G422/522 Advanced Topics: Alluvial Fans Lab
Tectonic Geomorphology / Fault Analysis

INTRODUCTION

(Note: much of this exercise is derived from work by Wells and McFadden at the University of New Mexico; and Hemphill-Haley and others)

Tectonic geomorphology is the analysis of the interrelationships between tectonics or surface deformation and surface processes / landforms. Recent advances in tectonic geomorphology have incorporated quantitative definition and analysis of landforms based on map and field data. The objective is to quantify the amounts, timing, and relative/absolute rates of tectonic processes. This information has wide application to the field of seismic hazards analysis.

Fault-bounded mountain fronts are common in the Basin and Range Province. Steens Mountain in southeastern Oregon comprises part of this structural province. Steens Mountain is bounded to the east-northeast by the Steens fault zone, a 100-km-long zone of north-trending normal faults that separate Steens Mountain from the Alvord Valley. Steens Mountain represents a westward-tilted, tectonic block, and has been subject to Quaternary faulting (refer to Figures 1 through 4 for an overview of the general geologic setting).

The objective of this lab is to apply methods of tectonic geomorphology to the eastern front of Steens Mountain, with the goal of assessing the relative status of neotectonic activity.

METHODOLOGY / TECHNIQUES

Task 1 - Map Out Mountain Front Geomorphology

A. Figure 5 is a Geologic Map of the Steens Mountain Area by Hemphill-Haley and others. Also refer to the 11 x 17 photocopy of the Steens-Alvord Hot Springs area. Familiarize yourself with the geology by drawing in map contacts from Fig. 5 on the 11x17 copy. Use the contour patterns and cultural features to guide you in the map-transfer process (think of landform, process, and deposit; in the context of topography, as related to surficial / bedrock geology). Draw / color / label the following: bedrock-mountain front contact, alluvial fan deposits, play/lake deposits, and the trace of the Steens fault zone (and related strands).

Task 2 - Mountain Front Morphometry

Overview of Methodology

Bull developed a set of morphometric techniques to assess the relative degree of tectonic activity along mountain fronts in the Great Basin. The theoretical approach is as follows: tectonic uplift along the mountain front, canyon cutting in the range block, and sedimentation/erosion in the basin; collectively affect the fluvial systems which cross the mountain front. Tectonically active mountain fronts maintain high relief and steep slopes, while inactive fronts degrade through erosion processes.

Bull developed two mountain-front morphometric parameters to assess tectonic activity: Mountain Front Sinuosity (S) and Valley-Floor Width-Height Ratio (Vf). S measures the degree of sinuosity along the topographic base of the mountain front escarpment.

$$S = Lmf / Ls$$

where Lmf = actual length of the topographic junction of the mountain front (actual trace of the bedrock-piedmont contact), and Ls is the straight-line length of the front segment.

Tectonically-active mountain fronts will tend to be of high relief and straight with S ~1.0. Tectonically-inactive mountain fronts will increase in S value as the topographic junction is increasingly modified in an irregular fashion by the processes of stream erosion (mountain canyons) and pedimentation (along the mountain front).

The Vf ratio is defined as the ratio of the valley floor width (Vfw; of streams directed out of the mountain towards the front) to the mean height of the right and left valley divides (Erd and Eld equal elevation of the right and left valley sides, respectively), as measured relative to the elevation of the stream channel (Esc). Thus:

$$Vf = Vfw / \text{mean valley height} \quad \text{or}$$

$$Vf = Vfw / (((Eld-Esc)+Erd-Esc))/2)$$

where Vfw = valley floor width, Esc = elevation of stream channel, Eld = elevation of left valley divide, and Erd = elevation of right valley divide.

Valley heights and widths are measured directly from topo maps along a transect, oriented perpendicular to the average valley trend. The transect is located in the range block, upstream from the mountain front. Low Vf values (<1.0) are associated with narrow, steep v-shaped canyons (high relief) associated with active mountain fronts. Vf ratios increase with decreasing amounts of tectonic activity, as canyon bottoms downcut and laterally erode over time (in a stable, local base-level setting).

Procedures for Task 2.

(1) Use the 11 x 17 topo sheet of Steens Mountain to determine S and Vf values for the front. One S value will be derived for the mountain front segment shown in the map area. Determine Vf values for the following mountain-block canyons: Little Alvord Creek, Pike Creek, Dry Creek, Indian Creek, and Tuffy Creek

a. draw Ls as a straight to gently curved line on the piedmont adjacent or tangential, to the base of the mountain front segment on the map. Pencil in the best approximation of Lmf, i.e. the actual piedmont-mountain front junction as defined by the abrupt steepening of the topo lines.

b. measure the length of Ls and Lmf, calculate S

c. Using the canyons listed above, calculate Vf for each. The cross-valley transect should be located roughly 1/10 of the total basin length up from the mouth at the piedmont. Try to use a consistent method of selecting each transect location, equidistant, upstream from the piedmont junction.

d. measure Vfw by approximating the valley bottom width, and determine the heights of the right and left sides (consider right and left as you look down-canyon). Tabulate all data and calculate Vfw. Average the Vf values for the mountain front segment depicted on the 11 x 17 map.

e. Classify the Steens mountain front on the basis of the following:

Class 1 Mountain Front: S = 1.0-1.6, Vf = 0.01-1.0 (active front)
Class 2 Mountain Front: S = 1.4-3.0, Vf =>0.5-1.0
Class 3 Mountain Front: S = 2.0-3.0, Vf > 3.0-4.0 (inactive front)

Task 3 - Fault Scarp Morphology

Figure 6, Figure 7, and Appendix A illustrate the methods of fault scarp degradation analysis. The model is that fresh, recent fault scarps will tend to have sharp, angular cross-sectional profiles. With time, erosion and mass wasting will degrade the profile, thus providing a method of estimating ages since surface rupture. Refer to Appendix A for an overview of the techniques.

