Unit 3: Geodetic Survey of a Fault Scarp – Student Exercise

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Fault scarps form when a fault ruptures the earth surface in a seismic event and are topographic evidence of past earthquakes. The study of fault scarps leads to important insight into the history of faulting during the Quaternary, and provides a way to constrain magnitude and frequency of paleoseismic events. The magnitude of a slip event can be estimated using maximum fault displacement to magnitude relationships. Frequency may be derived from scarp morphology. In the case of normal faults, scarps are observed to initially form as a step-shaped landform. Over time, fault scarps deteriorate due to erosional processes. Their peak slopes decrease, and the overall shape of the step degrades. The form of the scarp may also indicate it was formed by multiple slip events, and the offset of each of these events with the relative ages estimated from the morphology of the surface can be used to calculate the frequency of events.

Scarps fall into two categories: weathering-limited and transport-limited. Weathering-limited scarps do not weather as quickly as material is transported away; these scarps are generally composed of bedrock. The eroded material sometimes present at the base of a bedrock scarp can be used for erosion models to predict recurrence intervals. It is generally assumed that scarps develop in unconsolidated material initially reflect the propagation of the fault plane to the surface. Transport-limited scarps weather more quickly than material is transported away, so over time these scarps tend toward the angle of repose of the material composing the scarp. This can be modeled as a diffusion process.

Introduction:

In this unit, you will apply the skills of survey design from Unit 1 to design a survey to characterize a fault by estimating displacement and magnitude of slip event(s) on the fault. Keep in mind all skills learned previously, such as collecting appropriate metadata, sketching both the outcrop and the survey setup, and considering the ultimate research question while designing the survey. Once the survey is complete, you will construct a history of the fault, based on measurements of displacement(s), frequency of events, and model the erosional processes modifying the morphology of the fault scarp.

Project Description:

Below is a description of the workflow to follow when working on this project. This exercise is expected to take eight to ten hours, with additional time to quantify the deformation history using the data produced in the field.

NOTE: *All survey instruments should be treated with care. These instruments are used by many scientific researchers and may be on loan from a community pool maintained by UNAVCO or your institution. These instruments are in high demand, so careful and cautious handling of the equipment is essential, both for the success of the immediate project but also for others who depend on the equipment being in excellent working condition at the end of the day.*

Field Notes and Metadata Collection:

While in the field, record field notes as you would on any other field day (weather, rock type[s], measurements of strike and dip or other features, a sketch of the outcrop) as well as detailed metadata related to the scans. Metadata includes a sketch of the survey design, including camera locations / collection path or scanner locations, target locations, and study area; justification (including the limitations) of the selection of these locations; file naming conventions and locations; the surface texture, color and condition; who is present; and the object of the project (as well as anything else that seems important to recall from the survey when no longer in the field). If doing a TLS survey, comment on how the reflectance may affect the scan

In addition, describe and measure the fault scarp in your notes. What is the shape of the scarp? Does the scarp have a break in slope mid-scarp? What is the measured height of the scarp in the field? Do you interpret this as making up one event or two (or more?) What is the composition of the scarp? Does the composition change from the top to the bottom of the scarp? Considering these questions in the field will make the final write-up process significantly faster. As you take notes on these questions, you should also make a sketch of the scarp to complement your answers.

When not working on a scan, measure the elevations of a previously collected profile of the fault scarp provided to you. Take 28 elevation measurements of the profile—these should be equally spaced. You will use this in your final write-up for this unit.

You will also be measuring scarp profiles using traditional profiling techniques.

Data Exploration and Analysis:

You have been given both a *Field Methods Manual* and *Data Processing and Exploration Manual* for the method/s you will be using. The method of rotating, measuring, and exporting the data was covered in Unit 1, so this will be a review.

In addition, you will use your data to either create an erosion model to predict recurrence interval or a hillslope diffusion model to predict future scarp morphology. The hillslope diffusion model will be calculated in an Excel sheet provided to you; you will need to make the recurrence interval model yourself based on the steps outlined for you in the instructor presentation.

