

Characteristics of a Large Debris Flow Channel

R.J. Fannin

*University of British Columbia
Vancouver, British Columbia*

T. Rollerson

*Ministry of Forests, Vancouver Forest Region
British Columbia*

D. Hogan

*Ministry of Forests, Vancouver Forest Region
British Columbia*

D. Daust

*University of British Columbia
Vancouver, British Columbia*

Abstract

A large, active debris flow channel is located in the Tsitika Valley on Vancouver Island. While the valley is an environmentally sensitive watershed, debris flow activity at the site is a natural process of slope movement. The channel is nearly 2.5 km long from source area to depositional fan, and drops some 1000 m in elevation to the valley floor. Characteristics of the site are described with reference to the behaviour of coastal debris flows. Soils in the source area, the transportation and erosion zone, and on the depositional fan are classified with reference to particle size. An estimate of channel debris yield rate is made based on the field investigation.

Introduction

A long-term sediment monitoring program was initiated in the Tsitika River watershed in 1991 by the Ministry of Forests. In addition to monitoring the total sediment yield from the overall river basin, this program is designed to determine where sediment is produced and how it is transferred and stored within the watershed. A sediment source survey identified some 1211 sources, of which 89 were debris flows. Although this comprises only 7% of the total number of sources, preliminary estimates indicated that debris flows contribute over half of the total sediment load delivered to stream channels. The relative importance of debris flows to overall sediment production has also been documented in other coastal environments (Rood, 1984; Schwab, 1987).

One component of the monitoring program has involved characterization of a very large, active debris flow channel in the watershed. A description of debris movement on its fan is based on a survey of the channel in which the events occur. A classification of soils in the source area, in the gully and on the depositional fan is based on grain-size analysis. A video surveillance system has been installed to augment the survey data with continuing field observations of activity on the fan.

Site description

The Tsitika watershed is a part of the Nimpkish Provincial Forest, situated between Sayward River and Port Hardy on the east coast of Vancouver Island. Located in the Vancouver Island Mountain Ranges, it is an area of rugged terrain, ranging up to 1500 m in elevation. The study area was heavily glaciated during the Fraser Glaciation. Surficial soils were formed during and since the Fraser Glaciation. Drift of this glaciation includes glaciofluvial materials, till and, throughout Holocene time, colluvial materials. While the mid and lower elevation forests are dominated by Western Hemlock and Amabilis Fir, the higher elevation areas are occupied by Mountain Hemlock forests; there are limited areas of alpine tundra.

The site comprises a highly unstable gully headwall that is the major source of debris, a gully or flow channel, and a depositional fan. The active debris flow channel from source area to fan is nearly 2.5 km long. An air photograph of the site taken in 1987, Fig. 1, shows the depositional fan, the gully and the lower part of the extensive source area of the gully headwall. Debris flow activity at the site is not a consequence of forest harvesting operations. A ground survey of the site was used to develop the profile of the debris flow channel shown in Fig. 2.

The gully headwall area is approximately 650 m long. Thick glacial deposits overlying bedrock are cut by an open, deeply incised channel. Slope gradients at the back of the gully headwall are very steep, in the range 40° to 44° (85% to 95%). It comprises two distinct zones, separated by a significant rock step in a

narrow channel that is a feature of the bedrock control of the topography. The upper zone is very open, being some 25 to 100 m wide and 10 to 20 m deep, see Fig. 3. The lower zone is 15 to 30 m wide, and 4 to 17 m deep, becoming less markedly incised as it develops into the debris transport zone of the gully. Three sources of water were identified in the gully headwall area. Surface streamflow enters from the hillslope above. Groundwater flow is evident from gravels in the gully sidewalls. Snowmelt from trapped pockets in deposits of loose, unconsolidated debris is the third source.