Table 1 lists Scarp Offset (a) and θs data for a set of fault-bounded mountain fronts in the Basin and Range, including Steens. Refer to Figure 6 for definition of the geometric parameters.

(a) Download the data file from the class web site (go to the lab section, the file name is "tectlab.xls"

(b) Use Excel to calculate the following: (2*a) and Tanθs as depicted in Fig. 6, for each datum, at each locality.

(c) Using Excel, or other graphing software, create plots of Scarp Slope (Tanθs on y-axis, linear scale) vs. Offset (2a on x-axis, linear scale). Size and format the graphs of each mountain area, print as needed. You can combine plots on a single graph if it's not too messy. Use your artistic judgement. Label your plots, and list the diffusion-based age estimate for each fault zone.

(d) Plot a best-fit linear line to each data set, and determine the equation, also list the results of regression analyses (R square, etc.). We tried line-fitting (or adding trend lines) in Excel during the last exercise.

(e) Plot a graph of line slope (y axis, linear) vs. age (axis-axis, linear). Complete the questions below.

SUMMARY QUESTIONS

1. Summarize the results of the mountain front morphometry exercise for Steens. Provide a discussion of the geologic setting and an analysis with respect to tectonic activity.

2. Discuss the relationships between fault-scarp morphology and time since rupture. Evaluate the relationships between scarp slope, offset, time, and diffusive degradation.

3. List and discuss any limitations, false assumptions, and general short-comings of the techniques employed in this exercise. What are the limitations and caveats.

Table 1. Summary of Fault Scarp Morphology for Select Mountain Fronts in the Basin and Range

Scarp Offset (a) (meters)	Theta$_s$	Mountain Front	Diffusion-Based Age Estimate of Scarp (yr BP)
0.24	12.63	Fish Springs Range	3000
0.36	13.81	Fish Springs Range	
0.46	14.83	Fish Springs Range	
0.29	16.43	Fish Springs Range	
0.41	17.03	Fish Springs Range	
0.40	18.11	Fish Springs Range	
0.30	18.61	Fish Springs Range	
0.49	19.13	Fish Springs Range	
0.40	21.70	Fish Springs Range	
0.69	22.28	Fish Springs Range	
0.80	23.61	Fish Springs Range	
0.70	23.53	Fish Springs Range	
0.74	25.11	Fish Springs Range	
1.15	25.98	Fish Springs Range	
0.96	26.82	Fish Springs Range	
1.13	27.44	Fish Springs Range	
0.95	28.28	Fish Springs Range	
1.15	25.97	Fish Springs Range	
1.32	25.49	Fish Springs Range	
1.31	24.59	Fish Springs Range	
1.50	30.13	Fish Springs Range	
1.48	31.73	Fish Springs Range	
1.59	32.11	Fish Springs Range	
1.56	33.23	Fish Springs Range	
0.97	12.66	Oquirrh Mountains	32000
1.24	8.67	Oquirrh Mountains	
1.54	17.21	Oquirrh Mountains	
1.64	16.85	Oquirrh Mountains	
1.85	15.48	Oquirrh Mountains	
1.96	14.43	Oquirrh Mountains	
2.11	13.74	Oquirrh Mountains	
2.07	14.76	Oquirrh Mountains	
2.15	16.92	Oquirrh Mountains	
3.07	19.45	Oquirrh Mountains	
0.71	8.06	Sheeprock Mountains	53000
1.65	11.63	Sheeprock Mountains	
2.36	15.81	Sheeprock Mountains	
3.22	17.01	Sheeprock Mountains	
3.51	19.49	Sheeprock Mountains	
3.61	20.01	Sheeprock Mountains	
3.82	23.01	Sheeprock Mountains	
0.31	4.79	Drum Mountains	5000
0.35	4.89	Drum Mountains	
0.45	4.27	Drum Mountains	
0.51	6.19	Drum Mountains	
0.51	6.80	Drum Mountains	
0.50	8.62	Drum Mountains	
0.81	10.61	Drum Mountains	
0.67	12.77	Drum Mountains	
0.46	12.23	Drum Mountains	

