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Geophysical and geological analysis of a fault-like linearity in the lower Clackamas River area, Clackamas County, Oregon

Ronald Jay Schmela
Portland State University

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AN ABSTRACT OF THE THESIS OF Ronald Jay Schmela for the Master of Science in Earth Science presented September 10, 1971.

Title: Geophysical and Geological Analysis of a Fault-like Linearity in the Lower Clackamas River Area, Clackamas County, Oregon.

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

[redacted]

Leonard A. Palmer, Chairman

[redacted]

John E. Allen

[redacted]

Dan J. Cash

[redacted]

Dale E. Courtney

A fault-like linearity along the lower Clackamas River is evaluated by analysis of physiographic and structural alignments, geological relationships, and by gravity and magnetic data. The study has resulted in the verification of a structural feature extending along the Clackamas River and the eastern front of the Portland Hills.

Physiographic alignments were examined in twelve 15 minute and two 7-1/2 minute quadrangle maps. A significant northeasterly morphologic trend, N. 20° W. and N. 40° W., and other secondary trends, namely, the N-S, E-W, and N. 50-60° E., has developed in the Portland area. The consistent northwest trend is observed throughout the entire area studied which strongly suggests that the alignments are very good indicators of underlying structural features.

Structural alignments show that approximately 60% of the known mapped faults and fold axes concur with the dominant northwest physiographic trend. Seismic first motion analysis supports the established morphologic trend.

A series of regionally co-aligned morphologic and structural features striking S. 40-50° E. across the state of Oregon suggest the presence of a major structural fault system aligned with the Portland Hills-Clackamas River structural alignment.

The geologic cross sections developed from map and well data generally lack any tangible evidence as to the nature of the physiographic alignment. An apparent offset of the lower Pliocene Sandy River mudstone suggests movement as recent as middle Pliocene.

Geophysical information was obtained from six gravity traverses and three magnetic traverses. The consistency of the size and shape of the gravity anomaly, 2.18 milligals/0.2 mile, downdropped to the east, across the physiographic alignment defines the zone of a fault or a steep fold developed in the Columbia River basalt. The magnetic anomalies show a consistent change in the magnetic gradient corresponding to the structural zone.

VITA

The writer, Ronald Jay Schmela, was born in Pasadena, California on April 15, 1945. He graduated from Ventura High School, Ventura, California in June, 1963. He received his Bachelor of Science degree from the University of Redlands, Redlands, California in June, 1967. In 1969, he enlisted in the Oregon National Guard while attending the University of Oregon as a graduate student. Afterward he transferred to Portland State University in September, 1969 and has since been a graduate student.

GEOPHYSICAL AND GEOLOGICAL ANALYSIS OF A FAULT-LIKE LINEARITY IN THE LOWER CLACKAMAS RIVER AREA, CLACKAMAS COUNTY, OREGON

by

RONALD JAY SCHMELA

A thesis submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE
in
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1971

TO THE OFFICE OF GRADUATE STUDIES:

The members of the Committee approve the thesis of Ronald Jay Schmela presented September 10, 1971.

[redacted]

Leonard A. Palmer, Chairman

[redacted]

Dan J. Cash

[redacted]

Dale E. Courtney

APPROVED:

[redacted]

John E. Allen, Head, Earth Science

[redacted]

David T. Clark, Dean of Graduate Studies

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INTRODUCTION

Purpose and Scope

A fault-like linearity along the lower Clackamas River is evaluated by analysis of physiographic and structural alignments, geological relationships and by gravity and magnetic data. The objective of this investigation is to provide data which may verify the existence of a structural feature extending along the Clackamas River and the eastern front of the Portland Hills. Lava flows, alluvium and vegetation obscure the nature of the linearity thus requiring the use of indirect physiographic and geophysical methods.

To obtain the necessary data, twelve 15 minute and two 7-1/2 minute quadrangle maps were examined for physiographic alignments. Geophysical information was obtained from 6 gravity traverses, averaging 2 miles in length. The 166 gravity stations and 50 magnetic stations are plotted as cross profiles, correlated to surface geology. Geologic information was obtained from previous studies, especially from a report by Trimble (1963) and from analysis of well logs.

Location and Planimetric Base Control

The physiographic investigation included about 2623 square miles in northwestern Oregon and southwestern Washington as shown in figure 1. Physiographic alignments were plotted from twelve of sixteen 15 minute quadrangles bounded by 122°00' and 123°00' west longitude and 45°00' and 46°00' north latitude and two 7-1/2 minute quadrangles bounded by 122°45' and 123°00' west longitude and 46°00' and 46°7.5' north latitude.

The geophysical studies were conducted in a rectangular area, approximately 75 square miles, bounded between the following geographic points also shown on figure 1.

West Longitude	North Latitude
(1) 122°41'	45°24'
(2) 122°38'	45°28'
(3) 122°17'	45°18'
(4) 122°20'	45°14'

The six gravity traverses have been given locational names. Their location and the approximate location of each gravity station is indicated in figure 2. Starting from the northwest end of the investigated geophysical area the traverse names are: (1) Milwaukie, (2) Gladstone, (3) Redland, (4) Transmission Line, (5) Paradise Park, and (6) Estacada Traverse. All gravity stations were located by reference to U. S. Geological Survey 7-1/2 minute quadrangle

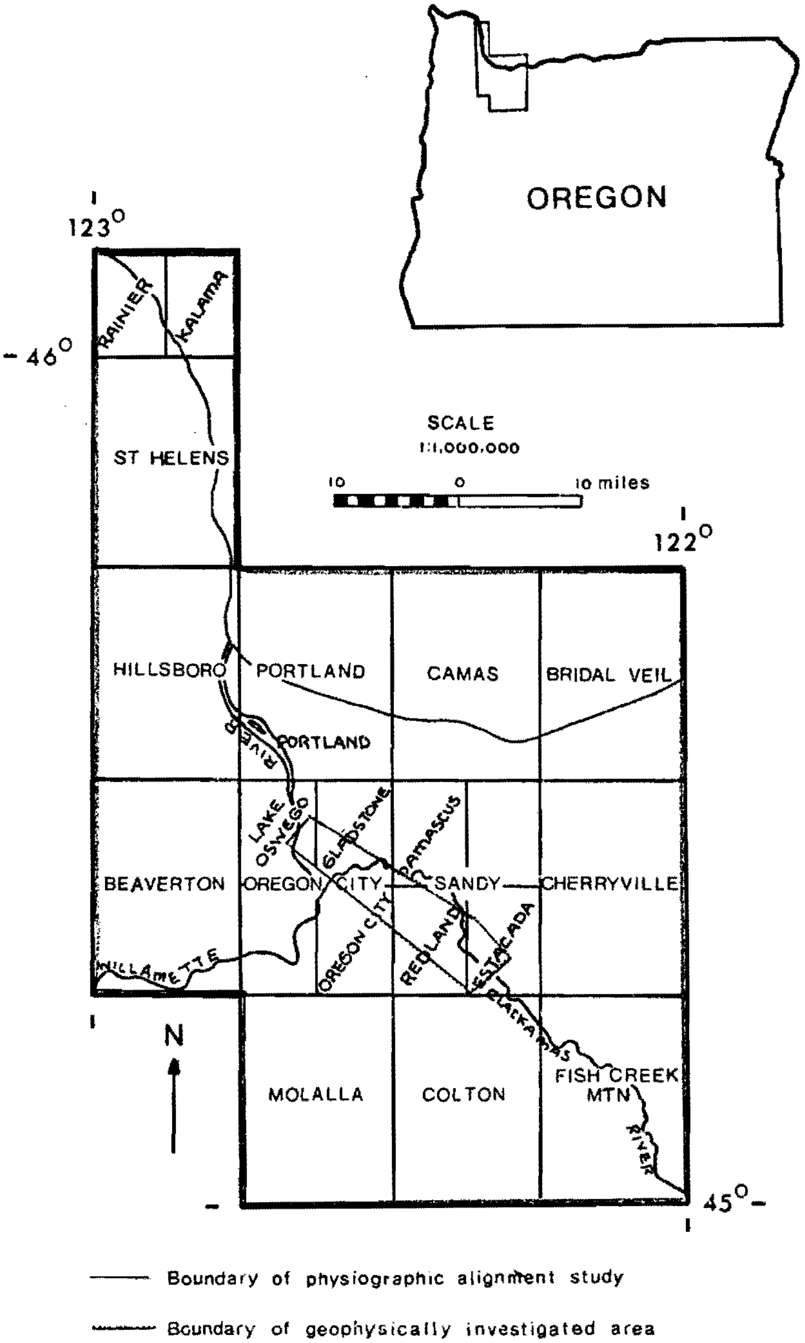


Figure 1. Location map.

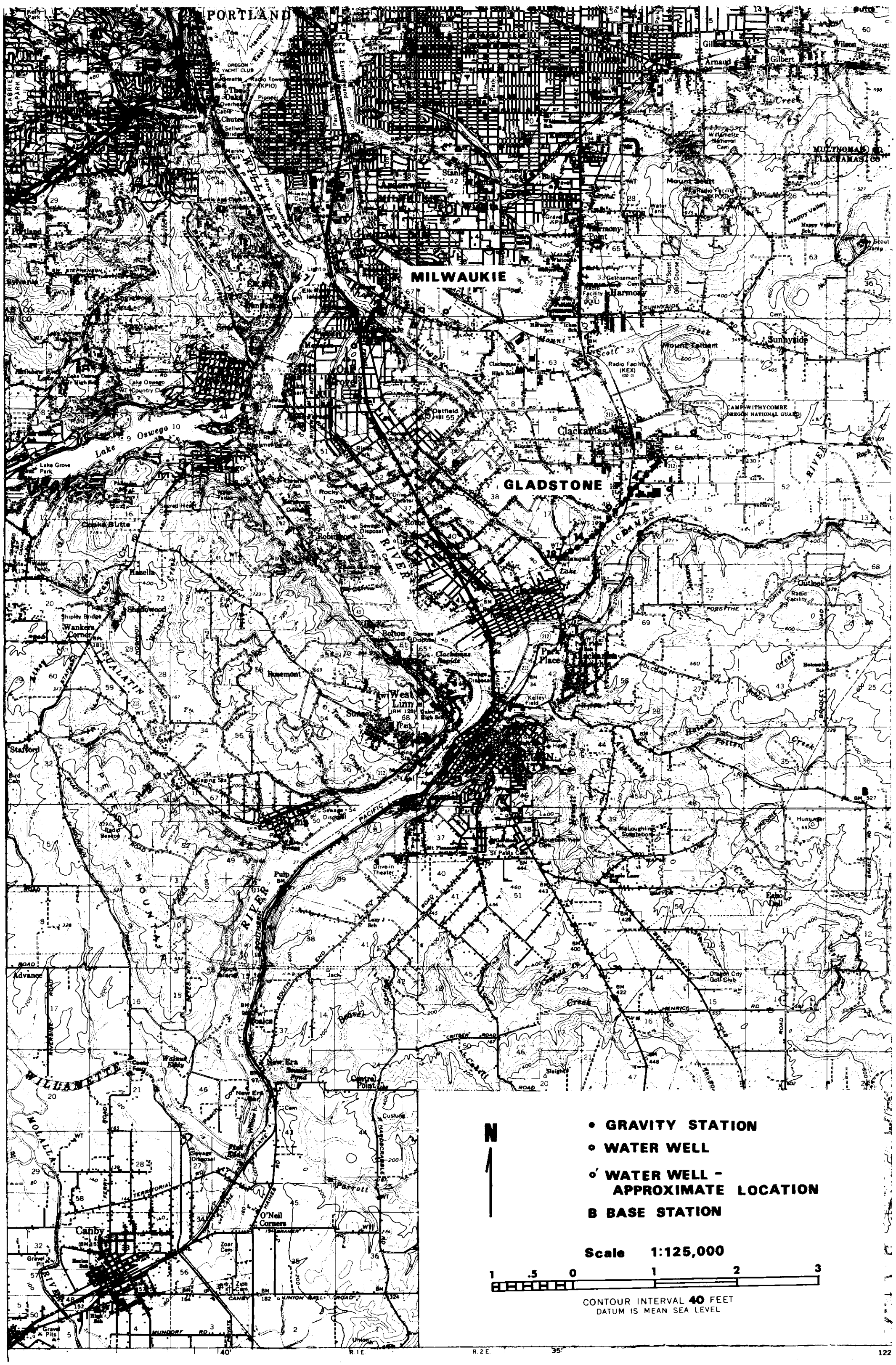


Figure 2. Location of gravity traverses, gravity stations, and water wells.

maps, namely, Lake Oswego, Gladstone, Damascus, Oregon City, Redlands, and Estacada.

All base stations were located from existing bench marks established by (1) U. S. Geological Survey, (2) U. S. Coast and Geodetic Survey, or (3) City of Portland. A full description of these bench marks is listed in Appendix I.

Elevation and terrain corrections were estimated in parts or all of the Hillsboro, Portland, Camas, Bridal Veil, Beaverton, Oregon City, Sandy, Cherryville, Molalla, Colton, and Fish Creek 15 minute quadrangle sheets.

The three magnetic traverses have been given locational names. Their location and the approximate location of each magnetic station is indicated in figure 3. From the northwest end of the geophysically investigated area the traverse names are: (1) Gladstone-M (M stands for magnetic), (2) Fischers Mill-M, and (3) Estacada-M Traverse.

Previous Work

Several geologic reconnaissance investigations have been conducted in the general area under study. Diller, who was first to believe a fault fronted the Tualatin Mountains (Portland Hills), studied the area in 1896 and later in 1915. Darton (1909), Washburne (1914), Williams (1916), Treasher (1924b), Gilchrist (1952), Elsey (1955) and others have made limited geologic studies in the area.

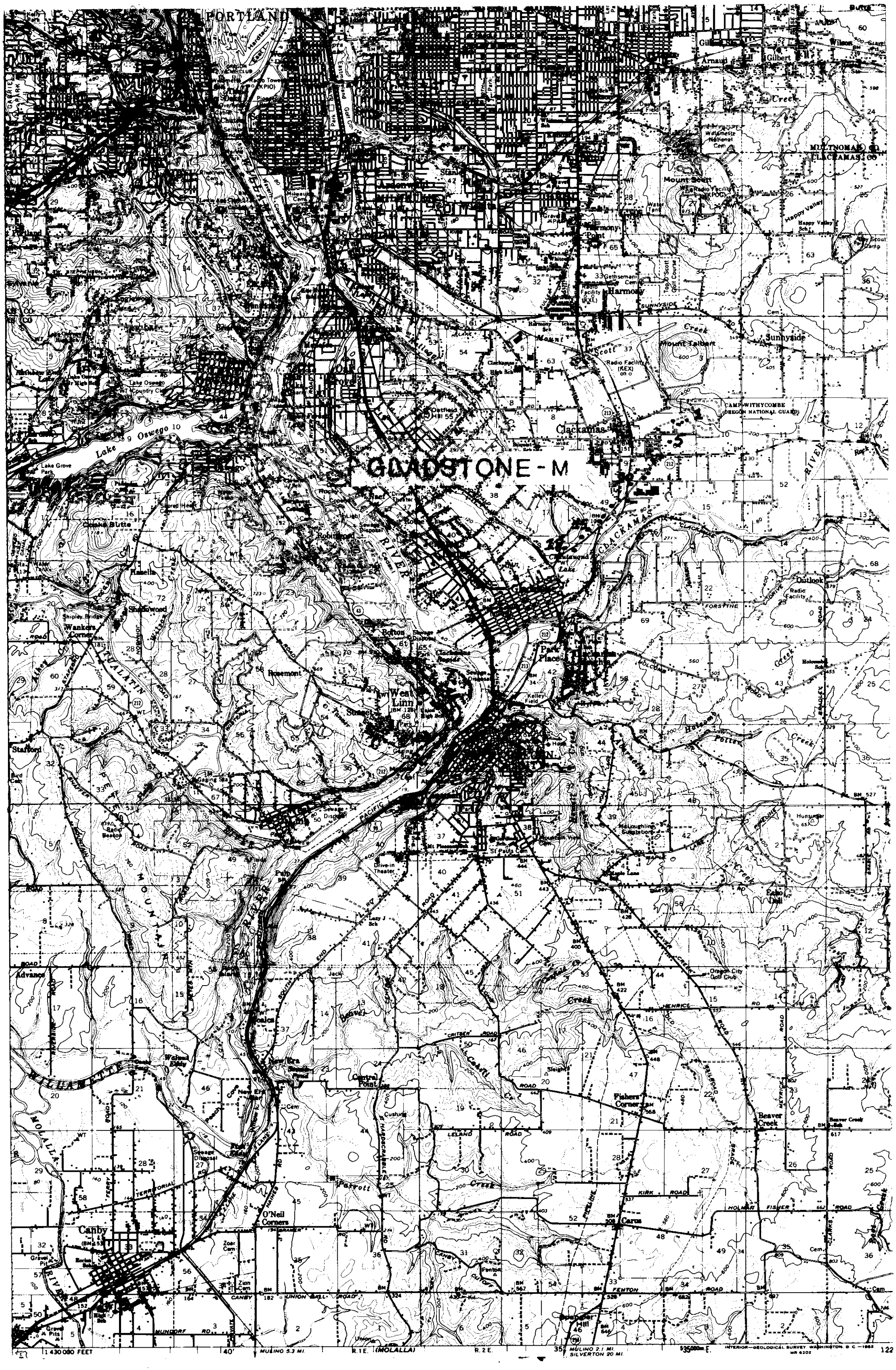


Figure 3. Location of magnetic traverses and magnetic stations.

Recent geologic studies since about 1955 have been more detailed than their predecessors. The first comprehensive study was conducted by Trimble (1957 and 1963). Peck and others (1964) studied the northern part of the Western Cascade Range in Oregon and Snavely and Wagner (1964) conducted a geologic sketch of northwestern Oregon. Wells and Peck (1961) published a Geologic Map of Oregon West of the 121st Meridian. The Troutdale formation was first described by Hodge (1938). Treasher (1942b) published a reconnaissance map covering the Portland, Camas, Oregon City, and Sandy quadrangles.

Brief historical accounts which include the Portland area are contained within publications by Hodge (1933), Treasher (1942a), Stauffer (1956), Baldwin (1957 and 1964), Snavely and Wagner (1963), Trimble (1963), Mackin and Cary (1965), and Hogenson and Foxworthy (1965). The effects of the Spokane (Missoula) Flood have been reviewed by Bretz (1925, 1928, 1956, and 1959) and Allison (1932, 1933, and 1935).

Earthquake studies in the region include those made of the November 5, 1962 earthquake by Dehlinger and Berg (1962), Westphal (1962), and Dehlinger and others (1963). The January 27, 1968 and May 13, 1968 Portland earthquakes have been studied by Heinrichs and Pietrafesa (1968) and Couch and others (1968), respectively. Schlicker and others (1964) studied the earthquake geology of the

Portland area; Berg and Baker (1963) reviewed Oregon earthquakes from 1841 to 1958 and Couch and Lowell (1971) studied the earthquakes and seismic energy release in Oregon.

Gravity studies in the area include absolute gravity stations established in Oregon at the Portland International Airport and at the Portland Custom House by Wollard (1958). Woollard and Rose (1963) published a regional Bouguer gravity map for the state of Oregon. More recent regional gravity studies in Oregon have been conducted by Berg and Thiruvathukal (1965, 1967a, 1967b, and 1967c), Thiruvathukal and Berg (1966), Thiruvathukal, Berg, and Henricks (1970). Bromery and Snavely (1964) and Blank (1966) discuss geophysical surveys in western Oregon.

General references on geophysical techniques as used in this study are discussed in texts such as Nettleton (1940), Heiskanen and Meinesz (1958), Gutenberg (1959), Dobrin (1960), and Heiland (1968). Density determination for gravimeter observations is given by Nettleton (1939). Hammer (1939) and Sandberg (1958) discuss terrain correction techniques. Interpretation of anomalies is discussed by Nettleton (1940, 1942, and 1954), Dobrin (1960, and Skeels (1963).

Fieldwork

Fieldwork was done during winter and spring of 1971 with some preliminary work fall, 1970. The fieldwork involved establishing lateral and vertical control and making instrument readings.

Lateral and vertical control was established by use of an automobile odometer and by reference to physiographic and topographic features on the 7-1/2 minute quadrangle maps. Use of a Paulin microaltimeter was not practical due to diurnal barometric fluctuations. To assure the detail of the local gravity and magnetic anomalies a station spacing with one tenth mile interval was established. The gravity and magnetic stations were located for convenient access. The routes of the traverses are located upon established roads in the area. The Transmission Line traverse, however, was conducted entirely off surface roads. Topographic description of this line, the John Day-Keeler No. 1, was supplied by Portland General Electric. The description greatly facilitated the correct location of each station along the line.

The instrument readings for gravity were made from a Worden[1] gravity meter - Master Model (Meter No. 575) loaned by the Department of Oceanography at Oregon State University. The instrument has a sensitivity of .1037 milligals per division (ABSOLUTE). The meter is self-compensating for normal ambient temperature changes but can be operated with or without thermostating. For the purpose of this study, the sensitivity of the instrument is excellent. The

---

[1] Trademark of Texas Instruments Incorporated

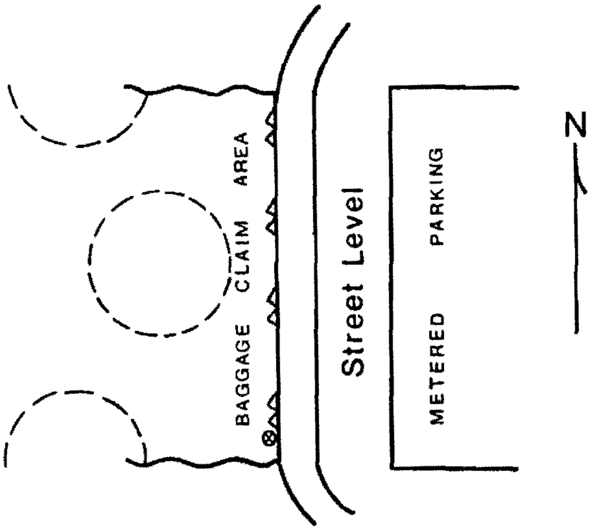
instrument is able to detect gravity differences as low as 0.01 milligals.

Closed loop traverses were made on all observed readings to correct for instrument drift, earth tides, and other factors that might influence the observed reading. Gravimetric field observations were planned with assistance and advice from Dr. Richard Couch, Oregon State University. The method is described in more detail under drift corrections.

Two existing absolute gravity stations were occupied so that the study could be tied to a national gravity network. This allows correction of values to terms of absolute gravity. The absolute gravity stations that were established by Woollard (1958) are located at Portland International Airport and at the Portland Custom House (figure 4). The corrected values are 980648.24 and 980647.23 milligals, respectively (Woollard, 1958).

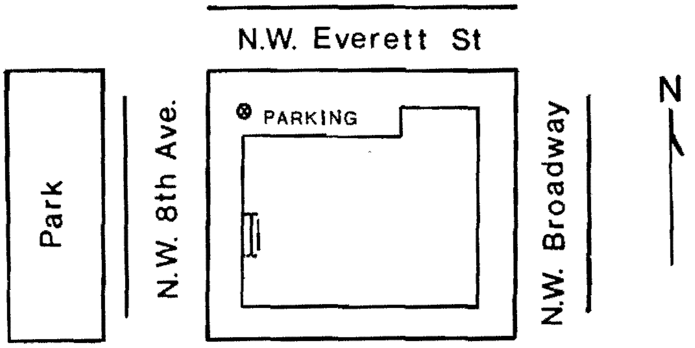
A Model MF-1[2] fluxgate magnetometer loaned by the Center of Volcanology of the University of Oregon was used to obtain the magnetic data. The instrument has a maximum total range of ± 100,000 gammas. The meter is a vertical component magnetometer which is self-compensated for temperature variations and requires no directional orientation. The instrument reads directly in gammas. The

[2] GISCO - Geophysical Instrument and Supply Company



PORTLAND INTERNATIONAL AIRPORT

980648.24



PORTAND CUSTOM HOUSE

980647.23

Figure 4. Location of gravity base stations in Portland, Oregon (after Rinehart and others, 1964; gravity values after Berg and Thiruvathukal, 1965).

operation of the magnetometer was conducted under guidance of Dr. Richard Blank, University of Oregon.

In order to correct for diurnal variations and other factors influencing the observed readings, the magnetic stations were occupied using the closed loop traverse method described for the gravity meter.

All data for both the gravity meter and the magnetometer are presented in Appendix IV and V. All elevations are in feet above mean sea level. All gravity and magnetic readings have been corrected for drift and diurnal variations.

PHYSIOGRAPHIC AND STRUCTURAL ALIGNMENTS

Morphological analysis of linear landforms represented on topographic maps was performed to evaluate alignments for structural significance. Twelve 15 minute and two 7-1/2 minute U. S. Geological Survey topographic quadrangle maps were studied and analyzed for quantitative distribution of length and orientation of alignments. Geologic maps were similarly evaluated for orientation of faults and fold axes and compared to the morphologically determined orientations.

