THE RUBBLE CREEK LANDSLIDE

GARIBALDI, BRITISH COLUMBIA

by

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ABSTRACT

During the late winter of 1855-56 or early spring of 1856 about 33,000,000 cubic yards of volcanic rock slid from the high cliff known as The Barrier, near Garibaldi, B.C. This debris travelled down a rather sinuous path along Rubble Creek valley to its confluence with Cheakamus River about 4 miles from the Barrier and about 3400 feet lower.

The initial material appears to have travelled as a high velocity tongue of debris which swept from one side of the valley to the other as the debris stream rounded curves eventually to be deposited on Rubble Creek fan. Velocities calculated from the superelevation of the debris as it rounded three different curves indicate that the debris was moving between 88 and 110 feet per second. A minimum velocity of 80 feet per second was calculated using the principle of conservation of energy where the debris overtopped a small hill at the apex of the fan. All of the trees in the path of this slide were uprooted and carried away. The trees adjacent to the slide were scarred and bruised by moving debris.

The initial high velocity tongue was apparently followed by mud flows which deposited large rounded boulders and poorly sorted, volcanic debris on an area of the fan which was not covered by the initial slide. This material was apparently slow moving, as it piled up high on the uphill side of some trees which later died and fell across the top of the debris. Some xenolithologic debris cones similar to those found at Sherman Slide in Alaska and elsewhere also occur in the area of mudflow material.

The slide deposit is formed of angular poorly sorted volcanic clasts weighing up to about 250 tons. The slide debris can be distinguished from underlying fan deposits by the lack of fine gravel and silt sized particles in the fan material. Deposits of debris similar to the debris of the 1856 slide, beneath some of the fan deposits, show that an earlier slide may have occurred.

The mechanism which triggered the landslide is not known, but blockage of a subsurface drainage system, which drains the area behind The Barrier and escapes as springs at its toe, could have raised groundwater pressures enough to trigger the slide. In addition, as the area is one of recent volcanic activity a local earthquake may have been the immediate cause. In any event the underlying cause for the landslide was that the excessively steep and high cliff face of lava was apparently deposited against glacial ice, and subsequently, lost support when the ice melted.

Studies using a scale-model of the topography of the area and bentonite slurries were carried out to find out if the movement of the 1856 slide could be modelled and if so, could the movement of possible future slides be predicted. Although no mathematical basis was developed for the modelling it is thought that if a material could be found which modelled the complex movement of the 1856 slide, future slides could also be modelled. Although modelling of the 1856 slide was not entirely successful several insights were given into the movement and deformation of prototype slides of the same type as Rubble Creek Slide.

There has been at least one destructive slide in the area of Rubble Creek fan in the recent past and because it cannot be demonstrated that conditions have changed substantially since the 1856 slide it is only prudent to accept the possibility of the occurrence of another slide in the near future.

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INTRODUCTION

A major rockslide which occurred in early 1856 in the Garibaldi area, as shown on Figure 1, became of interest in 1973 when a new housing development was proposed for an area on the toe of the slide. The British Columbia Department of Highways refused to permit the development on the grounds that there was a danger of additional rockslides. During the spring of 1973, this refusal was contested by the developer and subsequently upheld by the Supreme Court of B.C.

The information contained in this thesis is mainly from a study of the rockslide carried out in the summer of 1973 for the Department of Highways. The purpose of the study was to collect information about the 19th Century slide and to investigate the potential for further slides. In addition, scale-model studies were carried out in order to help assess the dangers to the development area from potential slides of a similar nature to the slide of 1856.

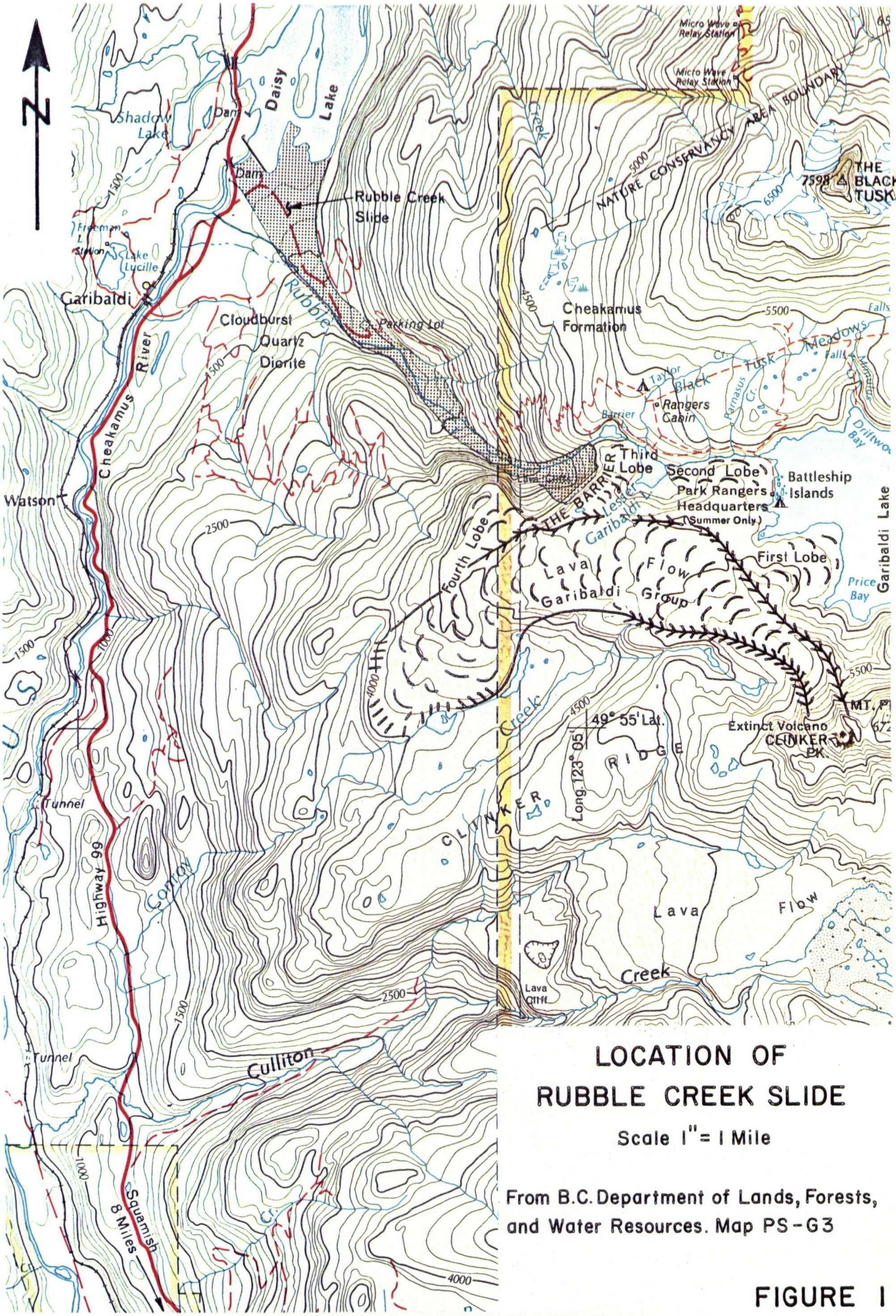
Earlier geological investigations in the area have not dealt specifically with the rockslide but rather with the regional geology (Mathews, 1958) and the construction of a hydroelectric dam at the toe of the rockslide (Terzaghi, 1954 and 1960).

FIELD STUDIES

1. Geological Setting

The source of the rockslide was the steep slope at the head of Rubble Creek known as "The Barrier". From The Barrier the rockslide travelled about 4 miles down Rubble Creek valley to its junction with Cheakamus River valley. Cheakamus River flows south through a channel cut in the toe of Rubble Creek fan, as shown on Figure 1. In 1957, a hydroelectric dam was completed across the Cheakamus River just upstream of its confluence with Rubble Creek. The reservoir has flooded the northern corner of the fan including the distal end of the slide debris to an elevation of about 1261 feet above sea level.

Rubble Creek valley is trapezoidal in cross-section, with a floor that slopes 7 1/2 degrees downstream and walls that rise a few thousand feet at angles of about 30 degrees. The walls are formed by a thin mantle of soil underlain on the northeast side of the valley by conglomerate and greywacke of the Cretaceous Cheakamus Formation and on the southwest by the older, Cloudburst quartz diorite (Mathews, 1958). Near Rubble Creek, the structure and bedding in the sedimentary rocks generally trend north and dip steeply east. During the late stages of glaciation, dacite lava flowed from Clinker Mountain and formed precipitous terminal faces where it was ponded against ice remaining in the valleys below elevation 4000 feet (Mathews, 1952). Four lobes of lava flowed laterally to the north from the main flow (Figure 1). Water has been ponded behind the second and third lava lobes to form Garibaldi and Lesser Garibaldi Lakes respectively. The third lobe was the source of the



LOCATION OF RUBBLE CREEK SLIDE

Scale 1" = 1 Mile

From B.C. Department of Lands, Forests, and Water Resources. Map PS-G3

FIGURE 1

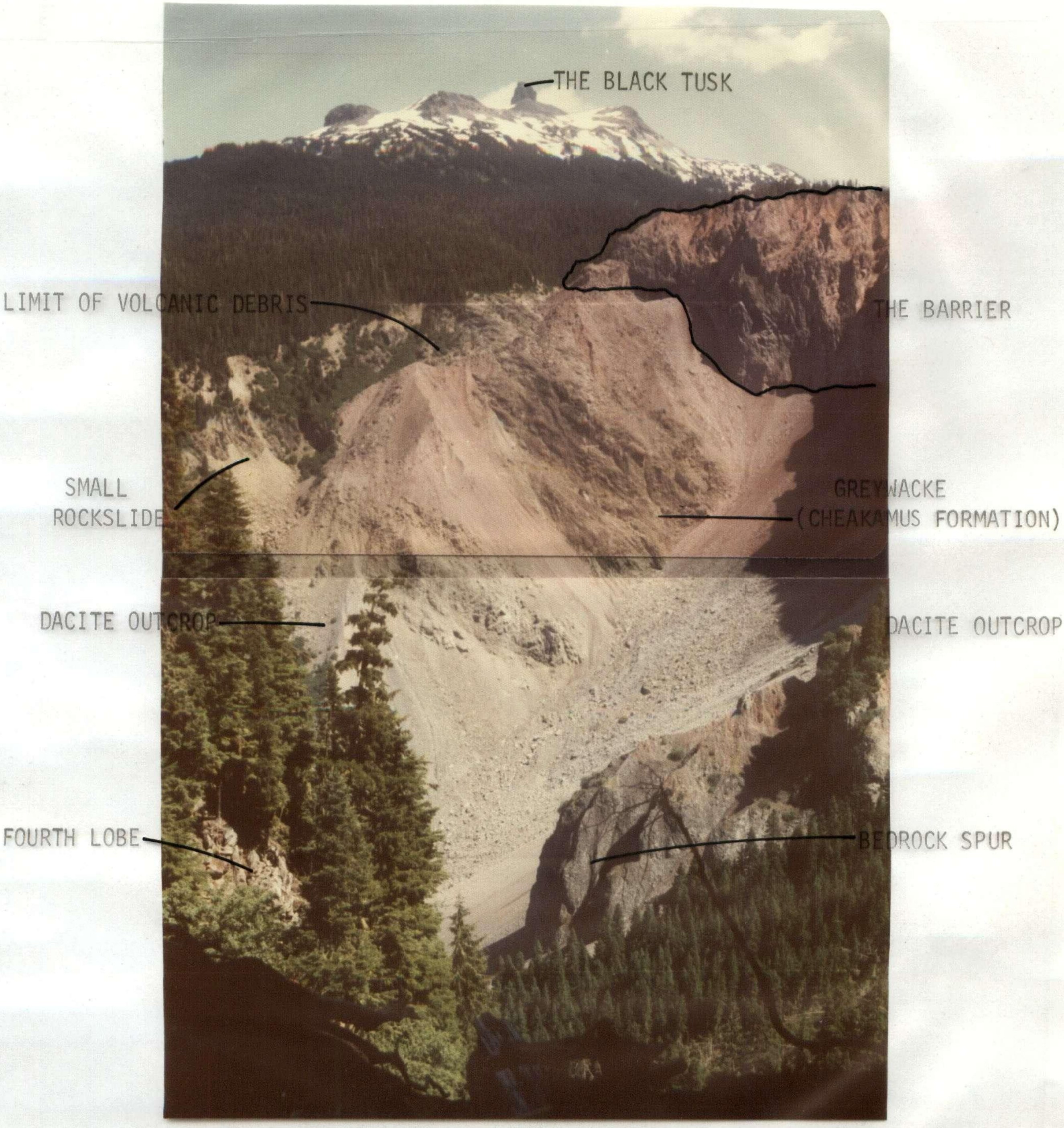
the rockslide and the scarp which remains is The Barrier. West of The Barrier, the fourth lava lobe forms an impressive cliff about 1500 feet high with an average surface slope of about 64 degrees.

2. Geology of the Source Area

The failure of the third lava lobe (Figure 2) was localized by the side of the pre-volcanic valley on the north, by steep joints on the east and by some unknown surface beneath the talus on the south. These features may be seen in Photograph 1.

Prior to the deposition of the lava, the side of the valley on the north had been worn smooth and covered by a discontinuous mantle of glacial and fluvial debris a few feet thick. This surface trends east and slopes about 37 degrees south. Details of the surface are largely determined by a set of joints which dip 40 degrees south and by bedding in the greywacke. The joints form a series of steps and the bedding forms low ridges angling downslope. A small rockslide has occurred along a combination of the joints and the bedding, as shown on Figure 2.

The dacite found on the north slope is mainly loose, active talus derived from the rubble ridge which marks the northern depositional limit of the volcanics in this area. However, several small blocks of black dacite also occur high on this slope. These blocks of dacite are intact although highly jointed and the lava columns in the dacite generally plunge at a steep angle to the valley wall. It is thus apparent, that the dacite blocks are still in their original depositional position. These black outcrops as well as the northern limit of volcanic debris can



Photograph 1

North wall of Rubble Creek Valley adjacent to the Barrier.

be seen on Photograph 2. The debris which forms the ridge is bedded and contains large intact blocks of highly fractured dacite. This debris is similar to that which forms the surface and edges of the lava flow elsewhere and is not thought to be normal talus.

The main scarp of the slide, the Barrier, is a 700 foot high lava cliff which reaches elevation 4800 feet. The cliff is skirted by talus derived mainly from a layer of red, volcanic rubble which forms a steep, loose slope about 200 feet high at the top of the nearly vertical cliff. Rockfalls from the red rubble layer are common and make close examination of the cliff-face hazardous. Vertical columnar joints in the center of the flow are conspicuous from a distance and appear to form the strongest set of joints in the cliff. Joints which dip very steeply out of the slope also occur as may be seen in the shadow near the centre of Photograph 3. These planar joints are usually found in gray lava near the center of the flow and slabs of this material commonly occur in the slide debris. Flat-lying discontinuities in the lava are also conspicuous particularly where they bend into parallelism with the volcanic-greywacke contact at the north end of the Barrier.

Except in a few small areas of bedrock which crop out through the talus, the rest of the failure surface is buried. The outcrops are located close to the toe of the Barrier in the upper part of the talus slope (Figure 2 and Photograph 3). The rock in these outcrops is black dacite with columnar joints and cross joints which divide it into about 4 inch blocks. These outcrops indicate that at least part of the failure

Photograph 2

Northern limit of third lava lobe,
looking towards Barrier Lake.

surface beneath the talus was through bedrock. The large bedrock spur toward the right side of Photograph 3 is formed from black dacite which is cut by closely spaced columnar joints with axes at a steep angle to the surface of the outcrop (Photograph 4). The upper part of this outcrop is formed from vaguely bedded, red dacite-rubble (Photograph 5). The trees growing on top of this rubble are similar in size and species to trees found to the south which clearly pre-date the slide. Thus showing that this outcrop did not participate in the 1856 slide. The closely spaced columnar joints indicate that the present surface is near the original depositional surface. The scarp on the north side of this spur marks the southern limit of the slide. A cross-section through this area is shown on Figure 3.

According to local residents, the long talus slope south of the outcrop on the extreme right of Photograph 3 has been the source of several small talus slides during the last 30 years which have cut into the adjacent vegetated slope.

The fourth lava lobe is similar to the third except that its interior is, for the most part, hidden by a surface layer. The surface layer is characterized by remarkable, columnar joints which generally point outwards from the face of the lobe, as illustrated on Photograph 6. Columns usually point in the direction of heat loss during cooling therefore it is probable that the present face is essentially parallel to the original depositional face. Deeper within the flow, the columns are much thicker and more or less vertical. The tendency for the columns to point downward near the toe of the fourth lobe indicates that the bottom

Photograph 3

The Barrier

Photograph 4

Black dacite near toe of Barrier, fourth lava lobe and Rubble Creek fan in middle distance.

Photograph 5

Bedding in the red rubble which overlies the outcrop shown in Photograph 4.

of the flow is probably nearby. This lobe is capped by a layer of red dacite rubble similar to the third lobe. A cross section through the fourth lobe is shown on Figure 3.

A series of crushed zones near the toe of the fourth lava lobe (Figure 2) can be seen in Photograph 7. These zones are more than 100 feet long and contain several feet of crushed and rotated lava columns. Although the attitudes of these surfaces are difficult to measure, they strike roughly northeast and dip steeply northwest. Vertical discontinuities which separate slabs from the face of the lava lobe are common. One such slab about 150 feet high can be seen on Photograph 4. Several rubble-filled troughs 10 to 20 feet deep and a few hundred feet long parallel the break in slope along the top of the fourth lobe.

3. Slide Path

The passage of the slide debris down Rubble Creek valley was recorded in a number of ways. The slide left a thin but nearly continuous coating of volcanic debris which is easily distinguishable from the local rock and the glacial deposits. The upper limit of this continuous coating can usually be located within a width of 20 feet and only widely scattered volcanic fragments are found above it. It is the location of this limit which has been marked on Figure 4. Debris scattered above this limit is not common but is more often found downstream of transverse ridges which have obstructed the movement of the slide.

Lateral ridges occur locally along the edge of the slide path. They are varied in shape from flat terraces on the valley walls, only a few feet across, to steep-sided ridges 20 feet high.

Photograph 6

Columnar jointing, 4th lava lobe.

Photograph 7

Crushed zones near the toe of the 4th lava lobe.

Many of the trees found above the debris limit have had their bark torn off near the base. The scars which remain face upstream and slightly toward the valley axis. They commonly have deep bruises extending into the woody part of the trunk and in two instances, an angular piece of volcanic debris was found actually embedded in the wood. Photograph 8 shows one of these rocks embedded in a tree. The tree has a scar typical of many trees found near the edge of the slide path.

The trees living within the slide area are more closely spaced, smaller and younger than those outside. The ages of about 150 of the largest trees on both sides of the slide limit were determined, by counting the annual rings. Those within the slide path were found to be younger than 113 years whereas many of those outside the path were more than 200 years old. The remains of some older trees were observed in the depositional area of the slide (see following section) but, upstream of this, the slide path was swept clean.

A line connecting the centroids of cross-sections of the slide as it passed down the valley is also shown on Figure 4. This line is thought to approximate the path of the center of gravity. As such, it has been connected to the center of gravity of the slide deposit and to the center of gravity of its reconstructed source position. Lines drawn perpendicular to the path of the center of gravity and joining debris limits on opposite valley walls slope as much as 10.5 degrees. A series of cross-sections transverse to the direction of slide movement are shown on Figure 5. These cross-sections illustrate the path of the slide mass as it banked from one side of the valley to the other. The longitudinal section of the slide path graphically illustrates the remarkable efficiency and travel-distance of the slide.

Photograph 8

Cedar tree with volcanic rock embedded just above the knife.

Photograph 9

Iron oxide surface layer which marks the base of the most recent slide debris near the mouth of Rubble Creek.

The debris limits are broadly curved except downstream of transverse ridges such as those at point A on Figure 4. It can be seen that the height to which the slide reached drops over 100 feet from the upstream side of this ridge to the downstream side. This appears to be a "shadow effect" such as occurs downstream of an obstruction in flowing water.

4. Depositional Area

A small part of the slide debris was deposited in the valley of Rubble Creek but most of it was deposited on its alluvial fan. The fan can be divided into three sectors containing dissimilar surface deposits.

The northernmost sector, Sector I (Figure 4), contains the bulk of the slide debris. Logs of drillholes near the damsite, seismic surveys along several roads and surface observations indicate the depth of slide debris in this area to be about 32 feet. The surface is hummocky with many closed depressions and small mounds. The upper part of this section is characterized by elongate mounds which trend downslope. Running water has cut gullies and generally modified the surface in the area.

Three parallel ridges of debris occur on the edge of the granitic knob at the apex of the fan. These ridges probably represent successively lower levels of moving debris which at one time, at least, overtopped the knob. In addition, a mound of debris is found just upstream of the granitic knob. This mound is 40 feet higher than the surrounding land and is separated from the knob by a saddle-like depression. A coniferous forest has developed in this area since the slide. The southwest boundary of this section is marked by a steep slope 6 to 25 feet high which divides the elevated area of hummocky topography on the northeast from a lower section on the southwest. The distal end of the deposit in Sector I is beneath the surface of the reservoir and was not observed.

The middle sector of the fan, Sector II, is the smallest and contains only a very small amount of slide debris. Many of the tree stumps left from the logging about 30 years ago have well over 200 annual rings. The roots of many of these stumps have been buried by a foot or two of dacite debris but they obviously lived through the slide. A layer of gravel cemented with iron oxides is found just under the surface in this area. The layer can be followed up Rubble Creek to a point about 1900 feet above the highway bridge. The oxidized deposit is more sorted, rounded and bedded than typical slide debris. It is thought to be near the pre-slide surface of the fan. Photograph 9 shows this rusty surface layer near the present day surface at Rubble Creek. A terrace deposit of volcanic debris exists along the Cheakamus River. Many trees have been buried in this terrace deposit, some of which have been subsequently exhumed. None of the living trees on this terrace was found to be older than the slide even though many trees growing a few feet above the terrace were older. The terrace was probably formed during rapid aggradation of the Cheakamus riverbed immediately following the landslide.

The southernmost sector of the depositional area, Sector III, covers the fan from Rubble Creek south. It is characterized by large fields of subrounded cobbles and boulders with very little matrix at the surface. Many of these areas support little vegetation other than moss and lichens. The boulders range up to 6 X 6 X 10 feet in size

(Photograph 10). The material beneath the surface layer of boulders is very poorly sorted volcanic debris. This sector has a generally uniform topography except for gullies marking former locations of Rubble Creek which has apparently changed its channel several times since the slide, and some shallow gullies which tend to start and die out a few hundred feet downslope. The boundaries of the area are very sharp and volcanic debris was not found much beyond the present extent of the fan except on the West bank of the Cheakamus River where debris occurs about 15 feet above the railway track. The boundary of volcanic debris was not easily traced near its western end because of the subsequent road and railway construction in the area, however, the debris appears to have reached an elevation on the west bank of the Cheakamus approximately equal to that of the top of the east bank of the river. Many buried trees occur along the boundaries of Sector III, these trees were growing prior to the slide and buried by it without being tilted, broken, or having their bark torn from the trunk. Only one area of buried trees was found in the interior of Sector III. The age of some of these trees was determined by a count of their annual rings to be greater than 200 years. The trees were apparently buried by the slide although still standing and then they died and fell on top of the debris, as shown on Photograph 10. The debris piled up 6 feet high on the upstream side of the trees and a depression was formed on the downstream side. Some of the boulders piled against the trunk were 2 to 3 feet in diameter. This is in marked contrast to the other areas of the slide where the pre-slide vegetation was carried away and even trees adjacent to the slide path were scarred and broken.

Photograph 10

Buried trees near the center of Sector III on Rubble Creek fan.

Photograph 11

Xenolithologic debris cone in Sector III Rubble Creek fan. Tree stump is more than 60 years old.

About 1000 feet downhill of the buried trees in Photograph 10, two curious features were observed. The pile of red rubble, shown on Photograph 11 and a similar mound found 40 feet away are debris cones similar to those found on the slide deposits at Sherman Peak (Shreve, 1966) and elsewhere. The mound shown in the photograph has a stump on it which was over 60 years old, hence it is probable that the mound was not man-made. The adjacent mound rises only a few feet above the surrounding boulder field and it is composed of the same poorly sorted, red rubble as the mound in the photograph. The material ranged from silt-size to at least 1.5 feet in diameter. There does not appear to be a large block of debris underlying these mounds as observed at Sherman slide for example (Shreve, 1966).

5. Debris Characteristics

The debris which forms the slide deposit is a loose, unsorted mixture of angular volcanic fragments ranging in size from fine silt (Terzaghi, 1954) to more than 15 feet diameter.