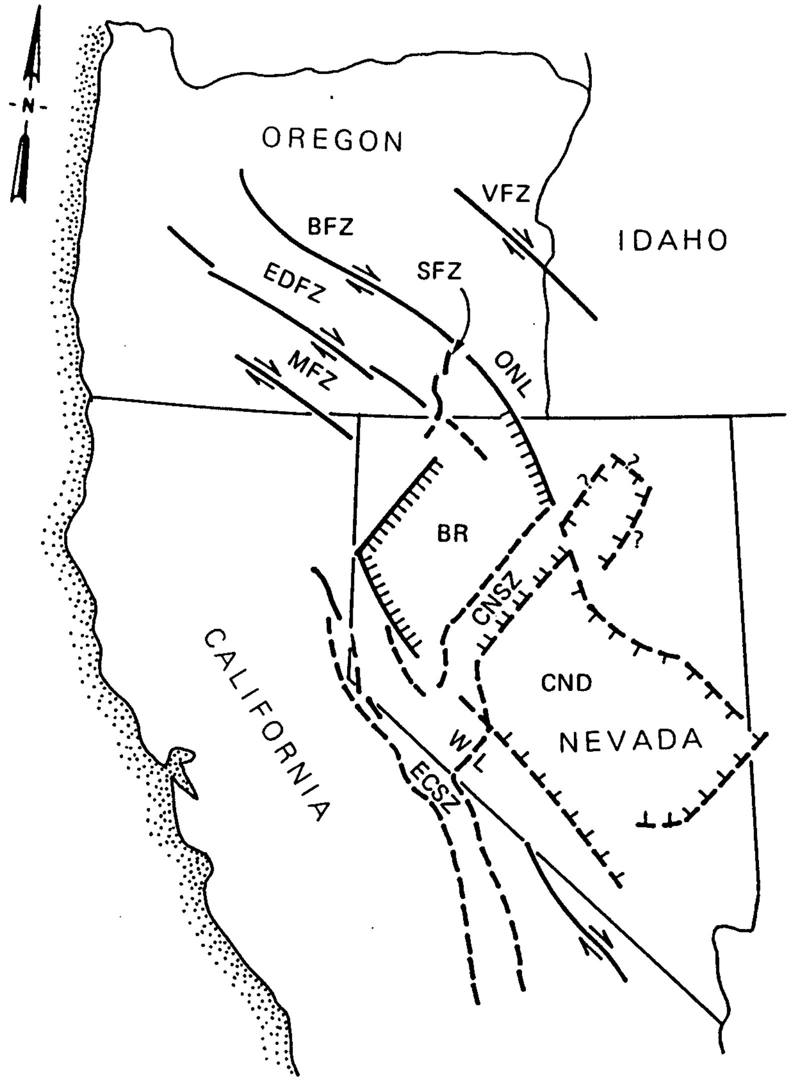
WEB SITE –
LAB DATA SECTION

TECTLAB.XLS

Table 1. Summary of Fault Scarp Morphology for Select Mountain Fronts in the Basin and Range

Scarp Offset (a) (meters)	$Theta_s$	Mountain Front	Diffusion-Based Age Estimate of Scarp (yr BP)
0.26 / 0.46	12.23 / 12.03	Fish Springs Range / Drum Mountains	3000
0.81	12.74	Drum Mountains	
0.91	13.71	Drum Mountains	
0.90	14.29	Drum Mountains	
0.96	14.35	Drum Mountains	
0.87	15.89	Drum Mountains	
0.67	15.84	Drum Mountains	
0.67	14.28	Drum Mountains	
0.75	18.10	Drum Mountains	
0.80	18.11	Drum Mountains	
1.02	16.54	Drum Mountains	
1.01	15.55	Drum Mountains	
1.26	14.94	Drum Mountains	
1.27	13.22	Drum Mountains	
1.33	16.98	Drum Mountains	
1.30	17.54	Drum Mountains	
1.26	18.01	Drum Mountains	
1.21	17.90	Drum Mountains	
1.22	19.46	Drum Mountains	
1.39	19.11	Drum Mountains	
1.38	19.28	Drum Mountains	
1.47	19.05	Drum Mountains	
1.45	19.36	Drum Mountains	
1.29	20.78	Drum Mountains	
1.42	22.03	Drum Mountains	
1.80	23.02	Drum Mountains	
1.75	24.54	Drum Mountains	
2.17	25.21	Drum Mountains	
2.24	25.07	Drum Mountains	
2.34	24.61	Drum Mountains	
2.25	20.63	Drum Mountains	
2.91	21.73	Drum Mountains	
2.87	25.10	Drum Mountains	
3.35	25.34	Drum Mountains	
0.86	16.97	Steens Mountain	3000
0.92	18.07	Steens Mountain	
0.75	19.32	Steens Mountain	
0.67	21.29	Steens Mountain	
1.15	20.26	Steens Mountain	
1.28	21.86	Steens Mountain	
0.85	24.24	Steens Mountain	
0.76	24.18	Steens Mountain	
1.03	26.45	Steens Mountain	
1.02	27.43	Steens Mountain	
1.26	27.60	Steens Mountain	
1.57	29.50	Steens Mountain	
1.58	30.66	Steens Mountain	

[redacted] - Oblique aerial view to the north along the steep eastern escarpment of Steens Mountain.
FIG. 1

