AN INVESTIGATION OF TALUS SLOPE
DEVELOPMENT IN THE SIMILKAMEEN VALLEY
NEAR KEREMEOS, B. C.

by

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We accept this thesis as conforming
to the required standard

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July, 1972
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Date July 1, 1972.
ABSTRACT

Talus form and development in the Similkameen Valley near Keremeos, British Columbia was investigated. Initial observations suggested that talus formation in the region was entering a passive stage and subsequent analysis has confirmed that the talus slopes are tending towards stability. Volcanic ash exposed on one talus slope allowed the calculation of relative rates of past and recent talus accumulation which supported a 'diminishing sediment yield' concept.

Analysis of climate data recorded at Keremeos since 1930 revealed a high frequency of frost cycles. This suggests the importance of frost action as a mechanism of weathering along the exposed headwalls and it is thought that the occurrence of abundant and massive talus forms in the region is basically the result of frost weathering in association with lithologic controls. A fence structure designed to capture rockfall debris yielded fair results and substantiated the validity of using vegetation as an index of stability on talus slopes.

A weak but not monotonic increase in sediment size downslope was detected on a number of slopes, contradicting an initial visual impression. Debris sampled along lateral profiles on one talus cone is significantly larger at the 1% level than debris sampled along the central profile. Some correlation between size and angle is implied, since the lateral profiles are also steeper; it is hypothesized that transport mechanisms down the sides are different from those along the center of the cone. Readily observable cross-slope sorting,
resulting in the development of longitudinal strips of fine and coarse debris, is explained in terms of differential mass movement mechanisms. It is concluded that the talus slopes studied are complex and influenced by a variety of processes in addition to primary deposition.

The mapping of one talus cone at a five foot contour interval provided the basis for a detailed analysis of talus form. A sample of the debris size taken simultaneously with the mapping of the surface allowed for the calculation and establishment of a fourth degree trend surface, an examination of which is made in conjunction with the map and photos of the cone. Practical implications of the development of talus as applied to this region are discussed.
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CHAPTER I - INTRODUCTION

Near Keremeos in British Columbia the phenomenon of talus development is readily observable. Initial interest for the investigation was prompted by the abundance and great size of the talus forms found in the region (see Map 2). Since preliminary observations suggested that talus development was entering a passive stage and that the rate of formation in the past must have been more rapid, the research was launched under the hypothesis that the talus slopes in the Keremeos area were tending towards stability.

A. **Regional Geology.**

The area studied (see Map 1) is properly a part of two major physiographic divisions of British Columbia that extend along the Similkameen River (see Holland, 1964). The area on the north side of the river is on the southern flank of the Thompson Plateau, part of the Interior System of British Columbia. The area on the south side of the river is part of the Okanagan Range of the Cascade Mountains contained in the Western System. Geology and structure (see Map 3) transcend the region, however, and being part of two major physiographic divisions seems to exert no geologic influence on the development of talus.

It is assumed that all of the slopes must have formed since the last retreat of the Cordilleran Ice Sheet from the area, giving them a geologic age of 10000 (+) years (see Fulton, 1971, p.v and p. 17.) The valley is very steep-walled and deep and represents the incision of the Similkameen River into a plateau surface. The
MAP 1. SOUTHWESTERN B.C.
MAP 2. SIMILKAMEEN VALLEY AT KEREMEOS, B.C.

SCALE 1:70000

COMPILATION FROM B.C. AERIAL PHOTOGRAPHS TAKEN IN 1966

REFERENCE

HIGHWAY OR ROAD
PERMANENT STREAM
INTERMITTENT STREAM
RIVER
TERRACE
TALUS CONES
BOUNDARY OF FIELD AREA

PIN CUSHION MOUNTAIN
MAX-WN TEMP INSTALLATION

KEREMEOS

N

K MOUNTAIN
mean elevation at river level is 1500 feet a.s.l. rising steeply to an elevation of approximately 6000 feet on the north side of the river and approximately 7000 feet on the south side; thus average relief is of the order of 5000 feet. The U-shaped cross-section of the valley (see Photo I-1) suggests that it must have been shaped by the movement of ice through it and the steepness of the valley walls is probably attributable to scouring by glaciers. The general direction of movement of the Cordilleran Ice Sheet in the area was from north to south but observed glacial striae along the valley walls indicate that the ice followed the course of the valley in this confinement, moving in a west to east direction. It seems that the major ice sheet split around the north end of the Okanagan Range near Princeton into two lobes, one of which turned to flow to the southeast
parallel with the Lower Similkameen Valley. After the retreat of the continental ice sheet a period of valley glaciation ensued, resulting in a steepening of the valley sides, redistribution of detrital material, and formation of cirques on some of the higher peaks. The steep rock faces thus produced along both sides of the valley in this stretch offer a situation geometrically ideal for the development of talus.

The Similkameen River has a fairly steep gradient, dropping 150 feet in the twelve mile stretch of valley studied. Some flood plain development has occurred on the postglacial valley fill but is not wide enough to accommodate extensive meander development. South of Keremeos the valley widens and an extensive flood plain with well developed meander loops can be observed. Figure I-1 represents a typical section of the valley.

The climate of the valley bottom is classed as BSk according to Koppen's classification ranging to Dfb on the uplands. A low annual total of precipitation and a high annual range of temperature prevails within the confines of the valley (see Figure I-2). Keremeos averages ten inches of precipitation annually including about twenty-six inches of snow. Summers are hot with temperatures exceeding 100°F not uncommon. Typical vegetation is of the parkland variety in the valley bottom, i.e., short grass with a scattering of Douglas fir and ponderosa pine, ranging to sub-alpine coniferous forest on the higher cooler and wetter slopes. The dryness of the area is definitely reflected in the vegetation and, where overgrazing has occurred, sagebrush has replaced the natural grassland. The dryness is basically the result of a rainshadow effect produced by the Coast and Cascade
FIGURE I-I. A TYPICAL CROSS-SECTION OF THE SIMILKAMEEN VALLEY NEAR KEREMEOS, B.C.
The average was obtained from data for an eleven year period recorded on the Upper Bench Road, Keremeos, B.C. The fairly high temperature range (45°F.) illustrates the continentality. Precipitation is low, however, having a mean annual total of 10 inches; it is concentrated in June in the form of convectional storms.
Mountains to the west and is accentuated in the summer by the extension of hot, dry continental air from the south. The coastal mountains are also effective in producing a continental influence by cutting off the moderating effects any maritime air would have. A definite moisture deficit exists at lower elevations and most crops require irrigation.

The rocks of the area studied are arranged in a closely folded band formation normal to the general east-west trend of the valley (see Map 3). They have been identified and mapped by Bostock (1939) as a succession of cherts, lavas, limestones, and other sedimentary forms of Permian age and younger. Colours are very drab and from a distance as well as close up give the rocks a dull appearance. As evidenced by the abundance and great size of talus forms observed the rocks along this stretch seem very susceptible to disintegration under the effects of weathering.

B. Mechanisms Involved in the Formation of Talus.

Talus is by definition an accumulation of rock debris at the base of an exposed rock face or cliff. This accumulation is the net result of gradual decomposition and disintegration of the rock face by the processes of weathering and mass wasting. In time, the characteristically angular fragments produced become dislodged individually or en masse under the influence of gravity falling free of the rock face to eventually assume a position of rest at the base of the cliff. With sustained weathering and rock fall activity the accumulation grows, assuming a slope referred to as the angle of repose. Rapp subdivides the advent of talus formation into three stages:
"1. Supply - fall of debris from the wall down to the surface of the talus. It is terminated by the primary deposition of the particles.

2. Shifting - the movement of the material down the talus slope after the primary deposition.

3. Removal or stability - movement of material away from the talus slope or stability of the slope by vegetation and eventual flattening of the profile and soil formation." (Rapp, 1960a, p. 6.)


The weathering of rocks can be defined as the process whereby solid bedrock at or near the earth's surface is reduced by physical and chemical means into sediment. Talus formation represents an initial product along the continuum of the weathering process and both physical and chemical forces are involved at this stage. Although chemical weathering is ultimately the more important of the two processes, mechanical breakdown during the initial stages of weathering, eg. talus formation, can play a major or even dominant role.

A number of weathering processes are recognized (see Reiche, 1962). Those of particular note for the present purposes are the physical processes of frost shatter, frost bursting and root wedging and the chemical processes of hydration, oxidation and solution. The importance of freeze-thaw cycles in association with water in rock weathering has been questioned and the definition of the effective limits for the same varies greatly. A frost cycle is defined as any fluctuation of temperature above and below 32°F. A freeze-thaw cycle implies a fluctuation of temperature above and below 32°F. of sufficient range for a definite freeze and thaw to occur. To exert a wedging action, the frequency of the cycle is
obviously crucial but the duration and range of the cycle is important as well. Cook and Raiche (1962) noted that freeze-thaw cycles in the Arctic are much less frequent than thought to be and found that the frequency is much greater in Southern Canada. Boyd (1959) found that in order for a freeze-thaw cycle to be effective it must occur through a range of 25° to 35°F. Fraser (1959) and others, however, set the effective range at 28° to 34°F. The implication of an effective range is that there must be a sufficient temperature fluctuation for a definite freeze and thaw to occur. But, much depends on the duration of the cycle. A frost cycle of a shorter duration will require a greater range in order to be effective. Wiman (1963) noted that most effective weathering occurred under so-called "Icelandic" conditions represented by one cycle every day rather than under "Siberian" conditions represented by colder temperatures but a cycle only every four days. It becomes apparent that the effective range probably varies a great deal. In reference to duration, Rapp (1957) classified frost cycles as follows:

1. Short frost cycle (several per day).
2. Daily frost cycle.
3. Frost cycle of several days duration.
4. Annual frost cycle.
5. Frost cycle of several years.

Stock (1968) noted that the effectiveness of "frost-riving" is largely determined by the thickness and seasonal distribution of snow cover and the amount of water incorporated in the rock at time of freeze-up. Andrews (1961) concluded that the importance of frost as a weathering agent has been vastly overstated. The tremendous force exerted by the freezing of water confined within the interstices of rock, however, cannot be denied and within the recognized limits outlined above
cannot be discounted as a major mechanism of weathering.

Some controversy over the effectiveness of root wedging exists. As yet, it has not been conclusively demonstrated that the growth of plant roots can exert a force sufficient to fragment rocks.

Of paramount importance in the processes of hydration, oxidation and solution is the action of water on rock in association with oxygen and carbon dioxide in the air. Fragmentation of rock by physical processes greatly accelerates the rate of chemical decay but, so long as the rock can be penetrated by water, chemical weathering can occur.

The rate and type of weathering is determined to a large degree by the characteristics of the rock in question. The susceptibility of the rock to fracture is an important control. The aspect of the beds and the degree of jointing as well as the resistance of the rock and its basic structure will greatly affect the rate. How effective weathering mechanisms are on a given rock face in turn determines the rate of rockfall activity and associated talus development.

2. **Rockfall and primary deposition.**

Rockfalls, and to a lesser degree rockslides and avalanches, are the major sources of debris resulting in the buildup of talus. Rapp (1960b) lists a number of rockfall-initiating mechanisms: frost bursting, thermal changes, heavy rains, snow block falls, ice block falls, chemical weathering, wind, creep, and earthquakes. Frost action is probably the most important of these mechanisms especially in climates characterized by frequent frost cycles. Rocks shattered and burst by frost action subsequently release fragments when the ice melts. Short term i.e., daily frost cycles, are important
especially in their effect on the shallower cracks. In this case rockfall by "frost-riving" (Rapp, 1960b) occurs. Some examples of rockfall initiating thermal changes are expansion and contraction caused by daily temperature variations or differential expansion caused by solar heating where different rock types are interbedded or beside patches of snow. The localized movement associated with differential expansion and contraction of the rock as heating and cooling occur may be an effective dislodgement mechanism. Rainfall can be an effective initiating mechanism by:

1. diminishing the internal friction along joints or other slip planes in the rock.
2. creation of high hydrostatic pressure in joints dammed by water transported debris.
3. thawing ice after previous frost bursting. (Rapp, 1960b)

Debris incorporated in snow or ice masses attached to the rock face may be carried along when these masses are released. Debris avalanches associated with the buildup of hydrostatic pressure in joints under heavy or prolonged rainfall are rare but are important since such a great volume of debris is released almost instantaneously. Wind can dislodge very loose fragments but is recognized as only of minor importance. Roots growing in cracks along the rock face may be an effective prying mechanism; especially when the trees are subjected to heavy winds. Creep of any material over the rock face eg. regolith, snow, may disengage loose rocks. Finally, rocks already dislodged can knock others loose if they bounce along the cliff face on their way down. Once dislodged, however, the individual rock fragments come under the exclusive control of gravity.

Individual rocks move down slope by sliding, rolling, skipping and free fall. In general, larger rocks will generate greater kinetic
energy because of their greater mass and thus will travel farther down slope. Where the individual fragment eventually comes to rest on the talus slope depends on a number of factors. A rock which has great mass and momentum may roll beyond the talus. Such large rocks typically form an apron at the base of the talus. The distance the rock falls from the headwall before encountering the talus slope can also affect the distance it will travel on the talus slope: rocks falling further will acquire greater momentum and will tend to travel farther down the slope. The slope of the headwall and the talus slope below, however, can affect distance travelled by individual fragments. Rocks falling from an essentially vertical cliff lose considerable momentum upon impact with the talus slope, especially if the slope angle of the talus near the apex is relatively flat. If the headwall is sloping, however, fragments can gain a considerable horizontal momentum which is much less dissipated upon contact with the talus slope and, with a bounding action, travel comparatively farther downslope. Momentum buildup on flatter sloping headwalls is also limited, however; especially if the headwall surface is rough. As the talus deposit grows in response to rockfall activity the surface characteristics developed further affect the mode and distance of travel of rockfall fragments. Growth may take place in layers parallel to the angle at which the materials come to rest. Distance travelled by each particle can range from a maximum equal to the total length of the slope down to a minimum of zero. Since the deposit rests against its source of debris, the headwall, some pieces obviously do not move downslope at all before they are covered under subsequent rockfalls. Rocks rolling down the surface will be affected by the
slope and degree of roughness of the surface itself. A given rock will travel farther on a steep slope than a flatter slope. A rock falling at high speed along the inclined surface will touch that surface only at the high points with its high points if the rocks comprising the surface are smaller than the rock rolling over them. According to Ritchie (1963) the size or shape of the rock has little bearing on its rolling characteristics except if it is long like a pencil which tends to retard roll through eccentric action. Angular momentum of a rock rolling over a surface of smaller rocks tends to increase until two things tend to slow it down: 1. a flatter slope and 2. larger materials to roll over. Energy is lost by impact as it comes in contact with pieces of its own size. Progressive slowing down causes the rolling rock to sink lower into the irregularities of the surface losing more energy by virtue of more contact with the surface. Momentum is eventually totally dissipated and the rock becomes trapped in a void between rocks of its own size or larger.

Fall sorting seems implicitly obvious, i.e., larger rocks have greater kinetic energy so should therefore roll further before coming to rest. Tinkler (1966) observed that the proportion of larger sediment sizes increases downslope on talus sampled in North Wales. He attributed this sorting to the effects of gravity. Gardner (1971a) noted a logarithmic decrease in the mean size of debris upslope on talus observed in the Lake Louise district. Behre (1933), however, noted the exact opposite on talus slopes observed in the Rocky Mountains and Caine (1967) found a tendency for rock size to decrease slightly downslope on talus observed in Tasmania but noted that the differences are not statistically significant. In view of the discrepancies, therefore, the general law
of fall sorting should be seen as the statement of only one process on talus slopes. It is clear that primary deposition must be dominated by this process, but subsequent modification of the surface of the talus slope is controlled by other processes.

The accumulation of rock debris in this way assumes an angle of rest referred to as the repose slope. The repose slope or angle of repose of unconsolidated material has been widely studied (Behre 1933, Meiner 1934, Van Burkalow 1945, Ward 1945, Andrews 1961, Melton 1965, Tinkler 1966, Rahn 1966). In the case of talus materials, large, angular, rough surfaced and densely packed rocks tend to support a higher angle of repose. The maximum angle of repose which can be attained by a given deposit of rock debris depends on the inertia required to overcome the internal friction. When the maximum repose slope is exceeded, the particles slide to readjust to a slope less than the maximum repose angle. The coefficients of sliding and static friction for rock debris have been placed at 28° and 34° respectively (Melton, 1965) and it is interesting to note that a consolidation of slope measure data on talus (Rapp 1960, Melton 1965, Caine 1967, Stock 1968, Gardner 1968, et al.) displays a range of 10.5° - 41.5° with modes at 28° and 33° respectively.

Whether or not a given deposit will assume the maximum angle of repose depends on the mode of deposition and the time elapsed after deposition. Deposits which are built up gradually with a minimum of disturbance will attain slopes closer to the maximum. A deposit comprised of a certain shape of particles arranged in an interlocking matrix or imbricated fashion could support itself to achieve an angle of rest which would exceed the theoretical maximum repose slope. In natural debris deposits, the process of weathering can result in a
cementing of the individual particles which will allow the deposit to exceed the theoretical maximum repose slope. Further, debris deposits held together by the root structure of a sufficiently dense vegetation cover could maintain slopes in excess of the theoretical maximum. Also, thin mantles of debris on a well bossed steep bedrock surface could be supported at angles exceeding the theoretical repose slope. As can be seen, however, some agent in addition to the internal friction of the particles must be operative before a debris deposit can exceed its theoretical maximum.

The initial establishment of a position of rest by rocks tumbling from the headwall may be only temporary; subsequent downslope movement may occur through mechanisms of mass movement.

3. Modification of the talus slope by mass movement mechanisms.

Readjustment of a talus surface can occur in a number of ways. The mechanisms involved come under the general heading of mass movement.

Spontaneous mass movement or movement exclusive of the effects of a carrying medium occurs when the shearing limit of the material comprising the slope is reached. Failure is produced in a number of ways. The addition of water through melt or precipitation increases the pore water pressure resulting in failure referred to as "mudflow". Solifluction is an important mechanism in permafrost environments. Water can also act as a lubricant. Behre (1933) noted that talus in the Rocky Mountains tended to remain stable in dry weather but became more mobile in wet weather. Icing along the points of contact has the same effect. If the slope becomes steepened by the addition of material, failure is eventually reached. Also, removal of material away from the base of the deposit i.e., basal sapping, produces failure.
Talus creep is another form of mass movement. The disturbance created by freeze-thaw action in water saturated talus results in a net downslope movement. Experiments and theoretical calculations by Scheidegger (1961) suggest that the expansion and contraction created by alternate daily heating and cooling are sufficient to cause net downslope movement referred to as "dry rock creep".

External disturbance of the deposit can produce mass movement. The impact of falling rock and raindrop impact have effect. The movement of any medium such as water, snow, or ice over the surface transports material downslope. Earth tremors and animal activity are additional sources of disturbance. Wind transport has been cited as a possible mechanism (Rapp, 1960b) but this is doubtful since most talus material is too large to be affected by wind.

Finally, through

"...the shifting and removal of the material the talus formation is levelled out, takes on a more concave profile and may be transformed, for example, into an alluvial cone." (Rapp, 1960,p.6)

The characteristic forms associated with talus development, however, require some explanation.

4. **Morphology of talus development.**

Talus proper develops essentially from rockfall activity under the influence of gravity. The slope produced represents the aggregate deposition of fragments rolling, sliding, or bouncing to an eventual position of rest. As the importance of water or avalanching snow as a transporting medium increases, talus forms grade into alluvial cones or avalanche boulder tongues and rockslide tongues (see Rapp 1959) having a distinct concave-up longitudinal profile. A variety of talus forms *per se*, are recognized.
To initiate the formation of a talus slope a rock face of steep slope must be exposed. Such a feature could be a cliff produced by fluvial or glacial erosion. Tectonic activity resulting in escarpments and fault blocks are further examples. The steep rock slope produced, from which the weathered fragments move by free or bounding fall to build the talus below, is variously referred as the mountain wall, rock wall, headwall or rock headwall, free wall, free-face or cliff face. The headwall, to initiate talus formation, must have a slope steep enough to allow for movement of fragments by sliding, rolling, bounding or free fall. Slopes much less than 40° will result in little or no talus formation since gravity is unable to overcome static friction at low angles. In general, the headwall has an inclination ranging from 40° to 90°.