Linear landforms may be significant indicators of the underlying geological structures. Differential erosion commonly reflects alignments such as faults, joints, or bedding (Ray, 1960; von Bandat, 1962).

The method used in analyzing linear landforms is not complicated and is not subject to significant interpreter bias. The procedure used in this study is illustrated in figure 5 and is as follows:

(1) Preliminary marking of all linear landforms on the topographic map longer than an arbitrary minimum preselected length of about 1/2 inch. The linear features include stream courses, ridge crests, and linear breaks in slope angle.

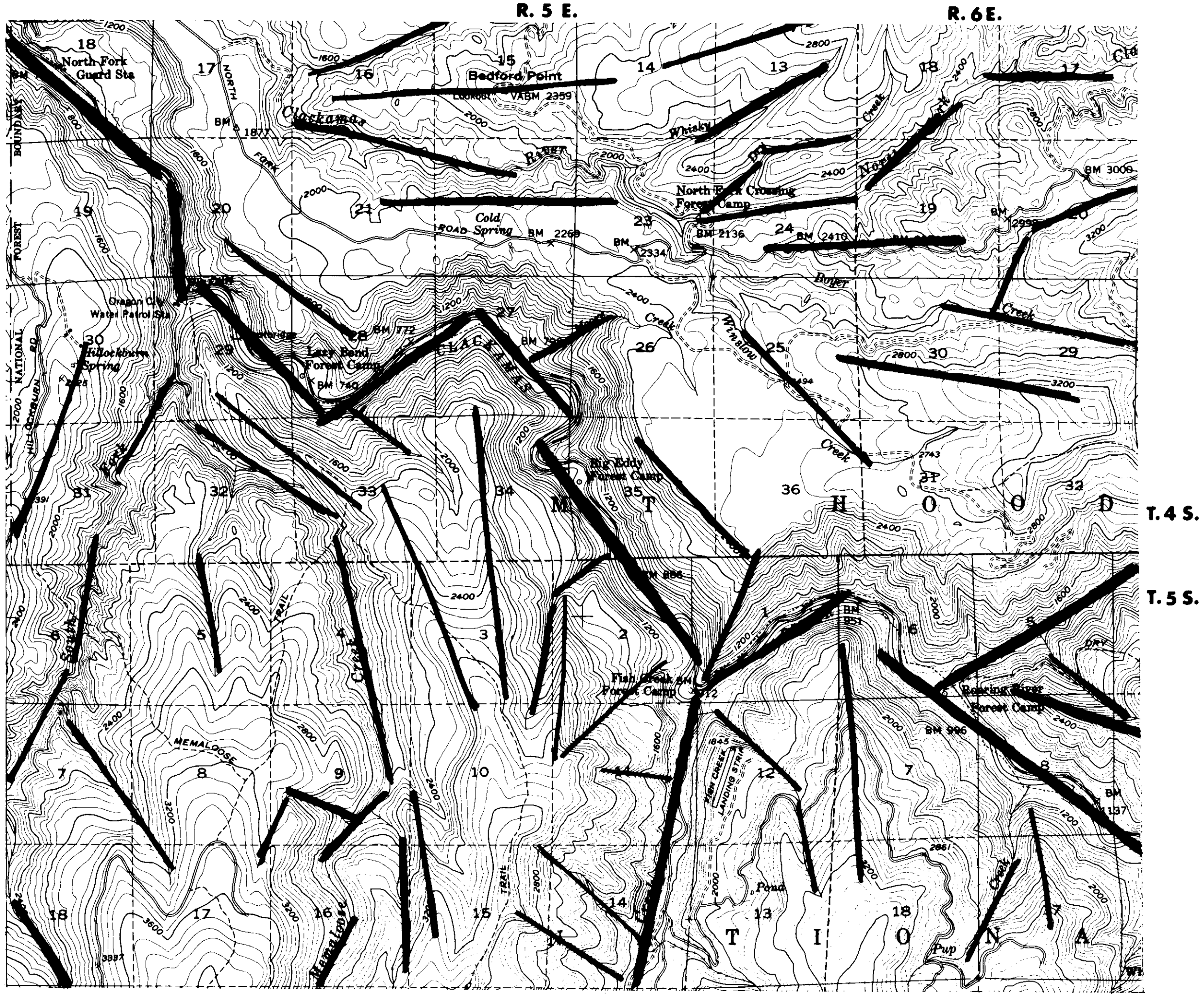


Figure 5. Demarcation of physiographic alignments. Portion of Fish Creek Mountain 15' quadrangle map.

(2) Measurements of length and orientation of each linear feature are tabulated in 10 degree orientation subdivisions for each quadrangle map.

(3) Calculation of percentage fraction of lineation lengths for each 10 degree subdivision for each map.

(4) Graphical plotting of alignment statistics in rose-type diagrams for each map.

(5) Summation of alignments for all maps into a composite rose diagram.

(6) Comparison with mapped faults and folds is done using steps 2 through 5 on published fault lines.

This procedure was followed for each of the 14 topographic maps and is tabulated in figure 6.

Anomalies from random orientation are believed to reflect the regional structural alignment of the area. In analyzing the fourteen quadrangles (figure 6, summary diagram) a strong regional preferred orientation is shown to be N. 20° and 40° W. There also exists a less prominent N-S and N. 50° E. preferred orientation. The prominence of the northwest trend over all other directions suggests significant underlying structural orientations.

Further confirmation of the structural significance of the northwesterly morphological trend is shown by the similarity to orientation of known fault trends, regional trends of fold axes, and trends

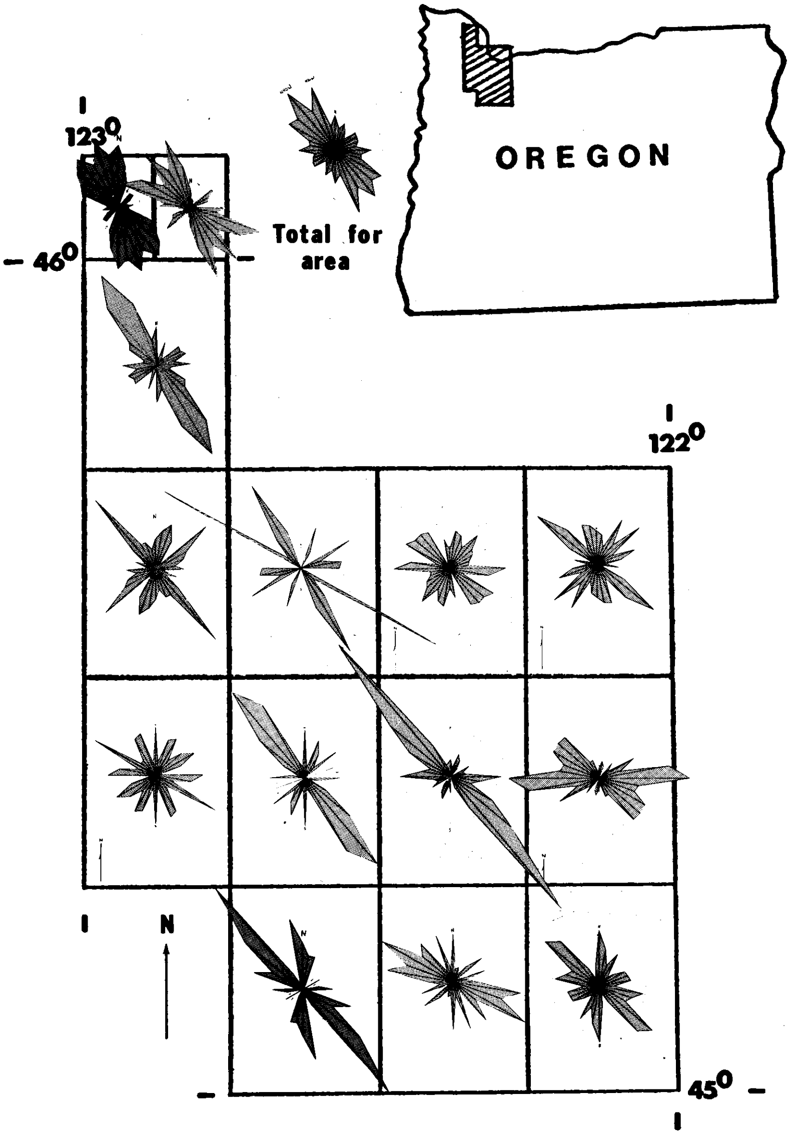


Figure 6. Orientation-length distribution of physiographic alignments measured in individual quadrangle sheets. Summary diagram represented by "total for area." Quadrangle names are listed on the location map, figure 1.

determined by seismic first motion analyses in the area. Faults that have been mapped in the Portland area show a very strong preferred orientation of N. 40° W. (figure 7). Secondary preferred orientations of N-S and N. 50° E. occur.

The regional trends of fold axes also reflect the dominant northwest trend. The structural folds generally prefer an orientation of N. 40-45° W.

Seismic first motion analysis of the November 5, 1962 Portland earthquake suggests a motion source of a northwest-trending, right-lateral strike-slip fault. The source motion data, however, fits a northeast-trending, left-lateral strike-slip fault equally as well (Dehlinger and others, 1963). Westphal (1962) suggested that the seismic activity was related to the Portland Hills fault. Gallagher (1969) indicates that the motion from the November 5 earthquake occurred along a normal fault striking N. 54° E. or along a right-lateral strike-slip fault striking N. 12° W. The motion analysis was reported most consistent with the N. 54° E. trending fault. This generally agrees with the secondary morphological and structural trend. The N. 12° W. trend, however, falls somewhat to the north of the major morphological and geologic trend in the area.

In general, the various Portland-area geologic alignment trends are consistently sympathetic and parallel to the Portland Hills fault and the Clackamas River alignment.

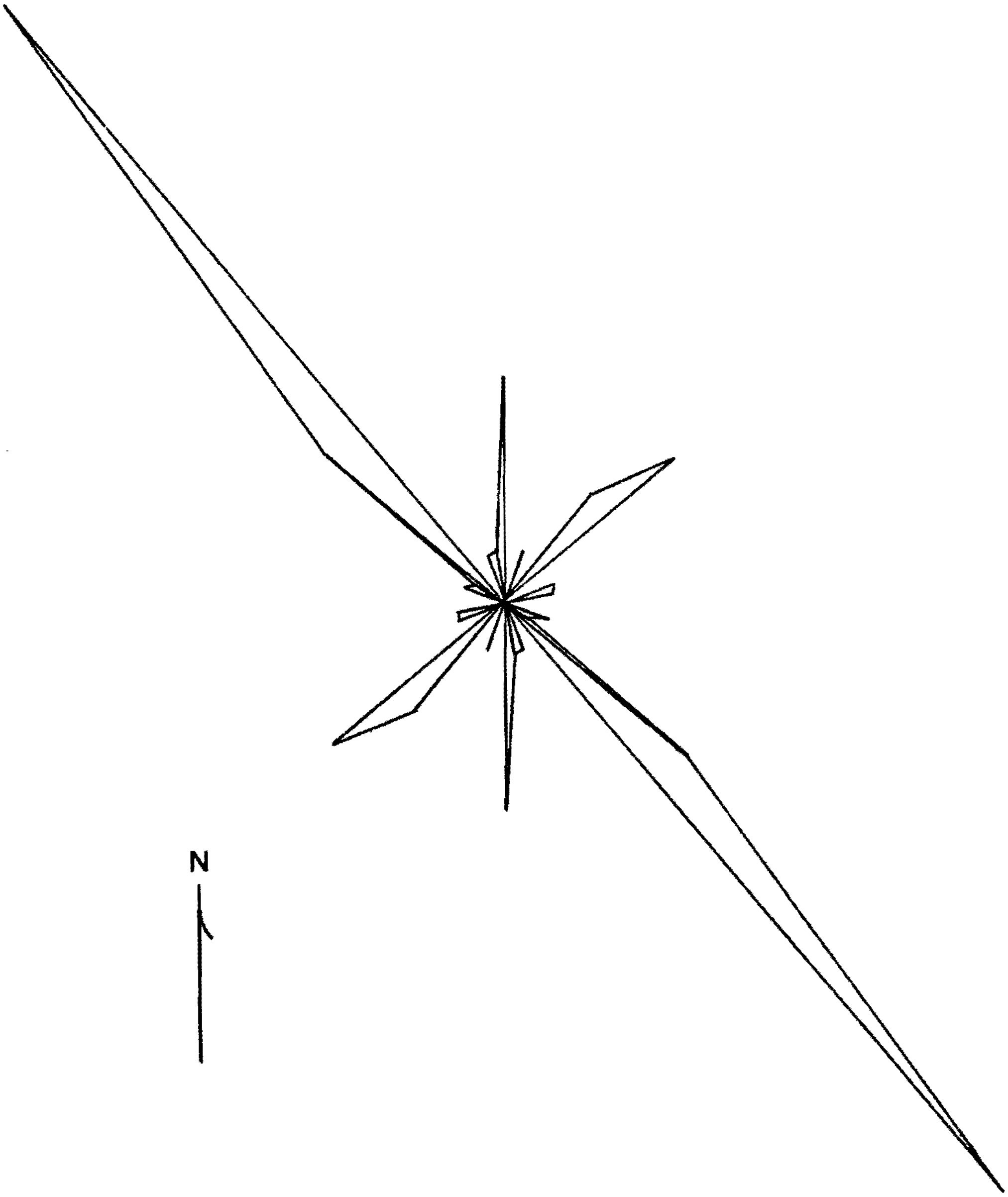


Figure 7. Orientation-length distribution of mapped faults in the Portland area (using data from Schlicker and Deacon, 1967).

Further confirmation of the significance of the northwesterly morphological trend is shown by a series of co-aligned linear morphologic features extending over 300 miles southeasterly across the state of Oregon. The regional features co-align with the Portland trend and include segments of the Metolius River, Crooked River, and the southern edge of Hampton Buttes. These prominent linear features align themselves in a general N. 40-50° W. S. 40-50° E. trend across the state of Oregon. The alignment is readily seen on the state 1:250,000 relief map, vertical exaggeration 2:1.

The geologic map of Oregon (Walker and King, 1969) shows numerous faults with a general regional trend of N. 40-50° W. occuring along the above mentioned trend.(figure 8). The Brothers fault zone is one segment of the co-linear features (Higgins and Waters, 1967). It is believed that the normal faults associated with the Brothers fault zone and the small monoclinal folds to the faults are a surface reflection of a deeply buried fault with lateral displacement (Walker, 1969). Furthermore, several volcanic vents are concentrated along this segment of the state wide alignment. These vents are generally of Pliocene and Pleistocene age, however, some may be as late as Miocene and early Holocene age which indicates the span of time associated with this area of crustal disturbance (Walker, 1969).

The significance of the dominant trend in the Portland area

Compiled by G. W. Walker and P. B. King, U.S. Geological Survey, in cooperation with Oregon Department of Geology and Mineral Industries, 1967

Figure 8. Geologic map of Oregon (Walker and King, 1969).

EXPLANATION

SEDIMENTARY AND VOLCANIC ROCKS

Quaternary alluvium, lake sediments, fluvio-glacial deposits, and pumice

Late Cenozoic basalt and andesite

Andesite and basalt of High Cascade Range

Younger Cenozoic (post-early Miocene) marine sedimentary and minor volcanic rocks

Younger Cenozoic (Miocene and Pliocene) nonmarine (continental) sedimentary rocks, ash-flow tuffs, some interbedded rhyolite flows and domes

Younger Cenozoic (Miocene and Pliocene) basalt and andesite flows and minor continental sedimentary rocks

Younger Cenozoic (Miocene and Pliocene) sedimentary and volcanic rocks, undivided

Older Cenozoic marine and estuarine sedimentary rocks and minor volcanic rocks

Older Cenozoic marine and nonmarine basaltic and andesitic flows and tuffs; includes related intrusive rocks

Older Cenozoic (Eocene, Oligocene, and early Miocene) volcanic and continental sedimentary rocks

Late Mesozoic sedimentary rocks

Mesozoic sedimentary and minor volcanic rocks in southwest Oregon (Dothan Formation). Pre- or post-Nevadan; in places metamorphosed

Mesozoic sedimentary and volcanic rocks older than Kimmeridgian (pre-Nevadan orogeny); in places strongly metamorphosed

Permian and Triassic sedimentary and volcanic rocks; in places strongly metamorphosed

Paleozoic sedimentary rocks; in places strongly metamorphosed

INTRUSIVE IGNEOUS ROCKS

Cenozoic gabbro and diabase

Granitic rocks, chiefly of Mesozoic age

Ultramafic and gabbroic rocks, chiefly of Mesozoic age

Major volcanic vents and domes of Cenozoic age

Large volcanic craters

Contact

Fault, dotted where concealed

appears to be supported by the physiographic and structural alignments, and by seismic first motion analysis. The indication of a major regional aligned fault is shown by co-aligned topographic features which are parallel to the mapped faults in the area. Therefore, it is believed that this strikingly linear feature may be indicative of a structural feature of major importance.

The time of origin and mechanism of the structural alignment is not well known. Mackin and Cary (1965) have shown major trend development along a northwest-southeast alignment resulting from the folding of the Eocene Weaver Plain. They indicate that the recent alignments are trends developed from the ancestral Calkins Range, named by Mackin and Cary (1965), a range dominant during Oligocene time in the Pacific Northwest region. Mackin and Cary believe that the Calkins Range represents "the last of a long series of crustal yieldings along this fundamental pre-Cascade direction."

The present morphologic trends may be a reflection of continued weakness in younger rock units along pre-established structural alignments. The further study of these linear features may bring new light to buried structures in the older rocks now covered with volcanics.

The preferred northwest orientation of the physiographic alignments is not in itself conclusive evidence for interpretation of the geologic structure. This statistical analysis method is intended as a preliminary indicator of probable structural features to guide geologic studies. However, the consistency and parallelism of geologic and seismic alignments strengthen the interpretation that it represents a geologic structural trend of major significance.

GEOLOGICAL INVESTIGATIONS

Geologic data was derived primarily from previous investigations, namely, Trimble (1963) and well logs on file at the office of the Oregon State Engineer, Salem, Oregon. The local geology and structure are briefly described in Appendix II. Appendix VI contains 50 of the deepest and most representative of the well logs used in constructing the geologic cross sections, figures 19 through 25 in map pocket. The drillers' logs have been interpreted for formational separation and edited for clarity of teminology and composition. The wells described in Appendix VI are located in figure 2.

Lithologic differences used in recognition of Miocene and Pliocene formational contracts are important to show geologic horizons in construction of the geologic cross sections. The depth of the Miocene Columbia River basalt is important to this investigation because the gravity and magnetic anomalies are based upon its presence below ground surface. The post Troutdale formations are primary indicators of recent rejuvenation of the Clackamas River. The well logs provide good data on the Pliocene units and their contacts, but poor data on the Columbia River basalt due to too few deep wells penetrating into the basalt.

GEOPHYSICAL METHODS

Gravimetric

Gravimetric information was obtained from six gravity traverses with a total of 166 gravity stations. A Worden gravity meter was used to test the possible presence of a consistent gravity anomaly across the observed physiographic alignment along a line co-linear with the eastern front of the Portland Hills and the Clackamas River. It is believed that the existence of an anomaly in this locality could be due to either a fault or a steep fold in the Columbia River basalt.

Gravitational anomalies result from lateral variations in the gravitational pull of the earth caused by contrasting near-surface densities. Sedimentary rocks are usually less dense than igneous formations. Locally, the density of the Columbia River basalt is from 2.72 to 2.94, averaging 2.84 gm/cc (data from Schlicker and Deacon, 1967). The sedimentary formations are estimated to be less than 2.4 gm/cc.

To use the gravity data for structural interpretation a series of corrections must be performed to correct for the station elevation, local topography, latitude, and instrument drift. The correction procedure is discussed in Appendix II - Gravity Reductions, and the corrected values are presented in Appendix III and shown graphically in profile on figures 19 through 25 in map pocket.

Magnetic

Magnetic data was obtained on three traverses with a total of 50 magnetic stations. A fluxgate magnetometer was used to examine the topographic alignment for a possible consistent magnetic anomaly.

All rock masses and rock types vary in their magnetic susceptibility due primarily to their content of magnetite and ilmenite. The magnetic susceptibility of sedimentary rocks is small as compared to igneous rocks (Dobrin, 1960). The existence of a magnetic anomaly in the investigated area would probably be due to change in depth of occurrence of the Columbia River basalt rather than to geometric changes in the overlying sedimentary rocks. It is possible, however, that an irregular distribution of magnetite in the overlying sedimentary units may alter the magnetic anomaly due to the Columbia River basalt.

The magnetic data has been corrected for diurnal fluctuations by applying the closed loop method as discussed under drift corrections for the gravity measurements. The corrected values are listed in Appendix IV and shown graphically in profile in figures 20, 24, and 25.

INTERPRETATIONS

Physiographic and structural alignments, geological relationships, gravity data, and magnetic data are analyzed for the possible existence of a structural feature aligned with the Clackamas River and the eastern front of the Portland Hills.

Physiographic and Structural Alignments

Physiographic alignments are significant in the Portland area as shown by the agreement with known structural trends. The degree of reliability of the physiographic alignments is dependent upon the unbiased and representative physiographic sample and the representation of known structure. It is my opinion that it would be difficult to bias the physiographic alignment selection by more than 5%. Furthermore, I expect that the known structure is not biased for any orientation.

The physiographic rose-type diagrams, figures 6 and 9, show that of all the physiographic alignments 50% represent the general northwest trend; nearly 25% represent the N. 20° W. and the N. 40° W. trend; and 21% represent other secondary trends, namely, the N-S, E-W, and N. 50-60° E. The prominent northwesterly trend is

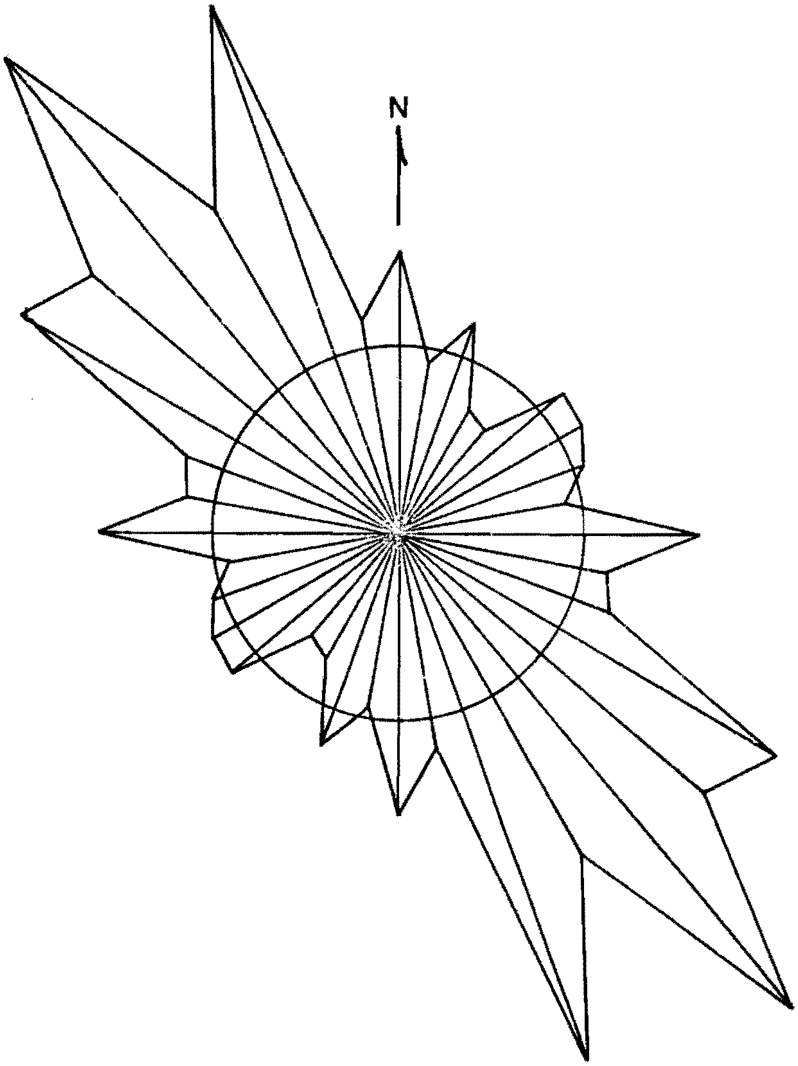


Figure 9. Summary of all orientation-length distribution of physiographic alignments. Area within the circle represents the area of random alignment orientation. Scale: 1 inch = 4%.

present even in the quadrangles nearest the west flank of Mt. Hood where a dominant east-west trend is expected from consequent drainage. Due to the consistency and prominence of the northwesterly morphologic trends a reliably strong structural framework orientation is indicated in the Portland area.

The physiographic alignments are a secondary effect caused by differential erosion. However, the consistency and prominence of the physiographic alignment trends strongly suggest that they are very good indicators of underlying structural features.

