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A preliminary investigation of the lithological characteristics of the Troutdale Formation in portions of the Camas, Sandy, Washougal, and Bridal Veil quadrangles

David Lee Cole
Portland State University

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Title: A Preliminary Investigation of the Lithological
        Characteristics of the Troutdale Formation in
        Portions of the Camas, Sandy, Washougal, and
        Bridal Veil Quadrangles.

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

Robert O. Van Atta, Chairman

Marvin H. Beeson

Paul E. Hammond

The study area encompasses a region of about 80
square kilometers, centered about Corbett, Oregon. Sieve
analyses suggest that the Troutdale Formation is composed
of a conglomerate, a coarse-grained sandstone, and a
siltstone lithofacies. Measured sections data show that
56 to 60 percent of the Troutdale Formation's exposures
are composed of the conglomerate lithofacies. The coarse-
grained sandstone lithofacies makes up 34 to 38 percent,
while the siltstone lithofacies makes up only 4 to 8
percent. Pebble count data show that the representation

of basalt varies from 69 to 100 percent, with an average
of 85 percent, while quartzite varies from 0 to 25 percent,
with an average of 9 percent. Geochemical data show
that at least one formal member and two informal members
of the Columbia River Basalt Group (Frenchman Springs,
Grande Ronde High Mg, and Grande Ronde Low Mg) compose
part of the detritus. The geochemical data also show
that rocks of the Boring Lavas or similar lavas are
intercalated with the Troutdale Formation, high in the
section. Grain mount petrographic data show that volcanic
rock fragments are the dominant component in the coarse
sand fraction of the Troutdale Formation. Many of the
volcanic rock fragments contain brown glass with an index
of refraction of 1.583 $\pm$ 0.001, which indicates a mafic
composition (silica content of 50 $\pm$ 1 percent). The
representation of volcanic rock fragments varies from
29 to 98 percent, with an average of 75 percent. Sedimen-
tary rock fragments, such as chert, vary from 0 to 17
percent, with an average of 5 percent. Biotite ranges
from 0 to 12 percent, with an average of 2 percent.
Two-thirds of the samples which contain sedimentary rock
fragments also contain biotite. Orthopyroxene varies
from 0 to 18 percent, with an average of 5 percent.
The samples with the three greatest amounts of orthopyroxene
do not contain sedimentary rock fragments or biotite.

The average bearing of paleocurrent measurements
is 285°. A rose diagram representation of the paleocurrent

data shows that the largest class interval (25 percent
of all measurements) is centered about a bearing of 285°.
Other class intervals indicate the presence of anabranches
and/or distributaries, flowing toward the northwest and
southwest.

A bed relief index value of 12.1, along with the
granulometric and measured sections data, strongly suggest
that the Troutdale Formation was deposited in the braided-
stream depositional environment. The pebble count,
geochemical, and grain mount data show that most of the
clastic material of the Troutdale Formation was proximally
derived. Distal sources also contributed significant
amounts of the detritus.

A PRELIMINARY INVESTIGATION OF THE LITHOLOGICAL

CHARACTERISTICS OF THE TROUTDALE FORMATION IN

PORTIONS OF THE CAMAS, SANDY, WASHOUGAL,

AND BRIDAL VEIL QUADRANGLES

by

DAVID LEE COLE

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The members of the Committee approve the thesis
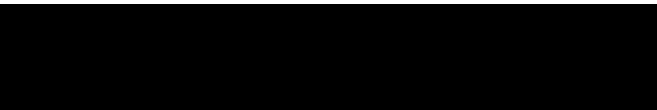of David Lee Cole presented November 3, 1982.

Robert O. Van Atta, Chairman

Marvin H. Beeson

Paul E. Hammond

APPROVED:

Gilbert T. Benson, Head, Department of Earth Sciences

Stanley E. Rauch, Dean of Graduate Studies and Research

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INTRODUCTION

Cataclysmic geologic events, such as vast outpouring
of lava, stretching for hundreds of kilometers, and
gigantic floods which backed up water into the Willamette
Valley, after rushing westward from as far away as Montana,
are part of the geologic history of the Pacific Northwest.
Studying the geologic record of the Pacific Northwest
is essential to understanding its geologic history.
Part of the geologic record of the Pacific Northwest
is known as the Troutdale Formation.

PURPOSE OF STUDY

In order to gain a better understanding of the
geologic history surrounding the deposition of the Troutdale
Formation, its lithological characteristics were investi-
gated, using various sampling and analyzing methods.
Analysis of the data derived from these methods helps
to answer fundamental questions concerning the sedimentary
rocks of the Troutdale Formation. The fundamental questions
which are addressed include the following: the provenance
of the Troutdale rocks, the development of a representa-
tive composite section of the Troutdale Formation, the
environment within which the sedimentary rocks of the
Troutdale Formation were deposited, and the presence of

granulometric and compositional trends within the Troutdale Formation. Answers to these fundamental questions are important, because they help to unravel the intricate and fascinating geologic history of the Pacific Northwest.

METHODS OF STUDY

In order to understand the evolution of knowledge concerning the geologic history of the Troutdale Formation, a summary of previous work is presented. Following the summary of previous work, is a section on the local geologic setting. After this, the methods used in the present report, and the data derived from these methods, are presented and discussed. Next, a section on depositional environment is presented. Finally, a summary of the report is given.

In order of their presentation, the sampling and analyzing methods used in this report are: sieve analyses, measurement and description of vertical sections, a bed relief index calculation, pebble counts, instrumental neutron activation analysis of basalt clasts, grain mount petrography, and attitude measurements of primary sedimentary structures for paleocurrent analyses.

LOCATION AND EXTENT OF STUDY AREA

The study area (Figure 1) encompasses a region of about 80 square kilometers (30 square miles), and is located in portions of the following quadrangles:

Camas (7.5 min.), Sandy (7.5 min.), Washougal (7.5 min.), and Bridal Veil (15 min.).

PREVIOUS WORK

In 1916, Williams published a report on the geology of the Columbia River Gorge, as interpreted from the Columbia River Highway. He referred to the Troutdale gravels as part of the Satsop Formation, which Bretz (1917) dealt with, shortly thereafter. Williams states that lavas are interbedded with the Troutdale Formation at Crown Point.

In 1917, Bretz correlated the deposits of the present-day Troutdale Formation with the Satsop Formation of Oregon and Washington. In his section dealing with the Satsop Formation in the Columbia Valley west of the Cascade Range, Bretz said that quartzite is a common constituent of these deposits up to a distance of 16 kilometers south of the Columbia River, but has not been found more than 24 kilometers from the master stream. He found no upward slope of the Satsop surface toward the Coast Range on the western side of the Willamette Valley. On this side, Bretz said that the Formation terminates against hills of older basalt.

Allen (1932) described the Troutdale Formation's composition, based on 23 measured sections, and seven arbitrary physical divisions, which are: (1) boulder beds with sizes above 15 cm, (2) boulder beds with sizes
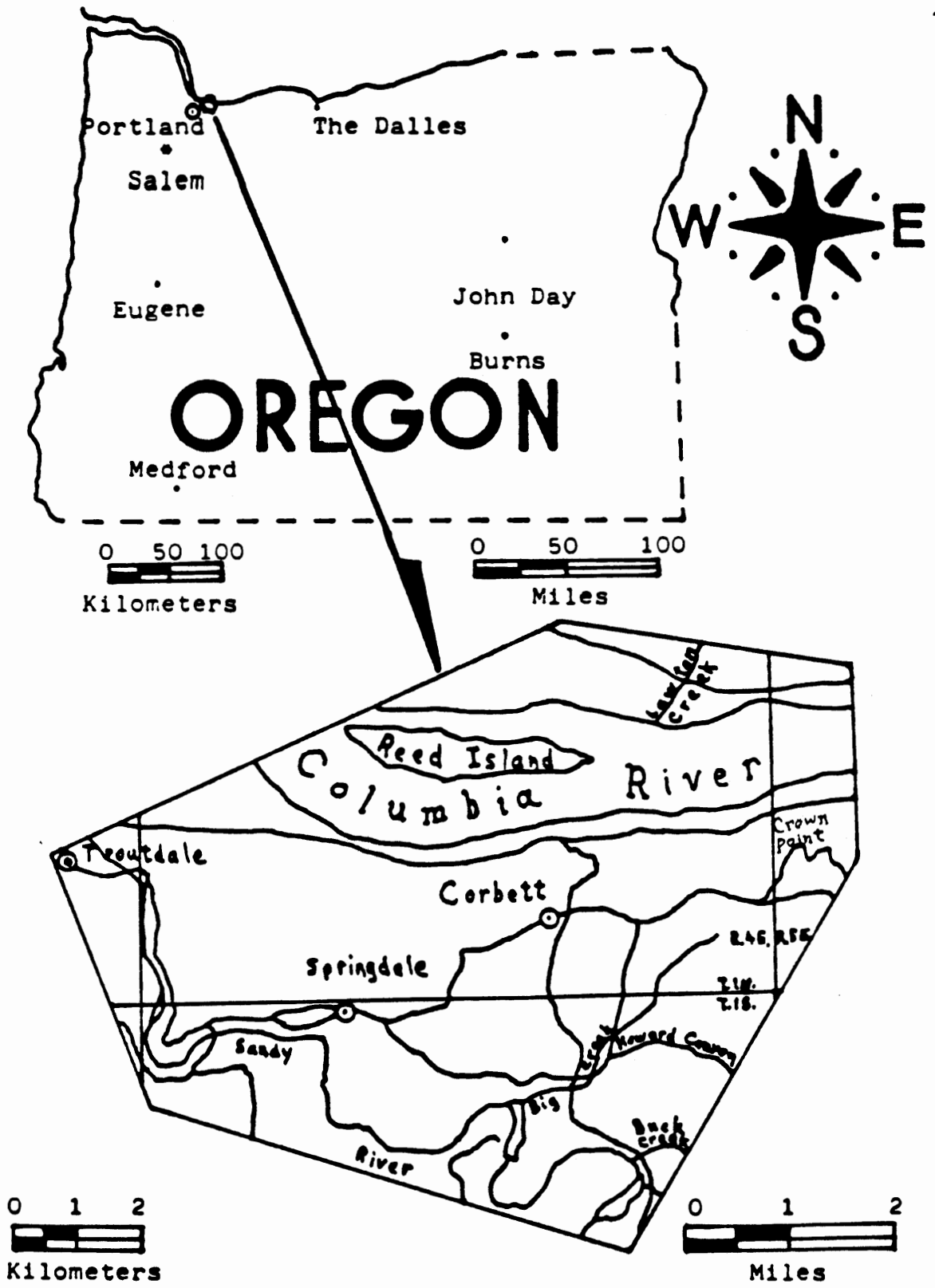
Figure 1. Location of study area.

between 8 and 15 cm, (3) pebble beds with sizes below 8 cm, (4) beds of pebbly coarse-grained sandstone, (5) beds of coarse-grained sandstone, (6) beds of tuffaceous sandstone, and (7) beds of clay or fine tuff. He found that coarse-grained sandstone composes at least a third of the Troutdale Formation, with the small pebble beds coming next with about one fourth. Allen also found from channel sampling the gravel at 50 localities that the average composition of that portion of the conglomerate beds whose clasts are smaller than 8 cm in length is 40 percent basalt, 30 percent quartzite, and 30 percent andesite, in a matrix of coarse-grained sandstone.

In 1938, Hodge named and described the Troutdale Formation, some five years after he informally introduced the term. His study dealt with only that part of the Troutdale Formation occurring adjacent to the Columbia River Gorge. Hodge found that the overall occurrence of the Troutdale Formation is lens-shaped, with the thickest portion occurring in the Willamette Valley in the vicinity of Portland, Oregon. To the west, the Troutdale Formation thins out against the Portland Hills. Hodge states that much of the crudely-developed bedding in the coarse, poorly sorted sedimentary rocks of the Troutdale Formation results from depositional conditions involving torrential, flood stage river flow. He says that where the bedding of the gravels can be determined, it dips to the south. The work of Trimble (1963), described below, discusses

the attitude of the Troutdale Formation's rocks in greater detail. Hodge noted that non-marine fossil flora are present in the Troutdale Formation, while fresh and salt-water fossil fauna are absent.

In 1942, Treasher published an outcrop geologic map of the Portland, Oregon area. The geology within his map area has since been modified and refined somewhat, but he nevertheless set forth a solid framework, in terms of a base map, from which to proceed with further studies of the area.

As part of their 1944 publication on Pliocene floras of California and Oregon, Chaney, Condit, and Axelrod, reported on a floral collection of 1046 specimens, which were obtained from the basal contact zone of the Troutdale Formation at Buck Creek and Camp Collins. Their report states that these fossil leaves are early Pliocene in age.

In 1952, Lowry and Baldwin published a report on late Cenozoic geology of the lower Columbia River Valley in Oregon and Washington. Their abstract, pertaining to the Troutdale Formation, includes the following information. Erosion-modified, anticlinal highs developed in the rocks of the Columbia River Basalt Group, and the lower part of the Troutdale Formation was deposited in downwarps along the Columbia River, while similar sediments were deposited in tributary valleys. These events probably took place during early Pliocene time. In their section

on Pliocene formations, Lowry and Baldwin state that,
contemporaneous with and interbedded in part with the
Pliocene stream deposits, of which the Troutdale Formation
is a part, are basic volcanic rocks of the Rhododendron,
Boring "agglomerate," "Cascan," and Boring Lavas formations.
The Columbia River, they state, was the medium from which
the Troutdale sands and gravels were deposited, as a result
of a rise in base level which accompanied submergence
in the region in Pliocene time. Furthermore, these workers
state that the total thickness of the Troutdale Formation
may have been nearly 610 meters in the Portland synclinal
basin. These authors state that an angular unconformity
separates the Troutdale sediments from the lavas of the
Columbia River Basalt Group at Crown Point, and that the
sediments here may be younger than those in contact with
the basalt in the deeper portion of the Portland syncline,
farther to the west. Finally, they recognize, as Williams
did, that there is a basalt flow interbedded in the Trout-
dale Formation at Crown Point.

