WHATCOM COUNTY Engineering

rec'd JAN 20, 1976

FINAL GEOTECHNICAL REPORT

Swift Creek Tributaries
Sumas River Watershed

Whatcom County, Washington

for

Soil Conservation Service

Contract AG53-scs-00041

January 15, 1976

W-75-332

CONVERSE DAVIS DIXON ASSOCIATES, INC.

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January 15, 1976

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Soil Conservation Service
Rm. 360, US Courthouse
Spokane, Washington 99201

Attention: Mr. Jerry L. Scrivner,
State Administrative Officer

FINAL GEOTECHNICAL REPORT
Contract No. AG53 scs-00041
Swift Creek Tributaries - Sumas River Watershed

In accordance with the provisions of our Contract No. AG53scs-00041, we herewith submit eight copies of the Final Geotechnical Report developed relative to the landslide on Sumas Mountain and the resulting deposition of sediments on the Swift Creek floodplain. Notice to proceed was given by you on July 17, 1975 and received by us on July 24, 1975 with performance beginning on July 22, 1975.

This report is divided into two parts: Phase I - Geologic Investigation, containing the description and results of the geologic mapping, subsurface test pit explorations, and laboratory testing of material samples; Phase II - Geologic and Engineering Analyses, containing the results of our preliminary evaluation of the feasibility of retarding the landslide movement via a landslide control structure or other means and the size, type, and location of potential sediment debris basins on the Swift Creek floodplain. The Phase II portion includes a summary of the Phase I basic data and may be utilized as a separate by those not desiring the detailed background data described in Phase I.

We wish to acknowledge the assistance of our subconsultants in carrying out the provisions of this contract. Hydrologic engineering and economic analysis services were provided by Kramer, Chin & Mayo, Inc., the aerial mapping was by H. G. Chickering, Jr., with ground control surveying furnished by Hammond, Collier & Wade-Livingstone Associates, Inc.

We also wish to acknowledge the assistance and co-operation of the Soil Conservation Service staff which included John A. Wilson, State Geologist, who also served as government representative, Jasper L. Holland, Engineering Geologist with the West Technical Service Center and Paul L. Malone, District Conservationist. Valuable background data and history of the problem was furnished by Bruce E. Meacham, former Executive Secretary, Whatcom County Conservation District.

CONVERSE DAVIS DIXON ASSOCIATES, INC.

Eugene R. McMaster

Eugene R. McMaster,
Vice-President

ERM:ttn
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GEOLOGIC INVESTIGATION

Swift Creek Tributaries
Sumas River Watershed

Whatcom County, Washington

for

Soil Conservation Service

Contract AG53-scs-00041

October 3, 1975

W-75-332

CONVERSE DAVIS DIXON ASSOCIATES, INC.

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1.0 INTRODUCTION

1.1 General

This report presents the results of Phase I of the geotechnical investigation along Swift Creek and its tributaries in the Sumas River Watershed.

As shown by the Vicinity Map, Drawing No. 1, at the back of this report, the project study area is located in Whatcom County near Everson in northwest Washington and encompasses the Swift Creek drainage area from its confluence with the Sumas River to its head on Sumas Mountain. Reportedly, starting in the late 1940's overbank flooding of Swift Creek resulted in the deposition of fine to coarse-grained sediments on the adjacent farmlands bordering the creek. This debris originated from a landslide located on the upper Swift Creek drainage area. Since that time, the amount and areal distribution of the sediment deposition has increased.

1.2 Purpose

The purpose of this investigation is to develop a geotechnical report with recommendations for controlling the mass soil movement of a landslide and/or means of containing sediments presently being deposited in the Swift Creek floodplain. To accomplish this, the investigation is divided into two phases; Phase I - Geologic Investigations and Phase II - Geologic and Engineering Analysis.

1.3 Scope of Work

The scope of work for the Phase I Geologic Investigation consisted of basic data gathering in order to provide information for the Phase II preliminary evaluation of the feasibility of retarding the landslide movement via a landslide control structure or other means and for determining the size, type and location of a potential sediment debris basin(s) located on the

Swift Creek floodplain. This phase included:

(a) literature search, aerial mapping and aerial photo interpretation,

(b) geologic field mapping, geophysical investigation, test pit explorations to determine subsurface conditions and collection of soil and rock samples, and

(c) laboratory testing of soil and rock samples including the analysis and interpretation of the test results.