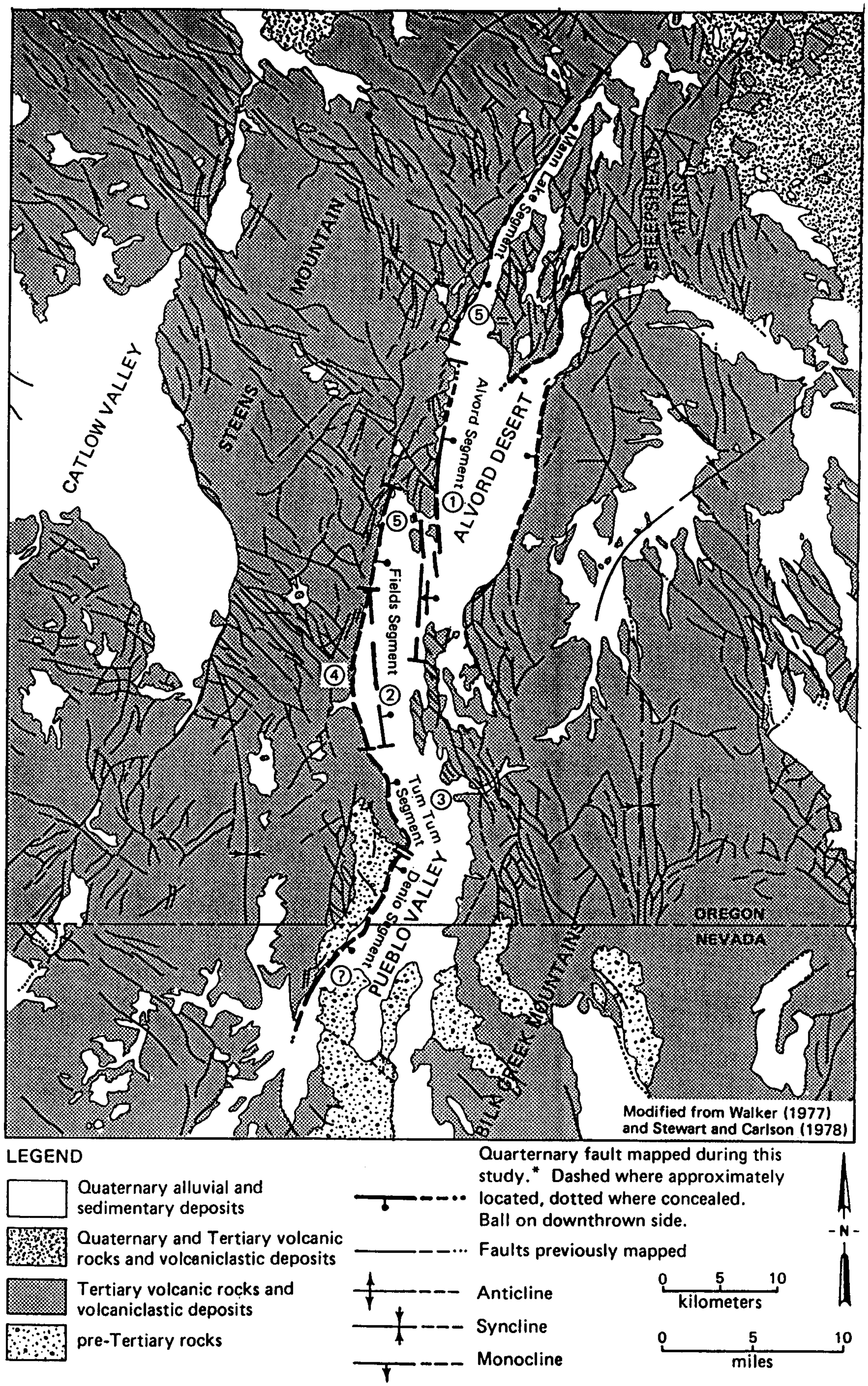


SFZ	Steens Fault Zone
BR	Black Rock-Carson Sink Zone of Extension
CND	Central Nevada Depression
CNSZ	Central Nevada Seismic Zone
ECSZ	Eastern California Seismic Zone
VRZ	Vale Fault Zone
BFZ	Brothers Fault Zone
ONL	Oregon-Nevada Lineament (Southern Extension of Brothers Fault Zone)
EDFZ	Eugene-Denio Fault Zone
MFZ	McLaughlin Fault Zone
WL	Walker Lane

Modified from Wallace (1977) and Lawrence (1976).

0 100 200 300 400 km

FIG. 2
[redacted] – Major structures of the western Basin and Range province.



* Faults along the western margin of the Alvord Desert mapped by Hemphill-Haley (1987) and this study.
Faults along the eastern margin of the Alvord Desert mapped by Lindberg (personal communication) and this study.
① Proposed ranking of segments according to age; smallest number corresponds to most recently faulted segment.

[redacted] FIG. 3 - Generalized geologic map of a portion of southeastern Oregon and northern Nevada showing proposed segmentation of the Steens fault.