Trimble (1963) separated the lower beds of the
Troutdale Formation, and named them the Sandy River Mudstone.
Trimble said that the distinct difference in lithologic
character and genesis between the Sandy River Mudstone
and the Troutdale Formation is sufficient basis for separat-
ing them. Trimble defined the contact between the Sandy
River Mudstone and the Troutdale Formation as the horizon
where the parallel-bedded siltstone and claystone of the

Sandy River Mudstone meet the lowermost coarse, lenticular sandstone and conglomerate of the Troutdale Formation. Trimble then states that the Sandy River Mudstone underlies the Troutdale Formation, and that the Boring Lavas overlie the Troutdale Formation. Trimble's sedimentologic and petrologic observations, pertaining to the Troutdale Formation, include the following:

(1) The Troutdale Formation is commonly well indurated, and the clayey alteration constitutes the principal cement.

(2) Irregular-lenticular bedding, planar bedding, and cross-bedding are present in the Troutdale Formation.

(3) Cobbly pebble conglomerate appears to constitute the entire Troutdale Formation near the east edge of his map area in Clark County, Washington. These beds are exposed in the valley of Lawton Creek.

(4) The conglomerate is chiefly a poorly stratified pebble conglomerate, which is composed of as much as 30 percent quartzite.

(5) The quartzite pebbles are well rounded.

(6) Locally, as in Sec. 6, T.1 S., R.4 E., the Troutdale deposits contain micaceous, quartzose sandstone.

(7) In the western area of his map, there is micaceous arkosic sandstone.

(8) In the southern part of his map, the sandstone is commonly tuffaceous.

(9) The sandstone is well sorted, and locally contains minor amounts of muscovite and quartz.

(10) In the eastern part of his map, the sandstone is largely a vitric sandstone, composed mostly of sideromelane grains.

(11) Grains in this sandstone are mostly coarse to very coarse sand size, although the sandstone is conglomeratic in places.

(12) Coverings of palagonite and clay surround the unaltered particles in this sandstone, which are of angular, black, fragmental glass.

(13) A layer of stratified fine sandstone, siltstone, and claystone is exposed along the Sandy River in the Camas quadrangle, and this stratum occurs about 30 meters above the Troutdale Formation's base. This is a persistent unit which locally contains leaves. This stratum is also exposed at the north end of the Stark Street Bridge.

(14) The upper contact of the Troutdale Formation is an erosional surface of considerable relief, upon which the Boring Lavas were extruded. Trimble's map also shows that in some areas, where the Boring Lavas are not present, Quaternary sediments are in contact with the Troutdale Formation.

(15) Bedding in the Troutdale Formation is almost horizontal, generally dipping less than 2° to the west or southwest in the eastern part of his map area, to the north or northwest in the southern part of the area, and generally southward in the north-central part of the area.

Howell (1957-1970) contributed field notes and maps which establish a previously undocumented fossil locality. At this locality above and south of Gordon Creek, Howell reports that the contact between the Sandy River Mudstone and the Troutdale Formation is exposed.

In 1975, Beeson, in collaboration with Johnson and Moran, published a report dealing with fault identification in the Portland area. Geochemical data on rocks of the Columbia River Basalt Group and Boring Lavas are contained in their report. The data forms a large part of the basis for the comparison and contrast with the geochemical data which was obtained on the basalt clast samples of the present report.

Beeson and Moran (1979) investigated the stratigraphy of the Columbia River Basalt Group in western Oregon. Necessary to their work was instrumental neutron activation analysis of Columbia River Basalt Group samples. Their geochemical information forms an important part of the basis for the geochemical analyses of the present report.

Anderson (1980) states that quartzite-bearing conglomerate is interbedded between the Pomona and Frenchman Springs members of the Columbia River Basalt Group, approximately 9 kilometers west of Hood River, Oregon.

Tolan (1982) investigated the stratigraphy from Crown Point to Bridal Veil canyon. In the vicinity of Crown Point, Tolan noticed, as have previous workers, that a lava flow is intercalated with the Troutdale Formation.

On the east side of Crown Point, along the old Columbia
River Scenic Highway, the basal contact of the Troutdale
Formation is exposed. Tolan states that the rocks which
underlie the Troutdale Formation at this locality are
basalts of a Priest Rapids intracanyon flow. Tolan also
states that, just east of this contact, the rocks of the
Skamania Volcanic Series, no younger than early Miocene,
are exposed. Furthermore, Tolan reports that rocks of
the Grand Ronde Basalt lie adjacent to these Skamania rocks,
to the east. Tolan said that the Troutdale deposits in
the Bridal Veil canyon show a westward channel direction,
and that at least some of these deposits may be as old as
12 to 14 million years (Tolan, personal communication, 1982).

LOCAL GEOLOGIC SETTING

The oldest rocks exposed in the vicinity of the
study area are basalts of the Skamania Volcanic Series.
These rocks crop out along the old Columbia River scenic
Highway at the eastern base of Crown Point, and are no
younger than early Miocene in age (Tolan, 1982).
Altered basaltic and andesitic volcanic rocks of the Skamania
Volcanic Series are exposed east and north of Prune Hill
(Trimble, 1963). The next oldest rocks are those of the
Columbia River Basalt Group, which are middle Miocene
in age, and are very widespread, occurring as far east
as the Oregon-Idaho border (Swanson and others, 1979).
Several members of three formations of the Columbia River

Basalt Group have been recognized in the vicinity of the study area. The oldest of these rocks in the area are those of the Grand Ronde Basalt, which occur both west and east of Crown Point (Beeson, 1982, personal communication). Next oldest are the rocks of the Frenchman Springs Member of the Wanapum Basalt, which crop out along the Sandy River at the mouth of Buck Creek. The basalts at Crown Point are those of an intracanyon flow of the Priest Rapids Member of the Wanapum Basalt. In the canyon of Bridal Veil Creek, rocks of the Pomona Member of the Saddle Mountains Basalt are exposed (Tolan, 1982).

During the uplift of the Cascade Range, large scale deformation of the rocks of the Columbia River Basalt Group took place, while local tectonism in the Portland area produced such major topographic features as the Tualatin, Chehalem, Cooper, and Bull Mountain anticlinal structures, and the Tualatin Basin (Schlicker and Deacon, 1967). Beeson, Johnson, and Moran (1975) report a complexly folded and faulted zone extending southeastward from, and aligned with the Portland Hills. Beeson and his colleagues (1975) found that major faulting of this zone trends N35W and includes the Portland Hills fault, a major right-lateral fault located along the eastern base of the Portland Hills. Beeson and others (1975) describe the Portland Hills as a complex anticlinal structure consisting of three subparallel folds.

Locally, the upper surface of the Columbia River
Basalt Group became deeply weathered and laterized (Trimble,
1963). Unconformably overlying the Columbia River Basalt
Group and filling the Willamette and Tualatin structural
basins are lacustrine and fluvial sediments of lower Plio-
cene age (Trimble, 1963). These include laterized pebbly
silt, clay, and sand of the Helvetia Formation, the Sandy
River Mudstone and the Troutdale Formation (Schlicker
and Deacon, 1967). The weathered sediments of the Helvetia
Formation directly overlie basalt in the Tualatin Valley
region where the sediments are considered to be correlative
with the Sandy River Mudstone (Schlicker and Deacon, 1967).
The sedimentary rocks of the Sandy River Mudstone and
Troutdale Formation underlie the Portland area to a depth
of about 520 meters (Lowry and Baldwin, 1952), while in
the Tualatin Valley these sediments extend to a depth
of about 460 meters (Schlicker and Deacon, 1967).

Intercalated with and overlying the Troutdale Formation
are rocks of the Boring Lavas, which include basalt flows,
tuff, breccia, cinder, and scoriaceous phases (Williams,
1916, Trimble, 1963). These rocks are prominently exposed
at Mt. Norway, Prune Hill, Crown Point, Chamberlain Hill,
Mt. Scott, Mt. Sylvania, Swede Hill, Mt. Tabor, Ross
Mountain, and in other areas. In contact with the deposits
of the Troutdale Formation and the rocks of the Boring
Lavas are Plio-Pleistocene piedmont and terrace deposits
(Trimble, 1963). These deposits consist of fluvially-derived

gravel, mudflow, and debris-flow materials, and are named, from oldest to youngest, the Walters Hill, Springwater, Gresham, and Estacada Formations (Trimble, 1963). Widespread lacustrine and fluvial deposition occurred in the Willamette, Tualatin, and lower Columbia River valleys in late Quaternary time (Trimble, 1963).

DATA PRESENTATION AND DISCUSSION

The following section presents the data derived
from the various sampling and analyzing methods used in
the present study to investigate the lithological character-
istics of the Troutdale Formation in the study area.
The data forms the basis for discussing answers to the
fundamental questions concerning the sedimentary rocks
of the Troutdale Formation in the study area. In review,
the fundamental questions addressed are as follows: the
provenance of the Troutdale rocks, the development of
a representative composite section of the Troutdale Forma-
tion, the environment within which the sedimentary rocks
of the Troutdale Formation were deposited, and the presence
of granulometric and compositional trends within the
Troutdale Formation.

TROUTDALE LITHOFACIES

Qualitative inspection of outcrops of the Troutdale
Formation in the study area reveals that the Formation
is composed predominantly of conglomerate and coarse-grained
sandstone, with minor amounts of siltstone. All three
of these lithofacies are exposed in the type locality,
along the Sandy River, at the Stark Street Bridge. The
appearances of the lithofacies here are typical of their

appearances throughout the study area. From the Stark Street Bridge locality, a sample of the conglomerate lithofacies, and a sample of the coarse-grained sandstone lithofacies were subjected to sieve analysis. Figure 2 shows the sample localities. Sieve analysis of the siltstone lithofacies was not performed because of the siltstone's fine-grained nature, its limited exposure, and because of the difficulty involved in dissaggregating the rocks.

The histogram of the conglomerate lithofacies sieve analysis sample is shown in Figure 3. The histogram of the coarse-grained sandstone lithofacies is shown in Figure 4. The cumulative size frequency curves for the conglomerate and coarse-grained sandstone lithofacies are shown in Figure 5. Table I summarizes the following parameters which were computed according to the procedures of Folk (1974) for each curve shown in Figure 5: M_Z, σ_I, Sk_I, K_G, where M_Z is the graphic mean, σ_I is the inclusive graphic standard deviation, Sk_I is the inclusive graphic skewness, and K_G is the graphic kurtosis.