The transportation and erosion zone is approximately 1600 m long. It is a channel of reasonably uniform cross-section, typically 10 to 15 m wide, that lies at a uniform gradient in the range 14° to 27° (25% to 50%). The transition from deeply incised channel in the gully headwall, to the main flow channel of the transportation and erosion zone, is controlled by hillslope topography and surficial soils. The upper and lower sections of this channel are quite different. Most of the upper section is scoured to bedrock, and is partially infilled with deposited boulders. Occasional levee deposits are present at curves in the path of movement. The lower section, before the gully opens out on to the depositional fan, also contains significant quantities of deposited boulders. However, erosion of the banks is occurring, and in some places trees have become lodged across the channel, impounding debris on their upstream side. Little scour to bedrock is evident. Rather the action of scour, where it occurs, is one of reworking fill material.

The gully exits from the forested hillslope on to the open slope of the valley floor, see Fig.4. The active debris fan overlies older

historic deposits. The surface of the depositional fan is 215 m long from apex to mainline roadside, some 20,000 m² in area, and lies at a uniform slope gradient of 14° (25%). Debris on the fan comprises sub-angular boulders, cobbles, and fragments of wood. Particle size sorting occurs on the fan, with larger boulders deposited near the apex. While fine sediment is washed off the surface of the fan, some fines are retained within the body of the material.

Soils

Soil samples taken from locations along the channel were classified according to the Unified Soil Classification System. The source area consists of thick deposits of glacial till overlying bedrock. The till comprises boulders and cobbles in a matrix of gravel, sand and silt. The coarse particles are sub-angular. The matrix is a well-graded material, typical of a glacial till, see Fig. 5. There are some fines in the clay-size fraction which exhibit little or no plasticity, and are likely rock flour.

Lower on the hillslope, soils in the transportation and erosion zone are more variable. Exposed cutbanks indicate the channel erodes through well-graded glacial deposits. The soil matrix includes clayey gravels and clayey silts. Near the valley floor there is evidence of fluvial sorting of the soils, with some interbedded lenses of sandy silts in deposits of colluvium.

The depositional fan comprises mainly boulders and cobbles. There are isolated deposits of fine gravels, sands and some silts. The deposits are typically sandy gravels on the upper part of the fan, and gravelly sands on the lower part of the fan.

Characterisation of debris movement

Any characterisation of debris movement in the source area, the transportation and erosion zone, and on the depositional fan must consider both the force to cause movement and the distance moved. Sidewall collapse of the glacial till into the channel, and subsequent creep of the loose material along the gully floor, are strongly in evidence. Conditions in the gully headwall suggest this downslope movement is assisted by streamflow, and to lesser extent by melt of trapped pockets of snow. Movement over long distances is less common. A levee deposit some 10 m long and 4 m high in the channel through the gully headwall observed in reach 13, at the end of the gully headwall, suggests such large events originate high in the source area, and are capable of travelling significant distances. It is likely these major events travel the complete length of the relatively steep, confined channel to the valley floor.

Morphological and vegetational evidence indicate that large changes have occurred on the surface of the depositional fan during storms that have a recurrence interval of between 10 and 20 years. The stream channel has shifted laterally across the surface of the fan during these infrequent, large magnitude storms. The contemporary channel has been in its present location since the early 1960s, approximately. A mainline log hauling road was built across the fan in 1981 and since that time there has been careful documentation of debris movement onto the road. Typically, storms which recur with a frequency of between 1 and 3 years cause minor changes to the fan that are associated with localized bank erosion.

Although these are relatively frequent events, they contribute substantial amounts of debris. The last major event in November 1990 delivered debris, in a series of pulses, onto the road. The quantity of debris on the fan was such that, following regrading of the road, the running surface was observed to be 2.5 m higher than before the storm.

Slope gradients at the back of the gully headwall are in the range 40° to 44° (85% to 95%), and are generally between 50% and 70% (27° and 35°) in this source area. The range of slope gradients in the transportation and erosion zone is between 14° and 27° (25% and 50%). The surface of the depositional fan is at a uniform gradient of 14° (25%). A review of slope gradients in gullies subject to debris flow activity on similar unlogged terrain is provided by VanDine (2), for the Howe Sound region. Initiating angles range between 20° and 57° , with steeper gradients associated with smaller drainage areas. Typically slopes greater than 10° are necessary to maintain movement of debris in a confined channel, and the average gradient (excluding any depositional fan) of events in the Howe Sound region is from 13° to 35° . The average gradient of the site in the Tsitika Valley, excluding the depositional fan, is 24° .