Write-up:

After collecting and exploring the geodetic survey data, create a write-up detailed below about the specifics of survey design and results of fault scarp analysis.

Project Report:

Part A: Survey Design Description

1. How did you design this survey to highlight the area of interest?
2. Provide a map of the camera locations / collection path or scan positions, target, and GPS locations with annotations justifying and explaining why those locations were chosen. Include any limitations on camera locations / collection path or scan, target or GPS positions.
3. If doing a TLS survey: Describe the target tie-point verification process, including a plot of the tie-points from RiScan Pro and the degree of correlation of the points. Use this

information to discuss the goodness of fit of the merged data sets and what could have been done to increase the goodness of fit.

4. If doing an SfM survey: provide a map of camera locations. Based on the calculated camera locations from the software, how could you have designed the survey better to highlight the feature of interest? Are any important portions missing or blurry? Use the function in the SfM software to generate a map of photo density. Does this map show you successfully surveyed the feature of interest? Why or why not?

Part B: Hillslope Diffusion Problem Set

See the additional sheet on hillslope diffusion your instructor provided you.

Part C: Fault Scarp Analysis 1

This section of the report is an analysis of three cross-sectional profiles through the fault.

1. Make figures of the profiles you generated with labels as well as a figure showing the locations of each profile on the scarp. Include the locations of the profiles you measured with traditional profiling methods.
2. Estimate moment magnitude using the given moment magnitude versus displacement graphs below.
3. Assume your measurement is the maximum displacement and use this to estimate surface rupture length using the maximum displacement versus surface rupture length graph below. Based on the type of fault and rupture length you calculated, estimate moment magnitude for your profiles.
4. Are these magnitude estimates similar?
5. If this displacement represents more than one event, report the displacement for the individual events as well and justify your reasoning as to why the scarp represents multiple events.

Part D: Fault Scarp Analysis 2 (Model)

Is your scarp transport limited or weathering limited?

If transport limited:

RiScan Pro and Agisoft do not have the capability to export profiles, so make measurements of your profiles manually by taking elevation measurements at set distances apart. You will need each profile to be composed of 28 measurements. Select one laser rangefinder profile and one LiDAR or SfM (depending on your survey method) profile to use for the next section.

Conduct a hillslope diffusion analysis.

1. Model the diffusion of the slope using the provided Excel spreadsheet. Input the provided older profile of the scarp to the spreadsheet and manipulate the k and dt values. If the age of the scarp is known, just manipulate the k (transport rate) values.
2. If you know the age of the scarp, choose a dt that makes the model represent the scarp in the present. How does this compare to the scarp you measured using traditional methods? A LiDAR profile?
3. Open a new spreadsheet. Input a LiDAR profile you measured in the field. What will the scarp look like in fifty years?
4. Manipulate the dt values. At what age does the step in the topography disappear?

If weathering-limited:

Use the height of the eroded material and erosion rate to create a model to estimate the recurrence interval. Pick a rate that makes sense given the vegetation, climate, and/or tectonic history of the area. To select, calculate recurrence intervals based on multiple rates and then explain which is most representative, with justification for your choice. It is easiest to do this section in an Excel spreadsheet, which can then be attached to your final write-up.

- fault scarp eroded material height, m (H)
- erosion rate, m/yr (ER)
- Recurrence interval, yr (RI)
- H / ER = RI

For both:

Write a brief description (1–2 paragraphs), based on the above calculations, of the deformation history of the fault.

Write a paragraph to answer the following questions:

1. What is the societal impetus to study fault scarps and why use TLS?
2. What are the most useful components of Unit 1 that you used for Unit 3? What did you need to change from what you did in Unit 1?