TABLE I

SUMMARY OF LITHOFACIES PARAMETERS

Lithofacies	M_Z	σ_I	Sk_I	K_G
Conglomerate	-3.6	2.0	+0.78	1.07
Coarse-grained Sandstone	1.0	0.96	+0.17	0.94
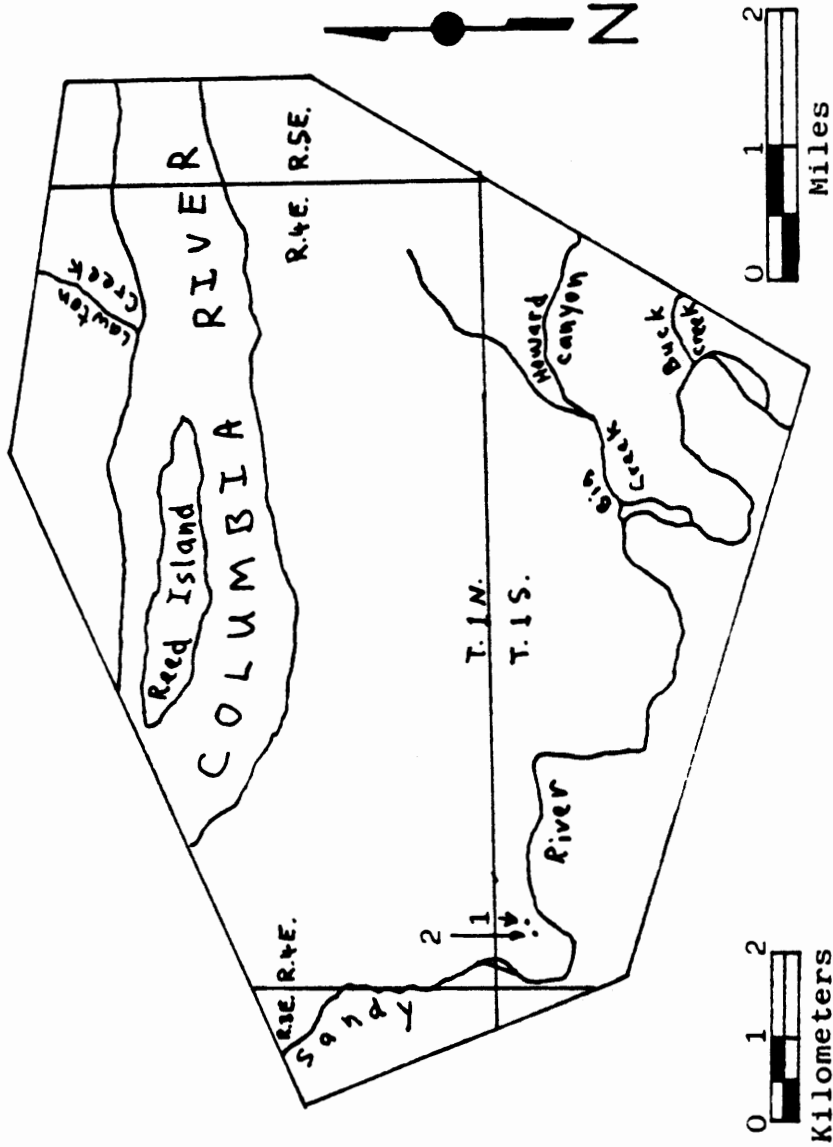
Figure 2. Location of sieve analyses samples.
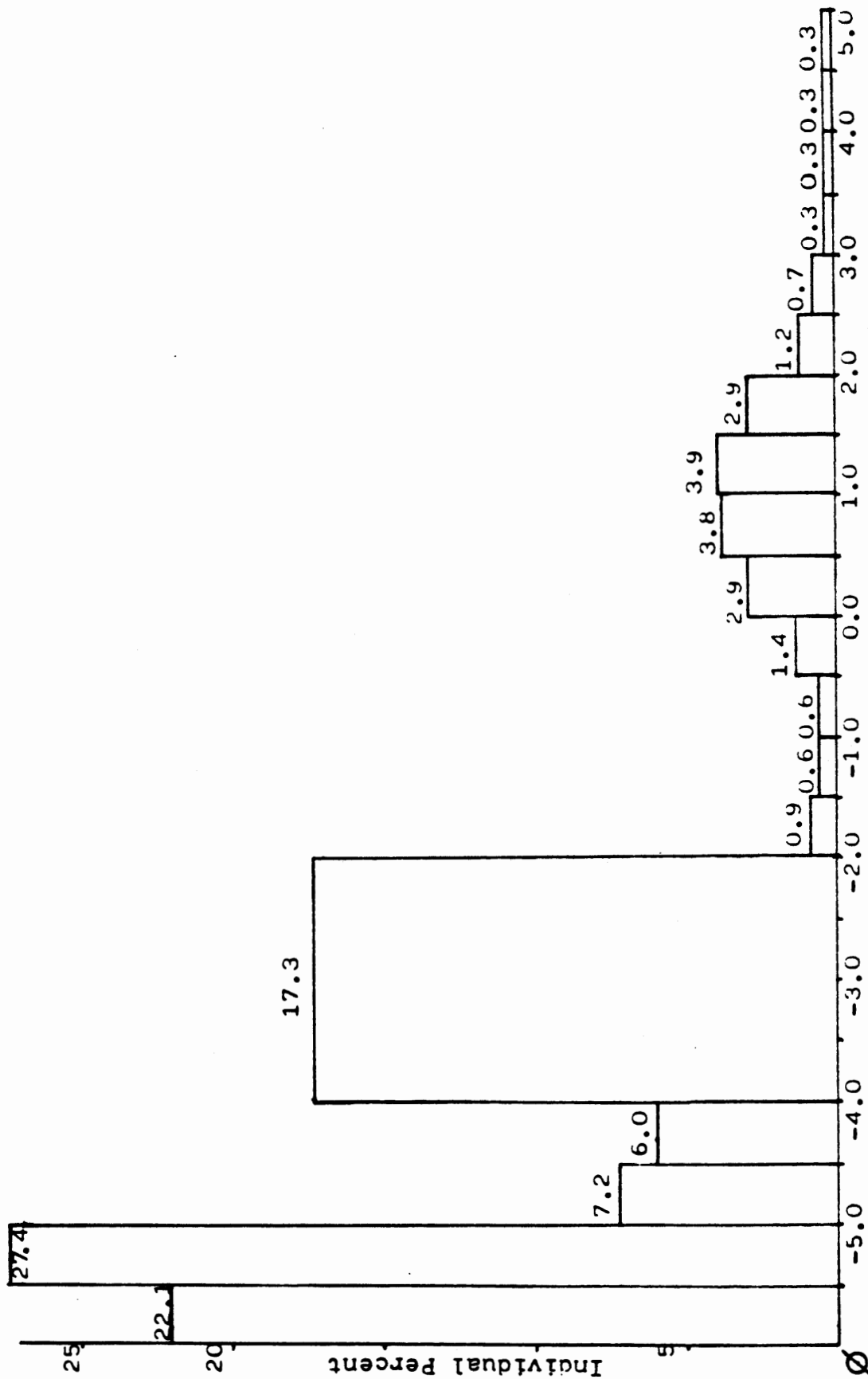
Figure 3. Histogram of conglomerate lithofacies sieve analysis. N=1.

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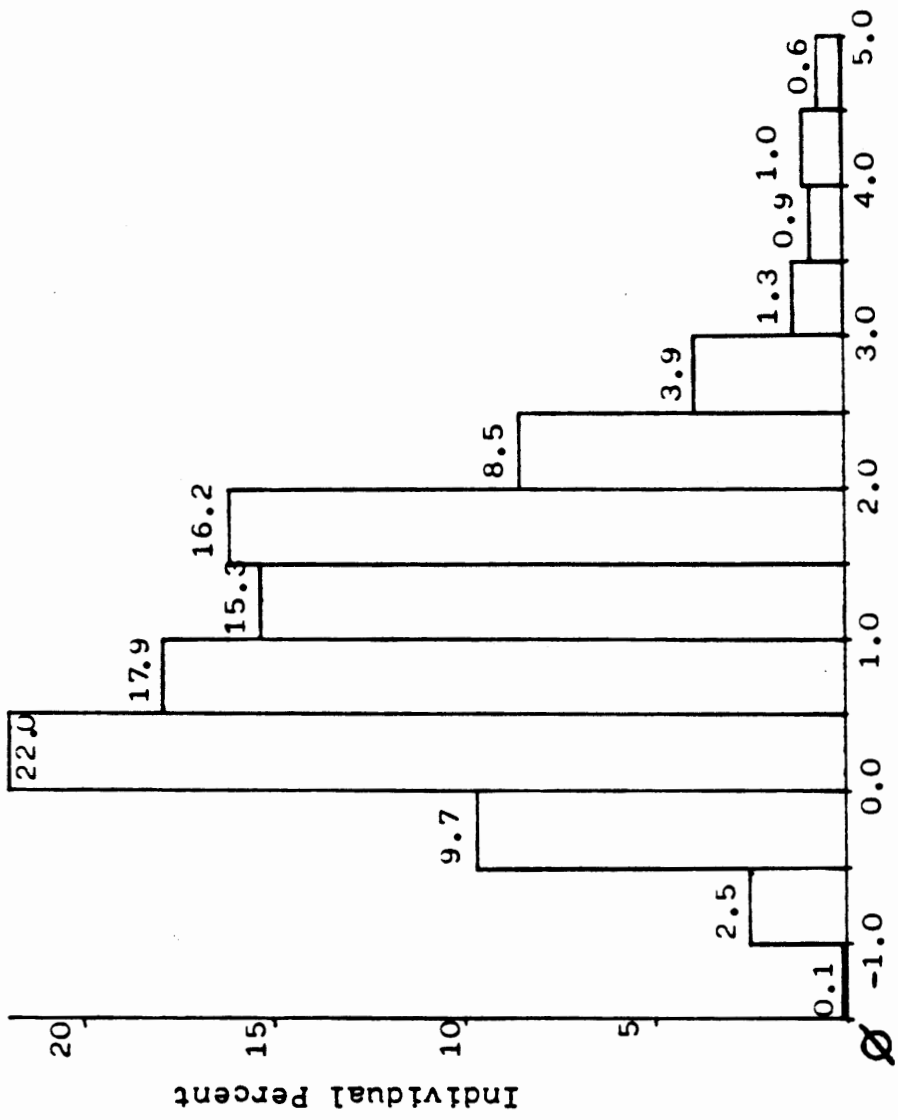
Figure 4. Histogram of coarse-grained sandstone lithofacies sieve analysis. N=1.

LEGEND
⊙— Conglomerate lithofacies.
▲— Coarse-grained sandstone lithofacies.
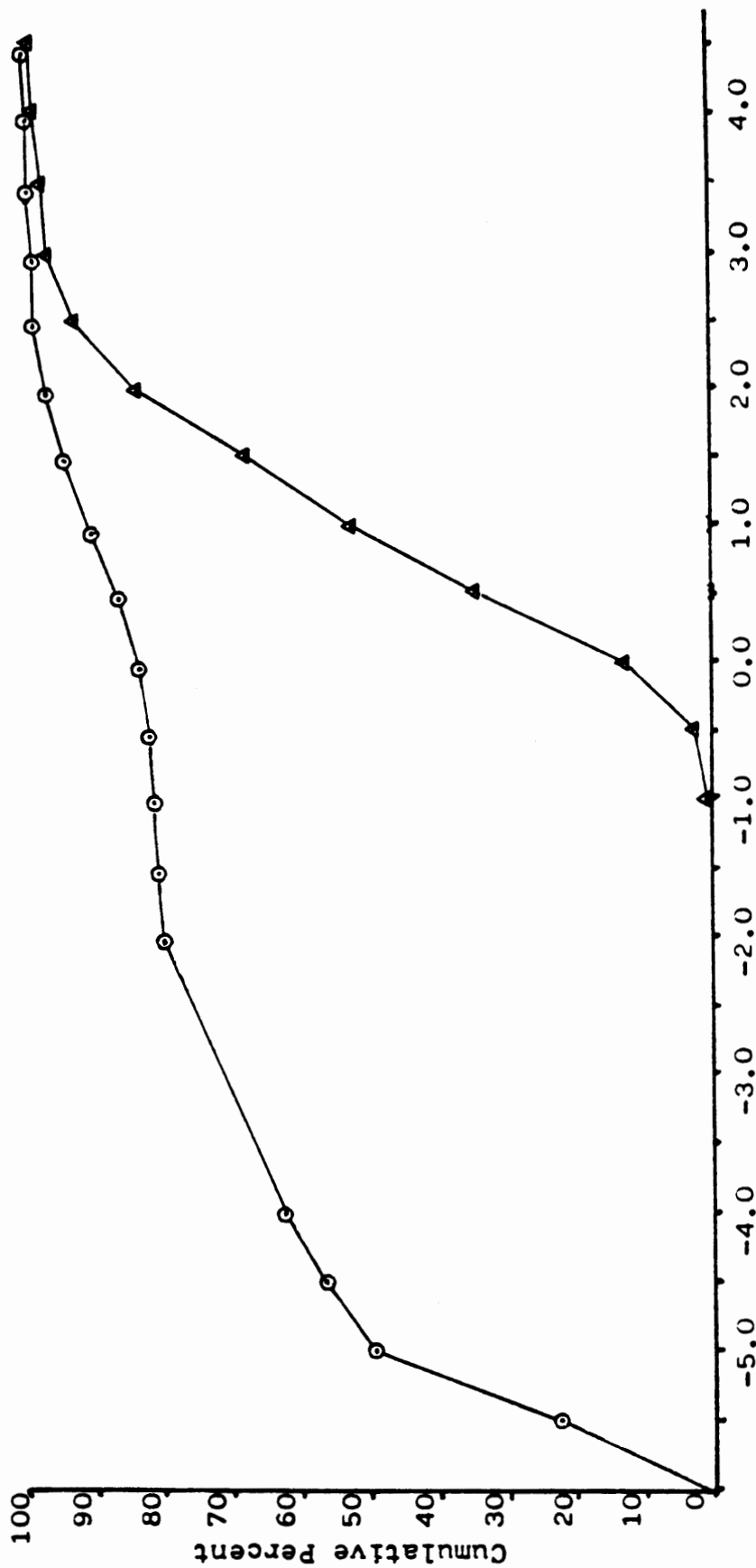
Figure 5. Cumulative size frequency curves of the conglomerate and coarse-grained sandstone lithofacies.

The sieve analyses show that the overall particle
size of the conglomerate lithofacies (-3.6 Ø = 12.1 mm)
is much larger than that of the coarse-grained sandstone
lithofacies (+1.0 Ø = 0.5 mm). From Table I it is apparent
that the Troutdale lithofacies are moderately to poorly
sorted, especially the conglomerate.

In order to facilitate the study of the Troutdale
Formation, it is considered in terms of the lithofacies
mentioned above. In the field, the lithofacies were distin-
guished according to the following criteria.

Conglomerate Lithofacies

The conglomerate lithofacies consists of cemented
gravel, in which the clasts over 2.0 mm in length are
rounded to well rounded. The matrix is composed of angular
to subrounded, fine to very coarse sand. Hydrochloric
acid tests reveal that calcareous cement is not present.
The cement apparently consists of clay minerals (Trimble,
1963). The conglomerate exhibits irregular-lenticular
bedding, planar bedding, and planar cross-bedding. The
volume proportion of gravel is variable, and where the
bulk of the rocks changes from gravel to sand, the conglomer-
ate grades into the coarse-grained sandstone lithofacies.
Conglomerate beds are occasionally found underlying and
overlying beds of both the siltstone lithofacies, and
the coarse-grained sandstone lithofacies.

Coarse-grained Sandstone Lithofacies

The coarse-grained sandstone lithofacies is composed of cemented sand, in which the grains are angular to sub-rounded. Most of the particles are medium to coarse sand (0.25 mm to 0.50 mm). Clay minerals are apparently responsible for the cohesion of the sandstone's particles (Trimble, 1963). The sandstone exhibits planar bedding, planar cross-bedding, and trough cross-bedding. Like the conglomerate, the gravel content of the sandstone is variable, and where the bulk of the rocks changes from sand to gravel, the sandstone grades into the conglomerate lithofacies. Beds of the coarse-grained sandstone litho-facies occasionally overlie and underlie beds of both the conglomerate lithofacies, and the siltstone lithofacies.