Grain size distributions for 17 samples of the fraction of the debris less than 0.5 inches in diameter, were measured using U.S. Standard Sieves ranging in size between #5 and #200 (Appendix). This fraction was found to be very poorly sorted having an average coefficient of uniformity (Cu) of 29 and a coefficient of curvature (Cc) of less than 1. Between 7 and 22 percent of each sample passed the #200 sieve (Earth Manual, USBR, 1968). A sample of the material underlying the oxidized layer at the mouth of Rubble Creek was also analysed. This sample was also well graded but less so than the other samples. It was relatively depleted of the fine gravel and fine sand sized material. The coefficient of uniformity was 8 and the coefficient of curvature was 1.4.

The water contents of the samples at the time of analysis ranged from 3 to 9 percent. These values are probably lower than the in situ water content because of losses after the sample was taken. Natural water contents of the fraction less than 3 inches diameter were found to be between 12 and 16 percent during construction of the storage dam (Terzaghi, 1960). For these natural water contents and an assumed specific gravity of the solids of 2.7 the minimum porosity of the debris would have to be 25 to 30 percent.

The relative density of the debris was indicated to be very low by the ease with which drill hole casing could be driven into the ground, (Terzaghi, 1960).

A total of 1234 pebbles, larger than about 0.08 inches, from 11 samples were classified as to size, lithology, roundness and sphericity (Krumbein, 1941). An attempt was made to find any regular variation in the lithologic composition of the slide debris. Samples were taken from all three sections and up to elevation 2580 in the creek valley. No consistent variation in composition could be detected. The sample from beneath the oxidized layer showed a preponderance of black dacite over gray dacite unlike the other samples. This sample suggests that the supply of material to the fan prior to the slide was more from the black outer layer of lava rather than the gray core of the flow. The average content of green greywacke such as that found on the north side of the source area was 6.5 percent. The average content of granitic pebbles and pebbles of unknown lithology was 3.5 percent of the total number of pebbles. The granitic pebbles appeared to be mainly diorite. The bulk of the samples was a volcanic rock like that which forms

The Barrier. An average of 42 percent of the fragments are gray, 30 percent are black and 18 percent are red. In many instances it was rather arbitrary whether a sample would be classed as black or gray.

The fragments have a very broad range of sphericities with a mean of about 0.68. Histograms were plotted of sphericities for each of the eleven samples using a cell width of 0.04. The distribution is very broad and the highest peaks are only 20 to 25 percent of the sample. An exception to this is the sample from beneath the oxidized layer which shows a relatively narrow peak and 30 percent of the sample in a single cell.

Frequency histograms were also plotted of the roundnesses measured for each of the eleven samples. These distributions are narrow and have an average mean of about 0.41. The range in means is from 0.3 to 0.5 and the range in individual roundness is from 0.1 to 0.7.

The frequency distribution of the length of the b-axes of the pebbles for sizes greater than 0.16 inches is similar for all samples except the sample from below the oxidized layer (Appendix). This sample has a much higher content of pebbles having b-axes longer than 2.52 inches.

6. Age

The earliest available reference to the slide is the journal of Major William Downie who travelled through the area in 1858. He described the area as follows:

"...about noon we struck into a lagoon, or a large tract of overflowed land, the Indians say this was over flowed three years ago. We found the cause of it as we came along, a Lake has broken away in the Mountains, and swept away ridge, after ridge, covering a whole forest of timber, with rocks and sand for the space of 6 or 7 square miles changed the course of the river, and not left a stump to be seen, where the tall timber stood three years ago, our trail over this was about two and a half miles..."

The history of the slide is also recorded in the annual rings of the trees growing on the debris or adjacent to the slide path. The rings of more than 150 trees were counted and without exception those trees growing on top of slide debris were less than 113 years old whereas those outside the path of the slide were commonly several hundred years old. The trees along the edge of the slide path, which survived the slide but were scarred by the debris, graphically illustrate the age of the slide. Two of these trees were sawn down and a count of their rings indicated that the slide occurred during the late winter of 1855-56 or early spring of 1856.

7. Volume

The volume of material between the reconstructed pre-slide surface (Figure 4), and the present surface is estimated to be 33,000,000 cubic yards. The inferred pre-slide surface is obtained by connecting the surface now found to the south of the source of the slide with the limit of volcanic debris north of the source. The volume compares well with the volume of debris which is estimated to be deposited in the valley and on the fan of Rubble Creek. The volume of material in the valley was estimated by calculating the amount of material required to form the present valley cross-section from a cross-section similar to a nearby valley. Culliton Creek valley was selected for comparison because it is a similar size, it is only a few miles south, there has been no major slide in it, it has steep volcanic cliffs near its source and it has a cross-section not unlike most other creeks in the area. The volume of slide debris added to the valley bottom was thus estimated to be 12,100,000 cubic yards including a small volume of debris which was subsequently removed. The depth of debris deposited on the fan can be estimated from borehole data near the damsite, the height of the scarp at the southern edge of the debris, the thickness of debris in excavations and the topographic relief associated with slide related features such as hummocks. The debris in this section has an average depth of 32 feet corresponding to a volume of 22,200,000 cubic yards. The total volume of debris in the slide deposit is thus 34,300,000 cubic yards which compares well with the volume (33,000,000 cubic yards) calculated through reconstruction of the contours at the source. The increase in volume from the source to the deposit accounts for some of the increase in porosity. which undoubtedly occurred during motion.

An estimated thickness of 6 feet for the slide deposit south of Rubble Creek corresponds to a total volume in this area of 3,200,000 cubic yards. This thickness is consistent with the thickness of debris observed in the banks of Rubble Creek, and the local relief in this part of the fan. The volume deposited in sections II and III is similar to the volume of an estimated 3,900,000 cubic yards which was removed from the upper part of the valley subsequent to the main slide. It is thought that this material was transported by mud flows and by Rubble Creek from the valley to the fan soon after the slide occurred.

Surface contours near the head of Rubble Creek were reconstructed for the time just after the volcanics were deposited. These contours bound a lobe-shaped steep sided mass similar to the 4th lava lobe (Alternative 2 Figure 4). The volume contained between these contours and the present surface is about 82,000,000 cubic yards. This volume is not consistent with the volume of the slide deposit and is therefore not a very reasonable estimate of the volume of the 1856 slide. However, it is an upper limit to the possible slide volume.

8. Evidence of Additional Slides

Although no slide debris older than the 1856 slide was seen on the valley walls an exposure of poorly sorted soil beneath fan deposits near the mouth of Rubble Creek suggests the possibility of an earlier slide. Evidence for what may have been a slide earlier than 1856 also exists in the form of some wood recovered from a drill hole, well beneath the base of the 1856 slide and two layers of wood in another drill hole. The basal layer of the 1856 slide is marked by wood therefore the additional layers may mark earlier slides.

The third lava lobe appears to have lost significantly more material since it was deposited than has the fourth lobe. This may be indicative of instability of the third lobe and perhaps additional slides. The low scarp above the trees on the right hand side of Photograph 3 may have been produced by sliding.

9. Hydrology

Rubble Creek Slide occurred in an area which receives about 68 inches of precipitation per year. Near the toe of the deposit, about 25% of the precipitation falls as snow but the proportion is much greater at the source of the slide. Most of the precipitation falls during the winter months. The average temperature is about 8°C. near the toe of the deposit.

The Garibaldi Lake system has a watershed above the Barrier of about 23 square miles. Except for occasional spillage from Barrier Lake during periods of high runoff, the lakes drain through the subsurface and emerge at the toe of The Barrier. The springs at the toe are buried by talus but at least two seepage paths are indicated by the temperature difference between the water from the springs. During June and July of 1973 the water temperature in the northern spring was 6.6°C. while the water in the other two springs was at 5.7°C.

Early investigations by the Water Resources Board indicated that the subsurface discharge beneath the Barrier was about 75-200 cubic feet/second consisting of 60-105 cubic feet/second from Garibaldi Lake and the rest from Lesser Garibaldi Lake. During this investigation, an attempt was made to measure the velocity of flow from Lesser Garibaldi Lake through use of a dye and a brine solution. The results were not conclusive however the conductivity of the spring water peaked about 5 hours after the brine was dumped in the lake.

10. Velocity

The high velocity of the landslide as it came down the valley is attested to by the removal of all the trees in its path as well as by the damage it did to the trees which bordered the path. In addition, where ridges transverse to the direction of slide movement were passed by the slide the upper limit of debris on the ground drops markedly from the crest of the ridge to the downstream side, such as near point A, Figure 4. This steep drop in the slide surface is similar to the drop in the surface of a stream of water as it passes around an obstruction. A third indication of the velocity of the slide is the superelevation of the debris on one side of the valley where it is curved, as shown on Sections 1 through 15, Figure 5.

Several estimates can be made of the velocity of a slide. The first and most commonly used method is to equate the kinetic energy the moving debris possesses at the base of a hill to the potential energy gained in climbing up the hill. That is:

$$1/2mv^2 = mgh$$

where m is a unit mass, v is the velocity at the base of the hill, g is the acceleration due to gravity and h is the height to which the debris climbed. It is assumed that the debris does not have a residual velocity at the top of the hill, that there is no loss in energy climbing the hill and that the thickness of debris does not change as it passes over the hill. For Rubble Creek there is some evidence for build-up of debris upstream of the granitic knob at the apex of the fan . However, the first two assumptions tend to counteract the effect of the change in thickness of debris and therefore the calculation may still be valid. In any event the height of the knob before the slide was about 100 feet and the calculated velocity is thus about 80 feet per second.

A second approximation of the velocity can be made from the superelevation of the debris on one side of the channel as it rounds a curve. As the direction of the velocity is changed a centrifugal force is exerted on the particles in the flow. In order to balance this force the surface of the mass is tilted towards the center of the curve so that the vector sum of the gravitational and centrifugal forces is perpendicular to the surface of the mass.

The path of the center of gravity of the slide debris was found by joining the centroids of the cross-sectional areas of the debris, as shown on Figure 5. The radius of curvature of the path was found for three curves, labelled X, Y and Z on Figure 4. The radius of curvature (R), maximum transverse surface slope within the bend (θ), and the velocity calculated (V) using the formula:

$$V^2 = Rg \sin \theta$$

are shown below:

	R	θ	V
X	2083 ft.	10.5°	110 ft/sec
Y	3332 ft.	7.5°	118 ft/sec
Z	1874 ft.	7.5°	88 ft/sec

It was assumed for these calculations that the debris flow reaches equilibrium with the centrifugal force as it rounds the bend; the flow was uniform; the flow lines were concentric; the flow was subcritical; the surface of the debris was close to the line joining the maximum height of debris on the valley walls and the debris was able to deform readily.

The assumption of equilibrium would appear to be valid particularly for curve X which has a radius of curvature which is constant for about 70 degrees of arc. Although there is less chance for equilibrium to have been reached through curves Y and Z, the general consistency of results indicates that if equilibrium was not reached it was not a major factor. If the debris did not reach equilibrium with the centrifugal force the calculated velocities would tend to be lower than the true velocities.

If the flow was non-uniform or the flow lines non-concentric the error would not be large (Morris, 1963) and would give a lower calculated velocity if taken into account.

For subcritical flow of water the Froude number must be less than 1, that is; the velocity for a mean depth of 200 feet, such as shown on cross-section 4, Figure 5, must be less than 80 feet/second. For supercritical or rapid flow the superelevation is affected by disturbances generated through the curve (Morris, 1963). As these disturbances would tend to increase the superelevation the calculated velocity would be too high. If this was the case, the true velocity would lie between the velocity calculated by assuming subcritical flow and the critical velocity. The effect of disturbances would be diminished by the sloping valley walls on the outer side of the curve. Although the true velocity cannot be calculated with certainty using this method unless the flow conditions are known, the velocity can be bracketed.

The debris mass underwent many rapid changes in shape as it moved down the valley. The mass appears to have moved with many of the qualitative characteristics, if not the quantitative characteristics, of a fluid. Thus it seems reasonable to assume that the cross-sections of the mass shown on Figure 5 are valid and that the mass could deform readily.

It seems reasonably certain therefore, that the velocity of the slide debris as it moved down Rubble Creek valley was between 80 and 118 feet/second. The best estimate is probably that derived from the superelevation as it rounded curve X, 110 feet/second.

11. Failure Mechanism

In order to develop a reasonable explanation of the initial failure of the third lava lobe it is important to know the conditions existing prior to the failure. Although it has been postulated that the slide was caused by the liquefaction of a talus deposit (Brawner, 1975) the geological evidence does not favour this hypothesis. The existence of the outcrops of lava on the north slope indicate that the material removed from this area was "in situ" lava rather than talus. The talus which now covers part of the north slope has been derived mainly from these outcrops and from the ridge of volcanic rubble near the limit of volcanic debris. The vague bedding and large intact blocks in this ridge indicate that the ridge is formed by rubble similar to that on the surface of the flow rather than formed by talus.

The rest of the failure appears to have occurred mainly through bedrock as indicated by the outcrops along the foot of The

Barrier and the scarp along the south side of the slide as well as the Barrier itself. It is very unlikely that a slide which was mainly talus would remove a layer of the underlying bedrock. In addition, it is unlikely that a talus deposit could accumulate against a cliff which served as its source and for the cliff to remain near vertical beneath the talus.

The sliding was probably localized along the unconformity at the base of the lava on the north side, and through discontinuities in the lava elsewhere. The material comprising the slide was most likely lava bedrock with an overlying layer of rubble, and perhaps a toe of talus.

Floods or increased water pressures beneath the Barrier have been variously cited as possible triggering mechanisms for the slide. Floods or waves of water from Garibaldi Lake are ruled out by the existence of trees which predate the slide within 10 feet of the bottom of the creek which drains Garibaldi Lake (Point B, Figure 4). It would not be possible for a large wave of water to pass this point without uprooting the trees in its path.

High water pressures may have occurred along the failure surfaces prior to the slide. Drainage of the Garibaldi Lake system is for the most part by subsurface flow which springs out at the toe of The Barrier. This flow seems to be restricted to zones near the base of the flow as no springs issue higher up the face of The Barrier. If the seepage path was blocked by an underground collapse or by ice forming at the exit during an extreme winter, very high uplift pressures could develop.

The Garibaldi area is near the boundary between seismic zones 1 and 2 (Milne, 1973) therefore the possibility of the slide being triggered by an earthquake cannot be ruled out. Although slide areas have been known to withstand large earthquakes before being triggered by earthquakes of smaller magnitude at a later date (Mathews and McTaggart, 1969), a major earthquake occurred in the area only a few years prior to the slide and it would seem that if the slope was in a condition to fail under earthquake accelerations in 1856 it would have been in a similar state in 1853 and would have failed during the 1853 earthquake. Records during these years are scanty, however, if an earthquake larger than the 1853 earthquake had occurred it is very likely that there would be some record of it. There is the possibility of a small earthquake having occurred in 1856 near the slide which would not have been noticed in the more populated areas but would have produced accelerations at the Barrier larger than the 1853 earthquake.

It can be concluded that an earthquake as the prime triggering mechanism is unlikely but cannot be ruled out completely. The development of high uplift pressures is the most probable triggering mechanism for the slide.

12. Transport Mechanism

Two of the most interesting features of the Rubble Creek landslide are the extremely high efficiency and high velocity of the slide as it travelled down the valley. The ratio of the maximum height dropped to the maximum distance travelled is 0.15, as shown on Figure 5.

This is a low value even compared to other high efficiency slides (Hsu, 1975, for example). This class of mass movement has been variously known as rockfall avalanche, debris stream (sturzstrom), debris avalanche, landslip, catastrophic landslide, or catastrophic rockfall. The efficiency exhibited by the Rubble Creek slide is what could be expected of a somewhat larger slide considering the general increase in efficiency with volume that has been reported by numerous investigators (Heim, 1932, Howard, 1974 and Hsu, 1975).

The efficiency of these slides has been explained in a number of ways, namely; fluidization (Kent, 1966), lubrication by underlying weak layers, air launch (Shreve, 1968), dust cloud (Hsu, 1975) high vapour pressures (Habib, 1975), transfer of momentum to the leading part from behind (Eisbacher, 1976), or simply fluid flow (Heim, 1881). Any explanation of the transport mechanism must take into account several features of these slides besides the high efficiency. These features include:

"(1) a chaotic arrangement of blocks without gravity sorting;

(2) a limited amount, or absence of, abrasion of constituent blocks;

(3) a high degree of fluidity at the time of emplacement;

(4) relative thinness compared with great horizontal extent, eliminating the possibility of stress transmission through a significant distance;

(5) very high speed of movement measured in seconds or in a very few minutes; and

(6) association with air blasts..." (Kent, 1966).

In addition to those features listed by Kent the following should be added:

(7) parts of the debris maintain a semblance of their original relative positions (Shreve, 1968);

(8) the debris can pass over the ground surface in some cases without disturbing it very much (Shreve, 1966);

(9) the ability to flow around obstacles near their distal end without greatly disturbing them (Buss and Heim, 1881, p. 40);

(10) the steep angle of repose of the material in lateral ridges and distal scarps; and

(11) the occurrence of similar slides on the moon (Howard, 1973).

In view of the fact that high efficiency rock slides have occurred under a very wide range of climatic, lithologic, topographic, gravitational and atmospheric conditions it seems imperative that the mechanism which enables these large masses to behave as they do should be inherent in the mass itself rather than in some outside conditions. In particular, the mechanisms of air launch, mud layer lubrication and air fluidization can be ruled out by the occurrence of similar slides on the Moon (Howard, 1974). In fact, the only conditions which appear to be necessary to generate a rockslide of this nature are a high initial velocity, disaggregation of the rock involved and a suitable path to follow.

An available explanation is that the rock debris is carried in a cloud of dust created by the initial failure and that the debris behaves as a fluid. There is some experimental evidence supporting this concept (Bagnold, 1954). He found that the resistance to shearing of grains suspended in a Newtonian fluid decreased at high rates of shearing. He also found that there was a dispersive grain pressure created when these grains underwent shear (see Hsu, 1975 for a discussion).

If it is accepted that the slide debris behaves as a fluid at high velocities then some predictions can be made on its behaviour using conventional fluid mechanics. For example, the velocity of the slide would be proportional to, among other things, the square root of the height of the wave of debris. For slide paths which are restricted so that the debris cannot spread out, the high velocity could be maintained for a longer distance. This could be an explanation for the anomalously long run out of the Huascaran and Rubble Creek slides.

An alternative transport mechanism for the Rubble Creek slide is that it was a water saturated debris flow. There is no reasonable source for the volume of water required to saturate the slide mass after it had gained porosity in the initial failure. There is a possibility that the initial slide occurred and subsequently the debris became saturated and was remobilized. It appears that this was the mechanism for transporting the debris to Sector III of the fan but it is an unnecessary complication to invoke to explain the main slide. One would expect some of the debris from the dry slide before it was remobilized as a wet slide to be still visible in the upper part of the valley but there is no evidence of this. The debris was deposited near the angle of repose for dry, cohesionless soil at the distal rim of the slide mass and in the lateral ridges. The slide debris in its present state has been observed to "flow like wet concrete" (Terzaghi, 1960). This is common behaviour for a loose, saturated soil and it need not be concluded that it is a special characteristic of the debris of the original slide nor that this was saturated when the slide occurred nearly 100 years prior to Terzaghi's observation.

The debris covering Sector III of the fan must have been moving slowly in order to move around the trees in this area without toppling them. Immediately after the slide the flow in Rubble Creek Valley would have been greatly hindered by debris and it is reasonable to expect that water normally brought down by stream flow would build up and saturate the loose slide debris in the valley. This debris and water mixture would be expected to move as mud flows until unhindered drainage by the creek was re-established. A lateral ridge on the south side of the creek at the apex of the fan (Point C, Figure 4) indicates that the main slide was moving in a direction which would restrict it to the north half of the fan. The material covering Section III near the apex of the fan spread out nearly at right angles to the direction of the lateral ridge. This is additional evidence for secondary mudflows. Much of the debris in the valley above the apex of the fan is in lobe-shaped mounds giving the appearance that the most recent movement was viscous flow. These lobes are not common in Sector I of the fan.

The debris cones may have been unsaturated debris rafted down on the surface of the mudflow. The similarity of these cones to sand cones formed during liquefaction by earthquakes and to the debris cones found on rapid, dry slides should not be overlooked.

13. Potential for Future Slides

The main reason for concern in this area, indeed the reason this investigation was begun is that a large rapid slide occurred recently. The repetition of land sliding from the same or adjacent source areas is a well documented fact (Mathews and McTaggart, 1969; Shreve, 1968; Crandell and Fahnestock, 1965; McDowell, 1962; and Browning, 1973; Patton, 1976).

The probability of another slide occurring should not be substantially different from the probability of a first slide occurring unless it can be clearly demonstrated that the conditions which led to the first slide have been substantially changed since it occurred. As this cannot be done at this time for the Rubble Creek slide it is only prudent to accept the possibility of a similar slide in the future.

The conditions which led to the 1856 slide began with the deposition of lava against ice in the valleys and the subsequent removal of the ice some 10,000 years ago (Mathews, 1952). This left steep slopes underlain by large volumes of material which have had their factor of safety against failure significantly reduced by removal of the ice in recent geological times. Generally, rock such as that involved in the Rubble Creek slide is strong enough to support itself; accordingly preexisting discontinuities are required for a slope to fail. The fourth lava lobe and north side of the third lobe are probably underlain by the sides of the pre-volcanic valley. Under the third lobe, the north side of the valley in conjunction with a discontinuity through the lava formed a surface oriented in such a way as to be conducive to sliding. The south side of the pre-volcanic valley is thought to be oriented in such a way as to be conducive to sliding of the fourth lobe.

In the third lava lobe future rockslides could occur along the intersection of the pre-lava valley wall and steep joints in the lava flow. Depending upon the orientation of the steep joints the plunge of this intersection is variable. Joint surfaces which have steeply plunging intersections are associated with smaller slide volumes in comparison with joint surfaces which have a shallowly plunging intersection. For example, a joint surface which intersects the old valley wall at a plunge of 15° would involve a potential slide volume of about 25,000,000 cubic yards.

In the fourth lobe as in the third, future rockslides could occur along the intersection of the pre-lava valley wall and steep joints in the lava flow. The side of the pre-lava valley appears to slope about 28° (Figure 4) towards Rubble Creek and slide movement could occur down this surface. The toe of this potential slide is buried by increasingly thicker deposits of material in Rubble Creek Valley from the western end of the lobe towards the east. This increase in toe support towards the east limits the total volume of rock which could slide from the fourth lobe at one time. The area, from the western limit of the fourth lobe to an eastern limit where the toe support becomes large (Figure 5), includes a potential slide volume of 76,000,000 cubic yards resting on the pre-lava surface.

Various mechanisms may trigger movement of these large masses. Increased groundwater pressures appears to be a likely mechanism especially for the third lobe because of the subsurface drainage which occurs beneath the lobe. Slide movement could be initiated in either lobe by an earthquake. Once slide movement begins the acceleration and transport of the mass is not fully understood and its behavior is best estimated by comparison with similar slides. Because the 1856 slide travelled down the full length of Rubble Creek Valley at a high velocity it should be considered that any future large slides could reach the populated areas of the fan at a high velocity.

SCALE - MODEL STUDIES

1. General

The mechanism by which slide masses, such as Rubble Creek slide, are transported to the depositional area is not fully understood and depends on a number of factors. Complex physical behaviour is often investigated through use of scale-models particularly in the study of fluid flow. The motion of Rubble Creek slide appears to have been fluid-like and many of the variables such as gravity, slope, density, side friction and internal strength which control fluid flow also appear to control slide movement. For the case of Rubble Creek slide, it was thought that if a fluid could be found which would model the complex path of the 1856 slide then this fluid could be used to predict the behaviour of potential slides of a similar nature from the same area. Similar studies, based on a trial and error method, have been carried out for the Elm slide (Hsu, 1975). Comparable model studies have been carried out for turbidity currents (Middleton, 1966).

For a scale factor of 1:2500 a unit length on the model (ℓm) is equivalent to 2500 times this length on the prototype (ℓp) (Hubbert, 1937). For this case the velocity in the prototype (Vp) is related to the velocity in the model (Vm), by the following relationship:

$$Vp = Vm \sqrt{\ell p / \ell m} = 50Vm$$

similarly for time:

$$tp = tm \sqrt{\ell p / \ell m} = 50\ tm$$

2. Experimental Methods

A topographic model of the area involved in the slide was constructed, as shown on Photograph 12. The model was made from corrugated cardboard cut in the shape of each 100 foot contour and spaced by wooden blocks. The cardboard was subsequently covered by plaster, sanded and painted. The final outside dimensions of the model were about 6 feet by 10 feet by 3 feet high.