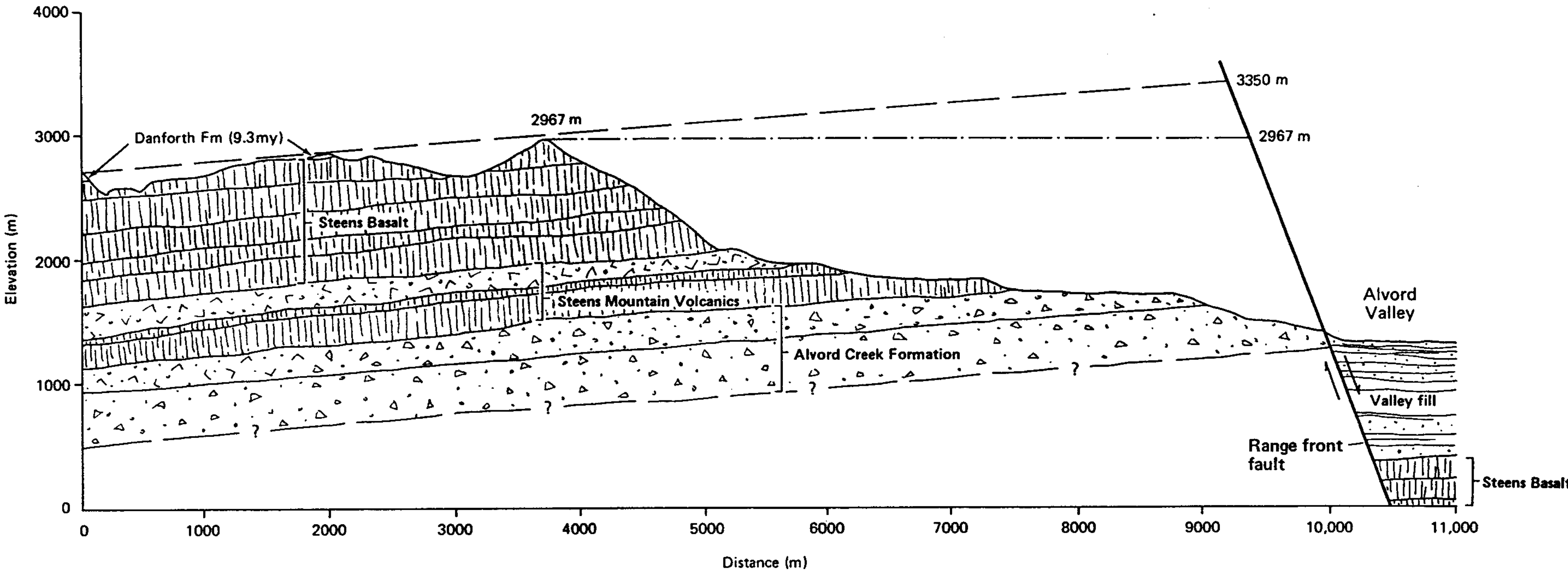
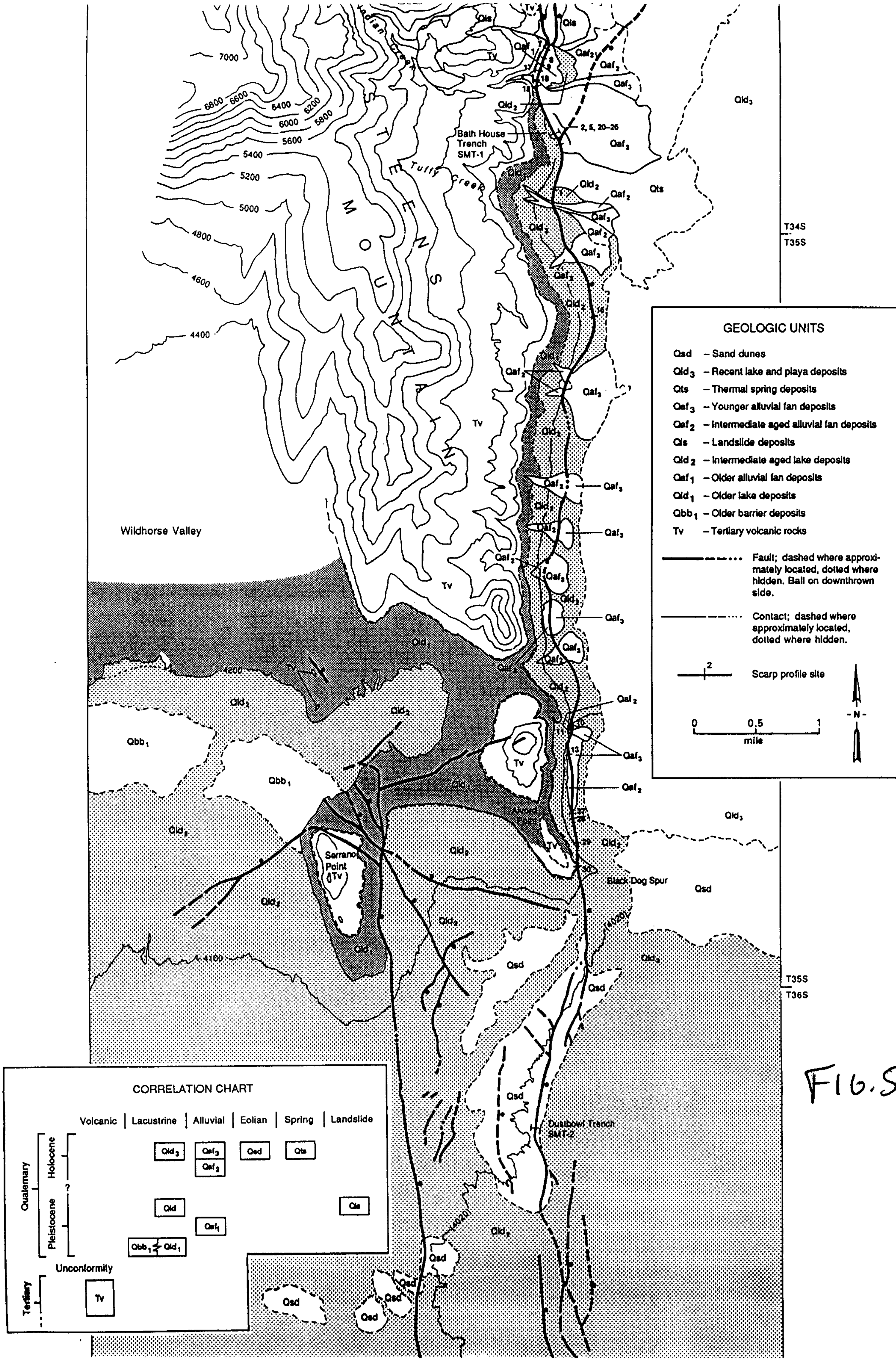
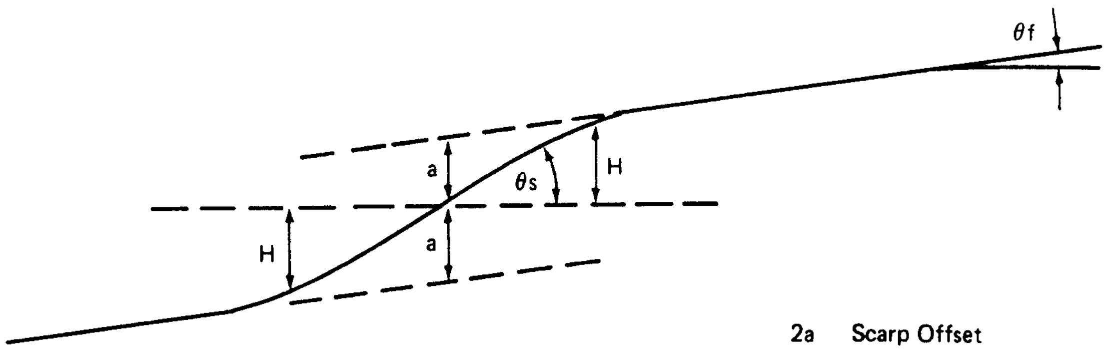