Siltstone Lithofacies

The siltstone lithofacies is composed of beds and laminae whose grain sizes range from medium sand to clay (0.50 mm to less than 0.0039 mm). The beds in the siltstone lithofacies exhibit planar bedding, planar cross-bedding, and trough cross-bedding. Fossil fauna of early Pliocene age (Chaney and others, 1944) are present in the siltstone lithofacies. Beds of the conglomerate and coarse-grained sandstone lithofacies are found both overlying and underlying beds of the siltstone lithofacies.

MEASURED SECTIONS

In order to develop a representative composite section of the Troutdale Formation in the study area, ten sections were measured. These sections were chosen because of their accessibility, and because they cover the study area well, considering the lack of laterally continuous exposures in this area. The measured sections data also provide information regarding granulometric trends within the Troutdale Formation.

The locations of the measured sections are shown in Figure 6. Sections 1 and 2 were measured directly, using climbing equipment and a graduated tape. Due to the inaccessible nature of the tops of the other eight sections, as well as the danger of hazardous rockfall, the remainder were measured using a combination of visual inspection and estimation, and topographic map interpretation. The thickness of each of the three lithofacies was measured at each section locality.

The data on the measured sections is given in Table II. Table III lists the section numbers, their top and bottom elevations, and their thicknesses. Figure 7 provides an explanation of the units shown in Figure 8, which is a correlation chart of the ten sections. From Table II, it is apparent that well over half (56 to 60 percent) of the Troutdale Formation's exposures in the study area are composed of the conglomerate
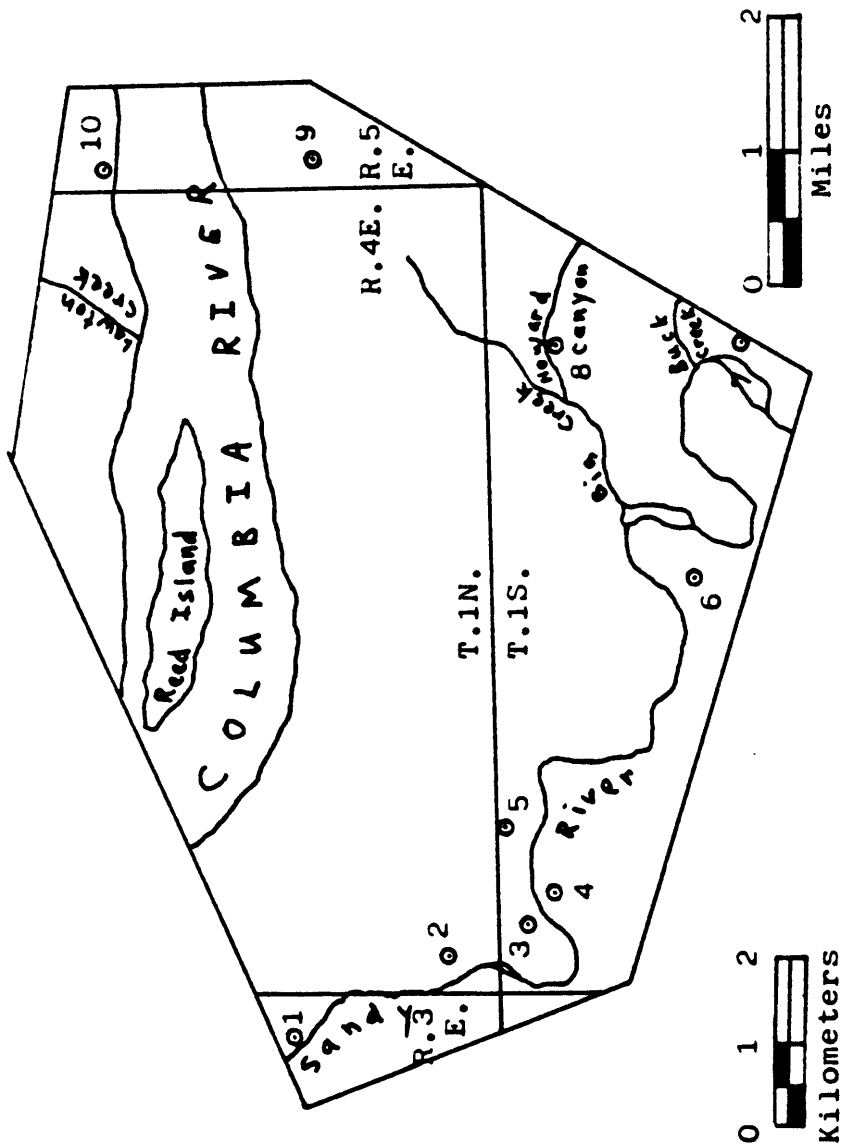
Figure 6. Map of study area, showing the locations of the ten measured sections.

TABLE II

DATA ON MEASURED SECTIONS

Section number	Location (in T.1S.,R.4E., unless otherwise indicated)	Conglomerate lithofacies thickness (in meters)	Coarse-grained sandstone lithofacies thickness (in meters)	Fine-grained lithofacies thickness (in meters)	Totals (in meters)
1	NW¼SE¼ Sec.25, T.1N., R.3E.	12	0	9	21
2	NW¼SW¼ Sec.31, T.1N., R.4E.	16	0	0	16
4	SW¼NE¼ Sec.6	27	3	0	30
3	SE¼NW¼ Sec.6	34	18	7	59
5	SW¼ Sec.32, T.1N., R.4E., N¼ NW¼ Sec.5	4	81	0	85
6	SE¼NE¼ Sec.9	1	19	8	28
7	Intersection of SW¼SE¼ Sec.11, SE¼SE¼ sec.11 & Sec.14	0	2	3	5
8	NE¼NE¼ sec.2	0	7	0	7
9	N½SW¼ Sec. 30, T.1N., R.5E.	30	26	0	56
10	W½NW¼ Sec.19, T.1N., R.5E.	147	3	0	150
Totals (in meters)		271	159	27	457
Lithofacies proportions (in percent) ± 2%		59	35	6	100

TABLE III

BASE ELEVATIONS, TOP ELEVATIONS, AND THICKNESSES
OF THE MEASURED SECTIONS
(Elevations in meters above sea level)

Section Number	Base Elevation	Top Elevation	Thickness
1	9	30	21
2	17	33	16
3	10	69	59
4	23	53	30
5	46	131	85
6	37	65	28
7	98	103	5
8	161	168	7
9	226	282	56
10	7	157	150

Qal	Alluvium
Qe	Estacada Formation
QTb	Boring Lavas
	Conglomerate Lithofacies
	Coarse-grained Sandstone Lithofacies
	Fine-grained Sandstone Lithofacies
Tsr	Sandy River Mudstone
Tcr	Columbia River Basalt Group

Troutdale Formation (Tt)

Figure 7. Explanation of units shown in Figure 8.

Figure 8. Correlation chart of measured sections. See Figure 7 for explanation of rock units. Numbers next to paleocurrent symbols give number of paleocurrent measurements made at each locality.

lithofacies. The coarse-grained sandstone lithofacies composes 34 to 38 percent of the Troutdale Formation's exposures. The siltstone lithofacies forms a minor portion of the exposures (4 to 8 percent).

From Figure 8, it can be seen that, except for section number 10, the basal contact of the Troutdale Formation occurs at higher elevations with increasing distances toward the east. This observation is consistent with the findings of Allen (1932, 1979), which is that the Troutdale Formation is exposed at higher elevations, the farther east one goes in the Columbia River Gorge. Figure 8 also shows that all possible lithofacies contact relationships are present. In addition, Figure 8 shows that the thickness of the Troutdale Formation as a whole varies with location. This points out that, from a grain size consideration, no simple sedimentologic trends, such as coarsening-upward, are apparent in the Troutdale Formation in the study area.

Within the study area, a representative composite section of the Troutdale Formation can be described. This section is a synthesized stratigraphic column which illustrates the relative proportions of lithofacies and their generalized sequences and contact relationships. Figure 9 illustrates the composite section. The composite section is composed almost entirely of beds of the conglomerate and coarse-grained sandstone lithofacies. In a vertical sequence, beds of the conglomerate lithofacies occasionally

alternate with beds of the coarse-grained sandstone litho-
facies. The thicknesses of these beds are seldom constant
in any outcrop, since, as mentioned above, these two litho-
facies occasionally grade into each other. Beds of the
siltstone lithofacies are present adjacent to the Sandy
River at measured section localities numbers 1, 3, and
6 (Figures 6 and 8). Beds of this lithofacies are not
exposed anywhere else in the study area. Based on Trimble's
work (1963) and the information of the present report,
the sedimentary rocks of the Sandy River Mudstone apparently
underlie the Troutdale Formation in the area adjacent
to the canyon of the Sandy River. However in the vicinity
of Crown Point, at measured locality number 9, the rocks
of the Columbia River Basalt Group underlie the Troutdale
Formation. Throughout much of the study area, such as
at localities number 1, 2, 5, 7, 8, and 10 (Figures 6
and 8), erosion and vegetation has covered the upper contact
of the Troutdale Formation. In other areas, such as at
localities numbers 2, 3, 4, and 6, deposits of the Estacada
Formation overlie the Troutdale rocks.

Although not mapped, deposits of the Estacada or
Gresham Formations are in contact with the Troutdale Forma-
tion in the NE¼ of Sec. 11, T.1S., R.4E. At first, the
appearance of this outcrop is very similar to that of
the conglomerate lithofacies. Close inspection of this
outcrop, however, reveals that the deposits are not those
of the Troutdale Formation's conglomerate lithofacies.

LEGEND	Meters	Graphic Log		Explanation
Conglomerate litho-facies with planar and irregular-len-ticular bedding.	300	Qe	QTb	Estacada Formation, Boring Lavas.
Coarse-grained sandstone litho-facies with planar bedding, planar cross-bedding, and trough cross-bedding.	200		QTb	Alternating beds of conglomerate and coarse-grained sandstone lithofacies. Beds of these lithofacies occasion-ally grade into each other. Interca-lated flows of Boring Lavas near up-per contact are present.
Gradational con-glomerate/coarse-grained sandstone lithofacies.				
Fine-grained sand-stone lithofacies with planar bedd-ing, planar cross-bedding, and plan-ar cross-bedding. Laminae of very fine-grained sand units are often contorted and sinuous.	100			Fine-grained sandstone lithofacies. Locally contains fossil flora. Beds of conglomerate and coarse-grained sandstone lithofacies underlie and overlie fine-grained sandstone lithofacies.
Qe: Estacada Formation. QTb: Boring Lavas. Tsr: Sandy River Mudstone. Tcr: Columbia River Basalt Group.	0			Basal contact with Sandy River Mud-stone locally contains fossil flora.
		Tsr	Tcr	Sandy River Mudstone, Columbia River Basalt Group.

Figure 9. Representative composite Troutdale section. Scale at left relates lithology to approximate formation position in meters above the formation's base. Maximum composite section thickness about 300 meters. Maximum exposed thicknesses vary from 0 to 150 meters in the study area. See text for detailed discussion on the formation's local characteristics.

The deposits of this outcrop lack the high degree of cementation characteristic of the Troutdale rocks. The outcrop also has a relatively high andesite clast to basalt clast ratio (approximately 1 to 1), which is quite atypical of the conglomerate lithofacies (maximum andesite clast to basalt clast ratio is 0.13 to 1, Table II). According to Trimble's (1963) criterion of topographic position, these deposits are those of the Estacada or Gresham Formation.

Throughout the rest of the study area, such as at localities numbers 1, 7, 8, 9, and 10, rocks of the Boring Lavas overlie the Troutdale Formation. On the west side of Crown Point, in the vicinity of section number 9, rocks of the Boring Lavas are intercalated within the Troutdale Formation. The base of this lava exhibits a conspicuous baked zone against the underlying Troutdale conglomerate.

In the vicinity of measured section number 10, measurements were made on an outcrop of the conglomerate lithofacies which exhibits irregular-lenticular bedding. The measurements allowed the calculation of the outcrop's bed relief index (BRI). The BRI is a measure of a bed's departure from a plane. The greater the irregularity of the bedding plane, the greater the BRI. Smith (1970) defined BRI as:

$$ BRI = \frac{2((T_1 + \ldots T_n)-(t_1 + \ldots t_n)) \pm T_{e1}, \ T_{e2}}{L} \ X \ 100, $$

where $(T_1 + \ldots T_n)$ is the sum total elevation of all

relative high points between adjacent lows, $(t_1 + \ldots t_n)$

is the sum total elevation of relative low points between

adjacent highs, L is the bed's horizontal traverse length,

and T_{e1}, T_{e2} are the heights of the extreme ends of the

traverse. If either extreme end adjoins a "low," the

value is added; if it is a "low" adjoining a "high," it

is subtracted. Figure 10 illustrates the outcrop and

the calculation of its BRI. A horizontal line was inscribed

with the pick end of a rock hammer into the outcrop.

The elevations of the highs and lows in Figure 10 are

in meters above the horizontal datum. The outcrop exhibits

a BRI of 12.1. Smith's (1970) study of the South Platte-

Platte River shows a range of BRI values of 1.4 to 5.3.

Cross-section profiles of the White River yield a range

of BRI values of 4.8 to 13.7 (Fahnestock, 1963).

