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Geology

QUATERNARY GEOLOGY OF THE SOUTH-CENTRAL OLYMPIC PENINSULA, WASHINGTON

By

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A dissertation submitted in partial fulfillment

of the requirements for the degree of

DOCTOR OF PHILOSOPHY

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Approved by Stephen C. Porter

Department GEOLOGICAL SCIENCES

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Date: May 29, 1970

We have carefully read the dissertation entitled Quaternary Geology of the South-Central Olympic Peninsula, Washington submitted by Robert James Carson III in partial fulfillment of the requirements of the degree of Doctor of Philosophy and recommend its acceptance. In support of this recommendation we present the following joint statement of evaluation to be filed with the dissertation.

The southeast Olympic Peninsula is mantled with a broad apron of glacial sediments deposited by large Quaternary glaciers originating in the Olympic Mountains and in the Cordilleran Ice Sheet of southern Canada. Older reports on the glacial geology of the Olympics suggested that advances of Olympic alpine glaciers and of the massive Puget Lobe were out of phase, and underwent their maximum advances at different times. One of the principal aims of this study was to examine the interrelationship of a former alpine glacier and the Puget Lobe in the one area where their terminal deposits interfinger. By carefully mapping moraines and terraces of the two glacier systems, Carson has shown the relative timing of the glacier advances and reconstructed the complex sequence of events which characterized the Quaternary glacial history of the region. His studies indicate that there were at least three and possibly four main episodes of glaciation, inferred from separate bodies of drift having distinctive weathering and morphologic characteristics. He was further able to demonstrate multiple advances of alpine glaciers during the most recent episode of glaciation.

In addition to regional stratigraphic studies of the glacial deposits, Carson has produced a detailed map of the distribution of glacial deposits and morphologic features for an area which had previously been largely unmapped. The detailed surficial geologic map should be of special importance for future ground-water, soils, and environmental planning studies in the southern Olympic Peninsula.

This dissertation constitutes an important contribution to the understanding of Quaternary environmental history in western Washington and provides information on past glacier fluctuations which is important in developing theories to explain former fluctuations of climate. As such, it should serve as the basic reference on the surficial geology of the southern Olympic Peninsula.

DISSERTATION READING COMMITTEE: Stephen C. Porter

Howard A. Coombs

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Doctoral Dissertation

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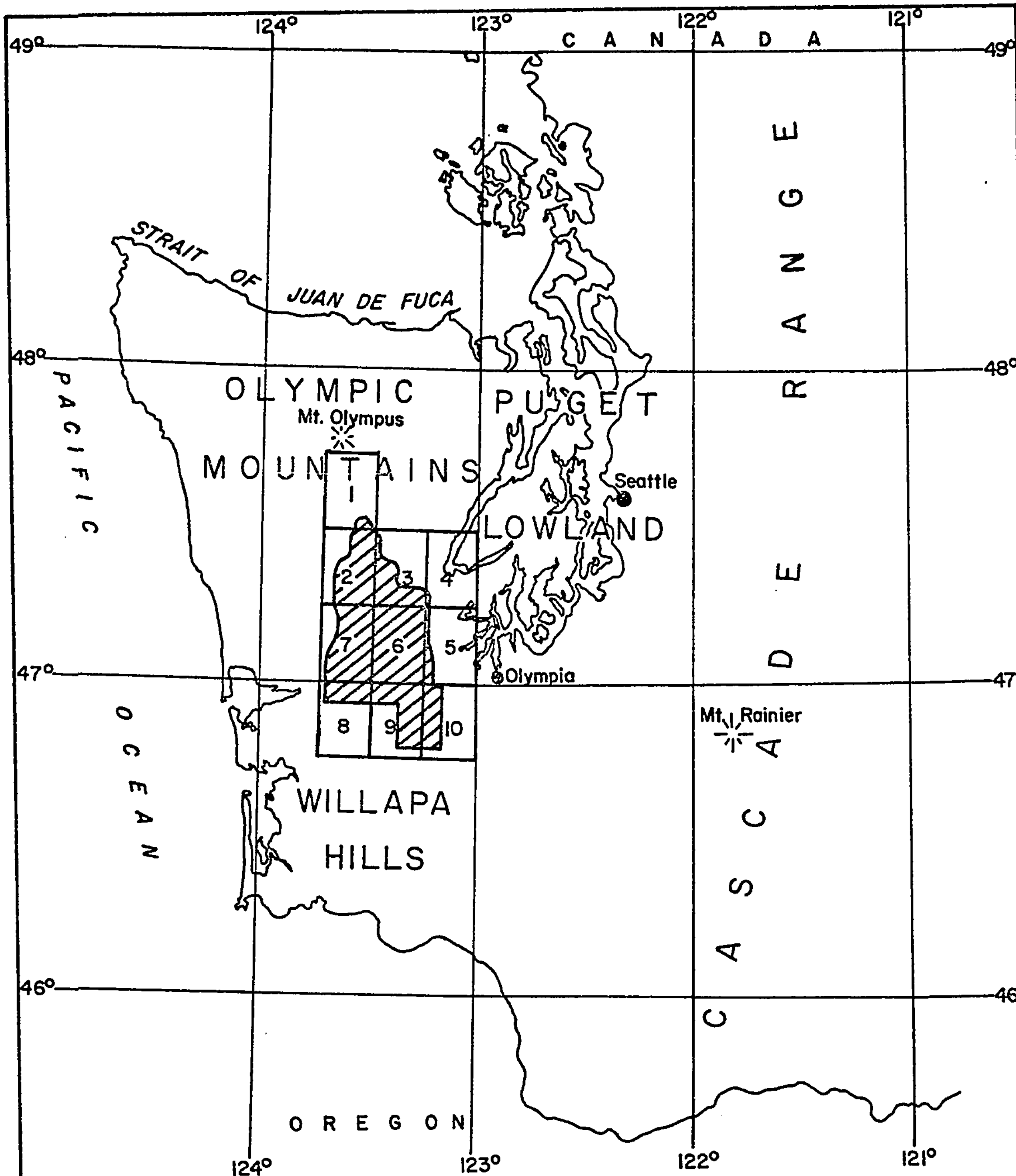
ILLUSTRATIONS

INTRODUCTION

Much of the lowland portion of the Olympic Peninsula of western Washington is covered with Pleistocene sediments deposited by alpine glaciers originating in the Olympic Mountains and by a lobe of the Cordilleran Ice Sheet flowing south from southwestern Canada. Earlier studies of glaciation in western Washington suggested that the maximum advances of Olympic alpine glaciers and of the Puget Lobe of Cordilleran ice were out of phase. The main purpose of this investigation was to study the relations in time and space between the Wynoochee valley glacier of the southern Olympics and the Puget Lobe. Terraces of the Wynoochee glacier and the Puget Lobe occur along the Satsop and Chehalis rivers, and terminal deposits of the two glaciers interfinger. Other objectives of the study were to determine the number of times that the south-central Olympics have been glaciated and to produce a map showing the distribution of glacial deposits and morphologic features. Information obtained during this study should bear directly on future evaluation and environmental planning with regard to water resources, forest management, agriculture, and land use.

Location and Access

The Olympic Peninsula lies in western Washington (Fig. 1) and has an area of approximately 5000 square miles. It is bordered on the west by the Pacific Ocean and on the north by the Strait of Juan de Fuca. To the east lies the Puget Lowland, and farther east is the Cascade Range. On the south the Olympic Peninsula is connected to the mainland by the low, broad valley of the Chehalis River, south of which lie the Willapa Hills.



U.S.G.S. 15-minute quadrangles numbered: Mt. Christie (1), Grisdale (2), Mt. Tebo (3), Potlatch (4), Shelton (5), Elma (6), Wynoochee Valley (7), Montesano (8), Malone (9), & Rochester (10)

Figure 1. INDEX MAP OF WESTERN WASHINGTON SHOWING AREA OF SURFICIAL MAPPING ON SOUTH-CENTRAL OLYMPIC PENINSULA

(Study area cross-hatched)

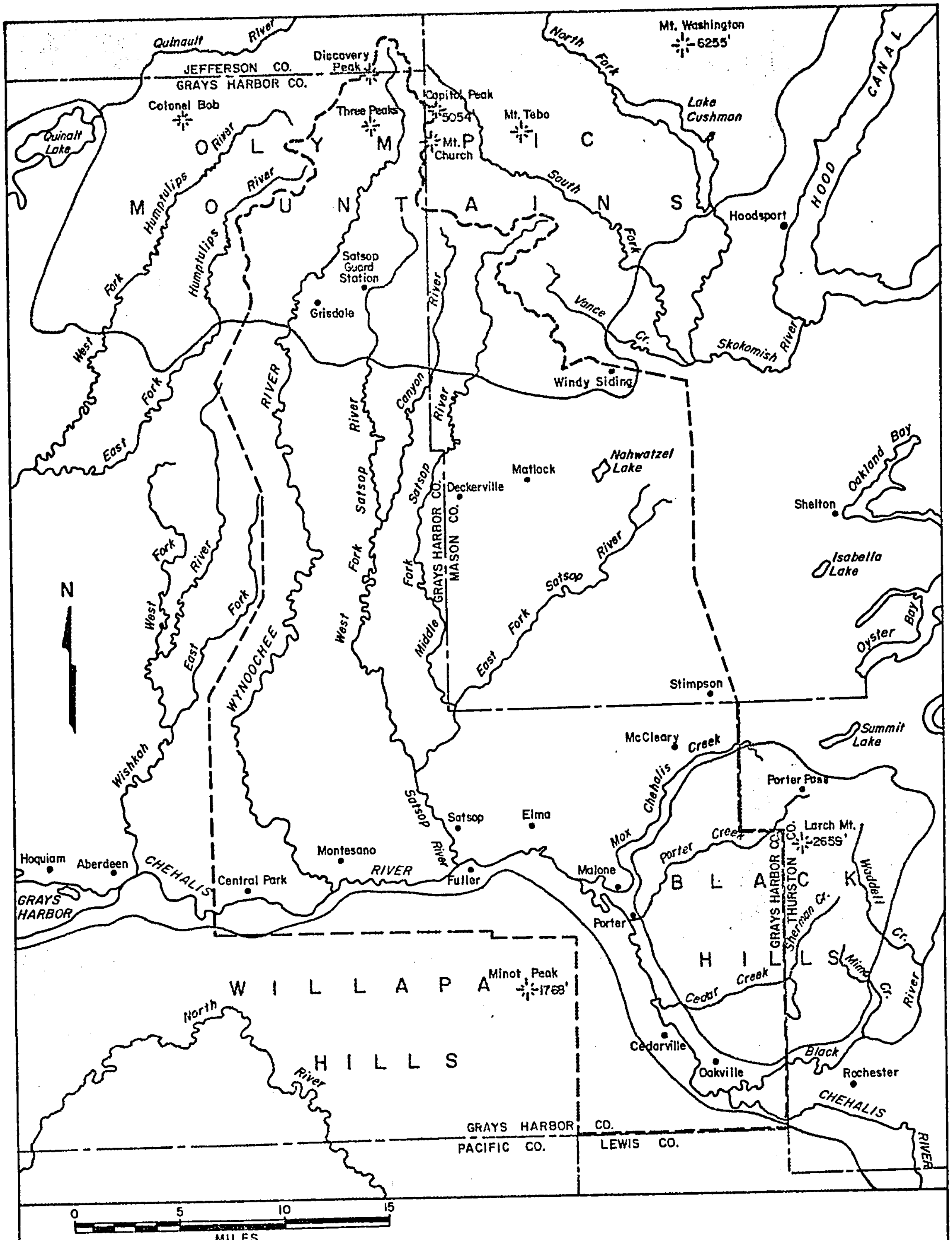
The study area includes most of western Mason County and eastern Grays Harbor County, and a small part of southern Jefferson County (Fig. 2). Montesano (population, 2486), Elma (population, 1811), and McCleary (population, 1115) are the three principal communities in the area. The main roads are State Highway 8 and U. S. Highway 12, and there are numerous smaller roads maintained by the state, the counties, the U. S. Forest Service, and private logging companies. Much of the study area is uninhabited and relatively inaccessible.

Earlier Studies

Willis (1898) recognized that the Puget Lowland had been glaciated more than once, and he separated the most recent glaciation (the Vashon) from an older glaciation (the Admiralty) by an interglacial interval (the Puyallup). Bretz (1913) determined the approximate limits of the Vashon Glacier on the southern Olympic Peninsula and noted the presence of pre-Vashon terraces. Three glaciations separated by nonglacial intervals were inferred by Hansen and Mackin (1949). Four glaciations subsequently were recognized by Crandell and others (1958) in the southeastern Puget Lowland:

- Vashon glaciation
  - Erosion interval (nonglacial interval)
- Salmon Springs glaciation
  - Puyallup nonglacial interval
- Stuck glaciation
  - Alderton nonglacial interval
- Orting glaciation (oldest)

The Vashon glaciation later was renamed the Fraser Glaciation, and the erosion interval was named the Olympia Interglaciation (Armstrong and others, 1965).



--- Border of area of surficial mapping

☐ Upland areas (border generally based on most prominent break in slope, ranging in altitude from a maximum of about 1200 feet along the Olympic front to a minimum of about 400 feet along the Chehalis River; isolated hills excluded)

Figure 2. SOUTH-CENTRAL OLYMPIC PENINSULA & ADJACENT REGIONS

Surficial geologic maps of areas immediately southeast and east of the south-central Olympic Peninsula have been published by the Washington Department of Water Resources (Weigle and Foxworthy, 1962; Noble and Wallace, 1966; Molenaar and Noble, 1970). In addition, Pease and Hoover (1957), Gower and Pease (1965), and Eddy (1966) mapped terrace deposits, landslide debris, and alluvium along the Chehalis River and adjacent areas. Rau (1966, 1967) noted areas covered with Pleistocene (?) deposits in the west-central part of the present study area.

A reconnaissance study of the alpine glaciation of the southwestern Olympic Peninsula was made by Crandell (1964), who found evidence for three probable Wisconsin ice advances and at least one pre-Wisconsin glaciation. Moore (1965) working near the lower Quinault and Humptulips rivers, mapped deposits of three alpine glaciations. Heusser (1960, 1964) used palynology to interpret the past climate of the southwestern Olympic Peninsula.

Acknowledgments

This research is a partial fulfillment of the requirements for a doctoral degree at the University of Washington. The supervisory committee chairman, Stephen C. Porter, made visits to the field; he and other members of the committee, A. Lincoln Washburn, Howard A. Coombs, and John T. Whetten, discussed the research with the writer on numerous occasions. Wallace M. Cady explained the bedrock of the Olympic Mountains, and Dwight R. Crandell made available his reconnaissance maps and notes on the glacial geology of the southern Olympic Peninsula. The writer is deeply indepted to these and many other geologists, without whose help the successful completion of the study would have been impossible.

Geologic mapping was accomplished with the help of William David (summer, 1968) and Stephen Hull (summer, 1969). Financial support was provided by a Grant-in-Aid of Research from The Society of the Sigma Xi and by grants from the Mazamas and Northwest Scientific Association. Additional support was obtained from Simpson Timber Company, the Humble Oil Education Foundation, and the Washington Department of Water Resources. Absolute dates were provided by the University of Washington Radiocarbon Laboratory under the direction of Arthur W. Fairhall. Aerial photographs and topographic maps were supplied by the U. S. Geological Survey (through Wallace M. Cady) and the Washington Department of Water Resources (through Robert H. Russell). Particular thanks are due to these organizations and individuals for their generous support.

GENERAL SETTING

Bedrock

The Olympic Mountains and the Black Hills (Fig. 2) are composed mostly of volcanic and metasedimentary rocks, whereas the remainder of the study area is mainly a region of weakly consolidated sandstone, siltstone, and mudstone. Detailed bedrock maps have been published for approximately half of the study area (Pease and Hoover, 1957; Gower and Pease, 1965; Rau, 1966, 1967), while the general distribution of the bedrock of the peninsula is shown on the Geologic Map of Washington (Huntting and others, 1961).

Most of the south-central Olympic Mountains is underlain by the Crescent Formation (Eocene). This unit forms an outer volcanic belt consisting of fine- to medium-grained basalt which includes submarine pillow lava, vesicular and amygdaloidal lava flows, and minor interstratified sedimentary rocks. The Black Hills and the highest peaks in the Willapa Hills also are underlain by Crescent basalt.

Immediately north of the Crescent Formation lies a narrow band of argillite and weakly metamorphosed graywacke. North of these metasedimentary rocks is a narrow inner volcanic belt of the Olympic Mountains, consisting of basalt flows, pillow lava, and flow breccia with minor amounts of red limy argillite. Rocks in the core of the Olympic Mountains are weakly metamorphosed graywacke, commonly containing interbeds of slate, argillite, volcanic rocks, and minor amounts of arkosic sandstone.

South of the Olympic Mountains and west and south of the Black Hills is a large area underlain predominantly by marine sedimentary rocks. The main lithologies include concretionary fossilferous mudstone and siltstone of the Lincoln Creek Formation (Eocene and Oligocene), micaceous carbonaceous siltstone and sandstone of the Astoria (?) Formation (lower and middle Miocene), and mudstone, siltstone, and sandstone of the Montesano Formation (upper Miocene) (Rau, 1967). These lithologies are relatively erodible, but less erodible units include a basalt member of the Astoria (?) Formation (Pease and Hoover, 1957) and a conglomerate member of the Montesano Formation (Rau, 1967).

Topography and Morphology

The topography of the south-central Olympic Peninsula is intimately related to the Tertiary bedrock in that the mountainous areas are regions of volcanic and metasedimentary rocks whereas the lowlands are underlain by sedimentary rocks. The pronounced topographic break along the steep southern front of the Olympic Mountains occurs near the contact of the resistant and nonresistant rocks.

The Black Hills and the southeastern corner of the Olympic Mountains show no definite evidence of recent alpine glaciation. Both areas have deep V-shaped valleys, but the southeastern Olympics have sharp ridges between the valleys whereas large, relatively flat interfluves lie between most valleys of the Black Hills. The northern and northeastern sides of the higher peaks in both areas exhibit cirque-like features which, if true cirques, probably formed before the last glaciation.

Landforms in the Wynoochee River drainage basin are largely the result of alpine glaciation. The four peaks with elevations greater than 4600 feet are horns, with aretes extending in several directions. The upper Wynoochee River and its major tributaries flow in U-shaped valleys with truncated spurs.

Much of the lowland area of the south-central Olympic Peninsula was glaciated by either the Puget Lobe of Cordilleran ice (advancing from the northeast) or the Wynoochee alpine glacier (advancing from the north). Southwest of the glaciated area is a region of well-integrated dendritic and trellis drainage. Rivers traversing the region meander between outwash terraces and bedrock walls.

Climate

Owing to its proximity to the Pacific Ocean and Puget Sound, the Olympic Peninsula has a relatively mild climate. The dominant effect of the marine influence is to produce cool summers and mild cloudy winters. Meteorological data are available for parts of the peninsula below an elevation of 1000 feet, but similar data for the Olympic Mountains have been recorded only at the Blue Glacier (elevation, 6900 feet) on Mount Olympus. Although the Blue Glacier is 20 miles northwest of the study area and lies higher than the maximum elevation in the south-central Olympics, the weather data probably are representative of conditions in the southern Olympic Mountains.

Figure 3 shows precipitation and temperature data for Oakville, near the southeast corner of the study area, and for the Blue Glacier. On the southern Olympic Peninsula precipitation increases slightly from east to west (toward the Pacific Ocean), and markedly from south to north (toward higher elevation). The mean annual precipitation is more than 220 inches near the headwaters of the Wynoochee River at elevations between 1500 and 5000 feet.