Construction is laborious for a model built in this way, but more important, it was very difficult to modify topography or slide configurations as desired.

Plexiglass sheets were fitted into slots in the plaster so that the sheets could be removed quickly to release a model slide. The path of the prototype slide was marked on the model so that the movement of a model slide could be compared to that of the prototype. Several volumes were tested to investigate the influence of volume on velocity and path. Three volumes (20, 30 and 81 million cubic yards) were released from near the source of the 1856 slide and a volume equivalent to 91 million cubic yards was released from the fourth lava lobe. Due to limitations on the shape of the plexiglass sheets the test volume released from the fourth lobe was about 20% larger than the volume equivalent to the potential slide described in the previous section. Because of the large error inherent in estimating potential slide volumes the 20% excess volume was not thought to be significant.

Most of approximately 100 test slides carried out fall into one of four different series of tests. The first series of tests (Series A) was designed to try out different possible modelling materials.

Photograph 12

Typical model slide showing coloured stripes. The slide material was horizontally layered at the start with red at the toe, blue at the top and brown between the two.

In all, about twenty different materials or combinations of materials were tried, including: water, sand, water and sand, plastic beads, beads and water, fine mica, fine mica and water, barite, barite and water, bentonite and bentonite-barite-water combinations. The bentonite slurries were made from tap water and commercial bentonite (Quik Gel, Baroid Industries Ltd.) with commercial barite (Baroid, Baroid Industries Ltd.) often as an additive. From Series A it became obvious that the only material tested which had any chance of modelling the prototype slide in detail was the bentonite-barite-water slurry.

Accordingly, a second series of tests (Series B), was carried out in order to determine the best combination of these materials to model the prototype slide. From Series B the particular mix which best modelled the slide path was chosen and this mix was used for a subsequent series of tests (Series C), in which different slide volumes and positions were tried. A fourth series of tests (Series D), was carried out with the model tilted at 1, 2 and 3 degrees using four mixtures having a range in viscosities from too thick to too thin.

As part of Series B four trial runs were made using bentonite-barite slurries made with the same measured weight of each ingredient. These tests were done in order to check the repeatability of the trial runs. In addition, the flow of all mixes through a funnel was timed in order to have a crude measure of their relative viscosities.

Food colouring was used to mark various layers in many of the slides in order to follow the movement of different parts. Plasticene blocks about a tenth of an inch in diameter suspended in the slurry were also used for this purpose.

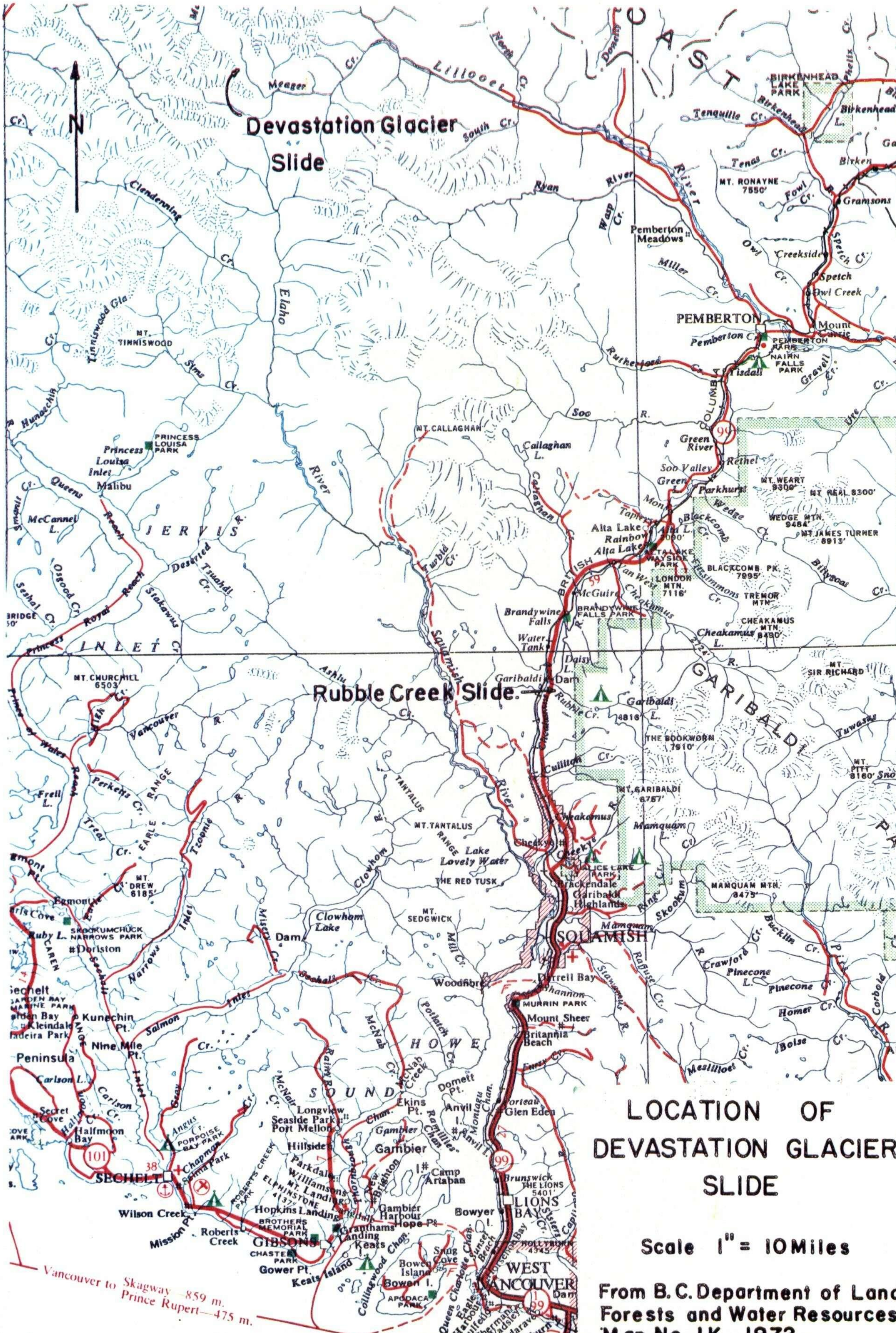
Twenty-four of the model slides were recorded on 8 mm movie film and later analysed frame by frame for velocity and pattern of movement (Figure 6). Notes and sketches were made of most of the other model slides.

3. Results of Model Studies

i) General

Although an attempt was made to obtain quantitative results through time-position measurements, the qualtitative results appear to be the most interesting. Some of the most remarkable observations were made when coloured layers of bentonite slurry were used for the slide material. In these tests the layer which was originally at the toe of slide remained along the leading edge of the slide when in motion and was deposited along the outer edge of the slide path and at the extreme distal end, as shown on Photograph 12. The layer which was originally placed in the middle of the slide at the source was deposited between the layer originally at the toe and the layer originally at the top. The top layer was deposited along the center of the flow.

The coloured layers also showed a striped pattern which is produced by differential movement between parts of the slide debris. This striping has been observed on many slide deposits and it is interesting to compare Photograph 12 with Photographs 13 and 14. The latter two photographs were taken of the Devastation Glacier slide which occurred during July 1975 near Pemberton, B.C. (Figure 7). This slide was composed of very weak recent volcanics which slid off a steep mountain side (Photograph 13) and thence down a valley for several miles before

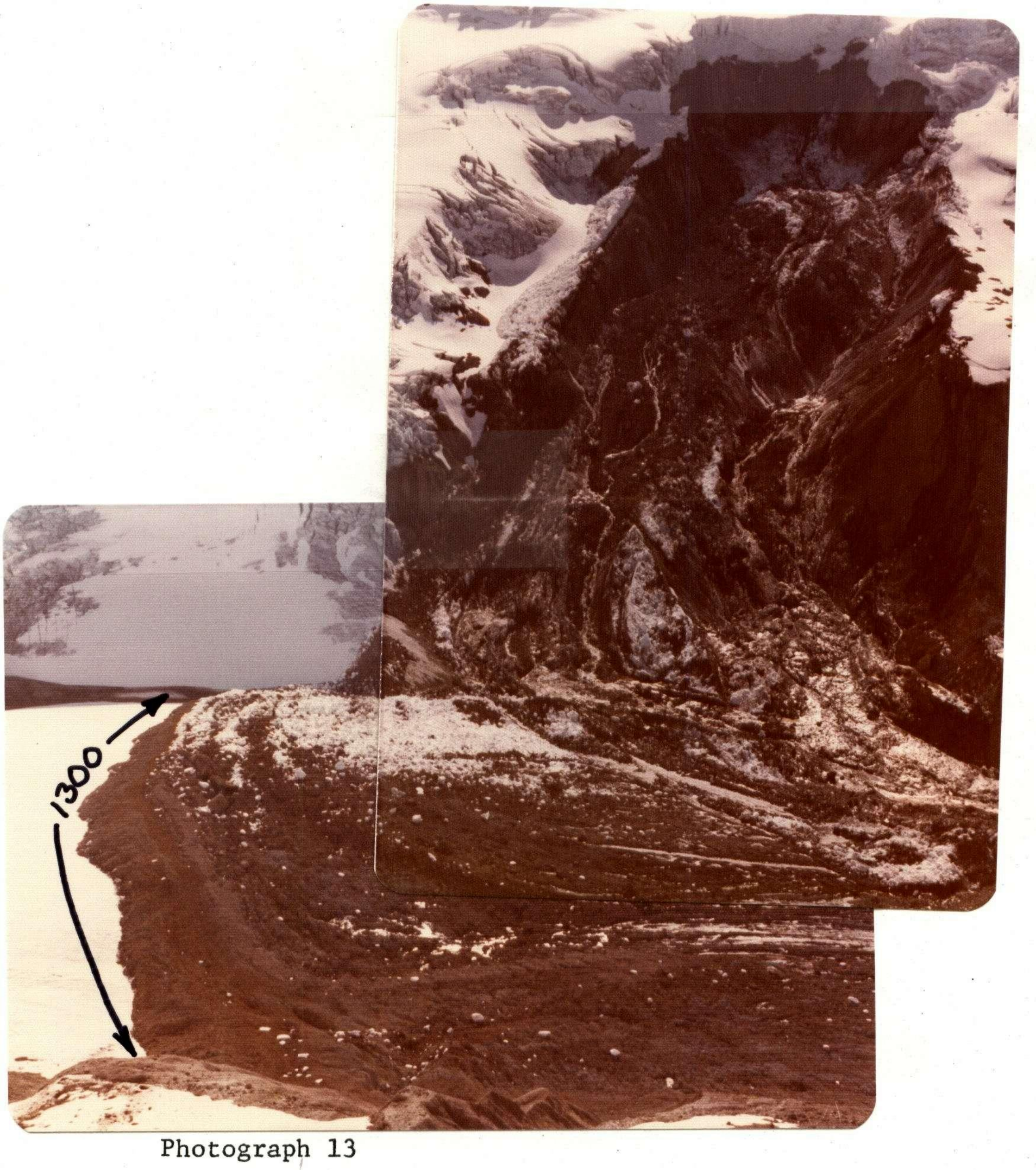


LOCATION OF DEVASTATION GLACIER SLIDE

Scale 1" = 10 Miles

From B. C. Department of Lands, Forests and Water Resources Map No. 1K 1972

FIGURE 7.



Photograph 13

Devastation Glacier Slide. Source area, striping in the debris and mud flows along far side of glacier. The mass slid toward the viewer, swept up on the near side of the valley, abruptly changed direction and moved to the right.

Photograph 14

Devastation Glacier Slide deposit, striping in the debris and imprint of subsequent mudflow.

Photograph 15

Devastation Glacier Slide Path, showing banking of the high velocity tongue as it rounded a corner (1, 2) and the nearly horizontal line of the subsequent mudflow (3).

coming to rest. It can be seen that the striping is almost parallel to the edges of the slide path and the deposit, similar to the model slides. The Devastation Glacier slide is similar to the Rubble Creek slide in that; it followed a long path down a gentle slope (Photograph 15) apparently at a high velocity after initially starting on a steep slope; it was composed of recent volcanic debris; it was followed by mud flows; the leading tongue swept up from one side of the valley to the other; the debris was poorly sorted and very broken up; and the debris appears to have been very fluid. It should be noted that the striping at Devastation Glacier slide was obviously only in the high velocity tongue which preceded the mudflows. This comparison between the model slides, Devastation Glacier slide and Rubble Creek slide is important in that it shows that the models exhibit some of the features of this type of natural slide. Therefore, more credence may be placed on other features which the models showed.

Two other secondary features shown by the model slide which were similar to the prototype slide were (1) relatively thick, steep-sided deposits along the edge of the slide path and (2) a triangular mound of debris deposited on the upstream side of the knob near the apex of the fan. These model features could be compared to the lateral ridges and the mound of debris at the apex of the fan which were observed at Rubble Creek.

The movement of the model slide is similar to the prototype in that they both show an initial rapid movement and a quick stop followed by secondary mudflows.

(ii) Test Series A

This series of tests was primarily carried out to determine what type of material would be most suitable for use in trying to model the slide. Dry materials such as uniform sand, plastic beads, fine mica, powdered barite and powdered bentonite were tried; however, none of these materials travelled far enough and they were thus unsuitable for modelling the slide.

Tests were also carried out with mixtures of the above materials and water as well as water alone. It was found that most of these mixtures were unsuitable. In the cases of sand and beads the water ran out of the mixture leaving the particles behind as a deposit near the top of the valley. The most promising mixture was found to be bentonite and water. This mixture was selected because a wide range of viscosities was available and the slurry was thixotropic. Because it is thixotropic there was some possibility of modelling the very fluid behaviour in motion, the rapid stop and the steep depositional slopes at the edges of the deposit.

(iii) Test Series B

Basically test series B was carried out to find which combination of bentonite, barite and water would best follow the scaled path of the slide. It was found that all combinations tended to flow too high on the first curve on the south side of the creek. It is considered that in this area the estimated elevation of the pre-slide valley floor was too high. Because of the way the model was constructed, however, the contours in the upper part of the valley were not changed. For several test slides, deflectors were put along this first curve in order to force the mud to follow the curve more closely. Thus deflected, the mud was found to follow the successive curves more closely.

The heights reached on curves below the first and above the apex of the fan were similar to the prototype; however, the maximum rises were offset downstream, perhaps because the first curve was too long and high. The last curve along the edge of the fan below the apex was never modelled properly. It is considered that the curves were all developed too far downstream and that the second from last curve, which would have directed the debris up the valley wall on the north side of the fan, did not have a chance to fully develop.

All model slides showed a rapidly decreasing velocity from the upper part of the valley to the lower part. The record of the prototype however, indicates that a relatively constant velocity was maintained along the path of the slide (pp 26 - 29) except below the apex of the fan where it spread out and stopped. A typical plot of the position of the leading edge of the bentonite slurry versus time is shown on Figure 6 and the velocities calculated from the trial tests are given in Table I.

If the mud was thickened enough so that it did not ride very high on the first curve, it also stopped its rapid movement near the apex of the fan. This was the main shortcoming of the bentonite-barite-water slurry for modelling the Rubble Creek Slide. In addition, the velocities given on Table I are much higher than

TABLE I

Slide Velocities From Model Studies

Trial No.	Volume (cc)	Equivalent Velocity (fps) Upper Half	Lower Half	Average
15-1	2000	246	207	226
24-1	2000	246	149	190
24-2	4000	266	255	261
24-3	4000	290	298	294
24-4	2000	220	199	210
24-6	2000	291	168	219
23-2	1300 *	200	168	184
23-3	2000 *	273	300	281
23-4	2000 **	256	153	197
23-5	2000 **	239	199	219
23-6	2000 **	183?	215	197
23-7	2000	290	244	279
23-8	2000	237	224	234

* Same mixture of bentonite and water

** Same mixture of bentonite and water

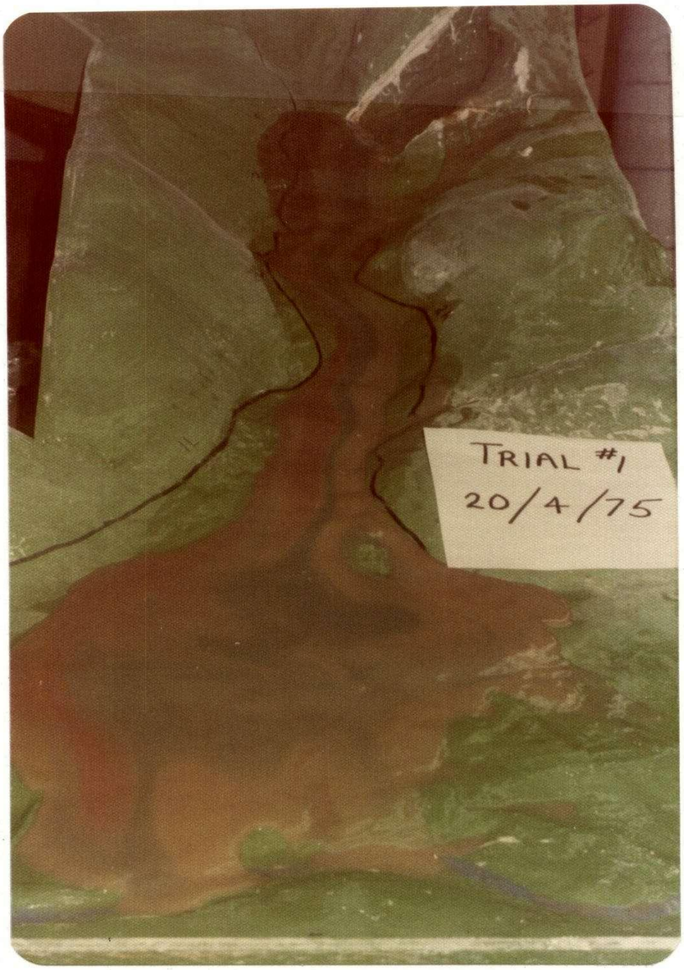
the velocities calculated for the slide (Section 10). It was found that mud with model velocities similar to those given in Section 10 did not travel the full distance down the valley. Trial 24-4 was typical of the models which best followed the path of the prototype. This mixture was composed of 80 grams of QuikGel, 1000 grams of Baroid, and 800 cubic centimeters of Ottawa sand in 2000 cubic centimeters of water.

All of the model slides slowed markedly when they spread out on the fan. This slowing is an expression of the control the height of a wave has on its velocity (compare turbidity currents, avalanches, dam bursts, etc.).

Repeated model slides using the same mixture of bentonite, barite and water produced essentially similar model slide paths and deposits.

(iv) Test Series C

Although most tests were carried out using a volume of mud similar to the estimated volume of the 1856 slide, several tests were carried out using smaller or larger volumes. It was found that the larger the volume for a given mixture, the farther and faster it travelled. The paths of slides from the same source area were essentially the same for all volumes although the larger volumes rode higher on the curves and were deposited farther down the fan and the smaller volumes rode lower on the curves and were deposited near the apex of the fan or in the valley. The model slides released from the fourth lobe moved directly across the valley and swept high up on the opposite side. After this first curve the slide followed a similar path to the slides from the third lobe. The final deposit covered a larger area of the fan. (Photograph 16).



Photograph 16

Model slide equivalent to 91,000,000 cubic yards from the Fourth Lava Lobe. Cheakamus Dam is on the lower left side of the photograph, source of slide on the upper right.

(v) Test Series D

In order to find out whether a slight tilting of the model in the direction of flow and a thicker mixture would more closely model the prototype path, several tests were carried out with the model tilted at 1°, 2° and 3°. It was found that the mixtures which travelled the full length of the slide path were still too fast to model the curves in the upper part of the path. It is thought that larger tilts would increase the slope of the valley floor by too large an amount for any credibility to be placed on the results without some theoretical basis.

CONCLUSIONS

The following conclusions can be drawn from the field and laboratory study of the Rubble Creek Slide:

1) The initial failure of the slide occurred along the contact of the volcanics with the glacial debris overlying the Cheakamus Formation on the north side, steep joints in the head scarp and through closely jointed volcanic rock below the head scarp;

2) The slide was dominantly composed of volcanic bedrock, rubble and talus;

3) The internal structure of the fourth lava lobe appears to be essentially the same as the third lobe and it also rests on pre-volcanic valley wall;

4) A tongue of debris travelled down the valley at a high velocity, sweeping from side to side and uprooting all vegetation in its path;

5) This tongue of debris was deposited on the north side of the fan and was followed by mudflows which modified the debris in the upper part of the valley and which were deposited on the south side of the fan, killing and burying the vegetation in this area;

6) The vegetation on a section of the fan in the shadow of the granitic knob at the apex of the fan was not destroyed at the time of the slide;

7) The debris in the slide deposits is very poorly sorted angular debris primarily volcanic in composition;

8) The debris can be distinguished from the underlying alluvial fan deposits by the absence of sorting in the 2 to 4 mm range and in the silt sizes;

9) The slide occurred during the late winter of 1855-56 or early spring of 1856;

10) The volume of the slide is estimated to be about 33,000,000 cubic yards;

11) There is some evidence of earlier slides in the form of deposits of wood and deposits of coarse unsorted debris beneath the fan deposits;

12) There is some evidence of later slides in the form of younger vegetation and lobe-shaped deposits along the valley adjacent to the base of the fourth lobe;

13) The slide maintained a velocity between about 80 and 118 feet per second down the low slope of the valley floor and through several changes in direction;

14) The slide may have been triggered by a build-up of ground water pressures although local earthquakes may also have been the cause;

15) The slide debris was probably transported as a self-suspending mixture of rapidly moving particles which behaved in a fluid-like manner;

16) Both the fourth lava lobe and the third lava lobe were deposited under conditions which make them much more susceptible to sliding than most other slopes in the area;

17) Scale models are a useful means by which to study the motion and some of the characteristics of slides such as Rubble Creek Slide;

18) The model slides as well as Rubble Creek and Devastation Glacier slides move as a high velocity tongue of debris followed by slower mudflows;

19) The striping observed in many slides can be explained by differential movement as the debris stretches out in the direction of motion;

20) The model tests suggest that the prototype slide velocity was less than about 200 feet per second;

21) The model slides indicate that larger slides travel farther and faster than smaller slides;

22) The model studies indicate that the velocity is also proportional to the thickness of the moving debris;

23) The model slides indicate that the path followed by a slide is largely determined by the topography and that large changes in direction without large losses in velocity are possible;

24) The model indicated that materials involved in flows such as the ones tested tend to maintain their relative positions, and this characteristic of landslide deposits is not necessarily an indication of sliding rather than flow;

25) It is only prudent to accept the possibility of the occurrence of another slide similar to the 1856 slide because it cannot be demonstrated that conditions have substantially changed since 1856.