The trend significance is further confirmed by exposed and mapped structural alignments which are directly observed with which physiographic alignments can be compared. Even though in the Portland area most faults are poorly exposed, approximately 60% of the known mapped faults and fold axes concur with the dominant northwest physiographic trend (Schlicker, Deacon, and Twelker, 1964; Schlicker and Deacon, 1967).

A locally prominent underlying structural feature is suggested by the dominant northwest trends. Surficial units reflect continued weakness along pre-established structural trends, possibly the Oligocene Calkins Range.

Geologic Thickness Relationships and Gravity Profiles

The lower Clackamas River area is made up of a sequence of Tertiary volcanics and terrestial sediments capped by Quaternary mudflows, terrace and channel deposits.

Geologic cross sections, figures 19 through 25 in map pocket, were drawn along the lines of the gravimetric and magnetic traverses to reconstruct the underlying geologic structures from well logs and maps in an attempt to test the possibility of offset in units along the alignment. Data available from well logs is not sufficient in itself to determine conclusively the nature of the subsurface structure along the alignment. The cross sections have been constructed from Trimble's (1963) geologic map, figure 15, and from well data, Appendix VI.

All gravity and magnetic traverses, except that of the Redland traverse, are suitably located to define the gravimetric characteristics of the physiographic alignment. The Redland traverse crosses the structural trend more obliquely than the other traverses. The gravity and magnetic profiles are plotted above the geologic cross sections, figures 19 through 25, so the underlying structural configuration, where known, may be compared to the corresponding anomaly.

The gravity measurements are sensitive to changes in depth of the denser Columbia River basalt and are considered significant. The gravity interpretations below are made for the entire area of study and are also made on individual traverses. The basic limitations are discussed in Appendix II.

Negative Bouguer anomalies observed in all six gravity traverses show the influence of low density Cascade Range volcanic rocks in causing a 2.5 milligal/mile decrease in gravity to the southeast, figure 10 (Berg and Thiruvathukal, 1967b). This eastward decrease in gravity can indicate either an eastward thickening of the crust or a less dense crust and/or a mantle of low density (Berg and Thiruvathukal, 1967c). The gradient extends southeastward from approximately -15 milligals in the Milwaukie area to approximately -65 milligals near Estacada, a distance of about 20 miles. The Bouguer values obtained in this survey are in general agreement with the Oregon gravity map (Berg and Thiruvathukal, 1967b). Isostatic and regional gravity analysis are beyond the scope of this investigation.

The traverses are discussed in order from the Milwaukie traverse, in the northwest, to the Estacada traverse, in the southeast.

<u>Milwaukie traverse</u> (figure 19 - in map pocket)

The water wells drilled in the abandoned Clackamas River channel are not normally deep enough to penetrate through the Sandy

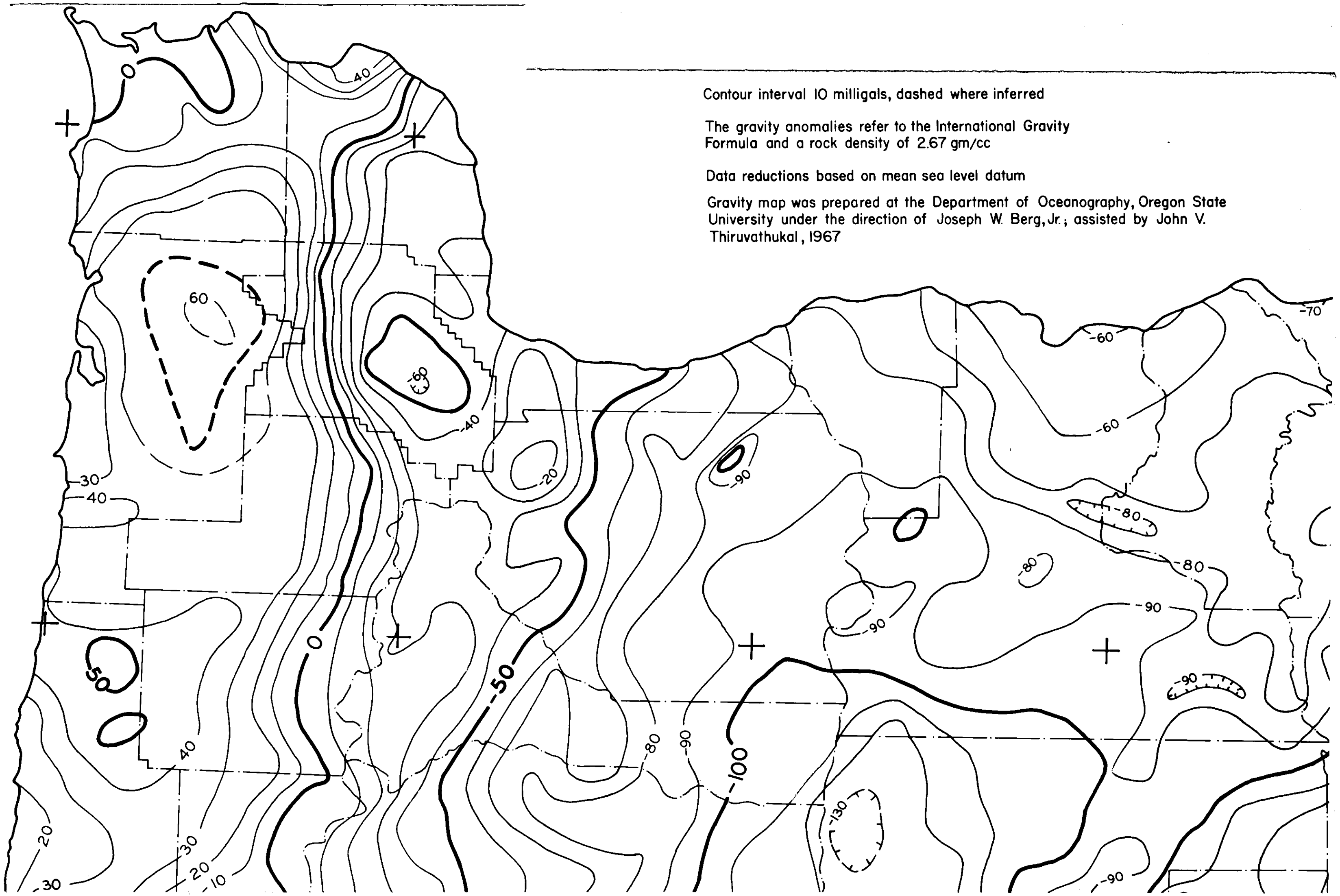
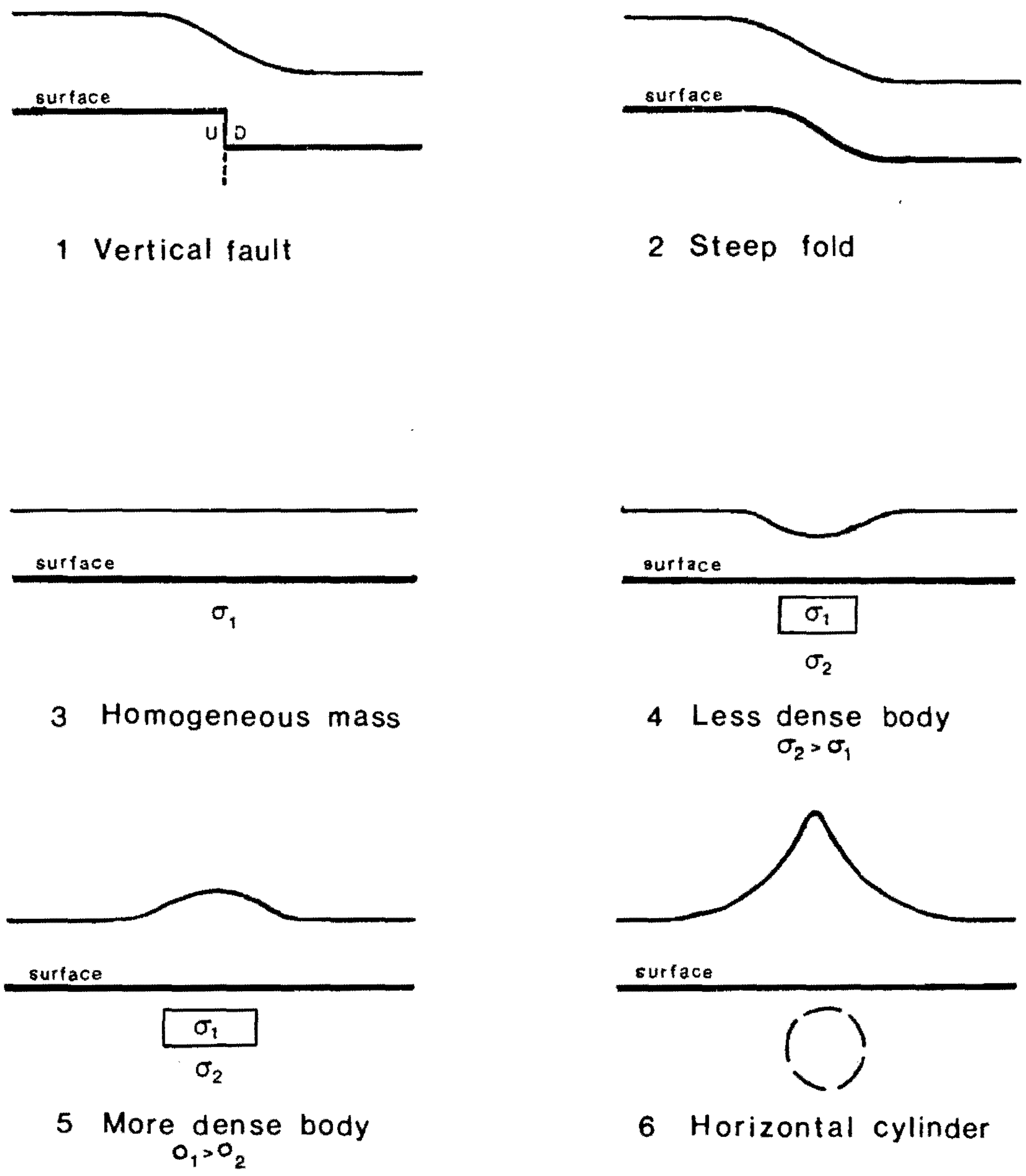


Figure 10. Complete Bouguer gravity anomaly map of northwestern Oregon (after Berg and Thiruvathukal, 1967b). No scale.

River mudstone into the Columbia River basalt, the formation which would most clearly reflect the presence or absence of a fault or fold. However, the well logs display an apparent offset of the surface of the Sandy River mudstone. The Omark Industries, Inc. well (1/2-31P1) penetrates the Sandy River mudstone at a depth of approximately 190 feet below sea level whereas the Camillo Giacchero well (2/1-1A) penetrates the mudstone at a depth of approximately 5 feet above sea level. The offset of the mudstone might also be caused by erosion by the Clackamas River and not entirely by faulting or folding.

Well logs do indicate the presence of the Columbia River basalt near the landsurface between Kellogg Creek and Waverly Heights. This suggests that the Portland Hills fault lies on the eastern edge of Waverly Heights.

The steep gravity gradient of 3.74 milligals/0.2 mile across the physiographic alignment indicates that the Columbia River basalt is either dipping steeply to the northeast or has been faulted down to the east at this location. Shapes of various typical gravity anomalies with their corresponding geometric subsurface structural forms are illustrated in figure 11, numbers 1 and 2 would correspond to the above mentioned geometric forms. A fault and a steep fold may have similar gravity anomalies. Balsillie and Benson (1971) present evidence favoring faulting in the Columbia River basalt as the cause of the linear escarpment along the Portland Hills. Their study



1 Vertical fault

2 Steep fold

3 Homogeneous mass

4 Less dense body $\sigma_2 > \sigma_1$

5 More dense body $\sigma_1 > \sigma_2$

6 Horizontal cylinder

Figure 11. Graphic representation of various gravity anomalies and corresponding geometric forms (Dobrin, 1960; Lahee, 1961).

utilized structural interpretation of columnar jointing to determine bedding plane orientation.

The precise location of the underlying structural offset is questionable. From the observed gravity gradient, the structural offset would be placed in the vicinity of station 2. However, additional data by an extension of the gravity traverse to the northeast might move the placement of the feature up to 0. 2 mile to the northeast. Well logs also allow placement of the offset up to 0. 2 mile to the northeast. The Portland Hills fault is not co-linear with Kellogg Creek, but Kellogg Creek is very straight and is parallel to the Portland Hills fault so I think it is possible that a minor branch fault parallels the creek.

Rock weakness along this segment of the Portland Hills-Clackamas River fault may form a zone of weakness followed by the abandoned channel of the Clackamas River. The apparent offset of the lower Pliocene Sandy River mudstone suggests movement as recent as middle Pliocene. This date, however, is strictly speculative.

<u>Gladstone traverse</u> (figures 12 and 20 - in map pocket)

The Gladstone traverse shows an apparent offset of the Troutdale formation and the Sandy River mudstone. In this locality the Sandy River mudstone may be offset as much as 120 feet as shown by

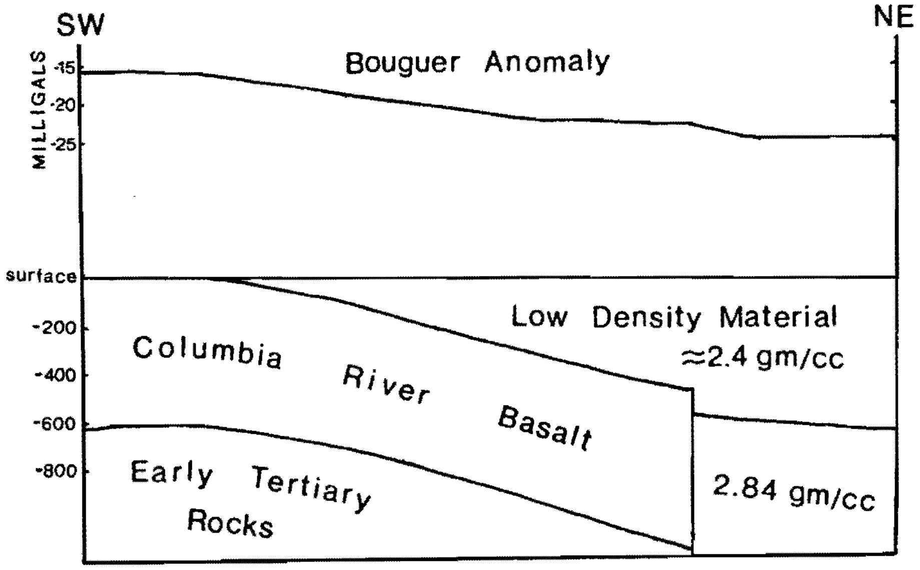


Figure 12. Graphic representation of one interpretation of the Bouguer gravity anomaly to geologic structure as seen in the Gladstone traverse.

the following wells: Byrum W. Morehouse (2/2-15D), Donald Hugart (2/2-16K), and Oak Lodge Water District (2/2-16K3). A possible fault or fold is indicated by the well log data.

The form of the gravity gradient between stations 4 and 5, at 1.45 milligals/0.1 mile, is suggestive of a fault or fold in which the Columbia River basalt was downdropped to the east. Movement of a fault may have caused the offsetting of the Troutdale formation and the Sandy River mudstone as indicated in the geologic cross sections.

Redland traverse (figure 21 - in map pocket)

The Redland traverse does not show any definite geologic data from well logs to indicate the presence or absence of a structural fold or fault. Interpretation of the Bouguer anomalies is also tenuous due to the obliqueness of the traverse with respect to the main structural trend.

The Bouguer anomaly does show, however, two distinct levels, one approximating -40.5 milligals (stations 1-14) and the other approximately -39.5 milligals (stations 15-29), which may reflect the underlying structure. By projecting the probable structural zone established by the Milwaukie and Gladstone traverses and that observed in the Transmission Line traverse to the Redland traverse, stations 14-16 would lie along the projected structural zone.

The consistent gravity anomaly which occurs across the physiographic alignment is reversed at this location. The gravity gradient dips to the south, thus suggesting the southern block was downdropped on the west. More gravity measurements are needed to determine the actual gravity distribution at this location and to allow a more conclusive interpretation.

Transmission Line traverse (figure 22 - in map pocket)

No definitive geologic data was obtained from well logs to indicate the presence or absence of a structural fold or fault along the physiographic alignment.

Several irregular gravity anomalies are shown in the Bouguer anomaly profile. The irregular appearance of the gravity profile between stations 21 and 31 is probably influenced by a combination of errors from the elevation corrections and from over compensation of the terrain correction values. There is no obvious geologic feature present which might explain the anomalies. There may be a Boring vent or dike concealed at depth.

An anomaly is defined between stations 10 and 13, just east of Clear Creek. A 3.0 milligal change in the observed gravity gradient is consistent with the other anomalies along the structural alignment. The gradient suggests a fault or fold between stations 11 and 12 with the Columbia River basalt downdropped on the east.

Paradise Park traverse (figure 23 - in map pocket)

The Paradise Park traverse lacks any subsurface geologic evidence for a fault or fold. The well logs indicate the general area where the Columbia River basalt dips below the Rhododendron formation. The approximate location of this interface is below station 23. Absence of the Troutdale formation on the eastern edge of the traverse is due to erosion by the Clackamas River prior to the deposition of the Estacada formation.

The Bouguer anomalies west of station 15 reflect probable sources of error from the elevation corrections rather than an irregular gravity distribution caused by the Columbia River basalt or by near surface Boring dikes.

A change in the gravity gradient is seen east of station 15, amounting to approximately a 1.5 milligal drop on the east side of the physiographic linearity. This suggests that the eastward side has been downdropped by a fault or fold.

Estacada traverse (figure 24 - in map pocket)

The well logs located near the Estacada traverse show no physical evidence for the existence of a structural fault or fold. One well, the S. S. Dunlop (3/4-21cb), penetrated into the Columbia River basalt at a depth of approximately 300 feet below sea level.

A steep gravity gradient of 2.46 milligals/0.25 mile across the physiographic alignment indicates that the Columbia River basalt either has been faulted or folded in the vicinity of station 9 and 10. The Bouguer anomaly suggests that the basalt has been downdropped east of station 8.

Significance of the Geologic Cross Sections and the Bouguer Anomalies

The geologic cross sections across the fault-like linearity from well logs generally lack any definitive data which may explain the nature of the alignment. However, the Milwaukie and Gladstone traverses do indicate the possible presence of a fault. Structural features cannot be confirmed or precisely located using presently available well log information alone.

Two gravity features are indicated by the Bouguer anomalies. The first is the more regional anomaly of a steadily westward decreasing negative anomaly that suggests a westward rising of the Columbia River basalt. This conclusion is supported by well log data.

The second feature is the consistency of the size and shape of the gravity gradients which average 2.18 milligals/0.2 mile, downdropped to the east, across the physiographic alignment. Its alignment and consistency of direction and size define the zones of a possible fault or steep fold. A composite Bouguer anomaly which corresponds to the possible structural zone is illustrated in figure 13.

The fault-like physiographic alignment is co-linear with the apparent offset of the Columbia River basalt as seen in the gravity profile. It is concluded, therefore, that the topographic linearity is most probably a reflection of a structural feature in which the Columbia River basalt is downdropped to the east.

Magnetic Profiles

All magnetic traverses cross the Portland Hills-Clackamas River alignment, figure 3. Simple interpretations of the magnetic anomalies are made for each traverse. The magnetic anomalies can be indicators of the underlying geologic structure associated with the alignment. Typical magnetic anomalies with their corresponding subsurface geometric forms are illustrated in figure 14. The anomalies show a consistent magnetic break across the alignment. The cause of this change in gradient is not understood.

The traverses are discussed from the northwest to the southwest. The traverses discussed are the Gladstone-M, Fischers Mill-M, and the Estacada-M traverses.

Gladstone-M traverse (figure 20 - in map pocket)

A steep magnetic gradient of nearly 80 gammas/0.25 mile is shown on the right hand side of the profile, stations 2-5. The

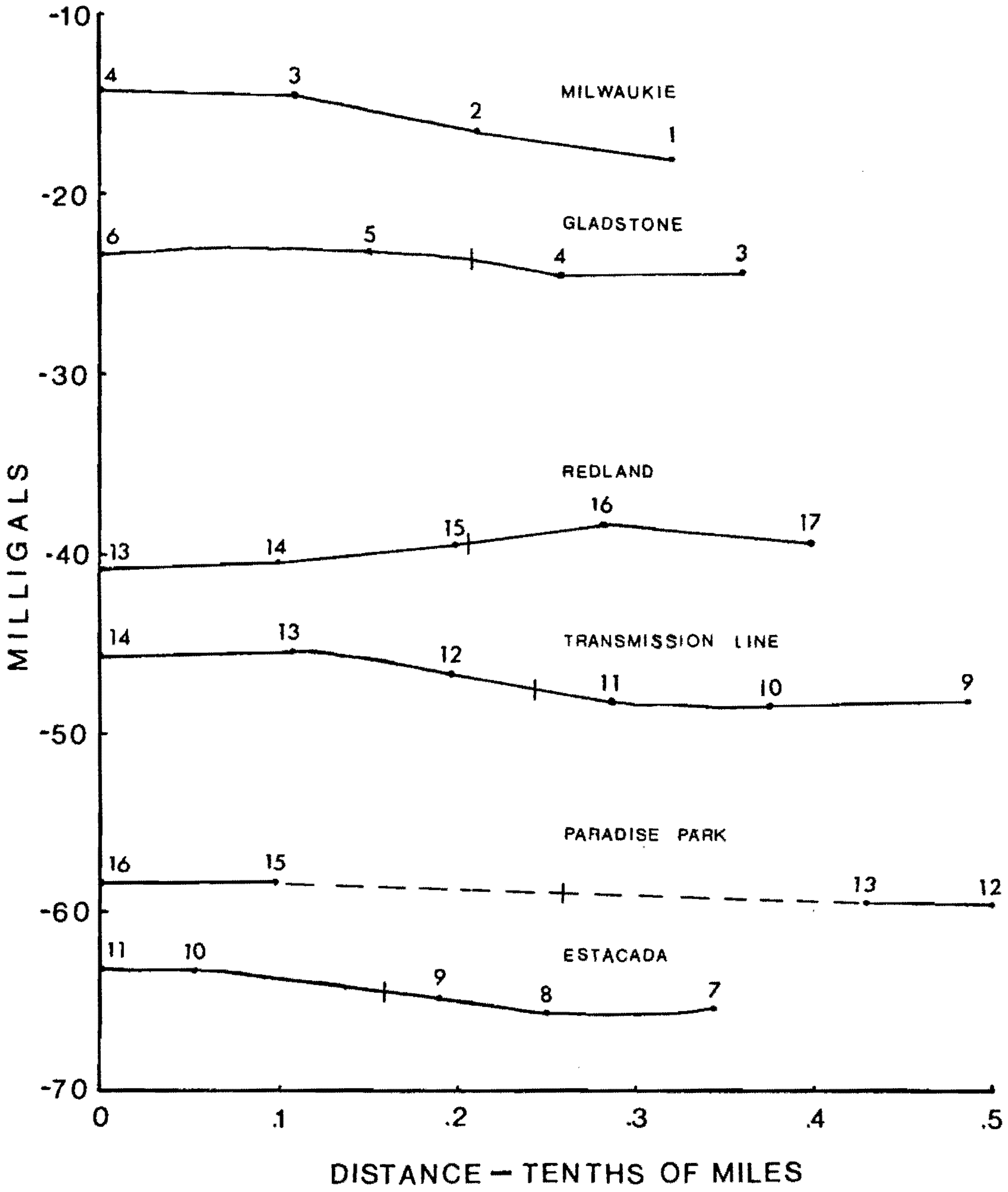
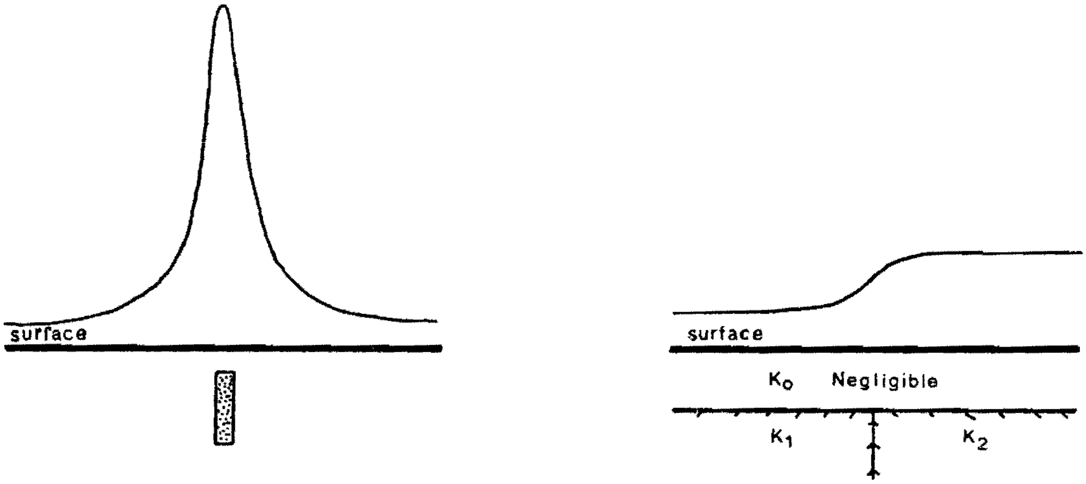
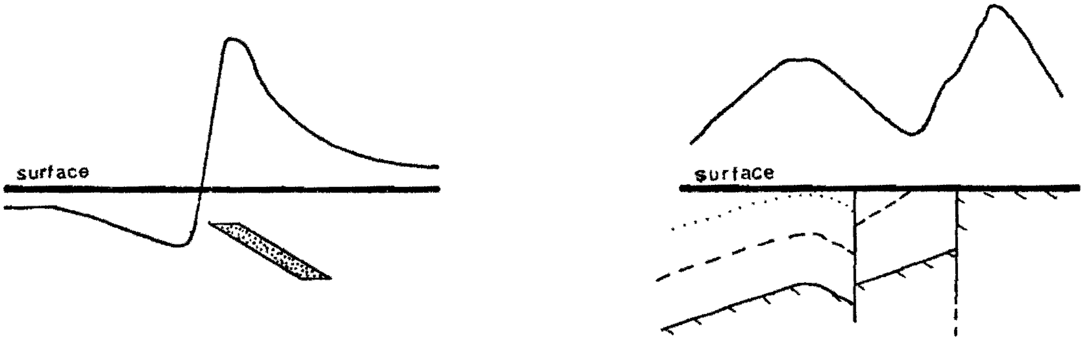


Figure 13. Composite Bouguer anomaly corresponding to the structural zone. Its central locality is marked by "|".