The temperature lapse rate for the southern Olympics is approximately $3^{o}F$ per 1000 feet of elevation (U. S. Weather Bureau, 1965a). The air temperature crosses the freezing point about 69 days annually at Oakville, and about 83 days per year at the Blue Glacier (U. S. Weather Bureau,

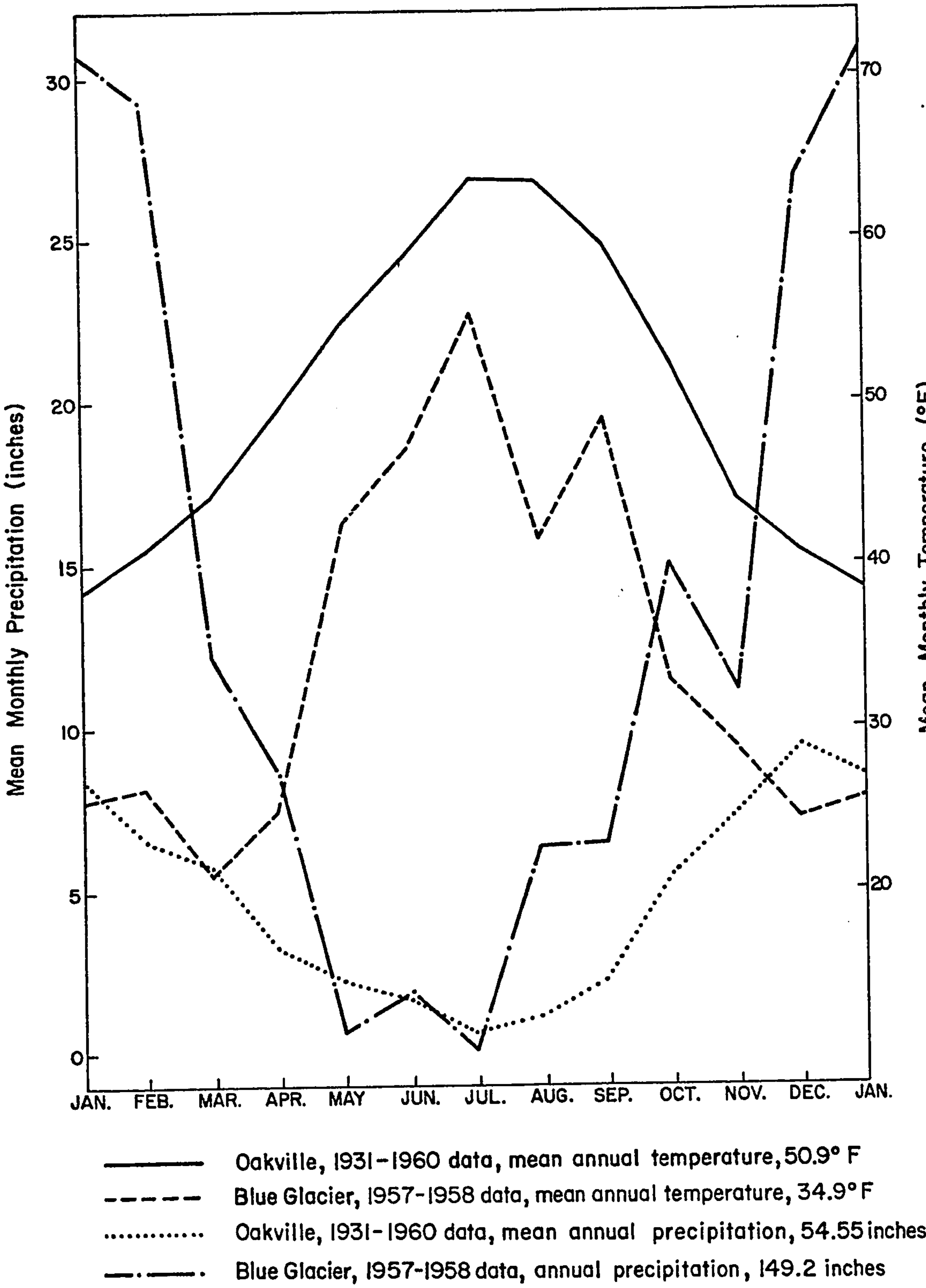


Figure 3. MEAN MONTHLY PRECIPITATION AND TEMPERATURE FOR OLYMPIC PENINSULA

(data from U.S. Weather Bureau, 1957-1958, 1965b)

1957-1958, 1965b). Snowfall increases with elevation, and the higher ridges are covered with snow from November until June. Peaks above 4600 feet in the south-central Olympics have permanent snowfields.

In late fall and winter, the prevailing winds are from the west or southwest. Cooling and condensation occur as the moist air reaches the coast and rises, and a wet season begins in October and lasts through April. In late spring and summer, prevailing winds are from the west and northwest, and the air over the Pacific Ocean is cooler than the surface of the Olympic Peninsula. The air is warmed and dried after it crosses the coast, resulting in a dry season from May through September.

Vegetation

The vegetation of the south-central Olympic Peninsula ranges from prairie vegetation to temperate rain forest. Luxuriant vegetation in much of the area covers potential exposures and makes cross-country travel quite difficult. The following vegetational summary is based on Ness and Fowler (1960, p. 4-5).

The native vegetation consists mainly of dense stands of conifers, beneath which are smaller trees, shrubs, and mosses. There are some small bogs and grassed prairies. Coniferous trees originally covered most of the area, but much of the accessible land has been farmed or logged. In most places the land has reforested naturally with the original species. With increasing altitude in the Olympic Mountains, the forests become less dense and the trees smaller.

Douglas fir, the dominant forest species, grows under many conditions but grows best where the soil is well drained. Western hemlock is generally associated with Douglas fir but is much less abundant. Western red cedar commonly grows on soils that have a good capacity to hold moisture. Although limited in the original forest, Lodgepole pine has become established on many of the drier, logged-off sites.

Deciduous trees, which include Red alder, Big-leaf maple, Vine maple, Dogwood, and Willow, grow in association with the conifers but are most abundant where there is sufficient summer moisture.

The ground cover consists largely of Salal, Oregon Grape, Rhododendron, Devil's-club, and many species of berries. Mixed with these plants are various ferns and mosses.

Weathering and Soils

The south-central Olympic Peninsula is a region of vigorous physical and chemical weathering, one result being deep soils in areas of pre-Fraser topography. The chief agents of physical weathering in the study area are probably frost action, organic activity, and unloading. The annual freeze-thaw frequency in the south-central Olympics is approximately 75 days. This figure is for air temperature and does not necessarily reflect the number of times that the ground freezes and thaws. Frost action should be particularly effective in areas not insulated by snow or vegetation. Weathering associated with organic activity is pronounced because of the great abundance of plant and animal life in the Olympics. Uplift and erosion, and isostatic rebound after glacier recessions, are possible mechanisms for unloading, which has furthered the development of cracks in the bedrock. Factors that promote chemical decomposition on the south-central Olympic Peninsula include mild climate with high annual precipitation, abundance of animals and plants, fine-grained sediment resulting from glaciation and mechanical weathering, and relatively unstable minerals in basalt and diabase.

The wide range of soil types on the south-central Olympic Peninsula is fully described in the Soil Survey of Mason County (Ness and Fowler, 1960). Zonal soils (reflecting the dominant influence of climate and organisms) include Brown Podzolic soils (in places grading to Gray-Brown Podzolic soils) and Yellowish Brown Lateritic soils. Intrazonal soils (reflecting the dominant influence of topography or parent material) include Humic Gley soils, Low-Humic Gley soils, and bog soils. Azonal soils (lacking distinct horizons because of their youth, steep topography, or resistant parent material) include Ando soils (derived from parent materials including volcanic ash) and Alluvial soils.

STRATIGRAPHIC USAGE

Geologic climate units and rock stratigraphic units are employed in discussing the stratigraphy of the south-central Olympic Peninsula. Geologic climate units are those established in the Puget Lowland by Crandell and others (1958) and Armstrong and others (1965). Rock stratigraphic units are named for local geographic features, except for the Vashon and Salmon Springs drifts which are continuous (except where eroded or buried) with the same drifts in the Puget Lowland. Table 1 summarizes the Quaternary stratigraphy of the south-central Olympic Peninsula.

Time Units			Geologic Climate Units		Rock Stratigraphic Units (and other deposits)		
					Puget Lobe	Wynoochee glacier	other
CENOZOIC	Quaternary	Holocene			alluvium, colluvium, and lake deposits		
		Pleistocene	Fraser Glaciation		Vashon Drift	Grisdale Drift: phases I, II, III, IV, V, VI	loess
			Olympia Interglaciation		Spoon Creek diamicton		
			Salmon Springs Glaciation		Salmon Springs Drift	Mobray Drift	Weatherwax Formation (lake beds)
			Puyallup Interglaciation	Correlations uncertain			
			Stuck Glaciation		Helm Creek Drift		
			Alderton Interglaciation				
			Orting Glaciation			Wedekind Creek Formation	

Table I. QUATERNARY STRATIGRAPHIC UNITS OF THE SOUTH-CENTRAL OLYMPIC PENINSULA

CRITERIA OF GLACIER SOURCE AREAS

The Wynoochee alpine glacier originated in the Olympic Mountains and therefore deposited drift of local origin only. The Puget Lobe originated in British Columbia and the North Cascades of Washington, where part of the terrain is underlain by granitic and high-rank metamorphic rocks. Most clasts in Puget drift in the study area, however, are Olympic types picked up as the Puget Lobe moved along the east and southeast sides of the Olympic Mountains eroding bedrock as well as earlier alpine glacial deposits. Table 2 lists mean values of pebble counts of Puget and alpine drifts. The best indicators of Puget drift are granite, granodiorite, diorite, and quartzite; quartz is occasionally found in alpine drift.

Table 2. MEAN PEBBLE COUNTS OF PUGET AND ALPINE DRIFTS ON THE SOUTH-CENTRAL OLYMPIC PENINSULA

	Percentage Composition	
Rock type	Puget drift	Alpine drift
Sandstone (mostly graywacke)	22	36
Basalt	26	27
Diabase and gabbro	12	17
Chert and jasper	9	3
Shale, argillite, and slate	2	2
Granite and granodiorite	7	0
Quartz and quartzite	3	0
Diorite	3	0
Others*	16	15

* Includes andesite, gneiss, epidote, conglomerate, Tertiary sedimentary rock, and undetermined lithologies.

CRITERIA OF AGE

The most useful criteria of relative age on the south-central Olympic Peninsula are depth of oxidation in till and relative heights of outwash terraces. Next in importance are weathering rinds on basalt clasts and morphology of the drift sheets. Two radiocarbon analyses of organic material have provided absolute ages and are discussed later.

Depth of Oxidation

Depth of oxidation is a useful criterion of relative age where drift is exposed at the surface and has not been disturbed. This criterion is much more reliable for impermeable drift, wuch as lodgment till, than for permeable drift, such as outwash and coarse-textured lake sediments. Table 3 lists the glacial deposits and their maximum depths of oxidation.

Weathering Rinds on Basalt Clasts

Stones in the drift of the south-central Olympics have weathered to different degrees and may be classified either as (1) unweathered, (2) thoroughly decomposed, or (3) partly weathered and characterized by a weathering rind. Although both basalt and graywacke clasts are common in most exposures, weathering rinds on basalt are more reliable. Basalt weathers faster than graywacke, and the light-colored weathering rinds contrast with the black unweathered basalt. Thickness of rinds on some graywacke stones tends to be variable owing to variations in texture.

Table 4 lists mean thicknesses of weathering rinds on basalt clasts in the various glacial deposits. The large standard deviations are probably caused by several factors, including (1) incorporation of older drift, (2) variation in texture and composition of the basalt, (3) variable thickness of loess cover, (4) depth of the clast below the surface,

Table 3. MAXIMUM DEPTHS OF OXIDATION OF GLACIAL DEPOSITS OF THE SOUTH-CENTRAL OLYMPIC PENINSULA

Deposit	Approximate Maximum Depth of Oxidation (ft)	Comments
Fraser		
Puget (Vashon) lodgment till	1	Increases near drift border due to incorporation of Salmon Springs Puget drift
Alpine (Grisdale) lodgment till		
younger	1	
older	3	Increases near drift border due to incorporation of Mobray drift
Outwash	5	Degree of oxidation variable, depending on depth to impermeable horizon
Lake beds	5	Degree of oxidation variable, depending on permeability
Salmon Springs		
Puget lodgment till	10	Oxidized portion typically reddish brown
Alpine (Mobray) lodgment till	10	Oxidized portion typically reddish brown
Outwash	20	Degree of oxidation variable, depending on depth to impermeable horizon; oxidized portion often reddish brown
Lake beds (Weatherwax Formation)	20	Degree of oxidation variable, depending on permeability
Pre-Salmon Springs		
Helm Creek (?) lodgment till	>10	Top possibly removed during Salmon Springs Glaciation
Helm Creek outwash	>10	Often purple, due to coating of manganese oxides
Wedekind Creek Formation	>30	Usually mottled

Table 4. WEATHERING RINDS ON BASALT CLASTS IN GLACIAL DEPOSITS OF THE SOUTH-CENTRAL OLYMPIC PENINSULA

Deposit	Thickness of Basalt Weathering Rind (mm) Mean	Standard Deviation
Fraser		
Puget (Vashon) lodgment till	0.1	+ 0.17 - 0.1
Alpine (Grisdale) lodgment till	0.3	+ 0.59 - 0.3
Outwash	0.5	+ 0.78 - 0.5
Lake beds	0.1	+ 0.15 - 0.1
Salmon Springs		
Puget lodgment till	1.2	± 0.63
Alpine (Mobray) lodgment till	2.2	± 1.7
Outwash	0.7	+ 0.94 - 0.7
Lake beds (Weatherwax Formation)	0.7	+ 0.88 - 0.7
Pre-Salmon Springs		
Helm Creek (?) lodgment till	3.3	± 2.0
Helm Creek outwash	2.6	± 2.5
Wedekind Creek Formation	6	± 3

Notes: 1. Clasts are from various depths in exposures of Weatherwax Formation, Helm Creek (?) till, and Wedekind Creek Formation. In other deposits, all clasts are from within three feet of the surface.

2. Most clasts in the Wedekind Creek Formation are completely weathered, and measurable rinds on basalt are rare.

(5) permeability of the drift, (6) climate, and (7) fluctuations of the water table. The thickness of weathering rinds increases toward the margin of each till sheet. The marked difference in size of weathering rinds of Salmon Springs Puget and alpine tills is probably due to incorporation of clasts of the Wedekind Creek Formation into the Mobray drift.

Terraces

Multiple terraces along the valley walls of the Chehalis River and many of its tributaries are associated with Helm Creek, Salmon Springs, and Fraser drifts (Plate II). Terraces are useful criteria of relative age because older terraces are higher than younger terraces, and older terraces generally are more dissected than younger terraces. Major terraces of the south-central Olympic Peninsula are shown in Figure 4.

Morphology of Glaciated Areas

Local relief, degree of drainage integration, and maximum slopes on alpine moraines were some of the principal supplementary criteria used in determining relative age of glaciated terrains. Areas covered by Fraser ice are characterized by low relief and poorly integrated drainage, as well as numerous lakes, bogs, and marshes. Areas covered by Salmon Springs ice but not by Fraser ice generally have moderate relief, well-integrated drainage, and only a few small bogs and ponds. The steepest slopes on Grisdale moraines range from 8 to 15 degrees, whereas the maximum slope angles on the older Mobray moraines range from 4 to 9 degrees.

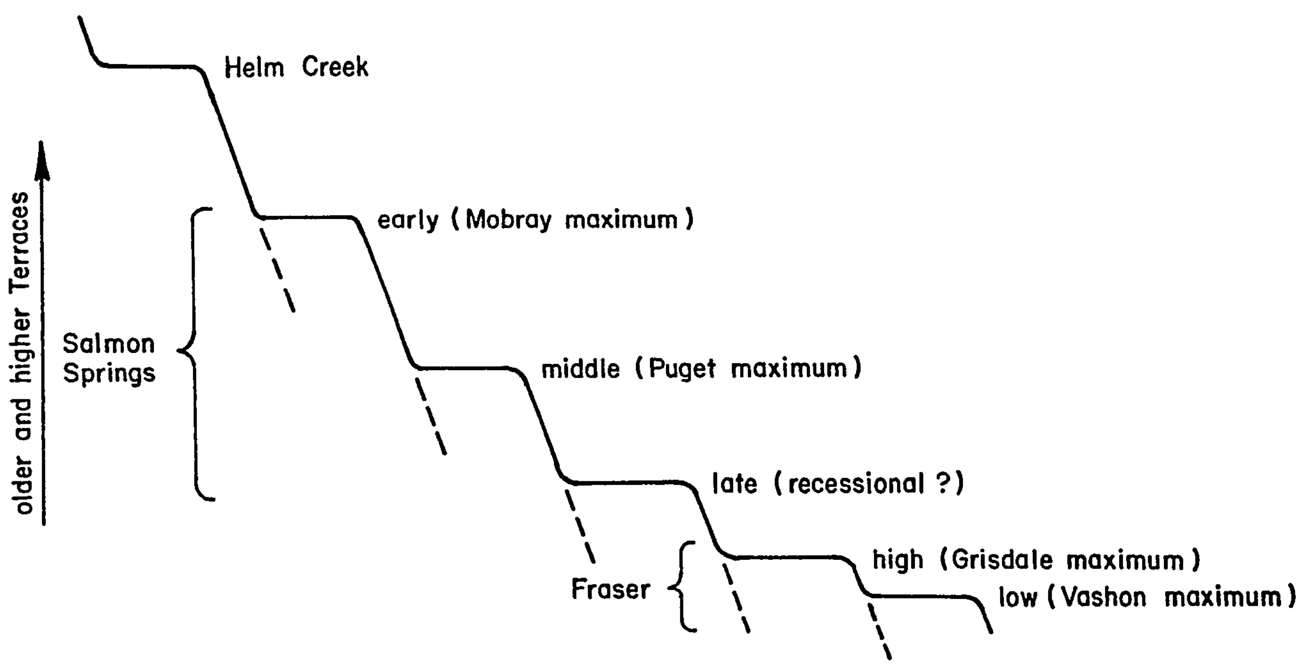


Figure 4. MAJOR TERRACES OF THE SOUTH-CENTRAL OLYMPIC PENINSULA

STRATIGRAPHY AND MORPHOLOGY

Wedekind Creek Formation

The oldest Quaternary deposit recognized on the south-central Olympic Peninsula is here named for Wedekind Creek, a tributary to the lower Wynoochee River. The type section, exposed along a logging road between the Wynoochee and Wishkah rivers (NW 1/4 sec. 32, T.19N., R.8W.), reveals 30 feet of intensely weathered gravels. The clasts usually are less than five inches in diameter, and generally are easily cut with shovel or knife. Because of the degree of alteration, lithology of pebbles and cobbles is difficult to determine. Most unweathered cores of clasts are graywacke or basalt; no rocks foreign to the southern Olympics were found. The matrix is rich in clay probably derived from weathering of the clasts and from the underlying Tertiary sandstones, siltstones, and mudstones. The Wedekind Creek Formation unconformably overlies sedimentary rocks as young as the Montesano Formation (upper Miocene). Lenses of sand and silt in the Wedekind Creek Formation resemble the Tertiary sedimentary rocks but contain much less muscovite. The formation usually shows good horizontal stratification and cross-bedding, but in places it is weakly deformed. The color of the formation is mottled, with red, orange, and brown dominating.

The formation is extremely patchy in distribution. To the north and northeast it disappears beneath drift of the Salmon Springs Glaciation. Almost all outcrops of the weathered gravels lie west of the Satsop River and north of the Chehalis River on interfluves at elevations between about 300 and 600 feet. Interfluves capped by the Wedekind Creek Formation often tend to be plateau-like, but generally are sharper where Tertiary sedimentary rocks are exposed. Aerial photographs and topographic maps offer little information on the extent of the Wedekind Creek Formation, and road cuts usually were necessary to determine its distribution. The geologic maps of Gower and Pease (1965) and Rau (1967) were helpful in delineating its extent in certain areas.

The original distribution of the formation is even more difficult to determine. The formation generally is found within four miles of the Wynoochee River, but some interfluves less than a mile from the river bear no gravel. Locally the topography rises above 600 feet and, therefore, presumably was too high for deposition of the Wedekind Creek Formation. In other places the formation probably has been removed by erosion.

Two small exposures in sec.18, T.21N., R.6W. are critical to the interpretation of the Wedekind Creek Formation. One, near the southwest corner of the section, reveals 10 feet of strongly weathered gravel resting on Tertiary siltstone, and overlain by Salmon Springs recessional outwash or ablation till of the Puget Lobe. Sediment exposed farther northeast at an elevation of about 1000 feet was identified as pre-Wisconsin till by Crandell (1964, p. 136). The sediment consists of eight feet of nonsorted, nonstratified diamicton containing decomposed stones. If these two exposures display outwash and till, respectively, the weathered gravels of the Wedekind Creek Formation must be the product of glaciation. Based on topographic distribution and on lithologic and weathering characteristics, these deposits are inferred to record at least one ancient alpine glaciation of the Olympic Mountains.

An alternative interpretation for the Wedekind Creek Formation is that it is a tectonic gravel shed from the Olympic Mountains during late Pliocene and early Pleistocene uplift (Danner, 1955, p. 34). Later glaciation has buried or removed possible evidence in areas critical to this interpretation. Outcrops of the Wedekind Creek Formation within nine miles of the southern front of the Olympic Mountains are extremely rare. Definite till of Wedekind Creek age would confirm the glacial interpretation, whereas gravel becoming coarser and thicker toward the Olympic Mountains might support both the glacial and the tectonic interpretations. Outcrops of the Wedekind Creek Formation south of the glacial limit do not suggest any progressive changes in grain-size distribution or thickness toward the Chehalis River.

