HILLSLOPE RESPONSE TO REGIONAL EROSIVE EVENTS; CHARACTERIZING ALLUVIAL FAN DEPOSITS IN WESTERN NEW ENGLAND

A Thesis Proposal Presented

by

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to

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of

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The following members of the Thesis Committee have read and approved this document before it was circulated to the faculty:

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Date Accepted: ______________

## ABSTRACT

Alluvial fans have the potential to record the depositional history of the drainage basin from which they are derived. The sediment record contained in fans can be used to determine both the timing and volume of large depositional events. Alluvial fans in the Huntington River Valley of Vermont record times of increased deposition since deglaciation (Zehfuss, 1996; Church, 1997). Those depositional periods were correlative between different fans in the Huntington River Valley, and may reflect erosion due to either local (isolated thunder storms) or regional (megastorms) forcing. By examining 6 to 8 fans throughout Vermont and eastern New York, I will determine whether alluvial fan deposition, and thus hillslope erosion, is regionally synchronous. The conclusions of this study will provide insight into how the landscape responds to natural and anthropogenic disturbances.

## INTRODUCTION

In regions where human development is continually changing the landscape, such as in the heavily populated northeastern United States, it is important to be able to predict the natural consequences of human activity in order to prevent wide-spread flooding, erosion, and pollution. The best way to understand how nature will respond to future landscape changes is to examine past landscape evolution. Alluvial fans are one tool that can be used to determine the amounts of hillslope erosion resulting from both natural phenomena such as large storms or forest fires, and also human-induced change such as clear-cutting. However, alluvial fans in the northeastern US have been largely overlooked in their capacity to quantify fluctuating rates of erosion throughout time. Examining areas where alluvial fans have been studied in the eastern United States (Figure 1), it is apparent that most studies have focused on the southern Appalachians. Considering that alluvial fans are often a recorder of local hillslope processes, alluvial fans can provide long-term sedimentation histories of many heavily populated areas of this country — a tool that could help us to predict natural responses to unnatural landscape changes.

In order for deposition to occur on alluvial fans, there must either be a reduction in the amount of forest cover, which reduces the soil cohesion originally provided by root networks, or an increase in the amount or duration of local rainfall (Pierson, 1980; Kochel, 1987). Previous studies of humid-region fans have shown that very large storm events are capable of triggering alluvial fan deposition even in fully forested regions (Kochel, 1990; Wells and Harvey, 1987; Pierson, 1980). Human activity, such as slashing and burning vegetation on hillslopes, has also caused large amounts of erosion and deposition on alluvial fans, often on a much larger scale than the natural phenomena (Church, 1997; Zehfuss, 1996; Bierman et al., 1997). By examining alluvial fans in many different drainage basins, I will be able to determine whether these disturbances cause erosion on a regional scale, or if the timing of hillslope erosion is solely dependant on the individual characteristics of each drainage basin.

## PREVIOUS WORK

Although alluvial fans occur in many different geographical settings, large studies of alluvial fan processes have traditionally examined sites in arid and semi-arid regions (Bull, 1964; Denny, 1965; Hooke, 1967; Beaty, 1970; Bull, 1972; Nilsen, 1982). Because alluvial fan processes depend heavily on the climate, topography, and erosion rates of the upstream basin, it is difficult to extend the knowledge gained form studies of arid-region fans to alluvial fans that form in other geographic settings. As a result, I have consulted studies that have examined fans in humid-tropical environments (Ruxton, 1970; Mukerji, 1976; Wescott and Etheridge, 1980), humid-temperate environments (Pierson, 1980; Mills, 1982; Kochel and Johnson, 1984; Kochel, 1990), humid-paraglacial environments (Ryder, 1971; Church and Ryder, 1972; Wasson, 1977), and glacial environments (Boothroyd and Ashley, 1975; Nummedal and Boothroyd, 1976).