1 Vertical body

2 Contrasting rock types
$K_2 > K_1$



3 Inclined body

4 Irregular section

Figure 14. Graphic representation of various magnetic anomalies and corresponding geometric forms (Dobrin, 1960).

anomaly is consistent with a Boring dike located approximately 500 feet below landsurface, figure 14, number 3.

The irregular nature of the profile found between stations 7 through 15 may indicate several breaks in the Columbia River basalt. The nature of these breaks is not known. The Columbia River basalt appears to be downdropped to the east from a combination of magnetic and gravity data.

Fischers Mill-M traverse (figure 25 - in map pocket)

The Fischers Mill-M traverse indicates a sharp gradient of nearly 615 gammas/0.4 mile between stations 2 and 6. The cause of the abrupt change in the magnetic gradient is unknown. The magnetic anomaly, at station 6, however, is consistent with the location of the physiographic alignment.

Estacada-M traverse (figure 24 - in map pocket)

Several single point anomalies are observed in the magnetic profile, stations 10, 11, 14, and 15. The cause of the anomalies is unknown. They could reflect a locally buried body with reversed magnetic polarity in relation to the surrounding rock.

The consistent magnetic anomaly which occurs across the Portland Hills-Clackamas River alignment is seen between stations 7 and 13. This change in gradient, approximately 900 gammas/0.15 mile, is apparent when a smooth curve is drawn to fit the magnetic stations, excluding the point anomalies. The magnetic gradient suggests a structural feature co-aligned with the physiographic alignment.

Significance of the Magnetic Anomalies

The magnetic anomalies show a consistent change in the magnetic gradient across the physiographic alignment which defines a structural zone of unknown nature, possibly a fault.

CONCLUSIONS AND RECOMMENDATIONS

The physiographic and structural alignments are significant indicators of underlying geologic structures. The consistency of the dominant northwest trend, N. 20° W. and N. 40° W., is observed over the entire area studied. The trend is considered to be a reliable structural indicator because the known faults and fold axes also present a matching dominant northwest orientation when statistically plotted.

It is believed that a major regional fault system probably exists along Portland Hills-Clackamas River alignment which may possibly extend as far to the southeast as the Steens Mountains. The dominant northwest trend of the co-alinear regional physiographic and structural alignments suggests the existence of the fault system.

The dominant local northwest trends are suggestive of underlying geologic features remnant from the Oligocene Calkins Range. The alignments, including the secondary northeast trends, may reflect continued or renewed weakness along these pre-established structural alignments.

The geologic cross sections developed from map and well data are considered to be as accurate as present data permits. The cross sections, however, do not present any tangible evidence as to the nature of the physiographic alignment.

The gravity traverses present a consistent and reliable indicator of an underlying structural feature corresponding to the physiographic alignment. The consistency of the size and shape of the Bouguer anomalies across the alignment defines the zone of a possible fault or steep fold developed in the Columbia River basalt. I tend to lean to the fault interpretation rather than a fold due to supporting evidence from seismic first motion analysis and by data presented by Balsillie and Benson (1971).

The magnetic anomalies further indicate the probable underlying geologic structure associated with the alignment. A consistent magnetic break occurs across the physiographic alignment.

In general, the various types of data have good consistency. The consistency strengthens their reliability as a structural indicator. The precise location of the observed structural feature is uncertain. The study establishes a probable zone in which a structural anomaly exists.

Recommendations

The area studied is not gravimetrically complex. The gravity profiles of this investigation indicate that much more subsurface information could be obtained from a more detailed gravimetric study of the Portland basin. The making of a gravity map with a contour interval of less than 5 milligals would probably define the underlying structure of the basin.

The magnetic profiles indicate much surface noise caused by local cultural features. It is suggested that an airborne magnetometer might better be used to construct a magnetic map of the area.

The analysis of the physiographic and structural alignments should be extended to include the entire state of Oregon. Their statistical analysis would contribute needed information to direct further geologic studies.

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APPENDICES

APPENDIX I

DESCRIPTION OF BENCH MARKS

The following bench marks were used as base stations for the gravity traverses. See "B" in figure 2.

(1) City of Portland CLB bench mark #679.
Location: SE corner of SE 13th and SE Malden in Sellwood, Oregon.
Elevation: Not listed. Map gives it as 121 feet.
Use: Used as base station in the Milwaukie traverse.

(2) U. S. Geological Survey bench mark #JX14 established in 1929.
Location: Intersection of Wise Road and the Southern Pacific tracks near Clackamas, Oregon.
Elevation: Listed as 112.6 feet.
Use: Used as base station in the Gladstone traverse.

(3) U. S. Geological Survey bench mark PRIM TRAV ORE STA No. 4.
Location: 1/2 block west of intersection of Redland Road and Grasle Road. Approximately 1/2 mile west of Redland, Oregon.
Elevation: Listed as 527 feet.
Use: Used as base station in the Redland traverse and Transmission Line traverse.

(4) U. S. Geological Survey bench mark PRIM TRAV STA No. 17 established in 1910.
Location: In Fischers Mill, Oregon at left of gas station and behind chainlink fence (in private yard).
Elevation: Listed as 293 feet.
Use: Used as base station for part of the Paradise Park traverse.

(5) U. S. Coast and Geodetic Survey bench mark Y429 established in 1946.

Location: In yard north of Currinsville, Oregon on Highway 211. A concrete block rests upon the bench mark.

Elevation: Not listed. Map gives it as 451 feet.

Use: Used as base station for part of Paradise Park traverse and all of the Estacada traverse.

APPENDIX II

GEOLOGY

Geologic Setting

Geographically, the lower Clackamas River area is part of the northern Willamette Valley. The Willamette Valley extends westward to the Coast Range and eastward to the Cascade Range.

The Clackamas River is a major tributary of the Willamette River. It heads in the Cascade Range and flows northwestward to the Willamette River at Gladstone, approximately one mile north of Oregon City.

In early Eocene time the lower Clackamas River area was part of a 400 mile long eugeosynclinal trough (Snavely and Wagner, 1963). The Clackamas and Portland area has since undergone several periods of uplift and deformation. Following the extrusion of the Columbia River basalt in middle Miocene time, the area became a structural basin between the upwarped ancestral Portland Hills and Cascade Range (Hogenson and Foxworthy, 1965). The Sandy River mudstone was deposited in a lake which formed in the deepening basin. Deformation of the Portland Hills, Cascade Range, and secondary upwarps (Oatfield Heights ridge) continued as the Columbia River and other streams flooded the area depositing the alluvial gravels of the Troutdale formation (Trimble, 1963). An erosional surface developed on the Troutdale formation on which late Pliocene to late (?) Pleistocene Boring lava extruded in flows and formed volcanic cones.

Post-Boring alluviation began in early Quaternary time forming a piedmont plain of mudflows and gravels. Locally, the Clackamas River formed valleys which were subsequently partially filled with mudflows and gravel deposits (Trimble, 1963). Following the effects of the glacial Lake Missoula flood waters, the Clackamas River became fully entrenched. Tectonic uplift had a part in causing the rejuvenation of the Clackamas River and may still now be in progress. The recent rejuvenation, however, could also be caused by non-tectonic processes such as an increase in stream competency associated with glacial retreat and lowering of sea level.

Stratigraphy

The Miocene and Pliocene rocks, especially the Columbia River basalt, are important to this study because the gravity and magnetic anomalies are based upon the distribution of the basalt and because the recognition of formational units in drill logs is important in constructing geologic cross sections. Post-Troutdale formations are important to this study primarily as an indication of recent rejuvenation of the Clackamas River.

No rocks older than middle Miocene crop out in the geophysically investigated area. The Scappose formation or the Skamania volcanic series underlies the Columbia River basalt. Tertiary volcanic rocks include the above, and the Columbia River basalt, the Rhododendron formation, and the Boring lava. Other Tertiary rocks being of terrestial origin include the Sandy River mudstone and the Troutdale formation. Quaternary formations include the Springwater formation, the Gresham formation, the Estacada formation, and other recent terrace and channel deposits.(figure 15).

Tertiary System

Skamania Volcanic Series

The late Eocene to early Miocene (?) Skamania volcanic series is composed of "altered basalt and basaltic andesite flows and associated pyroclastic rocks" (Trimble, 1963). The formation underlies the Scappoose formation and does not crop out in the geophysically investigated area or is it described in any of the well logs.

Scappoose Formation

The Scappoose formation is dated as late Oligocene to early Miocene age. Warren and Norbisrath (1946) describe it as a "gray, Qal - Alluvium

Qt - Terrace deposits

Qs - Sand and silt deposits

Qe - Estacada formation

Qg - Gresham formation

Qsw - Springwater formation

QTb - Boring lava

Tt - Troutdale formation

Tsr - Sandy River mudstone

Tr - Rhododendron formation

Tcr - Columbia River basalt

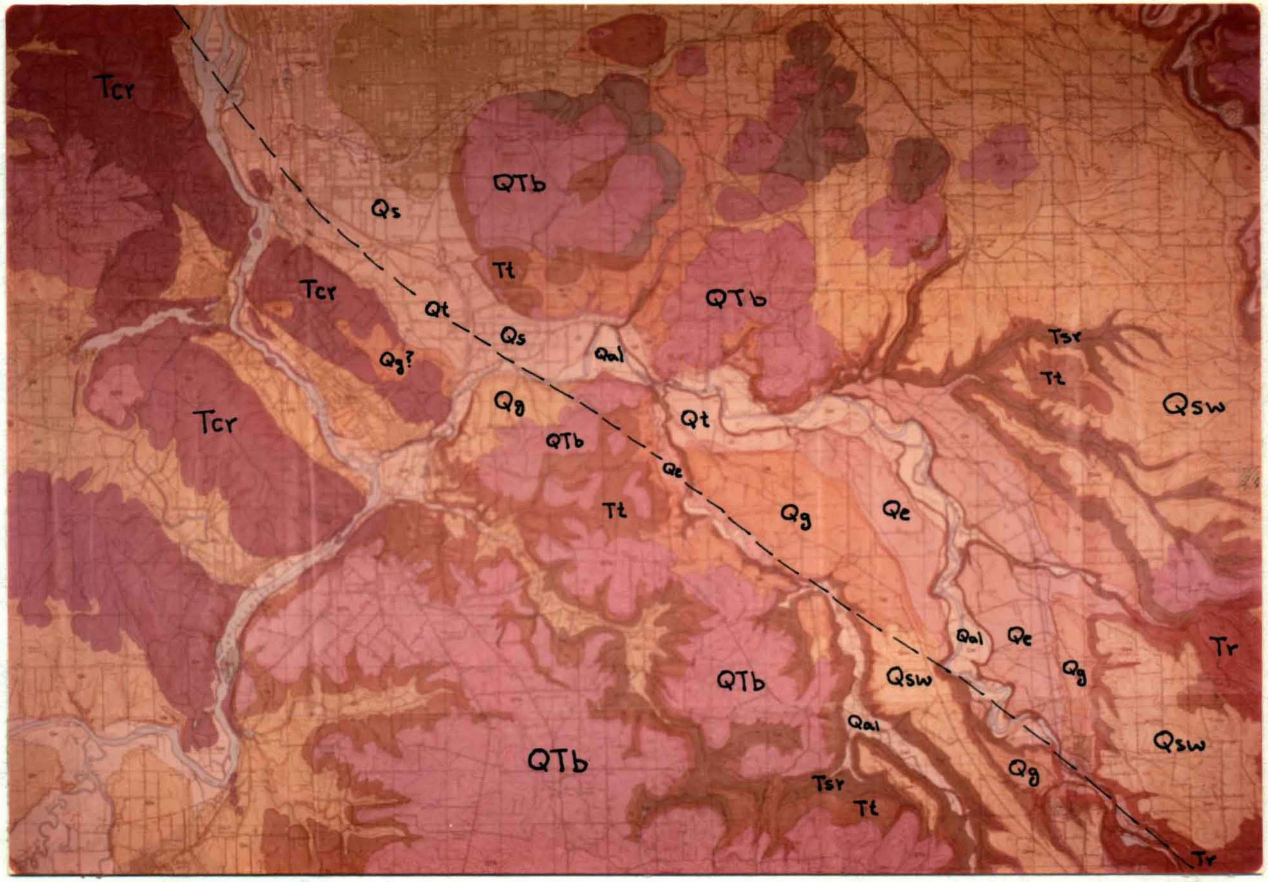


Figure 15. Geologic map of thesis area (Trimble, 1963). No scale.

yellowish-weathering, firm, fossiliferous, sandy, tuffaceous shale and shaly sandstone, commonly spotted with pumiceous material." Being of sedimentary marine origin, the formation contains connate saline water (Hogenson and Foxworthy, 1965). The City of Gladstone well (2/2-20F1) was drilled through the Columbia River basalt into a shale containing saline water at a depth of 620 feet below sea level. It is believed that the well bottoms in the Scappoose formation.

Columbia River Basalt

The middle Miocene Columbia River basalt is the oldest formation exposed in the lower Clackamas River area. In the investigated area the basalt crops out only in the Oatfield Heights ridge and Waverley Heights. The Portland Hills has well exposed outcrops. Oatfield Heights and the Portland Hills are anticlines comprised of Columbia River basalt and older rocks.

The petrologic features of the Columbia River basalt are discussed by Trimble (1963) and Peck, and others (1964). Weathered Columbia River basalt produces a yellowish-brown to a reddish-gray brown soil. V. T. Allen (1948) determined that local weathering occurs in places to depths of 170 feet. Average specific gravity taken from several quarries comprised of Columbia River basalt is 2.84 gm/cc (data from Schlicker and Deacon, 1967, p. 74-75).

Thickness of the Columbia River basalt varies with location.

Lowry and Baldwin (1952) have determined the thickness to be as much as 1000 feet in the Portland area. A well drilled by the Richfield Oil Company in the Portland Hills (SW1/4 sec. 23, T. 1 N., R. 1 W.) penetrated between 700 and 800 feet of Columbia River basalt (Balsillie and Benson, 1971). The greatest drilled thickness in the geophysically investigated area is about 610 feet of Columbia River basalt as seen from a well drilled for water by the City of Gladstone (2/2-20F1).

Stratigraphically, the Columbia River basalt unconformably overlies the Scappoose formation and the Skamania volcanic series and unconformably underlies the Sandy River mudstone in the vicinity of Gladstone, and the Rhododendron formation near Estacada.

Rhododendron Formation

The Rhododendron formation in the lower Clackamas River area is exposed along the Clackamas River southeast of Estacada. It is dated as middle to late Miocene by stratigraphic position and by plant fossils.

Locally, the Rhododendron formation consists of marginal volcanic mudflow breccia with lava flows intertonguing eastward (Trimble, 1963). Weathering of the formation results in a yellow-brown to reddish-brown soil.

A water well drilled in 1963 for S. S. Dunlop (3/4-21N) infers a thickness of 752 feet of Rhododendron formation. The well terminates in Columbia River basalt. The formation is believed to strike to the northeast and dips less than 2 degrees to the northwest in the lower Clackamas River area (Trimble, 1963). Wells drilled for Ardel Zach (3/4-9F) and Glen H. Hill (3/3-13A or H) penetrate the top of the Rhododendron formation indicating an apparent dip of 5 degrees to the southwest (S. 70° W.). See Paradise Park traverse in map pocket, figure 23..

Sandy River Mudstone

The Sandy River mudstone is early Pliocene in age. Its distribution is extensive in that the formation underlies most of the investigated area. Excellent exposures are found along the lower Clackamas River in what is now McIver State Park. Most exposures are heavily covered with vegetation and are distorted by slumping and landsliding.

Formational thickness varies depending upon locality. The maximum exposed thickness of the Sandy River mudstone in the studied area is 250 feet along the Clackamas River near Paradise Park. The formation thickens to the northwest from Estacada. A well drilled near Paradise Park for Glen H. Hill (3/3-13 A or H) indicates nearly 270 feet of mudstone to be Sandy River. The log of a well for Ernest Evanson (3/3-7M) shows 330 feet of strata to be

Sandy River mudstone. The C. D. Carlson well (2/3-18J) infers 419 feet of Sandy River mudstone. This thickening to the northwest may indicate the east flank of the Willamette syncline.

The well logs indicate lithologic units of sand, shale, clay, and silty clay which may be classed as sandstone, mudstone, and siltstone. Clay and silt are the principal units. Typically, a blue or gray clay is the key horizon used in separating the Sandy River mudstone from the overlying Troutdale formation.

Troutdale Formation

The lower Pliocene Troutdale formation is distinguished from the Sandy River mudstone by its sandstone and conglomerate composition. The Troutdale formation consists mainly of sandstone varying in composition from a tuffaceous sandstone in the Estacada area to more of a micaceous, arkosic sandstone northwest of the investigated area (Trimble, 1963). The Troutdale formation is distinguished by its cemented gravels from the overlying uncemented channel or terrace deposits.

The thickness of the Troutdale formation varies with location and degree of erosion prior to the deposition of the Boring lava and Quaternary formations. The City of Milwaukie well (1/1-36A) infers a thickness of nearly 240 feet of strata to be Troutdale. Donald R. Smith's well (3/3-14aca) shows only 130 feet to be Troutdale. The formation thins toward the slopes of the Cascade Range.

Tertiary and Quaternary Systems

Boring Lava

Treasher (1942a) described and named the Plio-Pleistocene basaltic flows and pyroclastic rocks as the Boring lava. Eruptive vents are present north and south of the investigated area which is part of the Boring lava plain.

The Boring lava varies in thickness depending upon proximity to a source vent and the paleotopography. Generally, the lava ranges from a few feet to several hundred feet in thickness. A well drilled for Robert Kiefer (3/3-15bb) in 1970 infers a thickness of 270 feet to be Boring lava.

The Boring lava has been weathered from depths as much as 15 feet (Schlicker and Deacon, 1967) to depths more than 25 feet (Trimble, 1963). Petrologic features are discussed by Treasher (1942b), Trimble(1963), and Peck, and others (1964).

Quaternary System

Springwater Formation

The early (?) Pleistocene Springwater formation is a piedmont deposit composed of fluvial gravel with interstratified mudflow deposits which were developed prior to the Clackamas River entrenchment (Trimble, 1963). The Robert L. Poore well (3/4-28C) infers nearly 100 feet to be Springwater deposits.

Gresham Formation

The Gresham formation, a high-level flood plain deposit, is of middle (?) Pleistocene age. The formation consists mainly of bouldery gravely with mudflow phases which occur as terraces ranging from 300 to 500 feet in elevation. In several locations the formation is nearly 150 to 200 feet below the Springwater formation. Weathering has not been as complete for the Gresham formation, 35 feet, as the Springwater formation, 75 feet (Trimble, 1963). The Eugene C. Shore water well (3/4-29bcc) infers a thickness of 70 feet.

Estacada Formation

The third terrace deposit of late (?) Pleistocene age is the Estacada formation. It consists mainly of gravel and mudflow deposits which lie nearly 100 feet below the Gresham formation. Locally, a well log for Stuart Puckett (3/4-8M1) shows 60 feet of gravels. The E. L. Williams well (3/4-7Q) infers 42 feet to be the Estacada formation. The formation has weathered to a depth of 10 feet in the Clackamas River area (Trimble, 1963).

Alluvium of Abandoned River Channel

These sand, silt, and gravel deposits of late Pleistocene or

Recent in age are present along the present Clackamas River channel and its abandoned channel that extends from Clackamas to Milwaukie. The deposits in the abandoned Clackamas River channel thicken to the northwest from a few feet, F. J. Mooney well (2/2-16B1), to more than 200 feet in the Omark Industries well (1/2-31P1).

Recent Alluvium

Recent alluvium occurs along the Clackamas River and Clear Creek mainly as gravel deposits with thicknesses less than 50 feet.

Structure

Broad synclines and anticlines typify the Portland-lower Clackamas River area. Surface evidence for faulting in the geophysically investigated area is lacking due to the recent volcanism, alluviation of the area, and thick soil cover.

The northwest-trending anticlinal ridges of the Portland Hills and Oatfield Heights ridges are the predominant surficial structural features in the area. Other northwest-trending anticlinal and synclinal systems exist to the west of the geophysically investigated area.

Schlicker and Deacon (1964) believe that a major normal fault flanks the eastern side of the Portland Hills which also controls the channel of the Clackamas River. The possible existence of this fault has been substantiated by studies by Balsillie and Benson (1971).

Additional evidence for the existence of the Portland Hills fault is presented and discussed in this report.

Outside of the investigated area Schilicker and Deacon (1964 and 1967) have mapped several northwest and northeast-trending normal faults. Northeast-trending faults have been suggested as the cause of other Portland earthquakes (Couch and others, 1968; Heinrichs and Pietrafesa, 1968).

A broad synclinal downwarp shapes the lower Clackamas River area which is underlain by the Columbia River basalt. The basalt has been depressed to an inferred depth of about 60 feet below sea level in the approximate center of the Willamette syncline as mapped on the Geologic Map of Oregon West of the 121st Meridian--Tectonic Map (Wells and Peck, 1961). Farther north in the Portland area, the Ladd well (39th and Glisan Streets) shows the basalt on the west flank of the Willamette syncline to be depressed to a depth of 1070 feet below sea level.

Faults probably exist at depth which would displace the gently sloping Columbia River basalt. Hogenson and Foxworthy (1965) have indicated a possible buried fault which conceivably strikes N. 30° E. in the vicinity of Regner Road, north of Sunshine Valley.

APPENDIX III

GRAVITY REDUCTIONS

Gravity reductions are applied to the observed gravity so as to reduce the gravity to an arbitrary datum plane of a known latitude. This artificial condition will then show any variations in the reduced gravity which can be attributed to density variations. The corrections to be applied are: the free-air, the Bouguer, the topographic, namely, the latitude and the terrain, and the instrument drift. The datum plane for all reductions is mean sea level.

Free-air Correction

The free-air effect accounts for the difference in the gravity field between the gravity station and the datum plane due to differences in elevation only, that is, without regard to the intervening mass of material. A correction value for this vertical gradient of gravity is given by Nettleton (1940) and by Dobrin (1960) as 0.09406 milligals per foot. The theoretical value of 0.09406h, h being the distance in feet from the gravity station to the datum plane, was added to the observed gravity.

Bouguer Correction

The Bouguer effect accounts for the material mass between the gravity station and the datum. A value of $0.01276\sigma h$ milligals per foot of thickness, where σ is density and h is the thickness of the slab, is given by Nettleton (1940).

The density factor is dependent upon the densities of the different lithologies found between the gravity station and the datum plane. An average density may introduce an error if contrasting lithologies occur in the area. Nettleton (1938) describes an indirect method in obtaining surface densities by reducing the observed gravity by different densities. The actual density is chosen by the smoothest reduced gravity profile. This survey, however, will use an average density of 2.67 gm/cc. In assuming an average density the interpretation must be made keeping in mind that some of the observed anomaly may be attributed to a density contrast located above the selected datum plane.

The Bouguer correction is subtracted from the observed gravity in this survey because the station elevation is higher than the datum plane which produces a net increase in the gravity value due to the attraction of the material between the station and the datum plane.