Helm Creek Drift

The highest prominent terraces along the Chehalis River rise to an elevation of approximately 320 feet. These high terraces extend up the Chehalis River from Satsop to a point 3 miles southeast of Elma, up the Satsop River to the outermost drift border of the Puget Lobe, and up the Wynoochee River to within 2 miles of the alpine drift border (Plate II). The outwash composing the high terraces of the Wynoochee, Satsop, and Chehalis rivers is here named for Helm Creek, a tributary to the Wynoochee River which dissects the terraces near their northern limit. Owing to a thick loess cover, outcrops of the Helm Creek Drift are rare. The type section is in a gravel pit west of the lower Wynoochee River at an elevation of approximately 320 feet (sec.20, T.18N., R.8W.). There the gravels exhibit moderate oxidation, good horizontal stratification, cross-bedding, and good sorting. Most stones are unweathered, and their maximum diameter is six inches. Many clasts have a dark purplish coating of manganese oxides, while others are colored reddish brown by iron oxides.

The weathering characteristics of Puget till exposed in the SE 1/4 sec.27, T.19N., R.6W. suggest it is intermediate in age between the Wedekind Creek Formation and Salmon Springs Drift. The till is tentatively assigned to the Helm Creek Drift because included basalt clasts have weathering rinds of approximately the same thickness as rinds on basalt in the high terraces. The Helm Creek (?) till is mottled orange and yellowish gray, and contains a much smaller ratio of clasts to matrix than in nearby Salmon Springs till.

Separate alpine and Puget terraces of Helm Creek age could not be distinguished on the ground or with aerial photographs or topographic maps; examination of the high terraces was difficult because many of the terrace segments are extensively forested and deeply dissected. The outwash terraces probably are the product of both alpine and Puget glaciers that extended nearly as far as glaciers of Salmon Springs age. Along the Wynoochee River the northernmost Helm Creek terraces rise steeply, as if graded to an alpine glacier terminus just north of the Salmon Springs drift border.

Salmon Springs Drift

Salmon Springs Drift was named and described by Crandell and others (1958, p. 394) in the southeastern Puget Lowland. At the type section in Pierce County glacial units are separated by nonglacial sediments. In the south-central Olympic Peninsula, Salmon Springs Drift includes till and outwash, and lake sediments associated with both Puget and alpine ice. No evidence in this area points to two separate major advances within the Salmon Springs Glaciation. Salmon Springs Drift in the southern Olympics may be related to either the early glacial episode or the late glacial episode of the Salmon Springs Glaciation.

Puget Lobe of Salmon Springs Ice

On the southern Olympic Peninsula the Puget Lobe probably extended as much as eight miles farther during the Salmon Springs Glaciation than during the Vashon Stade of the Fraser Glaciation (Fig. 5). Exposures of Salmon Springs Puget till are generally less than 10 feet deep and are most accessible along the Satsop-Cloquallum Road between Schafer State Park and Simpson Lake, and along Cougar Smith Road between the Middle and West Forks of the Satsop River. A few of these road cuts reveal reddish-brown oxidized till overlying either weathered Tertiary sedimentary rock or reddish-brown oxidized gravels. The weakly to moderately oxidized sandy gravels contain lenses of sand and are interpreted as outwash deposited in front of the advancing Salmon Springs glacier. One 11-foot exposure of Salmon Springs till is weathered to a depth of 9 feet.

Much of the area glaciated by the Puget Lobe in Salmon Springs time, and not covered with younger deposits, consists of thin drift or scattered erratics. The topography of this area is slightly more subdued than that of adjacent nonglaciated regions, and few moraines of the Salmon Springs Puget Lobe were found. A possible exception to the general lack of moraines is on the valley wall on the south side of the East Fork of the Satsop River. There drift extends to an altitude of approximately 325 feet, above which is colluvium derived from Tertiary sedimentary rock. On the hillside at elevations between 275 and 325 feet are a series of ridges, each 5 to 15 feet high. The features may be three lateral moraines or three interfluves adjacent to meltwater channels formed at about the time of maximum glaciation.

During the Salmon Springs Glaciation the upper limit of the Puget Lobe along the front of the Olympic Mountains stood approximately 500 feet above the subsequent limit of Vashon ice. Although no unequivocal Salmon Springs Puget drift was found along the Olympic front, several truncated spurs apparently rise above the Vashon limit.

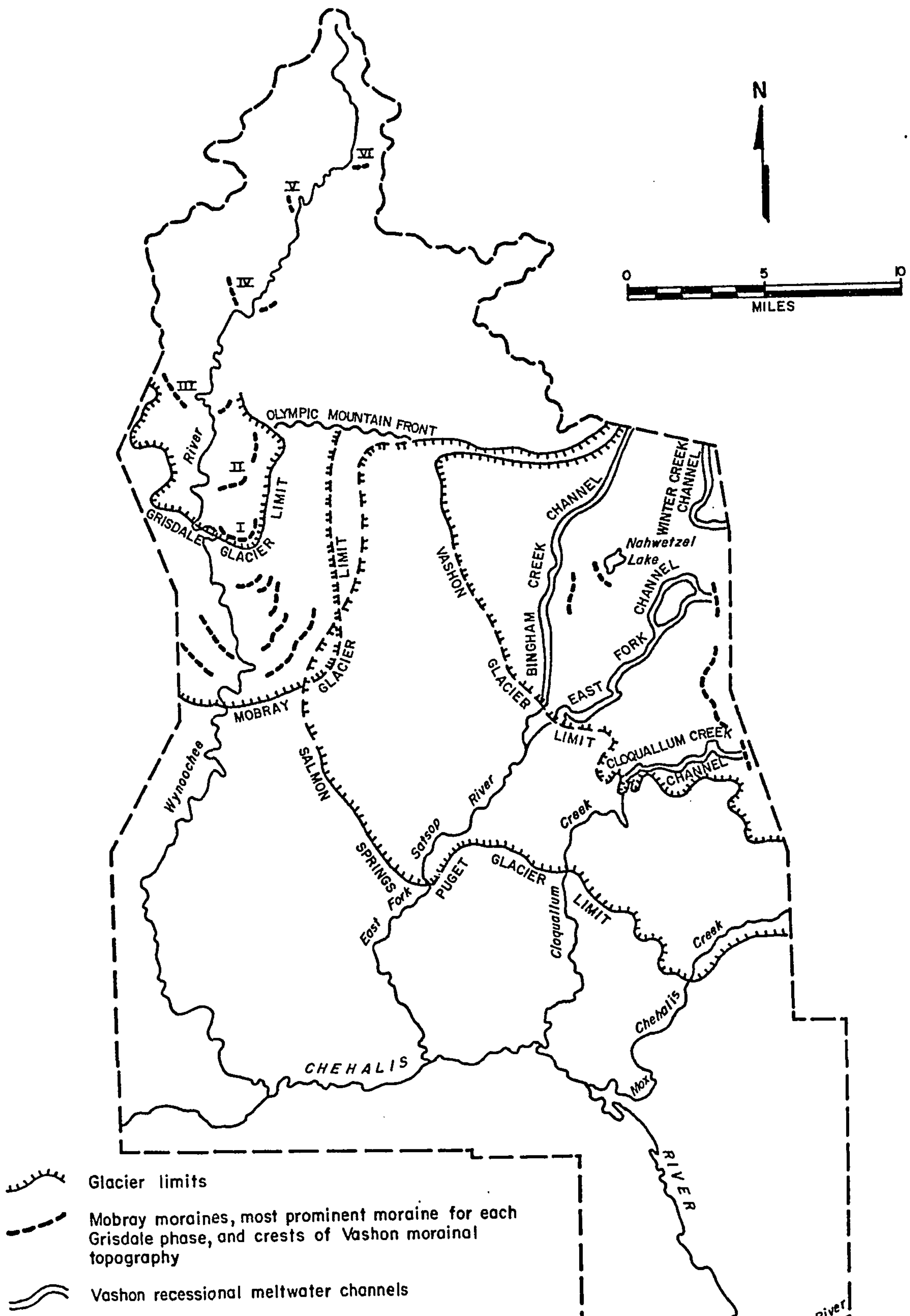


Figure 5. GLACIER LIMITS, PROMINENT MORAINES, AND VASHON RECESSIONAL MELTWATER CHANNELS, SOUTH-CENTRAL OLYMPIC PENINSULA

The Puget Lobe evidently caused two major drainage changes in this area during the Salmon Springs Glaciation. Kelly Road (secs.1 and 12, T.20N., R.7W.) and a logging railroad occupy a valley which was the pre-Salmon Springs route of the Canyon River to the Middle Fork of the Satsop River. Smith Creek (T.19N., R.7W.) occupies a large valley which was the pre-Salmon Springs connection between the upper part of the West Fork of the Satsop River and the lower part of the Middle Fork of the Satsop River. During the maximum glaciation, the Puget Lobe forced the rivers occupying these two valleys to more westward courses. The Canyon River cut a deep gorge through Tertiary sedimentary rock, and the West Fork found a new route to the main Satsop River. The absence of terraces along the lower Canyon River, and the small number of terrace segments along the lower part of the West Fork of the Satsop River can be explained by the relatively narrow valleys.

Salmon Springs outwash terraces extend from the limit of the Puget Lobe down the Satsop River and Mox Chehalis Creek. The only remnant of Salmon Springs outwash terraces that probably extended along Cloquallum, Power, Bush, Wildcat, and Sand creeks is two miles east of Elma on the southeast side of Cloquallum Creek. The eastern tributaries of the West Fork of the Satsop River (T.19N., R.7W.) and Cook and Falls creeks also were probably meltwater channels at the greatest extent of glaciation. The terraces extending down the Satsop River from the Salmon Springs drift border merge into terraces along the Chehalis Valley that are approximately 150 feet above the level of the Chehalis River. Salmon Springs terrace segments are distributed along the Chehalis River from Oakville to Central Park. Typical exposures reveal up to 40 feet of variably oxidized gravels overlain by 5 to 10 feet of loess. Thin beds and lenses of sand and silt are found throughout the cross-bedded gravels.

Salmon Springs meltwater may have crossed the Black Hills along Porter and Cedar creeks. At its maximum the Salmon Springs glacier projected eastward from Grays Harbor County toward Porter Pass and Summit Lake (Fig. 2). The headwaters of the North Fork of Porter Creek lie southwest of Porter Pass between two ridges more than 1600 feet in elevation. When the Puget Lobe terminated against the north side of the Black Hills at 1460 feet above sea level (Bretz, 1913, p. 31), meltwater must have flowed through Porter Pass (elevation, 1140 feet). Bretz (1913, p. 30) believed that Waddell Creek, on the east side of the Black Hills, was dammed by the Puget Lobe; the spillway for the glacial lake would have been the 820-foot divide between Waddell Creek and Sherman Creek, a tributary to Cedar Creek. In addition, Salmon Springs ice may have blocked Mima Creek; the spillway would have been the 717-foot divide between Cedar Creek and Mill Creek, a tributary of Mima Creek. Thus, the asymmetry of the drainage of the Black Hills may be explained by the former presence of ice on the northern and eastern sides of the upland. Most of the drainage of the Black Hills is southwest toward the Chehalis River.

The prominent terraces along the lower three miles of Porter Creek and the lower mile of Cedar Creek are graded to Fraser terraces along the Chehalis River rather than to Salmon Springs terraces. However, the weathering characteristics of the Porter Creek terrace gravels are similar to those of typical Salmon Springs outwash gravels. Terrace scarps along Porter Creek reveal reddish-brown, oxidized, clayey, sandy gravel overlying Tertiary sedimentary rock, but no exposures of the terrace deposits were found along Cedar Creek.

Mobray Drift

At first glance the till exposed along Cougar Smith Road east and west of the West Fork of the Satsop River seems to have been deposited by the same glacier. Oxidation to a depth of approximately 10 feet gives exposures on both sides of the river a reddish-brown color. On the west side of the river, however, the till contains pebbles and cobbles derived entirely from the Olympic Mountains. The distribution, lithology, and weathering characteristics of the till suggest that it was deposited by a glacier which originated in the upper Wynoochee Valley during the Salmon Springs Glaciation. The maximum advance of the alpine glacier reached approximately a mile south of the abandoned Mobray Lookout. The Mobray Drift is here defined as the till and outwash deposited during the Salmon Springs advance of the Wynoochee alpine glacier. The type section (SW 1/4 sec.35, T.20N., R.8W.) consists of 20 feet of lodgment till with boulders up to 21 inches in diameter. The uppermost 10 feet of oxidized till is reddish brown to orange, but grades downward into unweathered till which is yellowish brown to gray.

Exposures of Mobray till can be traced north to and within the limit of Fraser alpine ice, which is approximately six miles north of the Mobray drift border. Mobray till commonly is incorporated in the younger till, particularly near the Fraser alpine drift border. The easternmost exposure of Mobray till along the southern front of the Olympic Mountains occurs at the road junction in sec.15, T.21N., R.7W. Ice depositing this till may have flowed down the West Fork of the Satsop or east between Weatherwax Ridge and Reed Hill.

Little is known of the extent of Mobray ice within the Olympic Mountains. Some Mobray Drift is incorporated in younger till, but no definite outcrops of Mobray till were discovered. Gray unoxidized till with numerous striated stones overlies bedrock along the upper Wynoochee River (sec.20, T.22N., R.7W.). The till is overlain by laminated lake clays containing wood having an age of more than 40,000 radiocarbon years (UW-145).

Although the till may have been deposited before the Salmon Springs Glaciation, it is mapped as Mobray till because the lake beds are overlain by Fraser drift. Truncated spurs and Mobray drift above the inferred upper limit of Fraser alpine ice indicate that the Wynoochee glacier was approximately 500 feet thicker during the Salmon Springs Glaciation than during the Fraser Glaciation (Plate II).

At least five Mobray moraines exist between the Mobray drift border and the Fraser limit (Fig. 5). The two southernmost moraines are present on both sides of the Wynoochee River between 1 and 3 miles from the outer limit of Mobray drift. The three northern moraines were found only on the east side of the Wynoochee River but may correlate with an exposure of alternating layers of till and outwash on the west side of the river (sec.3, T.20N., R.8W.). The 3 to 5 lodgment tills may represent a single glaciation. The sediments probably indicate fluctuations of the Wynoochee glacier during the Salmon Springs Glaciation which may also have resulted in construction of the three northern moraines on the east side of the Wynoochee River.

Outwash deposited during the maximum Mobray advance was carried down the Wishkah, Wynoochee, and Satsop rivers. Along the Wynoochee River, the outwash descends from about 460 feet at the glacial limit to about 240 feet on the north side of the Chehalis Valley (Plate II). The terraces along the lower Satsop River at approximately 240 feet also probably were built during the maximum advance of Mobray ice. Mobray meltwater would have flowed one mile south along the West Fork of the Satsop River, then south-east down Smith Creek and the Middle Fork of the Satsop River. The Puget Lobe of Salmon Springs ice probably obliterated most of the evidence for former Mobray terraces along Smith Creek and the Middle Fork of the Satsop River.

Two terraces of probable Salmon Springs age exist along the Wynoochee River. In addition to the terrace representing the maximum alpine advance, there is a lower Mobray terrace. Exposures of Mobray terrace deposits reveal up to 30 feet of variably oxidized outwash, commonly overlain by up to 10 feet of loess. The outwash gravel contains lenses of sand and silt, and ranges in color from gray to reddish brown or purple.

The most prominent Salmon Springs terrace along the Chehalis Valley is associated with the maximum advance of the Puget Lobe. This terrace is at an elevation of 160 feet where it merges with the lower Mobray terrace near the mouth of the Wynoochee River (Plate II). The lower Mobray terrace can be traced up the Wynoochee River to a point two miles north of the maximum advance of Mobray ice. Just to the north lies a prominent Mobray moraine which rises to an elevation of about 600 feet. The relatively low elevation (300 to 360 feet) and gentle gradient of the terrace segments just south of this moraine suggest that the lower Mobray terrace most likely correlated with one or more of three Mobray moraines (having crestal elevations between 400 and 560 feet) lying farther north.

Weatherwax Formation

Road cuts on the southeast flank of Weatherwax Ridge reveal sediments with good horizontal stratification and generally poor sorting. Similar strata are exposed just west of the limit of Puget drift (as far east as Kelly Road, and almost as far south as the confluence of the Canyon River with the West Fork of the Satsop River). The type section for the Weatherwax Formation, which is named for Weatherwax Ridge, lies in the N 1/2 sec.16, T.21N., R.7W. The formation includes variably oxidized diamictons, gravel, sand, and laminated silt and clay. Some exposures of the formation include beds of alternating gravelly silty clay 1 to 2 feet thick and sandy gravel 3 to 10 feet thick. The clay-rich units are more oxidized, and the layers of sandy gravel often are cross-bedded. Stones in some beds of clay and silt may be ice-rafted. The color of the formation is quite variable, ranging from gray to yellowish orange and reddish brown.

Road cuts on the northeast flank of Reed Hill show that the Weatherwax Formation overlies Mobray till and was deformed by the Wynoochee glacier during the Fraser Glaciation. Late Salmon Springs terraces have been cut into the formation on the east side of the West Fork of the Satsop River. Stratigraphic relations and the nature and distribution of the formation indicate that a lake, here named Glacial Lake Weatherwax, existed between the Puget and Wynoochee glaciers during the Salmon Springs Glaciation. Channels in the deposits and the alternating coarse and fine sediments suggest that the level of the lake was fluctuating and (or) that the lake was repeatedly filled and drained. The extremely poor sorting of parts of the Weatherwax Formation may be the result of turbidity currents and subaqueous mudflows. Ferrians (1963) made a similar interpretation of nonsorted and poorly sorted diamictons interbedded with stratified glaciolacustrine sediments in the Copper River Basin of Alaska.

The maximum surface level of Glacial Lake Weatherwax was approximately 1080 feet. Although exposures of the Weatherwax Formation have been found only to an altitude of about 1000 feet, a topographic break at 1080 feet along the south side of the Olympic Mountains is interpreted as a strand line. Above 1080 feet rise steep slopes of bedrock and colluvium, and below 1080 feet is the greatly dissected, gently sloping upper surface of the Weatherwax Formation. Three small hills, each about half a mile from Little River, probably rose above the surface of the glacial lake.

Glacier ice was the most likely dam for Glacial Lake Weatherwax, formed by a merging of the Puget Lobe and the Wynoochee glacier along the West Fork of the Satsop River between Cougar Smith Road and the mouth of the Canyon River. Mobray Drift is found west of the West Fork of the Satsop River as far south as the Cougar Smith Road. Salmon Springs Puget drift is located on the east side of this river from the mouth of the Canyon River to the southern end of Muller Road. The lowest elevation of the Weatherwax Formation is about 440 feet near the mouth of the Canyon River. In order to have impounded a lake with a surface elevation of 1080 feet, the ice must have been at least 640 feet thick where the two glaciers joined.

The sources of water and sediment to fill Glacial Lake Weatherwax were numerous. The Weatherwax Formation is very thin near the central area of the former lake, so the Puget and alpine glaciers need not have merged for long. Sediment was supplied to the lake directly by the two glaciers, by icebergs, and by streams, as well as by mass-wasting from the steep south flank of the Olympic Mountains. The Canyon River and the Middle Fork of the Satsop River have large drainage basins that contain few, if any, cirques. Probably these two rivers were free of ice and discharged directly into the lake. Farther northeast the Puget Lobe dammed several drainages including the South Fork of the Skokomish River and Vance Creek (Fig. 2). The outlet of the large glacial lake along the South Fork was the 1300-foot pass at the southwest end of Spider Lake; the spillway of the small lake along Vance Creek was the 1500-foot pass 1.5 miles southeast of Spider Lake. Both glacial lakes drained into the Middle Fork of the Satsop River. The Middle Fork and Baker Creek probably found a route to Glacial Lake Weatherwax along the northern margin of the Puget Lobe.

Late Salmon Springs Terraces

Several terraces and meltwater channels of Salmon Springs age were cut after the draining of Glacial Lake Weatherwax and after the beginning of the retreat of the Puget Lobe. Many of the meltwater channels originally cut during the retreat of Salmon Springs glaciers carried meltwater during the Fraser Glaciation as well.

West Fork of the Satsop River. Meltwater from retreating Mobray ice dissected the Weatherwax Formation. Salmon Springs recessional terrace deposits are exposed along Cougar Smith Road on the west side of the West Fork of the Satsop River. Four feet of loess overlie about 10 feet of oxidized clayey sandy gravel and silty sand. The head of Smith Creek was blocked by Puget drift, so meltwater had to continue down the West Fork of the Satsop River (Plate II).