### Previous Work in the Appalachians

Kochel's study (1990) of alluvial fans in the southern Appalachian Mountains showed that small fans in that region are primarily composed of debris flow deposits. Studies of hillslope stability in New England have also identified the potential for debris flows and landsliding to occur in the northern Appalachians as a result of large storm events (Dethier et al., 1992; Ratte and Rhodes, 1977; Bogucki, 1977; Flaccus, 1958). In broad valleys, debris flows are likely to accumulate as an alluvial fan on the valley floor. Hence, small fans may be a conglomeration of debris flow events that represent individual large storms. Based on historical records of debris flow events in the Mid-Atlantic region, Kochel (1990) quantified the intensity and duration of rainfall required to generate the debris flows (Figure 2), and noted that the amount of rainfall necessary to produce a debris flow may vary with the topography and vegetation of the drainage basin. The storm magnitude required to generate significant erosion in mature forests would be similar to that observed for tropical hurricanes with a recurrence interval of 3,000 to 6,000 years (Kochel, 1990). Kochel also found sharp contacts and texture differences between the strata within the fans, and buried paleosols at intervals where there had been large periods of time between subsequent debris flows, suggesting that it is possible to identify and date individual storm events that have contributed to debris flows deposits.

## Previous Work in Vermont

In 1997, Church studied two alluvial fans in the Huntington River Valley, and suggested that hillslope erosion contributed sediment to Vermont alluvial fans in three ways: 1) erosion due to clearing of vegetation, 2) erosion triggered by catastrophic storms, and 3) erosion from continual soil creep which is washed onto the fan during large storms. Fan aggradation rates calculated by Church show that the amount of deposition on both fans were high during the early Holocene (1.1 and 3.7 $m^3y^{-1}$), but moderate over the next 8 ky ( $< 0.2$ $m^3y^{-1}$) (Figure 3). Aggradation rates increased dramatically to 2.3 and 7.0 $m^3y^{-1}$ after colonial settlement 180 years ago (Figure 3). Both of the alluvial fans studied by Church contain a buried soil horizon determined to be just prior to European settlement in age, based on $^{14}C$ dating of charcoal above and below the paleosol. An abundance of charcoal in the paleosol layer suggests that the native forest was cleared by settlers using slash and burn methods (Church, 1997). Fan aggradation rates at both of the study locations increased dramatically after the hillslope was cleared of vegetation. Hills adjacent to the two fans were re-forested during the 1940's and aggradation rates have dropped on both fans in recent years (Church, 1997). Church determined that 11% and 25% of each fan's total volume was deposited as a result of erosion from historical deforestation.

Zehfuss (1996) studied in detail three alluvial fans situated side-by-side on a low river terrace of the Huntington River. A paleosol A horizon was found in the three fans, representative of the stable, pre-settlement forest floor. The volume of sediment deposited on two of these fans was determined to be 5,000 $m^3$ since settlement, or one-third of the total fan volume (Zehfuss, 1996). Post-settlement deposition on the third fan was calculated to be two-thirds of the fan's total volume (5,500 $m^3$). These numbers reflect a tenfold increase in depositional rates on the alluvial fans resulting from the historical clear-cutting of forests (Zehfuss, 1996).

The results found by Church and Zehfuss show that times of increased erosion can be correlated between alluvial fans that experience the same phenomena. In other words, if two different hillslopes are exposed to the same series of storms, or to the same extent of vegetation removal, both hillslopes will erode and fans below them will aggrade. Since all five of these fans are located in the same river valley, it is not surprising that they would experience the same erosional effects from frequent, large storms and human interaction.

Brown (1999) has suggested that inorganic deposits in lake cores from Ritterbush Pond, Vermont can be attributed to intense storm events that caused erosion of the surrounding hillslopes. Based on the thickness of inorganic sediment observed in the lake cores, the storms that were eroding the hillslopes around Ritterbush Pond are of a size that would produce debris flows according to the Kochel diagram in Figure 2 (Kochel, 1990; Brown, 1999). Bierman et al. (1997) compared the results of lake and fan studies (Brown, 1999; Church, 1997; Zehfuss, 1996; Li, 1996) to other studies of the Holocene paleoclimate in New England, and concluded that hillslope erosion is sensitive to both climate and land-use changes. They suggest that hillslope erosion may be acting in response to large, regional disturbances, and that records of that erosion may be correlated across a large area of the northeastern USA. Thus, it is plausible that alluvial fans throughout New England will contain similar records of large, regional storms, or environmental disturbances.

