LANDSLIDE HAZARDS

IN

THE DALLES, WASCO COUNTY, OREGON

by

MICHAEL HUGH SHOLIN

A RESEARCH PAPER

submitted to

THE DEPARTMENT OF GEOGRAPHY

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1982

Directed by
Dr. C. L. Rosenfeld
<table>
<thead>
<tr>
<th>CONTENTS</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Figures</td>
<td>iii</td>
</tr>
<tr>
<td>List of Tables</td>
<td>iii</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>iv</td>
</tr>
<tr>
<td>Abstract</td>
<td>1</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>The Study Area</td>
<td>2</td>
</tr>
<tr>
<td>Location</td>
<td>2</td>
</tr>
<tr>
<td>Climate</td>
<td>4</td>
</tr>
<tr>
<td>Land Use</td>
<td>4</td>
</tr>
<tr>
<td>Previous Investigations</td>
<td>6</td>
</tr>
<tr>
<td>General Geology of The Dalles and Vicinity</td>
<td>6</td>
</tr>
<tr>
<td>Landslides</td>
<td>7</td>
</tr>
<tr>
<td>Geologic Setting</td>
<td>8</td>
</tr>
<tr>
<td>Rock Units and Structure</td>
<td>8</td>
</tr>
<tr>
<td>Landslides in the Chenowith Formation</td>
<td>10</td>
</tr>
<tr>
<td>The Dalles Landslide Area</td>
<td>13</td>
</tr>
<tr>
<td>Location and Extent</td>
<td>13</td>
</tr>
<tr>
<td>Classification of Movement</td>
<td>17</td>
</tr>
<tr>
<td>Movement of The Dalles Landslides</td>
<td>18</td>
</tr>
<tr>
<td>Conditions Leading to Slope Movement in The Dalles</td>
<td>20</td>
</tr>
<tr>
<td>Factors Which Contribute to Increased Shear Stress</td>
<td>21</td>
</tr>
<tr>
<td>Removal of Lateral Support</td>
<td>21</td>
</tr>
<tr>
<td>Surcharge</td>
<td>21</td>
</tr>
<tr>
<td>Transitory Earth Stresses</td>
<td>22</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>--------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Regional Tilting</td>
<td>24</td>
</tr>
<tr>
<td>Removal of Underlying Support</td>
<td>24</td>
</tr>
<tr>
<td>Factors Which Contribute to Low or Reduced Shear Strength</td>
<td>24</td>
</tr>
<tr>
<td>Composition of Rock or Overburden</td>
<td>24</td>
</tr>
<tr>
<td>Gross Structure and Slope Geometry</td>
<td>24</td>
</tr>
<tr>
<td>Changes in Intergranular Forces Due to Water Content and Pressure in Pores and Fractures</td>
<td>25</td>
</tr>
<tr>
<td>Social Aspects of Slope Movement in The Dalles</td>
<td>27</td>
</tr>
<tr>
<td>Hazard to Life</td>
<td>27</td>
</tr>
<tr>
<td>Hazard to Property and Costs of Damage</td>
<td>27</td>
</tr>
<tr>
<td>Response to Landslide Hazard in The Dalles</td>
<td>28</td>
</tr>
<tr>
<td>Conclusions</td>
<td>31</td>
</tr>
<tr>
<td>Footnotes</td>
<td>33</td>
</tr>
<tr>
<td>Appendix 1</td>
<td>44</td>
</tr>
<tr>
<td>Appendix 2</td>
<td>45</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Fig. 1. Location of The Dalles, Oregon. 3
Fig. 2. Climograph of The Dalles. 5
Fig. 3. Annual precipitation, The Dalles, 1895-1981. 5
Fig. 4. Geology of The Dalles and Vicinity. 12
Fig. 5. The Dalles landslide area according to previous investigators. 15
Fig. 6. Features of The Dalles landslide area. (In Pocket)
Fig. 7. Inclinometer readings of slope movements at The Dalles. 20
Fig. 8. Slope orientation of landslides in the Chenowith formation. 27

LIST OF TABLES

Table 1. Historic earthquakes affecting The Dalles, Oregon. 24
ACKNOWLEDGMENTS

Many individuals and groups have assisted in the preparation of this report. I would like to thank my advisors, Charles Rosenfeld and Philip Jackson, both of the Department of Geography, Oregon State University. Thanks are also due to Ron Bailey, Josephine County Planning Department; Donald Nichols, Chief, Engineering Geology Branch, U.S. Geological Survey; William Kockelman, Earth Science Applications Program, U.S. Geological Survey; Harold Haake, Acting Manager, Northern Wasco County Public Utility District; F. Beach Leighton, President, Leighton and Associates, Inc.; Will Auren, Field Operations Engineer, Northwest Natural Gas Company; Ed Taylor, STRAAM Engineers; R.C. Newcomb, consulting geologist; and to the individuals at The Dalles Public Works, The Dalles School District, The Dalles Public Library, Shannon and Wilson, Inc., The Dalles City Planning Office, and the Photogrammetry Section, U.S. Army Corps of Engineers, Portland District.

Special thanks go to John Beaulieu, Oregon Department of Geology and Mineral Industries, for initial encouragement.