Obviously a headwall of greater height will result in accelerated talus development since more area is exposed to weathering. The structure of the headwall controls the rate and mode of destruction by weathering. If zones of weakness exist a dissection of the headwall ensues, producing gullies or chutes (see Figure I-3). Because weathering is concentrated along these zones of weakness rockfall activity is greatest here and becomes channelled along the gullies or chutes. Rapp (1960a) noted that the frequency of rockfall is directly related to the degree of dissection of the headwall. In comparison to a relatively undissected headwall the area of rock directly exposed to weathering processes on a dissected one is much greater. In addition, water from melt and precipitation is channelled along the gullies or chutes. The force of this flowing water and that which becomes frozen in the joints will initiate further rockfall activity. A dissected headwall, therefore,
FIGURE I-3. EVOLUTION OF A CHUTE OR FUNNEL

STAGE 1. Chute develops initially as a cleft in the headwall above the talus deposit.

STAGE 2. Talus grows as a result of the rockfall concentrated by cleft above. As the headwall disintegrates the cleft is widened and deepened to form a chute or funnel.

STAGE 3. Up building of talus and downcutting in chute eventually results in the merging of the two forms.

STAGE 4. With continued talus growth, chute becomes layered with mantle of debris producing a continuous debris covered slope from the apex of the chute to the base of the cone.
should have greater rockfall activity.

Whether a headwall retreats more or less uniformly over the whole of the free face or unequally by dissection with formation of gullies or chutes will affect greatly the shape of talus developed below. In general, talus cones with a convex horizontal profile are associated with a concentrated rockfall source; sheet talus develops when all parts of the headwall supply material uniformly. A headwall undergoing dissection retreat might display a variety of forms. Sheet talus alternating with talus cones can occur. Individual cones may coalesce to form a compound talus slope (see Figure I-4). Where a thin mantle of debris collects on a steep surface the feature is called a debris slope. The debris remains much controlled by the underlying rock structure.

The depth of talus deposits can vary greatly ranging from very shallow collections on debris slopes to substantial depths in larger formations. Rapp (1960a) reported a range in depth from 1 to 35 meters but noted that maximum depths never amount to more than about 1/10 of the height of the talus slope.

Debris deposits which are composed of essentially homogeneous particles throughout should develop essentially straight slope profiles. The slope surface of such deposits approximates an inclined plane. Talus deposits, however, are never homogeneous throughout. Often, more than one rock type is present and the individual fragments are never exactly the same size or shape. Moreover, as a result of natural sorting which may occur along the transportation surface of a talus slope, different parts of the deposit may have distinctly different size and slope characteristics than others. The net effect of this heterogeneous
FIGURE I-4. COMPOUND TALUS SLOPE—individual cones coalesce to form a continuous talus deposit.

GULLY — cleft in a steep headwall through which debris is channelled by free or bounding fall to form a talus cone below. The gully usually remains detached from the actual talus accumulation. With sustained activity a gully becomes a chute.

CHUTE — a cleft which concentrates debris to form a talus cone. Notice that the transportational surface of the talus extends well up into the chute.

FUNNEL — a half funnel-shaped cleft in a headwall which is wide at its top and narrower below through which debris is concentrated to form a talus slope. As with the chute the talus accumulation extends well up into the funnel.
composition is to produce not only a wide variation in the repose angle among talus slopes but, more importantly, a variable profile on each individual slope. The profile of a talus slope represents the complex and delicate adjustment of the debris to the many factors which affect slope development in varying degrees along the profile some of which are listed below:

1. The mode of and the duration since deposition.
2. Internal friction as controlled by the type, size and shape of debris.
3. The degree of sorting in the debris.
4. The amount, type and distribution of vegetation.
5. Thickness of the mantle and underlying surface characteristics.
6. Settling and redistribution of debris mechanisms, e.g., creep, wash, compaction, weathering.

Attempts to explain the characteristic concave longitudinal profile of talus slopes in terms of the size sorting and repose slope concepts have not been successful. Many inconsistencies are apparent. Machatschek (1952) attributed the concavity of the profile to the sorting of material on talus slopes, i.e., from smaller to larger sizes of material down the slope. The basic assumption he used was that fines are capable of supporting steeper angles than coarse material. Behre (1933) explained the concave profile in terms of talus he observed in the Rocky Mountains. In this case the observed sorting was from larger to smaller material downslope attributed to the effects of weathering. He assumed that larger fragments can achieve higher angles of rest therefore producing a slope which is steep at the top and flatter at the bottom resulting in a concave profile. This relationship is demonstrated in Table I below:
Table I  
Size-Angle Relationship (Behre, 1933).

<table>
<thead>
<tr>
<th>Average Diameter in Inches</th>
<th>Average Slope in Degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>35°</td>
</tr>
<tr>
<td>6</td>
<td>35°</td>
</tr>
<tr>
<td>4</td>
<td>31° - 32°</td>
</tr>
<tr>
<td>2</td>
<td>32° - 34°</td>
</tr>
<tr>
<td>1/2 - 1</td>
<td>26° - 31°</td>
</tr>
</tbody>
</table>

His is only one set of data, however, and the results cannot be taken as universal. Scheidegger (1970) suggested that if the formation of a talus slope is due to talus creep then angles near the top, where sliding is initiated, should be steeper than those near the base, where the materials come to rest, resulting in a concave profile. The difference in slope might also be attributed to the difference in packing of the materials. Materials near the top of the slope may become more packed as a result of more concentrated rockfall activity. The materials with greater cohesion near the top would be capable of supporting steeper angles than the lesser packed materials downslope producing a concave profile. There seems to be no simple explanation for this phenomenon and observations of profiles which are essentially straight, composite concave - convex, and even convex (Rapp 1957) tend to complicate it further.

C. Problems Associated with the Study of Talus Dominated Landscapes.

1. Problems associated with mass movement mechanisms.

The central problem in an explanation of the features exhibited on a talus slope is the determination of the following: is the talus surface basically the result of primary accumulation processes or does it represent the modification of a surface by mass movement mechanisms after accumulation under rockfall activity? Whichever process
predominates greatly affects the type of surface produced. In youth, or times of accelerated rockfall activity, accumulation mechanisms would predominate; later, mass movement mechanisms will exert an effect and a composite form may result. In the final stages of development, or when rockfall activity abates, mass movement processes may come to predominate. Whatever the stage, the net effect of mass movement is to lower the slope. Perhaps slope can be taken as some indication of the process predominating, i.e., accumulation on steeper slopes; mass movement on gentler slopes. However, no limits have been established and a great deal more study will be required to define them — if in fact they exist.

Actual observations of movement on talus slopes are few. Most of the movement initiating mechanisms described in section B of this chapter are theoretical. Some insight into net and differential movement has been gained by driving steel stakes (Rapp 1960) into talus slopes at fixed locations and noting downslope movement over long intervals of time. Results indicate that the surface layers tend to move most quickly. Lines painted cross-axially on talus debris observed over long periods of time indicate differential movement along the surface especially on slopes where the debris is sorted into strips of fines and coarse material (eg. Stock, 1968). However, the cause of the sorting into strips and the reasons for differential movement noted are not understood. Scheidegger (1970) hypothesized that movement may take place as miniature landslips which occur when talus assumes a critical thickness and slope creating a critical toe circle along which the landslide will occur. An observation by Rapp (1960a, p. 61) seems to confirm this theory. However, observations of failure on sand slopes
(Van Burkalow, 1945) indicated that sliding does not occur along a circular surface but is, rather, laminar, being essentially parallel to the slope. Van Burkalow suggested that sliding on talus slopes must approximate this type of failure.

A related problem is the recognition of the degree of activity on a talus slope. Stakes and painted lines as described above afford a rough measure of activity. If remaining unaltered over long periods of time the slope is considered to be stable. Vegetation is also used as an indicator:

"A rough measure of the permanence of stability of a talus slope is also afforded by the growth of grasses or other small shrubs on it. The unsatisfactoriness of this criterion comes largely from the fact that the time required for grass to advance up the slope results in a lag; on account of the need for soil accumulation the slope may be essentially 'at rest' several years before it is even scantily occupied by the grass and may well stand for a decade before moderately carpeted." (Behre, 1933, p. 624)

Indirectly, rockfall activity is an indicator of the degree of activity or stability on a talus slope. Substantial rockfall activity will produce a very active surface. As rockfall abates the surface is better able to stabilize itself. Tarpaulin traps have been used as measures of rockfall activity (eg. Barnett 1966, Stock 1968); otherwise, little quantitative data regarding stability is available.

2. **Problems associated with the morphology and morphometry of talus.**

Descriptions of the form and shape of weathered cliff faces and associated talus accumulations are readily available; those by Rapp are particularly comprehensive. Talus forms are easily distinguished from similar debris accumulations such as avalanche boulder tongues, rock glaciers and alluvial cones. On some talus slopes a mound of rock fragments in the form of a ridge separated by a slight depression from
the base of the talus proper has been observed (Behre 1933, Bryan 1934, Andrews 1961, Stock 1968). A generally acceptable explanation for this phenomenon, however, has not been advanced. Behre explains it as the result of accumulated snow on the talus, between the cliff and the valley, which persists into late spring when most of the winter snow has melted. The snow on the talus is sheltered from the sun by the cliff. The wasting of debris from the cliff is active at this time of year because of the high frequency of freeze-thaw cycles. Debris accumulated on the snow pack slides and rolls easily off the snow pack and concentrates to form a ridge near the base of the talus called a "nivation ridge". Bryan (1934) does not agree with this terminology as it implies formation in respect to snow accumulation. He does not see this as the general case and offers the term "protalus rampart" as being a more suitable name.

A number of practical problems are encountered in morphometric analysis of talus slopes. Of significance is the depth of the talus deposit since shallow deposits can be much affected by the surface on which they rest. Determination of the depth of the deposit by excavation is difficult and indeed practically impossible on particularly deep deposits. Talus slopes in general are very steep and usually quite mobile. Survey work and especially mapping on such a surface is a particularly difficult undertaking. Sampling the debris also presents problems.

The most valid method of sampling is usually the completely random method whereby each individual in the population has a known chance of being selected in the sample. This tends to eliminate bias from the sampling program due to the temptation on the part of the sampler to choose samples which are "good looking" or "typical". Often, however, in geomorphology the data have a systematic trend which renders
the data economically unfeasible for completely random sampling. In such cases, some systematic method is employed which utilizes random sampling at a point, along a line, or within an area based on some predetermined pattern or system. In many cases systematic sampling methods compare favourably with completely random sampling. However, as Cochran (1966) notes, the

"...disadvantages are that they may give poor precision when unsuspected periodicity is present and that no trustworthy method for estimating $\text{V}(\sqrt{\text{sy}})$ from the sample data is known." (Cochran, 1966, p. 230)

The surface of a talus slope is a transportation surface along which debris is moving essentially in one direction, i.e., from the top to the bottom. Sampling on a systematic basis along this axis of transportation is particularly expedient on talus slopes especially, for example, to determine whether or not a significant downslope progression of debris size (sorting) exists. For size frequency analysis on the slope a two dimensional sampling grid is useful placing one axis of the grid parallel to the axis of movement on the slope and the other perpendicular to it. On a talus cone a more representative sample would be obtained using a radial grid since the direction of transport is not constant but radiates from the apex of the cone. In this way, as many sample stations could be established near the apex of the cone as there would be near the base with the number of samples at each station varying as a function of the area of each graticule. Establishing the number of samples required in a particular program is another problem. The number has to be large enough to give valid results yet small enough to be reasonably accommodated within the limits of the program. A practical problem encountered in sampling debris on a talus slope is the mobility

$\text{V}(\sqrt{\text{sy}})$ is the error variance.
of the surface. To sample without disturbance of the surface is difficult and practically impossible in certain cases.
CHAPTER II - HYPOTHESES AND METHODS OF INVESTIGATION

A. Lithologic and Topographic Controls.

The investigation was confined to a 12 mile stretch of valley upstream from Keremeos where talus development was observed to be concentrated. This occurrence of abundant and massive talus forms is a result of three factors: rock type, structure, and glacial history.

The first factor is the susceptibility of the cherts, lavas, limestones and other sedimentary rocks in the area to weathering. It was observed that disintegration of the rocks was quite general and complete throughout the 12 mile stretch. To the south, however, the rock forms grade into more resistant quartzite, schist and granodiorite. Upstream, the same basic succession of rock noted above continues (see Rice, 1966, p. 8). However, as one proceeds northwestward out of the region the rocks become increasingly more resistant as the result of increased metamorphism:

"All members of the group are more or less metamorphosed and near the contact with the Coast intrusions the alteration becomes intense. As the contact is approached the argillaceous sediments, particularly, become coarser grained; feldspar and biotite develop; and the schistose texture gives place, with a further coarsening of grain, to a gneissic texture so that the sediments grade into the granitoid rock of the main intrusive body." (Rice, 1966, p.8)

It seems then, that the weaker rocks found in the 12 mile stretch under study are more susceptible to weathering than those found immediately to the northwest and south.

The second factor is related to the general joint pattern exhibited by the rocks. The rocks dip steeply, usually greater than 60° (see Photo II-1), in a generally north to south direction (Map 3).

Since the orientation of the valley of the Similkameen trends generally east-west along the stretch studied, the planes present vertical zones
Photo II-1. **Headwall Near Old Tom Creek.**
The white bed of limestone in the rock face near Old Tom Creek illustrates the steep dip (72°) of the beds and the orientation of their strike normal to the valley.

Photo II-2. **Headwall Near Keremeos.**
Detail of rock headwall in the vicinity of Keremeos along the north side of the valley. Note the joint planes which aid the penetration by water and subsequent weathering.
of weakness along which weathering in association with water can
effectively proceed perpendicular to the strike of the valley (see
Photo II-2). Northwest and south of the 12 mile stretch, the orientation
of the joint planes matches that of the orientation of the valley thus
presenting planes parallel to the valley walls. Such a pattern allows
for fewer effective routeways along which weathering can proceed to
produce wasting effective for talus formation.

The third factor noted was the configuration of the valley. Along this stretch the valley is somewhat confined, having very steep
sides with the bedrock exposed along both sides. Movement of the
Cordilleran Ice Sheet in the area was basically from the north to the
south. This would have produced more pronounced scouring - and hence
broadening - in the north-south trending sections of the valley. The
east-west trending section therefore remains more exposed and vulnerable
to the processes of weathering and subsequent talus formation. Down­
stream, the valley broadens appreciably and the walls are less steep
with much of the bedrock protected with a mantle of till. Upstream,
the valley is also somewhat broader and the rocks here, too, remain more
protected by a till mantle.

B. Weathering Mechanisms.

The rocks exposed to the effects of weathering exhibit some
faulting and light folding. The net effect of the disturbance has been
to produce a slight metamorphosis in the rocks. Some granitic intrusion
has occurred but is rare in the region studied. Weathering has had a
most deleterious effect on these rocks but in varying degrees of
intensity. The cherts are most immune to decay and remain as the bolder
bluffs exposed along the walls of the valley. Unequal dissection of
the headwall is most characteristic, being concentrated in the zones of weaker sedimentary and volcanic rock, especially where faulting has occurred. The net effect has been to produce a variety of talus forms the most common being successions of coalesced cones.

Decomposition and disintegration of the rocks as the result of chemical and physical weathering respectively are readily observable in the rocks exposed. It is suggested that disintegration due to frost action and decomposition as the result of chemical action are the chief mechanisms of weathering.

"Frost bursting" and "frost shatter" as the result of water freezing within the interstices of the rocks are considered to be the dominant mechanisms of disintegration. The following points support this claim:

a) Water is available throughout the freeze-thaw period. (see Figure I-2)

b) The joint pattern, as discussed in section A. of this chapter, and the chemical weathering of the rocks (see Chapter III) provide for optimal penetration of the rocks by water.

c) Frost action could be effective along the headwalls since the light snow cover during the winter provides a minimum of insulation.

d) The shattered appearance of the headwall and the angularity and 'freshness' of much of the talus debris suggest frost action.

The frequency of frost cycles (provided water is available) to a large extent determines the effectiveness of the mechanism. In general, the

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2 Mrs. Russel, recorder for the Met. Station at Keremeos notes that snow cover in the area does not vary greatly from an average of about 12 inches. Also, from personal observations it was noted that the headwall is kept essentially bare of snow by the wind.
more frequent the cycles the greater the destruction of the rocks affected. To determine the frequency of frost cycles in the region, an analysis of climate data obtained from the Atmospheric Environment Service of the Ministry of Transport (Canada) was made. A continuous record for Keremeos station on the Upper Bench Road of that municipality is available from the year 1930 to the present. To correlate with these records a maximum-minimum thermometer was installed in the headwall at TC25 (see Photo II-3) and a frost cycles record for the week November 24 to December 1, 1967 was obtained. The thermometer was located on the headwall inside a rock crevice 150 feet below fence #1 (see following section) on the right side (interpret left or right, facing in the direction of transport down the talus slope) of TC25 so as to give a
reading representative of the temperature affecting the rock. Analysis of both sets of frost cycle data is made in Chapter III.

Decomposition due to chemical weathering is of primary importance in the region. The processes of oxidation, hydration, and solution seem most pronounced, as substantiated by observations in Chapter III.

A number of secondary physical weathering processes have limited effect in the region, including splattering effect of raindrops and the wedging action attributed to the growth of plant roots along planes of separation in the rocks (see observations in Chapter III).

C. Rockfall Mechanisms.

Upon investigation it was concluded that four rockfall mechanisms (Chapter I.B.2.) predominate. Of greatest importance would be release of fragments from rocks shattered and burst by frost action. Analysis of frost cycles in Chapter III supports this claim as well as the effectiveness of "frost-riving" as a mechanism. Rainfall could be an important release mechanism during June when precipitation, in the form of thunderstorms, in concentrated. Meltwater earlier in the spring could have the same effect. Expansion and contraction associated with alternate heating and cooling is probably an important dislodgement mechanism in the summer when temperatures exceeding 100°F. are not uncommon and cooling under clear skies at night is effective. Since many of the headwalls observed exhibit a relatively dense growth of stunted Douglas fir trees (see Photo III-6, p.87) root wedging could be important as well. Observations of the effectiveness of these mechanisms are included in Chapter III.

Creep is not an important release mechanism since little or no regolith develops on the very steep headwalls. Snow block and ice block
falls would have little or no effect in this area which has only a light snowfall most winters. Some observations of release caused by wind are included in Chapter III indicating that wind might be important.

D. Mass Movement Mechanisms.

It is suggested that differential shifting of debris due to mass movement mechanisms produces cross-slope sorting on the talus slopes studied and accounts for the development of strips of fine and coarse debris noted on most slopes (see Photos II-4 and II-5). Hypothetically, debris of a larger size is capable of greater mobility over the surface of a talus slope by virtue of its greater mass, allowing the development of greater kinetic energy (Chapter I.B.2.). Further, the potential for mobility for a given rock increases if the surface over which it will move is composed of fragments smaller than itself. The mobility of smaller
Photo II-5. Detail of Surface on CC52. Note strip of coarse material in foreground and successive strip of fines in the background. The packsack gives the scale.
rocks, therefore, is much restricted due to their limited capacity to develop kinetic energy. Also, rocks which are relatively small will most likely encounter rocks of the same size or larger on the slope over which they move. This further impedes their mobility. In view of this relationship between size and mobility and in light of observations made on talus slopes in the region studied, it is suggested that movement on these slopes occurs in two distinct ways. In general, movement downslope for the larger rocks occurs on an individual basis. Smaller particles, however, are usually incapable of individual mobility and therefore must move \textit{en masse} along slip planes in response to spontaneous mass movement mechanisms. To explain the process it must be hypothetically examined in detail.