## SIGNIFICANCE OF RESEARCH

My research seeks to answer the question: *When do hillslopes erode in humid climates?* The study will use alluvial fans, and the depositional records they preserve, to develop a history of hillslope erosion and sediment yield in western New England since the last glaciation approximately 12,000 years ago. Knowing sediment accumulation rates on alluvial fans will allow me to calculate erosion rates as a function of time, infer the frequency of large storm events in post-glacial New England, and estimate the influence of human land-use practices on hillslope stability.

My study will be examining fans that are not near each other, nor within the same river valley. It is possible that each valley has experienced different storm intensities and different erosion rates. However, it would be expected that larger, regional events such as hurricanes would still affect the entire state, and perhaps all of New England, although at different intensities in each river basin. My thesis research will thus examine in detail whether large erosional events are preserved in alluvial fan deposition on a regional or local scale.

## RESEARCH PLAN

### Work Completed

Since August of 1998, I have been learning the skills necessary for the field work involved with this project, and locating suitable fans for this study. My study requires alluvial fans that are no larger than 10m high at the apex. Larger fans would necessitate impracticably long field periods to thoroughly interpret the stratigraphy, and would require deep trenches to examine the fan interior. Small fans are not likely to show up on aerial photos or topographic maps. As a result, I needed to begin my study by addressing the question: *Where are small alluvial fans created and preserved?* A quick review of alluvial fans in the literature shows that alluvial fans are created where there is an abrupt change in slope, such as from a mountainside to a valley. However, many steep valleys in Vermont have large rivers at their base that are likely to wash away any sediment delivered from the slopes (Figure 4). Thus, the best place to find Vermont alluvial fans is in locations that are not only conducive to fan formation, but also fan preservation. Such locations include river terraces, large alluvial valleys where the river has not reached the hillside for a long time, or places where ephemeral streams dissipate before intersecting with a larger stream. The presence of large alluvial fans on the topographic maps appears to correlate well with areas conducive to the formation and preservation of smaller alluvial fans. This past summer, using the topographic maps, I identified areas of Vermont that met the criteria for both creating and preserving alluvial fans.

Topographic map locations that had favorable landscape characteristics were then field-checked in order to locate individual alluvial fans. Important characteristics of each fan include: 1. the fan must be intact and undisturbed; 2. the fan contains a pre-settlement depositional record; and 3. the fan must be in a moist location so that organic material for dating is preserved. So far, I have found 34 alluvial fans throughout Vermont and Quebec, with potentially seven meeting all of the characteristics listed above (Figure 5). Many of the fans I identified had recent deposition from the heavy rains this summer (the wettest summer for northwestern Vermont in over 100 years of historic record). I plan to select six to eight alluvial fans in Vermont and New York based on the characteristics mentioned above, in order to test the hypothesis that large depositional events may be correlative throughout western New England.

The Fall 1998 semester was spent acquiring skills to aid in the stratigraphic interpretation of alluvial fans. A course in Soil Identification provided me with the skills to accurately identify buried soil profiles, and to compare relative soil development ages within the profile. For example, if a layer of sediment has been exposed at the surface for a longer period of time, it will be in a different stage of soil development, and thus have a different color and texture than a layer that had been buried by sediment before a soil could develop. Advanced Field Geomorphology provided instruction in the set-up and use of GPS and Total Station equipment which I will use to survey the fan and trench locations. Additionally, the class opened a new trench in the Moultroup fan examined by Church's 1997 study and mapped the stratigraphy of the fan in order to decipher the depositional history. This provided me with an introduction to the type of trench logging I will be using for my study.