The manuscript was typed by Cheryl McLean, whom I also thank.
ABSTRACT: Human activity has led to the reactivation of portions of a Pleistocene landslide complex in The Dalles, Oregon. Slope movements are in rocks of the Chenowith formation: agglomerate, conglomerate, tuff breccia, sandstone, and siltstone. Slope movements occur in at least two distinct areas in The Dalles. At one, the shear surface is defined by the contact between the Chenowith formation and the underlying Columbia River Basalt. Data from inclinometer readings at the other area fail to reveal a well-defined shear surface. Slope movements in The Dalles cause tens of thousands of dollars worth of damage annually and may present a threat to human safety. So far there has been little organized response to this hazard.

INTRODUCTION

Landslides represent a common and diverse set of geomorphic processes. The presence of landslides in areas of human activity often results in a hazard to life and property. Human activities themselves frequently initiate slope movements or reactivate previously stabilized landslides. In The Dalles, Oregon, urbanization has led to the reactivation of a Pleistocene landslide in the Chenowith formation. Ground displacement appears to have
accelerated in recent years, causing extensive property damage and posing a possible threat to human safety. This investigation examines the geologic setting of landslides in The Dalles, as well as the conditions which led to reactivation of slope movement there. Human responses to the landslide hazard in The Dalles are also examined.

THE STUDY AREA

Location

The Dalles is a community of approximately 11,000 located on the Columbia River in northern Wasco County, Oregon (see Fig. 1). To the west, the Columbia River flows through a canyon of basalt cliffs (The Columbia River Gorge). To the east lies the Deschutes-Umatilla Plateau where youthful streams have carved steep canyons in the rolling plateau. Elevations in The Dalles range from 24 meters at the Columbia River to over 180 meters at the southernmost portions. The climb, however, is not gradual, but is broken by a series of scarps.

Drainage is accomplished by three small streams which feed directly into the Columbia River. Threemile Creek is at the eastern edge of The Dalles, Mill Creek at the west edge. The Dalles draws some of its municipal water supply from Mill Creek. The intermittent Dry Hollow, centrally located between and roughly parallel to Threemile Creek and Mill Creek, enters The Dalles immediately adjacent to an active landslide. As it crosses the city line, it is routed through a series of culverts and ditches.
Fig. 1. Location of The Dalles, Oregon.
and flows below the ground surface for much of the remainder of its course. Although Dry Hollow lacks water for much of the year, infrequent flash floods remain a hazard due in part to the inability of culverts to contain high flows.1

Climate

Climate in The Dalles is characterized by warm, dry summers and cool, moist winters (see Fig. 2). The average annual precipitation is about 330 mm (see Fig. 3), with over 90 percent falling from October to March.2 The Dalles lies in the rainshadow of the Cascade Mountains; mean annual precipitation increases dramatically towards the west. The runoff of local creeks reflects the low precipitation of the area: the Threemile Creek drainage basin (5.25 ha) has a mean annual runoff of only 81.3 mm.3 Mean monthly temperatures at The Dalles range from 1.2°C in January to 22.8°C in July.4 These extremes of temperature are modified by marine air moving up the Columbia River Gorge. Occasional extremely low temperatures at The Dalles result from the invasion of cold continental air masses. Very hot temperatures result from stagnant high pressure cells over the inland areas.5

Land Use

Most of the area presently affected by hazardous mass movement in The Dalles is characterized by urban residential land uses, mainly single-family dwellings, but also several churches, a junior high school, and a municipal reservoir. Portions of the
Fig. 2. Climograph of The Dalles (°C and mm).

Fig. 3. Annual precipitation, The Dalles, 1895-1981 (mm).
No data for 1912, 1913, 1967, and 1975. Source: N.O.A.A.,
Climatological Data (Asheville, NC: National Climate Center).
area remain as open space, namely the steep and rocky slopes along Scenic Drive and elsewhere. Immediately south of The Dalles are several irrigated orchards.

The presently inactive landslides in the southeastern portion of The Dalles are also characterized by single family residential land use, as well as a hospital and other structures. Land parcels tend to be larger here than in the active landslide area.

PREVIOUS INVESTIGATIONS

General Geology of The Dalles and Vicinity

The first detailed geologic work in The Dalles and vicinity was carried out by A. M. Piper. Although his major purpose was to describe groundwater resources, large landslides near The Dalles were mentioned briefly, although with no indication that any were active. The presence of active landslides within the city of The Dalles was not mentioned probably because movement had not yet commenced.

Recent publications describing the geology of The Dalles region are dominated by those of R. C. Newcomb. Again, these reports are concerned mainly with groundwater resources, but together they make up the most comprehensive work on the regional geology to date. Mass movements are treated only very briefly in these reports.

A recent work by J.D. Beaulieu is unique in that it emphasizes geologic hazards. Included in this report is a set of geologic
hazards maps. This report also contains the first published reference to hazardous mass movement in The Dalles.

**Landslides**

Numerous mass wasting processes are evident along the Columbia River and adjacent areas. Most of the geologists who have studied the region briefly mention landslides in their reports. Commonly mentioned are landslides in the Eagle Creek formation. This formation consists of boulder conglomerate, sandstone, shale, tuff breccia, and debris flow or slurry deposits. Slides are common along the Columbia River east of The Dalles where the Eagle Creek formation underlies the Columbia River Basalt. The legendary Bridge of the Gods is an old landslide of the Eagle Creek formation. Slides of this formation have been a recurring nuisance to the railroads and highways along the Columbia River.