Canyon River. Salmon Springs recessional outwash overlies the Weatherwax Formation or Salmon Springs Puget till along the present and former courses of the Canyon River. For a short time after the initial withdrawal of the Puget Lobe, meltwater probably flowed down the old course of the Canyon River near Kelly Road. Another meltwater channel was used as the Puget Lobe retreated over the low hills between the Canyon River and the Middle Fork of the Satsop River. The two channels join in the SE 1/4 sec.36, T.21N., R.7W.

Mox Chehalis Creek. Probable recessional Salmon Springs terraces extend along Mox Chehalis Creek from the glacial limit to where the valley becomes narrow southeast of McCleary (Plate II). Gravel pits in the terraces reveal 10 feet of weakly to moderately oxidized, gray to yellowish-orange, sandy gravel overlain by 2 feet of loess. In places about 2 feet of ablation (and lodgment?) till is interstratified with the gravel.

Chehalis River. The elevations of probable Salmon Springs recessional terraces range between about 150 feet north of Oakville to about 100 feet in Central Park. As with most other pre-Vashon terraces along the Chehalis River, few good exposures are encountered because of the loess blanket. A sand pit on the south side of the Chehalis River northwest of Fuller reveals 25 feet of gray, unoxidized, cross-bedded sand. In places the sand is iron-stained, contains platy iron nodules, and includes scattered lenses of cobbles and pebbles.

Spoon Creek Diamicton

A diamicton crops out discontinuously through approximately a mile along Spoon Creek, a tributary to the West Fork of the Satsop River. Road cuts expose 5 to 10 feet of yellowish-gray to reddish-brown nonsorted sediment containing angular and rounded boulders up to 2 feet in diameter. The diamicton is moderately compact and exhibits crude stratification. The unit is interpreted as mudflow sediment confined to the floor of one valley. The possibility that the diamicton is Salmon Springs or Fraser till is weakened by lack of other till in the vicinity.

The Spoon Creek diamicton is oxidized to an average depth of 4 feet. This depth of oxidation is too little for Salmon Springs Drift, but Spoon Creek may have eroded the top of the unit. The degree of weathering is too great for Fraser Drift unless the mudflow incorporated previously oxidized colluvium. The inferred mudflow sediment may have been deposited during the Olympia Interglaciation.

Fraser Drift

The Fraser Glaciation was separated from the Salmon Springs Glaciation by the Olympia Interglaciation. In the southern Puget Lowland the Olympia

Interglaciation is represented by the peat-bearing Kitsap Formation. No deposits definitely assignable to the Olympia Interglaciation were recognized in the south-central Olympic Peninsula.

On the basis of drift stratigraphy in the southern Puget Lowland the Fraser Glaciation is divided into the Evans Creek and Vashon stades. During the Evans Creek Stade alpine glaciers developed in the Cascade Range and the Olympic Mountains. During the subsequent Vashon Stade, the Puget Lobe of Cordilleran ice made its most recent advance into the southern Puget Lowland. On the south-central Olympic Peninsula the Fraser Glaciation is represented by both Puget and alpine drift.

Vashon Drift

Molenaar and Noble (1970) mapped most of southeast Mason County as covered with Vashon till, outwash, and lake sediments. The Vashon glacier limit in southwest Mason County extends to within three miles of the limit of the Salmon Springs Puget Lobe (Fig. 5).

Description of the drift. An ideal section of Vashon drift might reveal the following sequence:

Unit	Typical Description	Maximum Observed Thickness (feet)
4. Recessional outwash	Sandy gravel and pebbly sand; good sorting; horizontal stratification; cross-bedding	10
3. Ablation till	Poorly consolidated boulders and cobbles with lenses of pebbles and sand; weak sorting	5
2. Lodgment till	Stony, sandy, clayey diamicton; nonstratified	10
1. Advance outwash	Sandy gravel, sand, silt and clay; good sorting and stratification; deformed in places	25

All units commonly are gray in color and unweathered except for oxidation to a depth of 1 to 3 feet where exposed at the surface. Recessional outwash, ablation till, or scattered drift and erratics usually are at the surface; exposures of lodgment till and advance outwash are rare.

Most gravel pits in the study area are developed in outwash. Outwash beyond the drift border is at least 30 feet thick in some excavations, and has characteristics similar to recessional outwash.

Vashon Drift Border. Bretz (1913, p. 31) traced the margin of the Puget Lobe from Stimpson to the southeastern foothills of the Olympics. From Stimpson the Vashon terminus followed the east and north sides of the 960-foot hill north of the Cloquallum Truck Trail (Plate I). Meltwater probably filled the valley along the Cloquallum Truck Trail and overflowed west to Cloquallum Creek along the southern margin of the Vashon glacier.

The Vashon ice terminated against a small hill on the east side of Cloquallum Creek. Meltwater flowed south around the hill, uniting along Cloquallum Creek, then divided and took separate routes along Bush, Power, and Cloquallum creeks. The Cloquallum Creek channel continued to be used after the Vashon glacier began its retreat, and outwash probably dammed Stump Lake. As the Vashon ice entered the valley around Simpson Lake, it dammed a glacial lake which overflowed southwest to Cloquallum Creek and also along Dry Run.

From Simpson Lake northwest to between Matlock and Deckerville the limit of the Vashon glacier is not accurately known. The area contains low hills which project above extensive Vashon outwash plains. The hills are cored with Tertiary sedimentary rock and covered with thin Puget drift of the last two glaciations. It is difficult to distinguish between Vashon and Salmon Springs drifts there because exposures of till are few and weathering-rind data are inconclusive. Outwash from the region between

Lystair Lake and Deckerville was transported down the East Fork of the Satsop and its tributaries, such as Bingham, Dry Bed, and Decker creeks. This region, named the Matlock Pathway by Bretz (1913, p. 17-18), was the route for most of the meltwater from the southwestern part of the Puget Lobe.

North of Deckerville the Vashon glacier terminated against the hills east of the Middle Fork of the Satsop River. Meltwater gained access to the Middle Fork just south of the Olympic Mountain front and by way of three channels through the hills west of Decker Creek. On the southern front of the Olympic Mountains, Vashon till and erratics lie about 500 feet below the inferred upper limit of Salmon Springs ice.

Drift near Simpson Lake. A complex body of drift is exposed on the northwest side of a small 400-foot hill immediately southeast of Simpson Lake. The exposure contains oxidized till and lake sediments incorporated in relatively unweathered drift. As the Puget Lobe entered the valley around Simpson Lake, it dammed glacial lakes during the Fraser and earlier glaciations. The oxidized drift probably is Salmon Springs or older, and the unweathered lake beds contain logs having a radiocarbon age of about 12,600 years B.P. (UW-146 and UW-147). One possible interpretation is that the lake sediments buried trees living in the valley dammed by the Vashon glacier. As the ice continued to advance, it deposited till which incorporated the lake beds, the logs, and the older drift. If this interpretation is correct, the Vashon glacier must have reached its maximum position about 12,600 years ago. Several radiocarbon dates from the central and southern Puget Lowland suggest that the maximum advance of Vashon ice occurred about 14,000 years ago (Porter, 1970). A possible alternative explanation for the exposure and the dates is to assume that stagnant ice lay around Simpson Lake for some 1400 years. A constriction in the valley may have favored ice stagnation over normal retreat, and hills rising to elevations greater than 600 feet on the south and west sides of Simpson Lake would have shaded the ice. Trees may have grown on drift overlying the ice, and sand, silt, and clay may have accumulated in small lakes on the stagnant ice. As the ice finally melted, flow till may have incorporated both trees and lacustrine sediments. Clayton (1962, p. 76) cited radiocarbon dates from North Dakota indicating that stagnant ice, mantled by till, outwash, and lake sediments, took more than 2000 years to melt away. According to George Denton (personal communication, 1970) volcanic ash overlying forested stagnant ice of the Russell Glacier in Alaska is at least 1500 years old.

Grisdale Drift

During the Fraser Glaciation, the Wynoochee alpine glacier advanced to within about six miles of its maximum position during the Salmon Springs Glaciation (Fig. 5). Alpine deposits of the Fraser Glaciation are here named the Grisdale Drift for exposures and moraines in sec.20, T.22N.,R.7W., 1.5 miles northeast of Grisdale. At the type section, a road cut on the east side of the Wynoochee River, the Grisdale Drift consists of alternating layers of till and outwash.

Basis for subdivision. Fraser alpine glaciation is divided into six phases designated Grisdale I through Grisdale VI. Each phase is based on two or more of the following criteria: 1 to 6 moraines; a younger moraine crosscutting an older moraine (suggesting a readvance of the glacier); an outwash terrace (Plate II); lake and/or deltaic sediments deposited in a water dammed by one or more moraines.

There are at least 6 Grisdale I moraines and 2 Grisdale II moraines. The innermost Grisdale I moraine is crossed by the outermost Grisdale II moraine (sec.25, T.21N., R.8W.). Some of the Grisdale I and II moraines contain a great amount of oxidized reddish-brown till and may represent Mobray moraines overridden by Grisdale ice. An extensive outwash terrace is graded to the outermost Grisdale I moraine.

During the Grisdale III phase the southern margin of the Wynoochee glacier was west of Weatherwax Ridge. One or more of six moraines near the southwest end of Weatherwax Basin dammed a lake in the basin. Lake silts and clays on the northeast side of the innermost moraine are overlain by till, suggesting a readvance of the ice after the initial damming of the lake.

The Grisdale IV phase is represented by alternating layers of till and outwash exposed in road cuts on both sides of the Wynoochee River. Three lodgment tills, each 5 to 10 feet thick, suggest a fluctuating ice margin. Grisdale is built on part of an extensive outwash terrace graded to the two Grisdale IV moraines.

A delta complex lies just upstream of the confluence of the West Branch of the Wynoochee River with the main Wynoochee River. Delta sediments were found at a maximum elevation of about 940 feet, and probably were deposited in a lake dammed by the Grisdale V moraine. A segment of the moraine west of the mouth of Trout Creek rises to an elevation of 1035 feet.

Exposures of up to 12 feet of laminated clay and silt, cross-bedded sand, and pebbles are found along the Wynoochee River southeast of the Klone Lakes. A lake having a surface elevation of approximately 1050 feet was probably dammed by the Grisdale VI moraine. Outwash extends south from the Grisdale VI moraine, and a terrace segment between the mouths of Trout Creek and the West Branch of the Wynoochee River probably is graded to the moraine.

Description of the drift. The till and outwash of Grisdale phases I through III (older Grisdale drift) commonly are yellowish gray, whereas the deposits of Grisdale stades IV through VI (younger Grisdale drift) usually are light gray. No statistical difference could be detected in the weathering rinds on basalt clasts in the older and younger Grisdale tills. However, the older Grisdale till is generally oxidized to a depth of 2 or 3 feet, and the younger Grisdale till to only about a foot. Although the data are limited, basalt weathering rinds in Grisdale outwash have an average thickness of 0.7 mm for the terrace graded to Grisdale I moraines, and 0.2 mm for the terrace graded to Grisdale IV moraines.

Extent of Grisdale ice. During the maximum Grisdale advance, the southern portion of the Wynoochee glacier divided into four lobes. The southern lobe was the largest and was just barely able to override a 720-foot hill near the center of the Wynoochee Valley. The southernmost moraine lies southeast of the hill and indicates that during its initial retreat the glacier divided into sublobes on either side of the hill. On the west side of the glacier, two small lobes fed outwash into the Wishkah River. Between Weatherwax Ridge and Reed Hill, outwash from another small lobe reached a tributary of the West Fork of the Satsop River.

Farther north the limits of the Wynoochee glacier were more difficult to determine. Mapping of the ice margin around the upper Wynoochee River and its tributaries is based on the upper limit of Grisdale drift and on the locations of fresh cirques, aretes, and truncated spurs (Plate II).

The Wynoochee glacier merged with ice along the Humptulips River in many places. Ice partially filled the drainage divide west of Falls Creek, and also must have spilled from the Humptulips glacier into the Big Creek drainage because till was found in the cols northwest of the Middle and East forks of Big Creek. Merger of Wynoochee and Humptulips ice is indicated by the presence of till very near the divides between the West Branch of the Wynoochee River and the East and West Forks of the Humptulips River.

Till near other divides indicates that the Wynoochee glacier merged with ice in tributaries to the Quinault River and the South Fork of the Skokomish River. Ice flowed from the Wynoochee lobe toward the West Fork of the Satsop River as shown by till in the 2600-foot col west of the Satsop Lakes.

The upper limit of Grisdale ice lay at an elevation of about 3600 feet just south of the Klone Lakes, so that the Grisdale I glacier surface and the subdued arete extending southeast from Three Peaks were at nearly the same altitude. Three ridges on the south side of the arete are each 5 to 30 feet high and extend at least 200 feet horizontally. These may be either lateral moraines or interfluves adjacent to ice-marginal channels. The elevations and possible ages of these features are: 3500 feet, Grisdale I or II; 3000 feet, Grisdale III; and 2700 feet, Grisdale IV (Plate II).

Glacial lake sediments. The Grisdale glacier dammed lakes in the vicinity of the Satsop Guard Station and along Big Creek. These two lakes will be referred to informally as Glacial Lake Satsop and Glacial Lake Big Creek. Before the Fraser Glaciation, the upper part of the West Fork of the Satsop River probably flowed between Anderson Butte and Weatherwax Ridge to the Wynoochee River. Glacial Lake Satsop formed when this route was blocked by an advance of a lobe of Grisdale ice as far as the Satsop Guard Station. The maximum elevation of the lake sediments (about 1100 feet) is probably near the original elevation of the spillway east of Weatherwax Ridge. Overflow from Glacial Lake Satsop began carving the gorge of the West Fork of the Satsop River. Glacial Lake Big Creek formed during the retreat of the Grisdale glacier when part of the Big Creek drainage became ice-free before Weatherwax Basin. The outlet to the glacial lake may have been along the western margin of the Wynoochee glacier. Exposures of lake sediments along Sixteen Creek and Trout Creek suggest that glacial lakes formed in other tributaries which became free of ice before the main valley.

The sediments of glacial lakes Satsop and Big Creek are coarser and less oxidized than those of Glacial Lake Weatherwax. During glaciations mass-wasting probably is important on ice-free slopes, and the long narrow lakes must have received much colluvium from the valley sides. Outwash entered Glacial Lake Satsop from ice west of the Satsop Guard Station and at the northeast end of the lake. Glacial Lake Big Creek received sediment from the margin of the Wynoochee glacier and probably from Humptulips ice in the cols west of the lake. The bulk of the sediments can be explained by colluvium and outwash filling the two glacial lakes; subaqueous mudflows also may account for some. Typical exposures reveal up to 80 feet of weakly oxidized clay, silt, sand, pebbles, and rounded and angular cobbles. Sorting is poor to good, and bedding is thin to massive. Most units are horizontally stratified, but in places show intense deformation, probably due to penecontemporaneous slumping.

Lake and delta sediments commonly are exposed along the Wynoochee River, and for the most part were deposited in lakes dammed by Grisdale III, V, and VI moraines. In a few places it can be demonstrated that lakes existed in Weatherwax Basin before the Fraser Glaciation where deformed pre-Fraser lacustrine deposits are overlain by Grisdale till, or pre-Fraser lake beds lie higher than any downvalley Grisdale moraine crests. A radiocarbon date of $>$ 40,000 years B.P. (UW-145) from wood in lake deposits at one locality indicates a pre-Fraser age.

The lake sediments generally are pale-yellowish-brown laminated clay, silt, and sand, but in places contain considerable sandy gravel. Delta foreset beds are exposed to an elevation of about 700 feet along the lower two miles of Big Creek. The delta probably was built where Big Creek entered the lake dammed by the Grisdale III moraines. Formation of the delta began after the margin of the Wynoochee glacier had retreated northeast of the point where Big Creek enters Weatherwax Basin. The delta beds probably are younger than the deposits of Glacial Lake Big Creek, which was in existence while the creek was blocked by the Wynoochee glacier.

Post-Grisdale VI moraine. One small moraine, postdating the Grisdale VI moraine, lies at an elevation of 3750 feet on the southwest side of Discovery Peak. The altitude of the moraine and the weathering characteristics of the till in the vicinity suggest that the moraine is late Fraser and not Neoglacial.

The Klone Lakes and many cirques were examined for moraines. The Klone Lakes may be dammed by the scarp of a fault active during the Quaternary. The inferred fault strikes about N.20^{o}E. and is upthrown on the east side. Most of the cirque lakes examined have bedrock thresholds.

Fraser Terraces

Fraser terraces are graded to many of the Grisdale moraines and to the Vashon drift border (Plate II). The high terraces are graded to the Grisdale I moraines, and the low terraces to the Vashon glacier limit and later Grisdale moraines. Vashon outwash plains and meltwater channels beyond the inferred limit of Vashon ice are included with the low Fraser terraces (Plate I). Additional terraces of probable Fraser age lie along some of the minor tributaries to the Chehalis River.

High Fraser terraces. High Fraser terraces lead from the Grisdale drift border down the West Fork of the Wishkah River, the Wynoochee River, and the West Fork of the Satsop River. Along the Wynoochee River, exposures of the terraces reveal up to 85 feet of yellowish-gray, unoxidized sandy gravel. Grisdale meltwater, together with overflow from Glacial Lake Satsop, cut terraces into the Weatherwax Formation along part of the West Fork of the Satsop River.

Two levels of Fraser terraces exist along the Chehalis River, the higher terrace segments being less extensive than the lower. At least three possible explanations may be invoked for the high Fraser terrace along the Chehalis River. First, Grisdale outwash coming down the Wishkah, Wynoochee, and Satsop rivers may have created a local base level to which these tributaries and the Chehalis River were then graded. Second, the high terrace may be related to a proglacial lake formed when Vashon ice blocked the southern Puget Lowland. The surfaces of many of the terrace segments appear to be erosional and may have been cut by overflow from the proglacial lake. Third, terrace-like bodies of gravel along at least three tributaries (Gibson, Cedar, and Garrard creeks) resemble bars built across the mouths of the creeks. If bars, they may have been deposited by floodwaters passing down the Chehalis River when water in a glacial lake was suddenly released during the retreat of Vashon ice.

Sediment composing terraces along the small tributaries to the Chehalis River is seldom exposed. Profiles of terrace segments near the Chehalis River demonstrate that the segments are above the Vashon outwash terrace. Terrace segments along Rock and Williams creeks may correlate with the high Fraser terraces or may be Vashon or postglacial in age. They are mapped as high Fraser terraces because their projection appears to lie above the Vashon terrace. Terrace segments along Delezene Creek merge with the high Fraser terrace along the Chehalis River.

Low Fraser terraces. The Chehalis River received Vashon outwash and meltwater from many of its northern tributaries. The Black River was the main meltwater channel along the southeast side of the Black Hills. The Sand Creek outwash channel, extending southwest from McCleary, added to the flow along Mox Chehalis Creek. Outwash channels between Stimpson and Simpson Lake are tributaries to Cloquallum Creek. The channels between Simpson Lake and the northwestern limit of Vashon ice lead to the Chehalis River by way of the three forks of the Satsop River. The Puget Lobe dammed glacial lakes along Vance Creek and the South Fork of the Skokomish River (Fig. 2), and these lakes discharged into the Middle Fork of the Satsop River.

Between the Middle and West Forks of the Satsop River, a network of meltwater channels around small hills gives the appearance of small-scale scabland topography. The hills are composed of Tertiary sedimentary rock mantled with Salmon Springs Drift. The channels probably also carried meltwater as the Puget Lobe retreated during the Salmon Springs Glaciation.

The Vashon or low Fraser terrace and the modern floodplain become closer in elevation eastward along the Chehalis River. In places the terrace riser is indistinct. In other places a minor terrace (mapped with the low Fraser terraces) which may be a late-glacial recessional terrace was found between the Vashon terrace and the flood plain. A few low Fraser terrace segments were traced up the Wynoochee River behind the Grisdale drift border to the Grisdale IV (or possibly Grisdale III) moraines.