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APPENDIX

ADDITIONAL FIELD DATA

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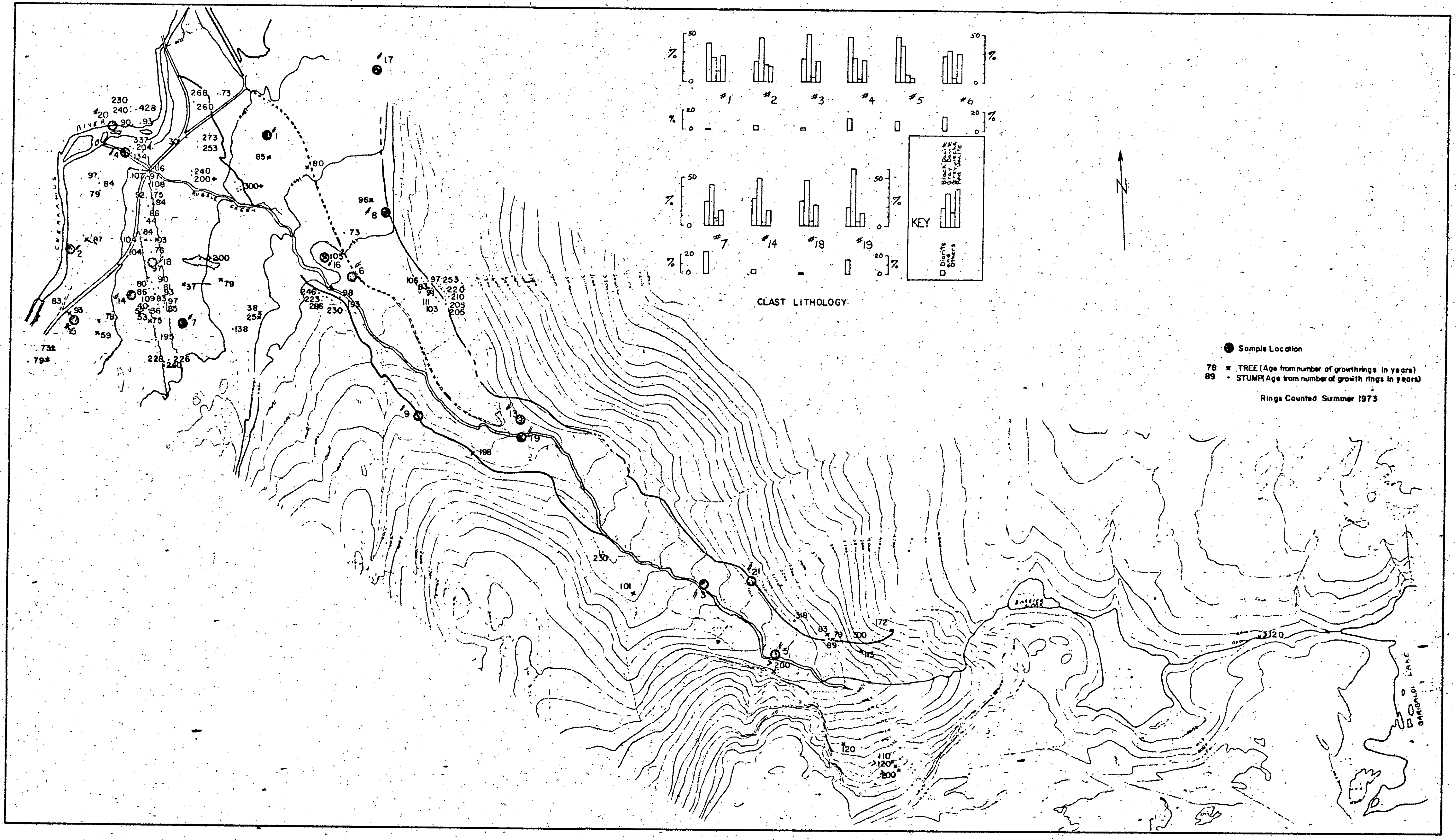
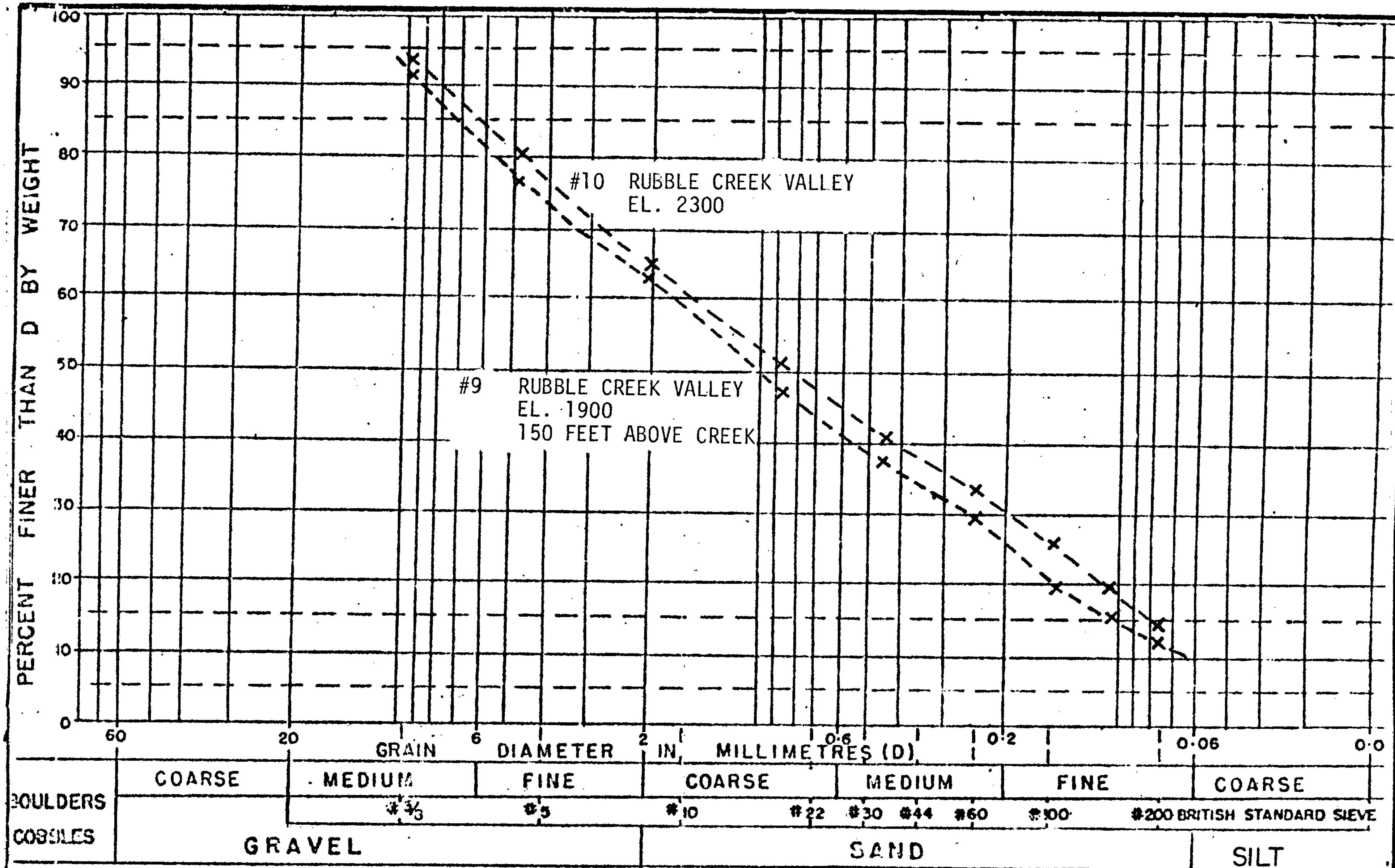

CLAST LITHOLOGY
KEY
Sample Location
78 TREE (Age from number of growthrings (in years).
89 STUMP (Age from number of growth rings in years)
Rings Counted Summer 1973
RIVER
CHEAKAMUS
RUBBLE CREEK
GARIBALDI LAKE

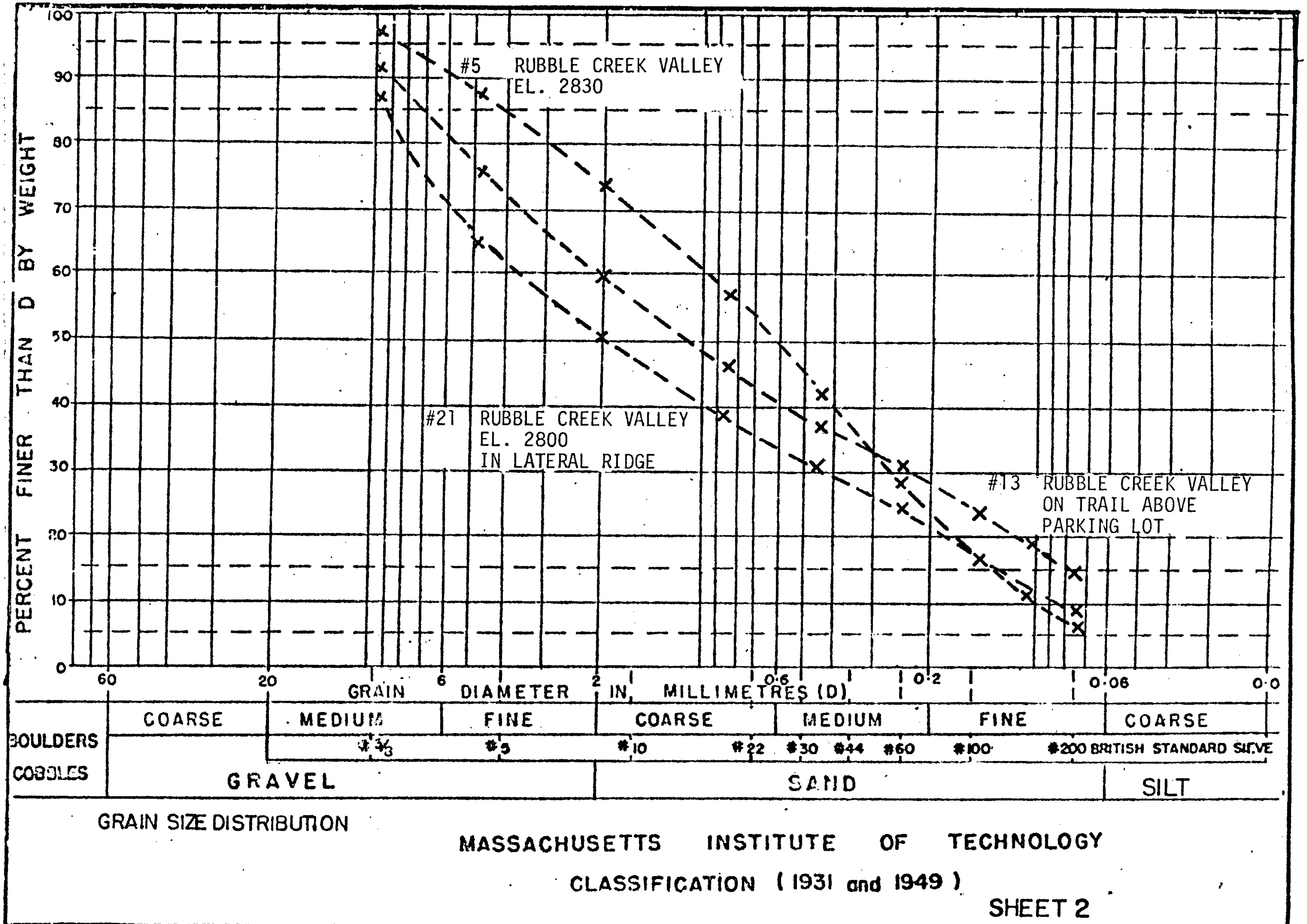


GRAIN SIZE DISTRIBUTION

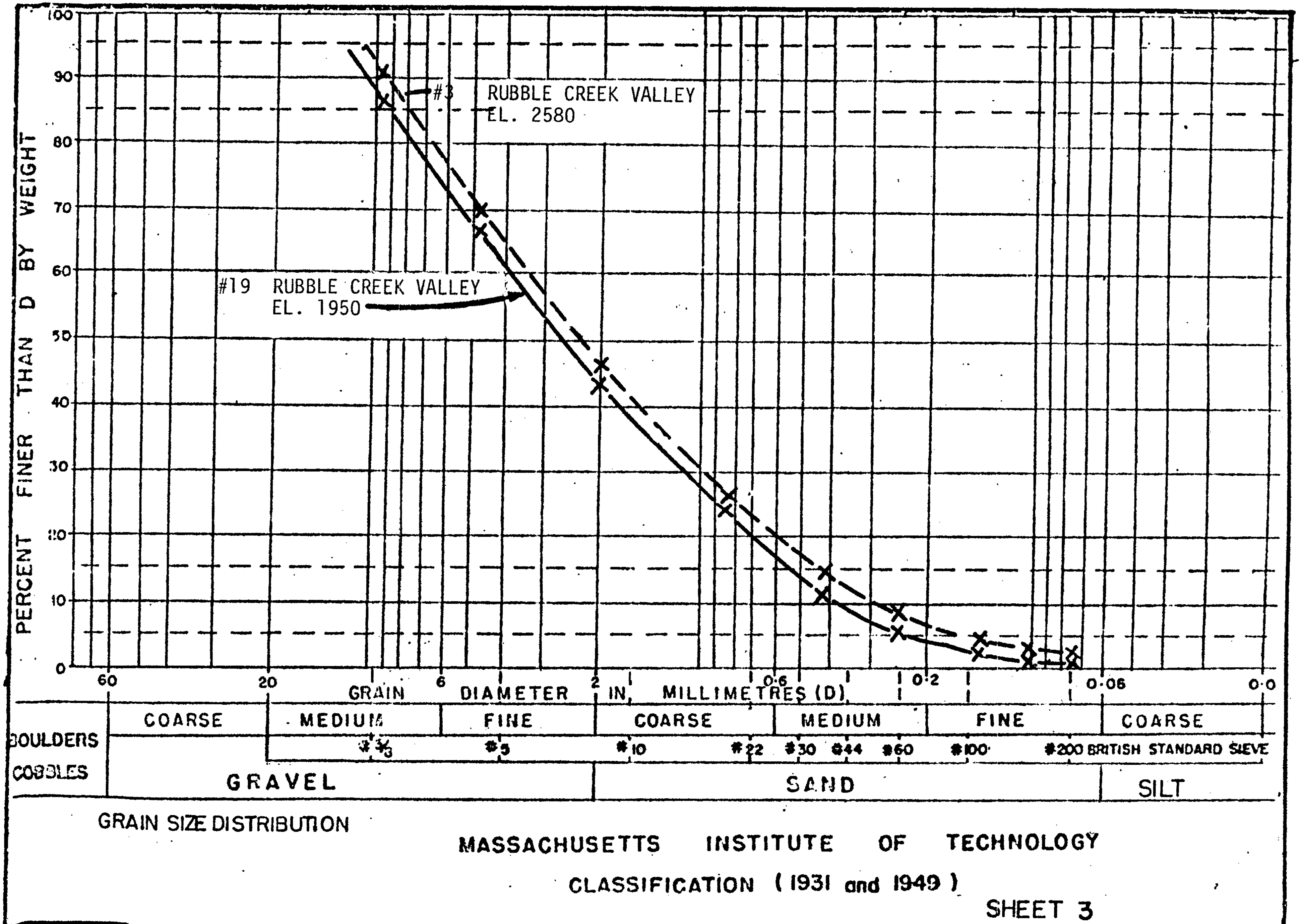
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

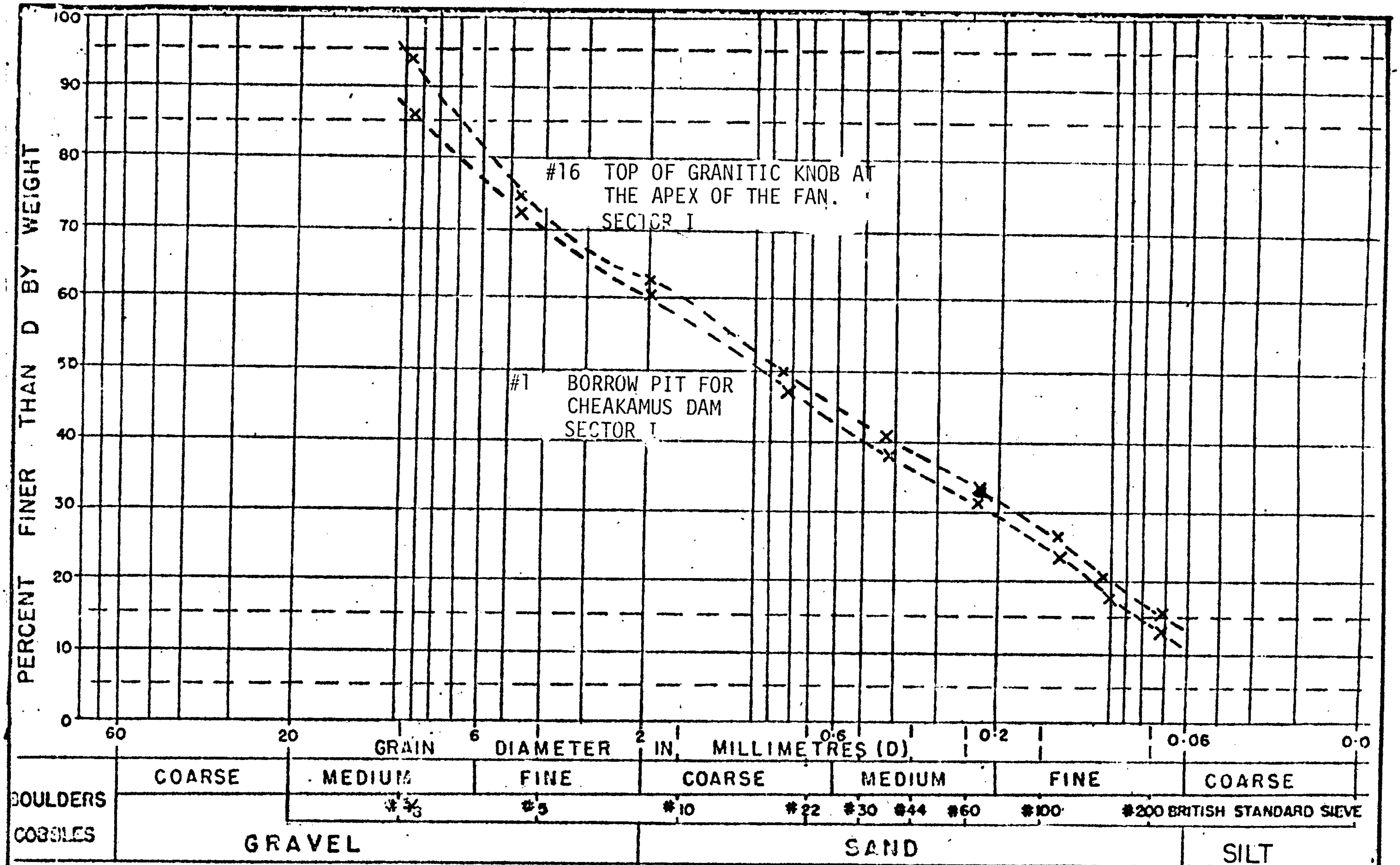
CLASSIFICATION (1931 and 1949)

SHEET 1



#5 RUBBLE CREEK VALLEY
EL. 2830
#21 RUBBLE CREEK VALLEY
EL. 2800
IN LATERAL RIDGE
#13 RUBBLE CREEK VALLEY
ON TRAIL ABOVE
PARKING LOT
PERCENT FINER THAN D BY WEIGHT
GRAIN DIAMETER IN MILLIMETRES (D)
COARSE
MEDIUM
FINE
COARSE
MEDIUM
FINE
COARSE
BOULDERS
COBBLES
GRAVEL
SAND
SILT
BRITISH STANDARD SIEVE
GRAIN SIZE DISTRIBUTION
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CLASSIFICATION (1931 and 1949)
SHEET 2


PERCENT FINER THAN D BY WEIGHT
100
90
80
70
60
50
40
30
20
10
0
#3 RUBBLE CREEK VALLEY
EL. 2580
#19 RUBBLE CREEK VALLEY
EL. 1950
60
20
6
2
0·6
0·2
0·06
0·0
GRAIN DIAMETER IN MILLIMETRES (D)
BOULDERS
COBBLES
COARSE
MEDIUM
FINE
COARSE
MEDIUM
FINE
COARSE
#5
#10
#22
#30
#44
#60
#100
#200 BRITISH STANDARD SIEVE
GRAVEL
SAND
SILT
GRAIN SIZE DISTRIBUTION
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CLASSIFICATION (1931 and 1949)
SHEET 3

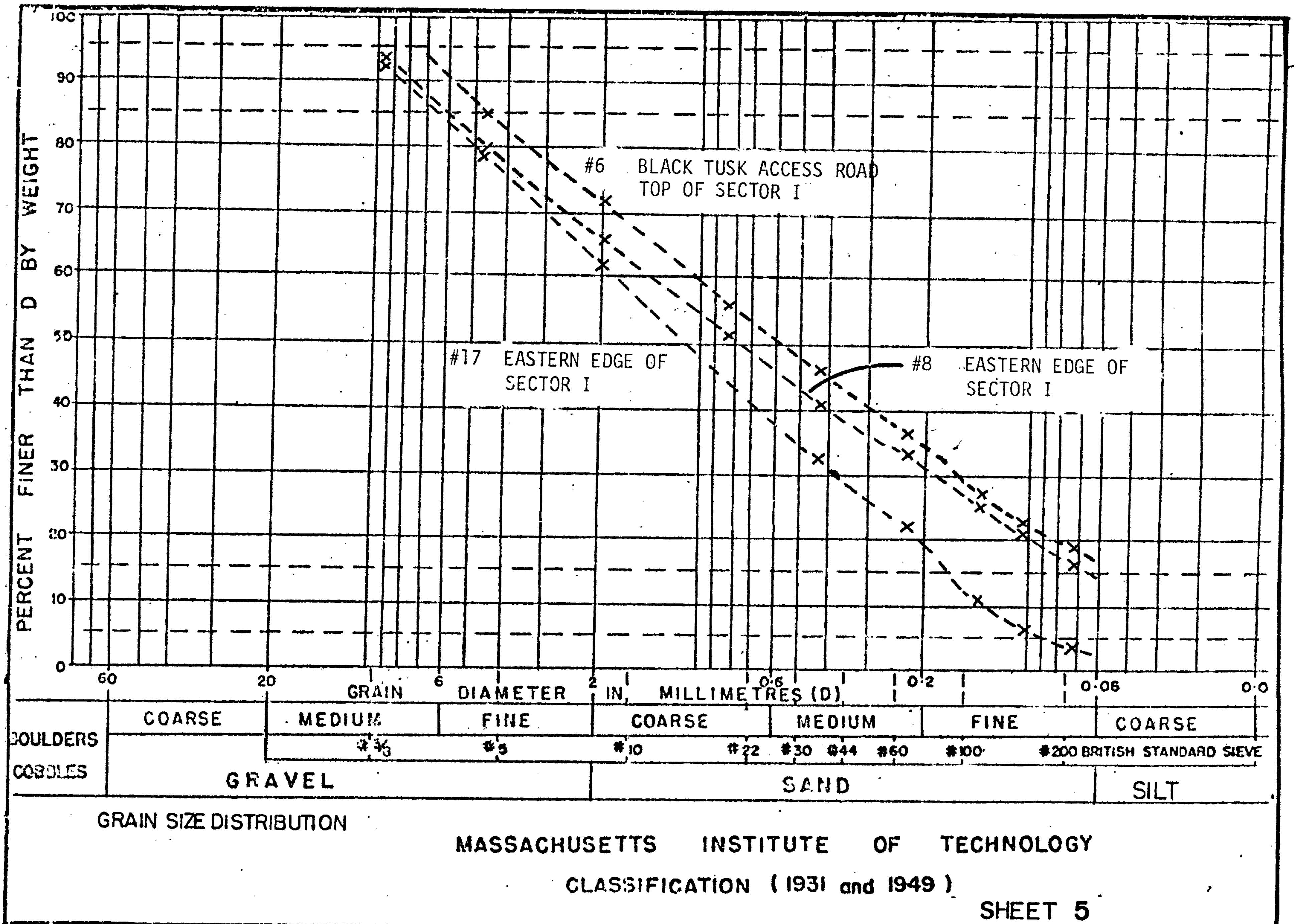


GRAIN SIZE DISTRIBUTION

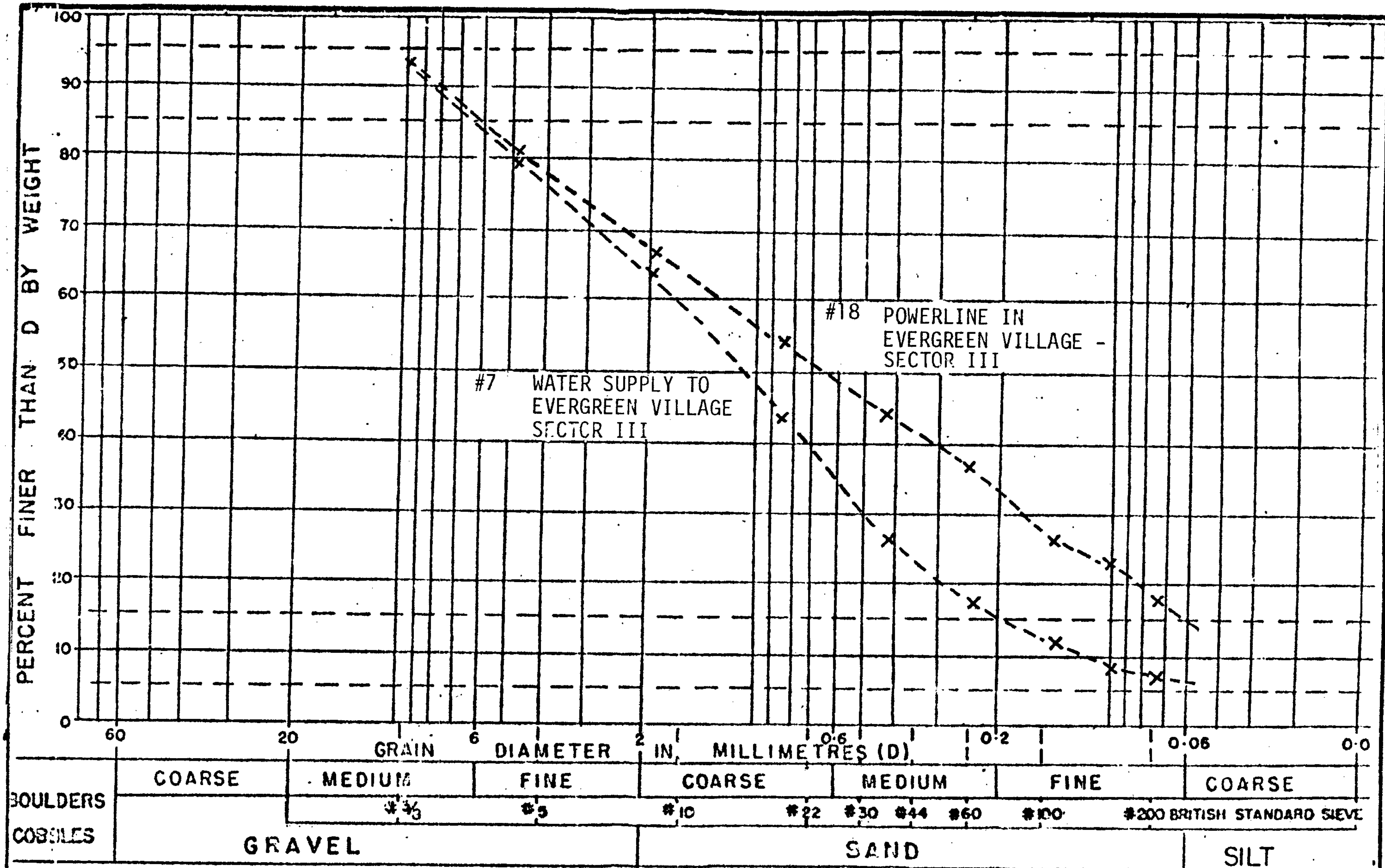
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CLASSIFICATION (1931 and 1949)