PETROGRAPHY

The petrography section presents and discusses the

data derived from three sampling and analyzing methods,

in terms of the provenance of the sedimentary rocks of

the Troutdale Formation. The first method involves pebble

counts performed on clasts which were derived from exposures

of the conglomerate lithofacies. The second method deals

with instrumental neutron activation analysis (INAA) of

basalt clasts sampled from one outcrop of the conglomerate

lithofacies. The third method involves grain mount

Figure 10. Bed relief calculation of conglomerate lithofacies outcrop in the vicinity of measured section number 10 (Figures 6 and 8). See text for discussion.
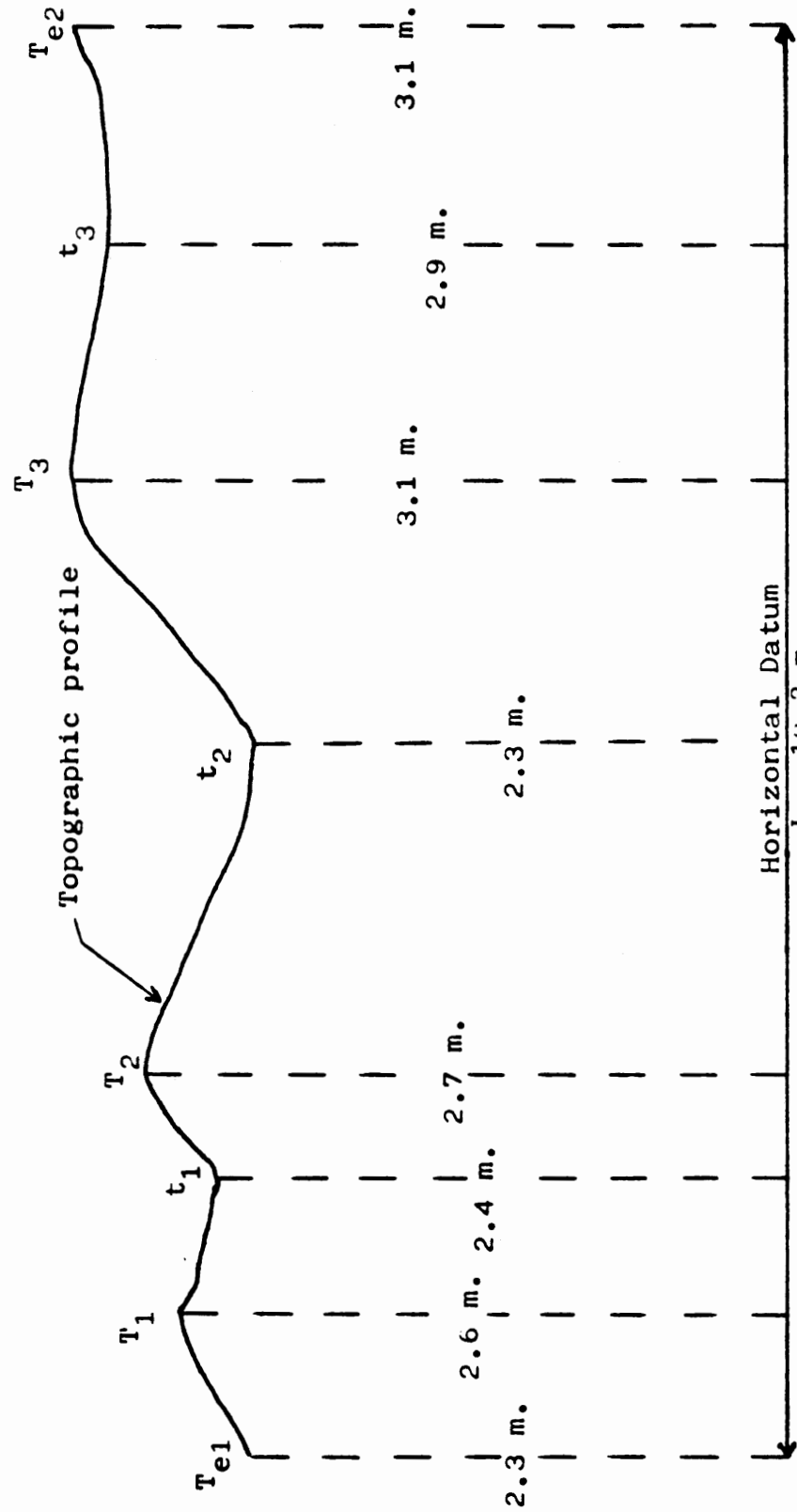
$$BRI = \left\{ 2\left[(2.6 + 2.7 + 3.1) - (2.4 + 2.3 + 2.9)\right] - 2.3 + 3.1 \right\}(100)/(19.8) = 12.1.$$

petrography of clastic particles derived from both the
conglomerate and the coarse-grained sandstone lithofacies.

Pebble Counts

At each of five localities, 100 pebbles were collected.
Figure 11 illustrates the locations from which these pebble
samples were derived. Note that localities 1 through
3 correspond respectively with the following measured
sections: 2, 3, and 9. Pebble sample localities 4 and
5 are included in the area in which measured section number
10 is located. The pebbles ranged in size from 36 mm
to 64 mm in length. Pebbles of this size range were chosen
because they are abundant in every outcrop which exposes
the conglomerate lithofacies. Because of this, it is
assumed that the estimates of the rock type distribution
at the sample localities, which the analysis of these
pebble samples provides, are representative of the entire
conglomeratic portion of the Troutdale Formation at the
sample localities, and this includes a range in clast
sizes from pebbles to boulders (4 mm to over 256 mm in
length, respectively).

At each sample locality the following procedure
was used. A square meter grid, divided into 100 equal
parts, was inscribed on the outcrop. The surface of the
outcrop was scraped off until a pebble was exposed in
each 10 cm subsection of the square meter grid. Each
pebble was broken open to reveal a fresh rock surface.
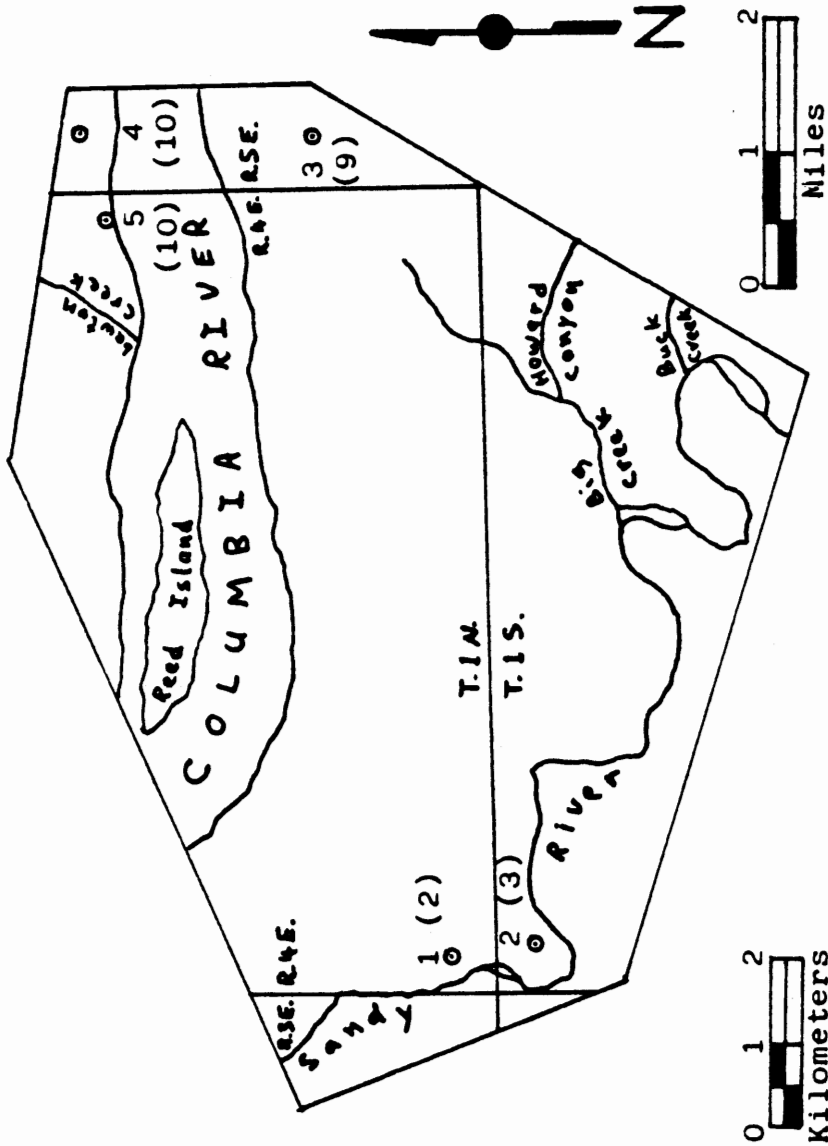
Figure 11. Map of study area, showing the localities of the five pebble samples. The numbers in parentheses correspond to the measured section localities, shown in Figure 6.

Then each pebble was identified in hand sample under a 12x hand lens, as to rock type. For a given rock type, each repetition of this procedure resulted in the total count for that rock type at that locality increasing by one. Since each sample contains 100 identified pebbles, the number of pebbles identified for each rock type repre- sents an estimate of the percentage of that rock type in the Troutdale Formation at the sample locality.

Table IV summarizes the pebble count data and includes the following information: (1) sample locality numbers, which correspond to those shown in Figure 11, (the numbers in parentheses refer to the corresponding measured section numbers), (2) map locations of the sample localities, (3) positions within the Troutdale Formation from which the samples are derived, (4) percentages of rock types in the Troutdale Formation at the sample localities, and (5) grand average composition.

To aid in making color determinations, the GSA Rock- Color Chart was used (The Geological Society of America, 1975). The five rock types identified in this pebble count were distinguished in hand sample, according to the following petrographic characteristics:

(1) Basalt - Medium dark gray (N4) to black (N1), occasionally weathered to dark reddish brown (1OR 3/4), aphanitic to porphyritic-aphanitic.

(2) Andesite - Light gray (N7) to medium gray (N5), porphyritic-aphanitic.

TABLE IV

PEBBLE COUNT DATA

Sample Locality Number	Map Location	Formation position and outcrop elevation (in meters)	Rock Type Proportion (in percent)					
			Basalt	Andesite	Quartzite	Lithic Tuff	Crystal Tuff	Micro-gabbro
1 (2)	NW¼ SW¼ Sec. 31,T.1N.,R.4E.	Lower half, 21 m.	100	0	0	0	0	0
2 (3)	SE¼ NW¼ Sec.6, T.1S.,R.4E.	Lower half, 21 m.	69	5	25	0	0	1
3 (9)	NE¼ SW¼ Sec. 30,T.1N.,R.5E.	Lower half, 216 m.	86	11	3	0	0	0
4 (10)	NE¼ NW¼ Sec. 19,T.1N.,R.5E.	Upper half, 104 m.	76	1	18	5	0	0
5 (10)	SE¼ NE¼ Sec. 24,T.1N.,R.4E.	Lower half, 6 m.	94	6	0	0	0	0
Grand Average Composition			85	5	9	1	1	<1

Locality numbers in parentheses correspond with measured sections locations (Figures 6&8).

(3) Quartzite - Mono to polychromatic, aphanitic
to phaneritic (crystals up to 1 mm in length), occasionally
with polychromatic relict bedding banding.

(4) Crystal lithic tuff - Polychromatic, porphyritic-
aphanitic, occasionally with stretched grain borders,
and phenocrysts up to 2 mm in length.

(5) Microgabbro - Dark gray (N3) to black (N1), medium-
grained (½ mm in length).

These petrographic characteristics cover the range
of the clasts examined in this pebble count. These
petrographic characteristics do not necessarily cover
the range of all clasts present in the Troutdale Formation.
For example, there may be quartzite clasts present in
the Troutdale Formation in which crystals are larger than
1 mm in length. Plutonic and vein quartz are present
in the Troutdale Formation. All quartz pebbles were counted
as quartzite in order to emphasize the presence of distal
sources. The petrographic characteristics listed above,
however, were sufficient to allow the pebble samples to
be identified and analyzed.

As the data in Table IV show, basalt is the dominant
rock type at every sample locality. Nowhere does its
representation fall below 69 percent. Quartzite follows
basalt as the next most abundant rock type. The proportion
of quartzite attains a maximum of 25 percent at pebble
sample locality number 2. Locality number 2 is the only
place where a rock of microgabbroic texture and composition

was found. Only locality number 4 contains crystal lithic
tuff clasts. The data were combined to yield an average
composition according to the following procedure. The
percent representation for each rock type was added, over
the five localities, and the sum obtained was divided
by 5 and rounded to the nearest whole percent. It is
apparent then, from Table IV, that basalt accounts for
the vast majority of the clasts over the five sample
localities with an average representation of 85 percent.
Quartzite is the next most abundant rock type with an
average representation of 9 percent. The average represen-
tations of andesite and crystal lithic tuff are, respective-
ly, 5 percent and 1 percent. One clast out of 500 was
identified as microgabbro. Its representation is therefore
less than 1 percent. There are no studies that deal with
the sediments of the Troutdale Formation which indicate
that the proportions of rock types present in the 36 mm
to 64 mm size fraction of the conglomerate lithofacies
are significantly different than the proportion of rock
types present in other size fractions. Because of this,
it is assumed that the pebble sampling method described
above, yields valid estimates of the rock type distribution
at the sample localities for the gravel fraction of the
Troutdale Formation, which includes clast sizes from
4 mm to over 256 mm in length. Because basalt is the
dominant rock type in the pebble samples, and because
pre-Troutdale basaltic rocks are abundant in this area,

it seems certain that at least some of the basalt in the
pebble count samples represents proximal sources. At
pebble sample locality number 2, the representation of
quartzite attains 25 percent. Allen (1932) has stated
that in some places, the representation of quartzite is
as high as 30 percent. He attained this figure in Bridal
Veil Canyon (Allen, 1982, personal communication). Allen
used a channel sampling method to obtain his pebbles at
this locality which is out of the present study area to the
east. He feels that any discrepancy between the maximum
quartzite content obtained in his and the present study
may be due to both the location and the sampling method
(Allen, 1982, personal communicaton). Regardless of any
such discrepancies, the pebble count data shows that quart-
zite forms significant amounts of the gravel fraction
of the Troutdale Formation at the sample locations. Since
pre-Troutdale quartzite source regions are located no
closer than north eastern Washington, the presence of
quartzite shows that distal sources played significant
roles in supplying material to the Troutdale Formation.