Rockfall activity from the headwall is the source of supply for the debris comprising the talus slope. Fragments both large and small are continuously added and in this way the deposit grows, maintaining a slope which, under normal circumstances, is commensurate with the angle of internal friction of the material. Rockfall debris will encounter the talus slope at or near its summit (in the case of a cone near the apex and indeed, if a chute or funnel has developed, far above the summit of the talus slope). To preserve a more or less constant slope on the talus deposit some of this debris must migrate downslope. Some of the larger rocks would be able to move immediately to the base of the slope. It was noted that an apron of larger boulders occurs at the base of most slopes observed in the region (see Morphology this Chapter). Not all of the rockfall debris can move directly to the base of the talus, however, as do the boulders which accumulate to form the apron. Some become immobile almost as soon as they encounter the
surface of the talus deposit, especially the smaller rocks... Some of the larger ones may move a fair distance downslope but all eventually become lodged at some point on the talus surface. However, accumulation will be greatest at or near the apex or summit of the talus where rockfall activity is concentrated. This disproportionate rate of accumulation will produce the development of steeper slopes at the top of the talus deposit with a successive decrease in angle downslope. This may in part account for the concave profile observed on talus slopes studied in the valley (see observations Chapter III). The angle near the top of the deposit cannot continue to increase indefinitely, however. At some point the shear stress within the material will exceed the internal friction of the fragments and failure will occur. The materials will slide en masse or as individuals thus reducing the slope of the surface to one below that which produces failure. With successive rockfall the slope near the top of the talus may again be built up, only to be readjusted by failure.

The readjustment probably never involves the entire talus slope at the time of a particular event. Rather, the readjustment is probably localized and would alternate back and forth across the slope thus preserving the basic symmetry apparent on any talus deposit. It is suggested that this readjustment due to spontaneous mass movement accounts for the sorting which produces a pattern of alternate strips of fine and coarse material observed on most talus slopes in the region (see Photos II-4 and II-5). To explain the mechanism, a consideration of the mass movement process in detail will be made.

Upon release by spontaneous mass movement the size of the individual fragment will be crucial in determining how far it will move
before again coming to rest. The larger fragments, once mobile, are capable of moving greater distances downslope. The smaller fragments tend to move only short distances, if at all, because of their small mass and inability to move over the surface irregularities of a slope which is composed for the large part of fragments greater than or equal to their own size. In this way the larger pieces would tend to divorce the smaller ones near the summit of the deposit. The larger ones move downslope until contact with either a decreased slope or fragments of a comparable size reduces their momentum sufficiently to bring them to rest. Some of the larger ones may travel to the base to become incorporated as part of the boulder apron. In this way concentrations of fines would develop near the top of the slope. As these concentrations of fines develop, their potential for movement en masse increases. They may become released en masse in the form of miniature landslides, the whole being capable of greater mobility than any one of the individual fragments comprising the mass. The individual fragments would ride easily over one another, filling in the surface irregularities they encounter to create fingers or strips of fine debris extending down the talus slope (see Photo II-6). On September 3, 1967 an observation of this phenomenon was made on CC7 (see Photo II-7). The mass of small-sized debris ($\leq 1.5''d.$) shows up in the photograph as a light brown patch which has moved downslope separating into four distinct fingers or lobes. The contrast in colour is due to the effects of weathering; the lighter fresher material had slid from above onto the drab weathered surface of the middle portion of the slope. A less recent but similar occurrence is visible as a more weathered but still detectable darker patch further to the right in Photo II-7. By the
Photo II-6. TC67. Note the light coloured projections on the right side of the cone indicating recent downslope migration of fines. The banded appearance due to alternating strips of coarse and fine debris on the surface is characteristic of talus observed in the region.

Photo II-7. CC7. Note fresh slide of fine debris (arrow).
following year the very fresh patch had become weathered so as to become barely detectable on the surface. A closeup view of the fines indicated that the new material was a layer some eight inches in depth. At the leading edge where the mass came to rest a definite lobe had developed giving the deposit a 'snout' shaped front.

Once this pattern of alternating bands of fine and coarse debris becomes established, successive readjustment due to mass movement would tend to accentuate it. Any large rocks moving downslope will be able to travel without much resistance over these deposits of fines and will most probably not come to rest on them. The larger rocks, rather, would concentrate along the coarse strips where rocks of a comparable size would impede their movement downslope. Otherwise, the larger rocks would tend to move further downslope because of their increased momentum. Also, the initial routeways established by the miniature landslides of fines become the most likely routes for successive en masse movement, these being the lines of least resistance in terms of a surface impediment. In this way the fine strips eventually extend their development to the very base of the talus deposit (eg. see Photo II-8).

Another observation tends to confirm the theory of development presented above. In all cases, the coarse strips of debris are much more stable than the fine. Walking upslope on talus in the region was relatively easy along a coarse strip but practically impossible along a fine strip. The mobility of the fines made the exercise analogous to walking 'up' a 'down' escalator. The difference in mobility suggests a difference in the way in which the rocks were deposited. According to the theory, rocks along the coarse strips accumulate on an individual basis allowing for imbrication. This creates a greater degree of
compaction resulting in greater stability. The fines, however, coming to rest *en masse*, are not allowed to fit together and remain very mobile under foot.

The theory presented above attributes the observed pattern entirely to sorting, produced as the result of spontaneous mass movement, on the slope. To determine whether or not other controls such as shape of debris should be considered, a fabric analysis was made by sampling debris on CC52. Samples were taken on one fine and one coarse strip adjacent to one another on the slope. A systematic method was employed on each strip taking 25 samples at each of 10 sites located at 50 foot intervals along the strip. In this way a total of 250 samples over a distance of 450 feet was obtained on each strip. At each site, the samples were selected as randomly as possible by grabbing each with eyes closed. The a(long), b(intermediate) and
c(short) axes were measured and recorded for each rock. The analysis is included in Chapter IV.

To detect net and differential movement to be used as a measure of the degree of activity on the talus slopes, a series of lines were painted. In particular any significant difference in behaviour on fine as compared to coarse strips of debris was sought. On December 3, 1966 two lines each 50 feet in length were painted on TC22, the largest talus cone observed in the region. Yellow paint in pressurized tins was used. Similar lines 100 feet in length were painted on May 16, 1967 above and below fence #1 on TC25. In August, 1967 a line 750 feet in length was painted on CC52, the position of the line being established by telescopic alidade. The line transected a section of the series of coalesced cones on CC52 which exhibit a well developed pattern of fine and coarse strips. The observed disturbance of these lines and additional observations made on talus slopes in the region were used as a measure of the importance of other mass movement mechanisms including: talus creep, avalanche transport, water transport, and wind transport. The results of these observations are included in Chapter III.

In order to paint a line on a talus slope one must necessarily disturb the surface. Any movement which subsequently occurs could be the direct result of the disturbance created. There seems to be no effective way of differentiating between movement attributable to natural mass movement mechanisms and that attributable to the disturbance created while painting the line. When walking over a talus surface, individual rocks become displaced downslope. Sometimes whole masses of debris slide to readjust to a lower angle. The net effect is to produce compaction of the debris immediately below the line being painted. Any movement
which occurs along the line may simply be an adjustment of the slope above in response to the disturbance below. Results, therefore, should be interpreted cautiously.

E. Morphometry and Morphology of Talus in the Similkameen Valley Near Keremeos.

1. Morphometry.

As a major hypothesis of this thesis it is suggested that the talus slopes in the Similkameen Valley near Keremeos are entering the final stages of development and are tending towards stability. Initial observations of the talus forms investigated suggested that the talus slopes were entering a passive stage of development. It is assumed that all the talus forms in this region have developed since the retreat of the last Cordilleran Ice Sheet from the area since scour would have erased any talus previously developed. Therefore, the talus developed in this region probably has an age of about 10000 years (Fulton, 1971). Talus formation was probably rapid following the retreat of ice from the area. The headwalls, bared to the very floor of the valley would have presented a substantial weathering surface and in the cold humid post-glacial climate would have resulted in a rapid rate of rockfall. Since the initial rapid growth, however, talus formation has probably undergone an ever decreasing rate of development.

The main criterion used to substantiate this stability hypothesis is the degree of vegetation cover. As noted in Chapter I.C.I., vegetation can be a very useful and valid index. Very active slopes subject to frequent rockfall activity and mass movement do not, in general, have a vegetation cover. In this sense, the mobility of the surface serves as an impediment to the establishment and growth of plants. As rockfall
activity abates and, as the surface of the talus slope becomes more
stable, vegetation is able to establish a foothold. The establishment
of a vegetation cover does not, however, imply the cessation of activity.
Indeed, the talus slope may continue to grow if rockfall activity continues.
What is implied, rather, is that activity is on the decline indicating an
approach towards at least temporary if not permanent stability.

All talus slopes observed had some form of vegetation cover on
them. For most, the cover was not complete being concentrated near the
top and/or near the base of the slope. Some slopes observed had a complete
cover indicating a high degree of stability and essentially the completion
of the talus phase (see Photo II-9). The establishment of some form of
plant cover on all talus slopes observed is interpreted as an indication
that the rate of talus development near Keremeos is decreasing. Further­
more, this passive stage of development is not considered to be a
temporary phase with rejuvenation to occur sometime in the future;
rather, it is interpreted as the approach of the final stages of talus
development. To substantiate this claim, it is necessary to consider
the probable evolution which has occurred since the talus phase began.

After the last retreat of ice from the area (10,000\+ B.P.) the
headwalls along the valley were probably bared to their maximum extent;
probably to the floor of the valley. It can be assumed for the purposes
of this theory that the profile of the valley was essentially U-shaped
this being characteristic of a glaciated valley and, with certain
modifications, the basic profile observable at the present time.
Initially, therefore, the headwall in cross-section probably appeared
as illustrated in stage 1 of Figure II-1. Rate of talus development would
be rapid at this stage since a maximum surface along the headwall would
be exposed to the effects of weathering and the post glacial climate
Photo II-9. TC2. Note the complete vegetation cover and the trail crossing the cone indicating a high degree of stability. Little of the headwall remains exposed most having been covered by the talus building up against it. Rockfall activity will continue but at a subdued and ever decreasing rate. This talus has entered its final stage of development.
FIGURE II-1. TALUS DEVELOPMENT AT KEREMEOS

A. STAGE 1

MAXIMUM EXPOSURE OF HEADWALL

ROCK HEADWALL

MINIMUM SURFACE OF ACCUMULATION

TALUS SIMILKAMEEN RIVER

B. STAGE 2

EXPOSURE OF HEADWALL DECREASES

ROCK HEADWALL

SURFACE AREA OF TALUS INCREASES

TALUS SIMILKAMEEN RIVER
would favour a rapid rate of weathering due mainly to frost shatter. Also, the area of accumulation on the talus itself would be small allowing for a rapid growth rate. As soon as a talus deposit begins to form, however, the rate of growth would decrease as illustrated in stage 2. It can be seen that the rate of development at this stage would be much reduced as compared to stage 1. A concept of 'diminishing sediment yield' can be applied. As the talus deposit grows in size it covers more of the headwall from which it derives its supply of debris. The rate of supply, therefore, decreases. Also, as the talus deposit increases in size so does its surface area. At any successive level of development the talus requires more debris for a specified increment of growth than it did for the previous level. But, the rate of supply decreases at each successive level producing a net decelleration in the rate of growth. At some point the effectiveness of rockfall activity, now at a much reduced rate, becomes much reduced having to cover a talus surface which has increased greatly in area. At this point the talus would be entering its final stage of development and the establishment of vegetation on its surface would serve as an indication of approaching stability.

The degree of stability noted in the region varies a great deal, however. Some of the slopes yet appear to be active. Certainly, rockfall activity continues along the headwall exposed. However, these talus slopes have grown to vast proportions and have covered the greater portion of the headwall that was originally exposed. For example, TC22, one of the larger cones, extends through approximately 1500 feet of relief and measures some 2500 feet along its base and 3000 feet along its longitudinal profile. Talus slopes of this magnitude can reduce the
effects of even substantial rockfall activity.  

A measure of the degree of present activity on talus slopes in the region was obtained from two fences designed to capture rockfall debris constructed on TC25 and TC49 in the latter part of May, 1967. To test the hypothesis, one fence was constructed on a talus cone which was judged to be relatively active (see Photo II-10) and the other on a cone considered to be more stable (see Photo II-11). The main stability criterion used was vegetation cover; a more dense growth considered indicative of greater stability. TC25, considered to be the more active cone, was also the larger of the two. As can be seen in Photo II-10, a well developed chute extending far back into the headwall complements this cone. Fence #1 was constructed at the entrance to the chute near the apex of the cone. So positioned the fence would capture that debris falling from the headwall in the vicinity of the apex of the cone as well as that debris travelling through the chute en route to the talus slope.

Galvanized chicken wire six feet wide with a two inch mesh was used to construct this fence which measured 188 feet in length (see Figures II-2 and II-3). Rockfall and transportation through the chute is most concentrated along its outer edges, the center remaining more stable as a result of the vegetation (trees, shrubs, grasses) which has become established there. Part of fence #1 is illustrated in Photo II-12.

Fence #2, constructed on TC49 is 185 feet long and of the same design as fence #1 (see Photo II-13). TC49, however, was judged to be less active than TC25 and in this respect served as a basis for comparative study. TC49 proved to be a transitional form of talus, however.
Photo II-10. *Site of Fence #1 on TC25.* The fence was constructed just above the largest Douglas fir tree at the apex of the cone where it grades into the chute above it. Note how the configuration of the chute tends to accentuate the major joint pattern in the rock comprising the headwall.

Photo II-11. *Site of Fence #2 on TC49.* The fence was constructed at the apex of the cone at the point where it coincides with the headwall in the photograph. Note heavy growth of vegetation indicating greater degree of stability.
FIGURE II-2. FENCE NO. 1 ACROSS CHUTE AT TC 25

FIGURE II-3. DETAIL OF FENCE
Photo II-12. Fence #1 on TC25. Note the headwall in the background and more stable central portion of chute.

Photo II-13. Fence #2 on TC49.
Observations of a channel near the apex of the cone indicated that fluvial action was affecting development on the cone. An inspection of air photos confirmed this (see Photo II-15). A substantial catchment basin has developed above TC49 which would serve to concentrate the flow of water onto the talus. The chute above TC49 was essentially void of debris indicating that water must flow through it (see Photo II-14 below).

Modification and deposition due to fluvial effects, however, are minor on TC49.

Both fences were sampled on two separate occasions. On September 5 and 6, 1967 fences #1 and #2 respectively were sampled. Since the accumulation period ran from the end of May until the beginning of September a sample for the frost-free season was obtained. On
Photo II-15. **Headwall, Associated Talus, and Similkameen River at TC49.** Note degree of vegetation cover on TC49 indicating a stable slope. Note also the well developed catchment basin above the cone resulting in the development of a fluvial channel at the apex of TC49 (see arrow).
June 12 and 13, 1968 they were again sampled. The accumulation period from September to June provided a sample for the period of frost activity in the region. The results of this sampling program are included in Chapter III.

An ash deposit observed on CC44 near the confluence of the Ashnola and Similkameen Rivers afforded a rough measure of the rate of past talus development in the area and was used to test the validity of the 'diminishing sediment yield concept' advanced in this thesis.

On CC44 at a point where a cut for the Southern Trans-Canada Highway truncates a series of cones of this group a layer of volcanic ash preserved at depth on the largest cone (see Photo II-16) has been identified (Ryder, 1970, p. 196) as that of the Mazama eruption which occurred to the south of the region 6600 years B.P. (Powers & Wilcox, 1964, Westgate et al., 1970, Fulton, 1971). The ash deposit neatly divides the talus deposit (of which it is a part) into that debris which was deposited in the interval 10000 - 6600 B.P. (3400 years) and that deposited since deposition of the ash (6600 years). The contact between the talus deposit and the river terrace on which it has developed is clearly defined in the road cut (see Photo II-17). Therefore, a record of the evolution of at least one of the talus slopes in the area is available. Employing a telescopic alidade and stadia rod the cone in question was surveyed to obtain a rough measure of the volume of debris built up prior to the deposition of the ash as compared to the volume built up since the ash deposit. The results of this analysis are included in the observations of Chapter III.

It was hypothesized that a talus cone, especially one with a chute or funnel extending up from its apex, should have different slope
Photo II-16. Mazama Ash Deposit at CC44. Arrow shows contact between talus and terrace of the Similkameen River on which it rests.

Photo II-17. Talus Resting on River Deposit at CC44. Zone of contact between talus of CC44 and terrace of the Similkameen River, on which the talus rests, is clearly visible. Note degree of compaction of talus debris which allows it to support a near vertical slope in the road cut.
and debris distribution characteristics along the sides of the cone as compared to the middle. Any talus slope is a transportation surface over which debris is moving in a downslope direction. On a cone, however, movement is most concentrated and consistent along the central axis. To note any significant difference, therefore, a number of profiles were established employing the abney level and measuring tape method. (A simple technique was chosen that would allow for a simultaneous sampling of the debris size on a systematic basis. King (1966) notes that slopes measured by this method are accurate to 1/2°.) All profiles were obtained starting at or near the apex of each cone and then measuring slope segments at 100 foot intervals downslope (or shorter if the irregularity of the terrain warranted it). The slope angle for each segment was obtained by siting from station to station with an abney level while standing erect. Suitable natural targets above and below were chosen to keep the profile oriented in as straight a line as possible. On TC21 three profiles were established (one medial and two lateral) and debris size (a, b, and c axes) was sampled at ten foot intervals along each. On TC25 two profiles were taken; one down the center and the other down the right side of the cone. Debris size was sampled only along the central profile of this cone.

Observations made suggested that no downslope sorting occurs on talus slopes in the region. Methods to validate this hypothesis were sought. The samples of debris taken in association with the establishment of the profiles discussed above served as one method to test for downslope sorting. Another used was the establishment of a series of traverse grab samples on a number of cones. In all, four talus cones were sampled employing a systematic method. A number of cross-slope walks
were made on each cone taking samples at ten step intervals. On each of
TG48 and TG67 a total of four traverses were made; on TC3 and TC26 a
total of six and seven traverses respectively were made. The traverses
were evenly spaced on each cone to include one traverse at or near the
apex, one at or near the base, and two or more in between. Samples were
taken at each ten step interval by reaching behind and selecting the
first rock touched. The lengths of the a, b, and c axes for each rock
were measured and recorded. The data collected are analyzed in Chapter IV.

To serve as a basis for detailed slope analysis, debris sampling,
and talus morphometry, a talus cone of intermediate size was mapped at
a large scale. A cone (TC26 on Map 2) with a south-facing aspect was
chosen since the south-facing slope of the valley exhibits a greater
degree of talus development. Also, the amount of vegetation cover on the
cone suggested that it was intermediate between very stable and active
cones, both of which are found in the valley. TC26 has a rockfall chute
(see Chapter I.B.4.) leading up from its apex which is characteristic of
most cones in the area. Finally, a cone rather than some other talus
form was chosen since the cone form is most prevalent in this valley.
A cone of intermediate size was chosen to facilitate mapping. (Much
larger cones are present in the area but the task of mapping TC26 alone
took the writer and a rod man two weeks to complete.) The cone mapped
is 1800 feet long, 1200 feet wide (at the base) and extends through
1000 feet of relief.