SHEET 4



PERCENT FINER THAN D BY WEIGHT
100
90
80
70
60
50
40
30
20
10
0
#6 BLACK TUSK ACCESS ROAD
TOP OF SECTOR I
#17 EASTERN EDGE OF
SECTOR I
#8 EASTERN EDGE OF
SECTOR I
60
20
6
2
0·6
0·2
0·06
GRAIN DIAMETER IN MILLIMETRES (D)
BOULDERS
COBBLES
COARSE
MEDIUM
FINE
COARSE
MEDIUM
FINE
COARSE
#10
#22
#30
#44
#60
#100
#200 BRITISH STANDARD SIEVE
GRAVEL
SAND
SILT
GRAIN SIZE DISTRIBUTION
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CLASSIFICATION (1931 and 1949)
SHEET 5

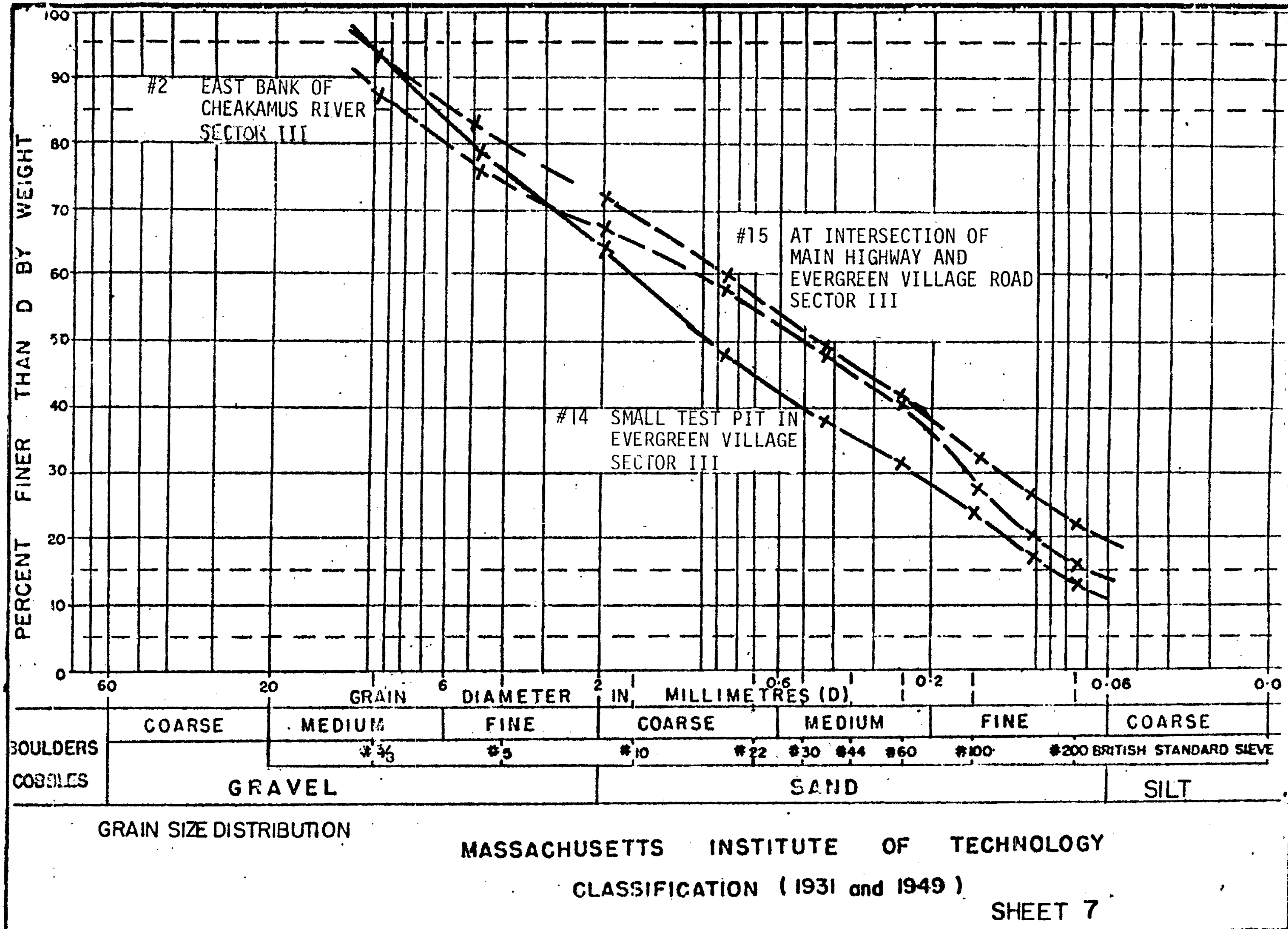


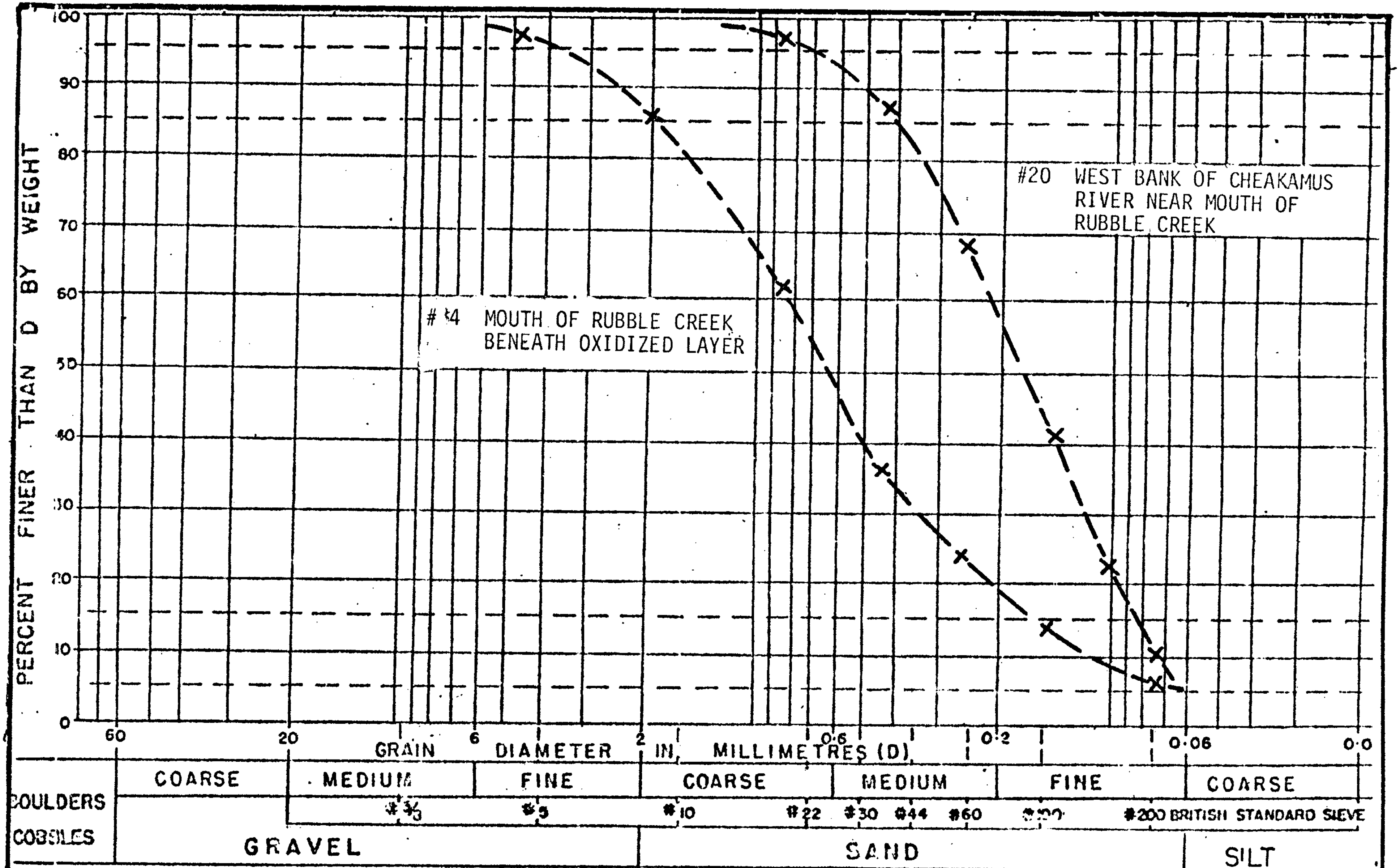
GRAIN SIZE DISTRIBUTION

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CLASSIFICATION (1931 and 1949)

SHEET 6


PERCENT FINER THAN D BY WEIGHT
100
90
80
70
60
50
40
30
20
10
0
#2 EAST BANK OF CHEAKAMUS RIVER SECTOR III
#15 AT INTERSECTION OF MAIN HIGHWAY AND EVERGREEN VILLAGE ROAD SECTOR III
#14 SMALL TEST PIT IN EVERGREEN VILLAGE SECTOR III
60
20
6
2
0·6
0·2
0·06
0·0
GRAIN DIAMETER IN MILLIMETRES (D)
COARSE
MEDIUM
FINE
COARSE
MEDIUM
FINE
COARSE
BOULDERS
COBBLES
#10
#22
#30
#44
#60
#100
#200 BRITISH STANDARD SIEVE
GRAVEL
SAND
SILT
GRAIN SIZE DISTRIBUTION
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CLASSIFICATION (1931 and 1949)
SHEET 7



GRAIN SIZE DISTRIBUTION

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

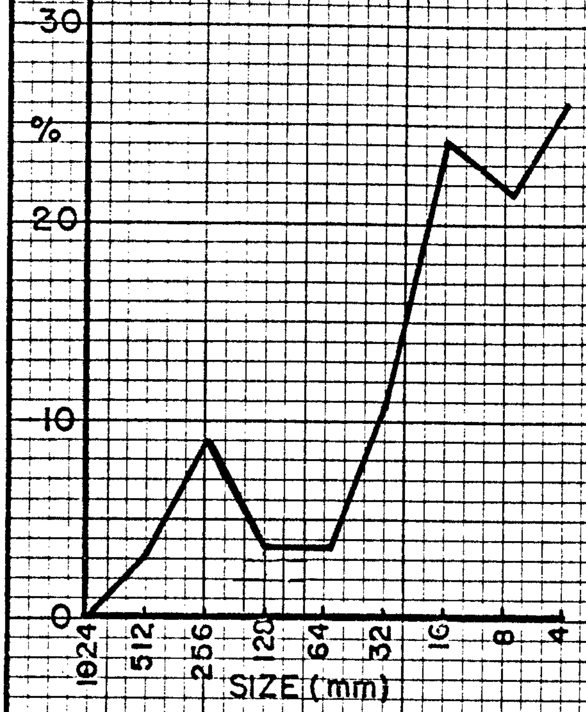
CLASSIFICATION (1931 and 1949)

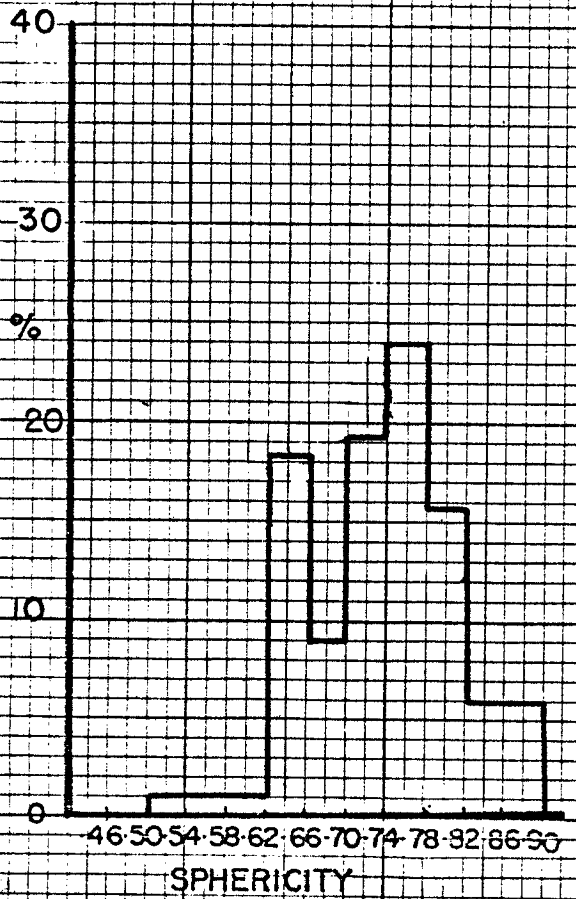
SHEET 8

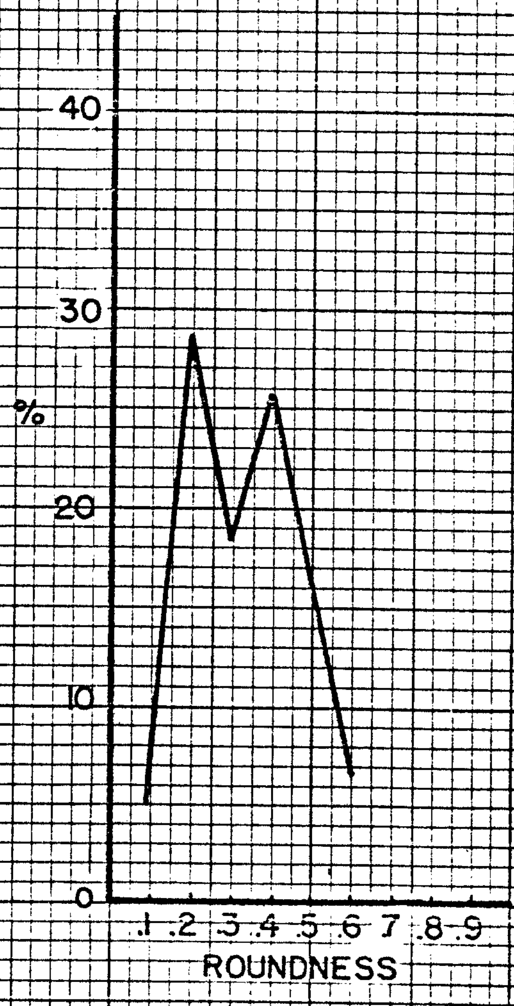
Sample No. 1
Date: June 5, 1973
Location: Cheakamus Dam Borrow Pit.

% of Fines <0.530" 50.0%

No. of Pebbles Counted 105





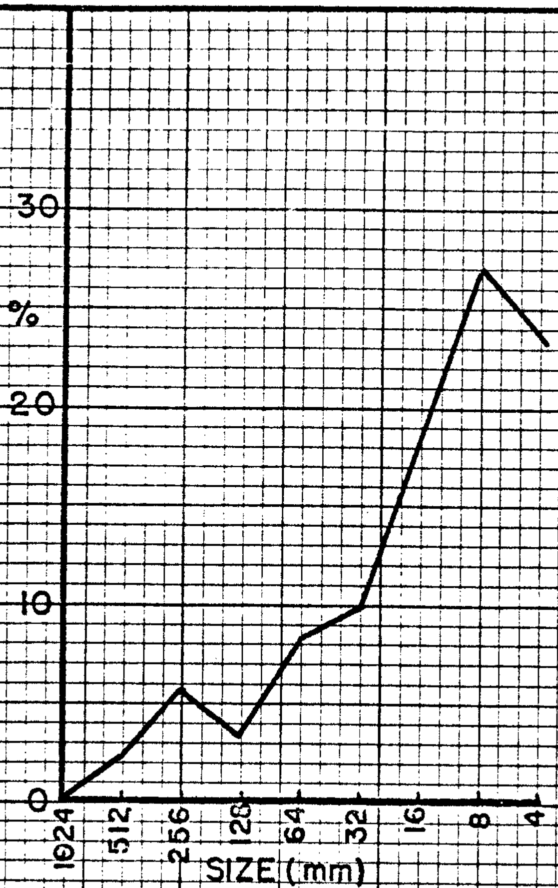


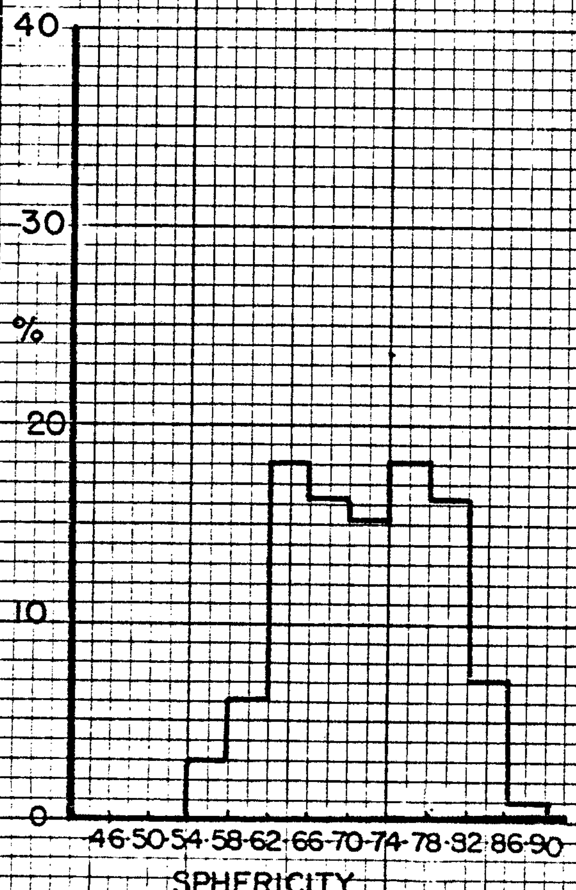
SHEET 1

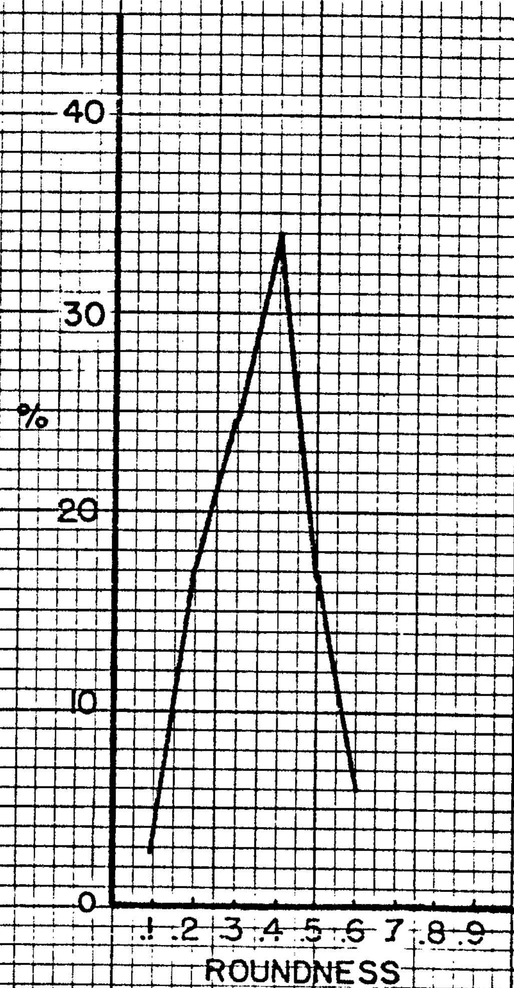
Sample No. 2
Date: June 5, 1973
Location: Left Bank of Cheakamus River.

% of Fines <0.530" 47.0%

No. of Pebbles Counted 118





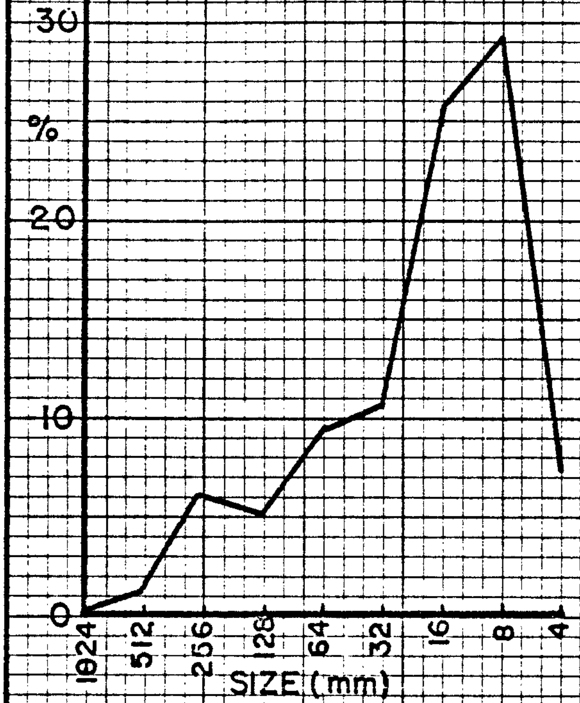


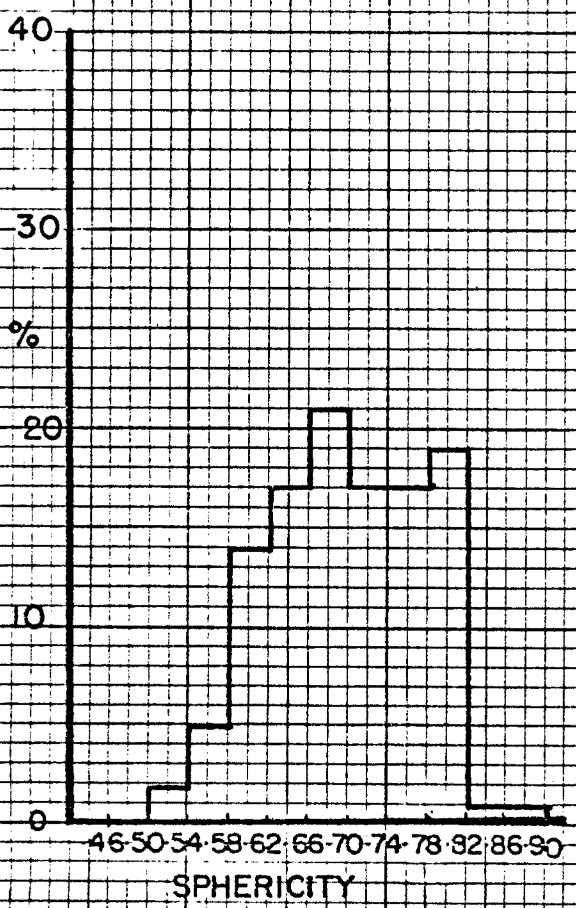
SHEET 2

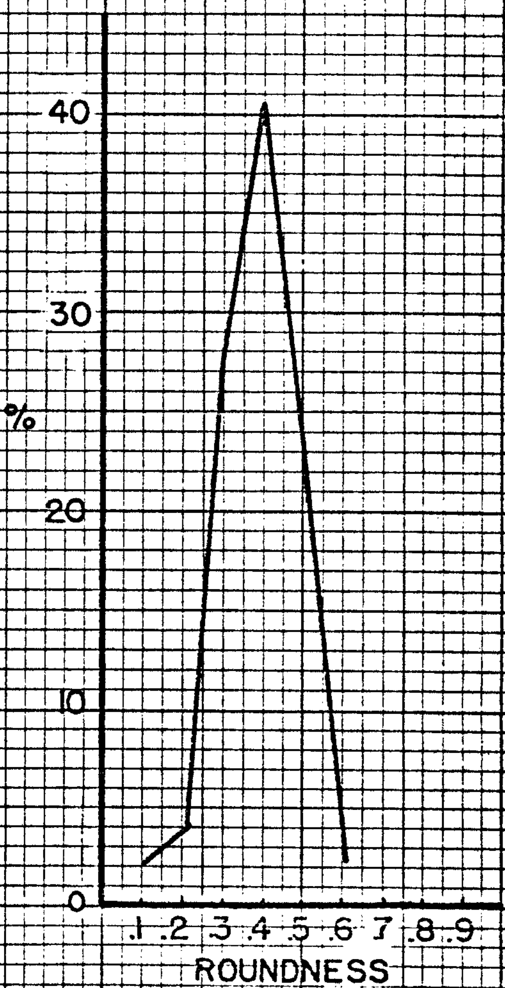
Sample No.: 3
Date: June 6, 1973
Location: Cutbank of Rubble Creek
Near El. 2580