Deposition of material in debris flow events usually occurs at gradients less than 10° , and the range of fan angles in the Howe Sound region is 8° to 18° . The range bounds that of the site in the Tsitika Valley, which is 14° . While it is recognized that interpretation of such slope gradients is dependent on confinement of the gully, and type and water content of the debris, this comparative review of the site confirms that events initiating in the source area are

likely to travel to the valley floor and deposit on the existing fan.

The magnitude of an event may be described by the total volume of debris material transported onto the fan, expressed by a channel debris yield rate (m^3/m). Hungr et al. (1) report derived channel debris yield rates for five documented events of known magnitude in the British Columbia coast range. The values lie between 5 and $18 \text{ m}^3/\text{m}$. An estimation of channel debris yield rate can be made for the site in the Tsitika Valley, based on the length of the transportation and erosion zone, and with reference to the measurements of transported fill material resident in this part of the channel. As such, it does not account for any contributing material from the source area and any erosion of the flow channel by the event itself. Rather the estimation simply implies that all debris resident in the channel is deposited on the fan, and is replaced by material from the source area and additional erosion of the channel. Using this approach, which is based on a concept of storage, leads to a predicted maximum channel debris yield rate of $27 \text{ m}^3/\text{m}$.

Work on debris flow channel morphology in the Queen Charlotte Islands (QCI), Fannin and Rollerson (unpublished), suggests there are two quite distinct types of channel or channelized debris flows: one is characterized by channels which remain relatively steep for their entire length (gradients generally greater than 15 degrees) while the other is characterized by channels which, though steep in their initial sections, have relatively gentle gradients in their lower reaches (generally less than 15 degrees). These two main types can be subdivided into single channel and multiple channel (more than

References

- (1) Hungr, O., Morgan, G.C. and Kellerhals, R. 1984. Quantitative analysis of debris torrent hazards for design of remedial measures. *Can. Geo. J.*, 21, pp. 663-677.
- (2) VanDine, D.F. 1985. Debris flows and debris torrents in the Southern Canadian Cordillera. *Can. Geo. J.*, 22, pp.44-68.
- (3) Rood, K.M. 1984. An aerial photograph inventory of the frequency and yield of mass wasting on the Queen Charlotte Islands, B.C. B.C. Min. of Forests, Land Management Report No. 34, 55 pages.
- (4) Schwab, J.W. 1983. Masting wasting: Oct-Nov 1978 storm, Rennell Sound, Queen Charlotte Islands, B.C. B.C. Min. of Forests, Research Note No. 91, 23 pages.
- (5) Fannin, R.J. and Rollerson, T. (unpublished). Debris Flows: Some Physical Characteristics and Behaviour. A paper submitted to the *Can. Geo. J.*, January 1992.