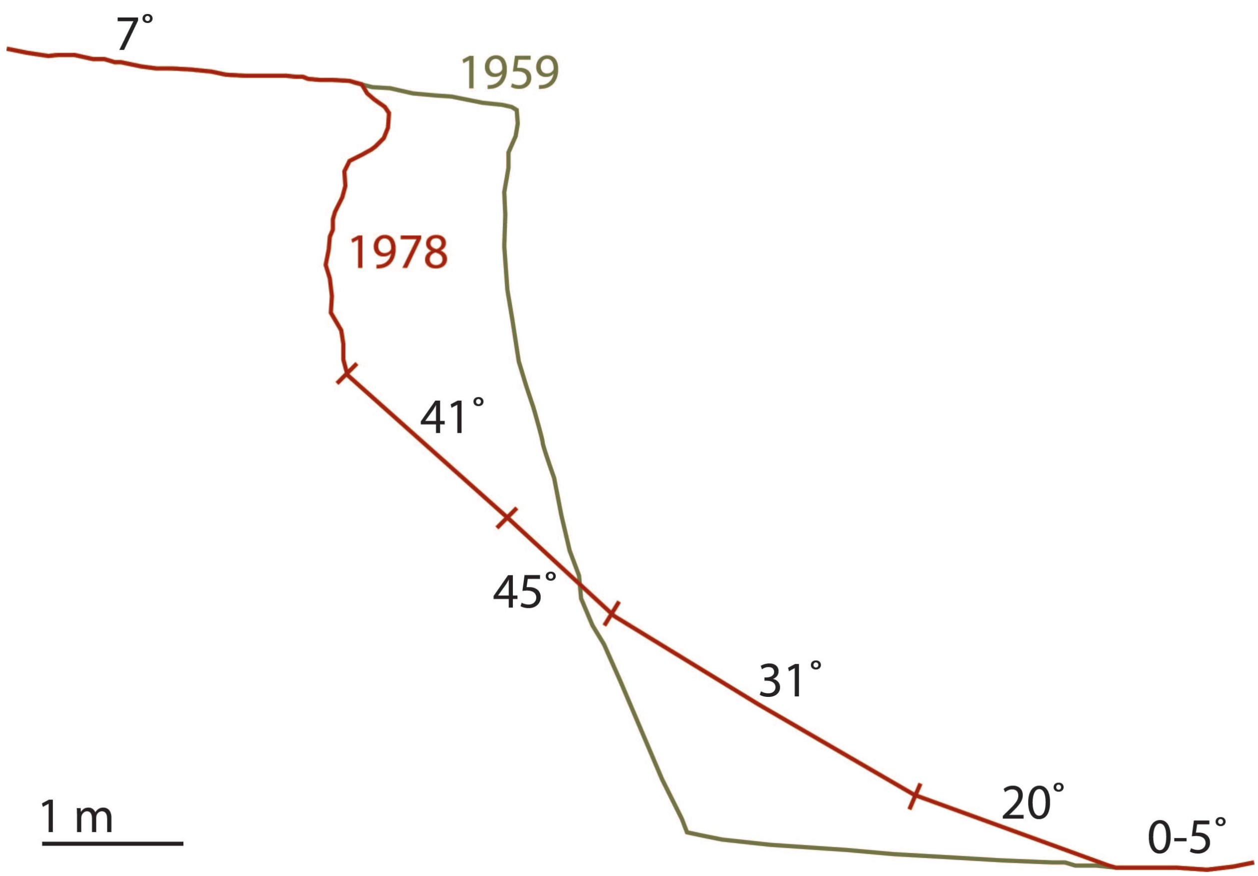