Another investigation looked at landslides along reservoirs in the upper Columbia River Valley of Washington. Included in this report are statistical analyses of various landslide parameters in order to achieve the ability to predict the probability of future landsliding. Landslides in this region occur in unconsolidated or semi-consolidated Pleistocene terrace deposits.

Other studies describe slides in the Columbia River Basalt. Such slides occur along bedding planes or clay-shale interbeds.

The slope movements in The Dalles occur in the Chenowith formation of the Dalles group. Slides in this group are also
present in the Antelope-Ashwood area, southeast of The Dalles. Large landslides near The Dalles are mentioned in several geologic reports. Although some evidence of slope instability within The Dalles existed at the time R. C. Newcomb conducted field work for his report (1962-1964), areas showing only minor or in place slumping were not mapped as landslides.

Bedrock slumps and slides are a characteristic feature of many other regions. Some areas in Czechoslovakia are subject to landslides where basalt flows cap tuffs, agglomerates, and clays. Landslides on the Palos Verdes Peninsula, California occur primarily in the Portuguese Tuff, a member of the Monterey formation overlying a basalt layer. Other areas of slow bedrock slumping include the Fort Randall Reservoir, South Dakota; Grand Mesa, Colorado; and the Atlantic Highlands of New Jersey. The relevant rock types are, respectively, bentonite interbeds in the Pierre Shale, basalt underlain by claystone, and clayey marine sands containing 15 to 70 percent glauconite.

GEOLOGIC SETTING

Rock Units and Structure

In late Miocene times (10 to 16 million years ago), the Columbia River Basalt extruded through a series of dikes. The molten rock spread westward at approximately 18 to 56 km per hour. The Columbia River Basalt is made up of several distinct flows, averaging 24 m in thickness; the total thickness in the study area is about 610 m. The Columbia River Basalt consists of hard,
dark basalt which exhibits jointing on both micro (15 to 30 cm) and regional (several kilometers) scales. The rock is generally unweathered, but is disintegrated to a depth of 6 m in places below its contact with the overlying Chenowith formation.\textsuperscript{23} A slight erosional unconformity exists between the Columbia River Basalt and the Dalles Group.\textsuperscript{24} Because the erosional relief on the basalt beneath the Dalles Group is small, little time probably elapsed between the end of the basalt outpourings and the deposition of the Dalles beds. Deposition of the Dalles Group during the Pliocene forced the Columbia River's course northward from its previous channel in the Mount Hood area.\textsuperscript{25} Between 12,000 and 32,000 years ago, the Missoula Flood removed much of the Chenowith formation near The Dalles, leaving steep, high meander scars in its wake.\textsuperscript{26} It is the instability of these slopes which has resulted in landslides in The Dalles.

The Chenowith formation consists of two parts. An andesitic debris fan of hard gray agglomerate, coarse boulder agglomerate, tuff breccia, and ash flows originated from sources to the southwest.\textsuperscript{27} These rocks pass northward and eastward into water laid fan deposits, including tuff, sandstone, and siltstone. These two facies interfinger in a broad zone near the lower part of Fifteenmile Creek in the vicinity of The Dalles.\textsuperscript{28} The total stratigraphic thickness of the Chenowith formation is about 150 m at The Dalles.\textsuperscript{29}

No other bedrock units are exposed in the study area. In places along the Columbia River and in the tributary valleys lie
Quaternary alluvial deposits. In some of the upland areas near The Dalles, often associated with the large slumps there, are thick talus deposits (see Fig. 4).

During the Cascadian orogeny of late Pliocene to middle Pleistocene, a broad downwarping of the earth's crust occurred in the vicinity of The Dalles. The axis of this major syncline, called the Dalles-Umatilla syncline, defines the course of Mill Creek, immediately west of The Dalles, then bends eastward and extends for 255 km to about 24 km east of Pendleton, Oregon. The Columbia River flows parallel to, but slightly north of, the synclinal axis in this region. At The Dalles, however, the Columbia River makes a southward bend and follows the synclinal axis for a short portion of its course. The folding which produced the Dalles-Umatilla syncline is responsible for the gentle northward dips of the Columbia River Basalt and of the Chenowith formation in the study area. The dip of the Chenowith formation near The Dalles is 1 to 2 degrees.

Landslides in the Chenowith Formation

Large bedrock slumps and slides, not uncommon in the Chenowith formation, were recognized by early investigators. E. T. Hodge ascribed the abundance of slides to the poor consolidation of the rock of the Dalles beds. He also noted that debris from the Chenowith formation "slide[s] and slump[s] continuously" into the adjacent canyons, implying that some landslide movement occurred at the time of his investigation, though perhaps
Fig. 4. Geology of The Dalles and Vicinity.

Explanation:

\[ \text{Qu} \]
Quat. unconsolidated deposits

\[ \text{Ql} \]
Quat. landslides

\[ \text{Ot} \]
Cascades fm.

\[ \text{Tpc} \]
Chenowith fm.

\[ \text{Tcr} \]
Columbia River Basalt

\[ \text{Fault} \]

\[ \text{Major fold} \]

only on a small scale.

A. M. Piper described (but did not map) landslides in the Chenowith formation. He mentions the large slumps east of The Dalles (in secs. 11 and 12, T.1 N., R.13 E.) and others along the north-facing bluffs south of the Columbia River. The instability of slopes in the Chenowith formation is exacerbated by the parallel dip and topographic slope. Slides in the Chenowith formation are frequently located at its contact with the underlying Columbia River Basalt.