% of Fines <0.530" ——

No. of Pebbles Counted 163







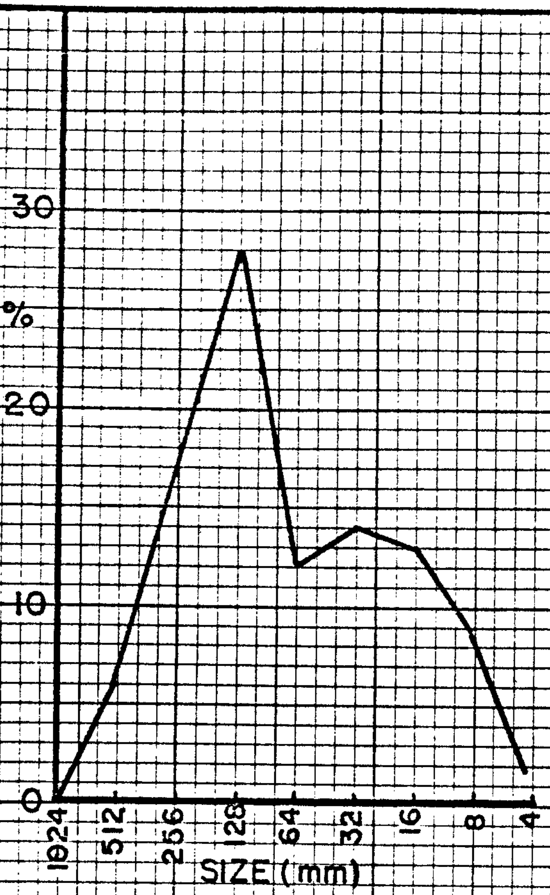
Sample No. 4

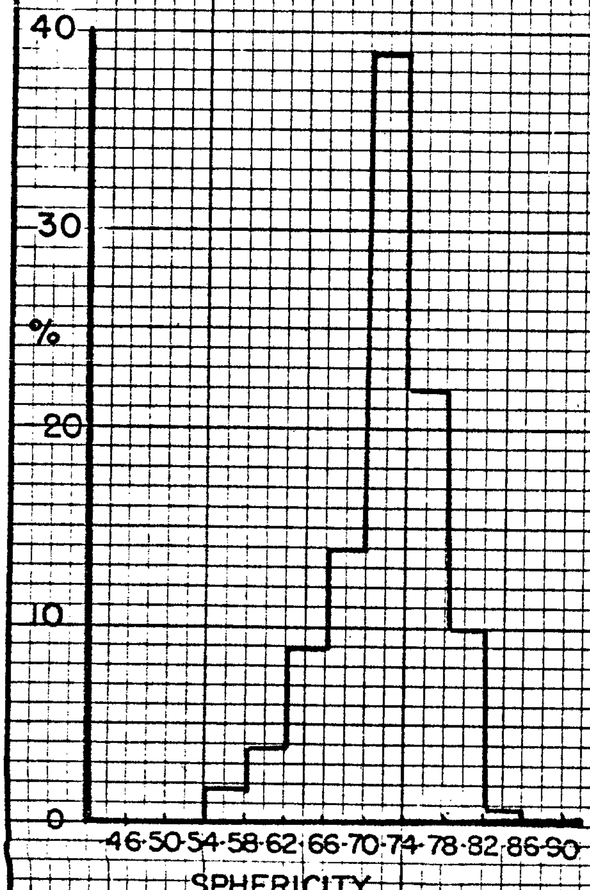
Date: June 21, 1973

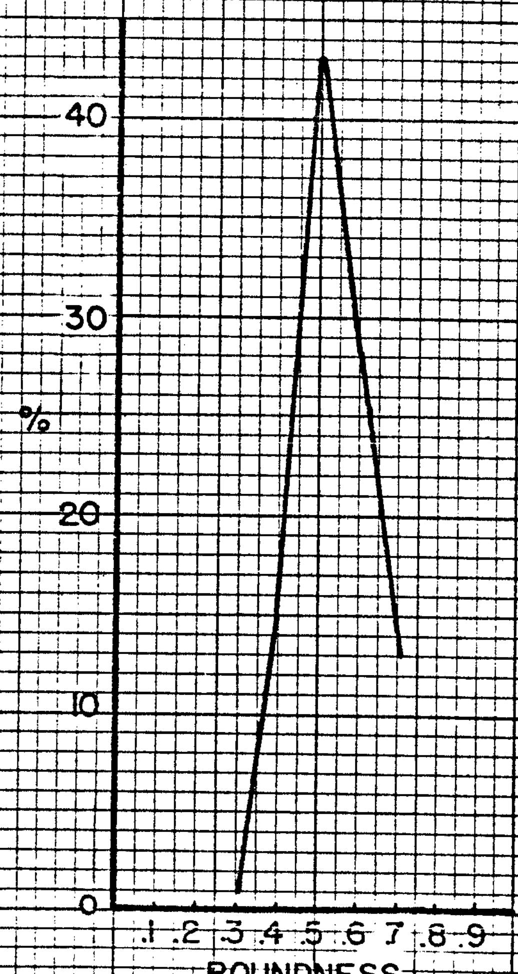
Location: Mouth of Rubble Creek Beneath Oxidized Layer.

% of Fines <0.530" 34.2%

No. of Pebbles Counted 100







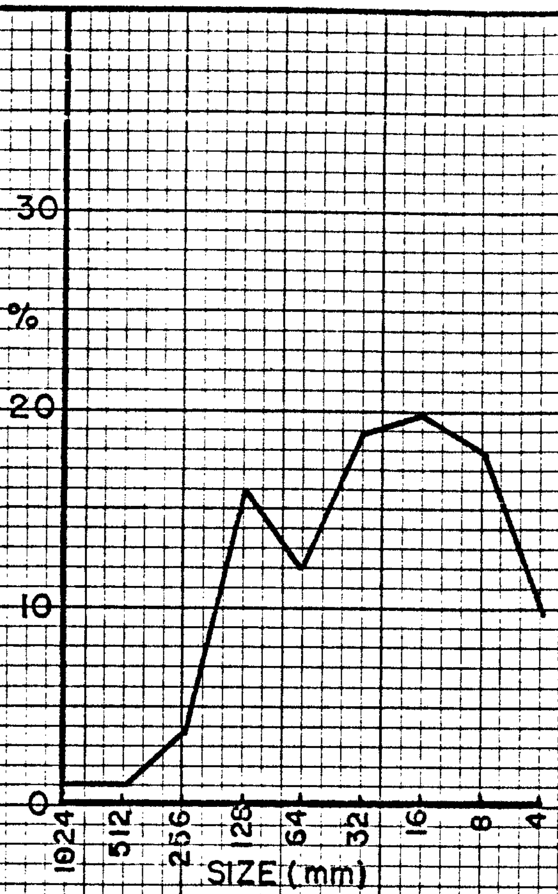
Sample No. 5

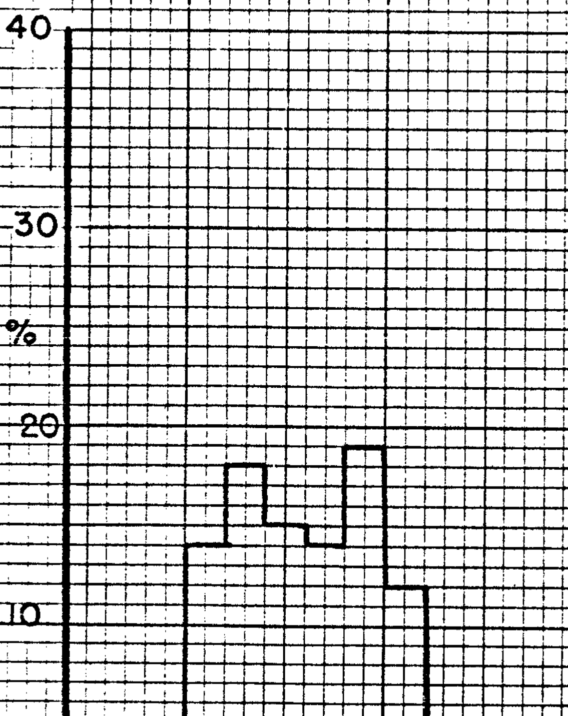
Date: June 22, 1973

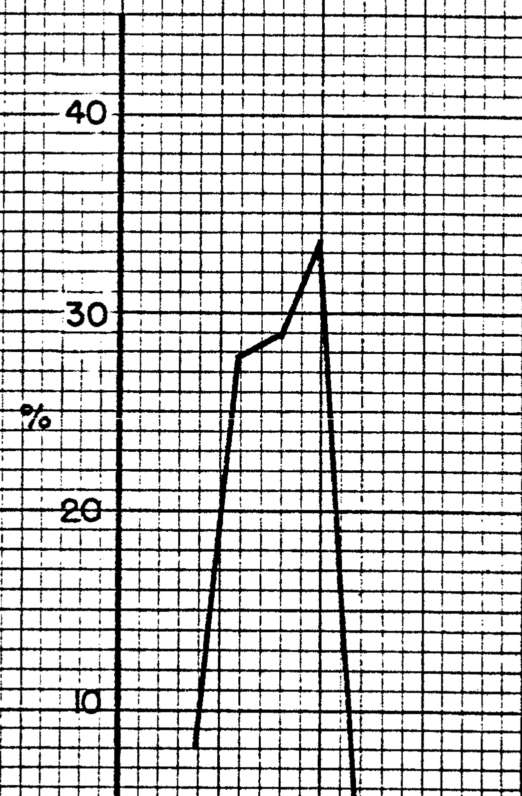
Location: Cutbank of Rubble Creek at El. 2830.

% of Fines <0.530" 28.2%

No. of Pebbles Counted 100



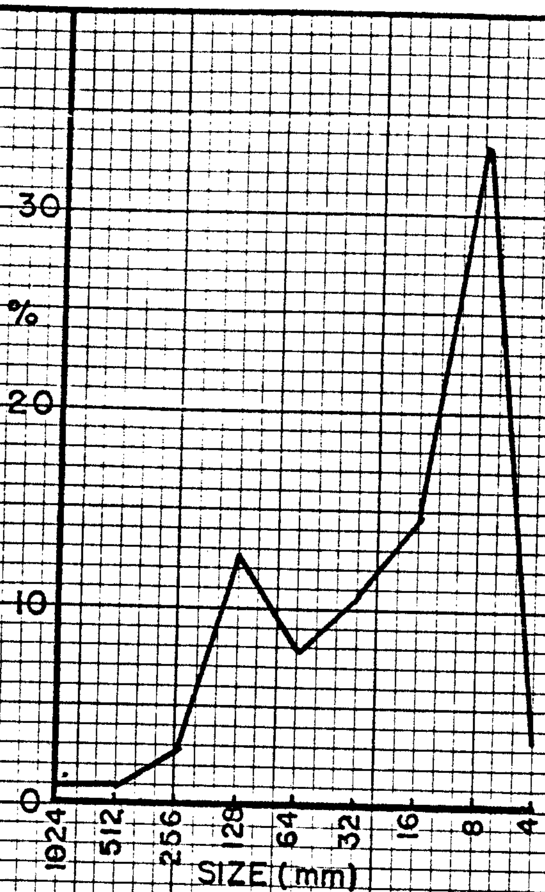


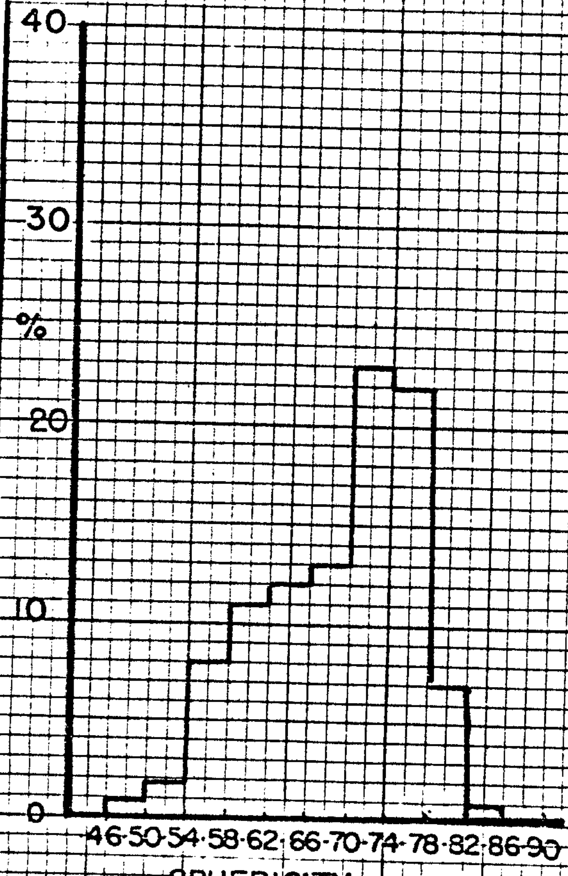


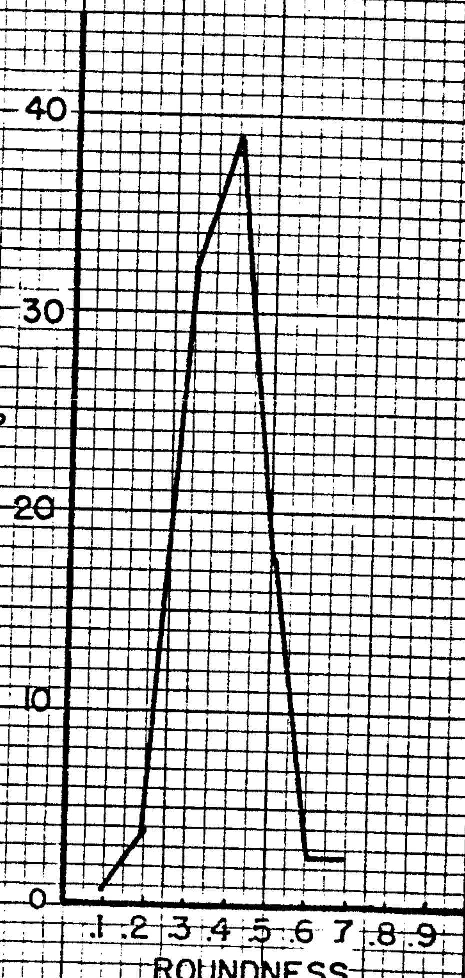
Sample No. 6
Date: June 23, 1973
Location: Black Tusk Road Cut.

% of Fines <0.530" 47.5 %

No. of Pebbles Counted 100







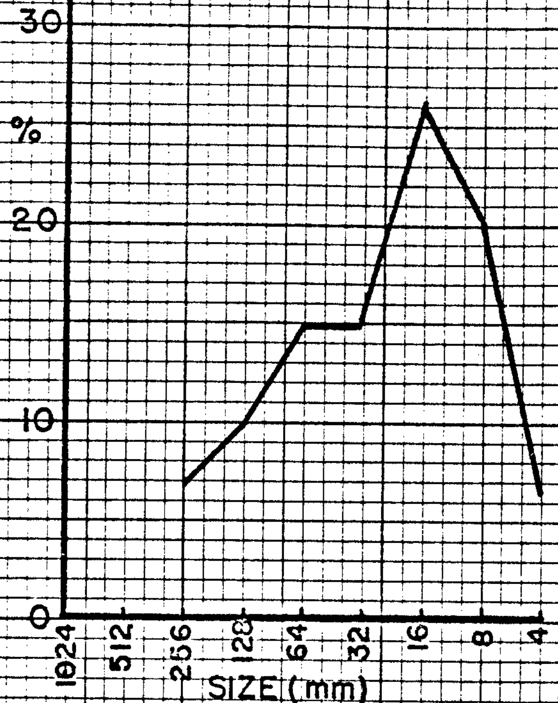
Sample No. 7

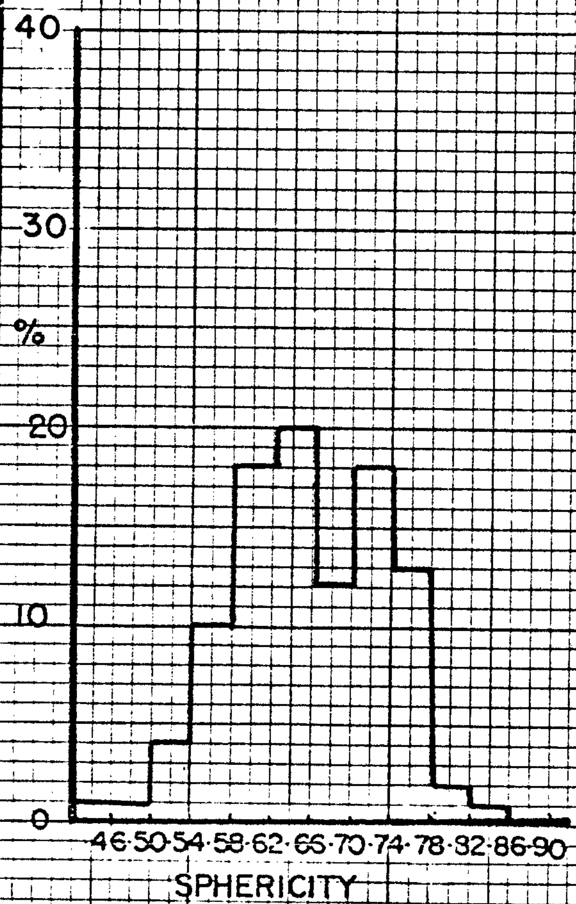
Date: June 23, 1973

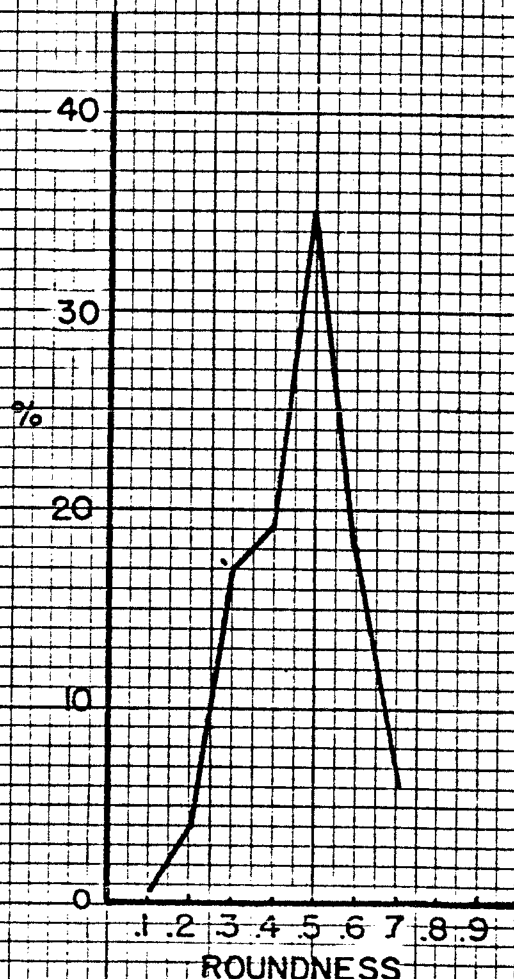
Location: Evergreen Village Waterline.

% of Fines <0.530" 41.5%

No. of Pebbles Counted 100



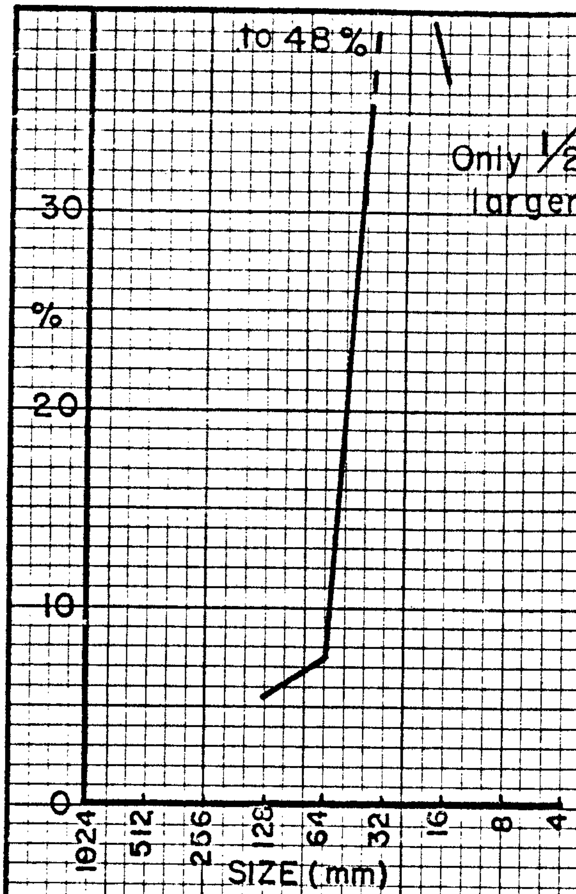


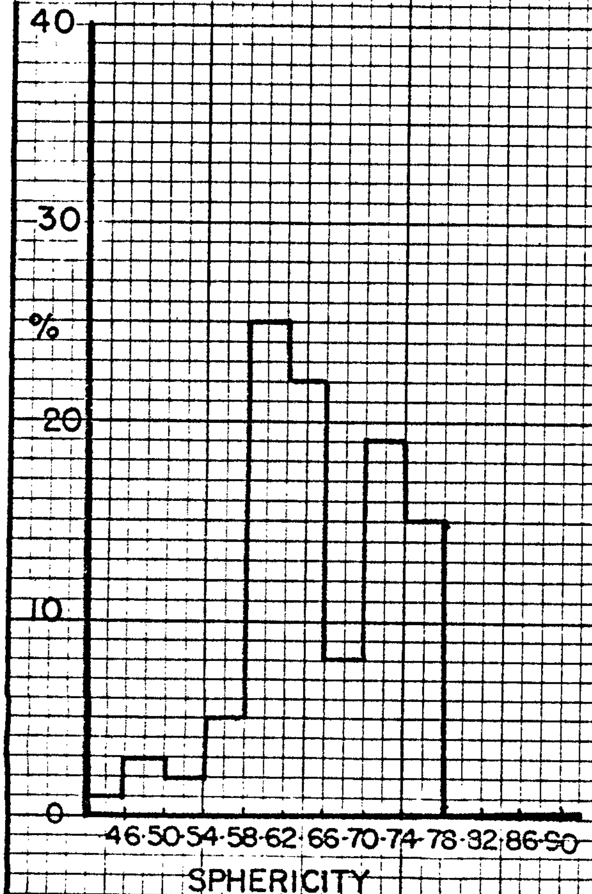


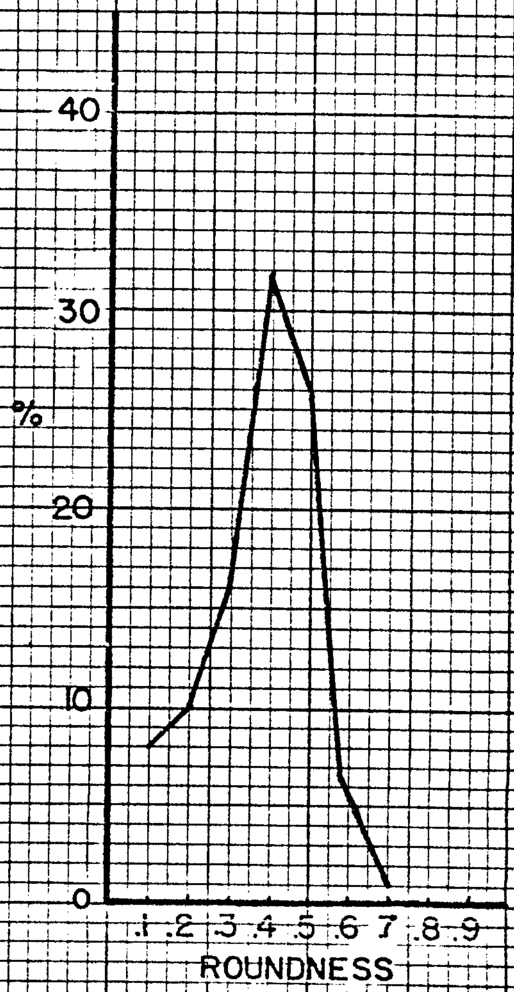
Sample No. 14
Date: June 29, 1973
Location: Test pit Evergreen Village.