Mounds. Bretz (1913) described mounds of two types on Vashon outwash. The Mima mounds were named for Mima Prairie on the east side of the

Black Hills, and the Ford mounds were named for Ford Prairie, southwest of Porter. No well-defined mounds were seen on Ford Prairie; in the more than half century since Bretz described the type Ford mounds they may have been covered by vegetation or largely destroyed by agricultural practices or by the meandering Chehalis River. According to Bretz (1913, p. 87), who tabulated the differences between Mima and Ford mounds, the Ford mounds are larger, higher, asymmetrical, and not uniform in size. The Mima mounds are composed largely of fine-grained black sediment whereas the Ford mounds consist mostly of cross-bedded sandy gravel. Bretz (1913, p. 107) believed that the Ford mounds are "composed largely of centripetally foreset gravel" deposited in pools between ice blocks stranded on the Vashon terraces. I cannot disprove this hypothesis of kettles and kames beyond the Vashon glacier limit. However, one gravel pit at Cedarville shows a cross-section through a Ford mound with the bedding all dipping in the same direction rather than centripetally. In Grays Harbor County, Ford mounds were found only around Cedarville and southeast of Oakville. The possible Fraser floodwater bars across the mouths of Gibson, Cedar, and Garrard creeks are all within two miles of the Ford mounds. A possible explanation for both the bars and the Ford mounds is a flood along the Chehalis River. The rushing water might have eroded the Vashon terraces in the center of the Chehalis Valley, creating the Ford mounds, and deposited bars in slack water along the tributary valleys. At least two factors weaken this hypothesis. First, the crests of the bars rise as much as 20 feet above the Vashon terrace. Second, other evidence of flooding, such as parallel elongation of the Ford mounds or giant ripple marks, is lacking.

Features Related to Recession of Vashon Ice

Morainal topography around Nahwatzel Lake. Bretz (1913, p. 32) wrote: "Lake Nahwatzel lies in the most extensive morainic country known in this region... Moraine hills here rise 50 feet above the lake on all sides." A recessional moraine may lie southwest of Nahwatzel Lake between Bingham and Outlet creeks. A smaller moraine may dam the southwest end of the lake. Kettle-and-kame topography north and south of the lake suggest ice stagnation.

Recessional meltwater channels. Four prominent recessional meltwater channels cross the area formerly occupied by the Vashon glacier (Fig. 5). The channel floors are underlain by Holocene alluvium, Vashon recessional outwash, older drift, and Tertiary bedrock. The Bingham Creek channel extends from Vance Creek over Windy Siding to the East Fork of the Satsop River. The retreating Vashon ice allowed the 600-foot col at Windy Siding to be used as an outlet to the glacial lake which formed along Vance Creek. The Winter Creek channel begins at the 450-foot col three miles east of Windy Siding and, when in use, was near the southwest margin of the Vashon glacier. Meltwater in the Winter Creek channel flowed in an over-all southeast direction. The East Fork channel trends southwest along Phillips and Stillwater creeks and the East Fork of the Satsop River. The Cloquallum Creek channel leads west from the Mud Lakes.

Morainal topography between Mud Lakes and Hanks Lake. Molenaar and Noble (1970) mapped morainal deposits between the Mud Lakes and Hanks Lake. The morainal deposits were described as loose and unsorted cobbles, gravel, and sand underlying hummocky topography. The morainal topography includes Vashon recessional moraines southwest of the Mud Lakes, west of Lost Lake, and east of the headwaters of Stillwater Creek. Kettle-and-kame topography is dominant around the Mud Lakes and Panhandle Lake. The

Cloquallum Creek and East Fork meltwater channels lead west from the morainal topography, which is the drainage divide between the Chehalis River and the creeks flowing east to Puget Sound. The kettles, kames, and moraines on the drainage divide, and the two meltwater channels, suggest a temporary halt during withdrawal of the Vashon glacier.

Loess

Deposits of sand and silt, inferred to have been deposited by wind, are common in the southwestern portion of the study area. Although most of the surficial sand and silt on the south-central Olympic Peninsula is probably loess, part of it may have been deposited by water. The loess blankets pre-Vashon deposits, influences their rate of weathering, and generally hinders geologic mapping. In most localities the surficial loess is yellowish gray and unoxidized, and probably dates to the Fraser Glaciation. At some localities it is underlain by oxidized and mottled sediment which probably is pre-Fraser loess.

Grain-size analyses were made on loess from two localities. Fine sand is the median grain size of Fraser loess overlying Salmon Springs outwash half a mile northwest of Satsop. Coarse silt is the median grain size of loess on top of an early Fraser terrace located on the east side of the Wynoochee River six miles north of the Chehalis Valley. The two analyses are consistent with the idea that the loess becomes finer grained and better sorted away from the Chehalis Valley. The loess commonly contains up to 10 percent of coarse non-wind-transported sediment. The cobbles, pebbles, and coarse sand comprising this fraction probably were incorporated by several means, including reworking by streams, uprooting of trees during storms, and burrowing activity of rodents.

The loess thins north and east away from the Pacific Ocean and the Chehalis Valley. Loess is up to 20 feet thick in the lower Chehalis Valley (near Satsop), up to 7 feet thick as far east as the southern Black Hills (near Oakville), and up to 5 feet thick at least 13 miles north of the Chehalis Valley (on the east side of the Wynoochee River). The dominant winds today are from the southwest; similar winds during the Fraser glaciation would have winnowed fine-grained sediment from the outwash in the Chehalis Valley. The gentle shelf off the Pacific coast would be another source of loess since it would have been exposed during the lowered sea level of glacial times.

Holocene Deposits

Alluvium

Holocene alluvium is present in alluvial fans and postglacial terraces and on modern floodplains. Alluvial fans are common where small tributaries issue from steep valley sides onto stream terraces. In many places low terraces that lie well below the Fraser terraces probably are postglacial. Modern floodplain sediments comprise the bulk of the Holocene alluvium.

Colluvium

Colluvium constitutes the products of mass-wasting, including landslides and slumps. The effectiveness of mass-wasting on the steep slopes is demonstrated by the general lack of Salmon Springs Drift on the southern Olympic front. The Puget Lobe was approximately 500 feet thicker during the Salmon Springs Glaciation than during the Fraser Glaciation, yet no unequivocal drift was found above the Vashon limit. Colluvium of variable thickness mantles most of the slopes and hinders geologic interpretation.

Landslides are common, and many have been mapped by Gower and Pease (1965) and Rau (1966, 1967). One particularly accessible and obvious landslide is just southeast of the confluence of Anderson Creek and the Wynoochee River. The presence of Wedekind Creek Formation and numerous terraces on the north side of the Chehalis Valley indicate that during the Quaternary the Chehalis River has been shifting south between Montesano and Central Park, resulting in oversteepening of the south bank which has caused several landslides in the Tertiary sedimentary rock. Landslides have dammed the upper Satsop Lakes and the Dry Bed Lakes. Slumps are common in drift along the Wynoochee River, and relocation of the road has been necessary because of active slumping a mile north of Grisdale.

Lake Deposits

Holocene lake deposits include sedimentary fills in bogs and meander-cutoffs. Most bogs are located on Fraser till and are sites of accumulation of peat and muck. Meander scars on postglacial terraces and the modern floodplain reveal places where oxbow lakes have been filled with fine-grained sediments.

CORRELATIONS

On the south-central Olympic Peninsula there are drifts representing at least 3 or 4 glaciations. The Wedekind Creek Formation probably was deposited during an ancient alpine glaciation of the Olympic Mountains. The Helm Creek, Salmon Springs, and Fraser drifts are believed to represent the last three major advances of the Puget Lobe and the Wynoochee glacier.

Tentative correlations of the surficial deposits on the south-central Olympic Peninsula and elsewhere in western Washington are shown in Table 5.

Wedekind Creek Formation

The oldest Pleistocene deposit southeast of the study area is the Logan Hill Formation, which is widely distributed southeast of the Black Hills in western Lewis County (Weigle and Foxworthy, 1962) and in southern Thurston County (Noble and Wallace, 1966). Weigle and Foxworthy (1962, p. 28) described the unweathered Logan Hill Formation as a mixture of gravel, sand, and minor silt and clay. Eastern outcrops of the formation include lenses of till. Pebbles and cobbles in the Logan Hill Formation are derived from nearby Tertiary sedimentary rocks and from igneous rocks in the western foothills of the Cascade Range. In Lewis County the formation is weathered to depths of 20 to 50 feet. According to Weigle and Foxworthy (1962, p. 29), "the Logan Hill Formation probably was deposited chiefly as outwash from alpine glaciers located east of the lowland, but the outwash doubtless was augmented by alluvial deposits carried into the basin by streams draining the surrounding foothills."

Bretz' (1913) "pre-Vashon red gravels of the Chehalis River" include not only part of the Logan Hill Formation in Thurston County but also the

Puget Lowland (after Crandell, 1965)		Thurston County (Noble & Wallace, 1966)	Southwestern Olympic Peninsula (after Moore, 1965)		South-central Olympic Peninsula: Wynoochee glacier		South-central Olympic Peninsula: Puget Lobe
Fraser Glaciation	Sumas Drift	Vashon Drift	Chow Chow Drift	moraine damming Quinault Lake	Grisdale Drift	Grisdale V and VI moraines	Vashon Drift
	Everson glaciomarine and marine sediments						
	Vashon Drift					Grisdale III (?) or IV moraines	
	Evans Creek Drift			outer Chow Chow moraines		Grisdale I, II, and III (?) moraines	
Olympia Interglaciation		Kitsap Formation					
Salmon Springs Glaciation	upper drift	Salmon Springs (?) Drift	Humptulips Drift		Mobray Drift		Salmon Springs Drift
	nonglacial sediments						
	lower drift						
Puyallup Interglaciation		pre-Salmon Springs (?) deposits					
Stuck Glaciation			Donkey Creek Till		Helm Creek Drift		
Alderton Interglaciation							
Orting Glaciation		Logan Hill Formation	Flat Lying and Slightly Deformed Sand and Gravel		Wedekind Creek Formation		

Table 5. CORRELATIONS OF SURFICIAL DEPOSITS ON THE SOUTH-CENTRAL OLYMPIC PENINSULA AND ELSEWHERE IN WESTERN WASHINGTON

(Correlations within the Fraser Glaciation and below the Salmon Springs Glaciation are speculative.)

deposits of some Helm Creek and Salmon Springs terrace segments in Grays Harbor County. Noble and Wallace (1966, p. 22) concluded that the Logan Hill Formation is fluvial and glaciofluvial in Thurston County. The lithologic and weathering characteristics of the formation are similar to those in Lewis County.

Based on distribution and weathering characteristics, the Wedekind Creek Formation is correlated with the Logan Hill Formation. The formations are inferred to represent probable ancient alpine glaciation of both the southern Olympics and the western Cascades.

Moore (1965) mapped "flat-lying and moderately deformed sand and gravel" on the southwestern Olympic Peninsula, and reported that the predominantly pebble-cobble gravels are weathered to a depth of more than 35 feet. The pebbles are so "decomposed that they can easily be cut with a pick" (Moore, 1965, p. 17). These gravels are tentatively correlated with the Wedekind Creek Formation because of apparently similar weathering and distribution.

Helm Creek Drift

Helm Creek Drift probably represents the Puget and alpine glaciation which immediately preceded the Salmon Springs Glaciation. Helm Creek terraces lie immediately above Salmon Springs terraces along the Chehalis, Satsop, and Wynoochee rivers. Weathering characteristics of Helm Creek (?) till are intermediate between those of the Wedekind Creek Formation and Salmon Springs till. In the southeastern Puget Lowland Stuck Drift represents the last recorded glaciation preceding the Salmon Springs Glaciation. Stuck Drift is everywhere overlain by younger drift, so a meaningful comparison of weathering characteristics cannot be made. On the basis of of stratigraphic position, Helm Creek Drift is correlated tentatively with Stuck Drift.

Noble and Wallace (1966, p. 23-26) described pre-Salmon Springs (?) deposits in Thurston County and reported that weathering of the deposits "is much more intense than that of Salmon Springs (?) Drift but is less intense than that of most Logan Hill exposures." Possible pre-Salmon Springs (?) gravels and till in southern Thurston County are thought to correlate with Helm Creek Drift in the south-central Olympic Peninsula.

Donkey Creek Till, deposited by an Olympic alpine glacier and exposed along the Humptulips River, was named and described by Moore (1965, p. 27-29). The till is weathered to a depth of at least 30 feet and contains basalt clasts with weathering rinds averaging 10 to 12 mm thick. The weathering characteristics of Donkey Creek Till suggest that it may be older than Helm Creek Drift.

Salmon Springs Drift

Salmon Springs Drift on the south-central Olympic Peninsula correlates with Salmon Springs deposits in the Puget Lowland. Humptulips Drift (Moore, 1965, p. 30) was deposited during the most extensive glaciation of the southwestern Olympic Peninsula. Moore (1965, p. 61) provisionally correlated Humptulips Drift with Salmon Springs Drift of the Puget Lowland. Based on the extent of glaciation and degree of weathering, Mobray Drift deposited by the Wynoochee glacier is correlated with Humptulips Drift.

Fraser Drift

In the southern Puget Lowland, the Fraser Glaciation is represented by alpine (Evans Creek) and Puget drifts. In the northern Puget Lowland Vashon and Sumas drifts of the Puget Lobe are separated by glacial marine sediments of the Everson interstade (Armstrong and others, 1965, p. 324). Moore (1965, p. 60-61) correlated Chow Chow Drift of the southwestern Olympic Peninsula with Fraser Drift of the Puget Lowland. He suggested that the Chow Chow maximum advance may be equivalent to the Evans Creek, and that the moraine damming Quinault Lake may be a Vashon equivalent. Based on the weathering characteristics of the drift and the extent of the ice, Chow Chow Drift appears to correlate broadly with Grisdale Drift, and the moraine damming Quinault Lake may correlate with the Grisdale III or IV moraines. Possible correlation of Grisdale Drift with deposits of the Puget Lowland are shown in Table 5.

Molenaar and Noble (1970, p. 16-17) named the Skokomish Gravel on the southeast side of the Olympic Mountains and believed that "the predominantly reddish gravel and sand" was deposited during the Olympia Interglaciation and possibly during the early phases of the Fraser Glaciation. The upper part of the Skokomish Gravel may be advance outwash of Olympic alpine glaciers and correlate with the high Fraser terrace graded to the Grisdale I moraine.

SUMMARY OF QUATERNARY HISTORY

Pre-Salmon Springs Glaciations

Prior to the deposition of the Wedekind Creek Formation the area south of the Olympic Mountains was probably a gently undulating plain with a relief of a few hundred feet. The Wedekind Creek gravels are fluvial and/or glaciofluvial sediments laid down in the low areas and not present on the higher hills south of the Olympics. The Wedekind Creek Formation could be a tectonic gravel deposited during uplift of the Olympic Mountains. Alternatively, the formation may indicate that the Olympics were high enough in pre-Salmon Springs time to be glaciated. Assuming the latter hypothesis to be valid, the inferred glaciers extended well beyond cirques on the high peaks and at least as far as the front of the Olympic Mountains, but not as far south as the subsequent limit of Mobray ice.

The Logan Hill Formation probably represents an ancient alpine glaciation of the western Cascades. In Thurston County, Noble and Wallace (1966) have mapped the Logan Hill Formation along the Chehalis River to within a mile of Grays Harbor County (Fig. 2). No exposures of the Wedekind Creek or Logan Hill formations were found from Thurston County to about a mile northeast of Montesano. If either formation was ever deposited along the Chehalis Valley between Rochester and Montesano, it has largely been eroded away. Perhaps a drainage divide existed in southeastern Grays Harbor County during deposition of the two formations, for relatively resistant basalt is exposed on both sides of a constriction in the Chehalis Valley between Oakville and Cedarville. Meltwater from Olympic alpine glaciers might then have flowed south in the area of the Wynoochee and Satsop rivers, and west through the lower Chehalis Valley. Meltwater from the Cascade alpine glaciers could have flowed south along the Cowlitz Valley.

The great difference in weathering of the Wedekind Creek Formation and Helm Creek Drift suggests that a long period of time passed between their deposition. During this interval the lower Wynoochee and Satsop valleys were cut, because the Wedekind Creek Formation is exposed on interfluves whereas Helm Creek terraces lie along the major valleys. Helm Creek Drift was deposited during a Puget and alpine glaciation nearly as extensive as the Salmon Springs Glaciation.

The previously inferred drainage divide in eastern Grays Harbor County might explain the lack of Helm Creek terraces southeast of Malone. Meltwater from the Puget Lobe and from alpine ice on the south-central Olympic Peninsula probably flowed south along Mox Chehalis and Cloquallum creeks and the Satsop and Wynoochee rivers. A drainage divide along the modern Chehalis River, somewhere between Malone and Oakville, would have blocked meltwater east of the Black Hills from the lower Chehalis Valley.

Salmon Springs Glaciation

The present drainage pattern of the south-central Olympic Peninsula was established largely by the end of the Salmon Springs Glaciation. Salmon Springs terrace segments along the Chehalis River indicate that the inferred former drainage divide in eastern Grays Harbor County had disappeared. During the Salmon Springs Glaciation the Puget Lobe probably pushed far enough up the northern and eastern sides of the Black Hills for meltwater to flow southwest along Cedar and Porter creeks. Two drainage changes occurred when rivers were pushed westward during the maximum advance of the Puget Lobe. The Canyon River formerly discharged into the Middle Fork of the Satsop River, but now flows into the West Fork of the Satsop River. The former course of part of the West Fork of the Satsop River was along the valley now occupied by Smith Creek.

The most extensive advances of the Puget and Wynoochee glaciers occurred during the Salmon Springs Glaciation. Some degree of synchroneity between the maximum positions of the Puget and Mobray glaciers is indicated by the Weatherwax Formation. Glacial Lake Weatherwax was dammed when the westward-advancing Puget Lobe met the southward-advancing Wynoochee glacier near the West Fork of the Satsop River. The Weatherwax Formation was deposited in the glacial lake between the two glaciers and the southern front of the Olympic Mountains. Channel deposits and alternating coarse and fine sediments in the Weatherwax Formation suggest that the lake was filled and emptied (partially or completely) more than once. Diamictons suggest that turbidity currents and subaqueous mudflows may have occurred.

Truncated spurs above the upper limit of Fraser Drift suggest that the Puget and Wynoochee glaciers probably were thicker or valley floors higher during the Salmon Springs and earlier glaciations than during the Fraser Glaciation. Only the highest peaks and ridges of the southern Olympics may have projected above a mountain ice cap during the Salmon Springs Glaciation. Outlet glaciers along the Wynoochee and Humptulips rivers, and possibly along the West Fork of the Satsop River, would have fed a piedmont lobe of ice on the lowlands south of the front of the Olympic Mountains.

When the alpine ice reached its maximum position, Mobray outwash was carried down the Satsop, Wynoochee, and Wishkah rivers. Five Mobray moraines exist in the places where the alpine ice paused or slightly readvanced during its over-all retreat. Wood from laminated silts and clays near Grisdale has a radiocarbon age of >40,000 years B.P. (UW-145);

these sediments probably were deposited in lakes dammed by Mobray or older moraines that subsequently were breached or destroyed.

The moraines and terraces provide a possible basis for determining, in time and space, the relationship between the Puget Lobe and the Wynoochee glacier. Puget terraces can be traced from the Salmon Springs and Vashon glacial limits down the Satsop and Chehalis rivers. Alpine terraces can be traced down the Wynoochee River from the Mobray and Grisdale moraines. The terrace graded to the Mobray glacial limit lies above the terrace graded to the Salmon Springs Puget glacial limit. This terrace relationship is interpreted as indicating that Mobray ice reached its greatest extent before the maximum advance of the Puget Lobe. The terrace graded to the Salmon Springs Puget terminus probably is also graded to Mobray moraines lying 3 to 5 miles north of the Mobray drift border. The alpine ice may have retreated some 3 to 5 miles before the Puget Lobe began receding.

The terrace relationships and the necessity of an ice dam for Glacial Lake Weatherwax dictate only one probable sequence of events. The Wynoochee glacier advanced to its maximum position and built the high Mobray outwash terraces. The Mobray terminus remained relatively stationary or retreated less than a mile as the Puget Lobe advanced to its maximum position. The resulting coalescence of ice dammed Glacial Lake Weatherwax. The Puget terminus remained relatively stationary while the Wynoochee glacier retreated far enough for the glacial lake to drain. The Wynoochee glacier then continued to retreat until its margin was 3 to 5 miles behind the Mobray drift border. Lower outwash terraces were graded to the new position of the alpine ice and to the terminus of the Puget Lobe. Eventually both glaciers withdrew from the south-central Olympic Peninsula.

Mobray till east of Reed Hill must have been deposited by ice flowing east in the vicinity of Reed Hill and (or) possibly south along the narrow valley of the West Fork of the Satsop River. If Mobray ice was relatively thin east of Reed Hill, the formation of Glacial Lake Weatherwax may have caused floating and calving of the glacier. Similarly, in the eastern part of the glacial lake the Puget Lobe may have experienced floating and calving to a lesser degree.