FIG 4 – Schematic cross-section of Steens Mountain near Little Alvord Creek. The Pike Formation is not shown at this location because it pinches out just south of the cross-section.

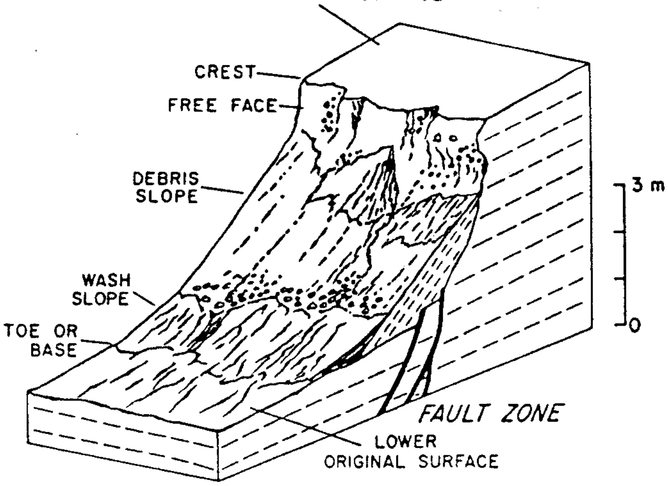

GEOLOGIC UNITS
Qsd – Sand dunes
Qld3 – Recent lake and playa deposits
Qts – Thermal spring deposits
Qaf3 – Younger alluvial fan deposits
Qaf2 – Intermediate aged alluvial fan deposits
Qls – Landslide deposits
Qld2 – Intermediate aged lake deposits
Qaf1 – Older alluvial fan deposits
Qld1 – Older lake deposits
Qbb1 – Older barrier deposits
Tv – Tertiary volcanic rocks
Fault; dashed where approximately located, dotted where hidden. Ball on downthrown side.
Contact; dashed where approximately located, dotted where hidden.
Scarp profile site
0 0.5 1
mile
N
CORRELATION CHART
Volcanic | Lacustrine | Alluvial | Eolian | Spring | Landslide
Quaternary
Holocene
Pleistocene
Tertiary
Unconformity
Wildhorse Valley
Bath House Trench SMT-1
Dustbowl Trench SMT-2
Serrano Point
Alvord Point
Black Dog Spur
Tuffy Creek
T34S
T35S
T36S
FIG. 5



