G422/522 Topics: Alluvial Fans
Lab Exercise: Watershed Morphometry and Fan Analysis in Humid Mountainous Terrains

Introduction

Alluvial fans occur in diverse climo-tectonic settings, and represent critical sites of sediment routing in mountainous watersheds. Fan storage within the fluvial system favors conditions where sediment supply exceeds transport capacity (Harvey, 1990). Although the alluvial fan literature is voluminous, traditional research is spatially biased towards the arid southwestern United States (Lecce, 1990). Fans in the central Appalachians provide a valuable record of humid-regime process, climate change, and debris-flow recurrence interval (Mills, 1983; Kochel and Johnson, 1984; Kochel, 1987, Eaton and others, 1997); however, relatively few studies have been completed in this region. In addition, Appalachian fans occur in hazard-prone footslope areas that are sites of increasing development (Kochel, 1992). Fan analysis provides a fundamental tool for regional hazards assessment.

The first step in systematic fan analysis is identification of watersheds that preserve a depositional record. This task requires a necessary understanding of sediment delivery mechanisms, fan morphology, and geomorphic conditions conducive to fan preservation. This lab exercise focuses on the latter two elements through comparative analysis of three watersheds underlain by the Acadian clastic wedge. These areas include the Fernow Experimental Forest, Tucker County, West Virginia; the North Fork basin, Pocahontas County, West Virginia; and the Little River basin, Augusta County, Virginia (Figure 1). Note all fans discussed in this exercise are small-scale, debris-flow dominated fans that occur and stream tributary junctions. Refer to Figure 2 for a model of fan occurrence.
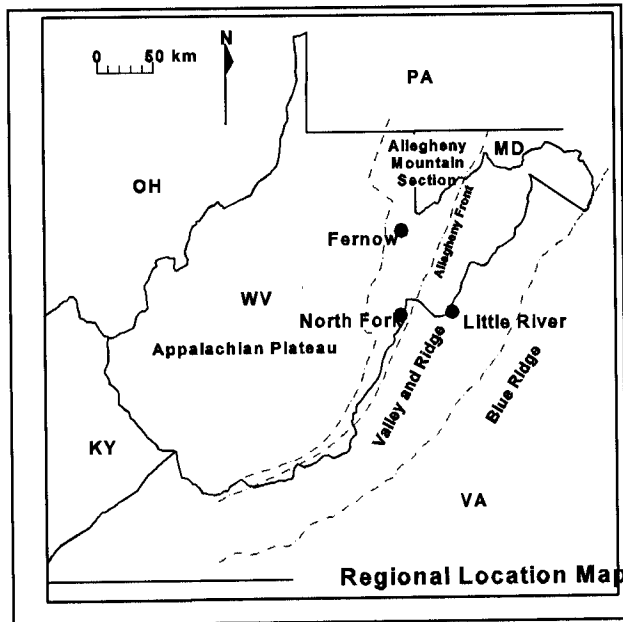

Figure 1. Location map of central Appalachian watersheds.

Surficial Map Units

Qc1 - Quaternary colluvium (side slope veneer, cobble- to boulder-diamicton)

Hch - Holocene channel deposits (alluvium; cobbles and boulders)

Qt2 - Quaternary terrace deposits (2-3 m above channel grade; alluvium; gravelly loam)

Hf - Holocene fan deposits (debris flow, cobble- to boulder-diamicton)

Qf1 - Quaternary fan-terrace deposits (fan surface ~4m above active channel grade; debris flow?-alluvium; cobble- to boulder-diamicton)