The Government Flat landslide, the largest bedrock slide in the area, displaces at least 5 km\(^2\) of material 100 m or more (see Fig. 4). This landslide, probably mid-Pleistocene in age, is no longer active; however, secondary slides which have developed within it presently show signs of movement.

The bedrock slides in the Chenowith formation are probably superficial features which do not effect strata below the level of the streams; however, many of the headscarsps are so nearly straight as to resemble fault scarps and movement along secondary faults, which is otherwise not indicated at the surface, may be partly responsible for the slumping. Only a few of the mapped landslides in the area are adjacent to a mapped fault, though some landslides in the Columbia River Basalt are atop or adjacent to one or two mapped faults. Any given landslide, however, probably owes its origin to a combination of factors. Due to the great variability in the degree of consolidation and
induration of the Chenowith formation, it is difficult to "predict" where a landslide "should" occur based only on structural or topographic factors. 37

THE DALLES LANDSLIDE AREA

Location and Extent

Precise boundaries of all the slope movements in The Dalles are not known. Many landslide features are obscured by urbanization, although some are brought out by urbanization. The first published map showing an active landslide area in The Dalles, based primarily on damage to structures, shows the slide to be about 1130 m wide and 335 m long. 38 This landslide is centered on Kelly Avenue, and extends from Riverview Street on the east to Washington Street on the west (see Fig. 5). The headscarp is most pronounced along Scenic Drive. Damage to sidewalks and streets south of Scenic Drive may also be landslide related (see Fig. 6). The slide appears to be gradually increasing in size by extension of the headscarp upslope.

Hazardous mass movement in The Dalles is not limited to the Kelly Avenue-Scenic Drive area. Geotechnical investigations at a proposed reservoir site (adjacent to the existing reservoir at Fourteenth and Union Streets) proved the occurrence of slope movement. 39 While movement here is not as rapid as at the Kelly Avenue landslide, landslide-related damage is visible on the old reservoir (see Fig. 6).

In another geotechnical investigation, an area encompassing
Fig. 5. The Dalles landslide area according to previous investigations. Top, inner area: "active landslide" (J.D. Beaulieu, op. cit., footnote 1, fig. 39); outer area: "landslide" (Shannon and Wilson, op. cit., footnote 40). Bottom, cross section (Shannon and Wilson, op. cit., footnote 40).
both the reservoir and the Kelly Avenue slides is mapped as a single landslide.\textsuperscript{40} This map is based solely on visual observation of the landscape; no subsurface work was carried out (see Fig. 5). Much of the area of this mapped landslide shows no evidence of recent movement, although street and sidewalk damage indicates the likelihood of movement in portions of this area. This entire area is an ancient landslide complex, portions of which have been (or could be) reactivated. The reactivation of an ancient landslide is not an uncommon occurrence. Often a dormant slide will begin to show signs of settlement and gradual consolidation. Renewed movement may take the form of accelerated creep, or a new shear surface may develop, usually an extension or modification of the original shear surface.\textsuperscript{41}

The problems of delimiting slope movements in The Dalles are not restricted to those of areal extent. The depth of movement varies as well. The term "landslide" implies that a mass of rock overburden moves, or "slides," along a more or less well-defined shear surface.\textsuperscript{42} The rate of movement with depth should be relatively constant until the shear surface is reached, where movement should decrease to near zero. This is indeed the case at the portion of the Kelly Avenue slide under The Dalles Junior High School. According to data from inclinometer readings (see Fig. 7), horizontal movement at this site (elevation 92 m) proceeds at a more or less constant rate until a depth of 5 to 6 m, at which point movement rapidly approaches zero.\textsuperscript{43} At the
Fig. 7. Inclinometer readings of slope movements at The Dalles. (a)-(c), The Dalles Junior High School. First reading, 1/29/81; last reading, 1/15/82. (d), The Dalles Reservoir. First reading, 12/7/81; last reading, 1/15/82; negligible east-west movement of this site. Source: Shannon and Wilson, op. cit., footnotes 39, 40.
reservoir site (elevation 104 m), located about 1340 m WNW of the Jr. High School, horizontal movement decreases gradually and regularly with depth, and no well-defined shear surface is apparent. The movement is near zero at the bottom of the inclinometer casing, 15.5 m below ground level; however, the material at this level is still considered to be landslide debris. This "landslide" may actually be deep-seated and relatively rapid creep, but deeper inclinometer readings might disprove this hypothesis. Nonetheless, no sharp boundary can be drawn between creeping and sliding movements, despite their many differences.

Classification of Movement

Since C. F. S. Sharpe's classic work on landslides, many others have devised landslide classification schemes. D. J. Varnes reviews most of these classifications, and offers a new classification, basically an update of his previous work. According to this classification, the Kelly Avenue landslide is a compound slope movement with a more or less curved failure surface at the top grading into a more or less planar surface at the foot. The rotational slumping at the top is evidenced by the downward and outward movement there (see Fig. 6). This apparent slumping may simply result from material moving into the space left as the slide mass moves downslope along a planar shear surface. At the toe of the slide, the presence of curbs which have separated from adjacent sidewalks suggests translational movement along the contact between the Chenowith formation and the
underlying Columbia River Basalt.