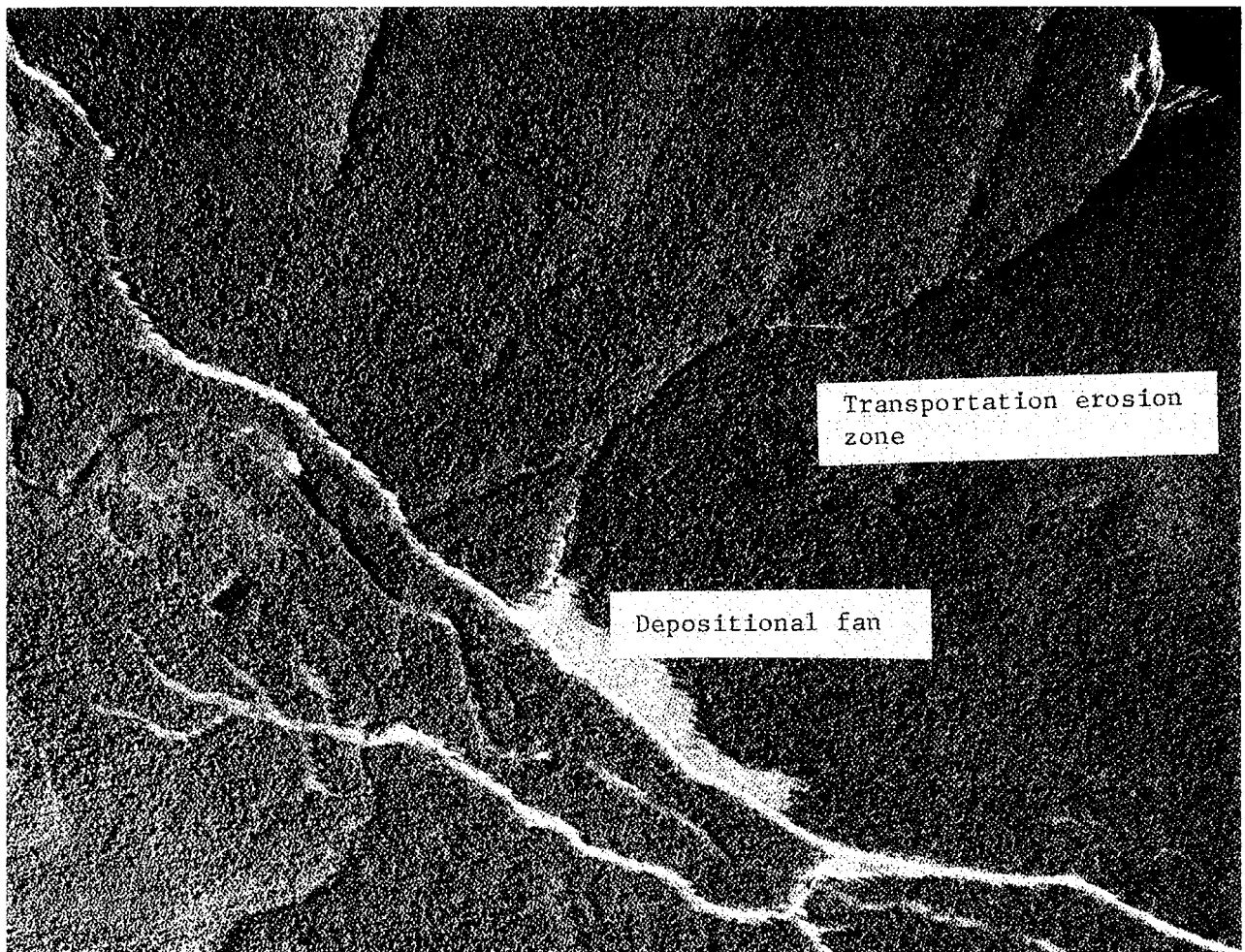


Figure 1. Air photograph of the site

one debris flow coalescing to form a larger flow) events. The two main types show somewhat different gradients in the deposition zone: the continually steep channels have a deposition of fan exhibiting an average gradient of 12° , while the steep/gentle channels exhibit an average gradient of 6° . The second type usually produces larger debris flows, with much longer runout zones (70 versus 190 meters). The characteristics of the Tsitika site would place it in the steep channel and steep fan category found in the QCI. Yet the channel is very long, hence the potential debris flow event size is large, and the runout zone is commensurately longer (200+ m). Runout length for the QCI debris flows was found to be strongly related to the size (volume) of the event. A predicted maximum debris yield rate of $27 \text{ m}^3/\text{s}$ for the Tsitika site is comparable with that of 18 events documented in similar channels in the QCI for which the mean yield is $12.4 \text{ m}^3/\text{s}$ and the standard deviation is $13.2 \text{ m}^3/\text{s}$. The large channel debris yield rate predicted for the Tsitika site is essentially a function of the large size of the channel and headwall area, and the abnormally large quantities of sediment which are being continually recruited from the deep, unstable glacial tills in the headwall area.