2.0 REGIONAL GEOLOGY

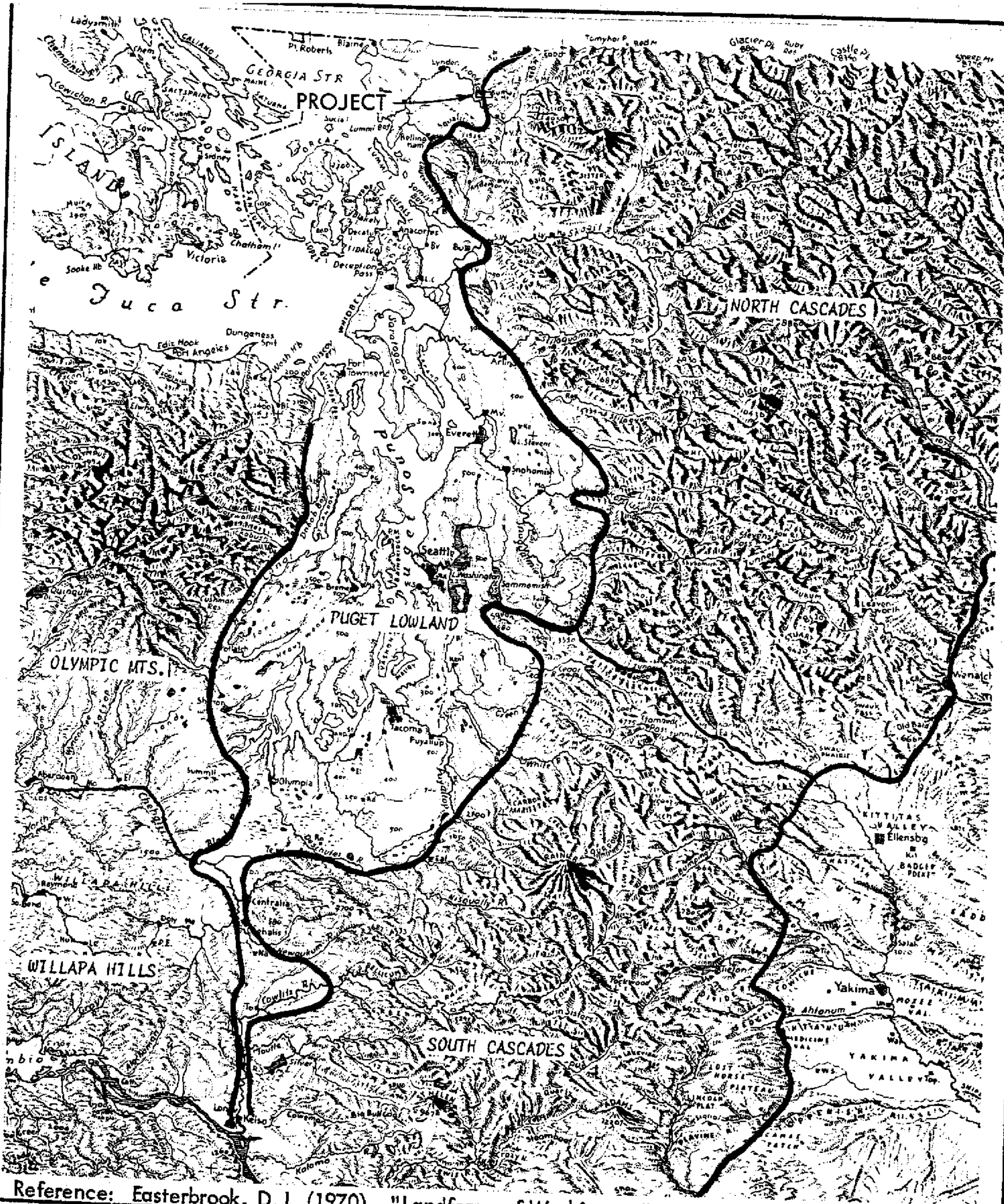
2.1 General

The project area straddles the boundary between the Puget Lowland Physiographic Province and the Cascade Mountain Physiographic Province; specifically the North Cascade subdivision as depicted on Figure No. 1. The Puget Lowland is an elongated north-south topographic and structural depression generally characterized by low relief. With a few exceptions the area generally lies below an elevation of 500 feet.