## Future Work

During the next summer season, I plan to survey each alluvial fan and its respective drainage basin using GPS and optical Total Station equipment owned by the University of Vermont Geology department in order to map accurately the topography of each site. Fan volume will be calculated using the equation for a right circular cone;

$$V = ((1/3)\pi r^2 h) \times (s/360),$$

where h is the relief of the fan at the apex, s is the sweep angle, and r is the average radius of the fan (Appendix A). Digitizing the total station data from the stream basin will provide me with a total volume of sediment missing from the gully. A comparison of the gully volume with the alluvial fan volume will indicate if much sediment was lost downstream of the fan.

Two long backhoe trenches will be dug into each fan to expose the interior structure. One trench will be oriented from apex to toe along the ridge of the fan, and the other will be oriented across the fan (perpendicular to the first trench). This orientation of trenches will provide a 3-D view of the interior sediment structure and layering. A detailed stratigraphic log will be made for each trench, with major layers identified. Samples of organic material (such as charcoal and wood) will be taken in order to get age estimates on strata, and will be Accelerator Mass Spectrometer radiocarbon dated at Livermore Laboratory in California. Aggradation rates for different layers of the fan can be calculated assuming that the slope of the fan has remained constant throughout time. The volume of sediment within one layer can be determined by subtracting the total fan volume at the bottom of the layer from total fan volume at the top of that layer. That volume is then divided by the difference in calibrated $^{14}C$ ages of the layer boundaries (Appendix B).

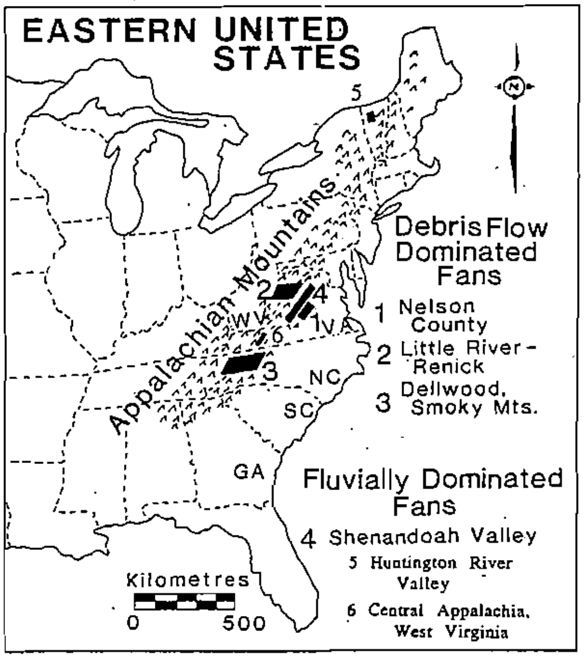
## EXPECTED OUTCOMES

There have been no other studies examining alluvial fans over such a large region of the northeastern United States, thus it is difficult for me to predict what I will find. However, my study is likely to have one of several outcomes:

1. Dating of fan deposits will show that large depositional events are correlative in the stratigraphy of alluvial fans throughout the region, suggesting that regional storms affect all drainage basins in a similar manner.
2. Only one or two events will be correlative amongst all of the fans, suggesting that only very large erosional events (triggered by climate changes, hurricane-force storms, or clear-cutting) will affect hillslopes the same way from basin to basin.
3. The only depositional event that will be correlative in all of the fans will be the result of clear-cutting by humans in the early 1800's. This scenario would make a strong statement about the influence of human activity on landforms in comparison to natural processes.
4. No events will be correlative between fans, showing that hillslope processes are strongly dependent on the characteristics of the individual drainage basin.

## CONCLUSION

My thesis will be the first to examine alluvial fans over a large region of the northeastern United States in terms of the depositional record they preserve. Any correlation I find between depositional events on different alluvial fans will contribute to a better picture of extreme storm frequency, climate change, and human impact since deglaciation over western New England. My study of alluvial fans in western New England will provide a valuable tool to evaluate when and how changes in storm frequency have occurred since glaciation, the influence of European settlement on slope stability, and whether human influence continues to affect slope stability and sediment yield in New England.