Mass movement elsewhere in The Dalles, such as at the reservoir site, can not be classified due to the lack of conclusive information. It is possible that movement here is similar to that at the Kelly Avenue slide.

Movement of The Dalles Landslides

A crude measure of the rate of movement of a landslide is obtained by comparing the total movement at some point to the time estimated to have elapsed since movement began. This technique is not applicable to the situation at The Dalles for two reasons. First, the time when movement began is unknown, and may vary from place to place in The Dalles. Movement has occurred for at least 10 to 20 years, and may have commenced much earlier. Second, the rate of movement appears to have accelerated in recent years. Examination of dated photographs indicates that vertical movement at the headscarp along Scenic Drive has been about 0.5 m since 1977.

At The Dalles Junior High School, inclinometer readings indicate surface movement of up to 5.8 cm during the period 12/16/80 to 1/15/82. Movement here is slightly more rapid immediately above the shear surface. Perhaps the weight of the slide material itself "shoves" the material at the shear surface along. Such an explanation is analogous to the "hydraulic ram" mechanism proposed for some landslides along the Columbia River Gorge, but on a much smaller scale. On the other hand, continued movement of this
slide may show this to be a transitory feature.

At The Dalles Reservoir, slope movement has been measured for only a short period of time. From 12/7/81 to 1/15/82, 1.2 cm of movement occurred at the ground surface (see Fig. 7). Although damage to the existing concrete reservoir indicates that ground displacement has occurred over the years, it is doubtful whether movement of greater than 1.2 cm per year has occurred for very long. Likewise, should this rate of movement persist or increase, the life of the reservoir may be shortened. Movement decreases almost linearly with depth and is close to zero at 15.5 m. There exists a slight change in the amount of movement at a depth of about 12 m; with successive readings of the inclinometer, this may prove to be the location of a shear surface, either within or at the bottom of the landslide.

Little seasonality is apparent with landslide movement at the Junior High School. Movements of from 0.6 to 1.2 cm are seen in both wet and dry months; at one of the inclinometers, the greatest recorded movement occurred during the month of June. The lack of seasonality may be due to the constant influx of water from upslope irrigation of lawns by residents of the area. Such additions of water in a semi-arid region such as The Dalles may equal or exceed the average annual rainfall. At the reservoir, the record of slope movement is not sufficiently long to make conclusions as to the seasonality of movement. The recorded movement of 1.2 cm in 5 weeks occurred after a very wet
winter--one of the wettest on record (see Fig. 2).

CONDITIONS LEADING TO SLOPE MOVEMENTS IN THE DALLES

Natural rockslide and avalanche mechanics are almost necessarily vague. This should not be surprising for almost all natural movements of geologic materials including the slides of the present day come to our attention after the fact. We often know little more than where the slide material was originally, when it moved, and where it came to rest. We are left to infer from often scanty evidence what 'caused' the slide, how 'fast' it moved, and so on.54

Although slope movements in The Dalles are current, and not necessarily "natural," some of the specifics of the mechanics of movement are speculative. It would be unwise to attribute slope movements in The Dalles to only a single "cause;" more likely the interaction of many factors led to slope movement there. Nevertheless, the factors deserve individual treatment for a fuller understanding of the landslide hazard in The Dalles. Perhaps with further investigations, particularly more subsurface work, the explanations offered here can be modified.

The organization of this section follows that of Varnes, who in turn drew from most of the classic references on landslide mechanics.55 The initiation of slope movement is discussed in terms of (a) factors which contribute to increased shear stress,
Factors Which Contribute to Increased Shear Stress

**Removal of Lateral Support.** As already noted, the Pleistocene Missoula Flood left steep slopes in the Chenowith formation. When the waters receded, these slopes were left standing at high elevations. Similar events have left unstable slopes in the abandoned meander scars of the Ohre River in Czechoslovakia.\(^{56}\) Rapid downcutting of smaller streams near The Dalles also produced steep, unstable slopes.

In addition to the removal of lateral support by natural agencies, the actions of humans may have also played a role. From studying aerial photographs, it has been determined that grading occurred between 1948 and 1956 along Scenic Drive and just north of East Sixteenth Place in the vicinity of a landslide headscarp. This grading may be partially responsible for migration of the landslide upslope, as is evident by street and sidewalk damage on Eighteenth and Nineteenth Streets, south of Scenic Drive. In addition, removal of lateral support may cause the rocks in the headscarp area to loosen, thus facilitating the penetration of water.

**Surcharge.** Surcharge refers to added weight atop or within the ground. In addition to increasing stress, surcharge also increases pore water pressure in the rocks below. Two surface features possibly relevant to slope movements in The Dalles are the weight of thick talus deposits, and the weight of buildings,
roads, and so on. With a landslide the size of the Kelly Avenue-Scenic Drive landslide, it is perhaps unlikely whether the combined weight of these features is significant.

Within the slide itself, the weight of water can be a significant factor. Sources of water include precipitation, natural ground water flow, irrigation of lawns, and leaks from broken sewer and water lines. Far more significant than its weight is the pore pressure exerted by water in the subsurface. This topic will be discussed in a later section.