The Puget Lowland is a product of both the subsidence of the earth's crust and the uplift of the Cascade Mountain Range on the east and the Olympic Mountains on the west. Superimposed across this north-south trend is a northwestern trending structural arch which is an extension of the Cascade Mountains into the lowlands. The rocks exposed along this feature represent the oldest in the Puget Lowland Province.

The North Cascade subdivision is characterized by steep mountains ranging in elevation from 4,000 feet to 10,000 feet with the highest being Mount Baker at an elevation of 10,750 feet.

The oldest rocks found in the region are Paleozoic graywacke, limestone, chert and shale which have been complexly folded and faulted. Overlying these are pre-Tertiary graywacke, shale, serpentine and peridotite. In late Mesozoic, the conglomerates and sandstones of the Chuckanut Formation which are continental in origin and represent a former vast alluvial floodplain where the energy of the transporting water was relatively high, were deposited unconformably over the underlying pre-Tertiary rocks.



Reference: Easterbrook, D.J. (1970), "Landforms of Washington"

PHYSIOGRAPHIC PROVINCES

PREPARED BY : WSB
CHECKED BY: HAS
APPROVED BY: ERM

SWIFT CREEK TRIBUTARIES - SUMAS RIVER WATERSHED
Contract No. AG53scs - 00041
for Soil Conservation Service

figure number 1

DATE: Sept. 1975
SCALE: - - -
PROJECT NUMBER: W - 75 - 332 - AH

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In early Tertiary, the Chuckanut Formation was folded, faulted and uplifted. With the uplift, erosion was renewed and some of the previously formed structures were reduced by erosion. A return to an alluvial floodplain environment resulted in the deposition of the Tertiary continental sedimentary rocks, the Huntingdon Formation, which presently outcrops along the foothills on the south and east margins of the lowland.

In late Tertiary, the uplift of the Cascade Range occurred causing deformation of the Huntingdon Formation and additional deformation of the Chuckanut and older formations. The deformation of the Huntingdon Formation was primarily in the form of uplifting and tilting of the beds accompanied by some minor faulting.

No rocks younger than the Huntingdon Formation are exposed in the region. Either this period of time was one of erosion or the rocks of this age have been removed by subsequent erosion.

2.2 Glaciation

The next period of deposition occurred during Pleistocene time. The Puget Lowland is known to have been invaded by continental glaciers at least four different times. These continental glaciers had their origin in the mountains of British Columbia. Each succeeding glacier reworked the previous deposits and buried them beneath younger deposits. In the northern Puget Lowland the evidence of multiple glaciation lies buried beneath the deposits of the last glacial advance and retreat. Evidence of earlier glaciation is based on older glacial deposits exposed in the southern portion of the Puget Lowland.

The last major phase of continental glaciation that invaded western Washington is referred to as the Fraser Glaciation. It began about 20,000 years ago and ended with its retreat from the area approximately 10,000 years ago. Most of the exposed glacial deposits in the northern Puget Lowland were deposited during this period which was comprised of three phases, each known as a "stade".

The oldest is the Vashon Stade which occurred 20,000 to 13,000 years ago. This comprises the time when the Vashon glacier occupied the northern Puget Lowland. At its maximum the glacier extended to a point approximately 15 miles south of Olympia, Washington and reached a maximum thickness in the Bellingham area on the order of 6,000 feet. The presence of glacial till, glacial striae and glacial erratics on top of some of the eastern Cascade Mountains gives evidence that these areas were also covered by ice to a present day elevation of approximately 6,000 feet. The lower mountains, such as Sumas Mountain, were totally buried by glacial ice during at least its maximum stand. A portion of the sediments deposited during the period when the glacier occupied the area was glacial till. It was deposited as a blanket over most of the area and consists of a heterogeneous mixture of clay, silt, sand and gravel. The weight of the overriding glacier resulted in over-consolidation of the till and underlying sediments. In its unweathered state till is a very dense soil with high strength, low permeability, a concrete-like appearance and is commonly referred to as "hardpan". In the low lying areas the glacial till is generally covered by younger deposits. It is best exposed along the flanks of the foothills and in pockets and discontinuous deposits on the lower mountains.