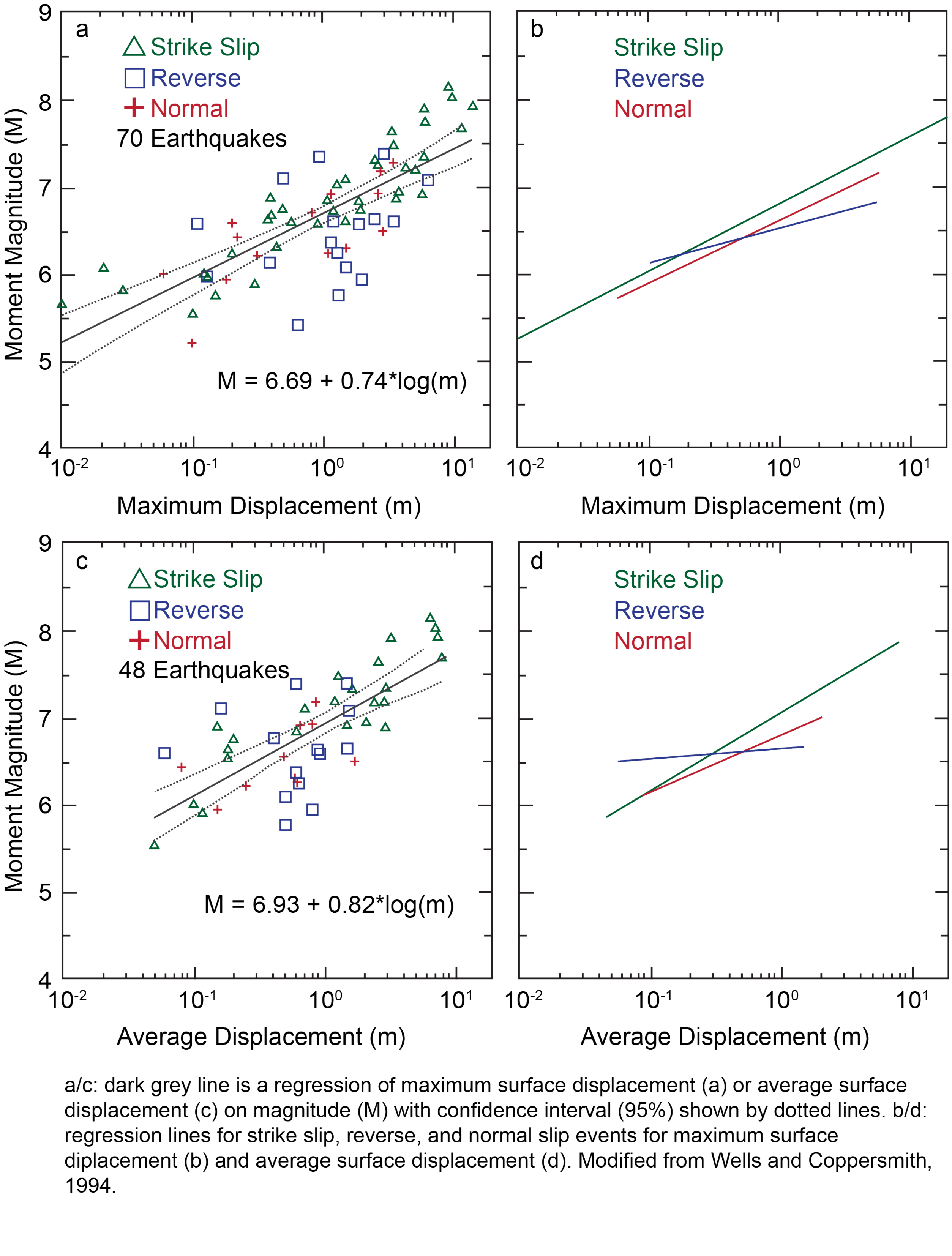