Instrumental Neutron Activation Analysis

Nine cobble-size clasts (64 mm to 256 mm in length),
derived from measured section number 2 (Figures 6 and
8), were subjected to instrumental neutron activation
analysis. These clasts were identified in hand sample
as basalt, and compared geochemically with a standard,

BCR-1. The analyses of these nine basalt clasts yielded elemental abundances of a total of seventeen major and trace elements in each of the basalt clast samples. The data for these nine samples and the standard are given in the Appendix. Table V presents the parent rock type determinations for the nine samples. The sample numbers of Table V correspond with those of the Appendix. These parent rock type determinations are courtesy of Beeson (1979, written communication). These determinations show that at least one formal member and two informal members of the Columbia River Basalt Group were sources for the sedimentary rocks of the Troutdale Formation in the study area. This information also shows that rocks of the Boring Lavas or similar lavas were sources which contributed material to at least the upper part of the Troutdale Formation.

Although the basalt clasts were cobble-size, it is reasonable to assume that these basalt types are present in the entire range of clast sizes in the conglomerate lithofacies of the Troutdale Formation in the study area. Since the rocks of the Columbia River Basalt Group are very widespread, they may have served as distally-located sources. However, this geochemical information corroborates the notion mentioned above in the pebble-count section, that the rocks in the Columbia River Basalt Group were proximal sources. The geochemical information also shows

TABLE V

GEOCHEMICAL PARENT ROCK-TYPE DETERMINATIONS
OF BASALT CLAST SAMPLES

Sample Numbers	Parent Rock-Type Determinations*
7	Boring Lavas
1, 4 (?), 6, 8	Frenchman Springs
3, 5	Grande Ronde (High Mg)
2, 9	Grande Ronde (Low Mg)
*Parent rock-type determinations are courtesy of Beeson (personal communicaton). Sample numbers correspond with those of Appendix.	

that extrusion of the Boring Lavas or similar lavas began,
prior to the cessation of Troutdale deposition.

Grain Mount Petrography

Samples of the coarse-grained sandstone lithofacies
and samples of the matrix material from the conglomerate
lithofacies were collected from ten localities and analyzed
under a petrographic microscope. The map shown in Figure
12 illustrates the localities from which these ten petro-
graphic samples were derived. Note that samples 1 and
2 correspond with measured section number 10, while samples
4, 5, 6, 8, and 10 correspond respectively with measured
sections numbers 6, 3, 8, 7, and 9.

Using the pick end of a rock hammer, sandstone and
conglomerate matrix materials were scraped off the outcrop
into a plastic bag. The samples were then taken back
to the lab where they were washed in a 250 mesh sieve,
in order to remove most of the fine, clay-size particles,
and then dried in an oven. Once dry, the samples were
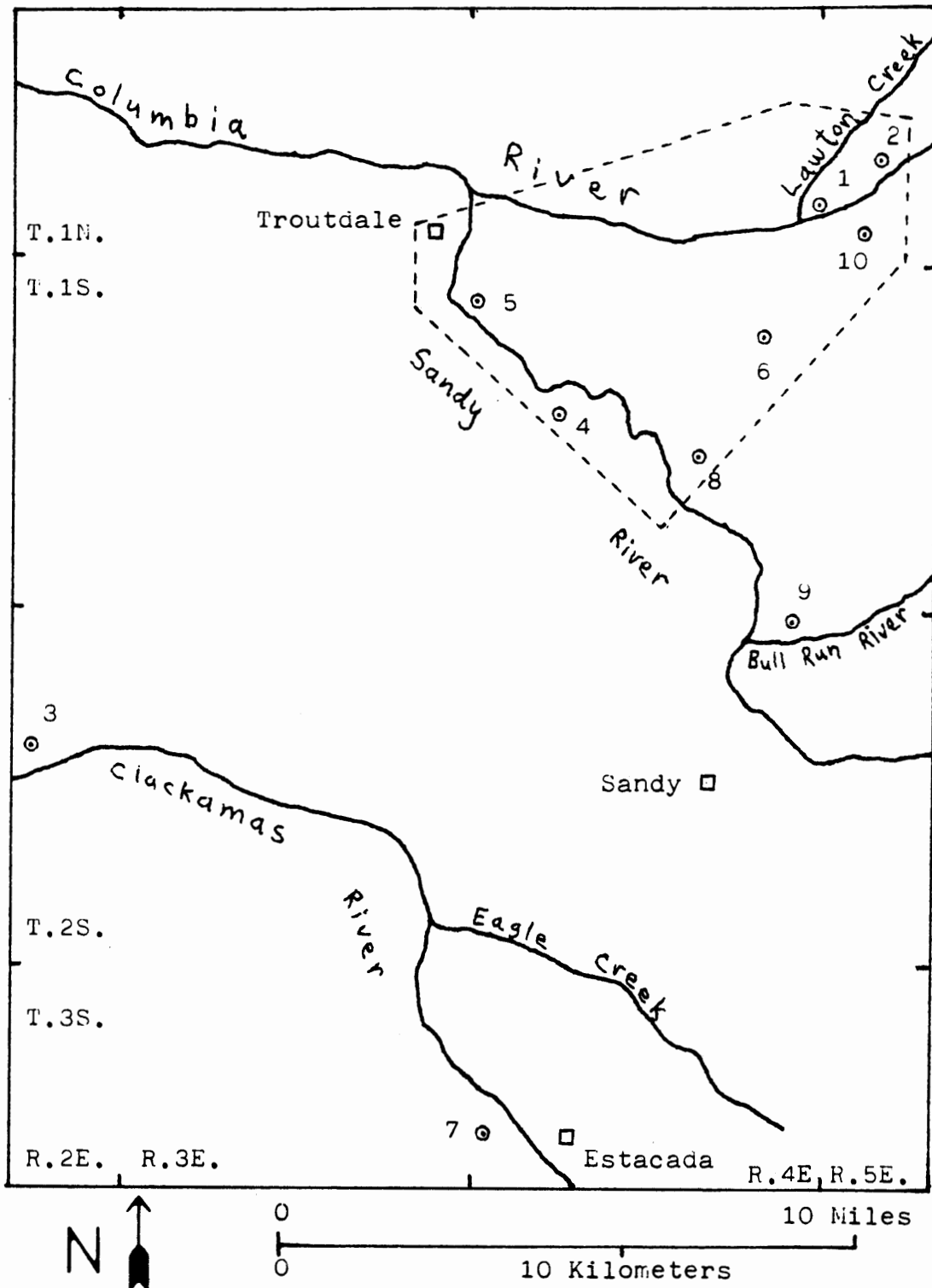
Figure 12. Sketch map of region, showing the locations of the ten grain mount samples. The study area is outlined.

sieved between 100 and 20 mesh screens, in order to provide
a convenient range in grain size. The utility of the
grain sizes is discussed in the next paragraph. Once
the grains were glued to slides, they were ground down
to thin section proportions (30 - 35 microns). The samples
were then scanned under a petrographic microscope in order
to identify the components present. The samples were
then stained for potassium and plagioclase feldspar, in
order to distinguish between the two. Finally, after
staining, the samples were line counted.

This grain mount petrography concentrated on the
identification of rock fragments, rather than doing a
complete petrographic analysis, for two basic reasons.
First, for any given identified grain, a rock fragment
provides more information, in general, about the source
rocks, than a single mineral. Secondly, since most of
the fine silt- and clay-size particles were elimianted,
the optical clarity of the remaining sample is noticeably
enhanced, thereby facilitating the identification and
counting of the samples' sand size components. Referring
to Figure 4, and keeping in mind that the grain mount
samples were sieved between 2.8 $\emptyset$ and 0.26 $\emptyset$ screen openings,
it is apparent that the vast majority (over 87 percent)
of the particles in the samples were subjected to petro-
graphic analyses. This analytical procedure provides
provenance information on essentially all significant
components (R.O. Van Atta, 1982, personal communication).

Table VI lists the sample numbers which correspond with those shown in Figure 12, the lithofacies from which the samples were derived, and the localities of the samples. Table VII summarizes the line counting results which were based on 300 identified grains per sample. In order to facilitate rapid line counting, all volcanic rock fragments were grouped together, rather than attempting to interpret and count more detailed groupings, such as silicic, intermediate, and mafic volcanic rock fragments. Any attempt to discriminate such detailed groups could be misleading. For example, a rock fragment whose overall appearance indicates it is a mafic volcanic rock fragment could actually be an intermediate volcanic rock fragment with feldspar and/or pyroxene grains broken off and missing. Since it is rare that large bodies of rock are composed entirely of one mineral, it is assumed that the single minerals counted in this grain mount analysis originally came from polymineralogic rocks. For example, the many plagioclase grains counted in this analysis are assumed to have originally been parts of larger rock masses, such as volcanic lava flows. In order to facilitate provenance determinations, rock fragments containing K-spar were counted in the same category as single K-spar mineral grains. No K-spar-bearing sources are present in proximal locations. Thus, the presence of K-spar, either as single minerals, or as part of rock fragments, indicates distal sources. The same procedure was applied to orthopyroxene and

TABLE VI

GRAIN MOUNT SAMPLE NUMBERS, LITHOFACIES, AND LOCALITIES

Sample Number	Lithofacies	Locality
1	Conglomerate matrix	Outcrop on north bank of Columbia River, at end of Mt. Pleasant Road, NE¼ SE¼ NE¼ Sec. 24, T. 1 N., R. 4 E.
2	Conglomerate matrix	Outcrop on north side of Washington Highway 14, NW¼ NE¼ NE¼ Sec. 19, T. 1 N., R. 5 E.
3	Conglomerate matrix	Outcrop on south side of Oregon Highway 224, along Clackamas River, SE¼ NE¼ SW¼ Sec. 14, T. 2 S., R. 2 E.
4	Coarse-grained sandstone	Outcrop on south side of Hosner Road, above Camp Collins and Sandy River, SE¼ SE¼ NE¼ Sec. 9, T. 1 S., R. 4 E.
5	Conglomerate matrix	Outcrop on north side of Crown Point Road and Sandy River, just west of Stark Street Bridge, NE¼ SE¼ NW¼ Sec. 6, T. 1 S., R. 4 E.
6	Coarse-grained sandstone	Outcrop on south side of Howard Canyon, SW¼ NE¼ NE¼ Sec. 2, T. 1 S., R. 4 E.
7	Conglomerate matrix	Outcrop on west side of McIver State Park, SE¼ NW¼ SE¼ Sec. 13, T. 3 S., R. 3 E.
8	Coarse-grained sandstone	Outcrop south of Gordon Creek, on side road off Gordon Creek Road, NW¼ NE¼ NE¼ Sec. 14, T. 1 S., R. 4 E.
9	Coarse-grained sandstone	Outcrop above Gordon Creek Road, near mouth of Bull Run River, SW¼ NW¼ SW¼ Sec. 32, T. 1 S., R. 5 E.
10	Conglomerate matrix	Outcrop above south side of Crown Point Road, below the Vista House, NW¼ NE¼ SW¼ Sec. 30, T. 1 N., R. 5 E.

TABLE VII

PERCENTAGES OF COMPONENTS IN GRAIN MOUNT SAMPLES

Component	Sample Number										Average Composition
	1	2	3	4	5	6	7	8	9	10	
Volcanic rock fragments	80	29	72	90	47	98	78	95	89	69	75
Sedimentary rock fragments	0	17	0	1	14	0	0	1	5	11	5
Plagioclase	2	27	13	2	20	1	2	1	1	8	8
K-spar	0	7	4	1	6	0	2	1	0	6	3
Clinopyroxene	0	1	0	2	3	0	0	2	4	2	1
Orthopyroxene	18	5	10	1	3	0	16	0	0	1	5
Biotite	0	12	0	2	6	0	0	0	0	2	2
Palagonite	0	0	0	0	1	1	1	0	1	0	<1
Hornblende	0	2	1	1	0	0	1	0	0	1	1
Totals	100	100	100	100	100	100	100	100	100	100	100

hornblende. Since it was found that clinopyroxene forms a common mineral in many rock fragments, it was counted only as separate mineral grains. This is also true for plagioclase. In the grain mount samples, the mineral biotite was not found associated with other minerals. Thus its representation in Table VII accounts for its presence in each sample as separate mineral grains. Palagonite, when encountered, was counted as a single component. Sedimentary rock fragments include quartzite, detrital quartz grains, cryptocrystalline quartz (chert), and very fine-grained particles composed of quartz and feldspar.