Mapping was accomplished during the summer of 1967 (June 27-30;
July 4,5; August 22-25; August 30 - September 3) by plane table survey
employing a telescopic alidade. A large scale map (1 inch to 100 feet)
with a 5 foot contour interval (± 1 foot assumed accuracy level) was
obtained (see Map 4A, p. 118). A baseline (see I,II,III,IV on Map 4A)
was established along the level talus apron by measurement with a steel tape (accurately as possible by using a spring balance to give readings under constant tension, and measurement in a short time interval so that temperature flux effects would be minimal) and levelling with the telescopic alidade and plane table. The four stations along the baseline were flagged with permanent wooden markers and were used as reference points to establish subsequent triangulation stations in order to complete the survey. Station II was chosen as the datum and assigned an arbitrary elevation of 100 feet. Thirty-one triangulation stations, to serve as a grid reference to establish a network of points of elevation from which contours could be drawn, were chosen. Elevation was calculated for each from the stadia intercept and angle reading on the rod. The plane table was then set up at each baseline station and triangulation station in turn. Correct orientation was maintained by siting back to at least three other reference points. The number and location of triangulation stations were strategically chosen so that no one alidade shot determining the elevation and location of a point would be at a distance greater than 150 feet or at an angle exceeding 25°. The positions of the first eleven triangulation stations were established by reference to at least three other reference points, at least two of which were baseline reference points, giving the lower third of the map the most accurate readings. As the survey proceeded upslope, it became increasingly difficult and eventually impossible to refer back to the baseline reference points in order to fix triangulation stations. By careful reference back to at least three adjacent triangulation stations subsequent triangulation stations were established with what was thought to be a fair degree of accuracy. In light of this fact, however, accuracy probably decreases
upslope on the map. The confinement of the rock walls in the chute above the apex of the cone obscured most of the downslope reference points resulting in probably the lowest degree of accuracy for this section of the map. Wooden lathe targets flagged with cardboard faced with a fluorescent orange emulsion served very well as markers for each of the triangulation and baseline stations. At each of the four baseline stations and thirty-one triangulation stations, a minimum of four and a maximum of 52 points of elevation were established by rod readings employing the telescopic alidade. Three hundred fifty-four such points were established. Elevation and position of a total of 389 points, then, were determined and served as the basis for the map. The field sketch was permanently fixed to an 18" x 24" plane table mounted on a removable tripod and was conveniently drawn on a sheet of frosted acetate. The survey was initiated at baseline point II. Rays were drawn from II to I, III, and IV and the proportionate map distance was scaled off thereby fixing the points on the map. Elevations of points I, III and IV were then determined by levelling in reference to station II arbitrarily established as the 100 foot datum.

The most frustrating and time consuming part of the survey was to keep the plane table level and correctly oriented at each station. This was especially difficult on the higher slopes of the cone where the angle exceeded 37° and the debris was very mobile. At each reference station a network of points was established at a density required to draw five foot contours with relative ease. The correct planimetric distance and elevation of each point were calculated from the alidade readings on the rod. The correct position was then established for each point on the map by scaling off the proportionate distance with a pair of dividers along a ray established by the alidade sitting on the rod.
Each rod station was selected to facilitate maximum expression of the terrain. The contours were drawn in the field as the survey proceeded and as much of the surficial detail as possible was noted some of which is contained in the overlay to Map 4A in Chapter III. No insurmountable obstacles were encountered, but the survey was not without problems, including the steep and unstable surface, the presence of trees and the gustiness of the wind.

On Map 4A only the contours which express the debris covered slope of the talus cone and associated chute were established by this survey. Those contours expressing the detail of the rock headwall, except for the rock spur (noted on the overlay), were extrapolated from air photos and serve to illustrate the basic form only of the rock headwall in the immediate vicinity of the talus cone, and should not be taken as correct.

A detailed sample of the debris on TC26 was taken in conjunction with the survey. One rock at each rod station was grabbed with eyes closed and its intermediate (b) axis was measured. An interpretation of the data collected is included in Chapter IV. In passing, it can be noted that very large rocks (> 3 ft. dia.) were observed only rarely on the talus slopes in the region. As already noted these larger rocks generally travel to the bottom of the slope where they accumulate to form a boulder apron. The few large ones observed at rest higher up on the talus slope were usually very flat or elongate in shape (see Photo II-18) which accounted for their unusual position on the slope.

2. Morphology.

The phenomenon labelled "nivation ridge" (Behre, 1933) "protalus rampart" (Bryan, 1934) and "protalus boulder accumulation" (Stock, 1968)
Photo II-18. TC48. Note very large boulder at rest on talus slope in association with characteristically smaller sized fragments. This boulder has a long axis of 10 feet, its very flat shape accounting for its unusual position on the slope.
was observed on one talus slope in the region. On TC67 near the base of the cone a transitional zone of crescent-shaped ridges can be observed leading out onto the boulder apron (see Photos II-19 and II-20). This phenomenon does not exist on any of the other talus slopes in the region and a reasonable explanation for its occurrence cannot be given. If it has developed according to the hypothesis advanced by Behre, 1933 (see Chapter I.C.2.) it must then be a relict form because of the following:

1. At no time during the investigation (1966 - 1972) was a substantial snowpack observed on TC67 (or any other slope).

2. Climate data since 1930 indicate that snowfall is characteristically light in this region.

It is feasible that these ridges could have developed according to Behre's theory but only in a climate regime characterized by heavier snowfall. As mentioned, this phenomenon occurs only on TC67. Because of its northern exposure and the existence of a substantial ridge to the east of the cone, TC67 remains sheltered a great deal of the time from the sun. On September 21, 1967 it was observed that TC67 remained entirely in shadow until 1:00 p.m. that day. A similar situation would exist during the spring months which could allow any substantial snow pack accumulated during the winter to persist late into the spring. It was observed that parts of some of the ridges have become buried as the result of more recent talus development which suggests that they might be a relict accumulation.

Boulder aprons have developed at the base of almost all talus slopes in the region (see Photo II-21). These aprons are the accumulation of those rocks which by virtue of their large size are able to move uninterrupted all the way to the bottom of the deposit. Initially most of these boulders would probably travel a fair distance beyond the talus
Photo II-19. TC67. The arrow shows the location of protalus ridges near base of TC67. Note also the river terrace near the base of the talus cone and well developed alluvial fan on the opposite side of the Similkameen River.

Photo II-20. TC67. Arrow shows the location of one of the protalus ridges on TC67. Note that the ridge occurs at the base where the characteristically sharp break in slope occurs. Note also the large size of debris comprising the ridge.
Photo II-21. **Detail of Boulder Apron at the Base of TC25.** Note the sharp break in slope where apron begins. The excavation in the foreground illustrates that the boulders extend at depth beneath the talus proper.

Photo II-22. **Boulder Apron on TC42.** Note the very sharp boundary between the boulder apron and the talus proper. Hard hat left of center gives scale.
deposit itself depending on the slope of the substratum. As the deposit grows, however, the rocks themselves serve as impediments to other rocks rolling to the base and a fringe deposit of these boulders would accumulate at the base. In all cases, the boundary between the talus slope proper (composed of much smaller debris) and the boulder apron is very sharp (eg. see Photo II-22); an abrupt change of slope can be noted as well. (Usually about 10°, i.e., at point of contact the talus would have a slope ranging from 30°-35°; the boulder apron correspondingly 20°-25°). The sharp break in slope indicates that the boulder apron must be controlled by mechanisms exclusive of those developing the slope above it since the difference in angle cannot be attributed to the difference in size of debris (see Chapter I.B.2). The materials comprising the talus slope by virtue of the greater depth of the deposit are more controlled by their internal friction and have a characteristically high angle at or near the angle of repose of the material. The apron, however, is a shallow deposit of boulders tending to be controlled by the slope of the substratum which is characteristically low in angle. (Most talus slopes in the area are built out onto a river terrace which bounds the valley on both sides. See Map 2.) There are not enough boulders available to build the deposit deep enough to allow it to develop a slope controlled by the internal friction of the rocks. The apron would be sustained as a leading edge of the talus extending farther out onto the surface as the talus deposit grows. It would be buried at its point of contact with the talus proper at the same rate as it would be extending itself out onto the surface. Figure II-4 illustrates in cross-section this mode of development. Observations (see Photo II-21) of a number of talus cones (TC5, TC21, TC22, TC25) which have been excavated at the
FIGURE II-4. DETAIL OF BOULDER APRON DEVELOPMENT
base to obtain riprap tend to confirm this mode of development. The layer of boulders comprising the apron extends beneath the talus deposit uninterrupted as far back as the excavations have been made.

It was noted that vegetation tended to be concentrated in two places on the talus slopes in the region: near the top of the slope and along the base in association with the boulder apron.

All talus slopes have some form of vegetation cover extending usually from about 3/4 of the way up to the top of the slope (see Photo II-4). The cover varies from a fairly dense growth of Douglas fir (dominant) and ponderosa pine to a low mat of grass, weeds and sage. The following hypotheses are advanced as an explanation for this distribution:

a) There is more moisture available for plant growth near the summit of the talus slope due to the concentration of runoff from precipitation and melt along the headwall. The effect would be greatest at the apex of talus cones where concentration through the cleft or chute in the headwall above occurs. Downslope, the effect is lost as the moisture percolates quickly through the permeable talus deposit. Also, any precipitation that does fall on the lower slopes of the talus infiltrates quickly and completely creating a dearth of vegetation.

b) If the debris size near the top of the talus slope is smaller (yet to be tested in this thesis) then it would be better able to support the growth of vegetation since soil formation is accelerated and plant growth is more possible in finer textured deposits.

c) Movement of debris on an individual basis near the top of the deposit as compared to movement en masse on the lower slopes would create less disturbance to vegetation attempting to establish itself on the slope. Therefore, conditions favour growth near the top of the slope.

d) Potential damage to vegetation by debris rolling over the talus surface probably increases downslope as the debris gains momentum on its trip down. On a number of occasions rocks were purposely set loose in the vicinity of the apex of a number of talus cones. In all cases, the rocks set loose either came to rest after a short roll or continued rolling
with acceleration until reaching the boulder apron at the base. As the boulders accelerated downslope their apparent potential for damage to vegetation increased. Obviously, this effect would pertain to only large debris capable of sustaining mobility to the bottom of the slope and it should be noted that all rocks set loose were the largest ones available. Small rocks are incapable of sustained roll over the rough surface of the talus.

It is suggested that all four hypotheses exert influence. The effect discussed in hypothesis (a), however, is considered to be very important and in the final analysis probably of greatest influence. To further substantiate hypothesis (c), it was noted at a point about 1/2 way up the slope on TC21 where a solitary sage bush, which had been able to establish itself along the upslope edge of a flat boulder, had been destroyed when overrun by mass movement of relatively fine debris. Additional evidence was observed on TC3. Vegetation strips consisting of saskatoon bushes and juniper trees extending quite far downslope on that cone were observed to coincide with the strips of coarse debris on the slope. The unvegetated surface between the strips of vegetation consisted of small sized fragments (≤ 3" d.). It is suggested that movement along the strips of coarse rock would be on more of an individual basis. The saskatoon bushes and juniper trees are gnarled and contorted, indicating some damage, but the plants are able to sustain growth. The strips of fine debris, however, remain unvegetated since movement probably occurs en masse in the form of miniature landslides.

On all boulder aprons a concentration of Douglas fir and ponderosa pine trees can be noted (see Photo II-23). This dense growth does not extend out beyond the boulder apron ending rather abruptly at its edges.
This concentration is best explained in terms of the following:

a) Water which has infiltrated the talus deposit may seep out along the base of the talus in the proximity of its boulder apron. This additional supply of water may be the requirement necessary to sustain a dense vegetation cover in the semi-arid environment.

b) Rather than having the meagre rainfall distributed evenly over the surface, the boulders of the apron by channelling the runoff may tend to concentrate it effectively thereby creating a network of favourable sites for tree growth between the rocks. This concept is illustrated in Photo II-24.

It is suggested that the effects outlined in (a) and (b) above account for the distribution noted.

An analysis of vegetation type on talus slopes in the area was made. The vegetation is of the dry parkland variety, i.e., short grass with scattered Douglas fir and ponderosa pine trees. The occurrence of Douglas fir as the dominant tree species is a reflection of its pioneer property of shade intolerance. On the talus slopes themselves, a total of what appeared to be 41 varieties of vegetation were observed
including: 5 grasses, 27 weeds, 6 shrubs and 3 trees. Next to Douglas fir (Pseudosuga menziesii), ponderosa pine (Pinus ponderosa) was the most common tree species. Some juniper trees (Juniperus scopulorum) were observed as well. The most common shrubs were: saskatoon (Amelanchier sp.), sage (Artemisia tridentata) and sumac (Rhus glabra). In general, the south side of the valley exhibits a more dense vegetation cover but the difference is not too significant. Talus slopes, however, on the south side of the valley exhibit a distinctly denser growth especially in the form of Douglas fir trees. This difference is attributed to aspect; a southern exposure being drier produces a more sparse vegetation cover.
CHAPTER III - OBSERVATIONS

A. Geologic Control.

A number of controls exerted by the basic geology of the rocks on rate of rock weathering and associated talus development are discussed in Chapter II.

Two basic rock formations predominate, i.e., the Shoemaker Formation and the Old Tom Formation (Bostock, 1939). Variations between the two were noted but it was found that these variations produced no discernible difference in the basic form or degree of development of the talus observed. There is some variation in the distribution of development, however (see Map 2).

In general, the south-facing slopes exhibit a greater degree of talus development than the north-facing slopes. The difference could be the result of a climate difference between north-facing as compared to south-facing slopes. Also, the headwall along the north-facing slopes is less continuous, being dissected frequently by streams tributary to the Similkameen River. At many points the bedrock remains covered under a layer of glacial till. These factors in conjunction with a more dense growth of vegetation have tended to inhibit talus development on the north-facing slopes. Two exceptions are worth mentioning.

Some of the largest and most active slopes are included in the series of eleven talus cones which have developed along the north-facing slopes of K Mountain. The dissection of the headwall has produced the development of two large talus cones with chutes which have merged to form a distinct "K" shape which gives this peak its name. The rocks of the Old Tom Formation exposed here exhibit a set of well-developed joints having a dip of $85^\circ$ and a strike perpendicular to the exposed face.
Water is able to penetrate these joints, resulting in rapid disintegration and substantial talus buildup. Another zone of concentrated talus development along the north-facing slope occurs just downstream from the mouth of the Ashnola River. Here, a series of six impressive talus cones (TC65 - 70) has developed along the rocks of the Shoemaker Formation exposed at this point.

The south-facing slope of the valley exhibits a relatively continuous succession of talus forms. The only significant break in the succession occurs where Shuttle, Keremeos, and Armstrong Creeks converge to broaden the valley immediately to the north of the Keremeos townsite. A succession of talus cones on the south-facing slope from Manuel Creek to Armstrong Creek occurs as an isolated group along the rocks of the Old Tom Formation and the argillite of the Barslow Formation. Talus development is again encountered on the slopes of Pincushion Mountain located to the northwest of the Keremeos townsite. Here, the most substantial and most impressive development in the area can be observed. The development on TC21 (see Photo III-15) and TC22 is spectacular. In all, nine large and several small talus cones form this group which have developed from the weak rocks of the Shoemaker Formation exposed here. Further examples are TC48 (see Photo III-21) where a huge funnel has developed in association with this cone and the large coalesced cone groups at CC51 and CC52.

An anomaly can be observed at CC38 near Old Tom Creek. At this point, the headwall remains essentially intact exhibiting only a very limited development of talus at its base. An inspection of Map 3 shows that the joint planes in the rock exposed here are parallel to the trend of the valley. So aligned, they present an aspect unfavourable
for weathering and the rocks remain little affected by weathering processes. No dissection has occurred along the headwall. The debris comprising the small amount of talus which has developed is generally large in size, an indication that dislodgement occurs in large plates parallel to the exposed face. The observation confirms the hypothesis that the aspect of the joints in the bedrock exposed along the valley exerts a significant influence on the degree of talus development since the remainder of the south-facing slope exhibits impressive talus development.

B. Weathering Mechanisms.

It was hypothesized that a variety of weathering processes is active in the region, resulting in the advanced state of disintegration observable on most headwalls (see Photo III-1). As discussed in Chapter II it is thought that both physical and chemical processes have

![Photo III-1. Weathered Rock Headwall at TC21.](image)

produced a rapid destruction of the headwalls forming the bold and abundant talus forms observable. A number of observations substantiate the effectiveness of these processes.
Frost shatter and frost bursting are considered to be the dominant weathering processes in the region. Climate data were examined to determine the frequency and magnitude of frost cycles.

The data recorded on the maximum-minimum thermometer installed inside the headwall at TC25 are found in Table II. To serve as a check, a standard thermometer was placed outside the headwall and its record is included in the table as well. Some difference between the temperature recorded at the times of observation between the maximum-minimum thermometer and the standard thermometer was noted. This was expected since one was placed inside a crevice on the headwall and the other outside. Initially, however, it was found that some difference existed between the standard thermometer and the maximum-minimum thermometer readings under identical conditions. The reading for the standard thermometer was assumed correct and the maximum-minimum records were adjusted as noted in Table II.

Coincidently, a most opportune week was chosen to make the observation since frost cycles occurred on six of the seven days of record; two of these (November 26 and 30) exceeded the effective range of 28°F and 34°F as defined by Fraser (1959). The observations serve to illustrate that frost cycles do in fact occur along the headwall. On the day of the November 25th inspection it was noted that ice had formed along the rock face the night before; this ice was already in the process of melting at eleven o'clock that morning indicating that freezing and thawing were occurring in association with the frost cycles. The readings obtained from this record correlate very well with the record for the same interval at the meteorological station (A.E.S., Canada) on the Upper Bench Road at Keremeos. The comparison is
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* All maximum readings adjusted -1.5°F. obtained as the mean discrepancy with standard thermometer.

** All minimum readings adjusted -.5°F. obtained as mean discrepancy with standard thermometer.

*** Maximum and minimum over a 28.5 hour period.
illustrated in Figure III-1. In general, the readings at Keremeos tend to exhibit a greater range. The difference is not great, however, being in the order of magnitude that could be attributed to the difference in temperature that would be expected within the shelter of the rock at TC25 as compared to the open air temperature recorded at Keremeos. Although the sample for purposes of comparison is small it does indicate that temperatures recorded at Upper Bench Road station in Keremeos are representative of those experienced along the headwall in the immediate vicinity of Keremeos. (TC25 is located approximately four miles upstream from the Upper Bench Road station).

The frequency of frost cycles (see Chapter I.B.1.) was tallied to obtain the monthly totals for the years 1930 through 1971 and the results appear in Table III. Each monthly total was subdivided into categories as follows:

1. FC = a frost cycle in the range 29°F-33°F, inclusive.
2. FD = a frost cycle in the range outside the limits established in (1) above but within the range 26°F-34°F, inclusive in accordance with the effective range of 28°F-34°F as defined by Fraser (1959).
3. BD = a frost cycle of the magnitude 25°F-35°F, inclusive or greater as defined by Boyd (see Fraser 1959) as the effective range.