During the waning of the glacier, corresponding to the relative rise in sea level, the Everson Interstade began approximately 13,000 years ago and continued until approximately 11,000 years ago. The glacial ice during this period had melted appreciably and is thought to have been only a few hundred feet thick and almost entirely floating in sea water. During this interstade, three major units were deposited. From oldest to youngest these consisted of the Kulshan glaciomarine drift, the Deming sand and the Bellingham glaciomarine drift. Both units of the glaciomarine drift consist of heterogeneous mixtures similar to the glacial till from the Vashon Stade. However, because the ice was floating, the sediments did not receive the overriding action of the ice and are thus markably less compact. In addition, with the influx of the sea water, marine life was reestablished and the glaciomarine drift contains fossils in the form of marine shells. The Deming sand was deposited during an intervening period when the sea level dropped to within 50 feet of its present level.

The last stade is referred to as the Sumas Stade which began approximately 11,000 years ago and lasted for approximately 1,000 years. During this period the terminus of the glacier remained relatively stable at a position just north of the Canadian border north of Sumas, Washington. Melt water flowing southward from the glacier built an outwash plain from the Canadian border to Lynden and from the Everson area westward to the vicinity of Ferndale. In the northern portion of the area in the proximity of the glacier these deposits consist primarily of gravel grading to sand in the southern portion. The meltwater flowing southward from the glacier created numerous channels and several of the channels have been preserved.

Since the end of the Pleistocene, the Puget Lowland has probably undergone little change. What modifications have occurred have been confined to wave cut erosion along the Puget Sound shoreline; some stream incision of the drift plain, primarily along the shoreline; some infilling of depressions and abandoned meltwater channels with recent sediments and organic accumulation; and in some instances the building of small alluvial fans into Puget Sound or onto the regional floodplain in the vicinity of the foothills.

2.3 Faults and Seismicity

There are no known active (movement during the last 10,000 years) faults in Whatcom County. The Puget Sound Lowland lies within Zone 3 of the Seismic Risk Map of the United States. Zone 3 is defined as an area where major damage can be expected corresponding to intensity VIII and higher of the Modified Mercalli Intensity Scale of 1931. In the last 133 years, the Puget Sound Lowland has experienced a number of large earthquakes. During this period of time there were a total of 42 earthquakes having a maximum intensity of at least VI, or were felt over 10,000 square miles.

2.4 Ground Water

The bedrock and unconsolidated sediments in Western Whatcom County has a wide range of water-bearing characteristics. Bedrock exposed at the surface or at shallow depths in the southern and eastern portions of the area in general has low permeability with little or no ground water. Where water is present, it occurs along joint and/or bedding planes or zones of fracturing.

The majority of the aquifers occur in the granular sediments deposited during the Fraser Glaciation. From oldest to youngest these are the Esperance Sand, the Deming Sand, the outwash sand and gravel from the Sumas Stade, and the recent floodplain alluvium. The aquicludes include the previously mentioned bedrock, Vashon glacial till, the Kulshan and Bellingham glaciomarine drift, and the silt and clay portions of the granular sediments.

In general, the ground water table is very close to the surface near Everson and at a depth on the order of 20 feet beneath the glacial outwash plains. Beneath the uplands, which are mantled with glaciomarine drift, the ground water generally lies within the underlying granular sediments where present.

3.0 PROJECT GEOLOGY

3.1 Geography

The project area is on and adjacent to the western slope of Sumas Mountain, extending approximately four miles east of Everson, Washington as shown on the Vicinity Map. The topography is variable, ranging from the relatively flat Swift Creek floodplain in the westerly part to the rugged slope of Sumas Mountain in the easterly part which rises from elevation 100 to elevation 3,000 feet within 2-1/2 miles. Steep canyons drain westward, eventually discharging into the Sumas River. Swift Creek occupies one of these canyons. Second growth timber, mainly Douglas fir, western hemlock and western red cedar cover the steep slopes above elevation 250 feet. The undergrowth consists of alder, willow, ferns, nettles and other small brush.

Prevailing westerly winds from the Pacific Ocean produce a modified oceanic climate with an average annual rainfall of 60 inches. Snow can be expected from November through April. Nearly 75 percent of the precipitation falls between September and May. The principal means of livelihood in the area are logging (highlands) and farming (lowlands).