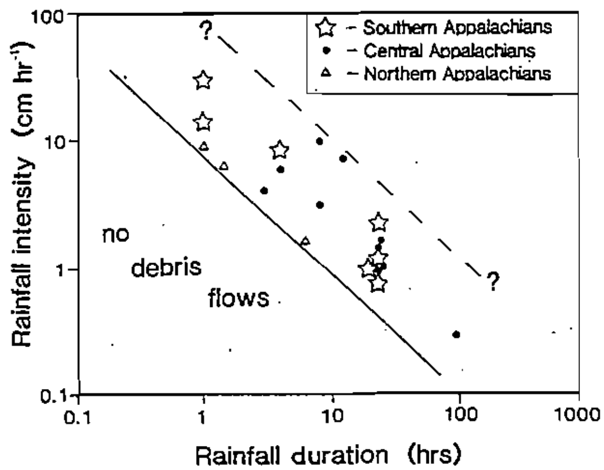




Figure 1: Map of the eastern United States showing the location of major alluvial fan study areas (After Kochel, 1990).

Figure 2: Intensity-duration relation for major debris-flow producing storms in the Appalachians. Debris-flows may occur at lower rainfall intensities as the duration of the storm increases (After Kochel, 1990).

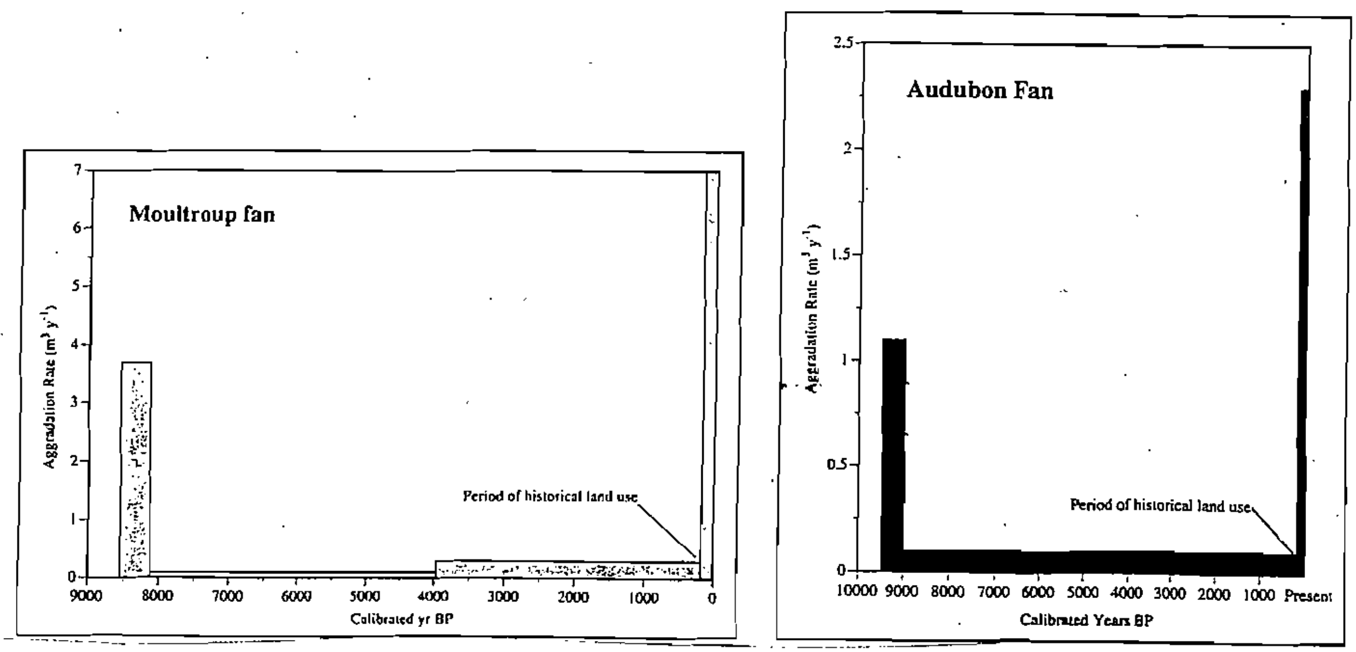



Figure 3: Rates of aggradation on the Moultroup and Audubon fans over the last 9,500 years. The highest aggradation rate coincides with the onset of historical land use in northwestern Vermont (Church, 1997).