Working with oils of known refractive indices it was found that many of the volcanic rock fragments in grain mount sample numbers 4, 6, 8, and 9 contain brown glass with a refractive index of 1.583 $\pm$ 0.001. According to Williams and others (1954), this indicates a silica content of 50 $\pm$ 1 percent. This is within the range that Williams sets for rocks of basic composition (45 to 52 percent silica). This information agrees with Trimble's (1963) conclusion that these brown glass particles are basaltic glass (sideromelane). Considering the labile nature of these components, plus the fact that many of these grains are angular, it seems certain that these components were derived from proximal sources.

The data in Table VII show that sedimentary rock fragments are present in some of the grain mount samples.

The representation of this component reaches a maximum value of 17 percent in sample number 2. Sample number 10 contains 11 percent of this component, nearly all of which is composed of detrital quartz grains, some of which exhibit shadowy extinction and contain trains of spherical crystallites, typical of metamorphic quartz. The literature contains no proof that there are or were rocks composed of these materials, located in proximal regions, that are pre-Troutdale in age. This information indicates that this component represents distal source rocks. The literature contains no information which shows that biotite-bearing rocks of pre-Troutdale age, are or were located in proximal source regions. This suggests that the presence of biotite reflects sediment contribution from distal source rocks. Table VII shows that the samples with the two greatest percentages of biotite coincide with the samples which contain the two greatest percentages of sedimentary rock fragments. This reinforces the conclusion that distal source rocks contributed materials to the coarse sand fraction of the deposits of the Troutdale Formation in the study area.

Orthopyroxene, particularly hypersthene, is common in such metamorphic rocks as granulites, charnokites, and thermally metamorphosed shales (Nockolds and others, 1978, and Battey, 1975). Hypersthene also occurs in basalts and andesites (Williams and others, 1954). According to the literature, no pre-Troutdale rock types such as

these are or were present in proximal regions. Orthopyroxene
attains its greatest representation at grain mount sample
locality number 1 (Figure 12). The absence of other distally-
derived components in this sample suggests that the ortho-
pyroxene was locally-derived. The next two largest percen-
tages of orthopyroxene are represented in sample numbers
3 and 7. These sample localities are well to the south
of the study area, outside the influence of the ancestral
Columbia River (Bretz, 1917). These two samples do not
contain distally-derived components such as sedimentary
rock fragments. This information suggests that the ortho-
pyroxene of these samples is locally-derived, such as
from basalts and/or andesites of the Cascade Range.

Compositional Trends

Referring to Table IV and Figure 11, it is apparent
that at the lowest elevation and at the western extreme
of the area sampled, the gravel is composed of basalt
(sample locality number 1). In contrast to this, at the
highest elevation and at the eastern extreme of the area
sampled, the representation of basalt is 76 percent (sample
locality number 4). This data, considered alone, would
suggest that the dominance of basalt increases in a west-
ward direction, to the exclusion of all other rock types
at locations anywhere west of sample locality number 1.
However, there is no such simple trend of increasing basalt
content in a westward direction, because at sample locality

number 2, which is west of locality number 4, the proportion
of basalt is lower (69 percent versus 76 percent).

From the data in Table VII, biotite appears to be
restricted to areas north of Gordon Creek (locality number
8, Figure 12). Sedimentary rock fragments appear to be
restricted to areas north of the Bull Run River (locality
number 9, Figure 12). Both biotite and sedimentary rock
fragments attain their maximum representation along the
Columbia River at locality number 2. The association
of biotite and sedimentary rock fragments near the Columbia
River suggests that the ancestral Columbia River was
responsible for transporting these distally-derived compon-
ents. The absence of these components in areas south
of the Bull Run River suggests that the influence of the
ancestral Columbia River was restricted to areas north
of the present day Bull Run River. The orthopyroxene
of grain mount sample numbers 3 and 7 (Table VII and Figure
12) probably came from relatively nearby sources, such
as the Cascade Range.

The petrographic data shows that much of the Troutdale
rocks are composed of mafic volcanic detritus. Mafic
volcanic sources of pre-Troutdale age were abundant in
the vicinity of the study area. Considering the labile
nature of these components, and abundant nearby source
rocks, it seems certain that most of the Troutdale rocks
were derived from proximal sources. While proximal sources
contributed most of the Troutdale rocks, distal sources

provided significant amounts of detritus to the Troutdale

Formation in the study area (25 percent quartzite, Table

IV, and 17 percent sedimentary rock fragments, Table VII).

PALEOCURRENT DIRECTIONS

To provide information regarding paleocurrent direc-
tions in the study area, 60 measurements were made on

various primary sedimentary structures. Specifically,

the structures measured include dip directions of bedding

planes, dip directions of foreset beds, direction of

imbrication in beds containing imbricated clasts, and

the direction of the axis of a channel fill structure.

Table VIII lists the localities of the measured structures,

as well as the corresponding measured section and petro-
graphic sample localities. This table also lists the

types of structures measured, and the measured values.

In order to provide a visual display of the data,

Figure 13 is constructed according to the following proce-
dure. The measured values at each of the nine locations

are averaged, and the averaged values so obtained are

plotted as arrows on Figure 13, their directions correspond-
ing to the averaged values or bearings, which are also

given alongside the arrows. It is apparent from this

display that the agent or agents which carried and deposited

the sedimentary rocks of the Troutdale Fromation in the

study area flowed in a direction with a strong westerly

component.

TABLE VIII

SUMMARY OF PALEOCURRENT DATA

Location of paleo-current measurements	Sedimentary feature measured	Measured values, in degrees from north (bearing)
NW¼SE¼ Sec.25,T.1N., R.3E. 1 (1)	axis of trough in coarse sand-stone	320,325,325
SW¼SW¼ Sec.30,T.1N., R.4E. 2	bedding planes	325,320
SW¼NW¼ Sec.31,T.1N., R.4E. 3	bedding planes	340,345
SW¼ Sec.31,T.1N., R.4E. 4 (2,1.*)	bedding planes	320,335,340
N½ Sec.6,T.1S., R.4E. 5 (3,2,5)	foreset beds, bedding planes	240,235,225,230, 230,235,220
SW¼ Sec.32,T.1N., R.4E., & NW¼ Sec.5, T.1S.,R.4E. 6 (5)	bedding planes	275,285,285,295, 295,270,275,280
NW¼NW¼ Sec.2,T.1S., R.4E. 7 (8,-,6)	bedding planes	310,305,295,320, 305,235,310,335, 285,315,305,245, 245,255,235
N½ Sec.24,T.1N., R.4E.8 (10,5,1)	imbricated clast beds, bedding planes	300,280,295,280, 290,285,295,275, 285,295,305
N½ Sec.19,T.1N.,R.5 E. 9 (10,4,2)	bedding planes	260,275,260,265, 250,260,245,240, 260

The average of all these preceding measurements: 285°. The numbers which follow the map locations corresond to those shown on Figure 13. One or more numbers in parentheses, following the paleocurrent measurement locality number, indicate the following: The first number is the number of the corresponding measured section, located in Figure 6, and depicted in Figure 8. The second number is the number of the corresponding pebble count sample locality, located in Figure 11. The third number is the number of the corresponding grain mount petrographic sample locality, located in Figure 12. The asterisk indicates the corresponding location where the basalt clasts were sampled, for INAA.
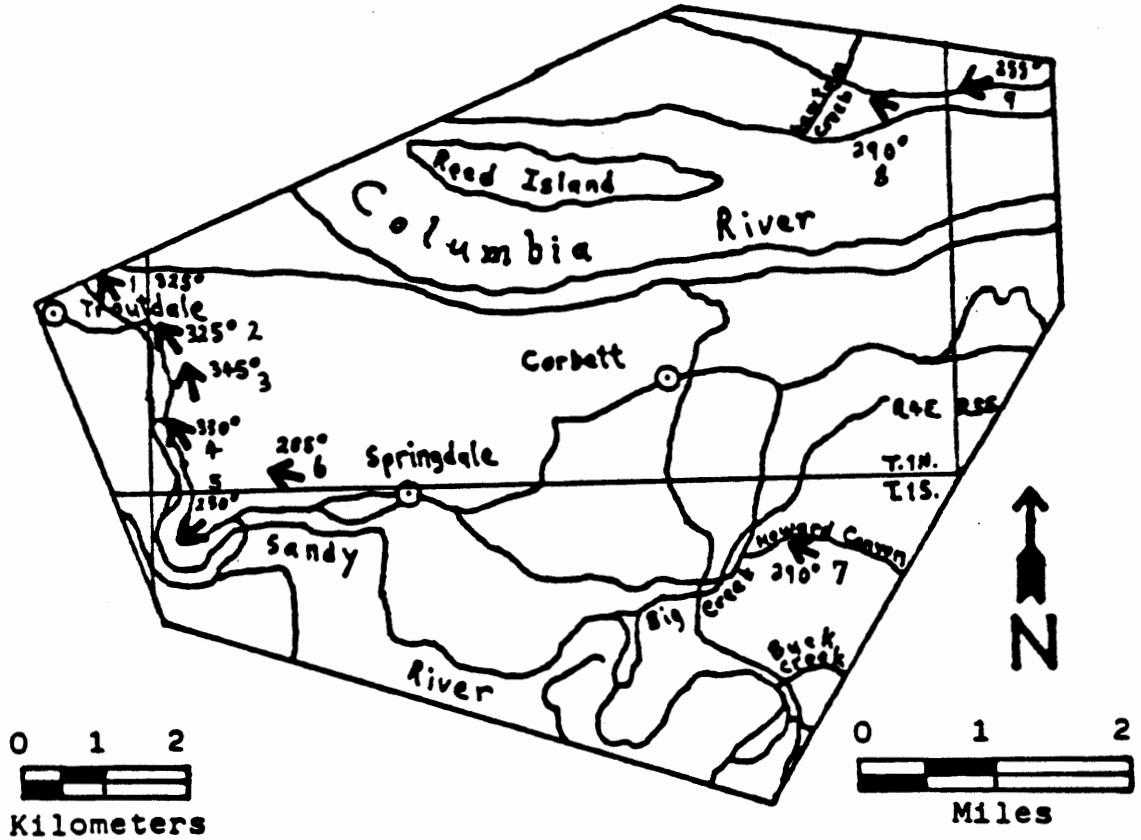
Figure 13. Map of study area, showing the locations and directions of averaged paleocurrent measurements. The numbers next to the paleocurrent arrows correspond with those in Table VIII.

Grand average
direction: 285°

Scale: 200mm=100%

0%   10%   20%
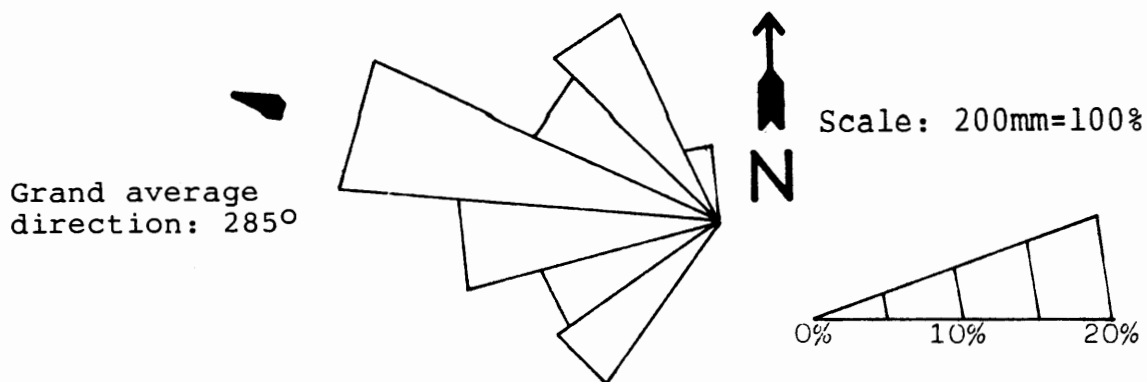
Figure 14.   Rose diagram representation of
paleocurrent data, tabulated in Table VIII.

A more graphic representation of the paleocurrent

data is shown in Figure 14.   This figure is a rose diagram,

which is a type of frequency distribution.   The seven

class intervals are 20° wide, and they encompass the range

of the measured values.   The size of each 20° interval

represents the percentage of all the measurements which

each interval bounds.   According to the scale on the diagram,

the greatest concentration of measured values falls within

a range of 275° to 295°.   This class is centered about

a bearing of 285°, which coincides with the average of

all the sixty measured values.   This reinforces what Figure

13 demonstrates, which is this: the main or dominant

direction of travel of the medium or media which carried

the sedimentary rocks of the Troutdale Formation, and

from which these clastic materials were deposited, was

westward.   The other class intervals may suggest that

streams flowing from the northeast and southeast also
made contributions to the deposits of the Troutdale Forma-
tion.

The presence of both distally-derived and proximally-
derived sediments, the distribution of these components,
and the granulometric characteristics of the Troutdale
sediments, combined with this paleocurrent data, suggest
that the ancestral Columbia River was a braided stream,
and was the main medium which carried and deposited the
Troutdale sediments in the study area. Although other
streams flowing from the northeast and southeast may have
also made contributions to the Troutdale deposits, the
other class intervals of Figure 15 could also be reflecting
the presence of side channels, distributaries, and/or
anabranches of the main, ancestral Columbia River, which
are common in the braided stream depositional environment.

DEPOSITIONAL ENVIRONMENT

Two basic models were considered, regarding the environment within which the sedimentary rocks of the Troutdale Formation were deposited. One depositional model, the alluvial-fan, was ruled out because the sedimentary rocks of the Troutdale Formation are not distributed in radial patterns, with a discernable apex and a discernable toe, typical of an alluvial-fan's geometry (Bull, 1972). The other model considered is that of the braided-stream depositional environment.