Detailed geologic mapping in the project area indicates that much of the easterly Swift Creek drainage area is occupied by a large 225-acre teardrop-shaped landslide. The majority of surface runoff in this area is channelized along the northern and southern boundaries of the landslide, although two flowing streams traverse the length of the slide. Bedrock units, identified during the geologic mapping, that occur in the Swift Creek landslide area include meta-sedimentary graywackes (Mz) which have been thrust over younger serpentinite (Jki) rocks. The serpentinite is overlain by massive tertiary continental conglomerates (Tc) which incline westerly. These rocks are cloaked by surficial material consisting of alluvium, glacial deposits and slide debris. The distribution of these materials are presented on Drawing No. 2 - Geologic Map of Landslide and Drawing No. 3 - Geologic Map of Floodplain. The various surficial materials and bedrock units are described in Section 3.2. Definitions of weathering, hardness, joints and texture are presented at the end of Section 3.5.

3.2 Surficial Materials

3.21 Modern Flood Channel and Flood Plain Deposits (Qfg). Field observations and laboratory tests indicate these deposits consist of very loose, poorly sorted, light gray to brownish gray gravel and sand derived from the landslide debris. The predominant size material is gravelly sand, with interbeds of medium to coarse-grained sand. The present Swift Creek drainage marks the boundary of modern flood channel deposits. Overbanking, during flood stages, has locally spread these materials to a thickness of approximately five feet. The known thickness in the channel exceeds 17 feet, as observed in Test Pit No. 1.

3.22 Landslide Debris (Qls). The teardrop-shaped landslide debris is a complex assemblage of several blocks of differing landslide mechanisms (as shown in Drawing No. 2). These mechanisms are: (1) rotational slump blocks, (2) debris flows, (3) planar block glides and (4) slump-earthflows. The composition of each individual slide block varies. However, the majority are comprised of a heterogeneous mixture of serpentinite, till, and conglomeratic boulders, in a sheared, weak matrix of clay, glacial till, weathered serpentinite, rock flour, and fault gouge. The milky, colloidal suspension observed in Swift Creek runoff originates from these fine-grained materials. Some of the relatively intact rotational slump blocks are capped by 30 to 50 feet of glacial till.

3.23 Alluvial Fan Deposits (Qaf). These deposits flank Sumas Mountain along the major east-west drainages. The Swift Creek alluvial fan is characterized by a reddish brown, heterogeneous, massive, very poorly sorted, muddy gravel. The predominant gravel size is a small cobble. Within the muddy gravel are intercalated lenses of poorly cross-bedded, loose, medium to fine-grained, brownish yellow sand. The alluvial fan gravels are relatively fresh, having little evidence of weathering and may well be on the order of 100 - 200 feet thick in the vicinity of Lebrant Road.

3.24 Glacial Recessional Deposits (Qgr). These gravel deposits are compositionally heterogeneous, poorly-bedded to well-bedded to cross-bedded, sandy reddish brown, small pebble gravel and coarse to fine-grained sand. The bedding commonly shows cut and fill channels from stream deposition; along with inclined (foreset) beds. The majority of the gravel clasts within the upper 10 feet of the surface have a discolored weathered coating of clay, iron-oxide, and calcium-carbonate. The granitic gravel clasts are partly decomposed and crumble easily suggesting this gravel unit is moderately weathered. Exposures outside of the study area are commonly terraced, having rather flat bluffs flanking Sumas Mountain.

3.25 Glacial Till (Qgt). The glacial till is a light bluish grey, massive, dense, hard, very heterogeneous mixture of gravel, cobbles, and boulders in a silty to clayey matrix. The larger boulders are usually granitic in composition and have been rafted into the project area from several miles distant by glacial action. Joints and fractures are sometimes coated with iron-oxides; producing a yellowish-red surface.

In the higher bedrock areas (elevation 2,000') the till occurs in sporadic, discontinuous patches less than 30 feet thick. The average thickness in the lower elevations is approximately 50 to 75 feet. Commonly, the upper (3 to 5 feet) surface is weathered to a loose, gravelly clay which is frequently capped by alluvium and till reworked by streams. Field observations indicate this reworked till has cross-bedded, loose lenses of medium-grain sand and small pebble gravel.