The free-air correction and the Bouguer correction may be combined into a total elevation correction of $(0.09406 - 0.01276\sigma)h$ or 0.060h miligals, where h is the distance in feet above mean sea level, for a density of 2.67 gm/cc (Dobrin, 1960).

Latitude Correction

The "international gravity formula" for the variation of gravity with latitude is given by Dobrin (1960) as

$$g = 978.049(1 + 0.0052884\sin^2\phi - 0.0000059\sin^2 2\phi) \text{ gals}$$

where ϕ is the latitude.

The latitude correction was individually computed for each station by use of a computer. Listed below is the source program.

```
      IMPLICIT REAL *8 (A-H, O-Z)
      ID=45
      M=15
2     IS=0
3     A=M
1     S=IS
      X=(3.1415926536/4.)*(1.+A/2700.+S/162000.)
      B=DSIN(X)
      C=DSIN(2.*X)
      G=978.049*(1.+0.0052884*B*B-0.0000059*C*C)
      WRITE (3,100) ID, M, IS, G
100   FORMAT(' ',I2, ' DEG ', I2, ' MIN ',I2, ' SEC ', 2X,'G = ',
         D16.10)
      IS=IS+1
      IF(IS.NE.60) GO TO 1
      M=M+1
      IF(M.NE.31) GO TO 2
      STOP
      END
```

The computer program is written in Fortran IV. Double precision was used due to the large calculated gravity figure. No data cards are needed. The program is designed so that a starting ϕ may be written into the program (ID=degree, M=minute, IS=second) with the resultant execution being printed out at one second intervals. Under the "free" operating limitations found at the computer facility at the University of Oregon no allowance for a predetermined final ϕ is written into the program. Minor revisions of the program would enable the operator to specify the ϕ for computer shut-down. Contained within the program is a routine which computes $\sin^2\phi$ and $\sin^2 2\phi$ for each second.

The output was used for the theoretical gravity values required in the free-air and Bouguer anomalies.

Terrain Correction

The terrain correction is supplementary to the Bouguer correction by accounting for the vertical attraction of topography both above and below the station. The Bouguer correction assumes an infinite horizontal slab which is seldom the case. Points higher than the station have an upward gravitational component which opposes part of the gravitational pull of the earth. Depressions or valleys also account for a smaller gravitational pull at a given station than the Bouguer effect accounts for. It is therefore necessary to add the correction for the attraction of the material which was subtracted in the Bouguer correction and the vertical upward attraction caused by hills.

Terrain corrections are usually accomplished by dividing the topography around a station into compartments within which the effect of the topography is computed. Several have designed templates for terrain corrections. Hayford and Bowie (1912), Hammer (1939), and Kane (1962) describe special techniques to approach the problem.

Kane's method utilizes a square template specifically designed to select elevation data from a digital terrain model and use of a digital computer. The system results in a substantial saving of time but the cost factor limits its use to large surveys.

The Hammer method

The Hammer method (Hammer, 1939), which was used to determine the terrain correction in this investigation, utilizes a circular template with radial lines dividing them into compartments, figure 16. The Hammer template is very similar to Hayford-Bowie's (1912).

To get the terrain effect of any particular compartment, the average elevation for that compartment is estimated and the difference between it and the station elevation is derived. Using the table prepared by Hammer (Table 1) the total terrain effect is then obtained for that particular compartment.

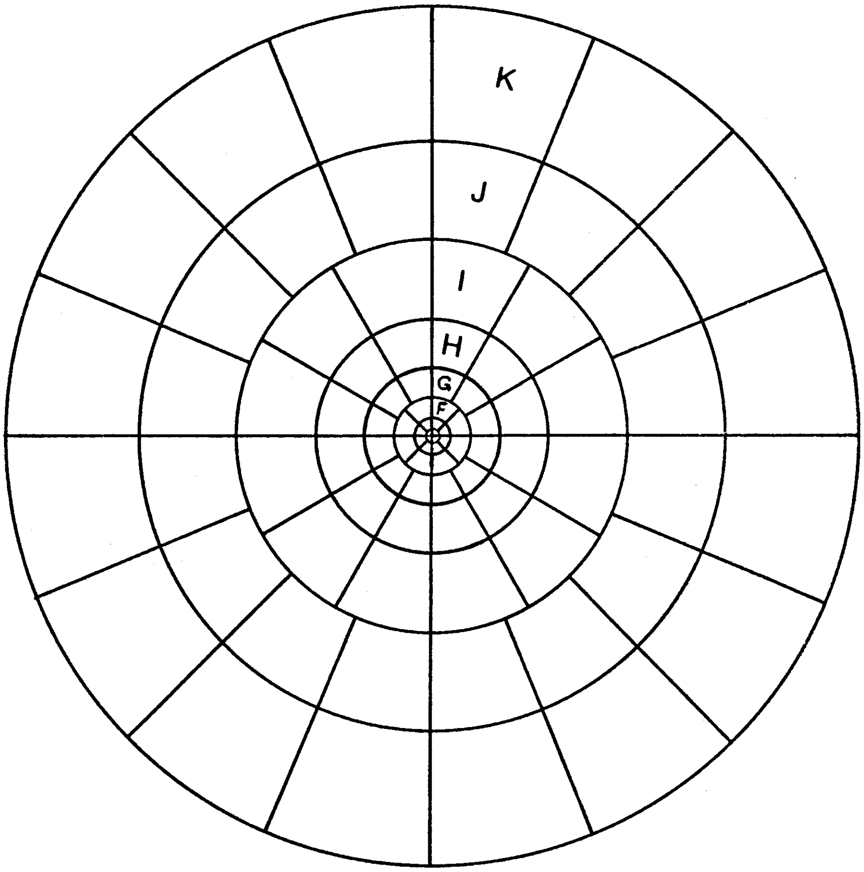


Figure 16. Terrain correction zone chart designed by Hammer (1939). To be used in conjuction with Table 1 for zones B through M. Scale: 1:175,000.

TABLE I

TERRAIN-CORRECTION TABLE

Zone B, 4 compartments, 6.56 to 54.6†		Zone C, 6 compartments, 54.6 to 175		Zone D, 6 compartments, 175 to 558		Zone E, 8 compartments, 558 to 1,280		Zone F, 8 compartments, 1,280 to 2,936		Zone G, 12 compartments, 2,936 to 5,018	
$\pm h$, ft	T	$\pm h$, ft	T	$\pm h$, ft	T	$\pm h$, ft	T	$\pm h$, ft	T	$\pm h$, ft	T
0 – 1.1	0	0– 4.3	0	0– 7.7	0	0– 18	0	0– 27	0	0– 58	0
1.1– 1.9	0.1	4.3– 7.5	0.1	7.7– 13.4	0.1	18– 30	0.1	27– 46	0.1	58– 100	0.1
1.9– 2.5	0.2	7.5– 9.7	0.2	13.4– 17.3	0.2	30– 39	0.2	46– 60	0.2	100– 129	0.2
2.5– 2.9	0.3	9.7– 11.5	0.3	17.3– 20.5	0.3	39– 47	0.3	60– 71	0.3	129– 153	0.3
2.9– 3.4	0.4	11.5– 13.1	0.4	20.5– 23.2	0.4	47– 53	0.4	71– 80	0.4	153– 173	0.4
3.4– 3.7	0.5	13.1– 14.5	0.5	23.2– 25.7	0.5	53– 58	0.5	80– 88	0.5	173– 191	0.5
3.7– 7	1	14.5– 24	1	25.7– 43	1	58– 97	1	88–146	1	191– 317	1
7 – 9	2	24 – 32	2	43 – 56	2	97–126	2	146–189	2	317– 410	2
9 –12	3	32 – 39	3	56 – 66	3	126–148	3	189–224	3	410– 486	3
12 –14	4	39 – 45	4	66 – 76	4	148–170	4	224–255	4	486– 552	4
14 –16	5	45 – 51	5	76 – 84	5	170–189	5	255–282	5	552– 611	5
16 –19	6	51 – 57	6	84 – 92	6	189–206	6	282–308	6	611– 666	6
19 –21	7	57 – 63	7	92 –100	7	206–222	7	308–331	7	666– 716	7
21 –24	8	63 – 68	8	100 –107	8	222–238	8	331–353	8	716– 764	8
24 –27	9	68 – 74	9	107 –114	9	238–252	9	353–374	9	764– 809	9
27 –30	10	74 – 80	10	114 –120	10	252–266	10	374–394	10	809– 852	10
		80 – 86	11	120 –127	11	266–280	11	394–413	11	852– 894	11
		86 – 91	12	127 –133	12	280–293	12	413–431	12	894– 933	12
		91 – 97	13	133 –140	13	293–306	13	431–449	13	933– 972	13
		97 –104	14	140 –146	14	306–318	14	449–466	14	972–1,009	14
		104 –110	15	146 –152	15	318–331	15	466–483	15	1,009–1,046	15

Zone H, 12 compartments, 5,018 to 8,578		Zone I, 12 compartments, 8,578 to 14,662		Zone J, 16 compartments, 14,662 to 21,826		Zone K, 16 compartments, 21,826 to 32,490		Zone L, 16 compartments, 32,490 to 48,365		Zone M, 16 compartments 48,365 to 71,996	
$\pm h$, ft	T	$\pm h$, ft	T	$\pm h$, ft	T	$\pm h$, ft	T	$\pm h$, ft	T	$\pm h$, ft	T
0– 75	0	0– 99	0	0– 167	0	0– 204	0	0– 249	0	0– 304	0
75– 131	0.1	99– 171	0.1	167– 290	0.1	204– 354	0.1	249– 431	0.1	304– 526	0.1
131– 169	0.2	171– 220	0.2	290– 374	0.2	354– 457	0.2	431– 557	0.2	526– 680	0.2
169– 200	0.3	220– 261	0.3	374– 443	0.3	457– 540	0.3	557– 659	0.3	680– 804	0.3
200– 226	0.4	261– 296	0.4	443– 502	0.4	540– 613	0.4	659– 747	0.4	804– 912	0.4
226– 250	0.5	296– 327	0.5	502– 555	0.5	613– 677	0.5	747– 826	0.5	912–1,008	0.5
250– 414	1	327– 540	1	555– 918	1	677–1,119	1	826–1,365	1	1,008–1,665	1
414– 535	2	540– 698	2	918–1,185	2	1,119–1,445	2	1,365–1,763	2	1,665–2,150	2
535– 633	3	698– 827	3	1,185–1,403	3	1,445–1,711	3	1,763–2,086	3	2,150–2,545	3
633– 719	4	827– 938	4	1,403–1,592	4	1,711–1,941	4	2,086–2,366	4	2,545–2,886	4
719– 796	5	938–1,038	5	1,592–1,762	5	1,941–2,146	5	2,366–2,617	5	2,886–3,191	5
796– 866	6	1,038–1,129	6	1,762–1,917	6	2,146–2,335	6	2,617–2,846	6	3,191–3,470	6
866– 931	7	1,129–1,213	7	1,917–2,060	7	2,335–2,509	7	2,846–3,058	7	3,470–3,728	7
931– 992	8	1,213–1,292	8	2,060–2,195	8	2,509–2,672	8	3,058–3,257	8	3,728–3,970	8
992–1,050	9	1,292–1,367	9	2,195–2,322	9	2,672–2,826	9	3,257–3,444	9	3,970–4,198	9
1,050–1,105	10	1,367–1,438	10	2,322–2,443	10	2,826–2,973	10	3,444–3,622	10	4,198–4,414	10
1,105–1,158	11	1,438–1,506	11	2,443–2,558	11						
1,158–1,209	12	1,506–1,571	12	2,558–2,669	12						
1,209–1,257	13	1,571–1,634	13	2,669–2,776	13						
1,257–1,305	14	1,634–1,694	14	2,776–2,879	14						
1,305–1,350	15	1,694–1,753	15	2,879–2,978	15						

Table 1 is to be used in conjuction with figure 16. Note: Prepared by Hammer (1939) and used with permission of McGraw-Hill Book Company. From Geophysical Prospecting by Dobrin (1960).

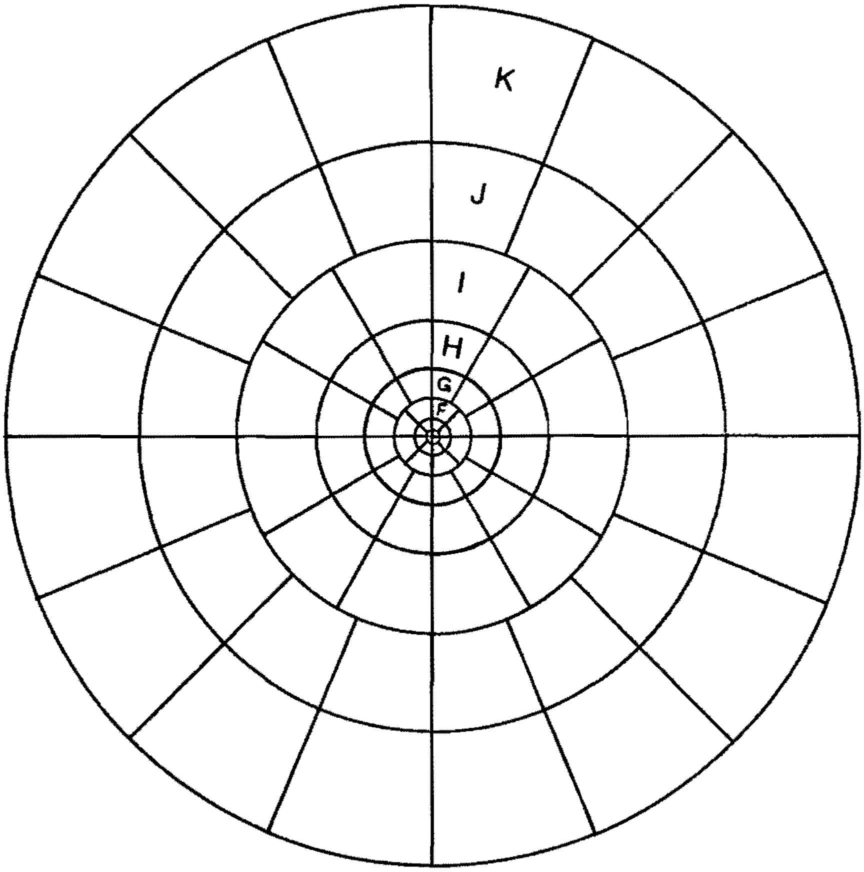


Figure 16. Terrain correction zone chart designed by Hammer (1939). To be used in conjuction with Table 1 for zones B through M. Scale: 1:175,000.

The density used by Hammer in deriving the table was 2.0. It becomes necessary, in most cases, to correct the total terrain correction for a given station by multiplying the total by a factor of $\sigma/2$, σ being the density selected. The table gives the terrain correction in units of 1/100 milligals and has a precision of about 0.1 milligals per station, dependent upon the accuracy of the maps used.

The table was computed from the formula for the gravitational attraction of a cylinder (Hammer, 1939) which corresponds to one zone or ring on the terrain correction template.

Drift Correction

Nettleton's closed loop traverse method, as was previously mentioned, was followed in making all instrument readings, Nettleton (1940). The base stations were established close enough to the line of each traverse so that it could be reoccupied within one or two hours. Gravity stations were occupied consecutively as schematically outlined in figure 17.

Ideally, the drift corrected values are those that would be observed if all the stations were simultaneously occupied at the time the first reading was made. The drift corrected values are the scaled differences between the reoccupied base stations values. The Worden gravity meter used in this study had a good closure resulting in a minimal drift error. An example of a drift curve for the

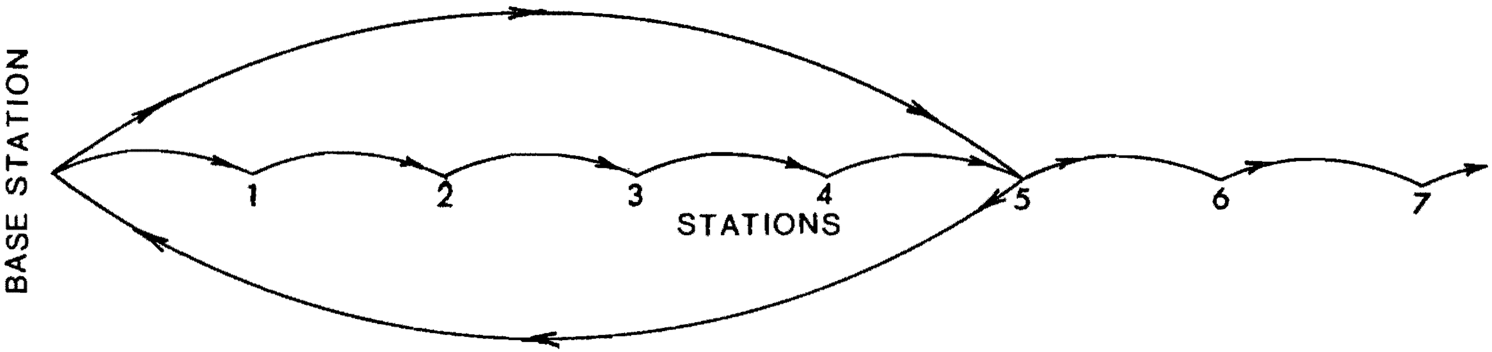


Figure 17. Schematic outline of closed loop traverse method.

Worden gravity meter is seen in figure 18.

Each base station was then tied to the absolute gravity stations described in figure 3. This procedure followed the loop method but only involved the base stations. The individual gravity stations were then rescaled to the differences found between the reoccupancy of the absolute gravity station at the Portland International Airport.

Accuracy of Reductions

Gravity reductions are subjected to numerous sources of error. Discussed are the more important sources of error with an estimation of the probable maximum error per station.

Instrument reading

The instrument sensitivity, which is the product of the instrument constant (0.1037) and the smallest unit of scale on the gravity meter (0.1), determines the maximum source of error.

Free-air correction

The correction factor of 0.09406 milligals per foot results in a correction of nearly 0.1 milligals per foot of elevation error. It is for this reason that elevations must be determined as accurately as possible. The final station correction is dependent upon the accuracy of the maps used if surveying techniques are not employed. This survey has a control accuracy of ± 5 feet, ± 10 feet on steep

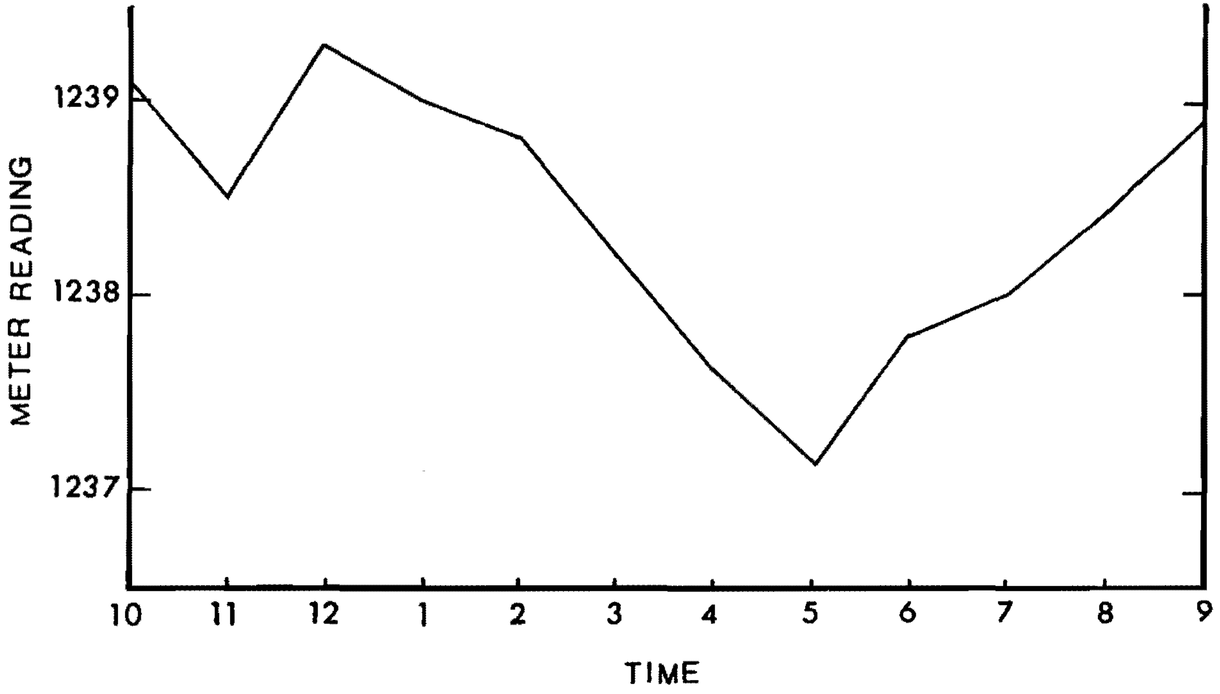


Figure 18. Drift curve for February 2, 1971.

slopes, which gives a maximum error of nearly 1.0 milligal (0.1 milligal per foot). In this survey, the maximum error only applies to 21 of the 166 gravity stations.

Bouguer correction

The Bouguer correction of $0.01276\sigma h$ milligals, where h is the thickness of the Bouguer slab, produced a maximum error of 0.034 milligals per foot at a density of 2.67 gm/cc. The total elevation correction (free-air minus Bouguer) results in a maximum gravity change of 0.66 milligals per foot of elevation at a density of 2.67 gm/cc.

Selection of surface densities can give rise to a large error in gravity reductions. An uncertainty of 0.1 gm/cc results in a 0.001h milligal error, where h is in feet. In choosing a uniform density, the resultant anomly represents the total vertical attraction of the contrasted body below the gravity station.

Latitude correction

The stations were individually corrected. The accuracy of the correction is then determined by the accuracy of the latitude measurement. A one second error in latitude produces an approximate error of 0.02 milligals.

Terrain correction

The terrain correction value is no more accurate than the elevation estimations, which are dependent on the contour interval of the topographic map used. These errors may vary from a significant amount close to the station to a negligible amount several miles from the station depending upon topography. A precision of about 0.1 milligals or better has been designed into Hammer's template and table. Elevation estimations are nearly negligible where topography is relatively flat, especially near the station. In the investigated area, accuracy is high and error is considered insignificant, except for those 21 stations located on steep slopes.

An inherent error is provided by the assemed density. This error is of the same magnitude as that found in the Bouguer correction. Considering the error in elevation estimation and the inherent density error, it is estimated that the total maximum error is less than 0.5 milligals per station.

Drift correction

During the course of a day the gravity meter will vary in the observed readings. The drift is due to the total effect of temperature changes, tidal effect, and the stretching of the internal operating components. The instrument used was self-compensating for ambient temperature changes which only leaves earth tides and the instrument drift to be corrected for.

Heiland (in Dobrin, 1960) gives a formula for calculating the tidal effect. The maximum effect of a complete tidal cycle is 0.3 milligals (Dobrin, 1960). This tedious calculation may be circumvented by applying the loop method. Base station reoccupancy was within two hours, giving a maximum error of less than 0.05 milligals.

Probable maximum error

The total maximum estimated error per gravity station is:

instrument reading	0.01
elevation correction	0.66
latitude correction	0.02
terrain correction	0.50
drift correction	0.05
total	1.24 milligals

This maximum error per gravity station would only apply if all of the errors applied were in the same direction. It is, therefore, believed that an average maximum error is less than 1.0 milligal.

The Bouguer Anomaly

The Bouguer anomaly is defined by Dobrin (1960) as

> "Observed grav. + free-air corr. - Bouguer corr.
> + topographic corr. - theoretical grav."

The observed gravity, g, as defined by Heinrichs (personal communication), is the "value of g at base station ± difference in meter reading at station and base station times meter constant." The other corrections have been previously defined.

If the density of the material found below sea level is everywhere equal, the Bouguer anomaly is expected to be zero. A departure from zero represents a relative variation of the densities below sea level. The anomaly, however, may also reflect the selection of the density by showing a contrast above sea level.

One station in the gravity survey has a known absolute value so all other relative gravity observations were changed from the relative to an absolute value by comparison. This value was used as the value of g in the defined observed gravity.

Appendix IV lists the absolute gravity under the observed gravity column and all other correction values for each gravity station. The absolute gravity is the non-corrected value at the station. All of the Bouguer anomalies are negative in the Portland area. The zero Bouguer contour line in Oregon appears on the west edge of the Willamette Valley. The Coast Range has positive Bouguer anomalies (figure 10, Berg and Thiruvathukal, 1967b).

APPENDIX IV

GRAVITY CORRECTION TABLES

Key to Correction Tables

COLUMN	
1	Station Number
2	Elevation (in feet)
3	Meter Reading
4	Meter Reading times meter constant (0.1037)
5	Observed Gravity*
6	Free-air Correction (0.09406h)
7	Bouguer Correction (0.03407h)
8	Terrain Correction
9	Theoretical Gravity
10	Degree of Latitude
11	Free-air Anomaly
12	Bouguer Anomaly

*Observed Gravity value obtained by the following steps:

(1) Take meter reading at an absolute gravity station (Portland International Airport, 1643.0).