Crandell and others (1958, p. 394) reported the presence of non-glacial sediments between Salmon Springs glacial gravels in the southeastern Puget Lowland and inferred that there were two advances of the Puget Lobe during the Salmon Springs Glaciation. According to Crandell (1965, p. 348), the Humptulips bog lies on older Salmon Springs (?) drift deposited by the Quinault alpine glacier. In the pollen record of the Humptulips bog, Heusser (1964) inferred two major glacial climatic episodes, presumably younger Salmon Springs and Fraser. No unequivocal evidence has been found on the south-central Olympic Peninsula for two major advances of either the Puget Lobe or the Wynoochee glacier during the Salmon Springs Glaciation. The Salmon Springs stratigraphy of the southeastern Puget Lowland and the pollen record of the Humptulips bog can be reconciled with the evidence in the south-central Olympics if the younger Salmon Springs glaciers were less extensive than the Fraser glaciers. Most evidence for a second major advance of Salmon Springs ice may have been eroded or buried during the Fraser Glaciation.

Little evidence has been found on the south-central Olympic Peninsula for the Olympia or earlier interglaciations. Dissection by streams resulted in terracing or complete removal of outwash plains and valley trains. The Spoon Creek diamicton suggests that mudflows may have been active locally during the Olympia Interglaciation.

Fraser Glaciation

During the most recent glaciation the Wynoochee glacier deposited Grisdale till to within six miles of the Mobray drift border, and the Puget Lobe deposited Vashon till to within three miles of the Salmon Springs Puget glacier limit (Fig. 5). Before the Fraser Glaciation, the upper part of the West Fork of the Satsop River probably flowed between Anderson Butte and Weatherwax Ridge to join the Wynoochee River. Early in the Fraser Glaciation, Grisdale ice blocked this route, thereby damming Glacial Lake Satsop. The spillway for the glacial lake was east of Weatherwax Ridge, and the overflow cut the canyon of the West Fork of the Satsop River.

When Grisdale ice was at its maximum position, outwash was carried down the Wishkah and Wynoochee rivers and the West Fork of the Satsop River. The terrace graded to the former Grisdale terminus lies above the terrace which was graded to the Vashon terminus, indicating that the alpine ice reached its maximum extent before the Puget Lobe.

Based on moraines and other criteria, the Fraser alpine glaciation is divided into six phases. A minor readvance occurred during phase II because the outermost Grisdale II moraine crosses the innermost Grisdale I moraine at an angle. A minor readvance also occurred during the Grisdale III phase, for lake beds behind the innermost Grisdale III moraine are overlain by till. At least one tributary valley became free of ice before the main valley, with the result that Glacial Lake Big Creek was dammed by ice in the Weatherwax Basin. After the Wynoochee Lobe receded past the mouth of Big Creek, the creek built a delta into a lake dammed by the Grisdale III moraines.

Multiple tills in two exposures near the Grisdale IV moraines indicate that several minor readvances took place during the Grisdale IV phase. An extensive outwash terrace graded to the Grisdale IV moraines probably was also graded to the Vashon terminus. Tracing this low Fraser terrace along the Wynoochee, Chehalis, and Satsop rivers suggests that the Wynoochee Lobe had retreated as much as eight miles by the time the Puget Lobe reached its Vashon maximum position.

Delta beds were deposited in the lake impounded by the Grisdale V moraine, and laminated sediments were laid down in the lake dammed by the Grisdale VI moraine. A late Fraser moraine was built just in front of a cirque on the southwest side of Discovery Peak.

Fraser loess blankets pre-Vashon deposits in the southwestern part of the study area. The loess thins to the north and east, suggesting that the dominant winds during the Fraser Glaciation were from the southwest. The probable sources for the loess were outwash in the Chehalis Valley and sediments on the gentle shelf off the Pacific coast.

Outwash from the Vashon glacier reached the Chehalis River by way of the Satsop and Black rivers and Cloquallum and Mox Chehalis creeks. Ford mounds lie on Vashon terrace segments along the Chehalis River on the south and southwest sides of the Black Hills. The mounds are more than five miles from the Vashon drift border on the southeast side of the Black Hills. Although Bretz (1913, p. 107) believed that the Ford mounds were gravel deposited in pools between ice blocks stranded on the Vashon terrace, another possibility is that the Ford mounds are erosional features formed after the Vashon ice began its recession. Glacial lakes in the western Cascade foothills may have been released suddenly, creating a flood along the Chehalis River which could have eroded the Vashon terraces and deposited gravel bars across tributary valleys. West of Ford Prairie, however, evidence of flooding appears to be lacking.

Vashon ice reached its maximum position 14,000 years ago. Widespread kettle-and-kame topography near the drift border indicates that the terminal part of the Vashon glacier became stagnant, and radiocarbon dates suggest that stagnant ice may have persisted on the southeastern Olympic Peninsula until at least 12,600 years ago.

Except in the terminal zone, deglaciation apparently was characterized by an actively retreating ice front. Four prominent recessional meltwater channels were cut across the area which the Puget Lobe abandoned. Two of these lead westward from a belt of morainal topography which lies 5 to 10 miles east of the Vashon drift border. The morainal topography may indicate that the Vashon glacier paused briefly during its retreat from the south-central Olympic Peninsula.

Holocene History

During the Holocene, postglacial terraces have been cut along many streams, alluvial fans have been built against terrace scarps and valley walls, and meandering streams have produced modern floodplains. Mass-wasting has resulted in a mantle of colluvium on many slopes, and land-slides and slumps have occurred frequently, particularly along the Chehalis and Wynoochee rivers.

No Neoglacial moraines were found on the four highest peaks surrounding the upper Wynoochee River. The snowline probably was too high for the development of glaciers in most cirques on these four peaks. However, two cirques at an elevation of about 4500 feet on the north side of Capitol Peak may have contained small glaciers during Neoglaciation.

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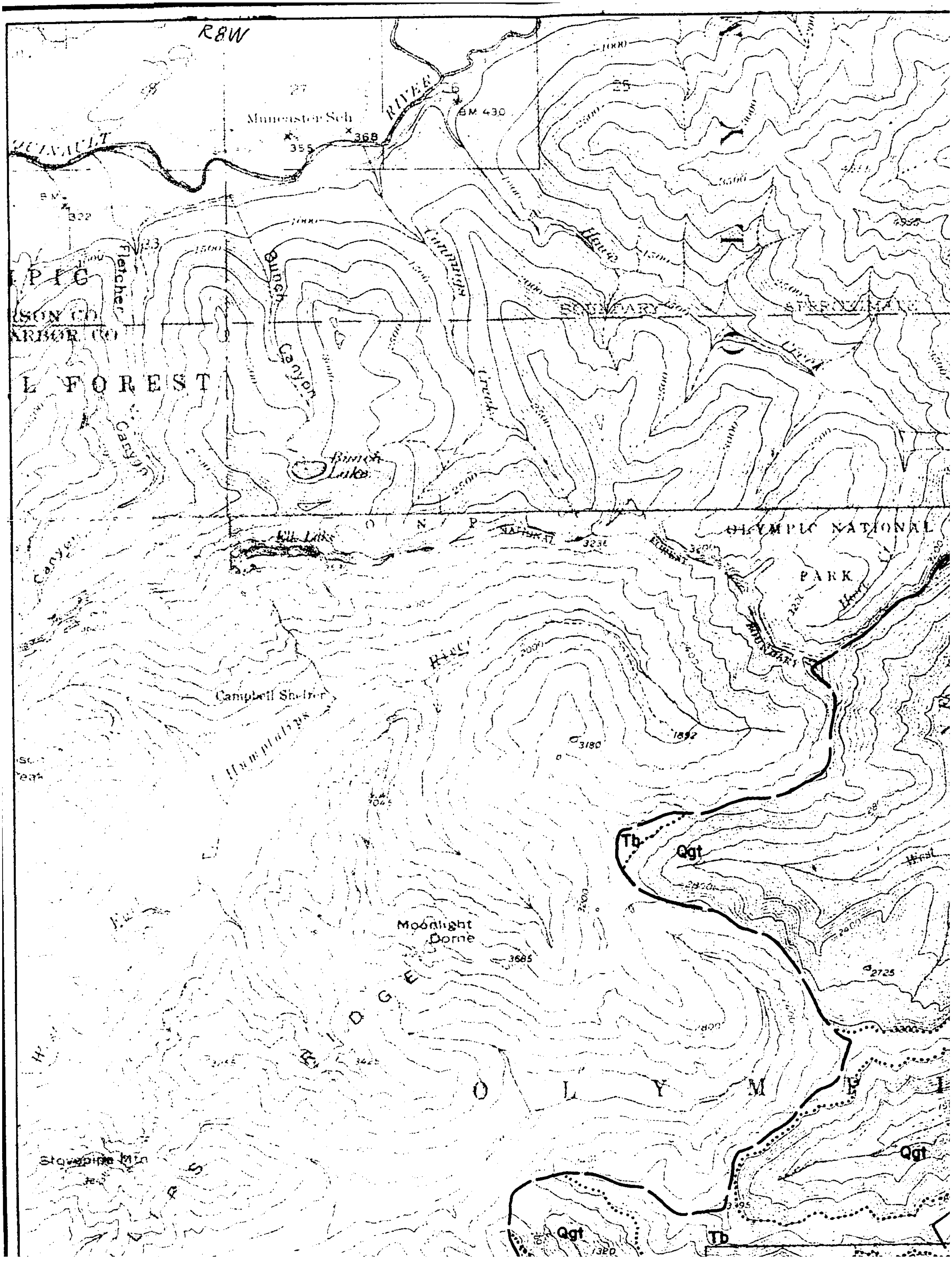
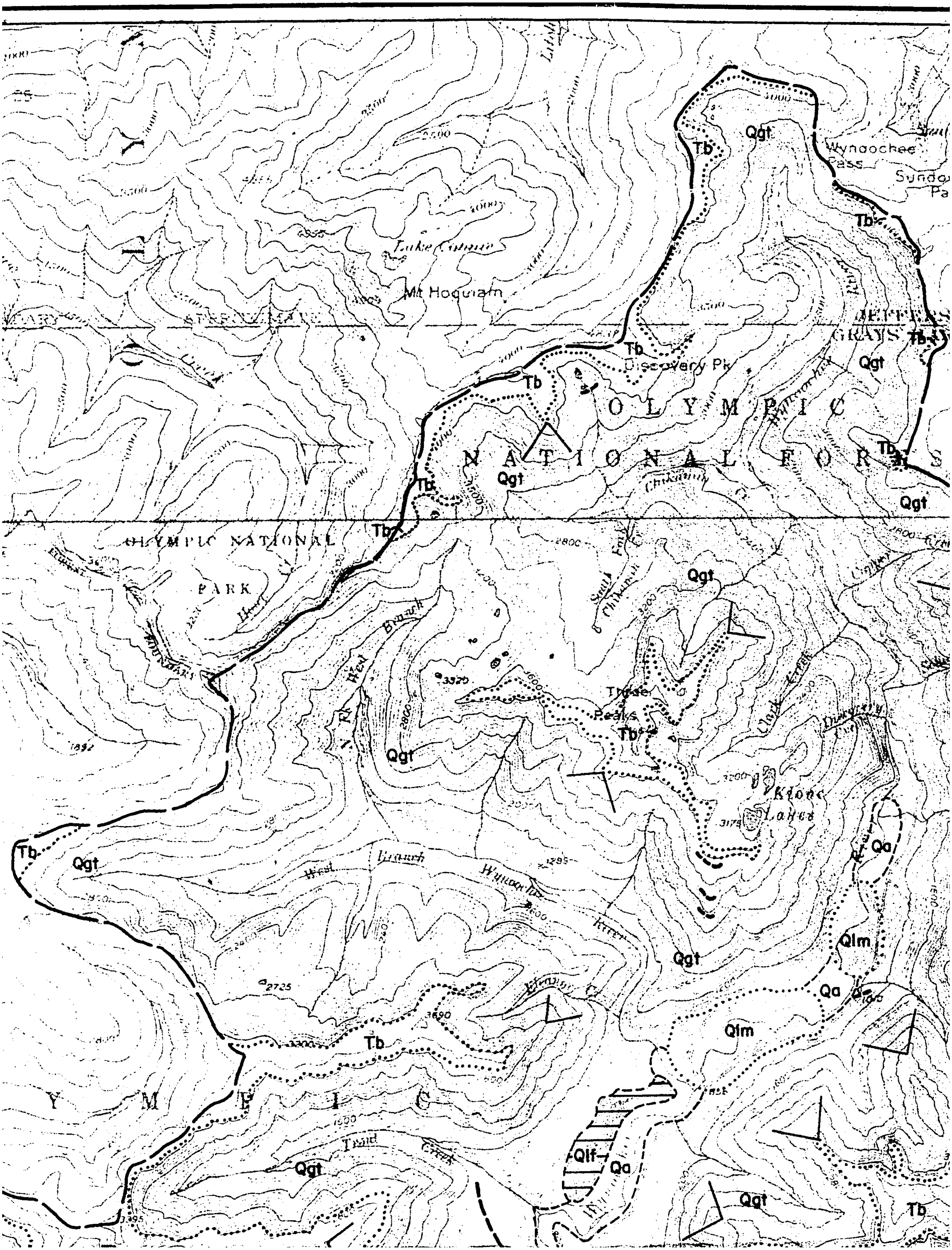
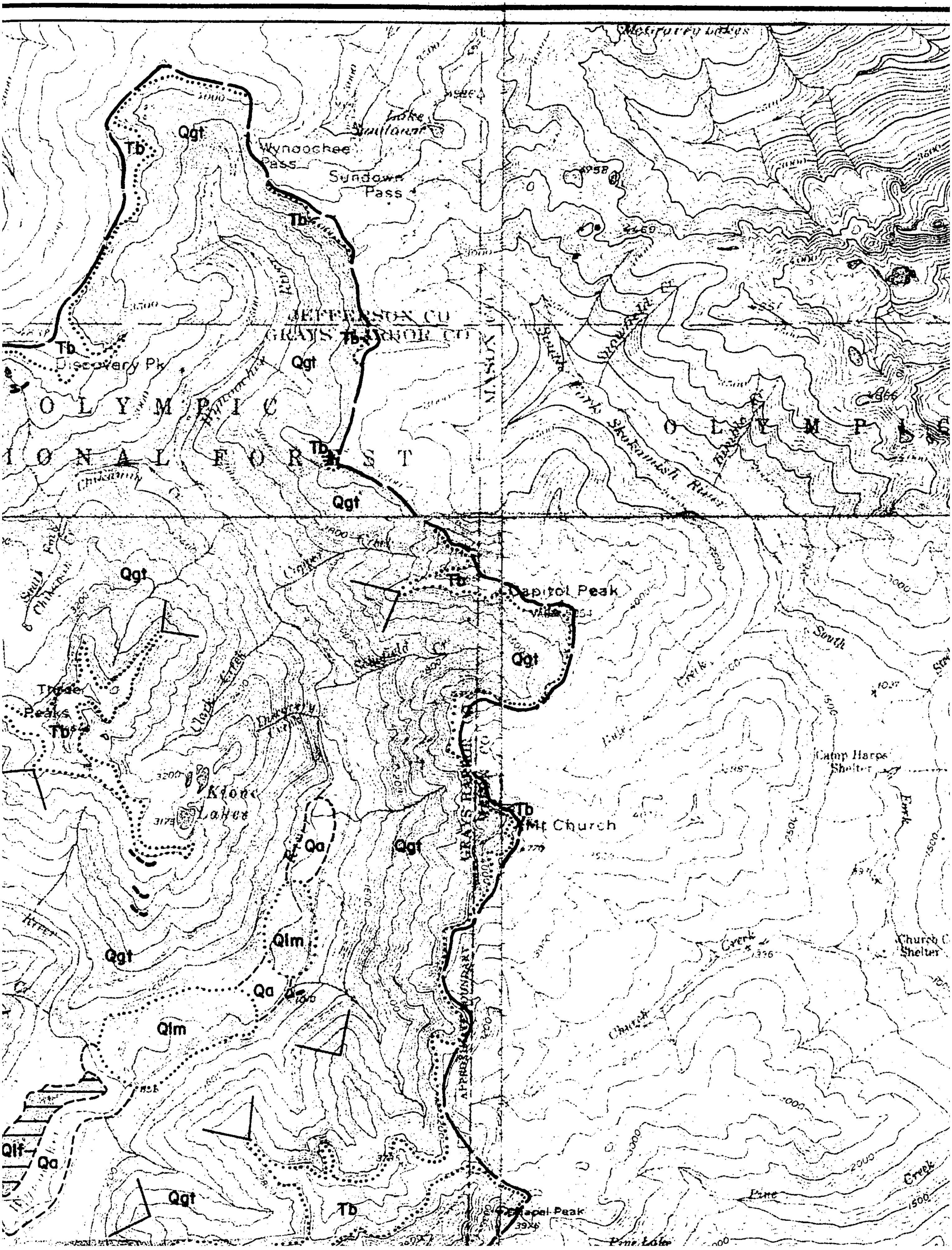
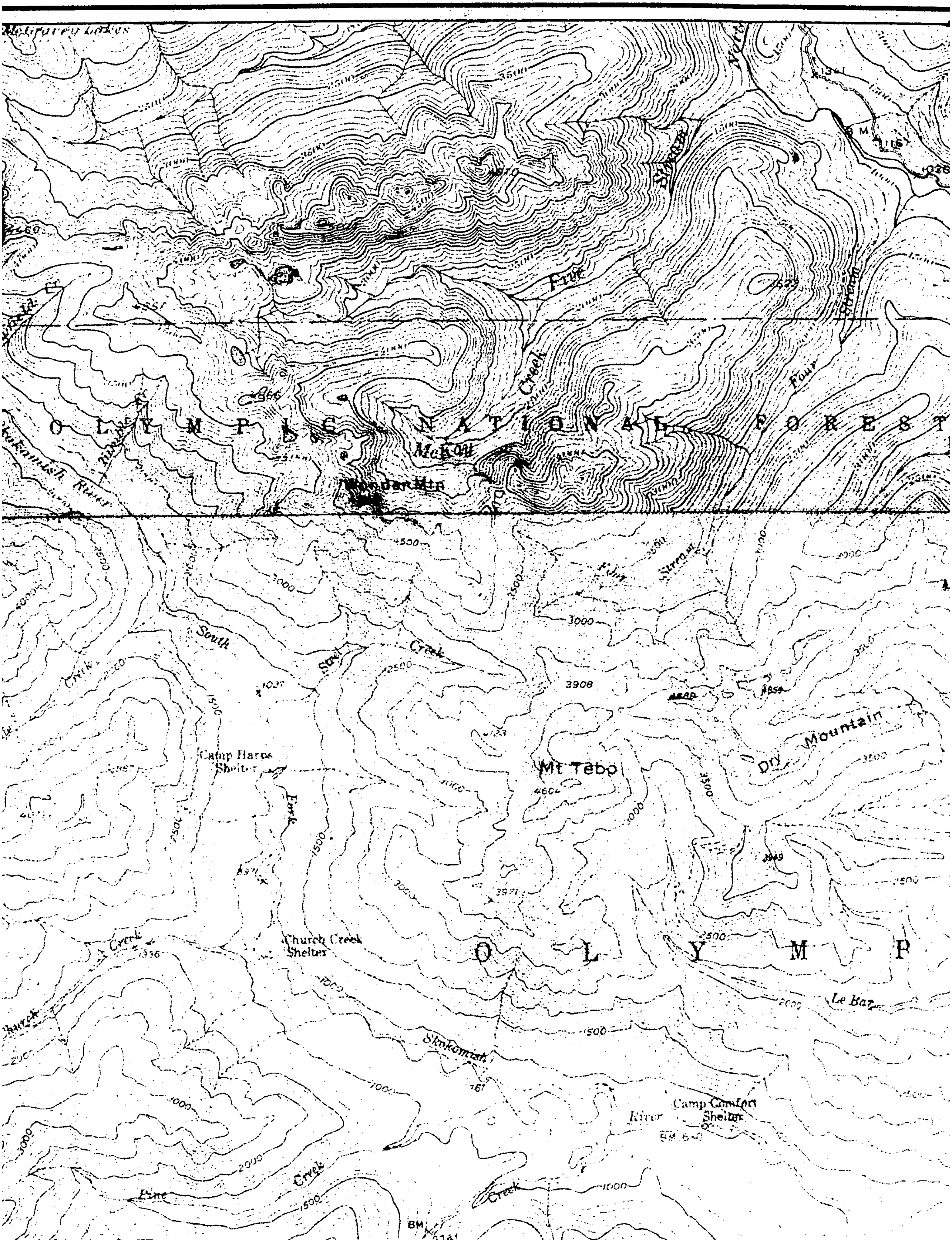