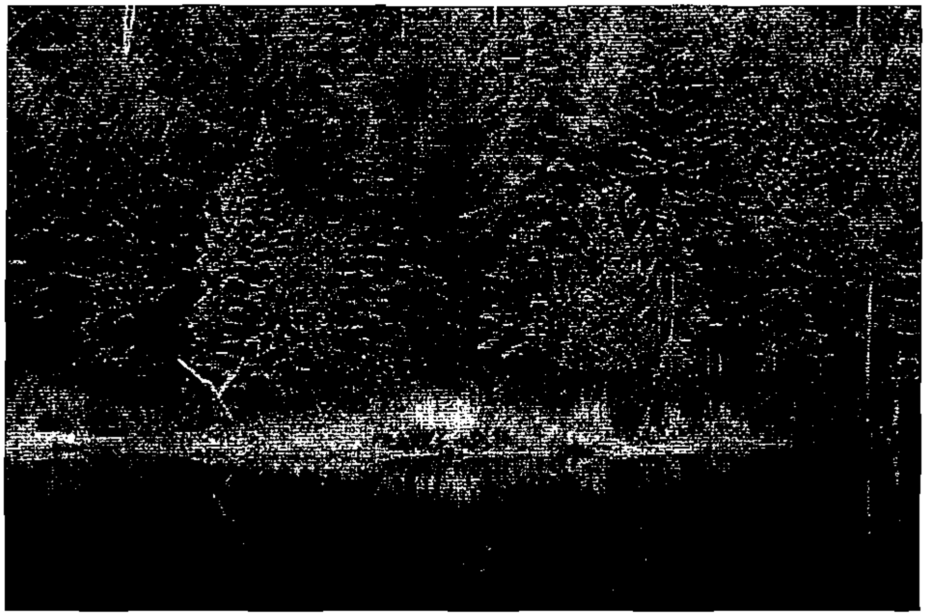


Figure 4: Photo of alluvial fan deposition into a nearby river. These deposits will eventually be washed downstream, and hence will not be preserved for interpretation. Photo courtesy of Anders Noren.

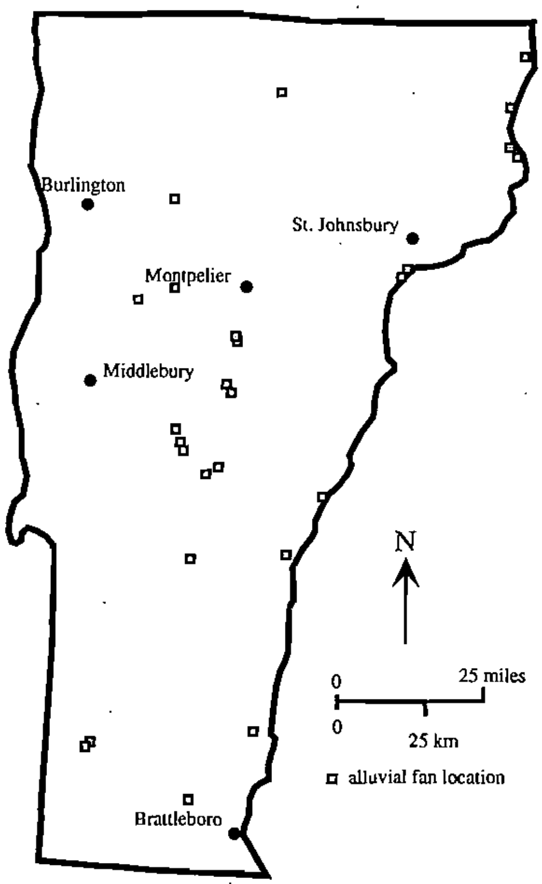



Figure 5: Locations of alluvial fans identified throughout Vermont. Please note that one box may represent more than one alluvial fan.