(2) Multiply meter reading by meter constant (0.1037) = 170.379).

(3) Find ± difference between step 2 and value in column 4 from the correction tables.

(4) Add or subtract difference from known gravity value at Portland International Airport, 980648.24 milligals.

MILWAUKIE TRAVERSE

Station	Elevation	Meter Reading	Meter Reading X Meter Constant	Observed Gravity	Free-air Correction	Bouguer Correction	Terrain Correction	Theoretical Gravity	Degree of Latitude	Free-air Anomaly	Bouguer Anomaly
BASE	121	1591.1	164.997	980642.86	11.38	4.12	.134	980671.84	45°28'10.0"	-17.60	-21.59
1	153	1577.8	163.618	980641.48	14.39	5.21	.164	980668.98	45°26'16.0"	-13.11	-18.16
2	115	1611.3	167.092	980644.95	10.82	3.92	.187	980668.86	45°26'11.5"	-13.09	-16.82
3	83	1649.6	171.064	980648.92	7.81	2.83	.206	980668.75	45°26'07.0"	-12.02	-14.64
4	37	1675.9	173.791	980651.65	3.48	1.26	.338	980668.63	45°26'02.0"	-13.50	-14.42
5	44	1675.1	173.708	980651.57	4.14	1.50	.399	980668.58	45°26'00.0"	-12.87	-13.97
6	76	1656.3	171.758	980649.61	7.15	2.59	.351	980668.54	45°25'58.5"	-11.78	-14.01
7	107	1633.7	169.415	980647.28	10.06	3.65	.322	980668.48	45°25'56.0"	-11.14	-14.47
8	146	1612.5	167.216	980645.08	13.73	4.97	.294	980668.41	45°25'53.5"	- 9.60	-14.28
9	165	1608.3	166.781	980644.64	15.52	5.62	.259	980668.31	45°25'49.5"	- 8.15	-13.52

GLADSTONE TRAVERSE

BASE	113	1528.8	158.537	980636.40	10.59	3.84	.219	980666.56	45°24'39.5"	-19.57	-23.19
1	111	1515.3	157.137	980635.00	10.44	3.78	.164	980666.21	45°24'25.5"	-20.77	-24.39
2	108	1517.1	157.323	980635.18	10.16	3.68	.144	980666.10	45°24'21.0"	-20.76	-24.30
3	105	1518.6	157.479	980635.35	9.88	3.58	.159	980665.99	45°24'17.0"	-20.76	-24.18
4	102	1516.5	157.261	980635.12	9.59	3.48	.138	980665.89	45°24'13.0"	-21.18	-24.52
5	101	1530.3	158.692	980636.55	9.50	3.44	.124	980665.80	45°24'09.5"	-19.75	-23.07
6	96	1525.4	158.184	980636.04	9.03	3.27	.178	980665.67	45°24'04.0"	-20.60	-23.69
7	95	1528.0	158.453	980636.31	8.94	3.24	.174	980665.60	45°24'01.5"	-20.35	-23.42
8	106	1520.7	157.697	980635.56	9.97	3.61	.212	980665.50	45°23'57.5"	-19.97	-23.37
9	115	1534.5	159.128	980635.81	10.82	3.92	.164	980665.42	45°23'54.0"	-18.79	-22.55
10	113	1534.5	159.128	980636.99	10.63	3.85	.152	980665.33	45°23'50.5"	-17.71	-21.41
11	109	1546.7	160.393	980638.25	10.25	3.71	.179	980665.19	45°23'45.0"	-16.69	-20.22
12	108	1556.4	161.399	980639.26	10.16	3.68	.158	980665.12	45°23'42.0"	-15.70	-19.22
13	129	1551.4	160.880	980638.74	12.13	4.40	.198	980665.02	45°23'38.0"	-14.15	-18.35
14	144	1558.4	161.606	980639.47	13.54	4.91	.232	980664.93	45°23'34.5"	-11.91	-16.59
15	160	1557.8	161.544	980639.40	15.05	5.45	.198	980664.82	45°23'30.0"	-10.37	-15.62
16	176	1548.7	160.600	980638.46	16.56	6.00	.215	980664.77	45°23'28.0"	- 9.75	-15.54
17	195	1542.4	159.947	980637.81	18.34	6.64	.184	980664.73	45°23'26.5"	- 8.58	-15.04
18	194	1541.4	159.843	980637.70	18.25	6.61	.179	980664.67	45°23'24.0"	- 8.72	-15.15

REDLAND TRAVERSE

Station	Elevation	Meter Reading	Meter Reading X Meter Constant	Observed Gravity	Free-air Correction	Bouguer Correction	Terrain Correction	Theoretical Gravity	Degree of Latitude	Free-air Anomaly	Bouguer Anomaly
BASE	527	1084.4	112.452	980590.31	49.57	17.95	.244	980660.75	45°20'48.0"	-20.87	-38.58
1	346	1158.5	120.252	980598.11	32.54	11.79	.113	980660.73	45°20'47.0"	-30.08	-41.76
2	344	1162.4	120.541	980598.40	32.36	11.72	.125	980660.85	45°20'52.0"	-30.09	-41.69
3	344	1166.3	120.945	980598.81	32.36	11.72	.108	980660.99	45°20'57.5"	-29.82	-41.43
4	336	1174.0	121.744	980599.60	31.60	11.45	.138	980661.16	45°21'04.0"	-29.96	-41.27
5	323	1183.6	122.739	980600.60	30.38	11.00	.207	980661.24	45°21'07.5"	-30.26	-41.05
6	345	1165.9	120.904	980598.76	32.45	11.75	.203	980661.37	45°21'12.5"	-30.16	-41.71
7	349	1165.9	120.904	980598.76	32.83	11.89	.212	980661.51	45°21'18.0"	-29.92	-41.60
8	377	1153.6	119.628	980597.49	35.46	12.84	.486	980661.63	45°21'23.0"	-28.68	-41.03
9	386	1147.2	118.965	980596.83	36.31	13.15	.254	980661.77	45°21'28.5"	-28.63	-41.53
10	386	1148.3	119.079	980596.94	36.31	13.15	.399	980661.88	45°21'33.0"	-28.63	-41.38
11	369	1168.6	121.184	980599.04	34.71	12.57	.611	980661.99	45°21'37.5"	-28.24	-40.20
12	349	1173.8	121.723	980599.58	32.83	11.89	.651	980662.12	45°21'42.5"	-29.71	-40.95
13	347	1178.9	122.252	980600.11	32.64	11.82	.494	980662.23	45°21'47.0"	-29.48	-40.81
14	329	1191.2	123.527	980601.39	30.95	11.21	.561	980662.37	45°21'52.5"	-30.03	-40.68
15	318	1206.4	125.104	980602.96	29.91	10.84	.828	980662.48	45°21'57.0"	-29.61	-39.62
16	300	1224.0	126.929	980604.79	28.22	10.22	1.032	980662.53	45°21'59.0"	-29.52	-38.71
17	277	1233.4	127.904	980605.76	26.06	9.44	.633	980662.68	45°22'05.0"	-30.86	-39.67
18	278	1238.8	128.464	980606.32	26.15	9.47	.547	980662.81	45°22'10.0"	-30.34	-39.26
19	266	1244.5	129.055	980606.92	25.02	9.06	.625	980662.94	45°22'15.0"	-31,00	-39.43
20	265	1242.5	128.847	980606.71	24.93	9.03	.649	980663.07	45°22'20.5"	-31.43	-39.81
21	267	1254.8	130.123	980607.98	25.11	9.10	.534	980663.20	45°22'25.5"	-30.11	-38.68
22	230	1267.4	131.429	980609.29	21.63	7.84	.557	980663.37	45°22'32.5"	-32.45	-39.73
23	220	1275.5	132.269	980610.13	20.69	7.50	.483	980663.49	45°22'37.0"	-32.67	-39.69
24	208	1280.0	132.736	980610.60	19.56	7.09	.421	980663.60	45°22'41.5"	-33.44	-40.11
25	197	1292.5	134.032	980611.89	18.53	6.71	.473	980663.74	45°22'47.0"	-33.32	-39.56
26	191	1294.9	134.281	980612.14	17.97	6.51	.645	980663.90	45°22'53.5"	-33.79	-39.66
27	182	1302.2	135.038	980612.90	17.12	6.20	.557	980664.04	45°22'59.0"	-34.02	-39.66
28	182	1301.6	134.976	980612.84	17.12	6.20	.387	980664.15	45°23'03.5"	-34.19	-40.00
29	179	1301.6	134.976	980612.84	16.84	6.10	.442	980664.26	45°23'08.0"	-34.58	-40,24

TRANSMISSION LINE TRAVERSE

Station	Elevation	Meter Reading	Meter Reading X Meter Constant	Observed Gravity	Free-air Correction	Bouguer Correction	Terrain Correction	Theoretical Gravity	Degree of Latitude	Free-air Anomaly	Bouguer Anomaly
BASE	527	1084.4	112.452	980590.31	49.57	17.95	.244	980660.75	45°20'48.0"	-20.87	-38.58
1	449	1040.8	107.931	980585.79	42.23	15.30	.068	980661.68	45°21'25.5"	-33.66	-48.89
2	444	1042.1	108.066	980585.93	41.76	15.13	.057	980661.58	45°21'21.0"	-33.89	-48.96
3	439	1044.4	108.304	980586.16	41.29	14.96	.056	980661.51	45°21'18.0"	-34.06	-48.96
4	435	1048.2	108.698	980586.56	40.92	14.82	.055	980661.39	45°21'13.5"	-33.91	-48.68
5	443	1042.4	108.097	980585.96	41.67	15.09	.056	980661.33	45°21'11.0"	-33.70	-48.73
6	443	1052.7	109.165	980587.03	41.67	15.09	.049	980661.27	45°21'08.5"	-32.57	-47.61
7	431	1059.8	109.901	980587.76	40.54	14.68	.051	980661.19	45°21'05.5"	-32.89	-47.52
8	410	1077.0	111.685	980589.55	38.57	13.97	.123	980661.09	45°21'01.5"	-32.97	-48.82
9	380	1083.2	112.328	980590.19	35.74	12.95	.231	980661.02	45°20'58.5"	-35.09	-48.04
10	350	1090.1	113.043	980590.90	32.92	11.92	.399	980660.94	45°20'55.5"	-37.12	-48.64
11	368	1083.7	112.380	980590.24	34.62	12.54	.300	980660.88	45°20'53.0"	-36.02	-48.26
12	347	1109.7	115.076	980592.94	32.65	11.82	.254	980660.80	45°20'50.0"	-35.21	-46.78
13	304	1144.9	118.726	980596.59	28.60	10.36	.290	980660.73	45°20'47.0"	-35.54	-45.61
14	279	1154.7	119.742	980597.60	26.24	9.51	.356	980660.64	45°20'43.5"	-36.80	-45.95
15	261	1163.3	120.634	980598.49	24.55	8.89	.638	980660.58	45°20'41.0"	-37.54	-45.79
16	280	1145.6	118.799	980596.66	26.34	9.54	.889	980660.51	45°20'38.5"	-37.51	-46.16
17	380	1097.6	113.821	980591.68	35.74	12.95	.659	980660.45	45°20'36.0"	-33.03	-45.98
18	416	1071.6	111.125	980588.99	39.14	14.17	.271	980660.38	45°20'33.0"	-32.25	-46.15
19	428	1061.0	110.026	980587.89	40.26	14.58	.212	980660.33	45°20'31.0"	-32.18	-46.55
20	451	1044.7	108.335	980586.20	42.42	15.37	.240	980660.25	45°20'28.0"	-31.63	-46.76
21	497	1032.2	107.039	980584.90	46.75	16.93	.238	980660.13	45°20'23.0"	-28.48	-45.17
22	548	999.7	103.669	980581.53	51.55	18.67	.399	980660.08	45°20'21.0"	-27.00	-45.27
23	573	977.0	101.315	980579.18	53.90	19.52	.539	980660.01	45°20'18.5"	-26.93	-45.91
24	485	1029.2	106.728	980584.59	45.62	16.52	.622	980659.95	45°20'16.0"	-29.74	-45.64
25	392	1098.6	113.925	980591.79	36.87	13.36	.559	980659.88	45°20'13.0"	-31.22	-44.02
26	418	1083.5	112.467	980590.33	39.32	14.24	.283	980659.81	45°20'10.5"	-30.16	-44.12
27	455	1077.4	111.726	980589.59	42.80	15.50	.230	980659.75	45°20'08.5"	-27.59	-43.09
28	482	1064.2	110.358	980588.22	45.34	16.62	.242	980659.71	45°20'06.5"	-26.39	-42.81
29	480	1063.4	110.275	980588.14	45.15	16.35	.350	980659.69	45°20'05.5"	-26.40	-42.40
30	415	1113.7	115.491	980593.35	39.04	14.14	.363	980659.64	45°20'03.5"	-27.25	-41.03
31	345	1163.6	120.665	980598.53	32.45	11.75	.603	980659.59	45°20'01.5"	-28.61	-39.76
32	289	1184.1	122.791	980600.65	27.18	9.85	1.060	980659.55	45°20'00.0"	-31.72	-40.51
33	276	1186.7	123.061	980600.92	25.96	9.40	1.375	980659.54	45°19'59.5"	-32.66	-40.68
34	393	1121.6	116.310	980594.17	36.97	13.39	.635	980659.46	45°19'56.5"	-28.32	-41.08
35	347	1156.0	119.877	980597.74	32.64	11.82	.539	980659.40	45°19'54.0"	-29.02	-40.30
36	424	1114.9	115.615	980593.48	39.88	14.45	.441	980659.31	45°19'50.5"	-25.95	-39.96
37	400	1135.0	117.700	980595.56	37.62	13.63	.390	980659.25	45°19'48.0"	-26.07	-39.31
38	340	1173.2	121.661	980599.52	31.98	11.58	.342	980659.17	45°19'45.0"	-27.67	-38.91

PARADISE PARK TRAVERSE

Station	Elevation	Meter Reading	Meter Reading X Meter Constant	Observed Gravity	Free-air Correction	Bouguer Correction	Terrain Correction	Theoretical Gravity	Degree of Latitude	Free-air Anomaly	Bouguer Anomaly
BASE	451	858.7	89.047	980566.91	42.42	15.37	.192	980658.26	45°19'08.5"	-48.93	-64.11
1	390	911.6	94.533	980572.39	36.69	13.29	.322	980658.70	45°19'26.0"	-49.62	-62.59
2	391	913.7	94.751	980572.61	36.78	13.32	.312	980658.65	45°19'24.0"	-49.26	-62.27
3	391	913.6	94.740	980572.60	36.78	13.32	.308	980658.61	45°19'22.5"	-49.23	-62.24
4	392	915.1	94.896	980572.76	36.87	13.36	.286	980658.57	45°19'21.0"	-48.94	-61.01
5	393	920.1	95.414	980573.27	36.97	13.39	.283	980658.52	45°19'19.0"	-48.28	-61.39
6	392	923.3	95.746	980573.61	36.87	13.36	.286	980658.46	45°19'16.5"	-47.98	-61.05
7	390	926.8	96.109	980573.97	36.69	13.29	.292	980658.42	45°19'15.0"	-47.76	-60.76
8	391	929.4	96.379	980574.24	36.78	13.32	.290	980658.38	45°19'13.5"	-47.36	-60.39
9	390	929.7	96.410	980574.27	36.69	13.29	.324	980658.35	45°19'12.0"	-47.39	-60.36
10	387	935.2	96.980	980574.84	36.40	13.19	.408	980658.30	45°19'10.0"	-47.06	-59.84
11	379	932.7	96.721	980574.58	35.65	12.91	.832	980658.26	45°19'08.5"	-48.03	-60.11
12	265	1014.0	105.152	980583.01	24.94	9.03	.561	980658.07	45°19'01.0"	-50.68	-59.71
13	252	1025.0	105.692	980583.55	23.70	8.59	.846	980657.95	45°18'56.0"	-51.55	-60.14
14	251	1021.7	105.950	980583.81	23.61	8.55	.975	980657.92	45°18'55.0"	-51.48	-60.03
BASE	293	1106.1	114.703	980592.57	27.56	9.98	.362	980660.00	45°20'18.0"	-39.87	-49.49
15	643	783.7	81.270	980559.13	60.48	21.90	1.725	980657.91	45°18'54.5"	-38.30	-58.48
16	645	793.5	82.286	980560.15	60.68	21.98	.686	980657.92	45°18'55.0"	-37.10	-58.39
17	654	787.5	81.664	980559.52	61.52	22.28	.526	980657.92	45°18'55.0"	-36.88	-58.63
18	650	794.4	82.379	980560.24	61.14	22.15	.379	980657.92	45°18'55.0"	-36.54	-58.31
19	633	811.9	84.194	980562.06	59.54	21.57	.328	980657.91	45°18'54.5"	-36.31	-57.55
20	629	819.5	84.982	980562.84	59.17	21.43	.310	980657.85	45°18'52.0"	-35.84	-56.96
21	637	812.0	84.204	980562.06	59.92	21.70	.322	980657.76	45°18'48.5"	-35.78	-57.16
22	635	814.4	84.453	980562.31	59.73	21.64	.308	980657.67	45°18'45.0"	-35.63	-56.96
23	641	811.3	84.132	980561.99	60.29	21.84	.320	980657.58	45°18'41.5"	-35.30	-56.82
24	652	806.9	83.676	980561.54	61.33	22.21	.348	980657.54	45°18'40.0"	-34.67	-56.53
25	658	802.4	83.208	980561.07	61.90	22.42	.465	980657.49	45°18'38.0"	-34.52	-56.48
26	655	803.4	83.313	980561.17	61.61	22.32	.578	980657.42	45°18'35.0"	-34.64	-56.38
27	627	828.5	85.915	980563.78	58.98	21.36	.709	980657.37	45°18'33.0"	-34.61	-55.26
28	545	888.5	92.137	980570.00	51.26	18.57	.778	980657.32	45°18'31.0"	-36.06	-53.85
29	469	933.1	96.762	980574.62	44.11	15.98	.561	980657.28	45°18'29.5"	-38.55	-53.97
30	400	973.3	100.931	980578.79	37.62	13.63	.611	980657.24	45°18'28.0"	-40.83	-53.85
31	360	1008.9	104.623	980582.48	33.86	12.27	.688	980657.17	45°18'25.0"	-40.83	-52.41
32	351	1012.9	105.038	980582.90	33.02	11.96	.519	980657.00	45°18'18.5"	-41.08	-52.52
33	360	999.8	103.679	980581.54	33.86	12.26	.922	980656.99	45°18'18.0"	-41.59	-52.93
34	415	971.8	100.776	980578.64	39.04	14.14	.877	980656.88	45°18'13.5"	-39.20	-52.46
35	457	941.6	97.644	980575.50	42.98	15.57	.834	980656.83	45°18'11.5"	-38.35	-53.09
36	512	901.3	93.465	980571.33	48.16	17.44	.510	980656.79	45°18'10.0"	-37.30	-54.23
37	554	877.8	91.028	980568.89	52.11	18.87	.494	980656.78	45°18'09.5"	-35.78	-54.16
38	600	870.8	90.302	980568.16	56.44	20.44	.348	980656.78	45°18'09.5"	-32.18	-52.27
39	640	856.4	88.809	980566.67	60.20	21.80	.274	980656.79	45°18'10.0"	-29.92	-51.45
40	655	860.2	89.203	980567.06	61.61	22.32	.236	980656.82	45°18'11.0"	-28.15	-50.23

ESTACADA TRAVERSE

Station	Elevation	Meter Reading	Meter Reading X Meter Constant	Observed Gravity	Free-air Correction	Bouguer Correction	Terrain Correction	Theoretical Gravity	Degree of Latitude	Free-air Anomaly	Bouguer Anomaly
BASE	451	858.7	89.047	980566.91	42.42	15.37	.192	980658.26	45°19'08.5"	-48.93	-64.11
1	808	609.5	63.205	980541.07	76.00	27.53	.561	980655.11	45°17'03.0"	-38.04	-65.01
2	796	611.2	63.381	980541.24	74.87	27.12	.634	980655.11	45°17'03.0"	-39.00	-65.49
3	794	608.0	63.050	980540.91	74.68	27.05	.689	980655.11	45°17'03.0"	-39.52	-65.88
4	762	633.1	65.652	980543.51	71.67	25.96	.696	980655.11	45°17'03.0"	-39.93	-65.19
5	743	643.9	66.772	980544.63	69.89	25.31	.704	980655.11	45°17'03.0"	-40.59	-65.20
6	726	651.9	67.602	980545.46	68.29	24.73	.772	980655.11	45°17'03.0"	-41.36	-65.32
7	721	651.9	67.602	980545.46	67.82	24.56	.898	989655.11	45°17'03.0"	-41.83	-65.49
8	722	646.2	67.011	980544.87	67.91	24.60	1.090	980655.11	45°17'03.0"	-42.33	-65.84
9	711	654.9	67.913	980545.77	66.88	24.11	1.618	980655.11	45°17'03.0"	-42.46	-64.95
10	475	804.0	83.375	980561.24	44.68	16.18	1.954	980655.07	45°17'01.5"	-49.15	-63.38
11	420	836.3	86.724	980564.58	39.51	14.31	2.018	980655.00	45°16'58.5"	-50.91	-63.20
12	464	813.3	84.339	980562.20	43.64	15.81	1.164	980654.92	45°16'55.5"	-49.08	-63.73
13	485	800.1	82.970	980560.82	45.62	16.52	1.107	980654.89	45°16'54.0"	-48.45	-63.86
14	497	787.7	81.684	980559.51	46.75	16.93	1.110	980654.87	45°16'53.5"	-48.61	-64.43
15	508	785.5	81.456	980559.32	47.78	17.31	.956	980654.86	45°16'53.0"	-47.76	-64.11
16	503	783.8	81.280	980559.14	47.31	17.14	.947	980654.86	45°16'53.0"	-48.31	-64.50
17	508	780.9	80.979	980558.84	47.78	17.31	.925	980654.85	45°16'52.5"	-48.23	-64.62
18	497	779.8	80.865	980558.73	46.75	16.93	1.056	980654.85	45°16'52.5"	-49.37	-65.24
19	505	782.7	81.166	980559.03	47.50	17.21	1.092	980654.85	45°16'52.5"	-48.32	-64.44
20	532	764.8	79.310	980557.17	50.04	18.13	1.039	980654.84	45°16'52.0"	-47.63	-64.72
21	585	734.4	76.157	980554.02	55.02	19.93	.753	980654.77	45°16'49.5"	-45.72	-64.90
22	620	720.5	74.716	980552.58	58.32	21.12	.613	980654.81	45°16'51.0"	-43.91	-64.42
23	637	706.6	73.275	980551.14	59.92	21.70	.599	980654.86	45°16'53.0"	-43.80	-64.90
24	643	703.4	72.943	980550.80	60.48	21.91	.565	980654.92	45°16'55.5"	-43.64	-64.99
25	635	707.8	73.399	980551.26	59.73	21.63	.594	980654.94	45°16'56.0"	-43.95	-64.99
26	634	707.9	73.409	980551.27	59.63	21.60	.642	980655.00	45°16'58.5"	-44.10	-65.06
27	649	688.5	71.397	980549.26	61.05	22.11	.672	980655.02	45°16'59.5"	-44.71	-66.15
28	697	666.7	69.137	980547.00	65.56	23.75	.756	980655.02	45°16'59.5"	-42.46	-65.45
29	753	641.6	66.534	980544.39	70.83	25.66	.844	980655.07	45°17'01.5"	-39.85	-64.67
30	804	616.1	63.890	980541.75	75.62	27.39	.856	980655.16	45°17'05.0"	-37.79	-64.32
31	832	589.8	61.162	980539.02	78.26	28.35	.818	980655.20	45°17'06.5"	-37.92	-65.45
32	847	582.7	60.426	980538.29	79.67	28.86	.722	980655.19	45°17'06.0"	-37.23	-65.37

APPENDIX V

MAGNETIC DATA

Gladstone-M Traverse

Station	Instrument Reading	Meter Scale	Total Gammas
1	-32	1K	-320
2	-44	1K	-440
3	-265	300	-265
4	+172	300	+172
5	+107	300	+107
6	+102	300	+102
7	+105	300	+105
8	+95	300	+95
9	+36	100	+36
10	+54	100	+54
11	-18	100	-18
12	+155	300	+155
13	+155	300	+155
14	+115	300	+115
15	+30	1K	+300
16	+43	1K	+430
17	+49	1K	+490
18	+45	1K	+450

Fischers Mill-M Traverse

1	-145	300	-145
2	-165	300	-165
3	-280	300	-280
4	-50	1K	-500
5	-62	1K	-620
6	-78	1K	-780
7	-62	1K	-620
8	-72	1K	-720

Station	Instrument Reading	Meter Scale	Total Gammas
9	-72	1K	-720
10	-48	1K	-480
11	-52	1K	-520
12	-41	1K	-410
13	-43	1K	-430
14	-39	1K	-390

Estacada-M Traverse

1	-194	300	-194
2	-51	1K	-510
3	-160	300	-160
4	-135	300	-135
5	+52	1K	+520
6	-33	300	-33
7	+14	300	+14
8	-15	100	-15
9	-100	3K	-1000
10	+176	3K	+1760
11	-94	1K	-940
12	-82	3K	-820
13	-30	1K	-300
14	-56	10K	-5600
15	-100	3K	-1000
16	-115	3K	-1150
17	-107	3K	-1070

APPENDIX VI

WELL LOGS

The wells discussed in this report follow the numbering designation according to the Federal rectangular system of land division. In the City of Gladstone well (2/2-20F1), for example, the part preceeding the hyphen represents the township and range (T. 2 S., R. 2 E.) south and east of the Willamette base line and meridian. The letters "S" and "E" have been omitted for wells lying south of the base line and east of the meridian. The number following the hyphen indicates the section (section 20), see figure 26 A and B, the letter refers to the 40-acre tract in the section (F), and the final number indicates the number of the well within the 40-acre tract. Thus, the City of Gladstone well (2/2-20F1) lies in the SE1/4NW1/4 sec. 20, T. 2 S., R. 2 E., and is the first well listed in the tract.