What is implied by both Fraser and Boyd is that the outside air temperature will have to drop significantly below 32°F before water trapped inside rocks will freeze and, correspondingly, will have to rise significantly above 32°F in order to melt any ice which has formed. In essence, they define the limits required to initiate ice wedging resulting in eventual shatter in rocks affected. However, much depends on the duration of the cycle. For short cycles even greater ranges would be required.
FIGURE III-1. TEMPERATURE CORRELATION BETWEEN STATION AT TC 25 AND A.E.S. STATION AT KEREMEOS
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<td>34</td>
<td>72</td>
<td>225</td>
<td>141</td>
<td>151</td>
<td>221</td>
<td>144</td>
<td>118</td>
<td>194</td>
<td>131</td>
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<td>Mean</td>
<td>2.05</td>
<td>.85</td>
<td>.18</td>
<td>5.62</td>
<td>3.52</td>
<td>3.78</td>
<td>5.52</td>
<td>3.60</td>
<td>2.95</td>
<td>4.85</td>
<td>3.28</td>
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<tr>
<td>Mean</td>
<td>3.08</td>
<td>12.92</td>
<td>12.07</td>
<td>11.11</td>
<td>15.58</td>
<td>13.31</td>
<td>2.48</td>
<td>30.75</td>
<td>19.78</td>
<td>19.50</td>
<td>70.03</td>
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</table>
Cycles extending over days or weeks may require a fluctuation of only one or two degrees above and below 32°F. in order to be effective. Much, too, depends on the depth of penetration of the water. A much greater range of longer duration would be required to freeze and thaw water locked deep inside the rock. Water near the surface would be affected by cycles of a much smaller range and shorter duration. Ultimately, all frost cycles are important since "frost-riving" occurs when water on the surface of an exposed rock surface freezes and thaws producing dislodgement of previously loosened fragments resulting in rockfall activity. A fluctuation in temperature one degree above and below 32°F. is usually sufficient for this mechanism to operate.

During the forty year record at Keremeos, a total of 2801 frost cycles has occurred for an average of 70.0 cycles per year. Of these, a total of 1571 or an average of 39.3 cycles per year were greater than or equal to the effective range of 28°-34°F. as defined by Fraser. A total of 780 or an average of 19.5 cycles per year equalled or exceeded the effective range of 25°-35°F. as established by Boyd. The results support the assumption that frost shatter is an important mechanism of disintegration of the rocks exposed in the region. Figure III-2 illustrates that the cycles occur with high frequency throughout the late fall, winter, and early spring seasons. As previously noted, precipitation is available in all months of the frost season. Disintegration by frost shatter could be sustained throughout the frost season but concentrated activity may occur during the late winter and early spring intervals. February and March are the months of highest frequency of freeze-thaw cycles. During these months more water from snow melt is available which would render freeze-thaw cycles at this time particularly effective. Concentrated
FIGURE III-2. MEAN MONTHLY FREQUENCY OF FROST CYCLES AT KEREMEOS

- TOTAL FROST CYCLES
- FRASER FREEZE-THAW CYCLES
- BOYD FREEZE-THAW CYCLES

FROST SEASON

FREQUENCY OF FROST AND FREEZE-THAW CYCLES
rockfall activity during the spring season, according to the observations of local residents of Keremeos, tends to confirm this assumption.

Frost bursting is probably an important mechanism as well. Freeze-thaw cycles are not required to initiate this mechanism; rather, low freezing temperatures of a long duration (e.g., several days or weeks) are required to freeze the water confined in porous rock. A study of the records for Keremeos indicates that temperatures do drop to very low levels (on occasion below 0°F.) and at times for intervals of a week and longer. At these times rocks which are saturated with water would be very susceptible to frost bursting.

Observations suggest that chemical action is an important weathering mechanism in the region. At many points along the unevenly dissected headwall and especially in the clefts where chutes have formed the rock is found to be in an advanced state of decomposition. The rock appears to be essentially 'rotten' and pieces could be broken off easily with the hands. Reddish-brown stain is readily visible along the planes of separation indicating oxidation. The crumbly texture is indicative of a volume increase which can be attributed to the process of hydration. This is most prevalent in the clefts where water from precipitation and melt would be most concentrated to react chemically with the rock in association with the oxygen and carbon dioxide of the air.

The effects of solution are considered important as well. Some evidence for this is illustrated in Photo III-2. A zone of mineral precipitation where a spring emerges on the headwall at TC25 was observed. It was concluded that the mineral here precipitated is derived by solution along the joints in the headwall above. Of all the rock types exposed in the valley, limestone would probably be most susceptible
Photo III-2. Observed Solution on Headwall at TC25. The photo shows the course of a small stream which emerges as an intermittent spring further up along the headwall. The dark coloured band is a zone of precipitation of mineral probably derived by solution from the headwall above. No water was flowing at the time of photography. Pack sack gives scale.

Various degrees of chemical weathering (Melton 1965; Ollier 1965) have been defined. Ollier's progression is given in Table IV below.

Table IV. DEGREES OF WEATHERING. (after Ollier, 1965)

<table>
<thead>
<tr>
<th>Degree No.</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Fresh; hammer tends to bounce off.</td>
</tr>
<tr>
<td>2</td>
<td>Easily broken with hammer.</td>
</tr>
<tr>
<td>3</td>
<td>Rock can be broken by a kick with the boots but not by hand.</td>
</tr>
<tr>
<td>4</td>
<td>Can be broken in hands but does not disintegrate in water.</td>
</tr>
<tr>
<td>5</td>
<td>Soft clay with grit; disintegrates if immersed in water.</td>
</tr>
</tbody>
</table>

Examples of rocks considered to be representative of Ollier's degrees 1, 2 and 4 are illustrated in Photos III-3, III-4 and III-5 (a and b)
Photo III-3. Weathering Degree No. 1 (Ollier, 1965)

Photo III-4. Weathering Degree No. 2 (Ollier, 1965)

Photo III-5. Weathering Degree No. 4 (Ollier, 1965)
respectively. No rocks having Ollier's degree 5 were observed on the talus slopes or headwalls investigated.

Finally, the growth of trees along the headwalls may produce some disintegration through the action of root wedging. Photo III-6 illustrates the establishment of stunted Douglas fir trees on one of the headwalls in the region. Whether or not the growth of roots can exert a force sufficient to disintegrate rocks as yet has not been demonstrated. However, the force is certainly great enough to dislodge rocks already disintegrated, and, in association with the prying action produced as trees sway in the wind, must be considered as an important rockfall initiating mechanism.
C. Rockfall and Primary Deposition.

Personal observations and accounts by local residents substantiate the occurrence of rockfall activity in the region. Local residents report activity frequently. The slope at TC14 and TC15 on K Mountain immediately to the south of the Keremeos townsite is referred to most often as the site of these observations. Substantial falls reaching almost to river level have been observed. Residents agree that rockfall activity is concentrated during the spring season. In the spring of 1966 a section of the wooden pipeline at the base of TC25 was torn out by debris travelling down this slope.

A number of observations of rockfall events were made:

1. May 27, 1967. A rock about 5 inches in diameter fell from the left headwall during inspection of fence #1 on TC25.

2. May 30, 1967. While working on fence #1 at TC25 much debris was seen and heard falling from the headwalls. Rain was falling at the time.

3. May 31, 1967. Rain which started the previous day continued falling throughout this day of observation. Much debris was observed falling from the right headwall while working on fence #2 at TC49.

4. June 15, 1967. Rocks could be heard tumbling down headwall while climbing up TC49 to inspect fence #2. Rain was recorded the day before.

5. Recently damaged Douglas fir trees attributed to rockfall activity were observed on TC25 (June 1968) and TC67 (September 1967), eg. see Photo III-7.

6. July 26, 1971. A large ponderosa pine tree located about 50 feet from the headwall about one-half way up TC26 was observed to have been damaged by recent rockfall activity. Five large branches had been broken from the tree.

In retrospect it should be noted that very little rockfall activity was observed in proportion to the time spent in the field. The record above, however, illustrates the importance of rainfall as a release mechanism.
in the region. Rain storms were recorded on only a few occasions during the investigation; observed rockfall activity occurred almost invariably in association with these storms.

Debris captured in the two fences constructed provided some measure of the rate of rockfall activity in the region and substantiated the hypothesis that vegetation could be used as an effective index of stability. At the commencement of each sample, the fences were prepared by clearing out any debris in or on the chicken wire barricade. To keep the wire mesh flush with the surface, several large rocks were placed along the upslope edge of the fence. These rocks were sprayed liberally
with yellow paint in order to be able to identify them if they became incorporated in the sample. Any that were, were excluded. In this manner both fences were set up for the first sample beginning May 31, 1967.

Fence #1 was subsequently inspected on September 5, 1967. Much evidence of rockfall activity and/or debris transport through the chute on TC25 was observed. The fence was considerably damaged on both sides near the headwall indicating the effects of rockfall activity. The initial assumption that the right side of the chute seemed most active was confirmed by the fact that most damage occurred on this side where about 35 feet of fence had been levelled. Two of the steel pipe posts had been considerably bent downslope and four of the 2" x 2" wooden stakes had been ripped out (see Photo III-8). It was concluded that this damage had been caused by a substantial avalanche of debris from the adjoining headwall on this side. In all, 139 rocks were captured during the interval May 31 through September 5, 1967. No estimate can be made of the sample lost where the fence had been levelled. Also, some rocks travelling at high speeds left only a hole in the fence as evidence (see Photo III-9). In these cases the diameter of the hole was taken as representative of the size of the rock and this was recorded as the measurement of the intermediate axis. A number of very large rocks were captured as illustrated in Photo III-10. Obviously, these rocks were not travelling at very high speeds when coming into contact with the fence. Total volume captured was calculated at 213,486 in.\(^3\) by taking the cube of the intermediate axis as representative of the volume of the rocks (this provides an overestimate of the volume; see Gardner, 1970) or approximately 123 cubic feet of debris.

On September 6, 1967 fence #2 was inspected. More rocks were
Photo III-8. Fence #1 on TC25. Observation Sept. 5/67 showing damage to fence attributed to rockfall. Note steel pipe post bent downslope.

Photo III-9. Fence #1 on TC25. Note hole about 12" d. in fence observed Sept. 5/67 indicating rock travelling at high speed.

Photo III-10. Fence #1 on TC25. Note large boulder captured by fence.
captured but these were generally small in size. As expected the larger portion of the sample and the largest rocks were captured by that section of the fence extending across the fluvial channel near the apex of TC49 (see Photo II-14, p.54). It was concluded that the existence of this fluvial channel accounted largely for the apparent stability of the rest of TC49. Rockfall debris would be effectively concentrated by this channel allowing the remainder of the slope to stabilize itself. The channel is V-shaped in profile, some 20 feet deep and 40 feet wide and extends about one-half way down the cone. There is not a substantial buildup of debris at the terminous of this channel, however, indicating that rockfall activity must be limited on this slope. Photo III-11 shows large debris captured by fence #2 at the bottom of the fluvial channel. The fence broke when an attempt was made to clear these boulders out after they were measured. In all, 275 rocks were captured. The combined volume of these rocks was calculated at 77,356 in.$^3$ or approximately

Photo III-11. Fence #2 on TC49. Large boulders captured by fence at bottom of fluvial channel. Taken September 6/67.
45 cubic feet of debris. This volume was substantially less than that captured for the same period at fence #1 and supports the hypothesis that TC49 is more stable than TC25.

After sampling, both fences were cleared of all debris and the damage done to them repaired. Both were again prepared for sampling; this time for the period extending through the frost season.

Fence #2 was again inspected on June 12, 1968 after nine months had elapsed. Unfortunately, the sample obtained in fence #2 for this second interval cannot be taken as representative. A much larger sample was obtained -- 589 as compared to 275 rocks in the previous interval -- but a major portion of the sample was lost. The section of fence extending across the fluvial channel had become completely levelled by debris moving down the channel. Since a major portion of the previous sample -- and especially all the larger boulders -- had been captured by the fence in the channel, it is assumed that the bulk of the volume was lost in the second attempt. Total volume in the absence of any large boulders was only 20,771 in.\(^3\) or approximately 12 cubic feet of debris, considerably less than the first sample. Some estimate of the volume lost can be made. In the first sample the volume of debris captured by that section of fence through the channel alone represented approximately 50% of the total sample. If this same relationship is applied to the second sample, then an adjusted total volume can be calculated:

\[
\text{adjusted volume (approximate)} = \frac{\text{volume captured}}{0.5} = 41,000 \text{ in.}^3 = 24 \text{ cubic feet}
\]

On June 13, 1968, fence #1 was inspected and sampled. A previous inspection without sampling had been made on November 24, 1967. At this
time, a number of large holes were patched up and an estimate of the size of the intermediate axis of the rocks making the holes was recorded and included in the June 13, 1968 sample. On June 13, the fence was found to be essentially intact although about 20 feet of fence -- again on the more active right side of the chute -- had been torn out by rockfall activity. It was not felt that a major portion of the sample had been lost, however. Measurement was completed as in the other three samples and a total of 1492 rocks was recorded. In the interval September 5, 1967 to June 13, 1968 a total volume, therefore, of 907,283 in.$^3$ or approximately 519 cubic feet of debris had been captured. The results of this sample tend to confirm the hypothesis that rockfall activity is concentrated during the frost season since the volume is more than three times as great as the previous sample. Compared to the adjusted volume calculated for the sample at fence #2, the second sample from fence #1 supports the initial assumption that TC25 is more active than TC49.

A frequency plot of the sample obtained from fence #1 (June 13, 1968) is shown in Figure III-3 (plots of the other samples exhibit a similar distribution). The plot illustrates that the distribution in size of intermediate axes would probably have a mode somewhere below 3 inches. Unfortunately, the mesh size of the wire used in the fences was 2 inches in diameter. Rocks having an intermediate axis of 2 inches or less could easily escape through the mesh. In view of this it is felt that no reliable way of estimating the mode can be employed. Chicken wire of a heavier gauge and smaller mesh size is available but was not used because of the cost factor. In retrospect, much better results would probably have been obtained using the more expensive wire. More of the smaller-sized debris would have been captured and the heavier gauge would have
FIGURE III-3. SEDIMENT SAMPLE FROM FENCE NO. 1
(AT TC 25 SEPT. / 67 - JUNE / 68)

FREQUENCY

INTERMEDIATE AXIS IN INCHES
provided a more sturdy fence.

The observations confirm the reliability of using vegetation as an indicator of stability. This index was used in determining the location of the two fences constructed. The more dense and complete vegetation cover on TC49 was interpreted as an indication of a more stable slope. Since the fences were approximately the same in length (fence #1, 188 feet; fence #2, 185 feet); and since the intervals of sampling were identical the results substantiate the assumption. The volume captured by fence #1 was significantly greater for both sample intervals. Since the results obtained represent only a crude estimate of the actual rockfall which occurred and, realistically, represent only that year for which a sample was taken, they cannot be taken as conclusive. However, in view of the fact that fence #1 has since been all but completely levelled by rockfall activity while fence #2 remains essentially intact, it is felt that the index can be used with some confidence.

D. Mass Movement Mechanisms.

Movement was detected on lines painted on TC22, TC25 and CG52 but it is felt that the results must be interpreted very cautiously (see Chapter II.D.).

Two lines each 50 feet in length were painted cross-slope on TC22 on December 3, 1966. These lines were subsequently inspected on May 12, 1967. Only the lower line could be found. Being only 50 feet in length, the possibility of the upper line being wiped out by sliding debris is likely. TC22 appears to be a relatively active talus cone and evidence of slides of the magnitude required to erase the line are visible on this cone. The lower line exhibited only minor disturbance over the five month interval. A few rocks had moved on an individual
basis but the line had remained essentially intact. No bending indicative of differential movement had occurred. On June 11, 1968 the lower line on TC22 was again inspected. On this occasion, some thirteen months after the initial inspection, the line exhibited widespread disturbance. The line transects four distinct strips of fine and coarse debris on the slope, i.e., fine, coarse, fine, and coarse from right to left across the slope. It was noted that more disturbance had occurred on the coarse strips as compared to the fine strips. All rocks along the coarse strips had at least moved out of position as illustrated in Figure III-4. A number of individual rocks had been displaced and had moved downslope as far as 113 inches from the line. The line painted across the fine strips did not exhibit as much disturbance although a number of individual rocks had moved varying distances downslope. Table V below is a summary of the displacement of rocks observed.

Table V. Displacement of Rocks on Line Painted on TC22.

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<th>Position</th>
<th>Number of Rocks Displaced</th>
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<td>1&quot; to 29&quot;</td>
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<tr>
<td>2. Coarse strip #1</td>
<td>15</td>
<td>2&quot; to 14&quot;</td>
</tr>
<tr>
<td>3. Fine strip #2</td>
<td>33</td>
<td>3&quot; to 113&quot;</td>
</tr>
<tr>
<td>4. Coarse strip #2</td>
<td>14</td>
<td>2&quot; to 20&quot;</td>
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</tbody>
</table>

Differential movement had occurred as well. The line on both coarse strips had become appreciably bent downslope as illustrated in Figure III-5.

On May 16, 1967 two lines each 100 feet in length were painted above and below fence #1 on the chute leading up from the apex of TC25. Both lines were located on the right side of the chute which appeared to be the most active part. These lines were inspected 3½ months later
FIGURE III-4. PAINTED LINE ALONG COARSE STRIP ON TC 22

--- ORIGINAL LINE

--- AS OBSERVED JUNE 11/68

FIGURE III-5. PAINTED LINE ON TC 22 (AS OBSERVED JUNE/68)
on September 5, 1967. The lower line had remained essentially intact, although part of the line had become bent about one foot downslope. The upper line was essentially obliterated during the same interval (see Photos III-12 and III-13). The installation of fence #1 no doubt contributed to the difference in the degree of disturbance between the two lines since debris travelling through the chute was being captured by fence #1 during this interval.

In the latter part of August 1967, a line 750 feet in length was painted on CC52 (see Map 2 and Photo II-4). To maintain an accurate level, the position of the line was established using a Keuffel and Esser telescopic alidade and stadia rod. The line was fixed to a suitable bench mark located at the base of a huge Douglas fir tree on the left side of the slope of CC52. The line was resurveyed on June 12, 1968. Readings along the line were compared to the bench mark reading of 4.76 feet by sighting onto the rod at approximate nine foot intervals along the line. A total of 89 readings made along the 750 foot line indicated a definite net downslope movement of the line. The difference in elevation was converted from feet to inches and these readings in turn were converted to net downslope movement according to the following relationship:

\[
\text{Net downslope movement in inches} = \frac{\text{vertical difference in inches}}{.57358}
\]

where: \( .57358 = \sin \text{ of } 35^\circ \), taken as the average slope of talus along the line.

Net downslope movement ranged from a minimum of .9 inches to a maximum of 15.6 inches with a mean displacement of 6.14 inches along the line. One negative reading (-1.3") was obtained. This anomaly is interpreted as an error in the survey rather than a net upslope movement. Again, as with the observations of the line painted on TC22 greatest movement
Photo III-12. Painted Line Above Fence #1 at TC25. As observed May 16, 1967.

Photo III-13. Painted Line Above Fence #1 at TC25. As observed Sept. 5/67. Note almost complete destruction of line. Note also distance large boulder has moved as indicated by arrows.
occurred along the coarse strips of debris. Assuming this differential movement is exclusive of the effects of the disturbance created by walking over the talus surface when painting the line then some difference in the mechanisms of mass movement affecting coarse debris strips as compared to fine debris strips is implied in the observations. Perhaps a variation in mode of deposition, degree of compaction, or fragment characteristics exerts some influence; but, no inference can be made at this time. An analysis of fragment parameters as related to coarse and fine strips of debris is included in Chapter IV.

Observations of mass movement mechanisms in the region are now presented. Water in the form of melt or precipitation is assumed important as a movement initiating mechanism. In this case the water serves as a lubricant along the points of contact in the deposit. If the deposit is resting at or near its critical angle and becomes saturated with water, the internal friction of the mass may be sufficiently reduced to initiate spontaneous mass movement in the deposit. Such failure was never actually observed during the investigation but indirectly it was substantiated on two occasions. On May 30, 1967 TC25 was climbed in order to inspect the fence which had been established on that cone. The normal route, which follows a strip of coarse debris along the right margin of the cone, was used. As always, the rocks remained fairly stable under foot providing for a good access route. While working on the fence above, a fairly heavy rain storm was experienced. Following the same route down it was noted that the coarse strip of rocks had become extremely mobile. Every rock stepped on, moved, and in some instances a whole section of the slope gave way when stepped on. Obviously, the rain had been instrumental in reducing the internal friction of the deposit. A similar
situation was recorded on the same slope on November 24, 1967 when the rocks which had become wetted by melting snow were observed again to be very unstable underfoot.