R8W
QUINAULT
RIVER
Muncaster Sch
368
355
BM 430
27
25
Fletcher
Bunch
Canyon
Cummings
Creek
Bunch Lake
Elk Lake
L FOREST
Canyon
BOUNDARY
OLYMPIC NATIONAL
PARK
Campbell Shelter
Humptulips
3180
1892
Tb
Qgt
West
Moonlight
Dome
3685
2725
Stovepipe Mtn
O L Y M P
3495
1320



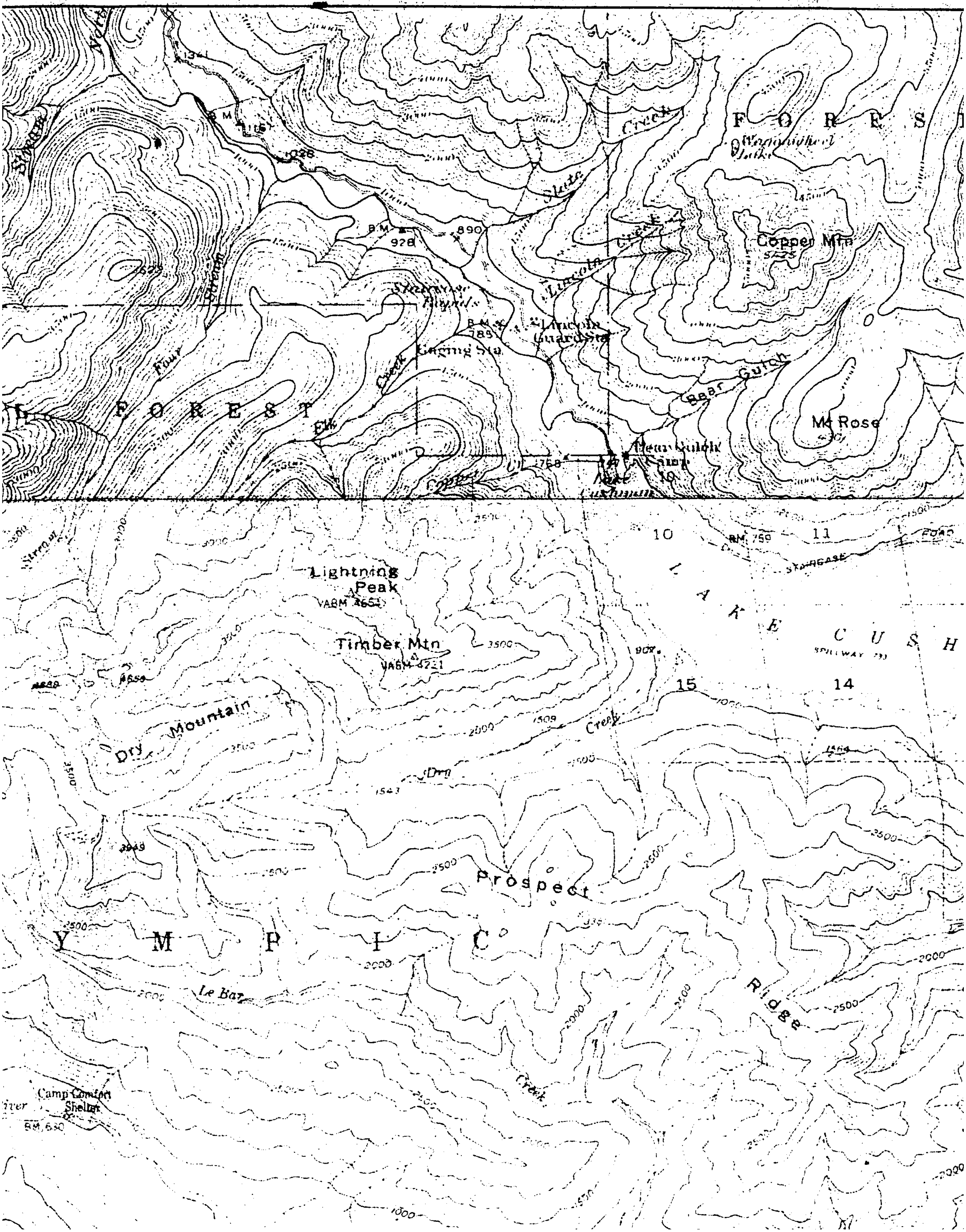
Lake Connie
Mt Hoquiam
Wynoochee Pass
Discovery Pk
OLYMPIC NATIONAL FOREST
GRAYS
OLYMPIC NATIONAL PARK
West Branch
Triple Peaks
Klone Lakes
Clark Creek
West Branch Wynoochee River
Qgt
Tb
Qa
Qlm
Qlf



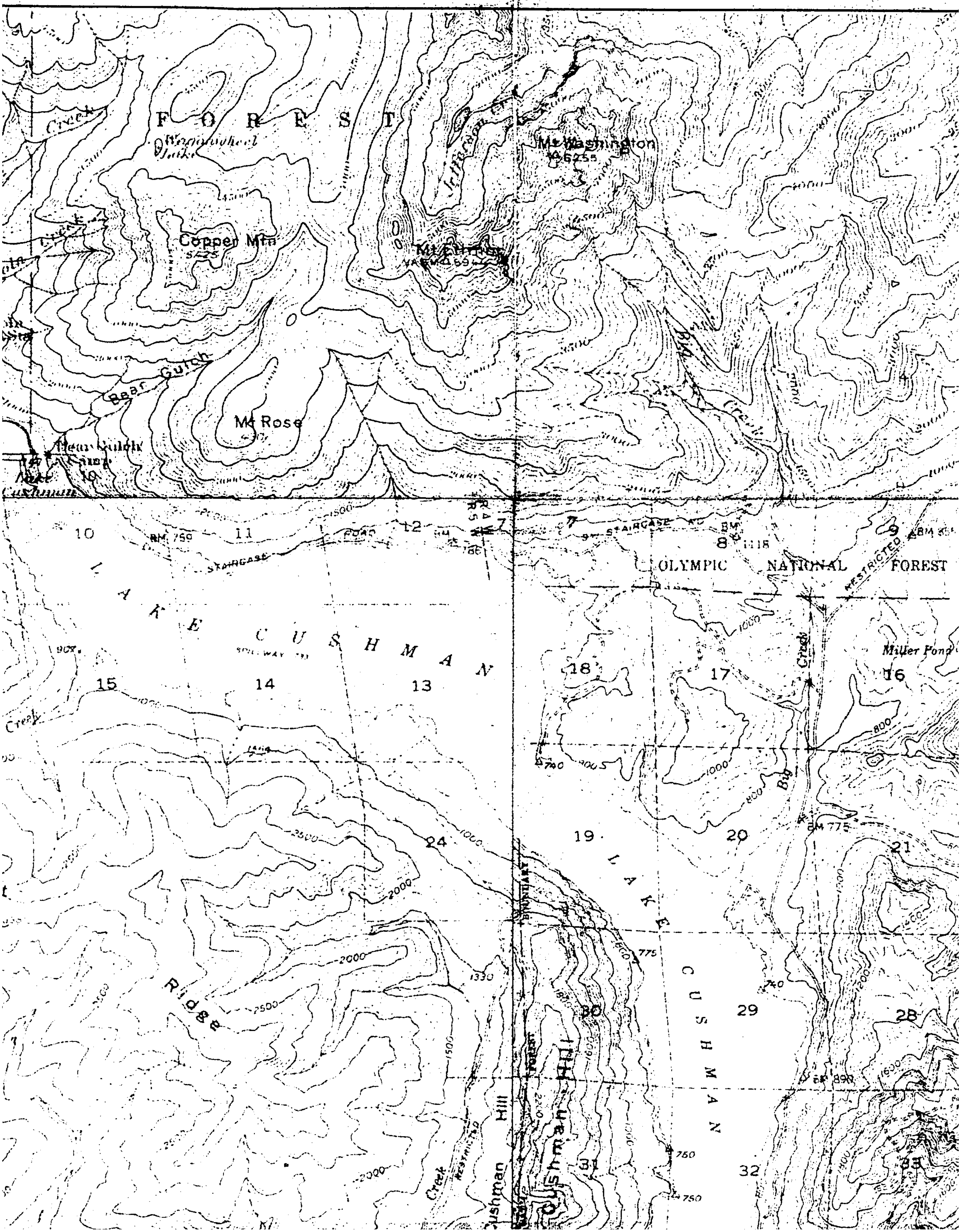
McGravey Lakes
Qgt
Tb
Wynoochee Pass
Sundown Pass
Lake Sundown
JEFFERSON CO
GRAYS HARBOR CO
MASON CO
Discovery Pk
OLYMPIC
NATIONAL FOREST
South Fork Skokomish River
Capitol Peak
South
Creek
Three Peaks
Klone Lake
Qa
Qlm
Mt Church
Camp Harps Shelter
Church Cr Shelter
Church
Qlf
Chapel Peak
Pine Lake
Pine Creek



O L Y M P I C   N A T I O N A L   F O R E S T
Wonder Mtn
Five
Creek
Four
Stream
South
Fork
Creek
Camp Harps
Shelter
Mt Tebo
Dry Mountain
Church Creek
Shelter
O L Y M P
Le Bar
Skokomish
River
Camp Comfort
Shelter
Pine
Creek
3908
4604
3000
2500
1500
1000
2000



F O R E S
Copper Mtn
5425
Creek
Lincoln Creek
Lincoln Guard Sta
Gaging Sta
Elk Creek
Four Stream
F O R E S T
Bear Gulch
Mt Rose
Bear Gulch Camp
Lightning Peak
VABM 4651
Timber Mtn
L A K E C U S H
15
14
10
11
Dry Mountain
Dry
Creek
Prospect
Ridge
Y M P I C
Le Bar
Creek
Camp Comfort Shelter
BM 650



F O R E S T
Creek
Mt Washington
6255
Copper Mtn
5425
Mt Ellinor
Bear Gulch
Mt Rose
Big
Creek
STAIRCASE
ROAD
BM 759
OLYMPIC
NATIONAL
FOREST
RESTRICTED
L A K E C U S H M A N
Miller Pond
Big
Creek
BM 775
BOUNDARY
Ridge
L A K E C U S H M A N
Cushman
Hill
Cushman Hill
Creek
RESTRICTED
10
11
12
7
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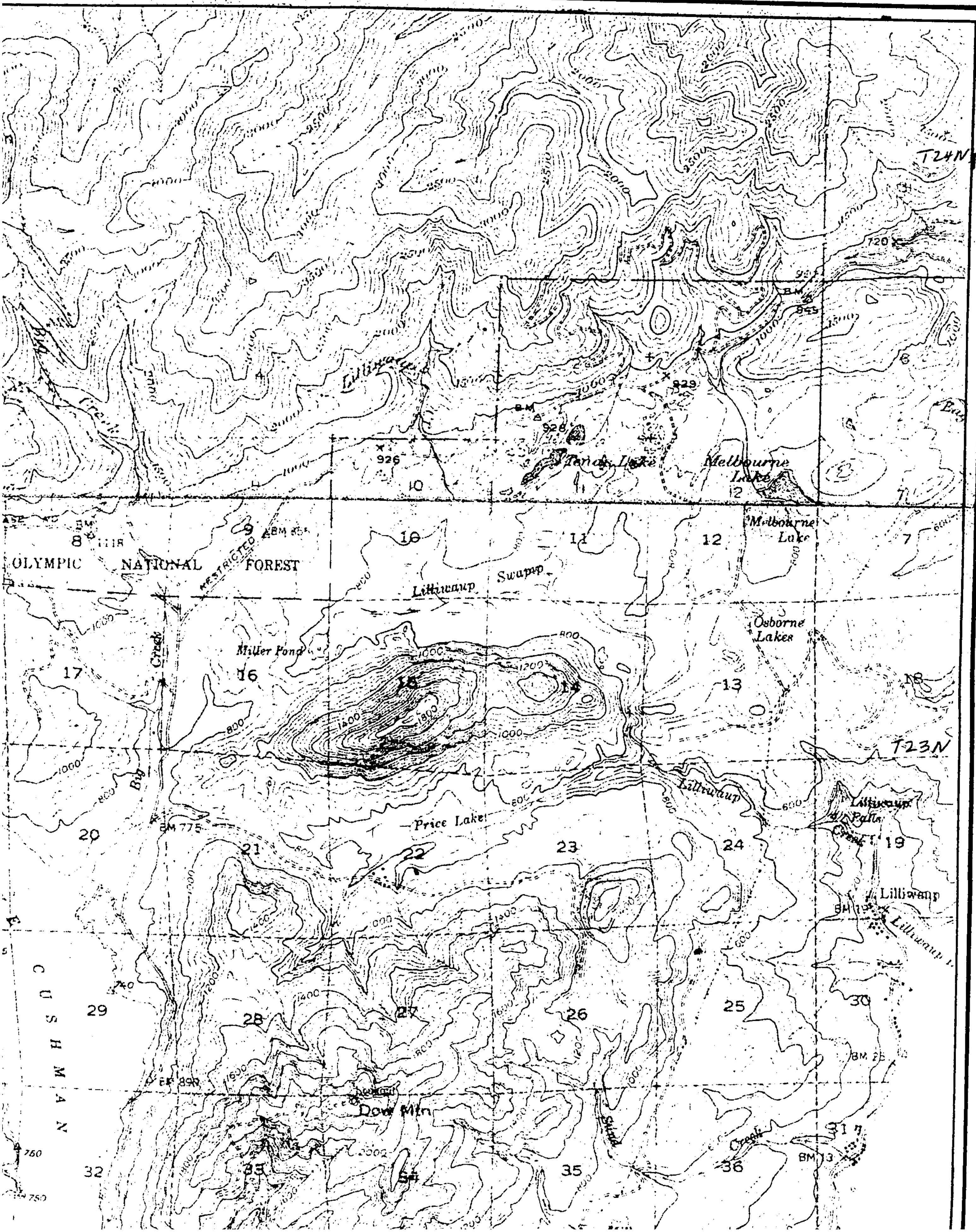
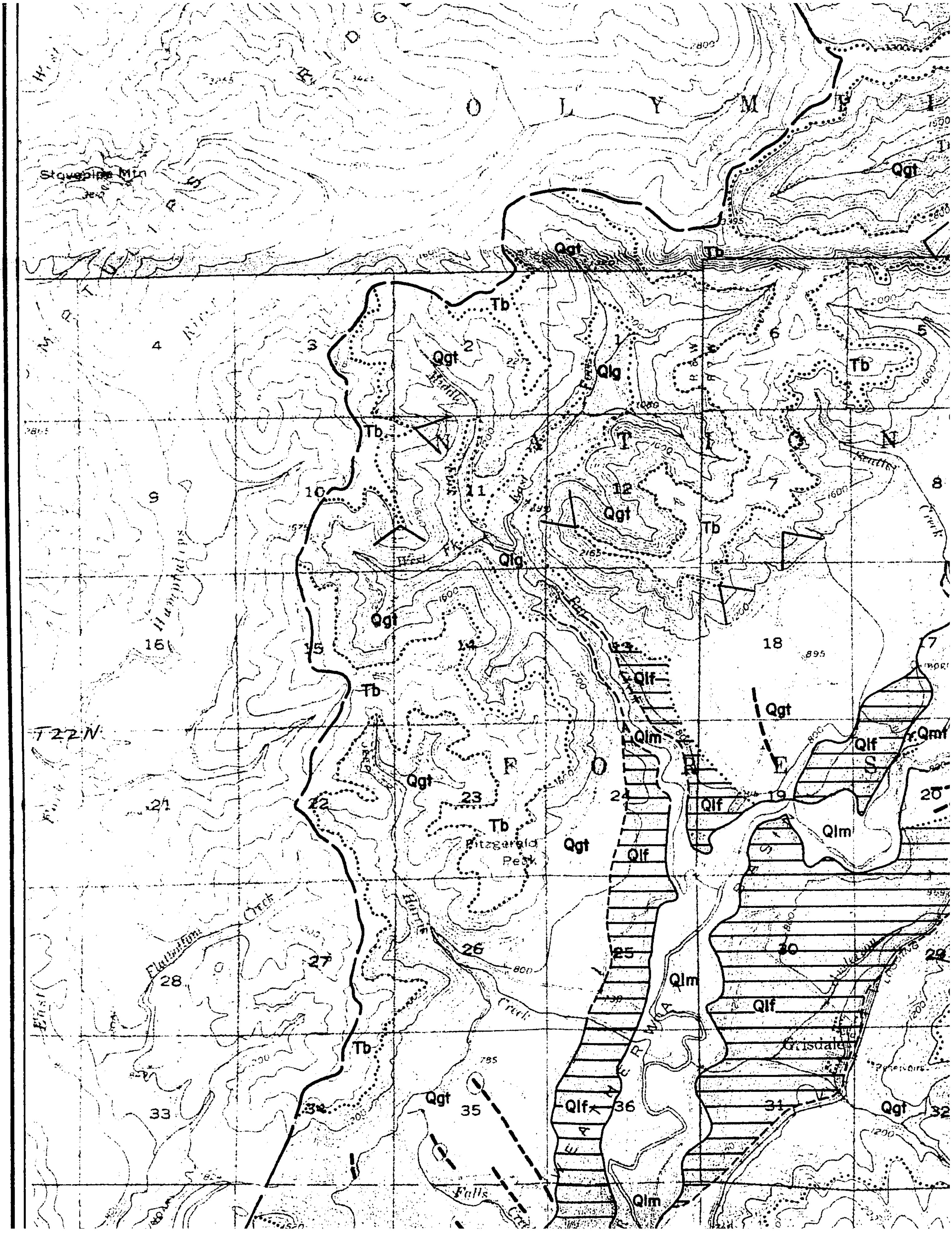
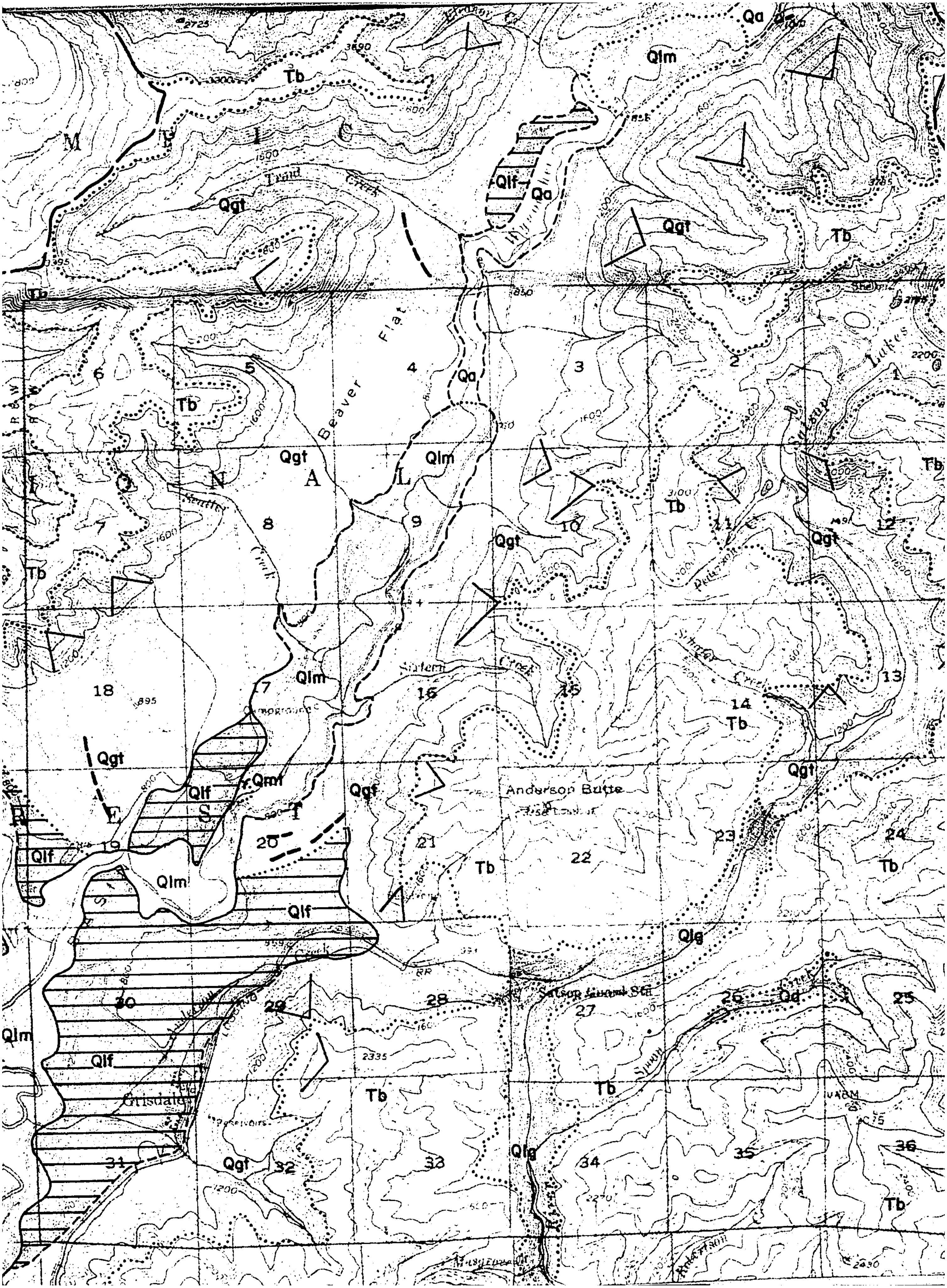