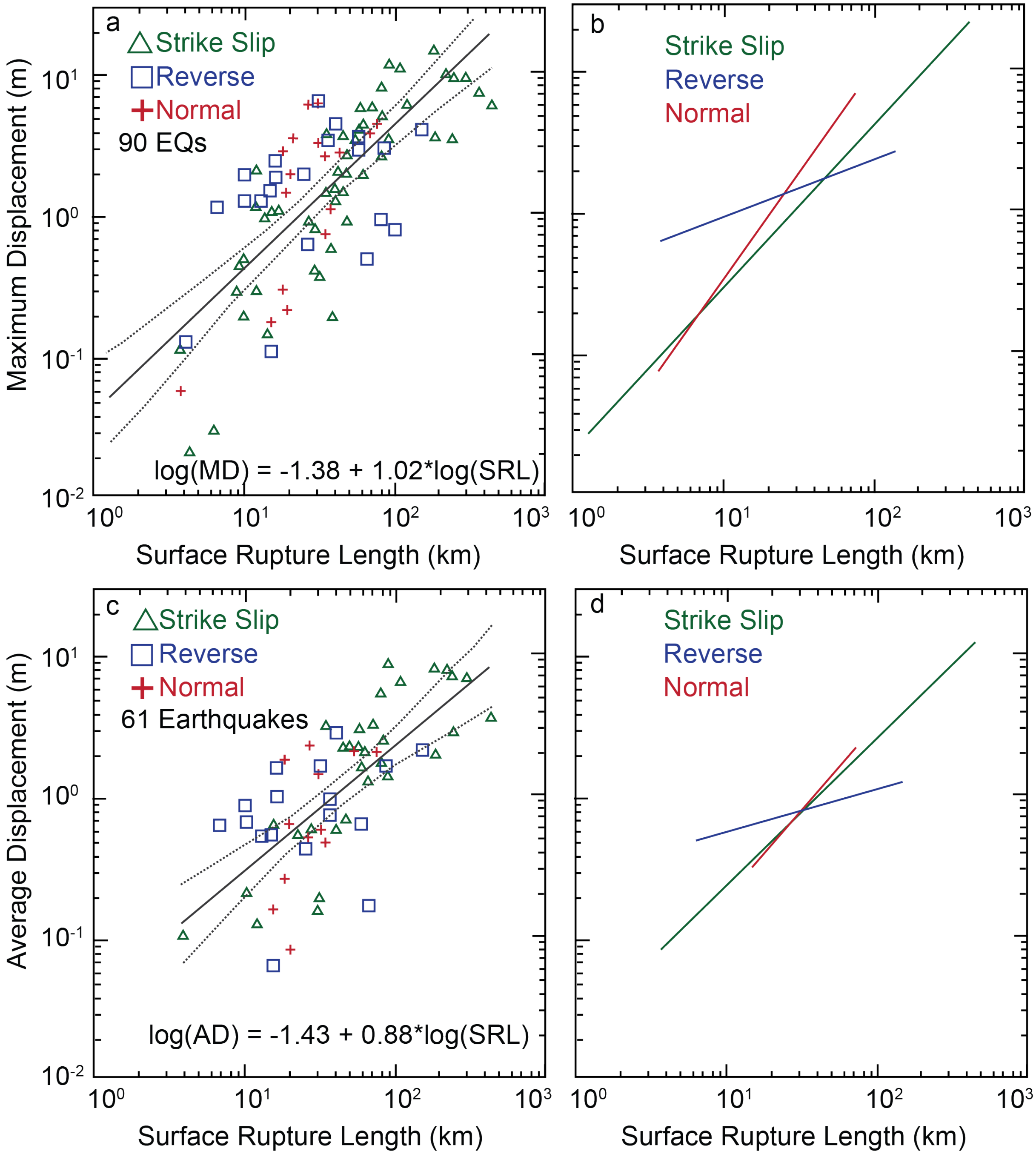
Figure 1. Example fault scarp evolution: Hebgen Lake, Cabin Creek location, 1959 and 1978. Modified from Wallace, 1980.