Qf2 - Quaternary fan-terrace deposits (fan surface ~10m above active channel grade; debris-flow?-alluvium, cobble- to boulder-diamicton)
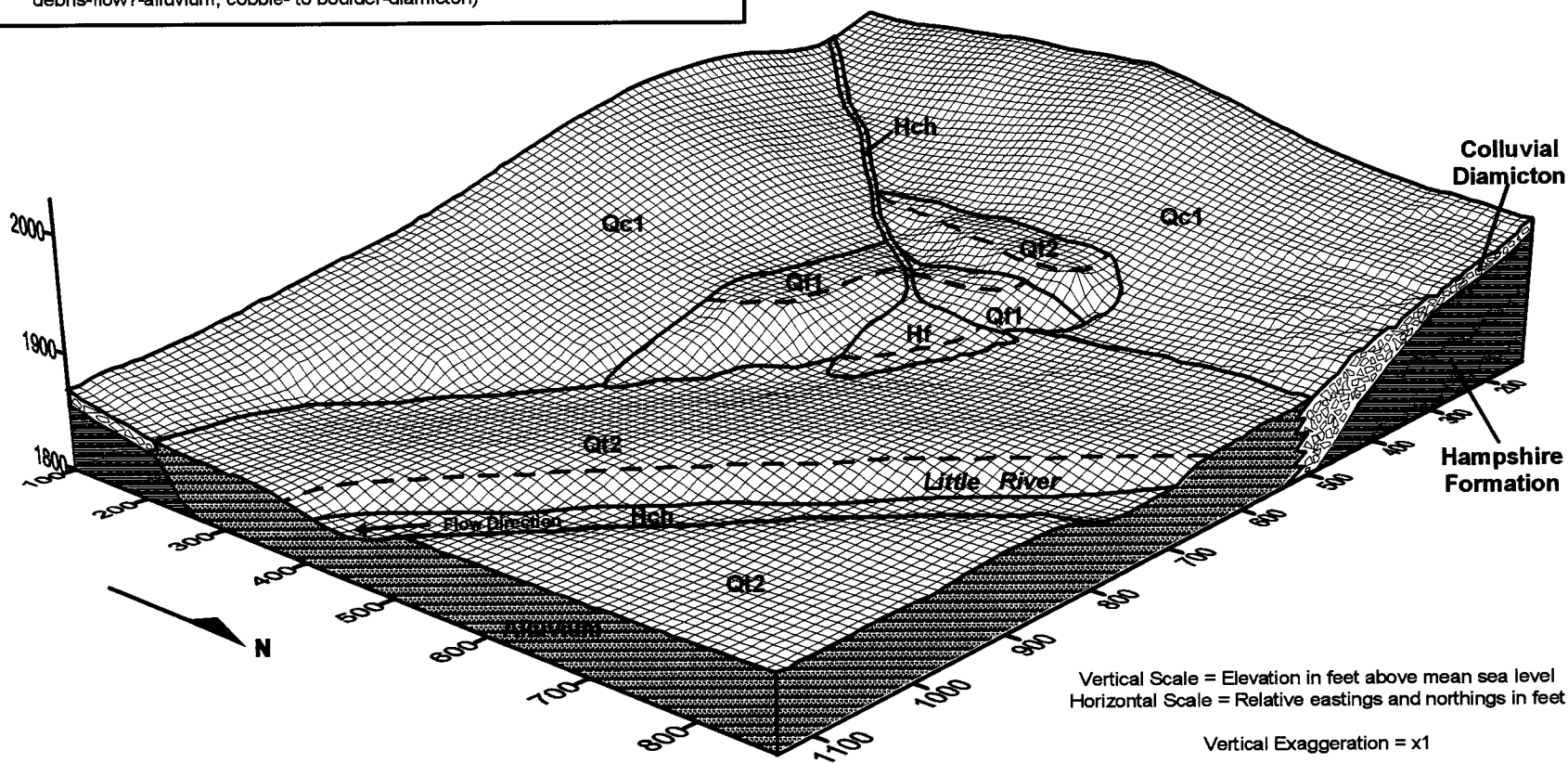

Colluvial Diamicton

Hampshire Formation

Vertical Scale = Elevation in feet above mean sea level
Horizontal Scale = Relative eastings and northings in feet

Vertical Exaggeration = x1

Figure 2. Generalized block diagram illustrating inset fan relationships at the Little River basin, Augusta County, Virginia.

METHODOLOGY

Part 1. Data Analysis

An MS Excel file is available for download at the class web site (www.wou.edu/taylor follows the links to the fans class page, then to the lab data section, click on "Data to Accompany Watershed Morphometry and Fan Analysis in Humid Mountainous Terrains).

> - a left mouse click on the link should result in a dialogue box that will allow you to save the file to your local hard drive, floppy, or network folder. Give the file a useful name (*.xls)

> - if not, then right click on the file and "save link as" to your local hard drive, floppy, or network folder (as above, give the file a useful name *.xls).