Video surveillance system

A video camera has been installed at the site to record activity on the depositional fan. It is used to make a daily recording, and can also capture periodic events. The control system for daily recordings comprises a timer circuit that connects directly to the circuit board of the camera through a series of relays. It allows for a recording of designated duration to be made at a designated time interval. The

existing setting of the control system is for a recording of 60 seconds duration to be made at a time interval of 24 hours. Power for the timers, the video camera and the relays is provided by a 12 V battery. The control system for periodic event recordings comprises a detector switch that is mounted some distance above normal streamflow in the channel, such that it will be triggered by passage of debris. The periodic event recording of a large debris flow moving on to the depositional fan will be used to support decisions concerning hazard control and mitigation, and to better understand sediment yield from the site.

Summary

The site is characterized by an extensive source area, a channelized transportation and erosion zone, and a large depositional fan. Soils in the source area are loose and very unstable. Water ingress is from surface and groundwater flow. The site is prone to debris flow activity and it is likely a major event will flow, without stopping, to deposit where the channel opens and the gradient flattens out onto the depositional fan. Prediction of event yield and travel distance for debris flows is facilitated by field investigation and comparison with other documented events, with emphasis placed on channel storage and channel width and gradient.

Acknowledgements

The work described in this paper has been supported by a research contract from the Ministry of Forests Research Branch. The field survey was performed by R.J. Fannin and D. Daust. Laboratory testing was performed by D.M. Raju.