Percolating water exerts on soil particles a pressure known as seepage pressure, which increases as a function of the seepage velocity. Ground water seepage no longer occurs from the slope face at The Dalles landslide areas, but subsurface sewer and water lines intercept some springs. The significance of seepage pressure here is debatable. The volume of water flowing from these springs, even when issued freely from the slope face (i.e. pre-urbanization), was relatively small.

Transitory Earth Stresses. Earthquakes are known to have triggered many landslides. Due to the relative lack of seismicity in the study area, this factor may not be significant; however, a possibility does exist that seismic events have influenced slope stability here (see Table 1). It has been recommended that structural designs involving mass movements incorporate a consideration of possible seismic acceleration.

Transitory earth stresses may also result from blasting and
## TABLE 1. HISTORIC EARTHQUAKES AFFECTING THE DALLES, OREGON.

<table>
<thead>
<tr>
<th>Date</th>
<th>Mercalli Intensity at The Dalles</th>
<th>Epicenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov. 24, 1866</td>
<td>IV</td>
<td>The Dalles</td>
</tr>
<tr>
<td>Dec., 1866</td>
<td>III</td>
<td>The Dalles</td>
</tr>
<tr>
<td>Feb. 29, 1892</td>
<td>IV</td>
<td>The Dalles</td>
</tr>
<tr>
<td>July 15, 1936</td>
<td>IV</td>
<td>Milton-Freewater, OR</td>
</tr>
<tr>
<td>Apr. 14, 1949</td>
<td>V</td>
<td>Olympia, WA</td>
</tr>
</tbody>
</table>

Source: J.D. Beaulieu, op. cit., footnote 1, pp. 56-57.
the movement of heavy machinery.\textsuperscript{61}

\textbf{Regional Tilting.} Such a slowly acting change obviously cannot "trigger" a landslide, but it may exacerbate other factors which increase slope instability. This apparently was the case at the disastrous rockslide which occurred at Mount Rossberg, Switzerland, in 1806.\textsuperscript{62} The movements of the earth's crust which produced the Dalles-Umatilla syncline left the Chenowith formation inclined toward the slope face.

\textbf{Removal of Underlying Support.} The "hydraulic ram" mechanism purportedly operating at places in the Columbia River Gorge may be operating at a much smaller scale within portions of The Dalles landslide area, as noted earlier.\textsuperscript{63}

\textbf{Factors Which Contribute to Low or Reduced Shear Strength}

\textbf{Composition of Rock or Overburden.} Much of the material of the Chenowith formation is inherently weak. Tuff, for example, is known as a rock type prone to landsliding.\textsuperscript{64} The agglomerate is only weakly cemented in places, and sloughs and slides into stream valleys.\textsuperscript{65} Clasts from the Chenowith formation often are weak enough to break by hand.

\textbf{Gross Structure and Slope Geometry.} Besides the inclination of the Chenowith beds towards a free face, discontinuities within this formation contribute to reduced shear strength. Minor planes of weakness and brecciated zones increase the instability of the Chenowith formation. A cemented stratum at the top of a conglomerate layer underlies another apparently unstable zone.\textsuperscript{66}
The contact between the Chenowith formation and the Columbia River Basalt also provides a plane of weakness. In addition, sandstone beds of the Chenowith formation are cross bedded and the foreset beds dip northward or northeastward.67

Slope orientation has been shown to be a significant factor in landslide distribution at some locations.68 The north facing slope on which The Dalles landslide area is located experiences reduced evaporation of surface and subsurface waters, and is thus more likely to become saturated, other factors being equal. Many landslides in the region occur on slopes with some northward exposure; however, this may be due more to factors such as the dip of the beds or the location of meander scars and their associated steep slopes (see Fig. 8).

Changes in Intergranular Forces Due to Water Content and Pressure in Pores and Fractures. An increase in pore water pressure represents the major contributing factor in the initiation of a landslide.69 Sources of water influx were mentioned previously. Water influx from broken sewer and water lines initiates a vicious circle: ground water displacement ruptures the pipes, and water from the broken pipes enters the slide mass, thus maintaining or increasing instability.

Another possible source of excess water is irrigation of orchards south of The Dalles. Many residents believe this to be the major factor in initiating slope movement.70 All of the nearby orchards are irrigated. From 1965 to 1974, 46 cm were applied
Fig. 8. Slope orientation of landslides in the Chenowith formation. (a), Shallow slides; (b), deep slides. Source: J.D. Beaulieu, op. cit., footnote 1; R.C. Newcomb, op. cit., footnote 8 (1969).
each year; this increased to 61 cm in 1975. However, when one examines the topography of the area, one is drawn to the conclusion that probably little irrigation water enters the immediate area of slope movements in The Dalles.

Probably more important than agricultural irrigation is water added to slopes from within The Dalles. The possibility that increased rainfall in recent years has aggravated movement also can not be disregarded (see Fig. 3). The increase of water pressure is further aggravated by the diversion or stoppage of springs which once issued freely from the contact between the Chenowith formation and the Columbia River Basalt. Spring blockage by asphalt is analogous to the freezing of a slope face which consequently increases pore water pressure. It is precisely in the area of the Kelly Avenue-Scenic Drive landslide where most of these springs once issued. Old maps show some of these springs. Thus even if the actual amount of water added to the slope had not increased, the increase in water pressure would likely have decreased stability there anyway.

Water pressure not water flow defines the stability of slopes.