Figure 2.



a/c: dark grey line is a regression of maximum surface displacement (a) or average surface displacement (c) on magnitude (M) with confidence interval (95%) shown by dotted lines. b/d: regression lines for strike slip, reverse, and normal slip events for maximum surface diplacement (b) and average surface displacement (d). Modified from Wells and Coppersmith, 1994.

Figure 3.



a/c: dark grey line is a regression of surface rupture length maximum displacement (a) or average displacement (c) with confidence interval (95%) shown by dotted lines. b/d: regression lines for strike slip, reverse, and normal slip events for maximum surface diplacement (b) and average surface displacement (d). Modified from Wells and Coppersmith, 1994.

Relationship between displacement length and earthquake magnitude M = Magnitude L = Length	
All rupture types	M = 5.08+1.16*log(L)
Strike slip rupture	M = 5.16+1.12*log(L)
Reverse or thrust rupture	M = 5.00+1.22*log(L)
Normal rupture	M = 4.86+1.32*log(L)

Based on Wells and Coppersmith, 1994

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Scan Resolution Parameter Worksheet

Use this worksheet to determine the optimal and realistic scan times based on desired scan resolution.

Beam diameter at instrument: __________m (RieglZ620 =0.014; RieglVZ400=0.00

Beam divergence: ___________radians (RieglZ620=0.00015; RieglVZ400=0.0003)

Constants for a given scanner

Table 1. Scan spacing

Scan site and scan number	Distance to target (m)	Spot size (m) [Dist*Diverg]+Diameter	Angle of Incidence to target	Ellipse max diameter (m): Spotsize/sine[Angle]	Optimal measurement spacing (m)	Actual spacing used (m)	Comments
	Min						
	Max						
	Mean						
	Min						
	Max						
	Mean						
	Min						
	Max						
	Mean						
	Min						
	Max						
	Mean						

Table 2. Scan time

Scan site and scan number	Horiz scan dist (m)	Optimal # horiz measurements	Vert scan dist (m)	Optimal # vert measurements	Time for optimal scan [#horiz * #vert * time/measurement]	Time for actual scan

Unit 3 Rubric – Geodetic survey of fault scarp

This rubric covers the material handed in for Unit 3 student assignment and is the summative assessment for the unit.

Component	Exemplary	Basic	Nonperformance
General Considerations	Exemplary work will not just answer all components of the given question but also answer correctly, completely, and thoughtfully. Attention to detail—as well as answers that are logical and make sense—is an important piece of this.	Basic work may answer all components of the given question, but some answers are incorrect, ill-considered, or difficult to interpret given the context of the question. Basic work may also be missing components of a given question.	Nonperformance occurs when students are missing large portions of the assignment, or when the answers simply do not make sense and are incorrect.
Part A: Survey Design Description **(7 points)**	6–7 points: Survey design to highlight scarp (2 points) Map with scanner, target, and GPS locations with justifications (2 points) Target tie-point verification, including a figure, degree of correlation, and explanation of the goodness of fit and how it may improve (2 points) OR reflection on collection path / camera locations with figure showing photo overlap and some discussion of how survey design may improve If all of the above in included and the material is presented in a clear, concise and well-written fashion (1 point)	3–5 points: Missing 1–2 of the listed characteristics for an exemplary report and may be poorly written/unclear; AND/OR All characteristics are present but lack detail or are incorrect, showing a lack of comprehension	0–2 points: Missing 2–4 of the characteristics, may be poorly written and unclear; AND/OR Most characteristics are present (1–2 missing) but are incorrect, showing a lack of comprehension
Part B: Hillslope Diffusion Worksheet (10 points)	9–10 points: Each question is worth one point.	5–8 points:	0–4 points:

Part C: Fault Scarp Analysis 1 **(3 points)**	3 points: Figures of profiles analyzed with a logical choice for data projection (1 point) Displacement measurements—all profiles (1 points) Earthquake magnitudes—all profiles (1 point)	2 points: Missing 1 of the characteristics for an exemplary report and may be poorly written or unclear; AND/OR All characteristics are present but lack detail or are incorrect, showing a lack of comprehension	0–1 points: Missing 2–3 of the characteristics, maybe poorly written and unclear; AND/OR Two characteristics are present but are incorrect, showing a lack of comprehension
Part D: Fault Scarp Analysis 2 **(10 points)**	9–10 points: Scarp type (1 point) Model for recurrence interval or hillslope diffusion; paragraph on deformation history of fault and comparison to expected results (6 points) Detailed and thoughtful answer to reflection question about learning experience and societal impetus (2 points) If all of the above is included and the material is presented in a clear, concise, and well-written fashion (1 point)	5–8 points: Missing 1–2 of the characteristics for an exemplary report and may be poorly written or unclear; AND/OR All characteristics are present but lack detail or are incorrect, showing a lack of comprehension AND/OR Answer to reflection question not considered or thoughtful	0–4 points: Missing 3 of the characteristics, may be poorly written and unclear; AND/OR Two characteristics are present but are incorrect, showing a lack of comprehension AND/OR Did not answer reflection question