## Appendix A

Fan Volume Calculation

(From Church, 1997)

The volume equation for a right circular cone can be used to estimate the total volume of an alluvial fan. Because the alluvial fan is only a percentage of complete cone, the equation is altered to include the sweep angle:

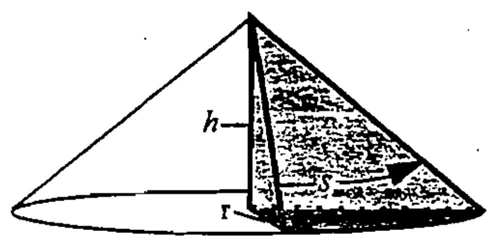
$$V=((1/3)\pi r^2h) \times (s/360)$$

V = fan volume

r = average radius of the fan

h = relief of the fan at the apex

s = sweep angle

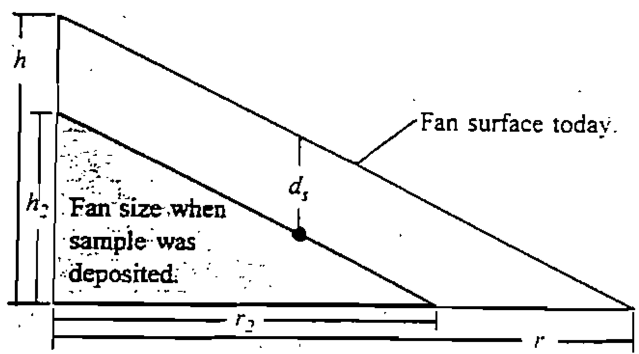


**Appendix B**

Aggradation Rate Calculation

(From Church, 1997)

To calculate aggradation rate, it is assumed that the fan surface has maintained the same slope and sweep angle throughout its history. To calculate an aggradation rate between two fan depths, the total fan volume must be calculated for each depth. For example, in the figure below, $h_2 = h - d_s$ where $d_s$ is the depth of a sample below the modern fan surface, $h_2$ is the height of the fan at the time that sample was deposited, and h is the modern fan height.

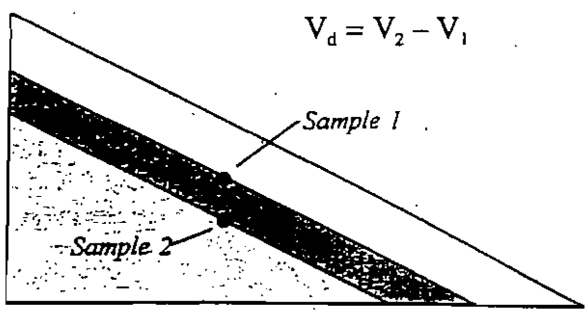



Then, the volume of the fan at the time the sample was deposited ($V_2$) could be calculated using the equation from Appendix A:

$$V_2 = ((1/3)\pi(r_2)^2h_2) \times (s/360)$$

The volume of sediment deposited between two sample depths ($V_d$) can be determined by subtracting the total fan volume for the lower sample from the total fan volume for the higher sample:

$$V_d = V_2 - V_1$$




The volume of that layer is then divided by the age difference of the two samples (using calibrated $^{14}C$ ages):

Aggradation rate = $V_d$ / (age of sample 1- age of sample 2)

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**Timeline**

Summer 1998
-Field Reconnaissance

Fall 1998
-Field Reconnaissance
-Coursework preparation

Spring 1999
-Field Reconnaissance (April/May)

Summer 1999
-Field Work, including surveying, trenching, logging, collection of carbon samples

Fall 1999
-Any wrap up field work
-Carbon dating analysis at Lawrence Livermore Laboratory
-Data analysis
-Presentation of preliminary results at GSA

Spring 2000
-Data analysis
-Write thesis
-Start looking for a job?

Beyond Spring 2000
-Keep writing
-Expect to finish in autumn, 2000

**Funding**
-NSF Career Grant, "Holocene Geologic Records of Episodic Sedimentation – Characterizing the Timing and Distribution of Hillslope Erosion and Extreme Hydrologic Events."
-EPA Star Fellowship: Submitted in November of 1998, will find out the results by June 1999