The state of Oregon now designates the location of the wells by a new lettering system, figure 25 C. For example, (2/2-20bd1) indicates the first well located in the SE1/4NW1/4 sec. 20, T. 2 S., R. 2 E. A well designated by (2/2-20bdc) would indicate a well located in the SW1/4SE1/4NW1/4 sec. 20, T. 2 S., R. 2 E.

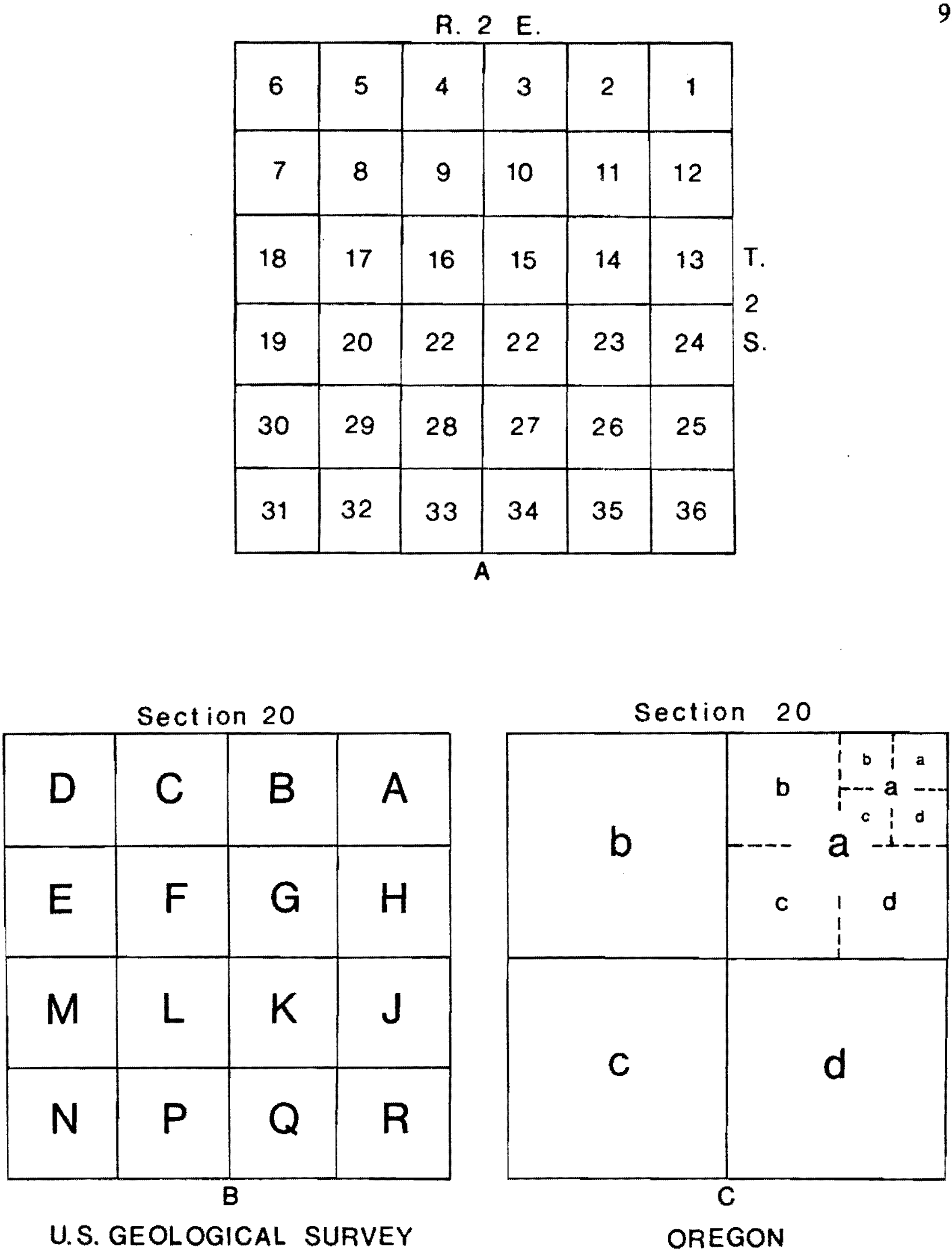


Figure 26. Explaination of well numbering system.

Drillers' Logs of Representative Wells

Materials	Thickness (feet)	Depth (feet)
1/1-36 A City of Milwaukie. 1960		
Alluvium of abandoned river channel:		
Topsoil	3	3
Gravel and sand	23	26
Gravel, loose, and sand (water)	20	46
Gravel, clay binder	15	61
Troutdale Formation:		
Gravel, cemented	32	93
Gravel, loose	3	96
Gravel, cemented	34	130
Gravel, clay binder	39	169
Gravel, cemented	4	173
Clay, sandy	8	181
Gravel, loose, and sand (water)	14	195
Gravel, cemented	79	274
Gravel, loose, and sand (water)	9	283
Gravel, cemented	6	289
Clay, blue and brown	5	294
Gravel, pea	4	298
Sandy River Mudstone:		
Clay, blue	6	304
1/2-31N1 Ambrose Calcagno. 1956		
Alluvium of abandoned river channel:		
Silt, sandy, yellow	20	20
Sand, coarse, pure, packed	15	35
Sand, trace of gravel	3	38
Sand, silty, micaceous (water)	52	90
Gravel, fine, loose (water)	7	97
Gravel, loosely cemented	6	103
Gravel, some loosely cemented	28	131
Gravel, loosely cemented (water)	47	178

Materials	Thickness (feet)	Depth (feet)
1/2-31P1 Omark Properties, Inc. 1964		
Alluvium of abandoned river channel:		
Fill	11	11
Gravel and boulders	18	29
Gravel, slightly cemented	18	47
Sand and gravel, some clay	25	72
Sand and gravel	35	107
Shale, blue	48	155
Gravel with clay	5	160
Sand and gravel	12	172
Gravel and clay	2	174
Shale, blue	27	201
Clay, sandy	8	209
Sand and gravel	6	215
Troutdale Formation:		
Gravel, cemented	25	240
Sand and gravel	11	251
Gravel, cemented	9	260
Sand and gravel	16	276
Decomposed formation	13	289
Sandy River Mudstone:		
Clay, brown	11	300
2/1-1A Camillo Giacchero. 1964		
Alluvium of abandoned river channel:		
Sand, fine, brown	39	39
Clay, sandy, green	8	47
Sand, fine, gray	46	93
Sandy River Mudstone:		
Clay, gray	25	118
Clay, brown	3	121
Clay, green	9	130
Sand, fine, gray	10	140

Materials	Thickness (feet)	Depth (feet)
2/1-1F Milwaukie Elks. 1966		
Columbia River Basalt:		
Topsoil	2	2
Clay, red	10	12
Rock, broken, soft	56	68
Basalt, gray	35	103
Basalt, black	20	123
Basalt, broken	25	148
Basalt, medium hard, black	6	154
Basalt, broken	4	158
Basalt, medium hard, black	3	161
Basalt, porous, black	14	175
Basalt, hard, black	16	191
Basalt, hard, gray	10	201
2/2-9B1 A. L. Alexander. 1927		
Alluvium of abandoned river channel:		
Soil and clay	5	5
Troutdale Formation:		
Gravel, cemented	11	16
Sand	2	18
Gravel, cemented	10	28
Gravel, cemented, and sand	5	33
Gravel, cemented	5	38
Sand	10	48
Gravel, cemented, sandy	7	55
Sand	6	61
Sand, cemented	4	65
Sand, fine	13	78
Gravel, cemented	2	80
2/2-9J Loren Mathews.		
Alluvium of abandoned river channel and Troutdale Formation:		
Topsoil	1	1
Gravel, heavy	39	40
Sand and gravel, big	7	47
Gravel	6	53

Materials	Thickness (feet)	Depth (feet)
2/2-10F Oak Acres Mobile Homes. 1967		
Alluvium of abandoned river channel and Troutdale Formation:		
Topsoil	6	6
Cemented gravel	39	45
Sand	2	47
Clay, blue	20	67
Gravel, hard	1	68
Clay, blue	8	76
Gravel	1	77
Clay, blue, sticky	3	80
Sand, gray, and gravel	35	115
Shale, green	12	127
Sand, gray, and gravel	13	140
Sand, gray, medium grain	6	146
Sand, fine	2	148
Sand, gravel, cobble rock	41	189
Clay, sticky	1	190
Sand, loose, and gravel	9	199
Clay, hard, sandy	2	201
Sand, loose, and gravel	24	225
Sandy River Mudstone:		
Shale, blue, sticky	5	230
Shale and gravel streaks	15	245
Sand and shale streaks	51	296
Shale	16	312
2/2-15D Byrum W. Morehouse.		
Alluvium of abandoned river channel and Troutdale Formation:		
Sand and gravel, cemented	113	113
Soapstone	75	188
Sand, fine (water)	14	202
Gravel (water)	2	204
Sandy River Mudstone:		
Clay, blue and clay, sand	96	300
Shale, green	20	320
Clay, gray with seams of sand, fine (water)	27	347

Materials	Thickness (feet)	Depth (feet)
2/2-16B1 F. J. Mooney. 1958		
Alluvium of abandoned river channel:		
Clay, gravelly, brown	4	4
Gravel, lightly cemented	11	15
Gravel, loose (water)	1	16
Gravel, lightly cemented	3	19
Troutdale Formation:		
Gravel, cemented, with layers of brown clay	12	31
Gravel, cemented (water)	8	39
Shale, gray	6	45
Gravel, cemented	6	51
2/2-16K Donald Hugart. 1970		
Recent alluvium and Troutdale Formation:		
Clay, brown	15	15
Gravel, large	17	32
Gravel, medium	8	40
Gravel	1	41
Sandy River Mudstone:		
Clay, gray, sandy	24	65
Clay, gray	45	110
Clay, blue, sandy	6	116
Clay, gray	29	145
Clay, gray, sandy	5	150
Sand, coarse	9	159
Clay, gray	1	160
2/2-16K3 Oak Lodge Water District. 1957		
Recent alluvium and Troutdale Formation:		
Loam, sandy, and soil	14	14
Gravel, cement, 6" and smaller, bound with brown clay	7	21
Boulders, large with clay binder	5	26
Sand and gravel, water bearing	1.5	27.5
Sandy River Mudstone:		
Clay, blue (light blue)	22.5	50

Materials	Thickness (feet)	Depth (feet)
2/2-20F1 City of Gladstone. 1949		
Lacustrine deposits:		
Clay and boulders	11	11
Clay, blue and yellow	29	40
Clay and sand	15	55
Shale, brown, sandy	20	75
Columbia River Basalt:		
"Shale rock" (weathered basalt?)	12	87
Rock, gray, solid	1	88
Rock, blue, hard	7	95
Rock, hard, fractured	15	110
Rock, solid	7	117
Clay and shale (weathered zone in the basalt?)	13	130
Rock, soft	5	135
Basalt, black	40	175
Basalt (water)	500	675
Basalt (water, saline)	10	685
Scappoose Formation:		
Shale, blue (water, saline)	7	692
2/3-18J L. D. Carlson. 1965		
Terrace deposits:		
Silt, brown	8	8
Gravel and boulders, cemented	16	24
Silt, blue	13	37
Sandy River Mudstone:		
Clay, blue, silty	37	74
Gravel	1	75
Clay, blue	39	114
Silt, blue	8	122
Sand, gray	19	141
Clay, blue, sticky	37	178
Clay, gray	7	185
Sand, gray	7	192
Clay, gray, silty	32	224
Clay, blue, sticky	63	287
Clay, gray	30	317
Silt, brown	7	324
Clay, blue	33	357

Materials	Thickness (feet)	Depth (feet)
Sandy River Mudstone continued:		
Sand, gray	13	370
Clay, gray	9	379
Clay, blue	11	390
Clay, gray	60	450
Shale, blue, crumbly	6	456
2/3-18N Leon Dow.		
Terrace deposits:		
Gravel, cement, and boulders	27	27
Sandy River Mudstone:		
Clay, blue, sticky	5	32
Clay, gray, sandy	19	51
Clay, blue, sandy	15	66
Conglomerate, green	4	70
Clay, gray	40	110
Clay, green, sandy	12	122
Clay, blue, sandy	14	136
Clay, gray, sandy	12	148
Sand, gray, coarse	1	149
Sand and gravel (1/2")	1	150
2/3-19M Tommy Gene Vanderflute.		
Estacada Formation:		
Topsoil, brown	1	1
Gravel, medium	20	21
Clay and sand, fine, gray	13	34
Sand, medium	8	42
Sandy River Mudstone:		
Clay, blue	19	61

Materials	Thickness (feet)	Depth (feet)
2/3-19N Charles N. Crisp. 1963		
Estacada Formation:		
Topsoil	2	2
Clay, brown	8	10
Clay, brown, sandy	30	40
Sandy River Mudstone:		
Clay, blue	8	48
Sand, brown, medium	1	49
2/3-27L Elbert Simpkins.		
Estacada Formation:		
Topsoil	1	1
Clay, brown, sticky	14	15
Troutdale Formation:		
Boulder and gravel conglomerate	34	49
Sandy River Mudstone:		
Clay, gray, sticky	75	124
Sand, gray, conglomerate	4	128
Clay, gray, sticky	19	147
Silt, gray, conglomerate	13	160
Clay, gray, sticky	25	185
Sand, gray, fine	3	188
Clay, gray, sticky	15	203
Silt, gray, conglomerate	11	214
Clay, gray, sticky	82	296
Sand, shale, gray	5	301
2/3-30D Alfred Aus.		
Gresham Formation:		
Clay, silty, yellow and brown	15	15
Clay, silty, gray	30	45
Gravel, loose, and sand, coarse	10	55
Sandy River Mudstone:		
Clay, gray	9	64

Materials	Thickness (feet)	Depth (feet)
2/3-30D Ernest T. MacFarlane.		
Gresham Formation:		
Sand, black, and gravel	4	4
Mud, blue, and gravel	10	14
Sandy River Mudstone:		
Clay	90	104
2/3-31D John F. DelVal. 1949		
Gresham Formation:		
Gravel and boulders, cement.	36	36
Troutdale Formation:		
Clay	24	60
Clay and clay, sandy	40	100
Clay and clay, sandy, some sand.	85	185
Sand and gravel, cemented	45	230
Sand and gravel, loose, coarse	12	242
2/3-31cac Adolph Deininger.		
Gresham Formation:		
Topsoil	1	1
Clay, brown	11	12
Troutdale Formation:		
Gravel, conglomerate.	27	39
Clay, brown	5	44
Clay, gray	10	54
Gravel, conglomerate, loose	13	67
Gravel and sand	20	87
2/3-31L Howard DeLano. 1959		
Gresham Formation:		
Clay	35	35
Troutdale Formation:		
Gravel, boulders, clay	29	64
Gravel, dry	2	66
Boulders, gravel and clay	9	75
Sand	2	77
Gravel, cemented	10	87

Materials	Thickness (feet)	Depth (feet)
Troutdale Formation continued:		
Gravel, some cemented (water)	10	97
Sandy River Mudstone:		
Clay, sand and silt, blue	9	106
Silt, blue, sandy, gravely	6	112
Silt, blue, and clay, gray	69	181
Gravel, clay, clay, sandy with sand streaks (water)	22	203
Clay, sandy	2	205
Sand (water)	2	207
Sand, gravel and clay	5	212
Clay, gray	17	229
Clay, sandy	2	231
Silt, blue-black	19	250
Sand, dry	4	254
Sand, coarse	2	256
Sand, gravel, clay streaks	11	267
Clay	3	270
2/3-31M Vernie Renaud. 1962		
Gresham Formation (?):		
Clay, yellow	4	4
Clay, yellow, and boulders	6	10
Clay, yellow, and gravel	30	40
Clay, yellow, sticky	9	49
Troutdale Formation:		
Gravel, yellow, cement	7	56
Sand and gravel, loosely cemented	28	84
Clay, yellow	2	86
Gravel, loose (water)	7	93
2/3-33abc Elmore Mostul.		
Gresham Formation:		
Clay, brown	3	3
Troutdale Formation:		
Gravel, cement, and boulders	72	75
Gravel, loosely cemented	20	95
Gravel, loose	10	105
Gravel, cemented, gray	16	121

Materials	Thickness (feet)	Depth (feet)
Sandy River Mudstone:		
Clay, brown	39	160
2/3-33G Logan Church Parsonage.		
Gresham Formation:		
Topsoil	1	1
Clay, brown, sticky	4	5
Clay, brown, conglomerate	19	24
Troutdale Formation:		
Gravel, brown, conglomerate	77	101
Gravel, loose	5	106
2/3-33Q J. E. Lanz. 1968		
Gresham Formation:		
Clay, orange, sticky	11	11
Clay, granular, tan	6	17
Troutdale Formation:		
Gravel, cement	30	47
Clay, brown	3	50
Gravel, loose	13	63
Rock, gray, soft	10	73
3/3-5G1 Washore Turkey Association.		
Gresham Formation:		
Clay, large boulders	35	35
Boring Lava:		
Lava, hard	59	94
Troutdale Formation:		
Sandstone	11	105
Shale	35	140
Sand, cemented	10	150
Shale	36	206
Rock, hard, sedimentary	9	215
Shale	35	250

Materials	Thickness (feet)	Depth (feet)
3/3-5da Jack Torrence.		
Gresham Formation:		
Topsoil	1	1
Clay, brown, sticky	41	42
Boring Lava:		
Rock, soft, brown	3	45
Rock, medium hard, gray	52	97
Troutdale Formation:		
Shale, brown, conglomerate	41	138
Sand, fine, loose, gray	5	143
Sand, fine, gray, conglomerate, packed	19	162
Sandy River Mudstone:		
Clay, brown	31	193
Shale, brown, conglomerate	6	199
Clay, black	4	203
Clay, gray, conglomerate, silty	11	214
Sand, fine to coarse, gray (water)	4	218
Clay, gray, conglomerate, silty	12	230
3/3-6J Ray Sievers.		
Boring Lava - weathered:		
Clay, brown	14	14
Clay, brown and blue	6	20
Clay, brown, gritty	45	65
Troutdale Formation:		
Sand, medium, yellow	20	85
Clay, brown	10	95
Clay, blue	8	103
Clay, green	12	115
Clay, gray	8	123
Clay, brown	26	149
Sand, fine, yellow	10	159
Gravel, small, and sand, coarse, cemented	36	195
Sandy River Mudstone:		
Clay, brown, gritty	14	209
Clay, blue, gritty	21	230
Clay, gray, gritty	11	241
Clay, blue, gritty	69	310
Clay, gray	61	371

Materials	Thickness (feet)	Depth (feet)
Sandy River Mudstone continued:		
Sand, fine	9	380
Clay, green	20	400
Clay, gray	70	470
Clay, green	10	480
Sand, medium, black	5	485
Clay, blue	2	487
3/3-7M E. Evenson.		
Sandy River Mudstone:		
Topsoil and clay, red	24	24
Clay, blue	28	52
Sand, blue	2	54
Clay, blue	29	83
Sand and silt, gray, dark	15	98
Sandstone, blue	9	107
Clay, blue	10	117
Sand and silt, gray	12	129
Clay, blue	23	152
Silt, gray	20	172
Clay, blue	53	225
Clay, blue, sticky	15	240
Silt, gray, and clay	12	252
Silt, gray (wet)	10	262
Clay, blue	18	280
Shale, blue	50	330
Columbia River Basalt (?)		
Weathered basalt	142	472
Shale, dark, hard	45	517
Sand and gravel	3	520
3/3-11G Melvin Welker.		
Springwater Formation:		
Dirt and gravel and boulders	17	17
Gravel and boulders, cement	30	47
Clay, brown	4	51
Troutdale Formation:		
Gravel, cement	12	63
Clay, brown	12	75

Materials	Thickness (feet)	Depth (feet)
3/3-13A or H Glen H. Hill. 1961		
Estacada Formation:		
Soil	3	3
Boulders	13	16
Sandy River Mudstone:		
Clay	5	21
Clay, blue	200	221
Rhododendron Formation:		
Rock and boulders	4	225
Clay, blue	58	283
Rock	32	315
Rock, soft	62	377
3/3-14A Herman Durschmidt.		
Springwater Formation:		
Clay, brown	23	23
Clay, brown, and boulders	2	25
Clay, brown	4	29
Troutdale Formation:		
Gravel, cement	26	55
Gravel, loose, cement	5	60
Clay, brown	12	72
Clay, gray	9	81
3/3-14aca Donald R. Smith. 1967		
Springwater Formation:		
Loam, brown	3	3
Clay, brown, and gravel, large	19	22
Gravel, large	2	24
Troutdale Formation:		
Gravel, cemented	59	83
Clay, gray	50	133
Clay, gray, and wood	19	152
Sandy River Mudstone:		
Clay, light blue	21	173
Clay, yellow, and gravel, white	9	182
Clay, gray	38	220

Materials	Thickness (feet)	Depth (feet)
3/3-15bb Robert Kiefer. 1970		
Boring Lava:		
Topsoil	4	4
Clay, red	18	22
Clay, brown	8	30
Clay, shale, gray	10	40
Lava, broken (2 gpm)	4	44
Lava, gray	226	270
Troutdale Formation:		
Clay, gray	47	317
Gravel (4 gpm)	4	321
Clay, gray	73	394
Gravel, pumice (18 gpm)	22	416
Clay, gray	14	430
Sand, coarse, and gravel, small	23	453
Sandy River Mudstone:		
Clay, gray	19	472
Sand, gray, medium	10	482
Clay, gray	92	572
Clay, black, hard	14	586
Clay	9	595
Sand, gray (30 gpm)	10	605
Clay, gray	70	675
Sand, gray (42 gpm)	7	682
Clay	5	687
Shale, gray	29	716
Clay, gray	26	742
Columbia River Basalt (?):		
Basalt, black	18	760
Basalt, black, soft	4	764
Clay, gray, hard and soft	71	835
3/4-7D Ralph (Simmy) Heiple.		
Estacada Formation:		
Terrace deposits	54	54
Sandy River Mudstone:		
Clays and some sands	46	100

Materials	Thickness (feet)	Depth (feet)
3/4-7Q E. L. Williams.		
Estacada Formation:		
Terrace deposits	42	42
Sandy River Mudstone:		
Clays and some sands	13	55
3/4-8M1 Stuart Puckett.		
Estacada Formation:		
Terrace gravels	60	60
3/4-9F Ardel Zach.		
Springwater Formation:		
Terrace gravels	25	25
Sandy River Mudstone (all?):		
Clay, gray	8	33
Clay, blue	42	75
Clay, brown, and shale	18	93
Clay, blue	67	160
Clay, gray	98	258
Clay, blue	37	295
Clay, gray	7	302
Clay, blue	2	304
Rhododendron Formation:		
Basalt, gray, soft	38	342
Basalt, clay, gray	2	344
Basalt, gray, medium hard	26	370
Basalt, gray, soft	20	390
3/4-18ba Floyd R. Ashworth.		
Estacada Formation:		
Clay, brown	1	1
Gravel, cement	46	47
Sandy River Mudstone:		
Clay, brown	4	51
Clay, gray	12	63
Clay, blue	42	105