In rock strata of differing permeability, a shear surface will tend to develop along the contact between the less permeable rock and the underlying more permeable rock. This results from the uplift force created by water in the more permeable layer. The most permeable layer of the Chenowith formation often occurs at or just above its base. Cores removed from the Junior High School
site indicate that the material immediately above the shear surface tends to be slightly more permeable than the material below; however, this relationship is not apparent from all cores. Other factors, such as minor planes of weakness or very thin clay seams, may determine the shear surface. 78

SOCIAL ASPECTS OF SLOPE MOVEMENT IN THE DALLES

Hazard to Life

Despite the fact that slope movements in The Dalles proceed at a very slow rate, the threat to human safety is not insignificant. After years of continual restoration, one of the buildings at The Dalles Junior High School will most likely be abandoned in the near future. 79 It is feared that the roof of this building may collapse due to lack of support as the main supporting beams slowly move away from each other. A church in the landslide area is also being abandoned for similar reasons. Whether or not any private residences are structurally unsound and thus a threat to the safety of their inhabitants is unknown.

Hazard to Property and Costs of Damage

Damage to both public and private property in The Dalles landslide area is quite extensive. Residents have spent thousands of dollars to save their homes from ruin, often employing somewhat elaborate methods. Similarly, large amounts of public funds are used to repair roads, sewers, and sidewalks, as well as the reservoir and the junior high school. As an example, total 1980-81
expenditures by The Dalles Public Works for repairs to streets, sewers, and water lines in the Kelly Avenue-Scenic Drive area amounted to over $80,000, and repairs in this area are an annual occurrence. Such costs are likely to increase in the future as landslide movement continues.

Certain indirect costs are also attributable to slope movements in The Dalles. These include the loss of tax revenue on houses devalued because of their location on the landslide, the loss of public and private funds which would have been spent elsewhere had landslide damage not occurred, the reduced real estate values and thus the loss of the homeowners' investments, and possibly an increase in utility rates resulting from future damage to utility structures.

Response to Landslide Hazard in The Dalles

Response takes several forms, depending on the group involved. Responses are seen in the actions of private firms, individual residents, and governmental bodies.

An example of a response by a private firm are the precautionary measures taken in the design and installation of natural gas lines in The Dalles. These include slip joints to allow for ground movement, and placement of right angle laterals at locations of maximum ground stability. In addition, leakage surveys in the area have increased and an emergency shut down procedure has been developed.
Homeowners' responses mainly take the form of structural and other improvements on their homes. Several homeowners have reinforced their structures in some way or another. Other "improvements" include the removal of the house from its foundation and the digging of a large pit perpendicular to the direction of ground movement. Homeowners are also constantly faced with repairing cracked walls, driveways, and fences. The long term efficacy of any of these improvements is doubtful.

The ultimate homeowner response is to move from the area. Judging from the profusion of "For Sale" signs on the homes in the landslide area, this is an option apparently chosen by many. Selling a house obviously damaged by ground displacements may prove to be difficult; however, landowners in The Dalles are not required by law to inform potential buyers of the landslide hazard.83

Various techniques are employed by government bodies to regulate land use in hazardous areas.84 Thus far, little action of this type has occurred in The Dalles. There does exist an ordinance which states that the City is not responsible for damage to newly built or improved structures in the "area of the City which is subject to earth movement." Property owners and developers must sign a waiver to this effect.85 This area is delimited on a map and corresponds to the active landslide described in an earlier report.86 In addition, certain restrictions to development within the designated landslide area are noted in
The Dalles comprehensive plan. 87

A technique not as of yet attempted in The Dalles is the removal or conversion of structures to a use less vulnerable to landslide damage. The feasibility of such an action depends "on the value of the structures, whether they can be successfully reinforced, their potential for triggering landslides, and the level of citizen concern." 88 This may be accomplished by public acquisition, abatement of a public nuisance, or nonconforming use provisions in zoning ordinances. 89 In a recent survey of residents of The Dalles, 55 percent surveyed favored the idea of purchasing buildings as they become extensively damaged for the construction of a park. 90

CONCLUSIONS

Landslide damage in The Dalles will most likely increase in the future. The threat to human safety can not be ignored. Due to the large area affected by slope movements in The Dalles and the fact that these areas are fully urbanized, stabilization of movement using engineering works is unfeasible. Response to the landslide hazard in other ways is necessary.

The presence of ancient landslides in the newly urbanizing area east of The Dalles deserves special attention. Springs along the Chenowith formation-Columbia River Basalt contact, present in old aerial photographs, seem to have disappeared. Some landslide related damage already exists downslope from these ancient slumps (see Fig. 6). When developing this area in the
future, the alteration of the natural hydrologic regime should be scrutinized to avoid possible reactivation of landslide movement on a larger scale.
FOOTNOTES


4NOAA, op. cit., footnote 2, p. 849.


7Piper, op. cit., footnote 6, pp. 138-139.


9 J.D. Beaulieu, op. cit., footnote 1.


11 J.D. Beaulieu, op. cit., footnote 1, p. 10.

12 F.O. Jones, D.R. Embody, and W.L. Peterson, Landslides Along the Columbia River Valley Northeastern Washington, Professional Paper


14 The Chenowith formation is a unit of the Dalles Group. The entire Dalles Group had previously been mapped as the Dalles formation, but is now recognized to consist of five distinct deposits. For further information, see S.M. Farooqui, J.D. Beaulieu, R.C. Bunker, D.E. Stensland, and R.E. Thoms, "Dalles Group: Neogene Formations Overlying the Columbia River Basalt Group in North-Central Oregon," *Oregon Geology*, Vol. 43 (1981), pp. 131-140.