3.3 Bedrocks

3.31 Tertiary Continental Sedimentary Rocks (Tc). These conglomeratic rocks consist of thickly bedded to massive, reddish brown to yellowish brown, well-cemeted to poorly-cemented, small pebble to small cobble gravel. These materials are known locally as the Huntingdon Formation. Interbedded with the conglomerate are subordinate sandstone lenses (up to 3 feet thick), which are dense to loose, well-cemented to poorly-cemented, cross-bedded and coarse to medium-grained. The well-cemented conglomerate horizons form hard, prominent, erosion-resistant ridges; the poorly-cemented sections are soft to moderately hard. This alternating "ridge and saddle" topography is depicted on Drawing No. 4 - Geologic Section A-A'. The general attitude of the conglomerate trends (strikes) nearly north-south and inclines (dips) westerly from 21° to 38°, averaging 25°. The conglomerate has a depositional contact with the serpentinite of $\pm 30^{\circ}$ in the downslope half of the landslide at the location shown on Drawing No. 2.

3.32 Sumas Mountain Serpentinite (Jki). The original rock that has been altered to serpentinite is a dense, very hard, fine-grained, dark green to greenish-black basic intrusive rock called peridotite and dunite. This rock has moderately widely-spaced to very widely-spaced joints. South of the landslide mass, this dense rock forms prominent, blocky outcrops with minor serpentine and chlorite coating joint surfaces. Around the periphery, and within the Swift Creek landslide mass, the bedrock is intensely serpentinized; i.e., highly weathered and completely altered to serpentine, chlorite and clay. These intensely serpentinized bedrocks contain several thick (10' to 20') shear - gouge zones of shattered rock fragments. Many of the slickensided fragments are rotated in a matrix of fine-grained rock flour and clay. The shattering is so intense that the rock easily breaks into small (one-inch diameter) fragments and rock flour.

The underlying sloping contact between the conglomerate and serpentinite is highly weathered, showing a spheroidal surface along joint faces. This contact is intensely iron-oxide stained containing earthly hematite and lateritic clays.

3.33 Meta-Sedimentary Rock (Mz). The meta-sedimentary rocks are predominantly graywacke and small pebble, graywacke conglomerate. These rocks are brown to brownish black, dense, very hard, very poorly bedded to massive and have widely spaced jointing. Metamorphism has produced a slightly schistose (platy) texture that stretches and flattens the small pebbles in a linear manner. These rocks form bold, blocky outcrops near the crest of Sumas Mountain and on other steep slopes.

3.4 Faults, Folds and Joints

In the study area, a low angle thrust fault, located on the north and east side of the landslide is suggested by: (1) older meta-sedimentary rocks topographically overlying the younger Sumas Mountain serpentinite, (2) a sheared fault gouge zone in serpentinite along the northeastern boundary of the main slide and (3) a northeast trending shear zone near the middle of the main slide. No other faults were observed in the study area.

The conglomerate trends nearly north-south and dips to the west suggesting a western limb of a large eroded anticline or a monocline. No other structural folds were observed at the site.

The Sumas Mountain serpentinite has a predominant north to northeast trending, near-vertical joint pattern. The majority of the joints are moderately-spaced to widely-spaced. Most joints show some degree of serpentinization. The closely-spaced joints, near the head of the landslide, exhibit polished clayey surfaces.

3.5 Surface and Ground Water

Springs and ground water seeps originate from bank storage in joints and permeable bedrocks, upslope of the slide mass. Springs also occur from bank storage in the Swift Creek landslide debris. At the time of the geologic mapping, these springs were observed to start with estimated flow rates of 1 to 3 gpm. Within several hundred feet the stream flow had increased to an estimated flow rate of 2 to 5 gpm. Upslope from the slide, the spring water is clear. However, springs originating in the slide debris, particularly in the lower third, are milky white and contain suspended rock flour and clay. Surface runoff is eventually channelized along the northern and southern boundaries of the slide. A small pond, formed by temporary damming within the slide mass, is located along a longitudinal depression, two-thirds upslope from the slide toe. This pond is approximately 10 to 20 feet deep, 50 feet wide and 200 feet long.