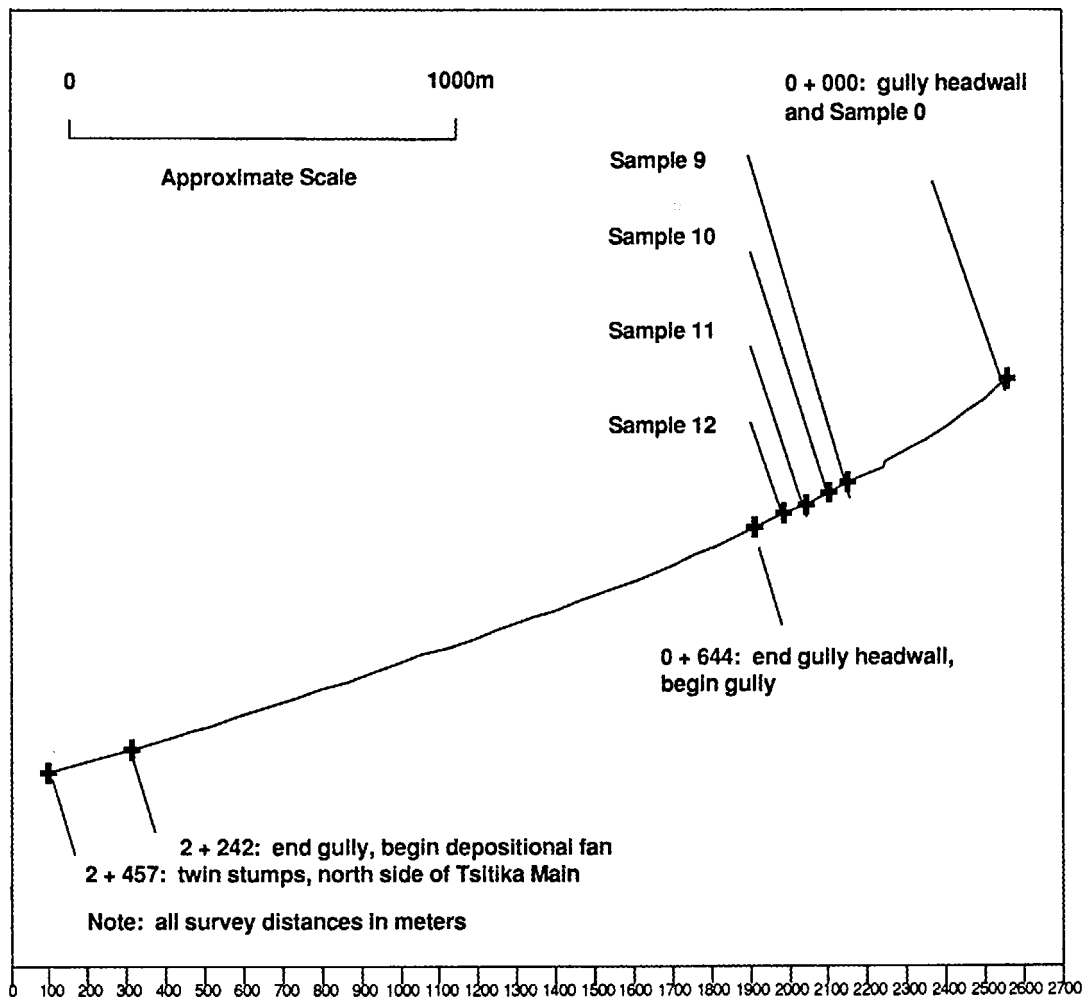


Figure 2. Profile of the debris flow channel

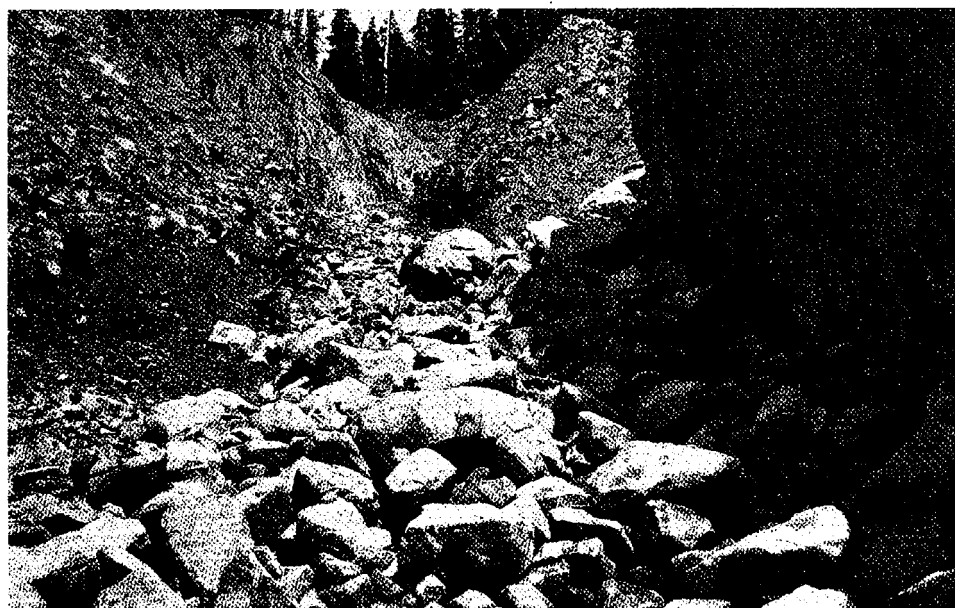


Figure 3. Source area