Mrs. Russel reports observing some very substantial debris slides on TC3 above her place of residence on the Upper Bench Road. She notes that debris moves down as a mixture of rock and snow during the winter season when snow covers the talus slope. Otherwise, releases have been observed as rocks rolling and bouncing over the surface at a high velocity creating a cloud of dust en route to the base of the talus. She further notes that the debris avalanches occur usually in association with a fall of rain or wet snow and none have been observed occurring during the summer season.

Wind has been considered a possible mass movement-initiating mechanism. On a number of occasions winds gusting at very substantial velocities were experienced while working on the talus slopes in the region. Most intense winds occurred late in the afternoon on particularly hot days during the summer in the form of convectional updrafts. These updrafts become concentrated into intense gusts near the apex of the cones especially where chutes or funnels have developed in the headwall. No actual disturbance of debris on the talus surface was ever observed, however.

Creep may be an important mass movement mechanism and may have been detected by the lines painted on TC22, TC25 and CC52. Freeze-thaw cycles might be an important creep-initiating mechanism in view of the high frequency of cycles in this area. In order to be effective, however, the debris must have a high water content. The dry Keremeos climate,

---

3 Recorder at A.E.S. Met. Station at Keremeos.
therefore, may tend to limit the effectiveness of this mechanism. Dry rock creep, the result of thermal expansion and contraction as postulated by Scheidegger (1961), may be important. Diurnal temperature ranges during the summer can be high providing ideal conditions for the operation of this mechanism.

As mentioned, debris slides composed of a mixture of snow and rock have been observed on TC3. Snow avalanche, therefore, may be another important mass movement mechanism but would be limited by the characteristically light snows recorded in the valley.

Evidence of flowing water acting as a transporting mechanism of debris was observed on TC49 and a number of the talus slopes along K Mountain. TC49 has already been identified as a transitional talus form which will probably eventually become an alluvial cone. Well developed catchment basins in the chutes and funnels above the slopes along K Mountain effectively channel the flow of water onto the slopes and evidence of wash is apparent. The characteristically dry climate, however, limits the effectiveness of this mechanism in the region. A number of alluvial cones were observed in the area but these forms are considered to be distinct from talus (see Photo III-14).

Disturbance of the talus surface by animals and people in the region must be considered an important movement-initiating mechanism. A sizeable population of goats and deer which inhabit the region were observed frequently on the slopes. Many of the talus slopes have game trails on them. Hunters, prospectors and mountain climbers frequent the talus slopes as well. The very mobile strips of fine debris found on most slopes provide ideal downslope routes for climbers.

Natural basal sapping of talus deposits does not occur in this
Photo III-14. Alluvial Cone Near TC43. Note the water-scarred gentler-sloped surface which identifies this feature as an alluvial cone. The dense vegetation cover indicates a greater availability of water. Arrow shows recent mudflow scar near center of photo.

region since most of the talus is perched high above river level on a terrace which bounds the valley on both sides along this stretch. Basal sapping has occurred on TC5, TC21, TC22, and TC25 where excavations to obtain riprap have been made. On these slopes, the talus immediately above the excavations has failed along slip planes extending several hundred feet upslope. The mass movement of the debris has resulted in the formation of slopes much steeper than those on the adjacent undisturbed talus.

E. Morphometry and Morphology of Talus Development Near Keremeos, B.C.

1. Morphometry.

Indications of stability on the talus slopes investigated were sought. A few of the slopes had well established game trails on them, eg. one was observed on TC25 just below the weed and grass cover found near the apex of that cone; a game trail observed on TC2 can be seen
in Photo II-9; about midway on the slope of TC22 another of these trails indicates a certain degree of stability since such features could not develop on active slopes.

The chutes and funnels which complement more than one-half of the talus slopes in the region provide another indication. In themselves, the chutes and funnels are an expression of the variable nature of the headwall exhibiting alternate zones of weak and resistant rock. The degree to which these features have evolved, however, indicates a late stage of development (see Chapter I.B.4.). All chutes and funnels observed in the region have reached the final stage of development. This observation is interpreted as an indication of impending stability and as such supports the stability hypothesis advanced in this thesis.

Calculations of respective rates of accumulation before and after the deposition of Mazama Ash at CC44 support the 'diminishing sediment yield concept' advanced in Chapter II to explain the impending stability of talus slopes in the region. A number of assumptions are made.

It is assumed that all of the talus debris at the site has accumulated since the last retreat of continental ice from the region. According to the hypothesis advanced, the rate prior to ash deposition (6600 years B.P.) should significantly exceed the rate after ash deposition. Figure III-6 illustrates in cross-section the situation at CC44. As exposed in the roadcut the Mazama ash occurs at an average depth of 10 feet below the surface of the talus although the depth varies greatly as illustrated in Figure III-7. Beneath this, an average of 15 feet additional talus material rests on the river terrace.

Before rates of deposition can be calculated, some assumption regarding the nature of the subsurface must be made. The exact profile
FIGURE III-6. MAZAMA ASH DEPOSIT IN TALUS CONE AT CC 44
FIGURE III-7. ASH DEPOSIT AS EXPOSED ALONG ROAD CUT AT CC 44

FIGURE III-8. MODEL OF TALUS CONE AT CC 44 (WITH ASH DEPOSIT)
of the boundary between talus and the surface on which it rests cannot be defined without excavation of the entire talus deposit. Some limits can be established, however. A maximum depth would be defined by an extension of the river terrace back to a vertical headwall, i.e., along line AB in Figure III-6. This situation is unlikely, however. A minimum depth is defined by line EF. It is assumed that the talus deposit must be at least this deep as defined by the depth exposed along the road cut if the observed slope of 34.8° is taken as representative throughout its development. This situation, too, is unlikely in view of the expected profile of a glaciated valley. The actual profile probably lies somewhere between these limits. A precise definition of the profile is not required for the present purposes, however. To test the hypothesis, a maximum and minimum volume of accumulation prior to ash deposition will be calculated and compared with the volume accumulated after ash deposition occurred.

A model of the talus cone at CC44 will be used (see Figure III-8) with the following assumptions:

1. The talus cone represents a segment of a right circular cone.

2. The talus cone is bounded by vertical faces of coalescence, i.e., the talus cone in question coalesces with adjacent talus cones.

3. H/L = a constant, i.e., the cone has maintained a constant slope of 34.8°.

The total volume in Figure III-8 is:

\[ V = \int_{0}^{N} A(h) \cdot dh \]

where, \( A(h) \) = the area of any one segment as a function of height and, \( dh \) = the increment of height.

In Figure III-8 the area of the sector of a circle of radius \( r \) which
subtends on angle of $\alpha$ radians is:

$$A = \pi r^2 \cdot \frac{\alpha}{2\pi} = \frac{1}{2} \alpha r^2$$

but, $r = \frac{L(H-h)}{H}$

therefore $V = \frac{1}{2} \alpha \int_{0}^{H} \left[ \frac{L(H-h)}{H} \right]^2 dh$.

or, $V = \frac{1}{6} \alpha L^2 H$, which is the formula for a segment of a right circular cone.

Now, $\alpha = 44.4^\circ$

$= 0.77445$ radians

and, in Figure III-8 (see Figure III-6 also):

- $H_T = 465'$
- $L_T = 647'$
- $H_M = 455'$
- $L_M = 633'$
- $H_B = 440'$
- $L_B = 612'$

Then, total possible volume accumulated in 10,000 years is:

$$V_T = \frac{1}{6} \alpha (L_T)^2 (H_T)$$

$$= \frac{1}{6} \alpha (647')^2 (465')$$

$\simeq 25.1 \times 10^6$ ft.$^3$

Maximum possible volume accumulated in 3400 years prior to ash deposition is:

$$V_{\text{max.}} = \frac{1}{6} \alpha (L_M)^2 (H_M)$$

$$= \frac{1}{6} \alpha (633')^2 (455')$$

$\simeq 23.5 \times 10^6$ ft.$^3$
And, minimum probable volume accumulated prior to ash deposition is:

\[ V_{\text{min.}} = V_{\text{max.}} - V_B \]

where, \( V_B = \frac{1}{60} (L_B)^2 (H_B) \)

\[ = \frac{1}{60} (612')^2 (440') \]

\[ \approx 21.3 \times 10^6 \text{ ft.}^3 \]

Therefore \( V_{\text{min.}} = 23.5 \times 10^6 \text{ ft.}^3 - 21.3 \times 10^6 \text{ ft.}^3 \]

\[ = 2.3 \times 10^6 \text{ ft.}^3 \]

The volume accumulated in 6600 years (post-Mazama time) is:

\[ V_{\text{PM}} = V_T - V_{\text{max.}} \]

\[ = 25.1 \times 10^6 \text{ ft.}^3 - 23.5 \times 10^6 \text{ ft.}^3 \]

\[ = 1.6 \times 10^6 \text{ ft.}^3 \]

Therefore, the maximum possible rate of accumulation prior to ash deposition is \( V_{\text{max.}}/3400 \) or 6921 ft.\(^3\)/year. The minimum probable rate before ash deposition is \( V_{\text{min.}}/3400 \) or 664.9 ft.\(^3\)/year. And, the rate of accumulation since ash deposition is \( V_{\text{PM}}/6600 \) or 241 ft.\(^3\)/year (this compares reasonably with the amounts captured on TC25 and TC49 in 1967-68, i.e., 642 ft.\(^3\) and 69 ft.\(^3\) respectively for fence #1 and fence #2). At best, the rate of accumulation before ash deposition was approximately 30 times that after ash deposition; at least, about three times greater. The results support the 'diminishing sediment yield concept' and substantiate that the rate of accumulation on at least one talus slope in the region has decreased during post-glacial time.

Longitudinal slope profiles established on TC21 (see Photo III-15) and reproduced in Figure III-9 illustrate that lateral profiles, in general, are steeper than central profiles (see Chapter IV). As illustrated, the profiles appear to be nearly rectilinear. All five profiles, however,
FIGURE III-9. SLOPE PROFILES ON TC 21 AND TC 25
are slightly concave gradually decreasing from $36^\circ - 37^\circ$ near the apex to $33^\circ - 34^\circ$ near the base. A sharp break in slope occurs where the boulder apron begins, a phenomenon observed in association with all boulder aprons investigated in the region. The profiles were established on two separate talus slopes but they are very similar throughout. Other observations of slope were made on talus slopes in the region and in general the slopes are steepest near the apex. Although additional profiles were not established it is concluded that the concave profile is the general case in the region.

2. **Morphology.**

The talus slopes observed in the region were classified according to a number of criteria. Basically, only two forms of talus have developed in the region. The very uneven dissection of the headwalls has resulted in the formation of either distinct talus cones (coded as TC on Map 2) or groups of cones which have become coalesced (coded as CC on Map 2). Talus slopes observed in the region have been classified in Table VI. The following criteria were used to classify the slopes according to size:

1. Huge (H) = slopes measuring $> 2500$ feet across the base and extending through $> 1500$ feet of relief.

2. Very Large (VL) = 2000 - 2500 feet across the base and extending through 1200-1500 feet of relief.

3. Large (L) = 1500-2000 feet across the base and having 1000-1200 feet of relief.

4. Medium (M) = 1000-1500 feet across the base and 500-1000 feet of relief.

5. Small (S) = $< 1000$ feet across the base and $< 500$ feet of relief.

Stability was judged according to the apparent degree of activity on the slope and the degree of vegetation cover. According to vegetation distribution, many slopes had more than one area of concentration,
### Table VI. CLASSIFICATION OF TALUS FORMS NEAR KEREMEOS, B.C.

<table>
<thead>
<tr>
<th>Identification</th>
<th>Headwall Configuration</th>
<th>Size</th>
<th>Aspect</th>
<th>Stability</th>
<th>Veg. Type</th>
<th>Veg. Dist.</th>
<th>Boulder Apron</th>
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<td>F</td>
<td>M</td>
<td>S</td>
<td>TTS</td>
<td>T</td>
<td>CC</td>
<td>B</td>
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</table>
Table VI. (continued)

<table>
<thead>
<tr>
<th>Identification</th>
<th>Headwall Configuration</th>
<th>Size</th>
<th>Aspect</th>
<th>Stability</th>
<th>Veg. Type</th>
<th>Veg. Dist.</th>
<th>Boulder Apron</th>
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<tbody>
<tr>
<td>TC46</td>
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<td>S</td>
<td>T</td>
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<td>B</td>
</tr>
<tr>
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<td>C</td>
<td>H</td>
<td>S</td>
<td>S</td>
<td>T</td>
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<td>T</td>
<td>T,B</td>
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<td>S</td>
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<td>T</td>
<td>T,B</td>
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<td>RA</td>
<td>T</td>
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<td>S</td>
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<td>T</td>
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<td>B</td>
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<td>T</td>
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<td>B</td>
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<td>S</td>
<td>S</td>
<td>A</td>
<td>T</td>
<td>T,B</td>
<td>-</td>
</tr>
<tr>
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<td>L</td>
<td>S</td>
<td>S</td>
<td>T</td>
<td>T,B</td>
<td>B</td>
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<td>RA</td>
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<td>RA</td>
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<td>S</td>
<td>TTS</td>
<td>T</td>
<td>T,B</td>
<td>B</td>
</tr>
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<td>CC</td>
<td>B</td>
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<td>S</td>
<td>A</td>
<td>S</td>
<td>T,B</td>
<td>B</td>
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<td>S</td>
<td>RA</td>
<td>S</td>
<td>T,B</td>
<td>B</td>
</tr>
<tr>
<td>TC23</td>
<td>F</td>
<td>VL</td>
<td>S</td>
<td>A</td>
<td>W</td>
<td>T,B</td>
<td>B</td>
</tr>
<tr>
<td>TC22</td>
<td>C</td>
<td>H</td>
<td>S</td>
<td>A</td>
<td>W</td>
<td>T,B</td>
<td>B</td>
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<td>S</td>
<td>A</td>
<td>W</td>
<td>T,B</td>
<td>B</td>
</tr>
<tr>
<td>TC20</td>
<td>D</td>
<td>VL</td>
<td>S</td>
<td>A</td>
<td>W</td>
<td>T,B</td>
<td>B</td>
</tr>
<tr>
<td>CC19</td>
<td>D</td>
<td>L</td>
<td>E</td>
<td>S</td>
<td>S</td>
<td>CC</td>
<td>-</td>
</tr>
</tbody>
</table>

Notes:

1. Identification (see Map 2).
   a) TC indicates a distinct talus slope.
   b) CC indicates a coalesced group of cones.

2. Headwall configuration.
   a) C indicates that a chute complements the cone or cones.
   b) F indicates that a funnel complements the cone.
   c) D indicates that the headwall is dissected but that no chute or funnel has developed.

3. Size.
   a) H indicates a huge talus slope.
   b) VL - very large.
   c) L - large.
   d) M - medium.
   e) S - small.

(over)
Table VI. (continued)

4. Aspect.
   a) \( N \) indicates a north-facing slope.
   b) \( S \) - south-facing.
   c) \( E \) - east-facing.
   d) \( W \) - west-facing.

5. Stability.
   a) \( S \) indicates a stable slope.
   b) TTS - tending towards stability.
   c) RA - relatively active.
   d) A - active.

6. Vegetation type.
   a) \( T \) indicates predominantly trees with weeds and grass.
   b) \( S \) - predominantly shrubs with weeds and grass.
   c) \( W \) - predominantly weeds and grass.

7. Vegetation distribution.
   a) \( T \) indicates a concentration at the top of the slope.
   b) \( B \) - concentration at bottom.
   c) \( S \) - concentration along side or sides.
   d) \( M \) - concentration in middle.
   e) CC - a complete cover of vegetation.

   B indicates that a boulder apron has developed at the base of the slope.
i.e., T, B, S for this criterion in Table VI would imply concentration of vegetation at the top, bottom and along the sides of the slope.

A good example of a huge coalesced cone is shown in Photo II-4. Photo II-10 shows a very large talus cone complemented by a well developed chute. Photo III-15 illustrates a huge distinct cone without a chute or funnel above it. TC48 with a well developed funnel is illustrated in Photo III-16.

Photo III-16. TC48. Note well developed funnel extending far into the headwall.

TC26 was mapped (see Map 4A) as outlined in Chapter II, and as shown in Photo III-17 is medium in size and complemented by a well developed chute. A boulder apron skirts the base of the cone and as illustrated on the overlay to Map 4A is distinguished by a sharp break in slope which is typical for boulder aprons observed in the region. The boulders comprising the apron on the left side are very large (some > 25 ft. dia.). The talus rests on the surface of a river terrace which is exposed along the left side as illustrated on the overlay. TC26 is bounded on both sides by adjacent talus cones with which it has coalesced the line of demarcation indicated by a definite V-bend in the contours.
LEGEND

ROCK HEADWALL (CONTOURS EXTRAPOLATED FROM AIR PHOTOGRAPH SG BOOK 73-74)

---baseline---

△ TRIANGULATION STATION

SATELLITE 400 FEET (ARBITRARY)

BOULDER APRON

COARSE DEBRIS

MAP 4A. TC 26

SCALE 1:2400

CONTOUR INTERVAL = 6 FEET

CONSTRUCTED FROM 1967 PLANE TABLE SURVEY

COMPILLED BY O. A. WORBOY 1968
upslope. The trough produced where they join is filled with large boulders. In essence, therefore, the boulder apron extends from headwall to headwall on TC26. As can be seen in Photo III-17 an uneven growth of Douglas fir and ponderosa pine trees has become established on the talus surface. The oldest trees were estimated to be about 100 years of age indicating a certain degree of stability on the slope. As can be seen in the photo the growth is concentrated near the apex where a continuous mat of bush, weeds and grass extends from about 2/3 the way up to the entrance to the chute (see overlay). Many dead trees are still standing but, as can be seen in the photo, many logs are strewn over the surface. Below the zone of continuous vegetation, the talus surface is sorted into distinct strips of fine and coarse debris which is characteristic of talus slopes in the region. The coarse strips are
usually quite narrow with the wider finer strips of debris between. The transition from coarse to fine, however, is abrupt. Longitudinal profiles of the cone are quite rectilinear but an inspection of Map 4A indicates that they are slightly concave, being steepest near the apex. The steep slope is maintained in the chute where a maximum of 38° is recorded. Debris was noted as being least stable near the apex and in the chute where slopes are steepest. Some interesting isolated features were noted.

Near the base on the right side two auxiliary cone-like features can be observed (see overlay). The one on the extreme right is most distinct and forms the boundary between TC26 and the adjacent talus cone. Both are covered with a dense growth of bush, shrubs, weeds and grass. The one on the right has a definite convex longitudinal profile, being steepest at its base where it merges with the boulder apron. The origin of these features presents an interesting problem. Both are covered with talus debris and are distinguishable only by their morphometric characteristics and their vegetation cover. Extending above the one furthest to the right to the rock spur on the right side of the chute are two distinct gullies separated by ridges on the talus surface. These gullies and ridges show up very well on Map 4A and are noted on the overlay. The features suggest fluvial action. Water channelled by the chute above during a particularly intense storm would be most concentrated along the cleft separating the rock spur from main headwall on the right. So concentrated, it could have produced the gullies observed either by channel flow or mudflow. The auxiliary cone-like feature at the base could represent the net accumulation of any debris transported downslope by the water.

Near the base on the left side a depression was observed on
the talus surface. This depression can be attributed to either compaction of the talus debris or, more probably, an irregularity on the surface beneath since the depth of the talus would be quite shallow at this point.