GEOLOGIC DEFINITIONS

Texture and Structure

Massive	more than 2 meters
Thickly-bedded	60 cm - 2 meters
Medium-bedded	200 mm - 60 cm
Thinly-bedded	60 - 200 mm
Very thinly-bedded	20 - 60 mm
Closely-foliated	6 - 20 mm
Very closely-foliated	less than 6 mm

Joint or Fracture Spacing

Very widely-spaced	more than 2 meters
Widely-spaced	60 cm - 2 meters
Moderately widely-spaced	200 mm - 60 cm
Closely-spaced	60 - 200 mm
Very closely-spaced	20 - 60 mm
Extremely closely-spaced	less than 20 mm

Hardness

Soft	can be dug by hand and crushed by fingers
Moderately hard	friable, can be gouged deeply with knife and will crumble readily under light hammer blows

Hard	knife scratch leaves dust trace, will withstand a few hammer blows before breaking
Very Hard	scratched with knife with difficulty, difficult to break with hammer blows

Weathering

Highly weathered	abundant fractures coated with oxides, carbonates, sulphates, mud, etc., thorough discoloration, rock disintegration, mineral decomposition
Moderately weathered	some fracture coating, moderate or localized discoloration, little to no affect on cementation, slight mineral decomposition
Slightly weathered	a few stained fractures, slight discoloration, little or no affect on cementation, no mineral decomposition
Fresh	unaffected by weathering agents, no appreciable change with depth.

4.0 SWIFT CREEK LANDSLIDE DATA

4.1 Ancient Landslide History

A short discussion of the geologic history is helpful for a clearer understanding of the setting and attendant problems associated with the ancient (pre-historic) Swift Creek landslide. The following is judged to be a reasonable reconstruction of past geologic events that contributed instability to the Swift Creek project area.

4.11 Geologic Background. During pre-Tertiary time, peridotite and dunite, that is now highly serpentinized, was intruded into a complex of older sedimentary rocks. The area was subjected to erosion that exposed the surface of the serpentinite. This surface was subjected to intense tropical weathering. In the process of rock decay, lateritic clayey residual masses accumulated in the upper parts of the weathered serpentinite surface. According to Moen (1962):

> "the dark-green serpentinite grades upward into a grayish-green clay.....above this is a grayish-brown, massive claystone. The lateritic clay zone that overlies the serpentinite does not exceed 8 feet....the claystone has a maximum thickness of 35 feet."

Tertiary continental sedimentary rocks (cobble conglomerates) were deposited on this clayey serpentinite surface. Field mapping confirms that the lateritic clay contact is at least 5 to 8 feet thick.

The massive meta-sedimentary (graywacke) rock of Mesozoic age, appears to have been thrust eastward, and overlies the younger serpentinite. Thrust faulting, near the head of Swift Creek landslide, is suggested by a thick fault gouge zone between the graywacke and serpentinite, and an intensely sheared zone, perhaps 100 feet thick, at the serpentinite contact. The age of this thrusting is probably middle Eocene.

The latest deformation, and westward tilting of these rocks, occurred during uparching of the Cascade Mountains in the Pliocene Epoch. The west flank of Sumas Mountain was then subjected to glaciation. Westward flowing streams incised steep-walled canyons into the smoothly carved surface left by glacial action.

4.12 Ancient Landsliding. Sometime after Fraser Glaciation ±10,000 years before present (ybp), the Swift Creek landslide debris probably moved downslope, en masse, to approximately the position observed today. This interpretation is based on the highly disturbed condition of the slide debris, and topographic expression; i.e., a large bowl-shaped depression upslope (east) of the present slide limits strongly suggested the ancient slide mass once occupied this "pull-a-way" area. Apparently the ancient slide debris was temporarily restrained by resistant conglomerate cliffs. The conglomerate cliffs form a constriction in the Swift Creek drainage course at the toe of the slide. This constriction is locally referred to as the "narrows".

4.13 Causes of Ancient Landsliding. The ancient landsliding appears to be directly related to the aforementioned geologic conditions (i.e., a westerly sloping lateritic clay contact, weak altered serpentinite, and an intensely sheared thrust fault zone) working in concert with a wet climate which cut deep drainage courses. The Swift Creek drainage courses removed support by eroding along the flanks and toe of the landslide. Earthquakes could have been a contributing factor, breaking loose the weak saturated, mass from the underlying clay contact. All, or a combination, of these geologic processes permitted the slide complex to move downslope into the void created by erosion of the peripheral slide debris at the "narrows". The ancient Swift Creek landslide was temporarily stabilized by the restraining conglomerate cliffs, until recently.