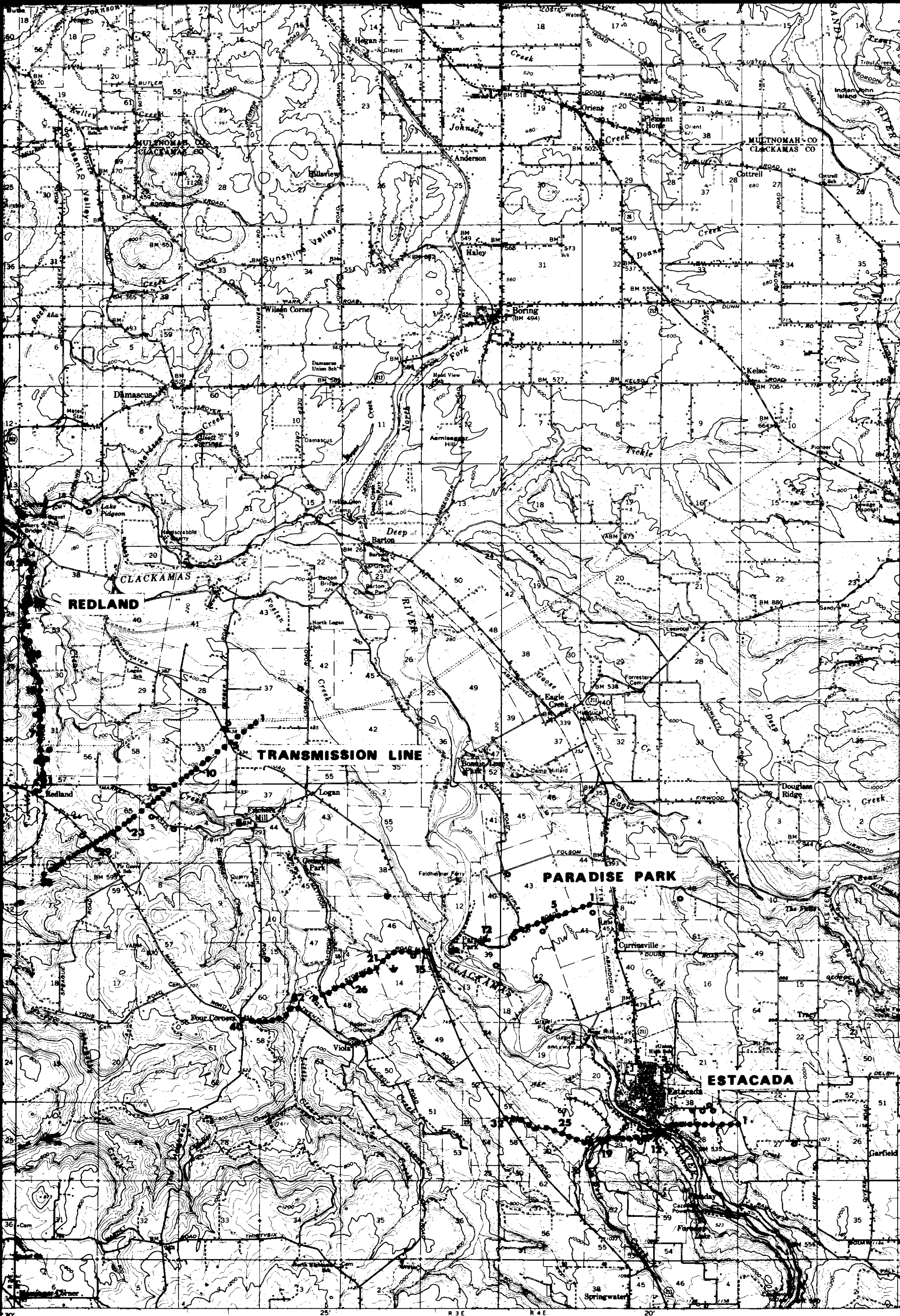
Materials	Thickness (feet)	Depth (feet)
Sandy River Mudstone continued:		
Sand, gray, fine	3	108
Clay, blue	130	238
Sand, gray, coarse	5	243
3/4-21M S. S. Dunlop (Well No. 1). 1963		
Rhododendron Formation:		
Clay, yellow, and boulders	18	18
Clay, yellow, granular	14	32
Clay, blue, sticky	28	60
Clay, gray, granular	15	75
Rock, gray, soft	119	194
Shale, bluish green	19	213
Rock, gray, soft	205	418
Rock, pinkish gray	22	440
Rock, bluish gray, soft	20	460
Shale, blue, with ribbons of brown	10	470
Rock, bluish gray	45	515
Shale, brittle, bluish gray	10	525
Rock, gray, soft	35	560
Rock, red, soft	3	563
Rock, blue, shaley, with white specks	99	662
Clay, blue	3	665
Clay or shale, green, gritty	15	680
Rock, bluish green	25	705
Rock, black	43	748
Rock, gray, dark (soft)	31	779
Rock, gray, hard	25	804
Columbia River Basalt (?):		
Shale, brittle, blue, with streaks	23	827
of hard gray rock (basalt?)	21	848
Rock, black, hard	11	859
Rock, gray, hard	34	893
Rock, bluish gray, softer	14	907
Rock, bluish gray, hard	18	925
Rock, gray, medium hard	19	944

Note: "Most all of the rock from 75 feet to 827 feet has lots of crystal or glass in it. From 827 feet on I believe it is mostly Columbia River basalt. Hole made no water below 150 feet"

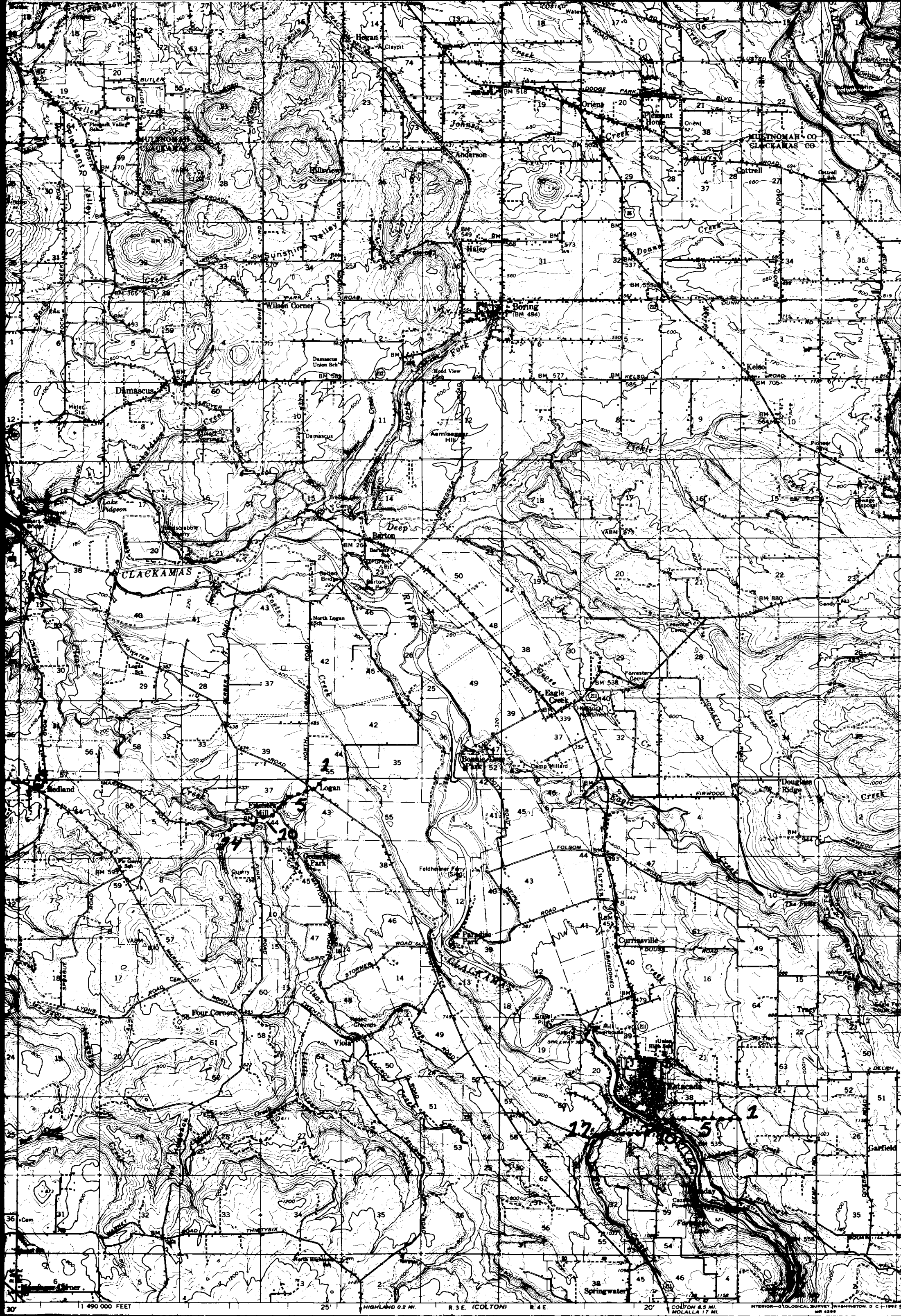
Materials	Thickness (feet)	Depth (feet)
3/4-27K Basil Weathers. 1968		
Springwater Formation:		
Clay and gravel	17	17
Clay, brown, sticky	5	22
Clay, gray, sticky	10	32
Clay, tan, sandy	13	45
Gravel and sand	11	56
Clay, brown	2	58
Gravel, cemented	9	67
Clay, brown	8	75
Sand, gray	2	77
Gravel	10	87
Clay, gray	3	90
Clay, pink	28	118
3/4-28B Robert E. McConnell.		
Springwater Formation:		
Clay, yellow, with boulders	26	26
Clay, yellow, sticky	8	34
Clay, orange	31	65
Clay, brownish yellow	33	98
Rhododendron Formation:		
Rock, bluish gray, soft	16	114
Conglomerate, yellow	16	130
Rock, bluish gray, soft	21	151
Rock, bluish gray, broken (water)	6	156
3/4-28B H. L. Duvall.		
Springwater Formation:		
Clay, brown	29	29
Boulders and clay	10	39
Sand	4	43
Gravel, cement	4	47
Gravel, loosely cemented	10	57

Materials	Thickness (feet)	Depth (feet)
3/4-28aba Robert L. Poore. 1964		
Springwater Formation:		
Clay, yellow, and boulders	15	15
Clay, white	7	22
Clay, blue	4	26
Clay, gray, granular	24	50
Clay, brown	6	56
Clay, red	16	72
Clay, light gray	13	85
Clay, tan	14	99
Rhododendron Formation:		
Rock, bluish gray	43	142
3/4-28baa Jack Broadhurst.		
Springwater Formation:		
Gravel, decomposed, and clay, yellow	25	25
Clay, white	10	35
Rhododendron Formation:		
Rock, blue, with white specks	10	45
Rock, bluish, with lots of quartz in it	25	70
Rock, bluish gray, with boulders	15	85
Rock, bluish gray, with white and red specks in it	40	125
3/4-29adc Kenneth Meeker.		
Estacada Formation:		
Clay, brown, sticky	13	13
Clay, gray	3	16
Gravel and boulders, cemented	16	32
Clay, brown, sandy	2	34
Gravel, cemented	11	45
Rhododendron Formation:		
Rock, gray, soft	64	109
Rock, medium hard	21	130

Materials	Thickness (feet)	Depth (feet)
3/4-29adb Norman Hall.		
Terrace deposits:		
Gravel, cemented, and boulders, large . . .	32	32
Clay, gray	6	38
Rhododendron Formation:		
Rock	120	158
3/4-29bcc Eugene C. Shore. 1970		
Gresham Formation:		
Topsoil, clay, brown, sandy	4	4
Clay, brown, layers of coarse gravel. . . .	18	22
Gravel, medium to coarse, with sand streaks	48	70
Rhododendron Formation:		
Rock, soft, broken	37	107
Rock, hard, fractured (water)	5	112



REDLAND
TRANSMISSION LINE
PARADISE PARK
ESTACADA
Jenne
Hogan
Orient
Pleasant Home
Cottrell
Anderson
Hillsview
Sunshine Valley
Haley
Boring
Wilson Corner
Damascus
Kelso
Pioneer Park
Barton
Eagle Creek
Redland
Logan
Four Corners
Viola
Currinsville
Douglass Ridge
Estacada
Springwater
Garfield
MULTNOMAH CO
CLACKAMAS CO
CLACKAMAS RIVER
Deep Creek
Eagle Creek
Tickle Creek
Goose Creek
Doane Creek
Johnson Creek
Clear Creek
Foster Creek
30'
25'
R 3 E
R 4 E
20'


Hogan
Claypit
Dodge Park Blvd
Orient
Pleasant Home
Anderson
Johnson Creek
Hillsview
Pleasant Valley Sch
Multnomah Co
Clackamas Co
Cottrell
Sunshine Valley
Haley
Doane Creek
Boring
Wilson Corner
Damascus Union Sch
Damascus
Kelso
North Fork
Aemisegger Hill
Tickle Creek
Lake Pidgeon
Deep Creek
Barton
Barton Bridge
Barton Park
Gravel Pit
Clackamas
River
Eagle Creek
Sandy
Leewood Camp
Forresters Camp
Bonnie Lure Park
Camp Millard
Douglass Ridge
North Logan Sch
Logan
Springwater Road
Redland
Fischers Mill
Feldheimer Ferry
Paradise Park
Currinsville
Four Corners
Viola
Clear Creek
Tracy
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R. 4 E.
20'
COLTON 8.5 MI.
MOLALLA 17 MI.
INTERIOR—GEOLOGICAL SURVEY WASHINGTON D C—1962
MR 4399

BOUGUER AND MAGNETIC ANOMALIES

WITH

GEOLOGIC CROSS SECTIONS

BY

RONALD J SCHMELA

1971

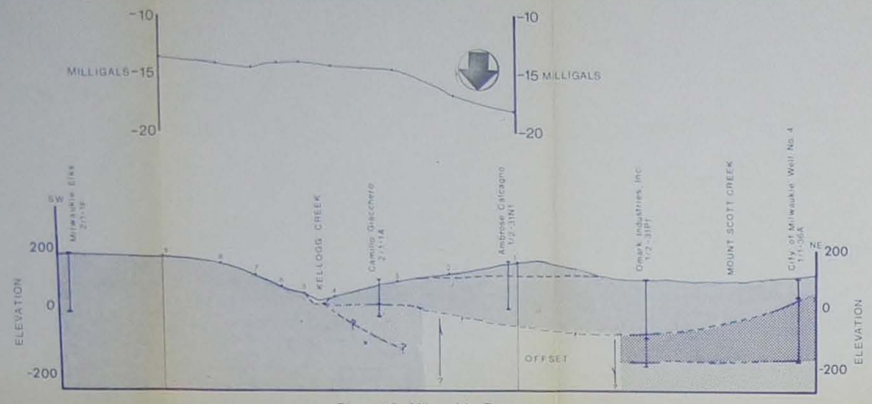


Figure 19 Milwaukie Traverse

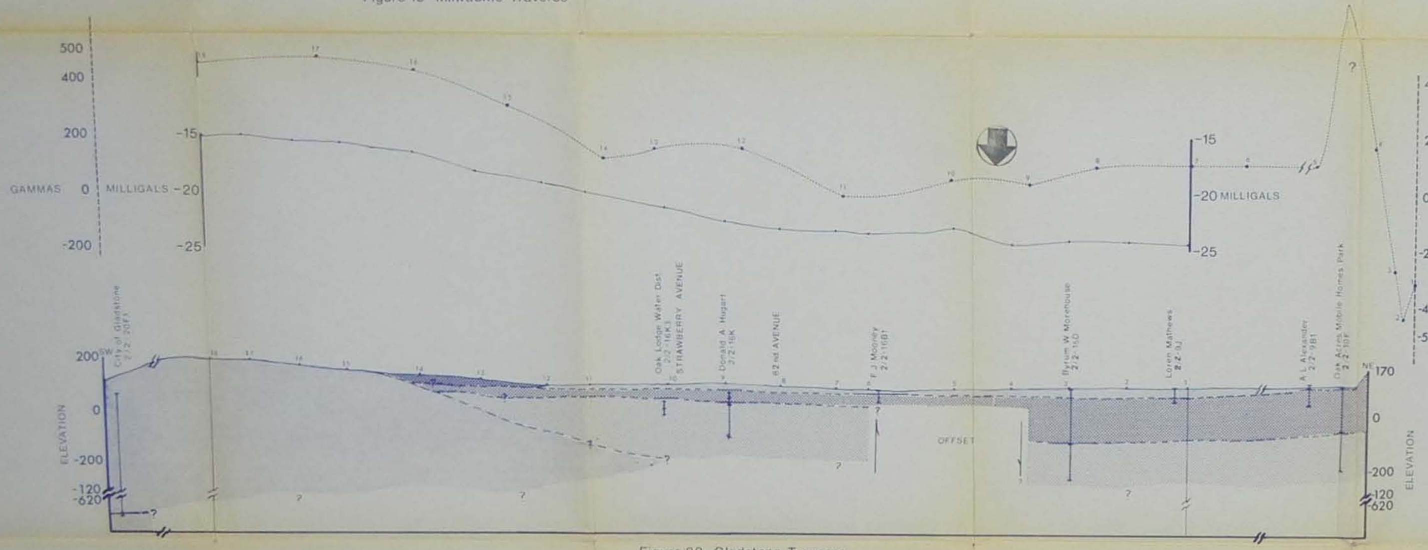


Figure 20 Gladstone Traverse

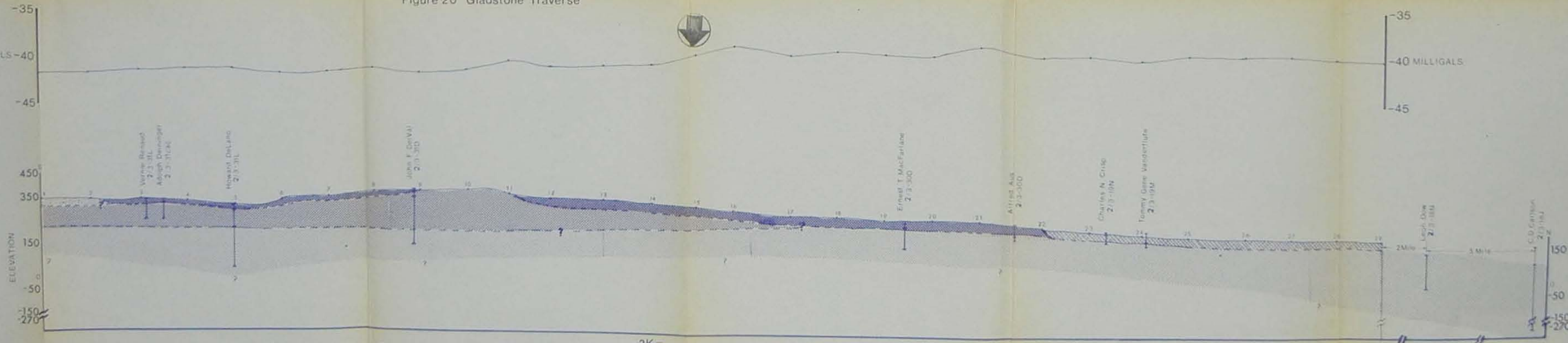


Figure 21 Redland Traverse

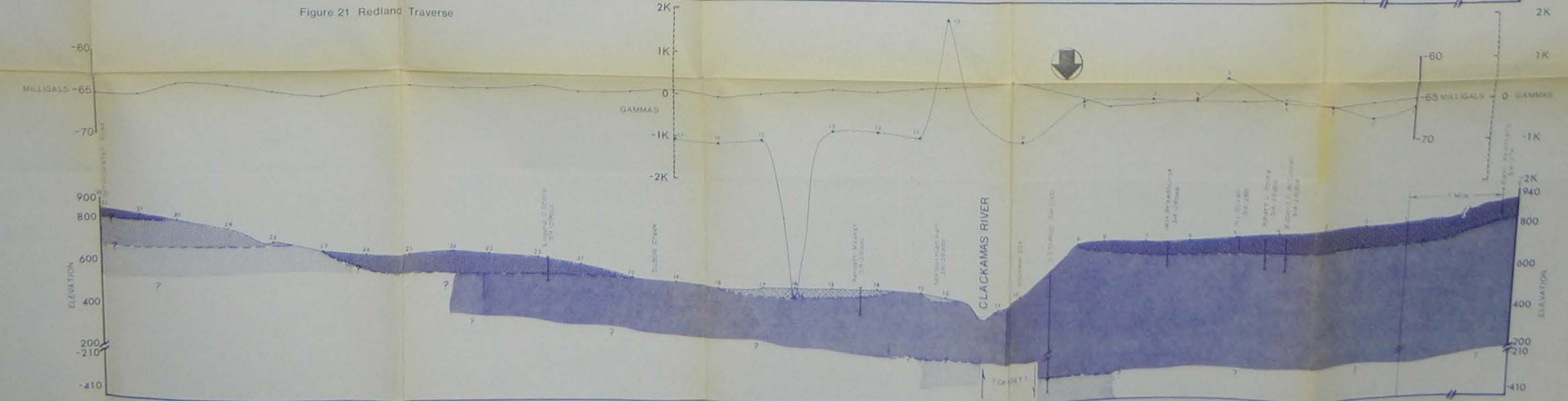
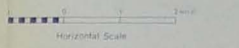


Figure 24 Estacada Traverse



Horizontal Scale

- ▢ Channel Alluvium
- ▨ Estacada Formation
- ▨ Gresham Formation
- ■ Springwater Formation
- ▨ Boring Lava
- ▨ Troutdale Formation
- ▢ Sandy River Mudstone
- ■ Rhododendron Formation
- ▢ Columbia River Basalt
- ▢ Scappose Formation

- Bouguer Anomaly
- Magnetic Anomaly
- Water Well
- Shortened Section

Geophysical and Geological Analysis of a Fault-Like Linearity
in the Lower Clackamas River Area,
Clackamas County, Oregon

BOUGUER AND MAGNETIC ANOMALIES

WITH

GEOLOGIC CROSS SECTIONS

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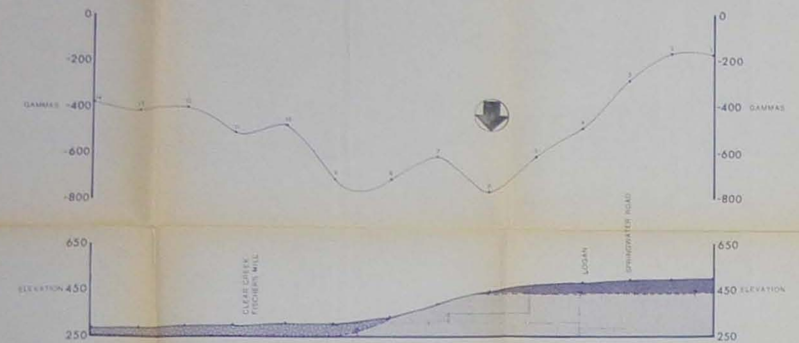

Figure 25 Fischers Mill Traverse

Horizontal Scale

- ▨ Recent Alluvium
- ▨ Estacada Formation
- ▨ Gresham Formation
- ▨ Springwater Formation
- ▨ Boring Lava
- ▨ Troutdale Formation
- ▨ Sandy River Mudstone
- ▨ Rhododendron Formation
- ▨ Columbia River Basalt

Bouguer Anomaly

Magnetic Anomaly

Water Well

Shortened Section

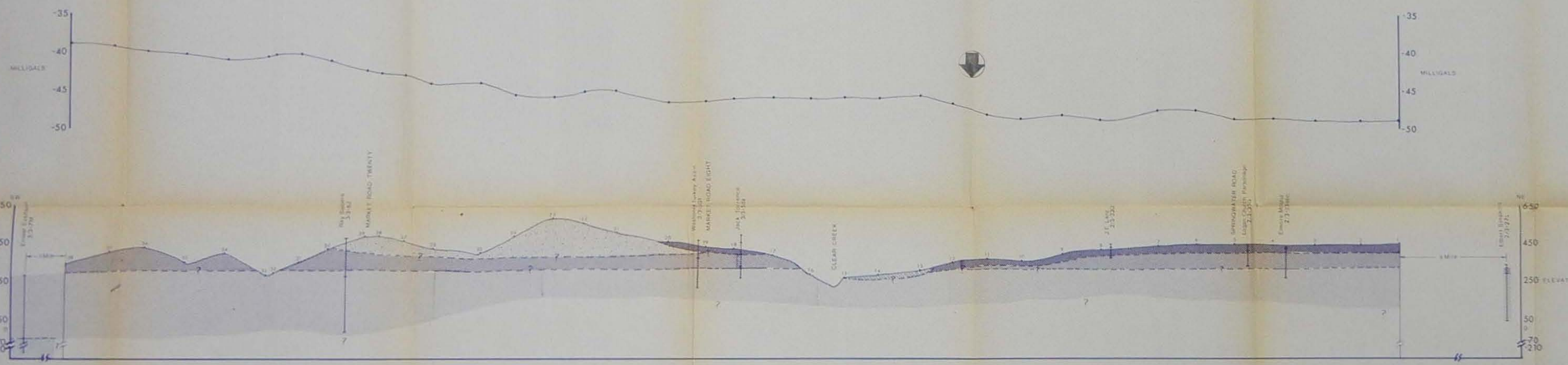

Figure 22 Transmission Line Traverse

Figure 23 Paradise Park Traverse

Geophysical and Geological Analysis of a Fault-Line Linearity
in the Lower Clackamas River Area,
Clackamas County, Oregon