17 R.C. Newcomb, personal communication, April 21, 1982.


22. J.D. Beaulieu, op. cit., footnote 1, p. 10.


25. J.D. Beaulieu, op. cit., footnote 1, p. 15.

26. J.D. Beaulieu, op. cit., footnote 1, p. 17.

33 A.M. Piper, op. cit., footnote 6, pp. 138-139.
34 J.D. Beaulieu, op. cit., footnote 1, p. 30.
35 A.M. Piper, op. cit., footnote 6, pp. 138-139.
38 J.D. Beaulieu, op. cit., footnote 1, fig. 39.
42 D.J. Varnes, "Slope Movement Types and Processes," in R.L. Schuster and R.J. Krizek, eds., Landslides Analysis and Control,

43 Shannon and Wilson, Inc., op. cit., footnote 40.


47 C.F.S. Sharpe, op. cit., footnote 42.


49 R.C. Newcomb, personal communication, April 21, 1982.

50 Shannon and Wilson, Inc., op. cit., footnote 40.


56 Zaruba and Menc1, op. cit., footnote 18, p. 183.


59 A.M. Piper, op. cit., footnote 6, p. 147. He estimated discharge from these springs to range from less than 1 to 5 gallons per minute (0.004 to 0.019 m³/min).

60 J.D. Beaulieu, op. cit., footnote 1, p. 58.

61 D.J. Varnes, op. cit., footnote 42, p. 27.

62 K. Terzaghi, op. cit., footnote 46, p. 94.

63 A.C. Waters, op. cit., footnote 51, p. 151.


67 A.M. Piper, op. cit., footnote 6, p. 124.


71 The Dalles Irrigation District, personal communication, May 5, 1982.


73 A.M. Piper, op. cit., footnote 6, p. 147.

74 P.W. Marr, Map of The Dalles, Wasco County, Oregon (The Dalles: The Dalles City Engineer, 1921). Scale, 1 inch = 400 feet.


77 A.M. Piper, op. cit., footnote 6, p. 146.

78 The presence of a slight slope break is also a factor in determining landslide location. See Fig. 5 and D.P. Krynine and W.R. Judd, Principles of Engineering Geology and Geotechnics (New York: McGraw-Hill Book Company, Inc., 1957), p. 645.

In some areas of Oregon, the presence of active landslides does not affect land values; however, this does not seem to be the case at The Dalles. See T.E. Hartsook, "Factors Affecting Rural Land Value in the Central Coastal Zone of Oregon," unpublished doctoral dissertation, Oregon State University, 1978.


A facsimile of the waiver is reproduced in Appendix 1.

J.D. Beaulieu, op. cit., footnote 1, p. 65. There is considerable evidence that landslide movement occurs outside this area. See Fig. 6.
87 The Dalles City Planning, *The Dalles Urban Planning Unit Comprehensive Plan* (The Dalles: The Dalles City Planning Department, 1979), p. 79. See Appendix 2 for these restrictions.


90 The Dalles City Planning, *The Dalles, Oregon, A Survey of Peoples Attitudes and Desires* (The Dalles: The Dalles City Planning Department, 1975), unpaged.
APPENDIX 1

Facsimile of waiver to be signed by property owner when obtaining a permit to build or remodel.

EXHIBIT TO BUILDING PERMIT NO. _____

DATED ________________

Property Description:

Wasco County Map No. ______________, Tract No. ____________
Addition ________________________, Block _____ Lot _____
or Deed Volume No. ________________, Page ________________

The owner and/or contractor understand that the property for which the attached building permit is issued, may be located within an area of the City which is subject to earth movement. In consideration of the issuance of the permit, the owner and/or contractor agree that the City shall not be liable for any damage, loss, expense, cost or inconvenience which either or both of them may suffer if there is an earth movement which affects the structure for which this permit is issued, or which affects the property on which it is designated to be located. The owner and/or contractor further understand and agree that the issuance of this permit and the acceptance of it by them shall operate as a disclaimer of all responsibility and liability on the part of the City for any of the foregoing.

________________________, 19__

Owner

Contractor
APPENDIX 2


Development in areas designated as active slide areas shall:

A. Require an engineering report that describes the problems and offers site specific alternatives necessary to solve those problems. Condition for site approval may include closer control of water infiltration, use of innovative foundation designs for new structures. After on site inspection and upon recommendation by the City Engineer or the City Planner construction may be prohibited in certain active landslide areas.

B. Provide adequate facilities for all runoff.

C. Avoid plugging springs.
Fig. 6. Features of The Dalles landslide area.
EXPLANATION:

- Damage to streets, sidewalks, structures, etc. probably due to slope movements.

- Overthrusting or bulging at toe of landslide.

- Small rockslide or talus cone.

- Areas where ground movement has caused separation of curb from street, street from sidewalk, etc. Perpendicular to direction of movement.

- Areas where backward rotation or in-place slumping is evident.

- Small slump.

- Areas of hummocky topography.

- Scarp showing signs of recent movement.

- Presently inactive scarp; sometimes grading laterally into a hill.

- Contact between Columbia River Basalt (north) and Chenowith formation.