% of Fines <0.530" 28.9%

No. of Pebbles Counted 136



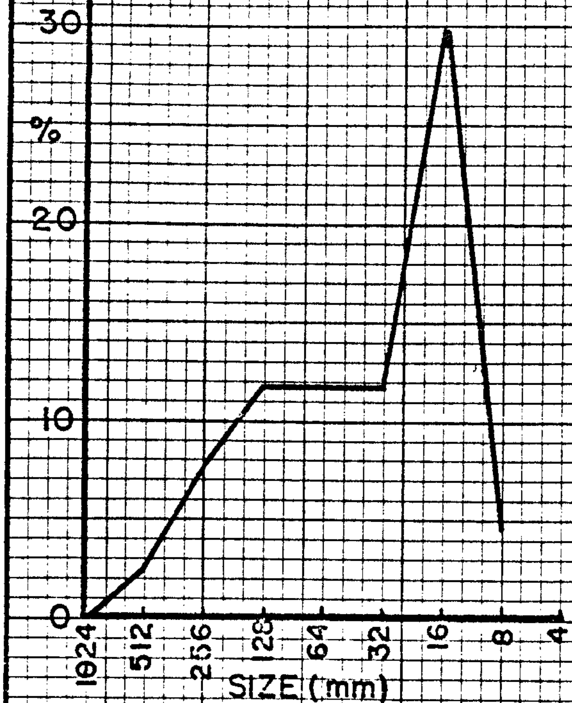


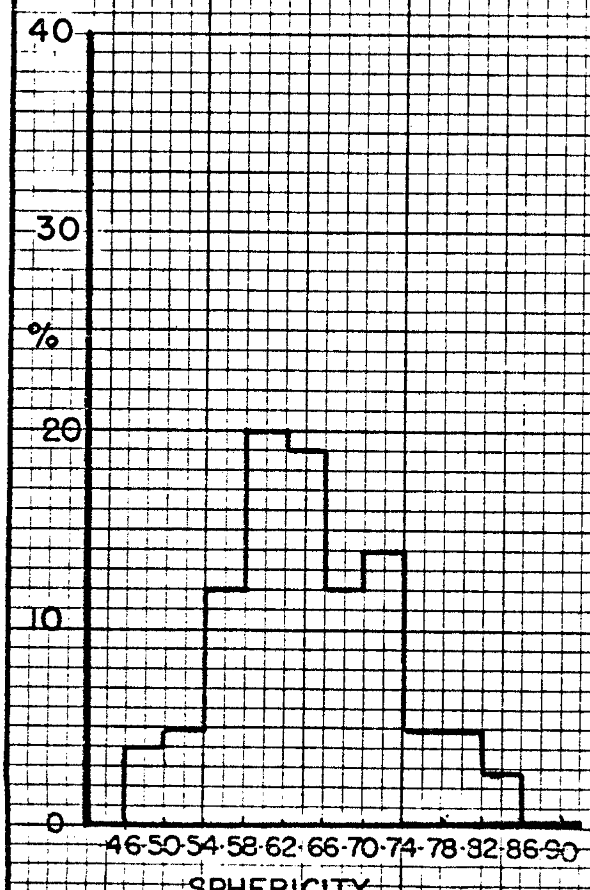


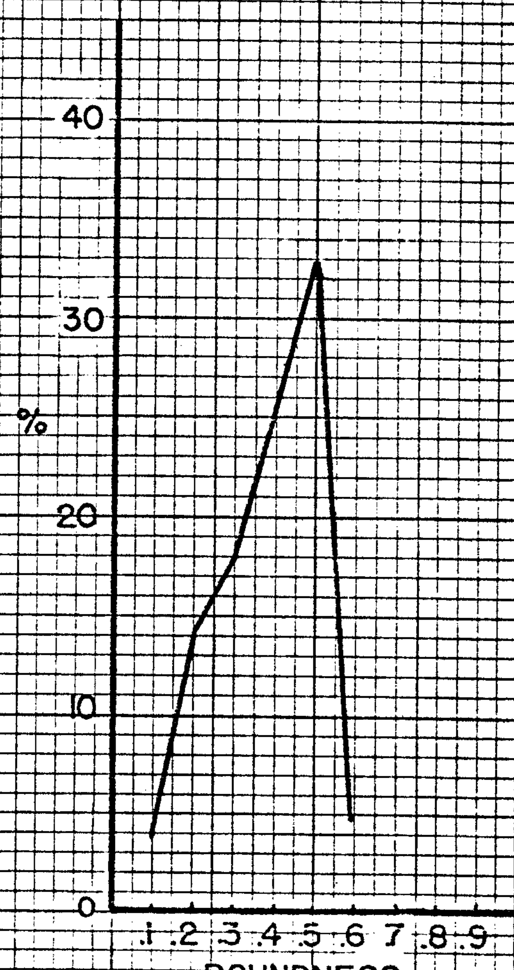
Sample No. 17
Date: July 4, 1973
Location: East side of Sector I

% of Fines <0.530" 30.8%

No. of Pebbles Counted 100



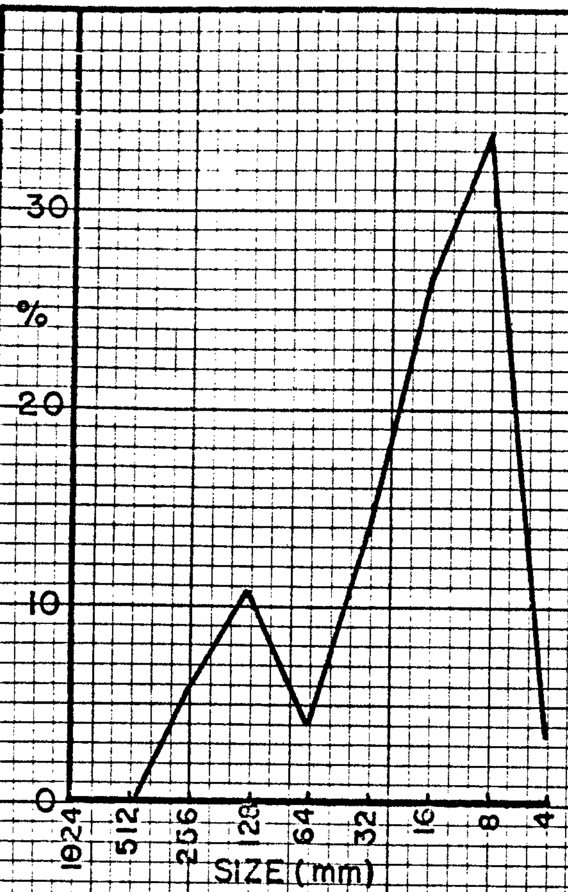


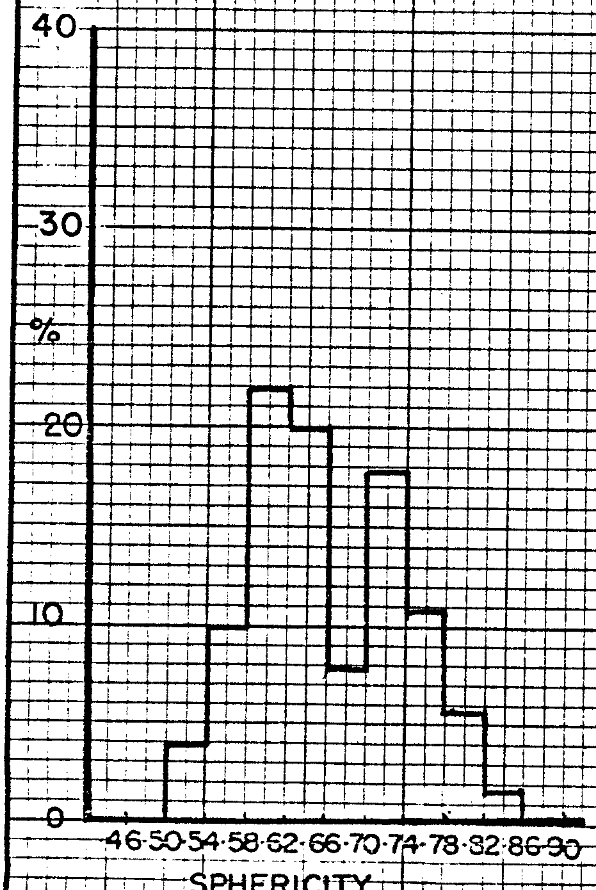


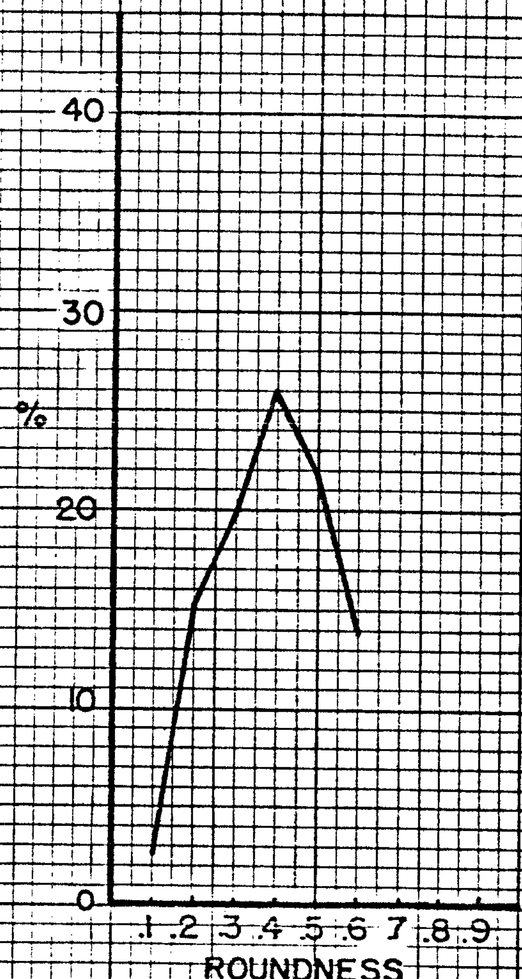
Sample No. 18
Date: July 4, 1973
Location: Powerline in Evergreen Village

% of Fines <0.530" 47.0%

No. of Pebbles Counted 112







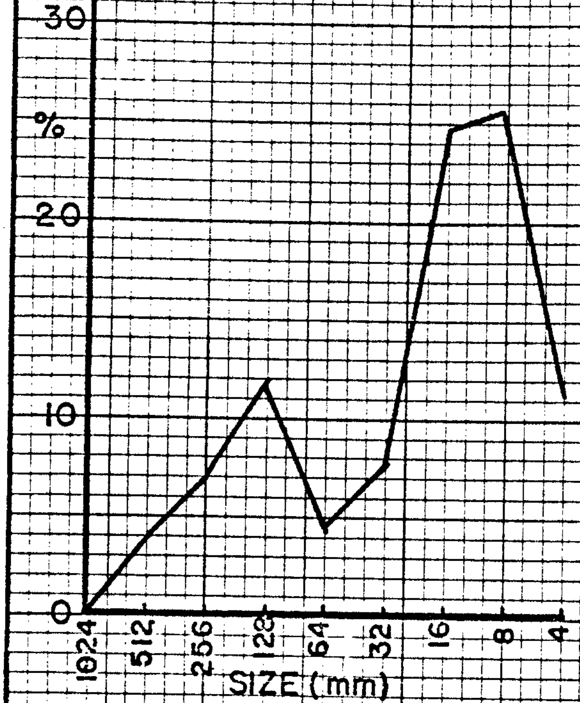
Sample No. 19

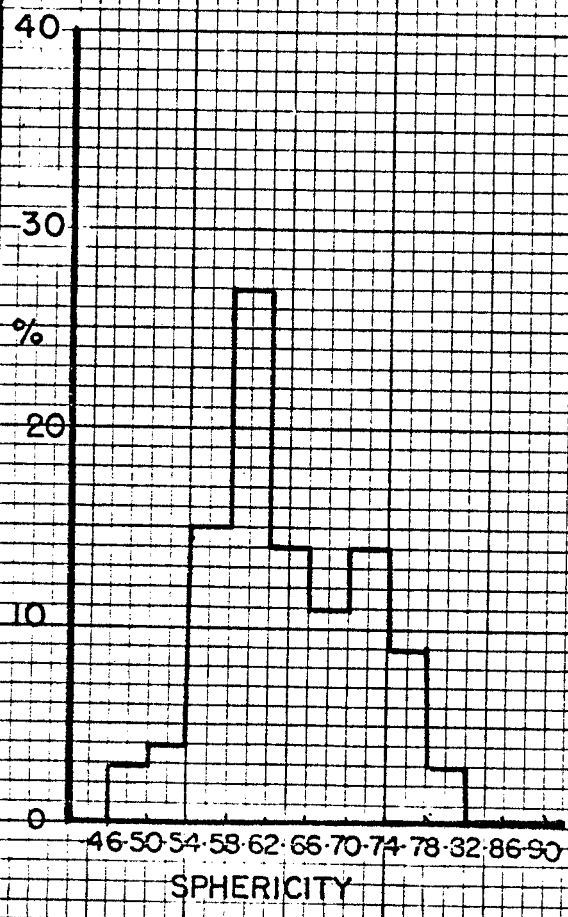
Date: July 4, 1973

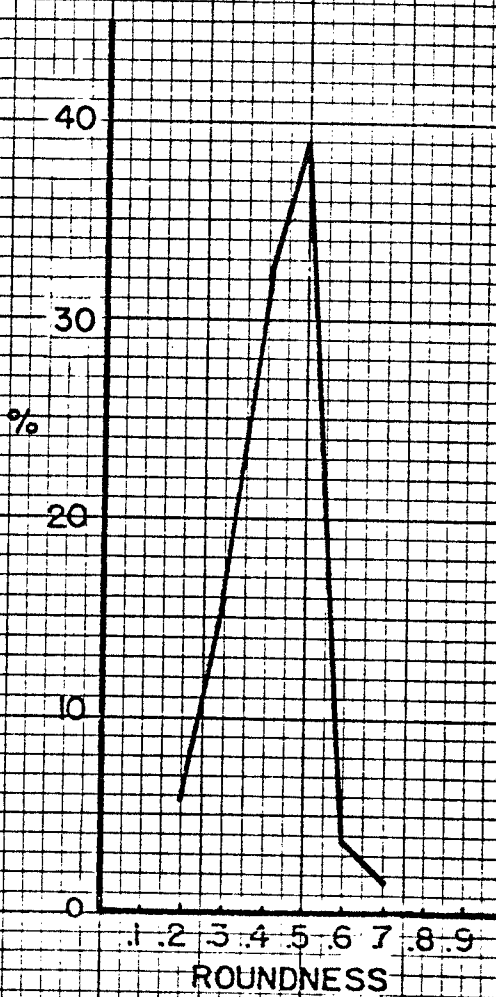
Location: South Bank of Rubble Ck.
El. 1950

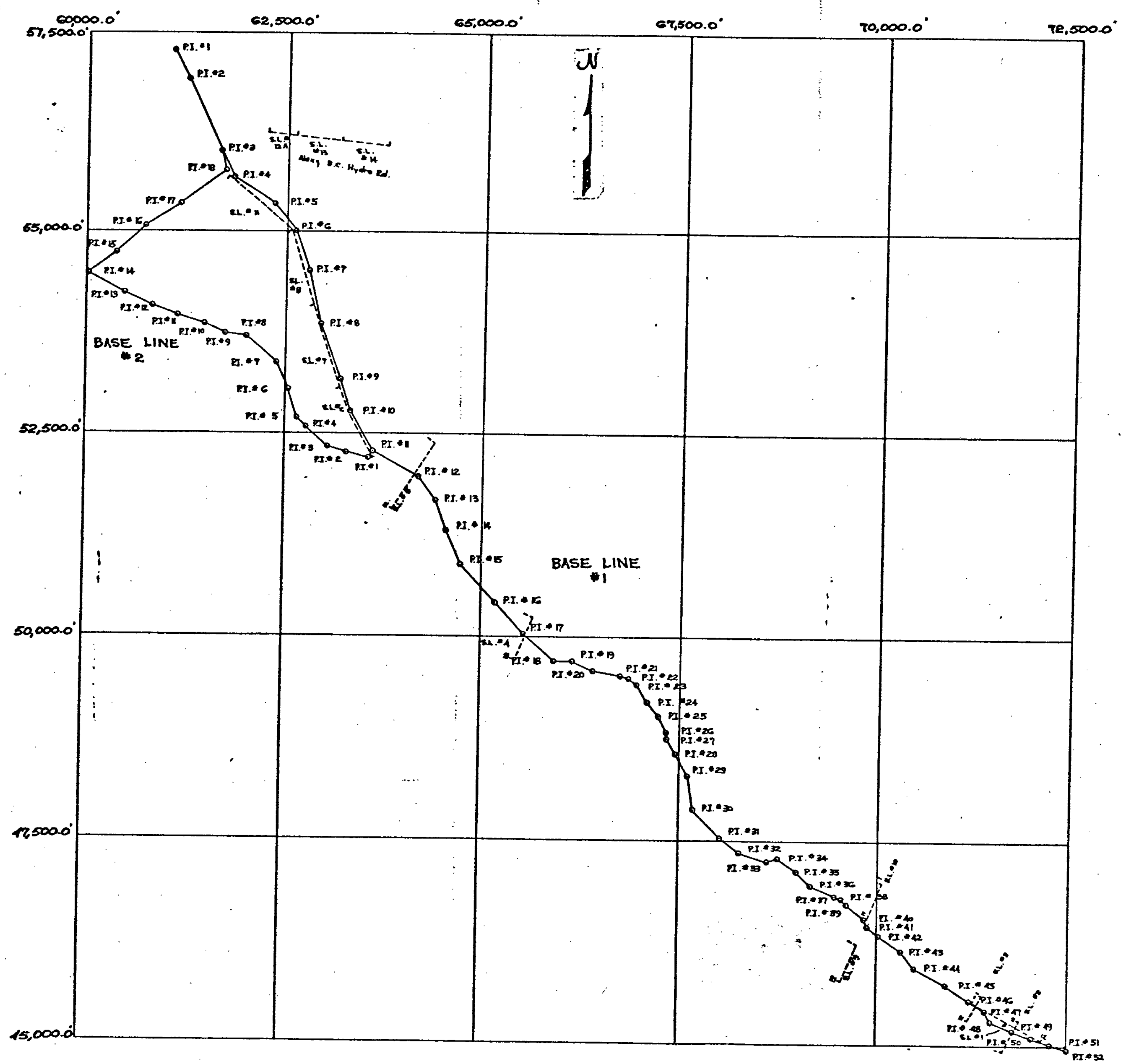
% of Fines <0.530" 34.4%

No. of Pebbles Counted 100









NOTES:

LANDMARK REFERENCES

BASE LINE #1 - ALL P.I.'s ARE ON THE NORTH SIDE OF CREEK

P.I. #1 - SOUTH END OF CONCRETE DAM.
P.I. #4 - P.I. #18 - EDGE OF ROAD
P.I. #19 - P.I. #33 - NORTH SIDE OF CREEK
P.I. #34 - P.I. #35 - ON RIDGE, NORTH SIDE OF CR.
P.I. #36 - NORTH SIDE OF CREEK
P.I. #37 - ON THE TRAIL
P.I. #41 - SIGNPOST (Black Tusk)

BASE LINE #2

P.I. #14 - NORTH END OF TIMBER BRIDGE OVER RUBBLE CREEK

GRID - B.C. HYDRO

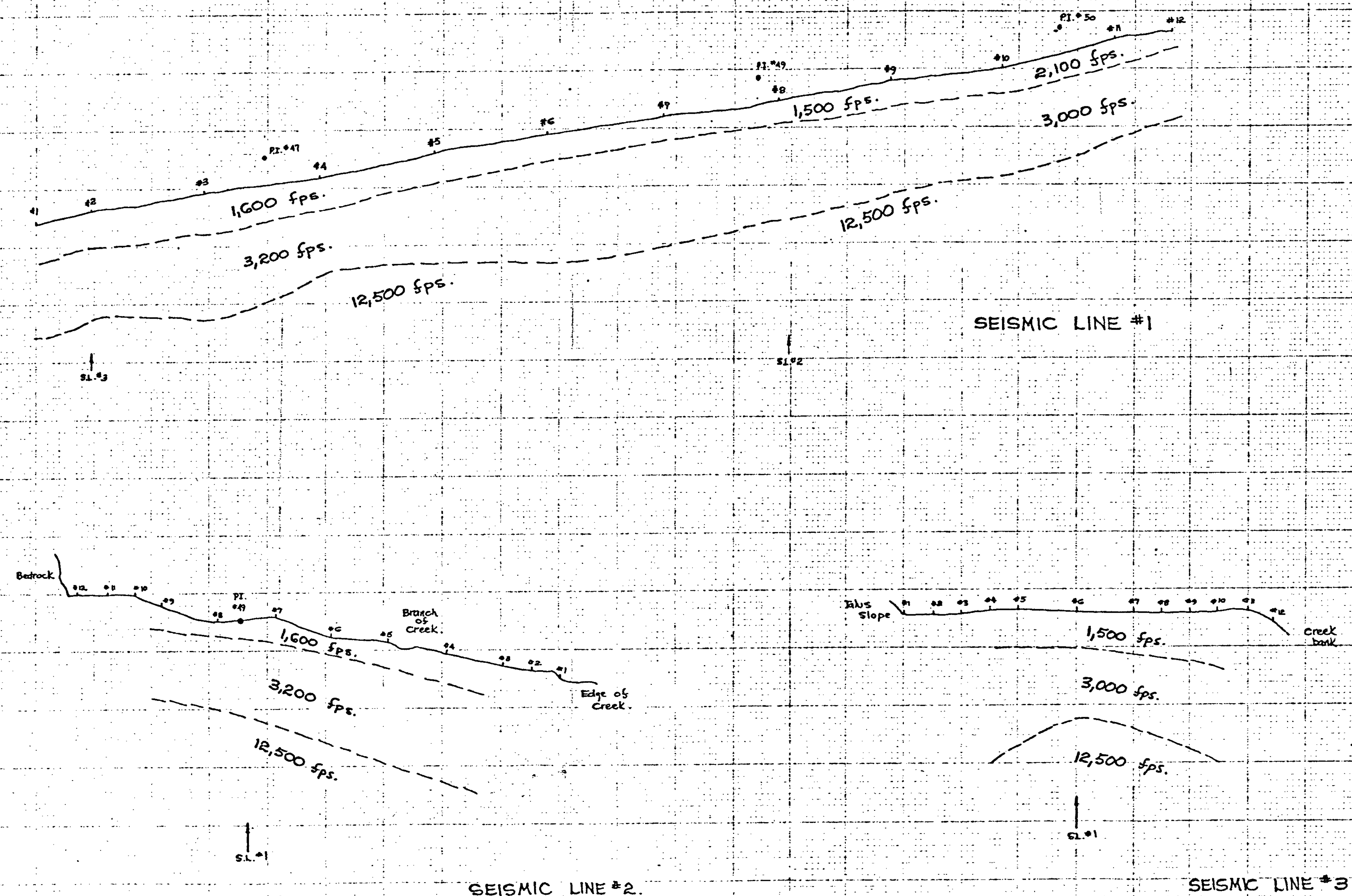
⊙ P.I. - POINT OF INTERSECTION
------ S.L. - SEISMIC LINES.

FOR TOPOGRAPHY MAP :- SEE LOCKWOOD PLAN 73-86, DONE FOR U.B.C.

BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH

RUBBLE CR. TRAVERSE
"THE BARRIER"
GARIBALDI PARK AREA.