The following data tables are available as separate worksheets in the Excel file:

> Table 1. Hillslope gradient data for three watersheds in the Appalachians.
> - side slope gradients (dec. degree) for Fernow, North Fork, and Little River
> - side slope lengths (m) for Fernow, North Fork, and Little River
>
> Table 2. Channel network data for three watersheds in the Appalachians.
> -total watershed drainage areas (km²) for Fernow, North Fork, and Little River
> -Fernow Strahler stream order, stream segment lengths (m), and stream segment gradients (m/m)
> -North Fork Strahler stream order, stream segment lengths (m), and stream segment gradients (m/m)
> -Little River Strahler stream order, stream segment lengths (m), and stream segment gradients (m/m)
>
> Table 3. Valley width data for three watersheds in Appalachians
> - Distance from drainage divide (m) for Fernow, North Fork, Little River
> - Valley width (m) for Fernow, North Fork, Little River
>
> Table 4. Morphometric data for debris-flow dominated fans at three Appalachian watersheds.
> - site ID (Fernow, North Fork, Little River)
> - Fan ID number
> - Fan Type (simple = 1 surface, complex = multiple inset surfaces)
> - Tributary Junction Type (i.e. the type of tributary junction where fans occur: e.g. 111 = first Strahler order intersects first order, 115 = first Strahler order intersects fifth order, 135 = third Strahler order intersects fifth order, and so on).
> - Total fan area (sq. km)
> - Fan Drainage area (sq. km)
> -Tributary Junction Angle (i.e. the angle of intersection between the fan-tributary and the master / receiving stream)
> -Valley bottom width of master tributary (m)
> -Slope of fan tributary (m/m)
> - Slope of receiving stream tributary(m/m)

Task 1. Review all the tables in the Excel workbook, familiarize yourself with the data.

Task 2. Go to the class web page and review the readings for the week of 03/05/01 ("A brief review of statistical techniques", and "A brief review of drainage basin morphometry from Ritter, 1995").
   - especially check over the t-test sections of the first reading
   - make sure you understand the watershed morphometric equations listed in Ritter, 1995.

Task 3. Read Appendix A. and use the Excel help menu as needed to decipher the common statistical and mathematical functions that are available with MS Excel Software.

Task 4. Systematically complete the following analytical tasks using MS Excel (or other software that you may have available).

> **NOTE: At each step listed below, format and print your results. Organize your graphs and data analyses so that they are straight forward, in order, and ready for grading! You will be keying process-based discussions at the end of the data analysis to your results, so make it organized!**

A. Complete a statistical summary of data presented in Table 1, including mean, median, standard deviation, maximum, mimimum, no. of observations for:

   - side slope gradients at Fernow, North Fork, and Little River
   - side slope lengths at Fernow, North Fork, and Little River

B. Complete a systematic t-test for data presented in Table 1, to determine significant differences between data populations.

   - use an alpha value of 0.05 (95% confidence interval)
   - systematic t-test for the following
           - Fernow- North Fork side slope gradients
           -Fernow - Lriv side slope gradients
           - NFork-Lriv side slope gradients
           - Fernow- North Fork side slope lengths
           -Fernow - Lriv side slope lengths
           - NFork-Lriv side slope lengths
   - use t-test results to reject or accept the null hypothesis that side slope gradients and lengths are, on average, the same for each study site.

C. Create scatter plots of side slope gradients vs. side slope lengths for the Fernow, Nfork, and Lriv (use different point styles for each data set).

   - use a linear x and y axis
   - if you see a linear relationship, perform a line-fit / regression analysis of the data
           ** if you remember from a previous lab:
                   #highlight the data points for a series on the graph
                   #from the menu, select Chart-Add Trend Line
                           ** set the options to display the equation and R-square value on the chart

   - if you see a power function relationship, then select the appropriate options on the Chart-Add Trend Line routine.

(NOTE: when performing a regression, the "R-Square" value employs a least-squares method to determine how well the data fit the determined function. An R-Square < 0.5 is pretty dismal, and R-square >0.7 to 1.0 is a good deal).

D. Using Table 2 determine drainage densities for each of the three watersheds

    (1) systematically sum the total lengths for the 1st, 2nd, 3rd... nth stream orders for each of the watersheds in question.

    (2) Systematically calculate the following drainage densities (m/km^2) for each of the three watersheds in question:

        (a) total drainage density (i.e. all stream segments for each watershed, total)
        (b) first order drainage density
        (c) second order drainage density...
        (d) nth order drainage density.

E. Using Table 2 determine the average stream gradients for each of the three watersheds:

    (1) average first order stream gradient, Fern, Nfork, Lriv
    (2) average second order stream gradient, Fern, Nfork, Lriv...
    (3) average nth order stream gradient Fern, Nfork, Lriv

F. Create a scatter plot (from Table 2 data), using linear axes, of stream gradient (y axis) vs. stream order (x axis). Show each of the watersheds as separate series, plot symbols on the graph.