Williams and Rust (1969) studied the Donjek River, which they classify as a braided stream. They state that in the braided stream environment, gravel (mean grain size greater than -1.0 $\emptyset$) is the most abundant lithotype. This is also true for the sedimentary rocks of the Troutdale Formation in the study area, because Table I shows that M_Z of the conglomerate lithofacies is -3.6 $\emptyset$, and Table II shows that conglomerate is the most abundant lithofacies. The cumulative size frequency curves of Williams and Rust (1969) suggest that there is a great variation in both grain size and grain size distribution within the braided-stream environment. The cumulative size frequency curves shown in Figure 5 demonstrate that, like the sediments of the Donjek River, the sedimentary

rocks of the Troutdale Formation vary greatly in both grain size and grain size distribution. These conditions seem to be characteristic of the braided-stream environment of deposition.

Williams and Rust (1969) show that in the braided-stream depositional environment, following gravel as the most abundant lithotype, the next most abundant lithotypes are composed of sand and silt, which commonly occur together. The sieve analysis and the measured sections data show that, after the conglomerate, the most abundant lithofacies (equivalent to the lithotypes of Williams and Rust) are the coarse-grained sandstone lithofacies and the siltstone lithofacies. As mentioned above, sand and silt occur together in the siltstone lithofacies of the Troutdale Formation in the study area, such as along the Sandy River at the Stark Street Bridge.

Smith (1970) studied the modern South Platte-Platte River and the ancient Shawangunk and Green Pond Conglomerates. He states that coarse, poorly sorted sediments favor the formation of longitudinal bars. The sieve analysis data show that the sedimentary rocks of the conglomerate lithofacies of the Troutdale Formation are coarse and poorly sorted, which suggests that these rocks may represent ancient longitudinal bars. Smith (1970) says that avalanche faces sometimes develop on the downstream margins of longitudinal bars, and usually have coarse upstream ends which grade into finer-grained downstream ends. Several

outcrops of the conglomerate lithofacies of the Troutdale

Formation in the study area exhibit planar beds which

dip as much as 31° in a downstream direction. Some of

these outcrops also expose rocks which grade from a cobble

conglomerate to a coarse-grained sandstone, in a downstream

direction. The rocks in these outcrops probably represent

ancient longitudinal bars, characteristic of the braided

stream environment of deposition.

Smith's (1970) study of the braided stream depositional

environment shows that longitudinal bars tend to have

a high bed relief index (BRI). Figure 10 shows a BRI

value of 12.1 for one outcrop of the conglomerate lithofacies

of the Troutdale Formation in the vicinity of measured

section locality number 10 (Figures 6 and 8), which exhibits

irregular-lenticular bedding. The study of Smith (1970)

suggests that this high BRI value of 12.1 is what one

would expect of proximally-located sedimentary rocks within

the braided-stream depositional environment. Although

the granulometric character of the outcrop suggests that

the rocks here were proximally derived, the compositional

data (Tables IV and VII) show that much of the detritus

came from distal sources.

SUMMARY

Qualitative inspection of the Troutdale Formation
in the study area reveals that three granulometrically
distinct and recognizable lithofacies are present. Sieve
analyses of samples collected in the type locality, confirm
in quantitative terms that at the sample localities, three
distinct lithofacies are indeed present. These lithofacies
are called the conglomerate, the coarse-grained sandstone,
and the siltstone lithofacies. More sieve analyses need
to be performed on the sedimentary rocks of the Troutdale
Formation throughout the region in order to establish
a firm foundation for the usage of these informal lithofacies
terms, and in order to establish the range in granulometric
parameters necessary for describing the distinguishing
characteristics of each lithofacies. Despite the lack
of extensive granulometric data, the information of the
present report provides a sufficient basis for the recogni-
tion, description, and further study of the Troutdale
Formation.

The methods used in the sieve analyses section of
this report follow the procedures of Folk (1974). The
mean grain size (M_Z) of the conglomerate and the coarse-
grained sandstone lithofacies are, repsectively, -3.6 $\emptyset$
and 1.0 $\emptyset$. The sorting (σ_I) for these lithofacies are

2.0 (poorly to very poorly sorted) and 0.96 (moderately

sorted). The cumulative size frequency curves show that

the sedimentary rocks of the Troutdale Formation vary

greatly in grain size and grain size distribution. Sand

and silt occur together in the siltstone lithofacies.

The sands in the coarse-grained sandstone lithofacies

are the best sorted of the three lithofacies.

The data from the measured sections show that in

the study area, conglomerate is the dominant lithofacies,

with an estimated volume proportion of 56 to 60 percent.

The coarse-grained sandstone lithofacies makes up 34 to

38 percent of the Troutdale Formation's exposures, while

the siltstone lithofacies forms a minor part of the Troutdale

Formation, with 4 to 8 percent. The measured sections

data allows the development of a representative composite

section of the Troutdale Formation in the study area.

This composite section is shown diagrammatically in Figure

9 and described above. During the field work for one

of the measured sections, an outcrop of the conglomerate

lithofacies which exhibits irregular-lenticular bedding

was measured, from which its bed relief index (BRI) was

calculated, according to the procedures of Smith (1970).

The BRI of this outcrop is 12.1.

The pebble count data show that basalt is the dominant

rock type of the conglomerate lithofacies in the study

area. Its minimum representation over the five sample

lcoalities is 69 percent. Its maximum is 100 percent,

and its average is 85 percent. Quartzite is the next
most abundant rock type, reaching a maximum representation
of 25 percent, and averaging 9 percent.

The instrumental neutron activation analysis (INAA)
shows that at least one formal member (Frenchman Springs)
and two informal members (Grand Ronde Basalt, High Mg
and Low Mg) of the Columbia River Basalt Group were sources
for the sedimentary rocks of the Troutdale Formation in
the study area. The INAA data also show that rocks of
the Boring Lavas or similar lavas were sources which contri-
buted material to the Troutdale Formation.

The grain mount petrographic data show that volcanic
rock fragments are the dominant component in the coarse
sand fraction of the Troutdale Formation in the study
area. Many of these volcanic rock fragments contain brown
glass which has an index of refraction of 1.583 $\pm$ 0.001,
which indicates a mafic composition. The representation
of sedimentary rock fragments averages 5 percent, with
a maximum of 17 percent. Biotite averages 2 percent,
with a maximum of 12 percent. Four of the six samples
which contained sedimentary rock fragments also contained
biotite. The representation of orthopyroxene averages
5 percent with a maximum of 18 percent. The samples with
the three largest amounts of orthopyroxene (18, 16, and
10 percent) do not contain any sedimentary rock fragments
or biotite.

The grand average bearing of 60 paleocurrent measurements is $285°$. A rose diagram representation of the paleocurrent data shows the class interval with the greatest percentage of measurements is centered about a bearing of $285°$. Other class intervals indicate the presence of streams flowing in northwesterly and southwesterly directions.

The granulometric data, the measured sections data, and the BRI calculation, when compared with literature data, suggest strongly that the sedimentary rocks of the Troutdale Formation in the study area were deposited in the braided-stream depositional environment. The pebble count, INAA, and grain mount petrographic data show that most of the Troutdale rocks were derived from proximally-located sources. Distal sources however, contributed significant amounts of such components as quartzite, sedimentary rock fragments, and biotite. The granulometric characteristics of some of the Troutdale rocks are typical of proximal areas within the influence of the braided-stream environment of deposition, despite the presence of distally-derived components.

Tolan (1982) informally proposes an upper member of the Troutdale Formation which is mostly basaltic and vitric, and a lower member which is quartzitic, micaceous, and arkosic. Projecting downstream the channel direction from where the Troutdale Formation is exposed in the canyon of Bridal Veil Creek, the Troutdale Formation is exposed

in the vicinity of Mt. Pleasant (Tolan, 1982, personal communication). A pebble count and grain mount sample were collected in this area. The samples came from high in the section, since the sample localities were within approximately 50 vertical meters of the overlying Boring Lavas. If in fact this is high in the section, then the rocks should exhibit basaltic and vitric characteristics of Tolan's upper member. Tables IV and VII show that the compositional characteristics of the Troutdale Formation here is quartzitic, micaceous, and arkosic, like Tolan's lower member. Further work is needed to establish whether the Troutdale Formation here is correlative with Tolan's lower member of the Troutdale Formation.

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APPENDIX

GEOCHEMICAL DATA ON BASALT CLAST SAMPLES

(First value is ppm unless % indicated, second value is error value)

FIRST COUNT

Sample	Sm		Lu		La		Yb		Sb		Sc	
1	6.99	0.08	0.51	0.08	25.20	0.70	3.20	0.50	0.20	0.30	37.80	0.30
2	5.86	0.07	0.29	0.07	21.50	0.60	3.50	0.40	0.30	0.20	37.80	0.30
3	4.92	0.07	0.26	0.07	18.00	0.50	2.70	0.40	0.20	0.20	37.00	0.30
4	6.92	0.08	0.39	0.08	26.60	0.70	3.40	0.50	0.20	0.30	39.10	0.30
5	5.06	0.07	0.31	0.07	17.30	0.60	3.50	0.50	0.20	0.20	38.50	0.30
6	6.65	0.09	0.33	0.08	22.80	0.70	3.40	0.50	0.30	0.30	41.00	0.40
7	6.31	0.08	0.19	0.07	21.00	0.70	1.80	0.40	0.50	0.30	26.90	0.30
8	6.29	0.08	0.30	0.09	20.20	0.70	3.80	0.50	0.40	0.30	44.20	0.40
9	5.89	0.08	0.26	0.07	21.10	0.60	2.90	0.40	0.40	0.30	33.30	0.30
Std.	6.60	0.05	0.55	0.05	26.00	0.40	3.40	0.30	0.69	0.17	33.00	0.18

FIRST COUNT (CONTINUED)

Sample	Fe %		Co		Na %		K %	
1	10.03	0.20	39.00	3.00	2.40	0.02	1.40	0.80
2	8.36	0.17	36.00	3.00	2.23	0.02	0.60	0.60
3	7.76	0.17	33.00	2.00	2.11	0.02	2.10	0.80
4	9.40	0.20	36.00	3.00	2.47	0.02	1.10	0.80
5	7.60	0.17	31.00	2.00	2.12	0.02	1.80	0.80
6	10.10	0.20	40.00	3.00	2.43	0.02	1.10	0.90
7	7.66	0.19	39.00	3.00	3.10	0.03	0.50	0.90
8	10.30	0.20	42.00	3.00	2.34	0.02	0.80	0.80
9	7.85	0.18	34.00	2.00	2.35	0.02	1.60	0.80
Std.	9.37	0.11	38.00	1.50	2.43	0.01	1.40	0.50

APPENDIX (CONTINUED)

SECOND COUNT

Sample	Yb		Nd		Eu		Ce		Lu		Ba	
1	3.50	0.50	31.00	5.00	2.15	0.10	59.00	2.00	0.63	0.10	890.00	190.00
2	3.60	0.40	29.00	4.00	1.95	0.09	53.00	2.00	0.61	0.09	760.00	160.00
3	2.90	0.40	31.00	4.00	1.81	0.08	48.00	2.00	0.60	0.09	580.00	160.00
4	3.60	0.50	31.00	5.00	2.53	0.10	62.00	2.00	0.66	0.10	930.00	190.00
5	2.90	0.40	29.00	4.00	1.90	0.09	45.00	2.00	0.65	0.10	520.00	160.00
6	3.30	0.50	36.00	5.00	2.19	0.10	62.00	3.00	0.63	0.11	670.00	200.00
7	2.90	0.40	24.00	4.00	1.97	0.09	56.00	2.00	0.57	0.09	420.00	150.00
8	2.90	0.50	26.00	5.00	2.27	0.11	57.00	3.00	0.63	0.11	900.00	200.00
9	2.80	0.40	18.00	4.00	2.04	0.09	52.00	2.00	0.56	0.09	790.00	190.00
Std.	3.40	0.40	29.00	4.00	1.94	0.07	53.90	1.80	0.55	0.08	670.00	140.00

SECOND COUNT (CONTINUED)

Sample	Cr		Hf		Sc		Fe %		Co		Th	
1	26.00	8.00	4.60	0.60	39.50	0.20	11.32	0.11	44.20	1.20	6.90	0.50
2	12.00	5.00	5.00	0.60	35.79	0.19	9.65	0.10	41.40	1.00	6.10	0.40
3	60.00	13.00	4.40	0.60	39.60	0.20	8.95	0.09	42.10	1.10	3.30	0.40
4	23.00	7.00	6.00	0.70	41.80	0.20	10.53	0.11	46.80	1.20	7.00	0.50
5	83.00	18.00	4.60	0.60	42.00	0.20	8.96	0.09	40.40	1.10	3.90	0.40
6	27.00	8.00	5.20	0.70	43.70	0.20	11.47	0.12	47.30	1.30	4.80	0.50
7	180.00	40.00	5.30	0.60	27.65	0.18	8.44	0.10	42.10	1.10	2.10	0.30
8	63.00	14.00	4.10	0.70	45.70	0.20	11.35	0.12	48.80	1.30	3.60	0.40
9	19.00	7.00	4.60	0.60	34.94	0.20	9.07	0.10	40.00	1.10	5.60	0.40
Std.	18.00	5.00	4.70	0.50	33.00	0.15	9.37	0.08	38.00	0.80	6.00	0.30