DRAWN	KFR	SCALE 1" = 833'	DATE 1/8/1973.
TRACED		PROJ. NO.	REG. NO. H
CHECKED		FILE NO. 01-11-58 A	DRAWING NO. R 89984 1 1



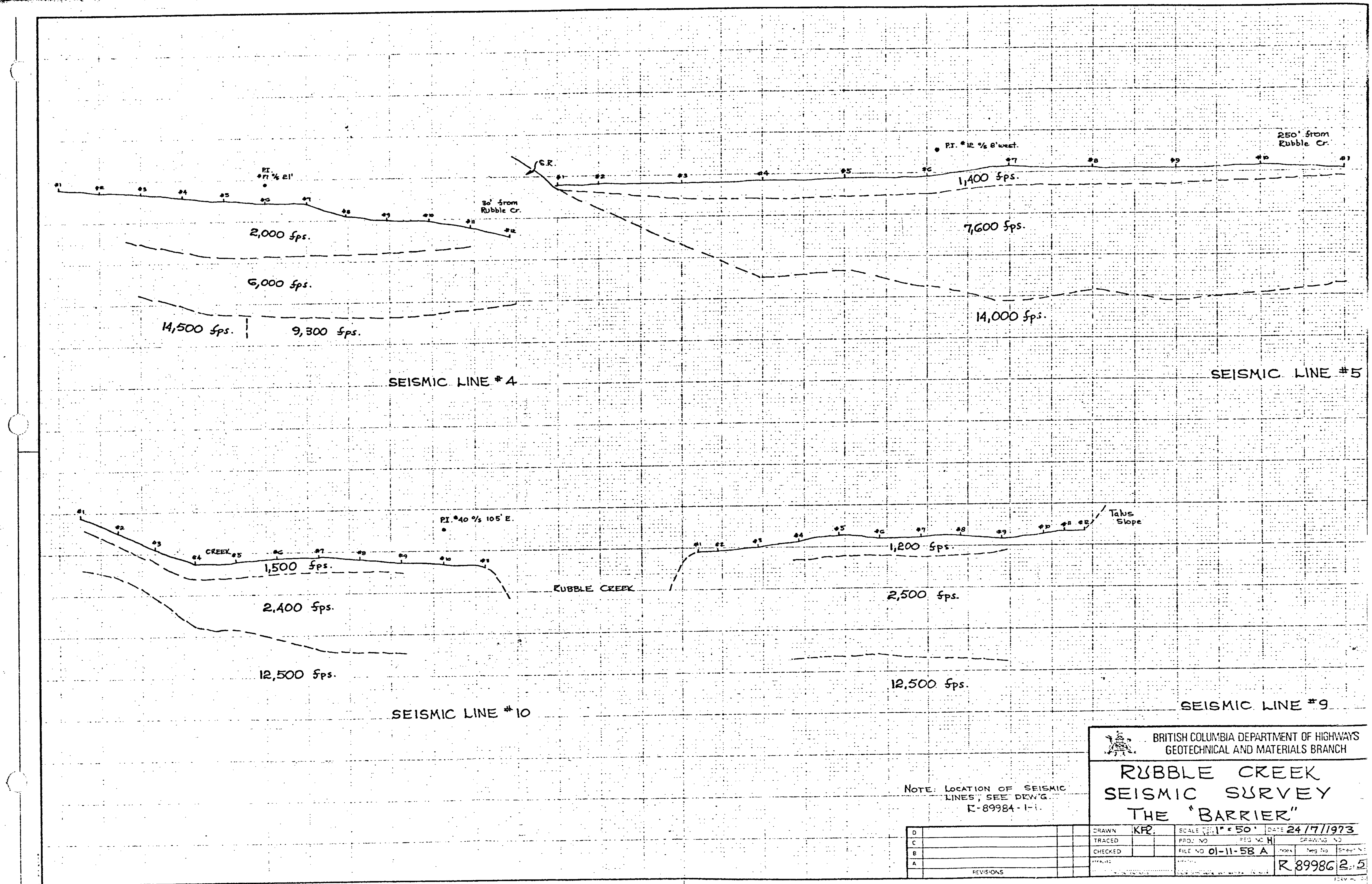
NOTE: LOCATION OF SEISMIC LINES, SEE DRW'G. R-89984-1-1.

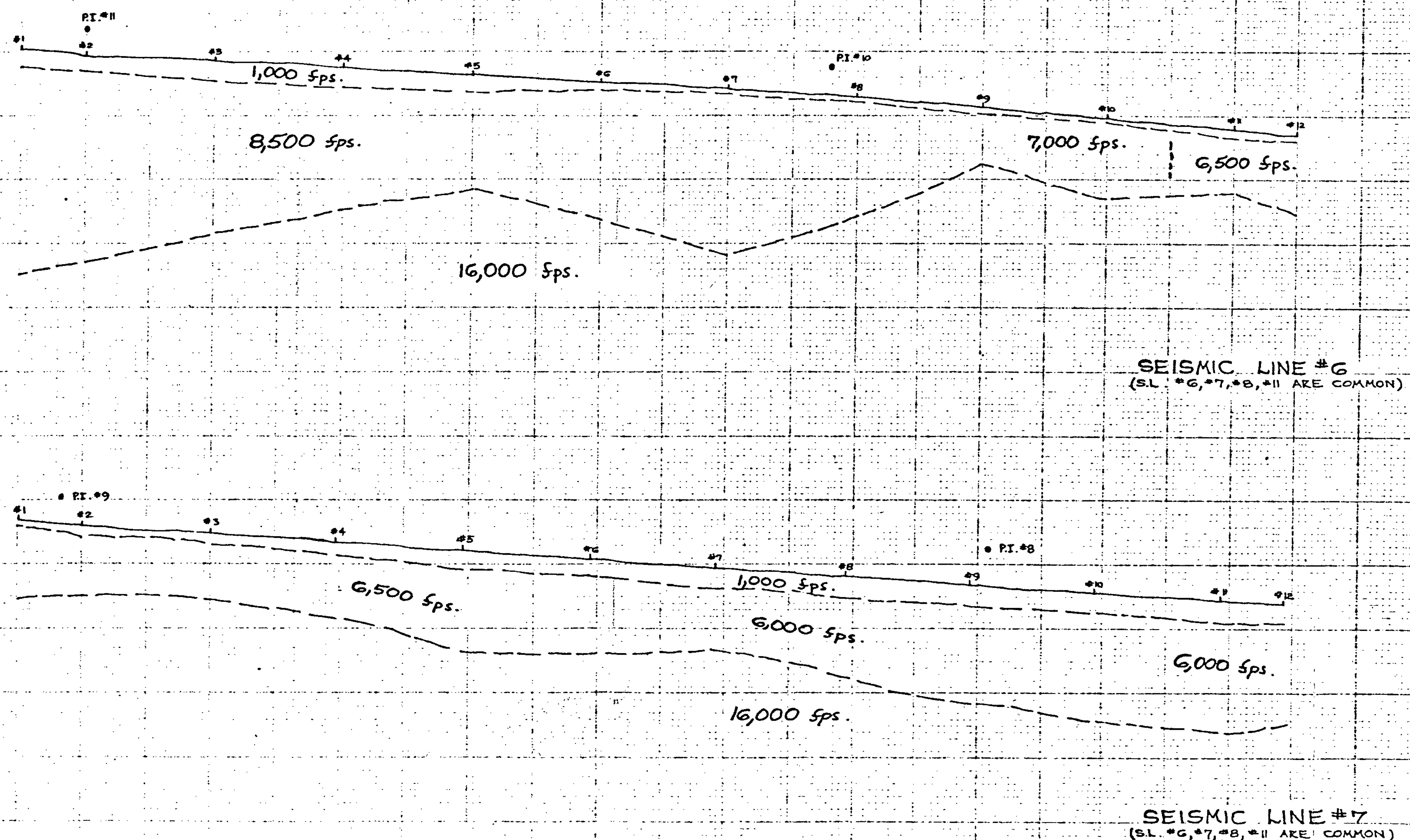
BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH

RUBBLE CREEK SEISMIC SURVEY THE "BARRIER"

DRAWN KFR	SCALE 1" = 50'	DATE 23/7/1973	
TRACED	PROJ NO	REG NO H	DRAWING NO
CHECKED	FILE NO 01-11-58 A	R 89985	Sheet No 1 of 5

REVISIONS: D, C, B, A


P.I. #11 % 21'
30' from Rubble Cr.
2,000 fps.
6,000 fps.
14,500 fps.
9,300 fps.
SEISMIC LINE #4
S.R.
P.I. #12 % 8' west.
250' from Rubble Cr.
1,400 fps.
7,600 fps.
14,000 fps.
SEISMIC LINE #5
P.I. #40 % 105' E.
CREEK
1,500 fps.
2,400 fps.
12,500 fps.
RUBBLE CREEK
SEISMIC LINE #10
Talus Slope
1,200 fps.
2,500 fps.
12,500 fps.
SEISMIC LINE #9
NOTE: LOCATION OF SEISMIC LINES, SEE DRW'G. R-89984-1-1.
BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH
RUBBLE CREEK
SEISMIC SURVEY
THE "BARRIER"
DRAWN KR.
TRACED
CHECKED
SCALE 1" = 50'
DATE 24/7/1973
REG NO H
FILE NO 01-11-58 A
DRAWING NO
R 89986 2 5
REVISIONS



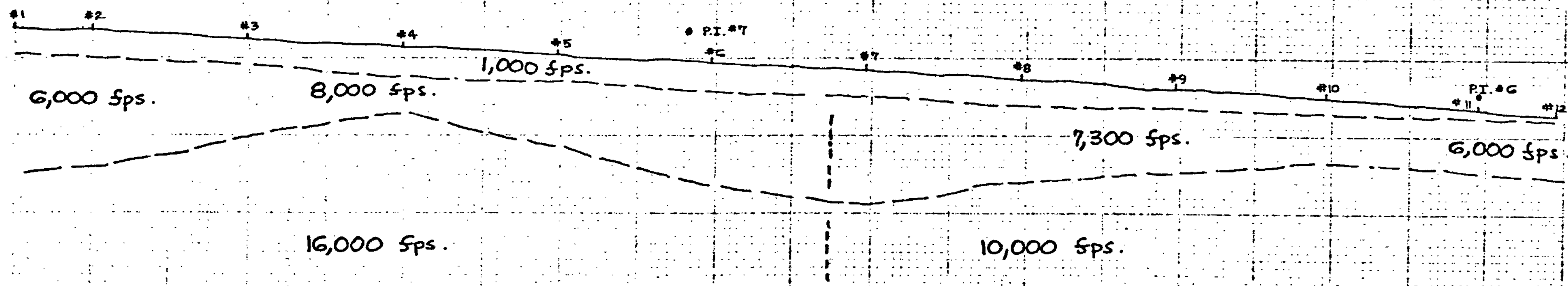
NOTE: LOCATION OF SEISMIC LINES, SEE DRW'G. R-89984-1-1

BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH

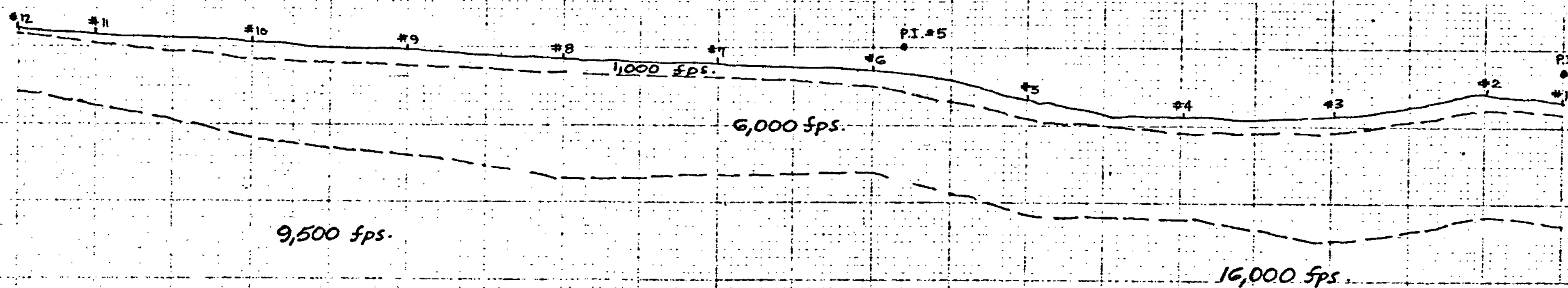
RUBBLE CREEK SEISMIC SURVEY THE "BARRIER"

DRAWN	KFR.
TRACED	
CHECKED	
SCALE	1" = 50'
DATE	24/7/1973.
PROJ NO	
REG NO	H
FILE NO	01-11-58 A
DRAWING NO	R 89987 3 5

REVISIONS: D, C, B, A



SEISMIC LINE #8
(S.L. #6, #7, #8, #11 ARE COMMON)



SEISMIC LINE #11
(S.L. #6, #7, #8, #11 ARE COMMON)

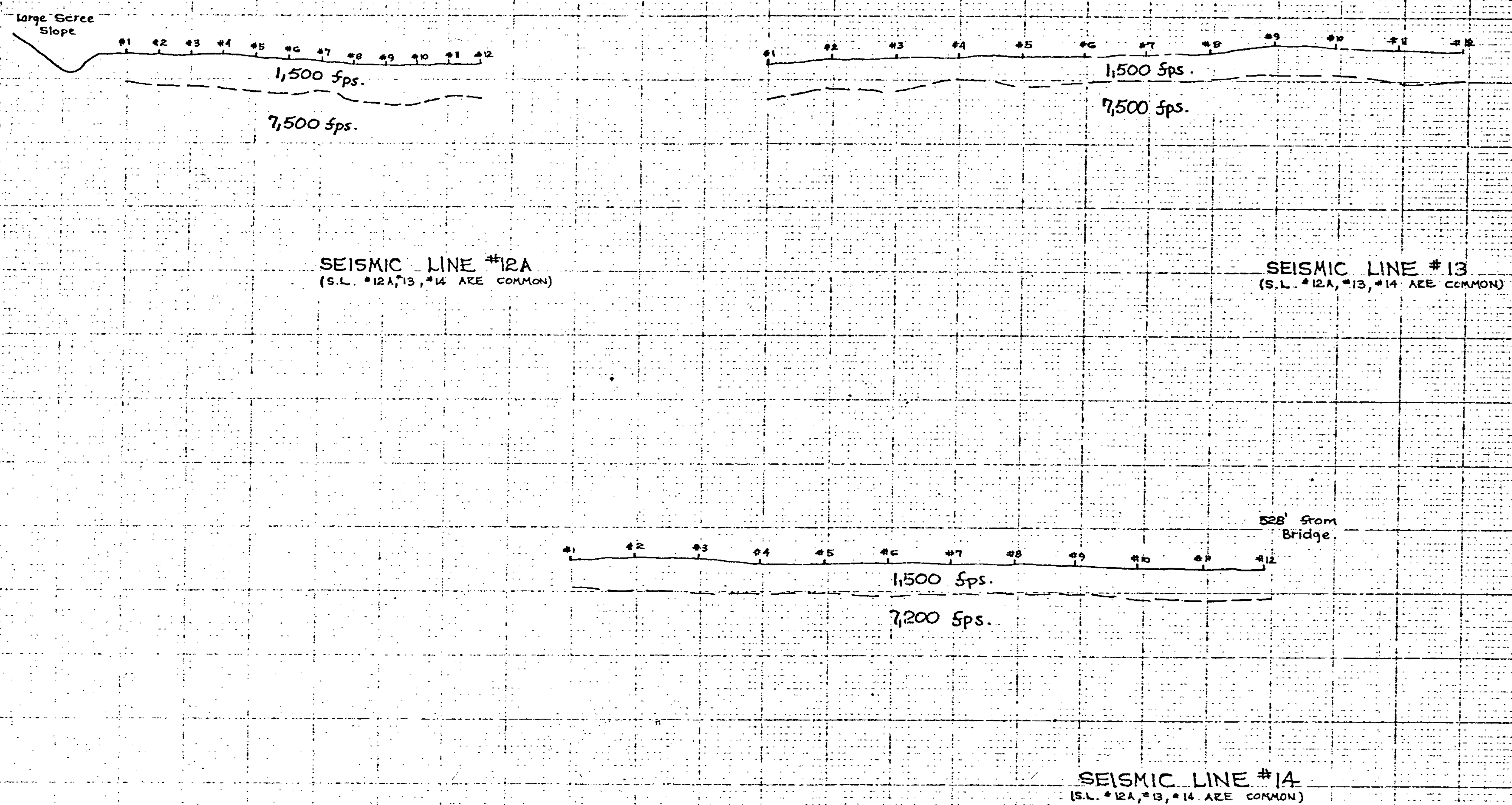
NOTE: LOCATION OF SEISMIC LINES, SEE DRW'G. R-89984-1-1.

BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH

RUBBLE CREEK
SEISMIC SURVEY
THE "BARRIER"

DRAWN XFR	SCALE 1" = 50'	DATE 24/7/1973
TRACED	PROJ NO	REG NO H
CHECKED	FILE NO 01-11-58A	R 89988 4 5

REVISIONS



NOTE: LOCATION OF SEISMIC LINES, SEE DRW'G. R-89984-1-1

BRITISH COLUMBIA DEPARTMENT OF HIGHWAYS
GEOTECHNICAL AND MATERIALS BRANCH

RUBBLE CREEK
SEISMIC SURVEY
THE "BARRIER"

DRAWN KFR.	SCALE 1" = 50'	DATE 24/7/1973	
TRACED	PROJ NO	REG NO H	DRAWING NO
CHECKED	FILE NO 01-11-58A		
		R 89989	5 5

REVISIONS: D, C, B, A

RUBBLE CREEK SLIDE
SCALE MODEL SLIDE
MOTION AND DEFORMATION

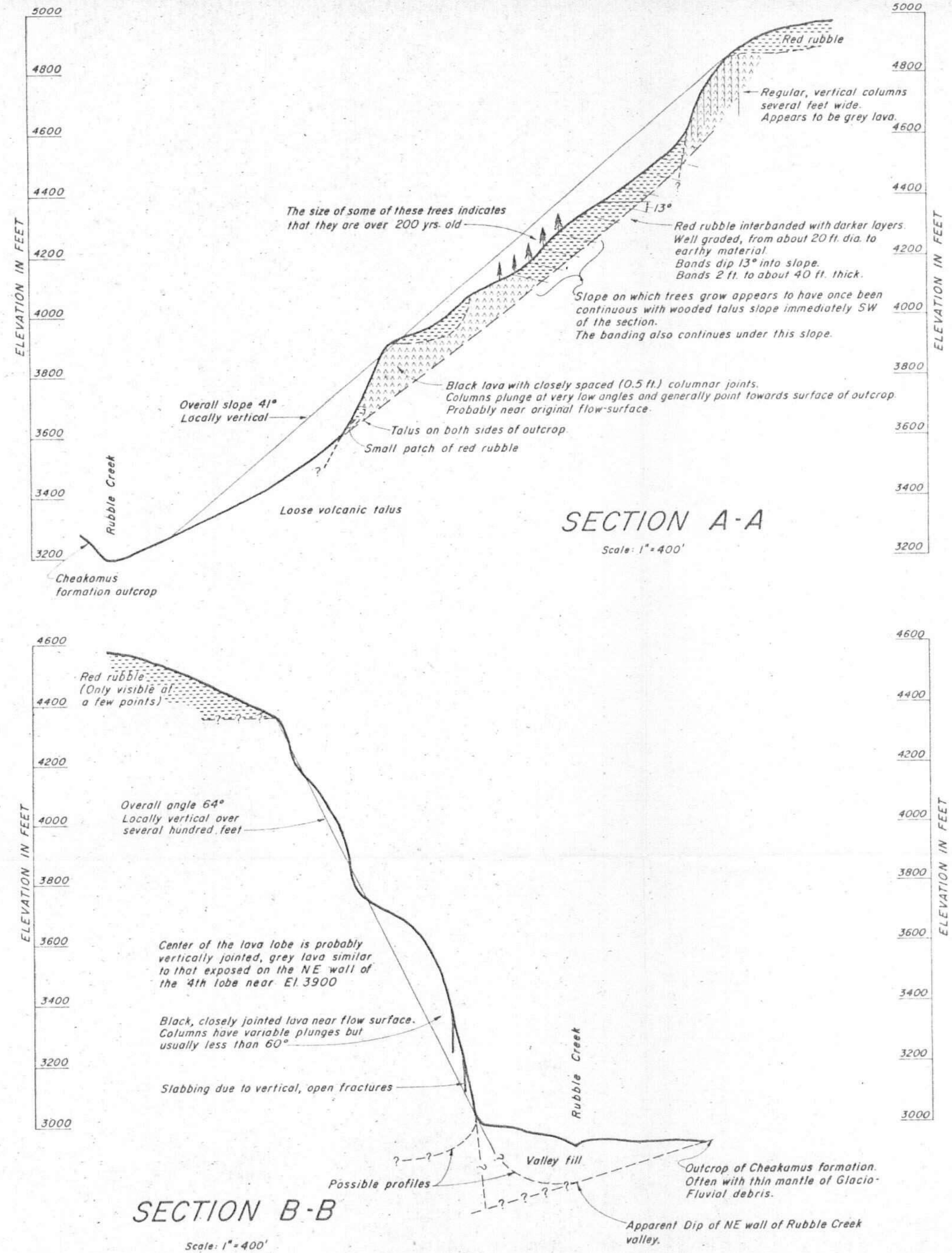
FIGURE 6

RUBBLE CREEK SLIDE
GEOLOGIC SECTIONS ALONG
SLIDE PATH

Scale 1:10000

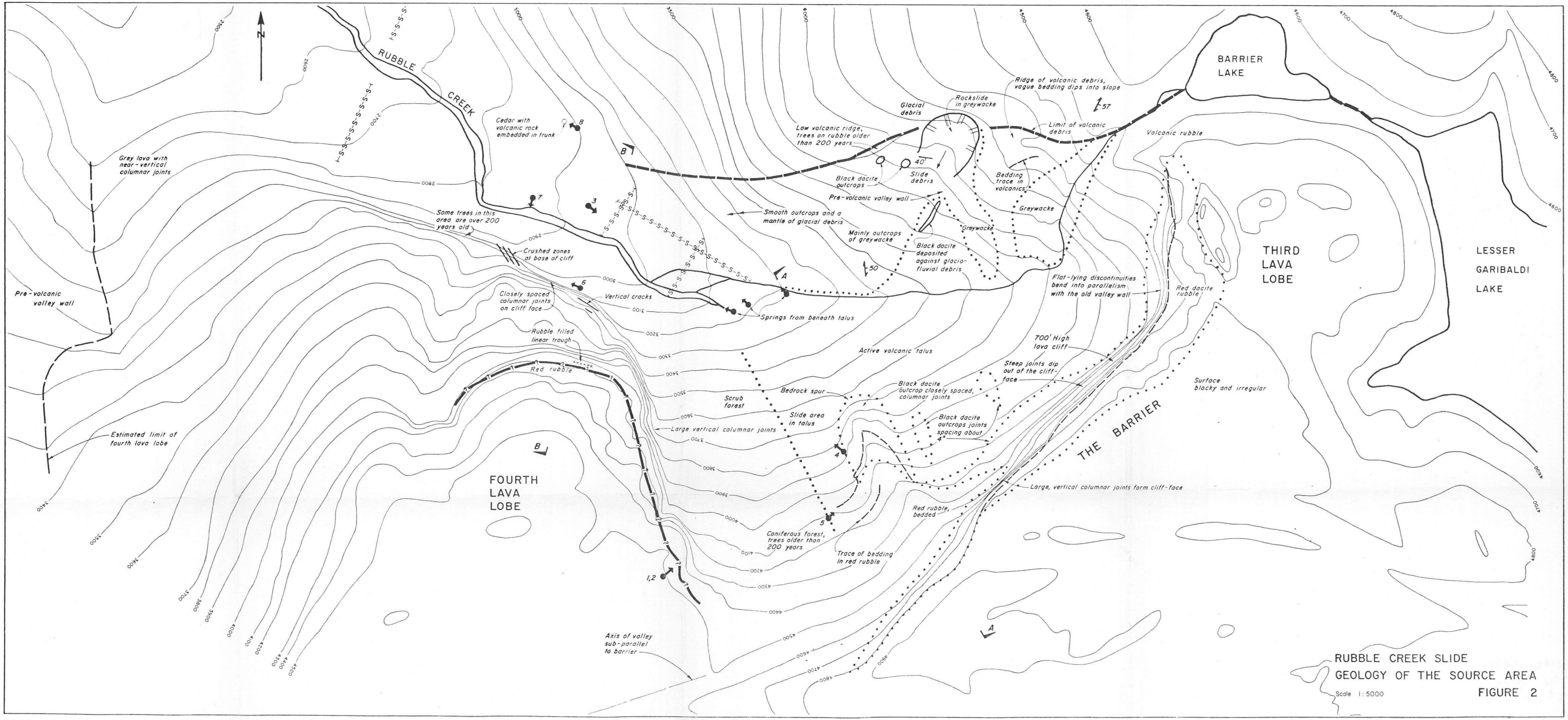
FIGURE 5

RUBBLE CREEK SLIDE
SLIDE PATH
Scale 1:10000
FIGURE 4



NOTE:
FOR LOCATION OF SECTIONS SEE FIGURE 2.

RUBBLE CREEK SLIDE
GEOLOGICAL SECTIONS
THROUGH SOURCE AREA
FIGURE 3



RUBBLE CREEK SLIDE
GEOLOGY OF THE SOURCE AREA
Scale 1:5000
FIGURE 2