G. Using Table 3 (valley width data), create a scatter plot (linear-linear) of Distance from divide (x axis) vs. Valley width (y axis) for each of the three watersheds.

    -use the Chart-Add Trend function to determine the best fit line, best fit linear equation and Rsquare coefficient for each of the three data sets (follow the procedures as in Task 4C above).

H. Using Table 4, complete the following fan summary analyses for each of the three watersheds:

    (1) a tally (frequency of occurrence) of simple vs. compound fans
    (2) average-median-standard deviation of valley-bottom width of master tributary
    (3) average-median-standard deviation of slope of fan tributary
    (4) average-median-standard deviation of slope of receiving tributary
    (5) average-median-standard deviation of total fan area
    (6) average-median-standard deviation of fan drainage area
    (7) average-median-standard deviation of tributary junction angle
    (7) log-log plot of fan area vs. drainage area (with power-function fit and R-square coefficient)

Part 2. Related Questions / Discussion

Key each of your answers to your analytical results above.

1) Comparatively, is there a statistically significant difference between hillslope gradients and lengths at the study sites? Explain / support your answer.

2) Given that these areas are within 100 km of each other (i.e. fairly close proximity), can you hypothesize what factors might be controlling the relationships between hillslope gradients?

3) Based on your results, which area has a greater likelihood of being associated with slope failure (e.g. landslide and debris flow)... or are both areas the same? Rank each area with respect to slope-failure potential using a relative criteria of lower vs higher.

4) Which area would likely have thicker soil/regolith deposits on the hillslopes? WHY?

5) Did you discover a functional relationship between hillslope gradient and hillslope length? Explain / support your answer.

6) How does hillslope length relate to the style of hydraulic process in a watershed? What would it likely control from a process standpoint?

7) Rank the watersheds in terms of drainage density.

8) Which watersheds display the highest stream gradients? Relate stream gradient to stream power and think about aggradation vs. degradation of the watershed. Which watershed should have the highest stream power and which the lowest (based on the data)?

9) Discuss the results of the fan-morphometry analysis. Identify the geomorphic conditions that are most conducive to fan development and storage in these types of landscapes. Think about all of the statistical parameters that you have generated, relate them to:

    a) type, abundance, and style of accommodation space
    b) style of process / delivery to fans
    c) which combination of morphometric parameters that you've analyzed, provide the greatest potential for fan accumulation and storage?

10) Discuss how knowledge of fan occurrence and fan preservation would be helpful in conducting a debris-flow hazards risk assessment for the Appalachian region.

11) Compare and contrast the occurrence and style of fans in the Appalachians to those associated with the southwestern U.S. In your discussion include: climate variables, tectonic variables, style of accommodation space, style of sediment delivery, scale of fan occurrence.

Basic Statistical Analysis of Data

1. The following is a summary of Excel stat function commands (Type these commands in the appropriate cell):

*note: *cell range* is the range of cell addresses to include in the command, for example if you wanted to add all cells in column B from row 2-20; the formula is   =sum(b2.b20)

Stat	Command
Mean	=average(*cell range*)
Median	=median(*cell range*)
Standard Deviation	=stdev(*cell range*)
Maximum Value	=max(*cell range*)
Minimum Value	=min(*cell range*)
No. of Observations	=count(*cell range*)

Try printing out your results:

-highlight all cells that you want to include in the print out
-file-print area-set print area
-file-print-print preview
     -select printer and print

2. Frequency Analysis

A frequency analysis measures the distribution of data across a number of ranges (or bins). Here's how to complete a frequency analysis with Excel.

-tools-addins-analysis tool pak (note: skip this procedure if "data analysis" is already an option under tools)

-tools-data analysis-histogram

input range: click in box, then highlight the "siltstone" column (don't include the column title)

bin range: click in box, then highlight the "bin range column" (don't include the column title)

click radio button on new worksheet ply (this will put answer on new worksheet), entitle it "histogram" in the worksheet ply box

click OK to conduct the analysis

Typical results for the analysis should look like this:

Bin	Freq
30	0
30.5	0
31	1
31.5	0
32	2
32.5	2
33	3
33.5	2
34	0
34.5	0
35	0
More	0

The bin intervals simply refer to the base value of the frequency range, for example:

30 = no. of values between 30-30.5
30.5 = no. of values between 30.5-31
31 = no. of values between 31-31.5.... etc.