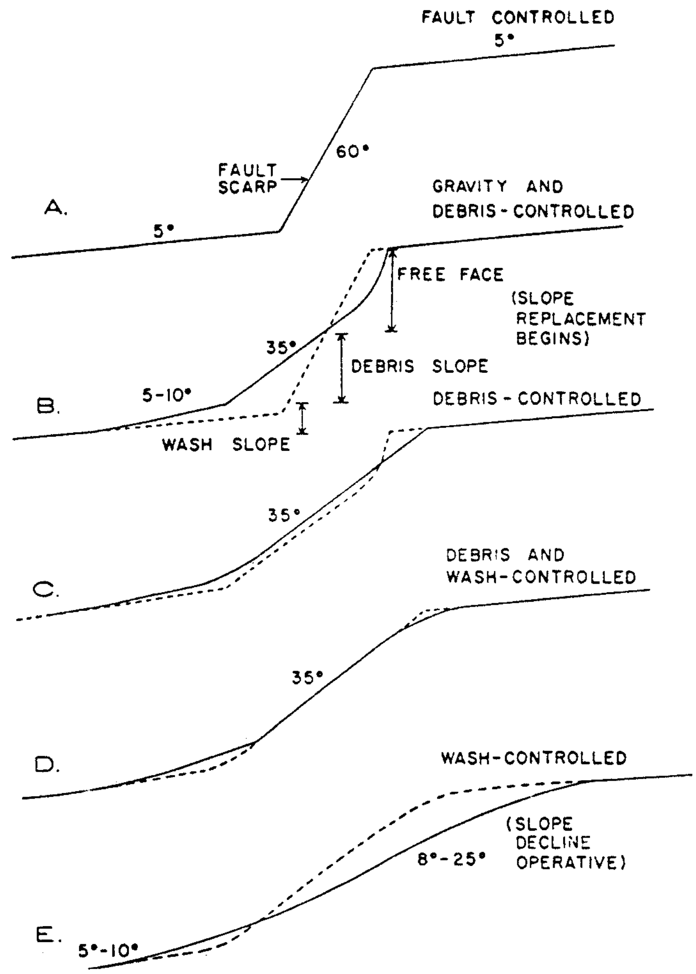
2a	Scarp Offset
2H	Scarp Height
θs	Scarp Slope Angle
θf	Far-field Slope

(after Hanks, et al., 1984)

FIG. 6 - Fault scarp geometry.



Block diagram of a fault scarp showing terminology used in this study.



Sequence of fault-scarp degradation. To show incremental change, dotted line represents solid line of previous profile.

Fig. 7. Figure illustrating scarp degradation model (from Wallace, 1977).

APPENDIX A - Scarp Degradation Analysis of the Alvord Fault

Geomorphic analysis of the eroded scarp of the Alvord fault provides other evidence of the fault's history and a rough estimate of the age of the most recent faulting event. The technique of scarp analysis has been developed and successfully applied elsewhere in the Basin and Range. Wallace (1977) and Bucknam and Anderson (1979) reported that the slope angle of an eroded scarp in a desert climate is dependent on the age and the initial height of the scarp. Furthermore, the profiles of such eroded scarps elsewhere in the Basin and Range resemble the standard mathematical function for evaluating errors for the solution to the diffusion equation for step-like initial conditions (Hanks et al., 1984; Hanks, 1986, personal communication). The various geometric components of the fault scarp as described by Wallace (1977) and Hanks et al. (1984) and are shown on Figure 16.

Twenty five profiles of the central and northern parts of Alvord fault were measured following the procedures outlined by Wallace (1977) and Bucknam and Anderson (1979). Profile sites were selected to avoid human and animal modification of the scarp or areas of more intense, localized erosion. Also, relatively less vegetated scarp areas were chosen in order to minimize measurement error. Of the 25 profiles measured, 18 were located in intermediate-aged lake deposits (Qld_2) and 7 were measured in older alluvial fan deposits (Qaf_1). A basal graben was located within the 7 profiles measured in the older alluvial fan deposits. The graben, acting as a sediment trap, does not allow material to move downward from the scarp to the farfield slope, therefore the slope does not conform to the profile that is similar to the error function (Hanks et al., 1984; Hanks, 1986, personal communication). Once the graben has been buried by sediment, the slope shape then begins to resemble the model profile. It can then be assumed that most fault scarps that have an associated graben have an initial period of time when degraded slope materials are filling the graben and not moving outward along the base of the scarp.

The error function model assumes that the scarp profile is the product of a single faulting event (Wallace, 1977; Bucknam and Anderson, 1979; Hanks et al., 1984). A scarp formed by more than one event will affect the model by providing a larger scarp height and a complex slope angle. The initial study conducted by Hemphill-Haley (1987) concluded that the scarp had a simple profile that was the result of only one faulting event. During this study the scarp was surveyed in additional places and profiles from the previous study were reviewed. The profiles of the scarp measured within the poorly consolidated lacustrine and fan deposits show a single scarp and not multiple scarps. A beveled upper slope surface is possibly preserved on the scarp located within the more indurated older alluvial fan deposits. Because of this possible degraded older scarp the error function model used in this study provides only a rough approximation of the timing of the recency of latest faulting. In the degradation analysis the constant for mass diffusivity incorporates all variables responsible for the modification of the scarp such as climate, aspect, and composition, but excludes time. Based on analyses of shoreline scarps of the pluvial Lakes Lahontan and Bonneville, Hanks et al. (1984) and Hanks and Wallace (1985) estimated that a value of $1.1 \times 10^{-3}\ m^2/yr$ was an appropriate general value for the Great Basin province. This same constant was used for over analysis of the Alvord fault scarp.

