.50
Tk	S- 7	1679	7429	5750	6590		4320	.66