3. Now let's graph the histogram data

-highlight both the bin and freq. columns of the histogram output (include the column titles)
- click on the chart icon on the Excel tool bar
-double-click on the "clustered column" chart option
-click the radio button with "series in columns"
- next
- type in a chart title, x and y axis title (e.g. x = siltstone slopes, y = frequency)
-next
-click radio button: object in "histogram" or in the present worksheet
-finish
-click on the graph so that the box is highlighted, then pull the edges of the graph to resize it, resize the graph so that it is readable.

- now highlight the histogram data cells and the graph cells

-file-printarea-set printarea
-file-print-print preview-print
... send the work to a printer for hardcopy output.

T-Test Analysis

NOTE: the dialogue that follows is from another lab exercise, but the general patterns and reasoning apply to the lab tasks at hand.

A t-test is a statistical method for determining if there is a statistical difference between two sample population means (for example are the siltstone slopes significantly steeper than the sandstone slopes?). As stated above, our "null hypothesis" in this case is that there is NO significant difference between the two data groups. Here's how we will test it using Excel:

> - tools - data analysis
> -choose "t-test: two-sample assuming equal variances"
> -Input / Variable Range 1: click in the box, then highlight the "silstone" column (include the column title)
> -Input/ Variable Range 2: click in the box, then highlight the "sandstone" column (include the col. title)
> - Hypothesized mean difference = 0 (i.e. we're hypothesizing no differences between means)
> -click on the "labels" box, telling excel that the first row has a column title in it
>
> -set Alpha = 0.05
>> ((1 - alpha) x 100% = the confidence with which we will make the test, e.g. alpha = 0.05, confidence = (1-0.05) x 100% = "95%" confidence that our test results are correct)
>
> -click on the radio button for "new worksheet ply" and type "t-test" in the box... this will tell excel to put the t-test results on a new worksheet, and it will call this worksheet "t-test"
>
> - now click on "OK" to run the test
> -set the print area-print preview-print the results

The results of the test should look like this:

t-Test: Two-Sample Assuming Equal Variances

	siltstone slope	sandstone slope
Mean	32.6	32.85
Variance	0.6	2.225
Observations	10	10
Pooled Variance	1.4125	
Hypothesized Mean Difference	0	
df	18	
t Stat	-0.47036	
P(T<=t) one-tail	0.321873	
t Critical one-tail	1.734063	
P(T<=t) two-tail	0.643747	
t Critical two-tail	2.100924	

Now, we will analyze the results. Excel t-test gives the sample mean, variance, degrees of freedom (no. of obs. - 1), a calculated "t stat", and a "critical" t-stat. To determine whether we accept or reject our null hypothesis, we compare the calculated "t stat" to the "t Critical two-tail", and should be read as + or -.

For example above, t Critical two-tail = 2.10 = either +2.10 or - 2.10 (i.e. it is two-tail)

 The t-critical two-tail is a statistic from a table. If the calculated "t-stat" is greater the "t-critical", then we REJECT the null hypothesis... in this case, it would be interpreted that there IS a significant difference between the silstone and sandstone slopes. If the calculated "t-stat" is less than the "t-critical", then we ACCEPT the null hypothesis... that there is no difference between siltstone and sandstone slopes.
In our result: t-stat = -0.47   t-critical = +/- 2.10

the absolute value of the t-stat is less than that of t-critical, hence we ACCEPT the null hypothesis... i.e. the siltstone and sandstone slopes are the same statistically (at least we a 95% sure, since we used an alpha of 0.05, remember).

Check List for Appalachian Fan Lab

Task 4A. Statistical summary of side-slope gradients
Task 4A. Statistical summary of side-slope lengths
Task 4B. T-test of side-slope gradients
Task 4B. T-test of side-slope lengths
Task 4C. Plot of slope gradients vs. lengths
Task 4D. Drainage density calculations (total, first order, second order ... nth order)
Task 4E. Calculation of average stream gradients at each site.
Task 4F. Plot of stream gradients vs. order vs. watershed area
Task 4G. Plot of distance from divide vs valley width
Task 4G. Best line fit of distance-valley width data
Task 4H.

      (1) a tally (frequency of occurrence) of simple vs. compound fans
      (2) average-median-standard deviation of valley-bottom width of master tributary
      (3) average-median-standard deviation of slope of fan tributary
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Related Questions