Figure 4.
Soils matrix of
the source area

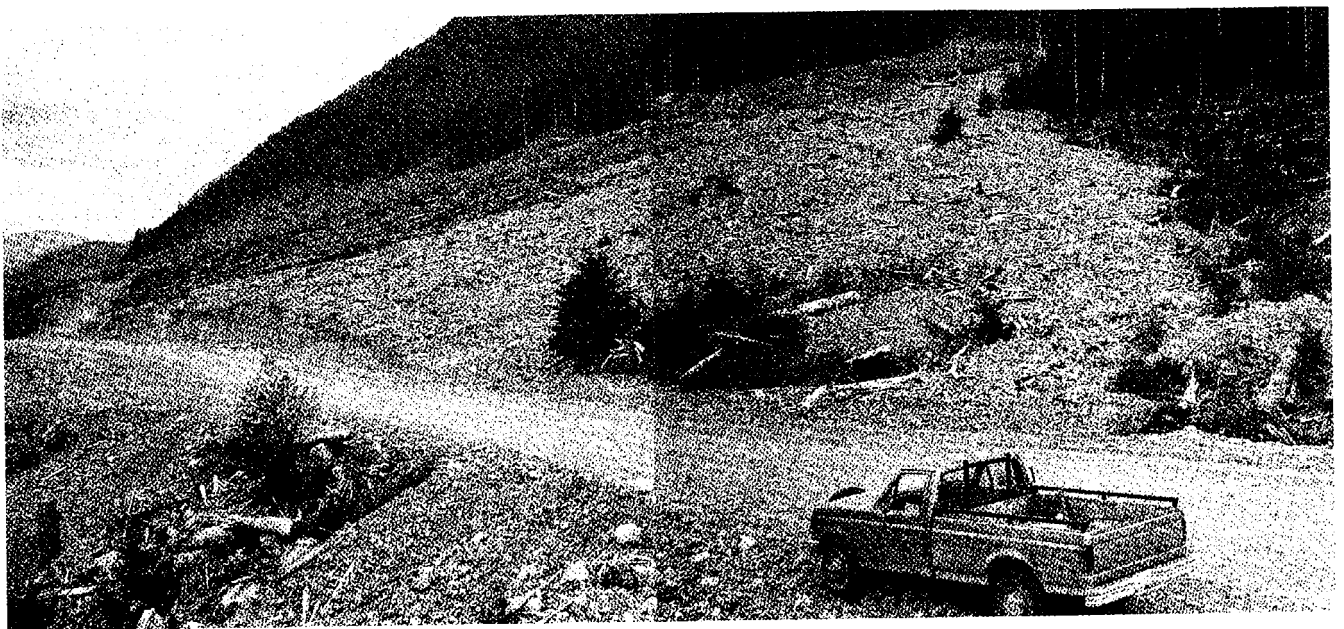
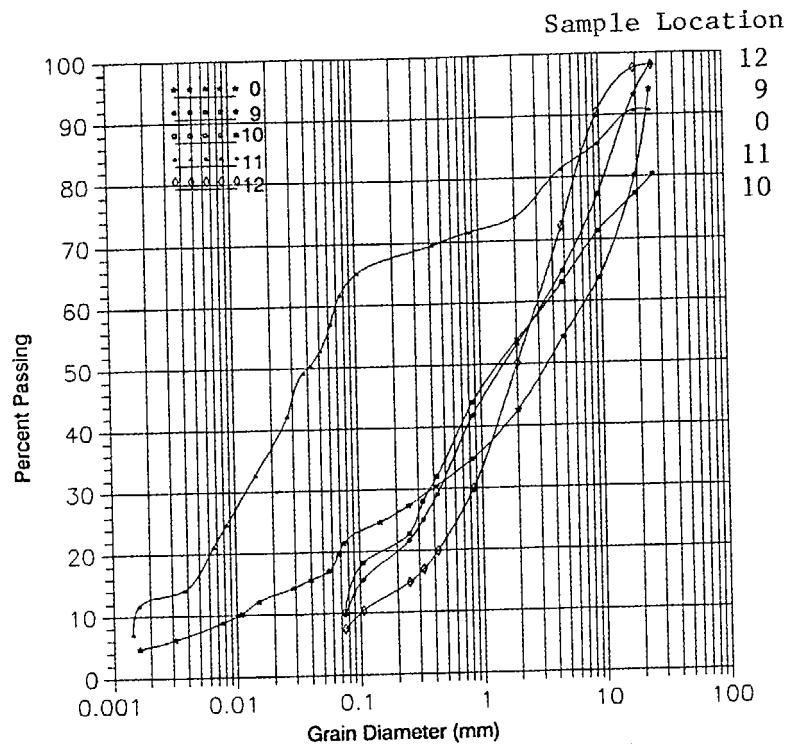


Figure 5. Depositional fan