The unequal dissection has produced a rock spur which protrudes a fair distance downslope as shown on the overlay and forms the right margin of the chute for about 1/3 of its extent. A cleft between the rock spur and the headwall on the right, which is bare of debris, channels some of the debris transported down the chute. An interesting phenomenon was noted on the left side of the chute where it joins with the headwall at the 900 foot level. At this point it appears that the level of the rubble which mantles the surface of the chute has suddenly dropped about 18". As Photo III-18 illustrates the surface of the headwall is covered with a fairly complete growth of lichens which ends abruptly about 18" above the debris indicating that the headwall has been recently exposed as a result of a drop in level of the debris. An explanation for the

occurrence could be a sudden sliding away of a considerable portion of
the debris in this part of the chute or a relatively instantaneous
compaction of the same. A claim stake marker is located on a ponderosa
pine stump at this point and a cache of blasting caps and assorted mining
tools were found in the headwall nearby. It is concluded that a prospector
was doing some blasting along the headwall and that the shock of the
explosion could have created the sliding or settling resulting in a
lowering of the debris surface. The debris maintains a very steep slope
at this point and is very mobile underfoot. It is feasible that the
sudden shock of an explosion could have produced the settling observed.

On June 15, 1967 an interesting phenomenon was observed at
CC44. The cut of the Southern Trans-Canada Highway through the base of
these cones is an essentially perpendicular wall composed of talus debris.
Through compaction and soil formation as the result of weathering the
talus debris has become most cohesive being able to support a slope near
90°. At one point along the cut, loose talus debris on the surface of
the talus slope immediately above the cut was being dislodged by a
particularly gusty wind noted that day. The debris being dislodged was
in the process of actively forming a miniature talus cone at the base
of the cut. The debris was being channelled by a cleft which had formed
at this point along the cut (see Photo III-19). As the debris came
into contact with the apex of the miniature cone, it tended to spread
itself out evenly preserving the characteristically symmetrical shape
of the cone. Most of the debris dislodged was fine and most stopped
before travelling more than one-half way down the miniature talus slope.
The larger rocks moved directly to the base of the deposit forming an
apron at the base. The sorting of the debris downslope was striking.
Photo III-19. Miniature Talus at GC44. Dust trail left by debris dislodged by wind from the talus surface of GC44 is visible at top of photo. Miniature cone formed from talus debris dislodged, which appears at the base of the cut, is about 6 feet high. Note coarser rubble at the base of the cone. Note also the very cohesive talus deposit through which the highway cut has been made.

Sand-sized particles remained at the top becoming covered as subsequent falls of debris occurred. From time to time masses of debris, already deposited near the apex, slid to readjust the slope. The slope of the deposit was measured by placing a survey rod flat on the surface and laying an abney level on the rod. It was found to have a constant slope of $34.9^\circ$.

At the base of a number of talus slopes in the region excavations to obtain a suitable riprap have been made. As a result of this basal
sapping, the loose surface layers immediately above the excavations have slid away exposing a much stabler talus surface beneath. The newly exposed surfaces rest at angles exceeding 38° as compared to 33°-34° for the adjacent undisturbed areas of the talus slopes. The material comprising the newly exposed steeper surfaces was found to be in a state of chemical decay. Soil formation had already begun and the debris in general tended to be more compacted. This greater degree of consolidation allows these materials to support much steeper angles.

The debris covered surfaces of the chutes and funnels which have formed above many of the talus slopes in the region are distinctly different from the talus surfaces below them. In general, the slopes of the chutes and funnels are greater than those on the talus slope below. Angles of rest are usually > 37°. This may be a reflection of the shallow depth of the debris in the chute or funnel allowing it to be supported at a higher angle determined by the slope of the bedrock surface on which it rests. In general, no observable downslope or cross-axial sorting is visible in the debris and a high degree of activity is indicated by the lack of vegetation on the surface of chutes and funnels (eg. see Photo III-20). The surface remains very active as this debris is conveyed down onto the talus surface below. Since the slope of the surface in chutes and funnels is steep, debris cannot accumulate to very great depths before sliding and removal from the chute or funnel takes place. It was noted that the cross-axial profile of the funnel complementing TC48 is concave-up as compared to the convex-up profile of the talus cone itself (see Photo III-21). At this point, the aspect of the bounding headwalls is such that the rockfall trajectories onto either side of the funnel are basically perpendicular to the axis of
transport downslope through the funnel. A cross-axial slope leading
down and perpendicularly out from the headwalls on either side of the
funnel has developed, producing the concave profile observed.

Photo III-20. Apex of Chute Above TC25. Note the lack of vegetation
on the surface of the chute and the intense disintegration of the
adjacent headwall.
Photo III-21. **Looking up at Funnel Above TC48.** Note the concave-up profile (arrows) of the funnel in the background as compared to the convex-up profile of the talus surface in the foreground.
CHAPTER IV - ANALYSIS AND INTERPRETATION

A. Profile Analysis.

Profiles established on TC21 and TC25 were used to test for a suggested difference between lateral and central profiles on talus cones. As plotted in Figure III-9 some difference in slope was detected. Table VIII illustrates the comparisons downslope for comparable slope sections on TC25 and TC21. The lateral profile on TC25 is an average of 1° steeper than the central profile; on TC21 the right and left profiles are an average of 0.8° and 0.3° steeper respectively than the central profile. In all three cases, therefore, the lateral profile was found to be steeper than the central profile. The error of individual slope measurements is ± 0.5° (King, 1966). However, the standard errors of the means of 10 measurements on TC25 and 15 and 14 measurements on TC21 listed in Table VIII are ± 0.15°, ± 0.12°, and ± 0.13° respectively. Lateral profiles, therefore, are steeper than central profiles measured.

Cobble a, b, and c axes were measured at 10 foot intervals along each profile on TC21. A definite difference in mean cobble size was detected between the lateral and central profiles. Cobbles, in general, are larger on the lateral profiles (see Table VII).

Table VII. COBBLE ANALYSIS ON LONG PROFILES TC21

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean along Right Profile</th>
<th>Mean along Center Profile</th>
<th>Mean along Left Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>a axis</td>
<td>4.9&quot;</td>
<td>2.6&quot;</td>
<td>4.0&quot;</td>
</tr>
<tr>
<td>b axis</td>
<td>3.1&quot;</td>
<td>1.7&quot;</td>
<td>2.8&quot;</td>
</tr>
<tr>
<td>c axis</td>
<td>1.8&quot;</td>
<td>1.0&quot;</td>
<td>1.7&quot;</td>
</tr>
</tbody>
</table>

A difference of means test (see Blalock 1960, pp. 173-176) was applied, the results of which are tabulated below:
### Table VIII.

#### A. COMPARABLE SLOPE SECTIONS TG25

<table>
<thead>
<tr>
<th>Position x 100 feet</th>
<th>Right-Center (in degrees)</th>
<th>Difference in Slope (in degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>37.0 - 36.0 = +1.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>37.5 - 35.0 = +1.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>35.5 - 35.0 = +0.5</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>36.0 - 34.5 = +1.5</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>35.0 - 35.0 = 0.0</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>36.0 - 34.5 = +1.5</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>35.0 - 34.5 = +0.5</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>35.5 - 34.0 = +1.0</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>35.0 - 34.0 = +1.0</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>35.5 - 34.5 = +1.0</td>
<td></td>
</tr>
</tbody>
</table>

#### B. COMPARABLE SLOPE SECTIONS TC21

<table>
<thead>
<tr>
<th>Position x 100 feet</th>
<th>Right-Center (in degrees)</th>
<th>Difference in Slope (in degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36.0 - 35.7 = +0.3</td>
<td>37.0 - 35.7 = +1.3</td>
</tr>
<tr>
<td>2</td>
<td>38.0 - 37.0 = +1.0</td>
<td>36.7 - 37.0 = -0.3</td>
</tr>
<tr>
<td>3</td>
<td>37.0 - 35.7 = +1.3</td>
<td>36.2 - 35.7 = +0.5</td>
</tr>
<tr>
<td>4</td>
<td>36.5 - 35.5 = +1.0</td>
<td>35.7 - 35.5 = +0.2</td>
</tr>
<tr>
<td>5</td>
<td>36.5 - 35.7 = +0.8</td>
<td>36.5 - 35.7 = +0.8</td>
</tr>
<tr>
<td>6</td>
<td>36.5 - 35.5 = +1.0</td>
<td>36.0 - 35.5 = +0.5</td>
</tr>
<tr>
<td>7</td>
<td>37.0 - 35.5 = +1.5</td>
<td>35.5 - 35.5 = 0.0</td>
</tr>
<tr>
<td>8</td>
<td>36.0 - 35.0 = +1.0</td>
<td>35.2 - 35.0 = +0.2</td>
</tr>
<tr>
<td>9</td>
<td>35.0 - 34.8 = +0.2</td>
<td>35.0 - 34.8 = +0.2</td>
</tr>
<tr>
<td>10</td>
<td>35.0 - 34.5 = +0.5</td>
<td>35.0 - 34.5 = +0.5</td>
</tr>
<tr>
<td>11</td>
<td>35.0 - 34.4 = +0.6</td>
<td>34.2 - 34.4 = -0.2</td>
</tr>
<tr>
<td>12</td>
<td>35.0 - 34.2 = +0.8</td>
<td>34.0 - 34.2 = -0.2</td>
</tr>
<tr>
<td>13</td>
<td>34.5 - 34.0 = +0.5</td>
<td>34.0 - 34.0 = 0.0</td>
</tr>
<tr>
<td>14</td>
<td>34.0 - 33.7 = +0.3</td>
<td>34.0 - 33.7 = +0.3</td>
</tr>
<tr>
<td>15</td>
<td>33.5 - 31.7 = +1.8</td>
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Table IX. DIFFERENCE OF MEANS TEST

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<th>Means</th>
<th>$\bar{x}_1 - \bar{x}_2$</th>
<th>df</th>
<th>$t$</th>
<th>2 Tailed Test at 1% Level</th>
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</thead>
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<td>(a axis)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>right vs. center</td>
<td>0.194</td>
<td>248</td>
<td>11.83</td>
<td>different</td>
</tr>
<tr>
<td>right vs. left</td>
<td>0.455</td>
<td>262</td>
<td>1.87</td>
<td>not significantly diff.</td>
</tr>
<tr>
<td>left vs. center</td>
<td>0.345</td>
<td>258</td>
<td>4.20</td>
<td>different</td>
</tr>
<tr>
<td>(b axis)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>right vs. center</td>
<td>0.278</td>
<td>236</td>
<td>5.22</td>
<td>different</td>
</tr>
<tr>
<td>right vs. left</td>
<td>0.309</td>
<td>278</td>
<td>1.14</td>
<td>not significantly diff.</td>
</tr>
<tr>
<td>left vs. center</td>
<td>0.235</td>
<td>235</td>
<td>4.67</td>
<td>different</td>
</tr>
<tr>
<td>(c axis)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>right vs. center</td>
<td>0.165</td>
<td>245</td>
<td>4.95</td>
<td>different</td>
</tr>
<tr>
<td>right vs. left</td>
<td>0.182</td>
<td>280</td>
<td>0.77</td>
<td>not significantly diff.</td>
</tr>
<tr>
<td>left vs. center</td>
<td>0.143</td>
<td>240</td>
<td>4.73</td>
<td>different</td>
</tr>
</tbody>
</table>

Means along lateral profiles are significantly different at the 1% significance level from means along the central profile but not from each other, even at the 5% level. Mean proportional and cumulative proportional frequency plots of the b axes according to Wentworth divisions in inches (Figure IV-1) further illustrate the difference. The similarity of the plots for the lateral profiles is most apparent whereas the plot for the central profile where the mode lies in a much smaller size category is strikingly different. A Kolmogorov-Smirnov test (Miller and Kahn, 1962, pp. 464-470) for goodness of fit validates this visual difference. Both the plots for the lateral profiles are significantly different from the plot for the central profile at the 1% significance level; the lateral profile plots are not significantly different at the 1% level from each other, however. The results indicate that some difference does exist in the characteristics between lateral as compared to central profiles along t

$4 \ 
t_{.05} = 1.960 \ \text{and} \ t_{.01} = 2.576 \ \text{for} > 120 \ \text{df.}$

5 Running means based upon 15 sample groups with a 5 sample overlap downslope on each profile.
FIGURE IV-1. MEAN PROPORTIONAL AND CUMULATIVE PROPORTIONAL FREQUENCY PLOTS OF b AXIS ALONG PROFILES ON TC 21
talus slopes investigated. This substantiates the hypothesis formulated in Chapter II. Some correlation between size of debris and angle of slope may exist which would suggest some difference in the mechanism of transport along central as compared to lateral profiles. It was earlier suggested that transport down the center of a cone would probably be more rapid and concentrated than transport along the sides. In this event, coarse debris would tend to accumulate more along the sides of the cone where its momentum would be reduced. Also, a steeper slope may be achieved along the sides where there is less disturbance. The results, however, are based essentially upon the observations on a single talus cone in the region.

B. Analysis and Interpretation of Downslope Sorting.

With the exception of the boulder aprons noted, it appeared that no observable downslope sorting occurs on the slopes studied, this being stated as a hypothesis in Chapter II.

Running mean plots of the b axes as measured along the profiles on TC21 and TC25 tend to contradict the hypothesis. The plots (Figures IV-2, IV-3, IV-4 and IV-5) indicate that a slight increase of grain size occurs upslope and downslope from the 200-400 foot position on all profiles. However, the 95% confidence range illustrates that only on TC25 is the difference statistically significant in an upslope direction. Downslope from the 200-400 foot position means are significantly different on all profiles at the 5% level. The change, however, is not monotonic and, as illustrated, is only a weak trend. It is interesting to note that a mat of grass and sage covers the upper third of both slopes and that the smallest mean b axes recorded on both TC21 and TC25 occur midway along this band of vegetation. This is probably best interpreted as an indication that vegetation is better able to establish itself at this point in
FIGURE IV-2. RUNNING MEAN PLOT OF b AXES
ALONG CENTER PROFILE ON TC 25

--- 95% CONFIDENCE RANGE (FOR THE MEANS)

BOULDER APRON BEGINS HERE
FIGURE IV-3. RUNNING MEAN PLOT OF b AXES ALONG RIGHT PROFILE ON TC 21
FIGURE IV-4. RUNNING MEAN PLOT OF b AXES ALONG CENTER PROFILE ON TC 21

MEAN b AXIS IN INCHES

95% CONFIDENCE RANGE (for the means)
95% POPULATION CONFIDENCE RANGE

DOENSLOPE DISTANCE IN FEET
FIGURE IV-5. RUNNING MEAN PLOT OF b AXES ALONG LEFT PROFILE ON TC 21

- 95% CONFIDENCE RANGE (for the means)
- 95% POPULATION CONFIDENCE RANGE

MEAN b AXIS IN INCHES

DOWNSLOPE DISTANCE IN FEET
association with the smaller grain size of the debris rather than as a control exerted by vegetation on the distribution of grain size. In this light the observation tends to confirm an hypothesis made earlier about the concentration of vegetation near the apex of talus cones in the region.

As illustrated in Figure III-9, the slope angle decreases slightly downslope from the 200-400 foot position with a corresponding increase in grain size. Some correlation between grain size and angle may exist in this respect which could explain the downslope trend. But, the results tend to contradict the correlation between larger-sized debris and steeper angle existing on the lateral profiles already discussed. The results suggest that different transport mechanisms are operational on different parts of the talus slope.

On TC25 the mean at the 1175 foot position is significantly larger (see Figure IV-2) than all others on that plot with the exception of the one at the 575 foot position. The debris at the 1175 foot position is part of the boulder apron and this significant difference would be expected.

Included with the plots on TC21 (Figures IV-3, IV-4 and IV-5) are the population confidence ranges of the material at each downslope position. It is interesting to note that these overlap on all three profiles suggesting that the differences which have been detected are weak. Distributions of all samples are positively skewed and kurtosis varies between slightly platykurtic and leptokurtic but no downslope trend is discernable. Sorting (as indicated by the Trask sorting coefficient) is good for all plots and shows no downslope trend; neither do Zingg shape and flatness and sphericity parameters. In particular, flatness and sphericity are remarkably uniform downslope.
A downslope difference in mean cobble size was detected through an analysis of the traverse samples on TC3, TC26, TC48, and TC67. However, the differences detected were weak and did not occur on all cones sampled. Downslope plots of mean b axis according to cross-slope traverse samples are shown in Figures IV-6, IV-7, IV-8 and IV-9. The 95% confidence range for the means indicates that debris sampled along the boulder aprons is significantly larger in all cases, as expected. Other weak downslope differences are indicated by the plots but no definite general trend exists. Again, as with the data collected along the profiles on TC21 and 25, the 95% confidence ranges for the populations of debris at each traverse overlap, indicating little correlation between size and downslope position.

Of the four cones sampled by traverse, TC3 exhibited the most pronounced trend of downslope sorting. The proportional frequency and cumulative proportional frequency plot of b axes on TC3 in Figure IV-10 illustrates the general increase in size downslope. Within cone plots are shown for TC3, TC26, TC48 and TC67 in Figure IV-11. A Kolmogorov-Smirnov test indicates that the distribution on TC3 is significantly different from that on TC26 at the 5% level; no other significant differences between cones exists. The difference detected would be related to the lesser progressive increase of grain size downslope on TC26 (Figure IV-7) as compared to that on TC3 (Figure IV-6). Also, TC26 has a significant proportion of grain sizes recorded in the smallest categories of the Wentworth divisions (Figure IV-11) which are lacking on TC3. The results suggest a difference in cobble characteristics between TC3 and TC26 which may be related to geology.

Skewness, kurtosis, Zingg shape, and flatness and sphericity
FIGURE IV-6. MEAN b AXIS PLOT OF TRAVERSE SAMPLES ON TC 3
FIGURE IV-7. MEAN b AXIS PLOT OF TRAVERSE SAMPLES ON TC 26

15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0

MEAN b AXIS IN INCHES

--------- 95% CONFIDENCE RANGE (for the means)
--------- 95% POPULATION CONFIDENCE RANGE

DOWNSLOPE TRAVERSE POSITION
FIGURE IV-8. MEAN b AXIS PLOT OF TRAVERSE SAMPLES ON TC 48

--- 95% CONFIDENCE RANGE (for the means)

--- 95% POPULATION CONFIDENCE RANGE

MEAN b AXIS IN INCHES

DOWNSLOPE TRAVERSE POSITION
FIGURE IV-9. MEAN b AXIS PLOT OF TRAVERSE SAMPLES ON TC 67
FIGURE IV-10 PROPORTIONAL FREQUENCY PLOTS AND CUMULATIVE PROPORTIONAL FREQUENCY CURVES OF b AXES ON TC 3

TRaverse 1

0 20 40
0.31 .63 1.25 .25 5 10 20 40
b AXIS IN INCHES

TRaverse 2

0 20 40
0.31 .63 1.25 .25 5 10 20 40
b AXIS IN INCHES (WENTWORTH DIVISIONS)

TRaverse 3

0 20 40
0.31 .63 1.25 .25 5 10 20 40
b AXIS IN INCHES (WENT, DIVS.)

TRaverse 4

0 20 40
0.31 .63 1.25 .25 5 10 20 40
b AXIS IN INCHES (WENTWORTH DIVISIONS)

TRaverse 5

0 20 40
0.31 .63 1.25 .25 5 10 20 40
b AXIS IN INCHES (WENT, DIVS.)

TRaverse 6
FIGURE IV-11. WITHIN CONE PROPORTIONAL AND CUMULATIVE PROPORTIONAL FREQUENCY PLOTS OF b AXIS

b AXIS IN INCHES (WENTWORTH DIVISIONS)
parameters calculated for the traverse samples indicate no downslope trend. Again, flatness and sphericity show remarkable uniformity downslope.