4.2 History of Modern Landslide Reactivation

4.21 Continuing Geologic Processes. Subsequent to the ancient sliding, ±10,000 ybp, erosion has continued to the present. Constant removal of lateral and downslope support in conjunction with weak, incompetent rocks and increased saturation are the most important factors in reactivating the ancient landslide. Judging from the earliest available aerial photographs and the age of secondary growth, the reactivation appears to have started at least 35 ybp, and probably earlier.

4.22 Landslide Mechanisms. The modern landslide mass is a very complex assemblage of several blocks of landslide mechanisms. These mechanisms are enlarging the landslide by sequential failure of adjoining blocks of ground, as depicted on Drawing No. 2 and No. 4. These mechanisms are: (1) rotational slump blocks, (2) debris flows, (3) planar block glides and (4) slump-earthflows. The following is a description of these mechanisms based on detailed geologic mapping of the slide mass.

1. Rotational slump blocks - characterized by head scarps or sharp topographic breaks up to 60 feet in height. The ground surface immediately downslope from the scarps is inclined into the hillside so that the timber is tilted upslope. The remaining surface of the slump blocks are relatively undisturbed except for the toe where an irregular, slightly hummocky surface shows a convex slope in profile.

2. Debris flows - exhibit the most irregular, disturbed surfaces. A distinct head scarp is generally absent and the material appears to have flowed in a viscous manner downslope. Trees are tilted in a random fashion and the surface is quite broken and erodes easily. In the debris flow at the toe of the landslide mass, accumulations of erosional debris and water produce a spongy surface that is dangerous to cross on foot. Over-steepened slopes with loose saturated debris, create unstable slopes with numerous open cracks and crevasses that are subject to continuous downslope creep movement.

3. Planar block glide - consists of conglomerate near the toe of the slide and has large, (10 to 25 feet wide, 300 feet long, 75 feet deep) crevasses and tension cracks that are oblique to the longitudinal axis of the main slide. Underlying the resistant conglomerate slab is a sheared, loose debris of serpentinite.

4. Slump-earthflows - comprise the majority of the active landslide mass. These are characterized by a narrow head that widens in a fan-shape so the toe is nearly four times as wide as the head. The surfaces of the slump-earthflows are irregular, slightly hummocky, and display numerous random, discontinuous surface cracks and trees tilted in every direction. The toe has longitudinal tension cracks throughout an oversteepened, bulbous slope.

4.23 Rate of Landslide Movement.

4.231 General. Various independent landslide blocks in the Swift Creek landslide are migrating slowly westward. These landslide blocks are continuously creeping downslope at differing rates judging from the relative age of vegetation growing over tension cracks and scarps. The estimated relative age of growth, on several landslide scarps, is presented on Drawing No. 2. Movement of the debris flows has been continuous since at least 1940. The southern block appears to have moved sometime before 1940, but has been relatively stable until approximately 10 ybp. Movement of the other three mechanisms (planar block, slump block and slump-earthflow) appears to be sporadic. The rate of movement probably increases in direct response to above average annual rainfall. The eastern and southern part of the slide is underlain, and bordered, by extensive ancient landslide debris that appears marginally stable based on scarps that are judged to be less than 10 years old.

4.232 Chronology of Movement. The most actively moving area is the downslope half of the active slide mass. Recent removal of support, by erosion, in this area has caused a "domino-effect" of increased slide activity in the upslope half of the slide mass. The chronology of this movement is graphically demonstrated on Figure No. 2 - Chronology of Landslide Movement, as judged from geologic mapping and interpretation of aerial photographs taken in 1940, 1955, 1966 and 1975.

This chronology strongly suggests that further eastward encroachment of the active slide, into the currently stable ancient landslide limits, is a distinct possibility.

4.233 Postulated Rate of Movement. In order to estimate the time frame it may take before the active landslide debris encroaches into the ancient slide debris, some rough calculations can be made. For instance, the head scarps of the slump-earthflows, in the upslope half of the main slide, are quite distant from the slump-earthflow masses; suggesting 300 feet of downslope movement in the past 10 years or so. Loosely translated, the upslope half of the main slide could be creeping downhill on the order of 30 feet per year. Taken one step further, if this