A graphical method of analyzing the degraded fault scarp shows that most scarps possess a nearly anti-symmetrical profile (Hanks et al., 1984). The error function predicts the fault scarp profile by the equation:

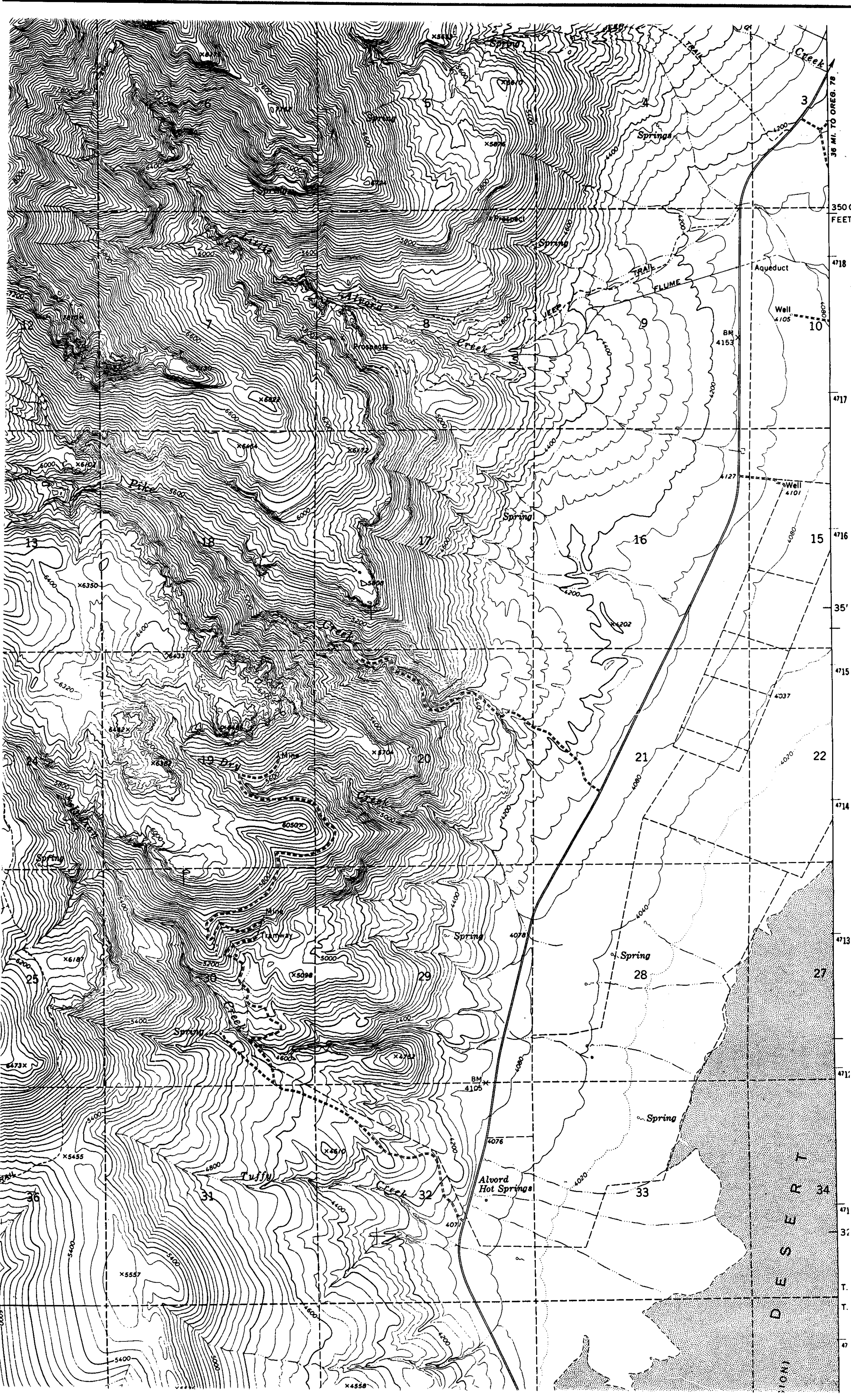
$$\mu = X/2\ (\kappa)$$

where "μ" is the error function, "X" is the location on the abscissa that corresponds to the error function value, "κ" is the mass diffusivity constant, (1.1×10^{-3} m^2/yr) and "t" is time. When the error function is equal to 1, the 84% amplitude point is attained. Therefore, the value for time, "t", can be obtained,

$$t = X_{84}/\kappa\mu = \frac{X_{84}}{1.1}$$

The scarp profiles were drafted with the point of zero anti-symmetry located with "X" and "Y" equal to zero. Points of convexity along the profile are assigned positive "X" and "Y" values, while the concave portions of the slope receive negative values. The X_{84} value, or the vertical value equal to 84% of the height of the convex slope, is graphically estimated. A horizontal line is drawn through the slope, and the "X" value (horizontal distance from zero along the scarp) is calculated. This X_{84} value is then entered into the error function equation. The solution to this equation is the product:

$$\kappa = X_{84}$$



Spring
Creek
TRAIL
36 MI. TO OREG. 78
Springs
350 000 FEET
Prospect
Little
Alvord
Creek
Spring
TRAIL
FLUME
JEEP
Aqueduct
Well
4105
BM
4153
Prospect
Pike
Creek
Spring
Well
4101
4127
Dry
Creek
Mine
Tramway
Spring
Spring
BM
4105
Tuffy
Creek
Alvord
Hot Springs
Spring
DESERT
1
5
4
3
12
7
8
9
10
13
18
17
16
15
24
19
20
21
22
25
30
29
28
27
36
31
32
33
34