C. Mass Movement as a Cross-slope Sorting Mechanism.

Plots of mean b axis along the fine and coarse strips on CC52 are illustrated in Figure IV-12. The plots are of adjacent strips of debris on the same slope and serve to illustrate that cross-slope sorting of debris exists. Also, a slight increase in size downslope is significant at the 5% level on the fine strip. As illustrated in Figure IV-13 this can be attributed to a progressive reduction in the frequency of the smallest sizes down the fine strip. This progression suggests sorting in conjunction with mass movement processes whereby smaller fragments come to rest first where debris moves downslope *en masse*, and tends to substantiate the hypothesis that movement occurs *en masse* along the fine strips. Since the same progression is lacking along the coarse strip a different mechanism of transport, as already postulated, is suggested.

Additional calculations from the data suggest no fragment characteristics which would tend to exert influence on the formation of fine and coarse strips. As expected, good sorting exists at all points along both strips. (Mean Trask sorting = 1.309 for the fine strip; 1.264 for the coarse strip.) Distributions are positively skewed and markedly platykurtic in general. Distribution of Zingg shape (Figure IV-14) displays no marked trends. The uniformity of flatness and sphericity as noted on all other downslope plots occurs on the fine and coarse strips as well as indicated by Figures IV-15 and IV-16.

All plots of flatness and sphericity parameters calculated from the data, which were collected using a variety of techniques on a number of slopes, indicate definite uniformity downslope. In addition, plots
FIGURE IV-12. PLOT OF MEAN $b$ AXES ALONG COARSE AND FINE STRIPS ON CC 52

---

95% CONFIDENCE RANGE (for the means)

COARSE STRIP PLOT
(mean = 3.959"")

FINE STRIP PLOT
(mean = 1.417"")

MEAN $b$ AXIS IN INCHES

DOWNSLOPE DISTANCE IN FEET
FIGURE IV-13. FREQUENCY PLOTS AND CUMULATIVE PROPORTIONAL FREQUENCY CURVES OF b AXES ALONG FINE STRIP ON CC 52 (downslope in feet)

b AXIS IN INCHES (WENTWORTH DIVISIONS)

b AXIS IN INCHES (WENTWORTH DIVISIONS)
FIGURE IV-14. ZINGG SHAPE DISTRIBUTION CC 52

COARSE STRIP

NUMBER OF COBBLES
0 5 10 15 20 25
0 50 100 150 200 250 300 350 400 450

DOWNSLOPE DISTANCE IN FEET

PERCENT
0 20 40 60 80 100
MEAN TOTAL

FINE STRIP

NUMBER OF COBBLES
0 5 10 15 20 25
0 50 100 150 200 250 300 350 400 450

DOWNSLOPE DISTANCE IN FEET

PERCENT
0 20 40 60 80 100
MEAN TOTAL

KEY

BLADE
ROLLER
SPHEROID
DISC

$\frac{b}{a} < \frac{2}{3}$  $\frac{c}{b} < \frac{2}{3}$  FLAT; ELONGATE

$\frac{b}{a} < \frac{2}{3}$  $\frac{c}{b} > \frac{2}{3}$  ELONGATE BUT SQUARE

$\frac{b}{a} > \frac{2}{3}$  $\frac{c}{b} > \frac{2}{3}$  BLOCKY OR ROUND

$\frac{b}{a} > \frac{2}{3}$  $\frac{c}{b} < \frac{2}{3}$  FLAT BUT SQUARE OR ROUND
**FIGURE IV-15. FLATNESS PARAMETER ALONG FINE AND COARSE STRIPS ON CC 52**

- **COARSE STRIP** (mean = 0.556)
  - 95% CONFIDENCE RANGE
  - FLATNESS = \( \frac{2c}{a+b} \) (limits are 0 to 1)
  - If close to 0, then very flat; if close to 1, then more of a cube

- **FINE STRIP** (mean = 0.509)
CUBE SHAPE

IF CLOSE TO 1, THEN SPHERE OR
IF CLOSE TO 0, THEN DISC SHAPE.

SPHERICITY = \sqrt{\frac{4\pi A}{b \cdot c}}

(\text{limits are 0 to 1})

95% CONFIDENCE RANGE

FIGURE 14-16 SPHERICITY PARAMETER ALONG FINE AND COARSE STRIPS
of Zingg shape indicate no discernable progression of change downslope, though all shapes are present. These observations tend to confirm Ritchie's hypothesis (Chapter I) that mobility of debris is independent of shape, i.e., shape of a rock does not inhibit its rolling ability unless it is elongate, e.g., shaped like a pencil. If shape exerted a control then some progressional change downslope in the parameters calculated would be expected; no change was detected, however. Further, the flatness and sphericity parameters calculated (see representative values in Figures IV-15 and IV-16) suggest that no eccentric shapes predominate in the debris which has accumulated in the form of talus slopes in the region. This suggests that jointing of the headwall exerts a uniform effect resulting in a non-eccentric pattern of fragmentation. This inference is further augmented by the basic balance in the distribution of Zingg shape exhibited by all plots. The results coincide with the observations made of the jointing along the headwalls in the region. In general, the rocks exhibit a very complete joint pattern as a result of the intersection of at least three distinct planes of jointing.

D. Morphometric Analysis and Interpretation.

The debris comprising the surface of TC26 was sampled in conjunction with the mapping program. The b axis of one cobble was measured at each rod station (a total of 276 measurements). In this way, a fairly complete--if not random--sample of the talus surface was obtained. From the detailed surface data collected a trend surface analysis was made. First through sixth degree regression equations involving x and y (independent position variables) and z (the dependent cobble measure (b axis) variable) were calculated. The fourth degree equation was chosen to plot a trend surface (see overlay to Map 4B) since the equation had a coefficient of
determination of .466 and was significant at the 1% level on the F test. The 6th degree equation explains 49.7% of the variance. The increased explanation, however, is not worth the increase in complexity involved with the higher order equations (see Table X).

What is most striking is the upward slope of the trend surface in the lower left portion of the cone. This is obviously the result of a concentration of very large-sized boulders in association with the boulder apron at this point (see discussion Chapter III.E.2.). In general the surface indicates larger cobbles all along the apron with a fringe extending up along the right side where TC26 merges with an adjacent cone. As already discussed, the trough of intersection where the cones coalesce is filled with larger cobbles as indicated by the trend surface. On the talus proper the trend surface indicates a zone of coarser cobbles down the center of the slope bounded on either side by zones of fines. It is interesting to note with an inspection of Photo III-17 that the zones of fines correspond closely to areas of concentrated tree growth as one would expect. As can be seen, the generalized distribution of fines and coarse material on the talus proper is oriented parallel to the axis of transportation down the cone. This suggests some control exerted by variable mass movement mechanisms on the slope. Larger cobbles, being capable of individual movement downslope may tend to accumulate along the central axis where transport is concentrated. The fines, incapable of individual movement downslope, could tend to accumulate near the apex initially. Upon assuming a critical angle, however, readjustment could occur by release en masse in the form of miniature slides which would tend to avoid the coarser accumulations along the central axis moving, rather, to accumulate along the lateral portions of the cone. This, of
Table X.  
TREND SURFACE ANALYSIS TC26; ANALYSIS OF VARIANCE AND ERROR MEASURES

<table>
<thead>
<tr>
<th>Surface</th>
<th>Sum of Squares</th>
<th>DF</th>
<th>Mean Square</th>
<th>Residual DF</th>
<th>Residual Mean Square</th>
<th>F</th>
<th>Coeff. of Determination</th>
<th>Standard Error</th>
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<tr>
<td>1 increment</td>
<td>.34</td>
<td>2</td>
<td>.17</td>
<td></td>
<td>276</td>
<td>.57</td>
<td>29.83*</td>
<td>.177</td>
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<tr>
<td>total</td>
<td>.34</td>
<td>2</td>
<td>.17</td>
<td></td>
<td>276</td>
<td>.57</td>
<td>29.83*</td>
<td>± 23.87</td>
</tr>
<tr>
<td>2 increment</td>
<td>.28</td>
<td>3</td>
<td>.92</td>
<td></td>
<td>273</td>
<td>.48</td>
<td>25.79*</td>
<td>.321</td>
</tr>
<tr>
<td>total</td>
<td>.61</td>
<td>5</td>
<td>.12</td>
<td></td>
<td>273</td>
<td>.48</td>
<td>25.79*</td>
<td>± 21.69</td>
</tr>
<tr>
<td>3 increment</td>
<td>.18</td>
<td>4</td>
<td>.45</td>
<td></td>
<td>269</td>
<td>.42</td>
<td>21.22*</td>
<td>.415</td>
</tr>
<tr>
<td>total</td>
<td>.80</td>
<td>9</td>
<td>.89</td>
<td></td>
<td>269</td>
<td>.42</td>
<td>21.22*</td>
<td>± 20.13</td>
</tr>
<tr>
<td>4 increment</td>
<td>.98</td>
<td>5</td>
<td>.20</td>
<td></td>
<td>264</td>
<td>.39</td>
<td>16.47*</td>
<td>.466</td>
</tr>
<tr>
<td>total</td>
<td>.90</td>
<td>14</td>
<td>.64</td>
<td></td>
<td>264</td>
<td>.39</td>
<td>16.47*</td>
<td>± 19.23</td>
</tr>
<tr>
<td>5 increment</td>
<td>.38</td>
<td>6</td>
<td>.63</td>
<td></td>
<td>258</td>
<td>.38</td>
<td>12.19**</td>
<td>.485</td>
</tr>
<tr>
<td>total</td>
<td>.94</td>
<td>20</td>
<td>.47</td>
<td></td>
<td>258</td>
<td>.38</td>
<td>12.19**</td>
<td>± 18.87</td>
</tr>
<tr>
<td>6 increment</td>
<td>.22</td>
<td>7</td>
<td>.31</td>
<td></td>
<td>251</td>
<td>.39</td>
<td>9.20**</td>
<td>.497</td>
</tr>
<tr>
<td>total</td>
<td>.96</td>
<td>27</td>
<td>.35</td>
<td></td>
<td>251</td>
<td>.39</td>
<td>9.20**</td>
<td>± 18.66</td>
</tr>
</tbody>
</table>

* significant at the 1% level.

** not significant at the 1% level.
course, contradicts the observations in section A of this Chapter where it was found that debris sampled along lateral profiles on TC21 was coarser than that sampled along the central profile. It should be noted, however, that the lateral profiles taken on TC21 were along the extremities of the cone where, as already noted in a discussion of the surface characteristics of TC26 (Chapter III.E.2.), a boulder fringe has developed. As illustrated by the trend surface on the overlay to Map 4B, however, the finer debris on TC26 is located between the coarser deposits along the center and the extremities of the cone. No profiles were established along comparable sections on TC21. The results suggest that accumulation and readjustment mechanisms on the slopes are complex and will require further study before they are completely understood.
CHAPTER V - CONCLUSIONS

A. Summary.

The massive and abundant talus forms in the Similkameen Valley near Keremeos, B.C. were investigated. It is assumed that all of the talus has accumulated in the last 10000 years and it is concluded that talus formation in the region is entering a passive stage of development. The slopes observed have grown to near maximum proportions, covering to a great extent the headwalls from which sediment is derived. A 'diminishing sediment yield concept' was applied and calculations of rates of accumulation afforded by the incorporation of Mazamaash in one talus cone support the concept. The net effect has been a reduction in the rate and influence of rockfall activity resulting in a tendency towards stability. This is substantiated by the establishment of vegetation on all talus slopes observed; samples obtained from fences designed to gauge rate of rockfall in the area confirmed the validity of using vegetation as an index of stability.

Lithologic control largely accounts for the form and degree of the talus development noted. The exposure of resistant cherts inter-bedded with weaker volcanic and sedimentary rocks has resulted in an uneven dissection of the headwalls under the influence of weathering. Talus cones occurring in isolation or as coalesced groups are the net result of the uneven dissection; south-facing slopes of the valley display greatest development.

The frequency of frost cycles suggests the importance of the mechanisms of frost shatter and frost bursting, these being considered the dominant weathering mechanisms in the region. Observations indicate
that the chemical processes of oxidation, hydration and solution are important as well. A number of secondary physical processes, including root wedging, may have limited effect.

Observed concentration of rockfall activity during the spring season suggests the importance of "frost-riving" as a release mechanism. Lubrication and buildup of hydrostatic pressure by water is also considered effective. The expansion and contraction associated with the characteristically high diurnal range of temperature in summer may be a sufficient force to set rocks loose. Attempts to measure rates of rockfall activity met with fair success in the construction of fences on TC25 and TC49. The loss of a substantial portion of certain samples, however, limits the effectiveness of the method.

Net and differential downslope movement of debris was detected on lines painted on three talus slopes in the region. In general, more disturbance and greater net downslope movement was recorded on coarse as compared to fine strips of debris. The reliability of this method of detecting mass movement on the slope is questioned in light of the disturbance to the slope when the line is painted. Notwithstanding, the observations made suggest that mechanisms of mass movement differ between fine and coarse strips. Further study of the phenomenon is warranted.

Spontaneous mass movement as the result of lubrication by water (rainfall and melt) was indirectly observed. A number of other mass movement mechanisms are recognized as important, including talus creep, flowing water, snow avalanche, animal and human disturbance and basal sapping.

It is thought that reasonable explanations have been given for the occurrence of boulder aprons and the distribution of vegetation
on talus cones observed in the region. A satisfactory explanation for
the occurrence of "protalus boulder accumulations" on TC67 could not be
given but it is thought that the ridges may represent a relict accumulation.

Measurements on TC21 indicate that debris along lateral profiles
is significantly larger at the 1% level than debris sampled along the
central profile. Also, some correlation between size and angle is implied
since the lateral profiles are steeper than the central profile. The
results substantiate the hypothesis that transport mechanisms down the
center are different from those along the sides of the cone. Further
study in this direction might be worthwhile.

According to initial observations made, it was hypothesized that
no downslope sorting of the debris exists on talus slopes in the region.
Analysis of data collected on longitudinal profiles and traverse samples
contradict the hypothesis; a slight increase in cobble size downslope
was detected. The trend is weak and not monotonic but an associated
downslope decrease in angle suggests a correlation between size and angle.
This contradicts the correlation between size and angle determined by
comparison of central and lateral profiles on TC21. The results indicate
that different transport mechanisms operate on different parts of the
slope.

Fine and coarse strips of debris found on most talus slopes
observed displayed no significant differences in fragment characteristics
which might account for the sorting observed. It is concluded that the
cross-slope sorting into fine and coarse strips of debris is a function
of variable mass movement mechanisms. It is suggested that the larger
cobbles accumulate on an individual basis along the slope whereas the fine
materials accumulate en masse in the form of miniature slides as strips
adjacent to the coarse material.

Calculation of Zingg shape and flatness and shericality parameters from data collected in a variety of ways indicates no detectable downslope trend. This observation tends to confirm Ritchie's hypothesis that mobility of debris is independent of shape. The lack of a predominant shape type is a reflection of the very complete jointing of the headwall.

The mapping of TC26 on a large scale for the purposes of morphometric analysis was attempted. A useful map was produced which verified some of the assumptions made regarding talus morphology in the region. Trend surface analysis based on sampling of the debris in conjunction with the mapping of TC26 provided good results. The fourth degree surface plotted explains 46.6% of the variance in the data and portrays the gross surficial detail of the cone very well. The generalized distribution of fines and coarse material portrayed by the trend surface on TC26 suggested control exerted by differential mass movement mechanisms. The distribution has been explained in terms of individual and en masse movement of debris on the slope.

The investigation has produced some interesting as well as worthwhile results. The attempt, however, is really only a beginning. Since the occurrence of abundant and impressive talus forms is rare in accessible regions it is thought that the Similkameen Valley near Keremeos, B.C. affords an ideal opportunity for an expanded study of the distribution, form and mechanics of talus development.

B. Practical Recommendations for the Region.

The occurrence of a substantial number of talus slopes near Keremeos presents advantages and disadvantages to the residents of the area. Both past and present talus activity have effect.
Perhaps the most welcome advantage is the ready supply of suitable riprap, located at the base of most slopes, which is used to protect the banks of the Similkameen River during peak flows. This debris would be ideal, as well, to use as fill in the construction of railway and highway beds.

Construction of highways in close proximity to talus slopes, however, can prove to be dangerous. At CC44, the course of the Similkameen River hugs the north side of the valley very closely. At this point the Southern Trans-Canada Highway has a cut which truncates a series of coalesced talus cones. This is potentially dangerous for any passerby in line with debris moving down the talus slope. A ditch skirts the edge of the highway between it and the cut but such a ditch would not be effective in containing the debris as such ditches are where cuts are made through shear rock faces (see Figure V-1). Ritchie (1963) suggested a series of fencing techniques to accommodate the
FIGURE V-1. ROCKFALL TRAJECTORIES

A. ROAD CUT THROUGH TALUS

B. ROAD CUT THROUGH ROCK
various trajectories of debris encroaching upon highways.

Rockfall produces additional problems in the valley. The accumulation of large boulders at the apron or base of talus slopes occurs frequently on level terrace land which is potentially arable. This land usually remains unproductive since removal of the boulders is costly. An exception appears in Photo V-1 which shows talus rubble gathered into strips near the base of talus cones at CC7. The land reclaimed in this way was planted in alfalfa. In the spring of 1966 a section of the wooden pipeline which has supplied Keremeos with irrigation water from the Ashnola River was torn out by debris moving down TC25. According to some of the local residents, such movement of debris with potential for damage occurs regularly along the talus slopes on K Mountain.


Canada Geological Survey. Map 341A Keremeos; Similkameen District, B.C. Department of Mines and Resources, Ottawa, 1939.


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APPENDIX.

A. Maps and Photographs Used.

Terrestrial photo coverage was obtained in the form of black and white prints and coloured slides using a 35 mm. camera. Air photo interpretation and the construction of a base map for the area were accomplished employing B.C. Government (Department of Lands, Forests and Water Resources, Victoria, B.C.) air photos listed below in Table 1:

Table 1: LIST OF AIR PHOTOS

<table>
<thead>
<tr>
<th>Photo #</th>
<th>Scale at River Level</th>
<th>Date of Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. B.C. 5007 - 65-84</td>
<td>1:10900</td>
<td>May 31/59</td>
</tr>
<tr>
<td>2. B.C. 5208 - 020-028 041-045</td>
<td>1:35700</td>
<td>Sept. 3/66</td>
</tr>
<tr>
<td>3. B.C. 5214 - 001-003; 037-039; 097-104; 125-127; 178, 179</td>
<td>1:35700</td>
<td>Sept. 3/66</td>
</tr>
</tbody>
</table>

Suitable topographic map coverage was available (Surveys and Mapping Branch, Department of Mines and Technical Surveys, Ottawa) and a list of the maps used is found in Table 2.

Table 2 LIST OF TOPOGRAPHIC MAPS

<table>
<thead>
<tr>
<th>Title of Map</th>
<th>Number</th>
<th>Scale</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Keremeos</td>
<td>Map 341A (82E/4)</td>
<td>1:50,000</td>
<td>1939</td>
</tr>
<tr>
<td>2. Ashnola</td>
<td>92H/1-E</td>
<td>1:50,000</td>
<td>1960</td>
</tr>
<tr>
<td>3. Penticton</td>
<td>82E/S-W</td>
<td>1:50,000</td>
<td>1965</td>
</tr>
<tr>
<td>(advanced print)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Hedley</td>
<td>92H/8-E &amp; W</td>
<td>1:50,000</td>
<td>1966</td>
</tr>
</tbody>
</table>
B. Additional Notes for Map 2.

The rocks as indentified by Bostock (1929, 1930) are as follows:

1. Independence Formation: chert, greenstone.
2. Shoemaker Formation: chert; some tuff, greenstone.
3. Old Tom Formation: greenstone; basalt flows, sills, bosses; some diorite.
4. Springbrook Formation: mainly conglomerate; some sandstone, shale.
5. Marron Formation: mainly basaltic laval; some breccia, tuff, conglomerate.
6. Olalla pyroxenite.
7. Olalla syenite.