T24N
T23N
Lilliwaup
Tenas Lake
Melbourne Lake
OLYMPIC NATIONAL FOREST
RESTRICTED
Lilliwaup Swamp
Miller Pond
Osborne Lakes
Price Lake
Lilliwaup Falls Creek
Lilliwaup
Dow Mtn
CUSHMAN
Big Creek
Creek



Stovepipe Mtn
O L Y M P I
N A T I O N
F O R E S
T22N
Fitzgerald Peak
Grisdale
West Fk
Humptulips
Qgt
Tb
Qlg
Qlf
Qlm
Qmf



Qa
Qlm
Tb
Qgt
Qlf
Qmf
Qlg
Beaver Flat
Anderson Butte
Grisdale
Satsop Guard Sta
Trout Creek
Beatty Creek
Peterson Creek
Lakes
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
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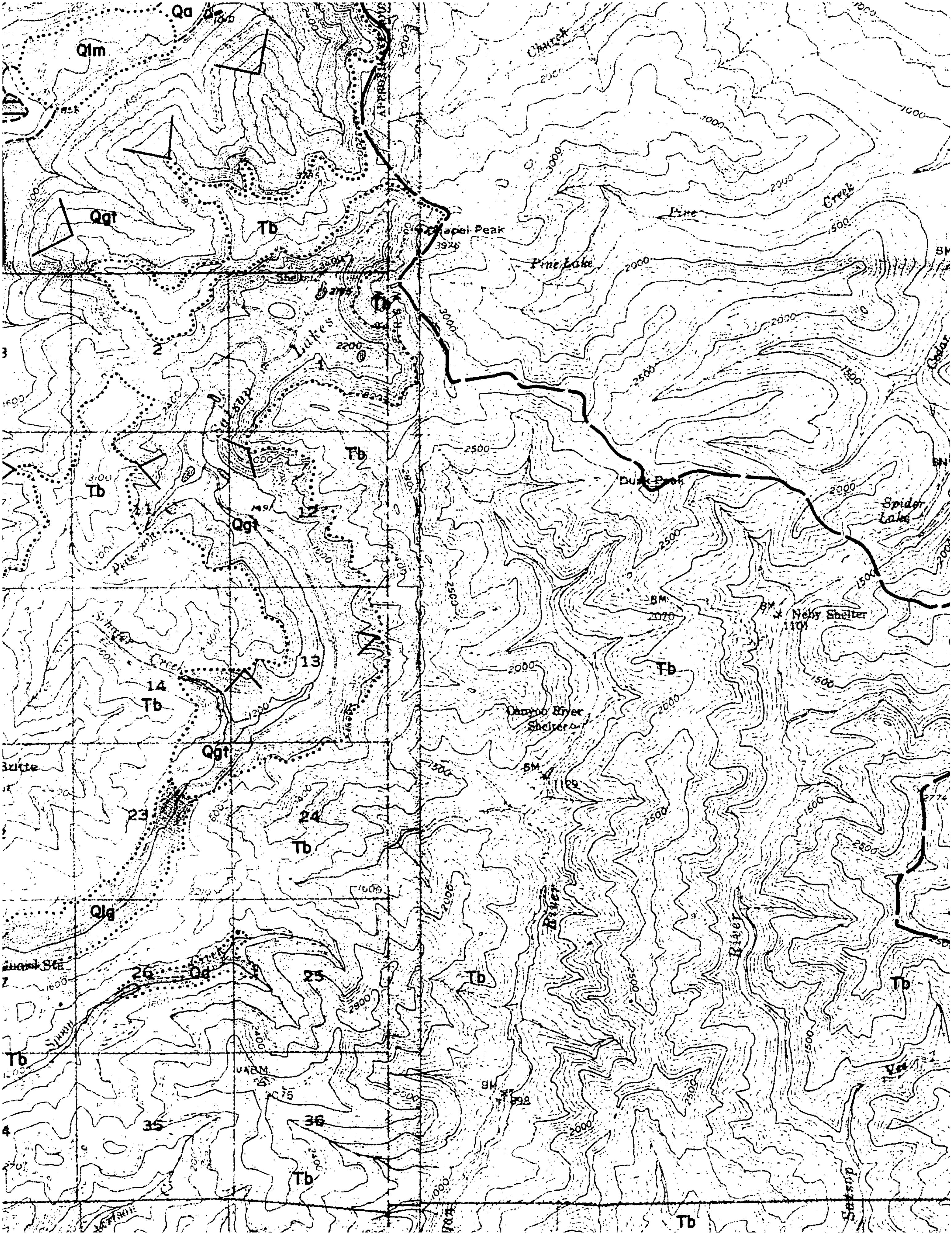
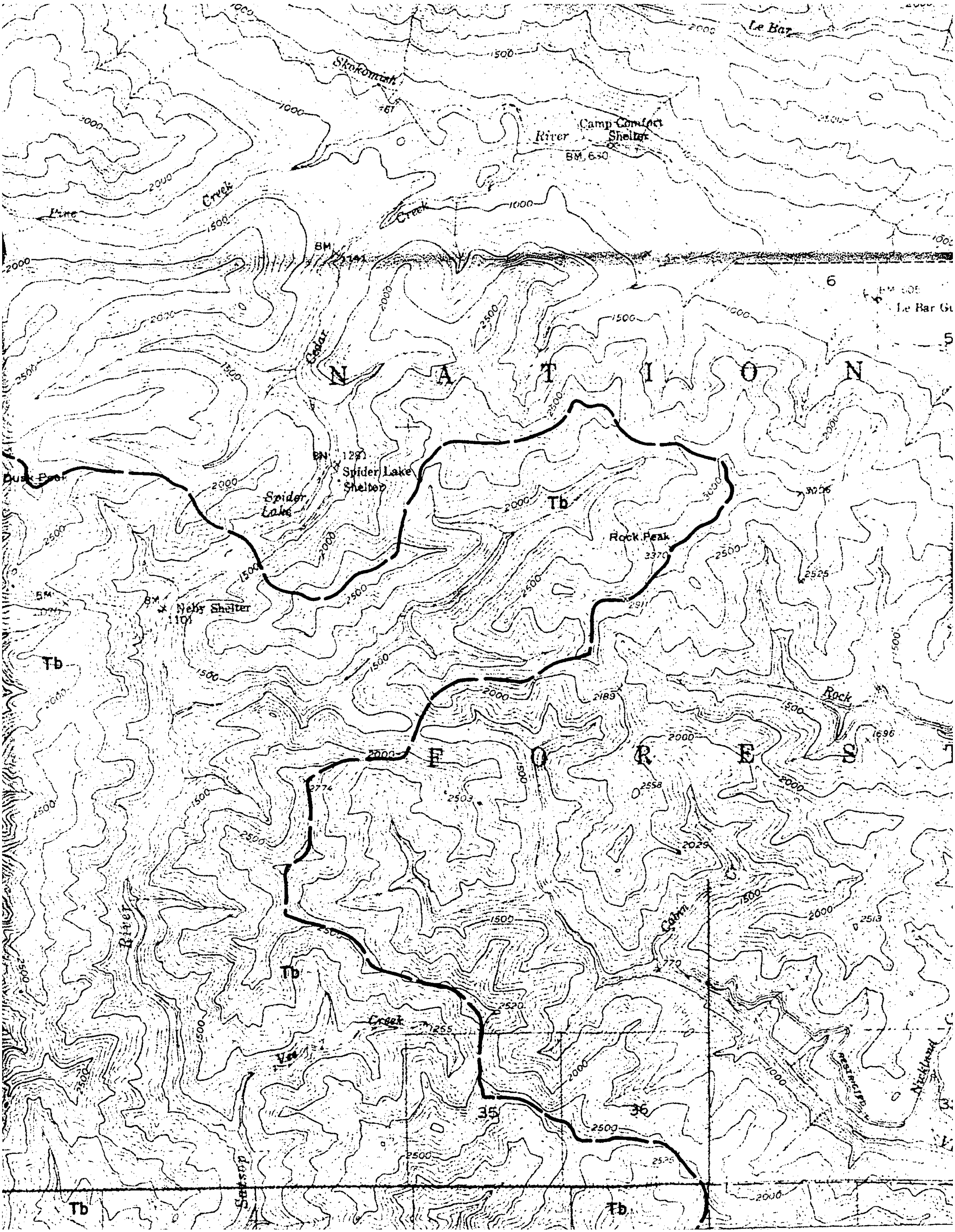
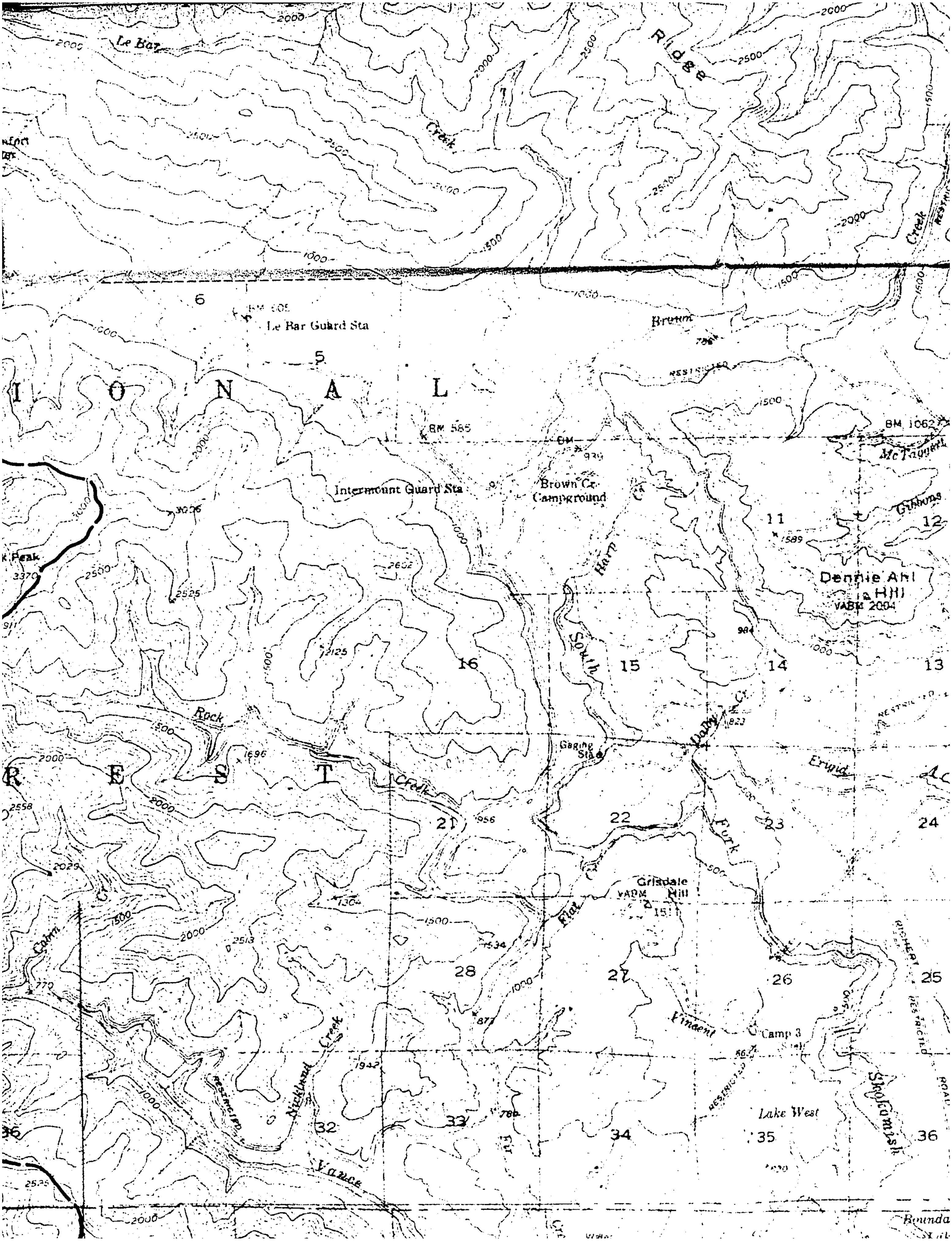
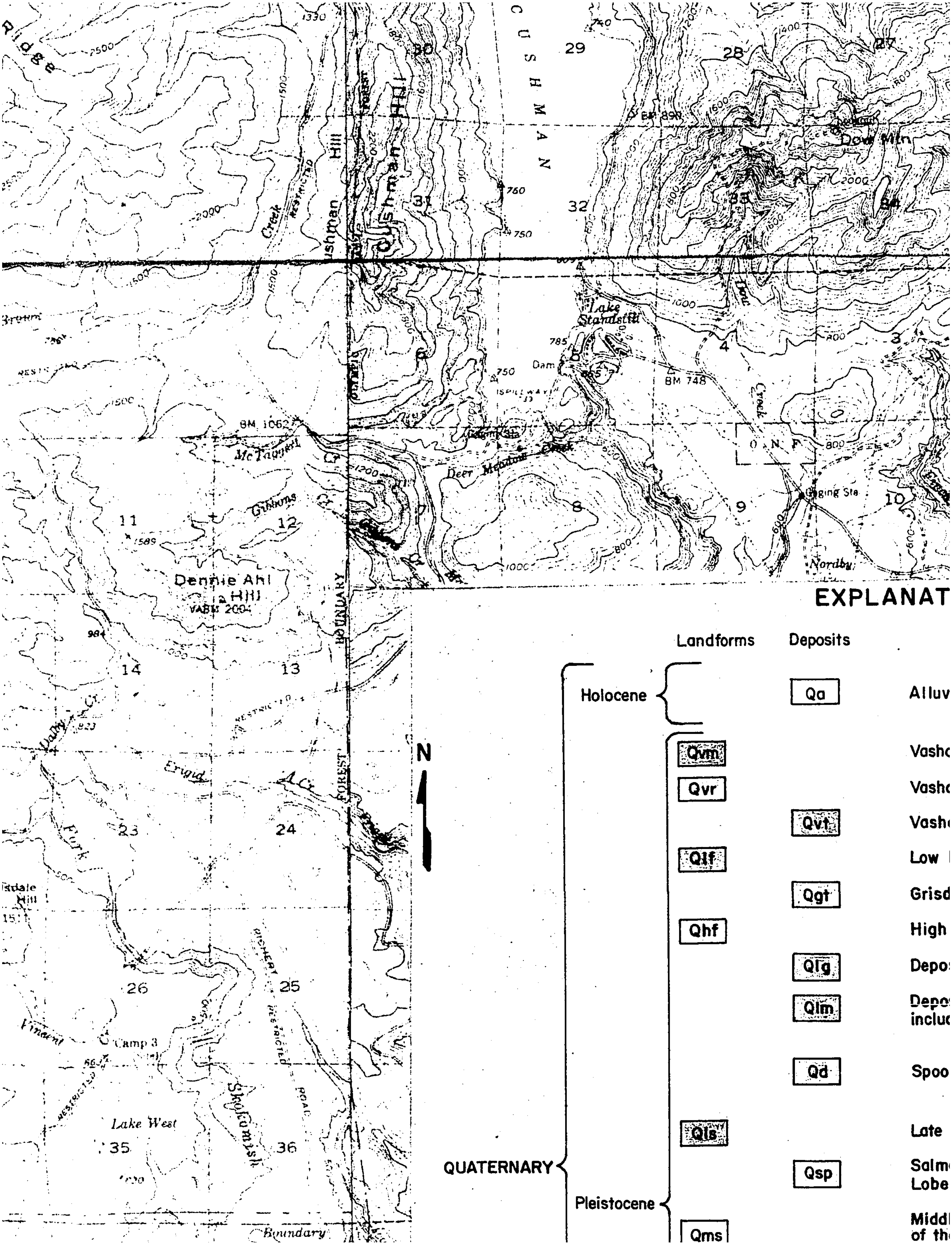

Qa
Qlm
Qgt
Tb
Church
Creek
Pine
Creek
Pine Lake
Lakes
Dusk Peak
Spider
Lake
Neby Shelter
Canyon River
Shelter
River
River
Qlg
Qd
Butte
1
2
11
12
13
14
23
24
25
26
35
36



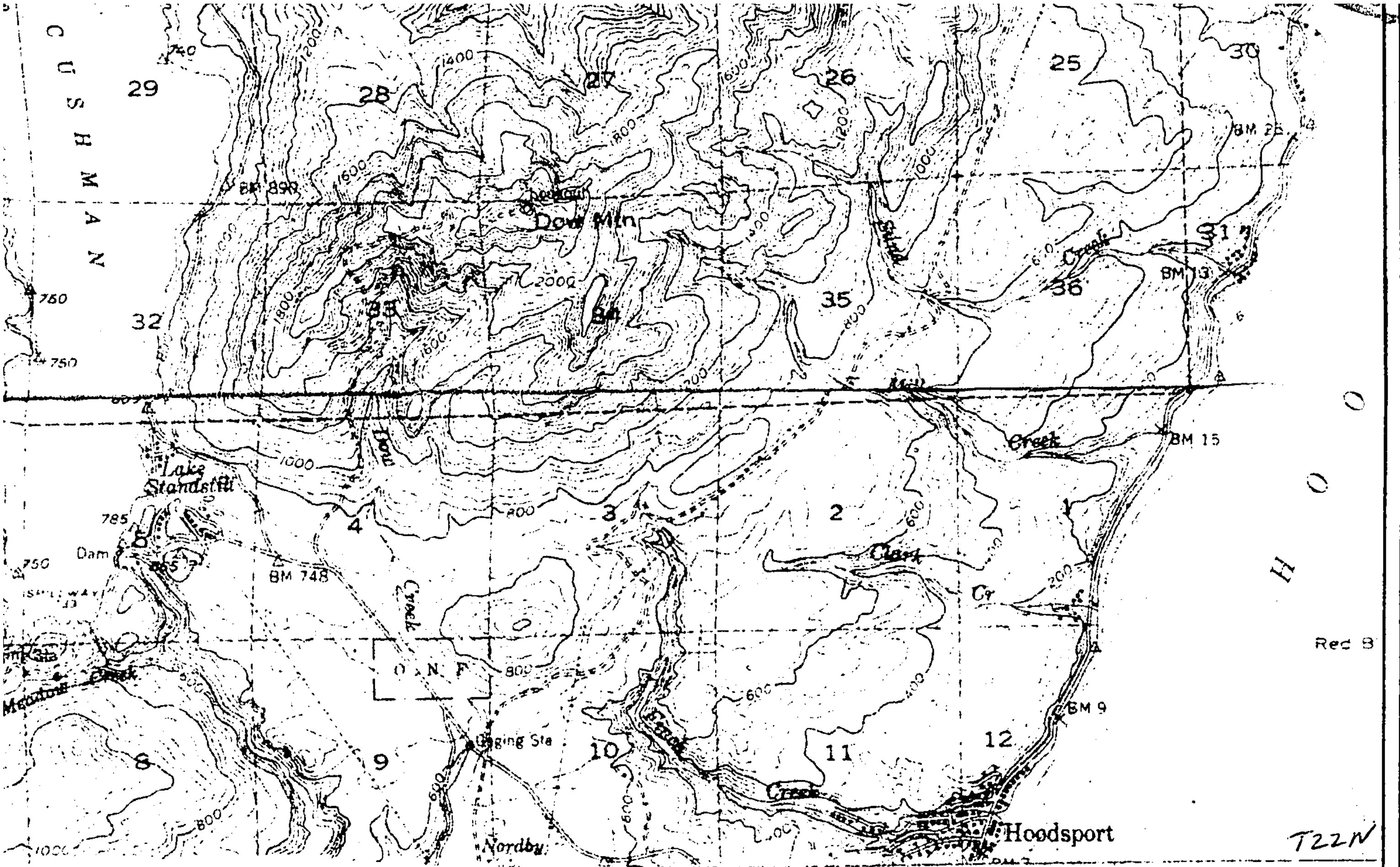
Le Bar
Skokomish
River
Camp Comfort Shelter
BM 650
Pine
Creek
Creek
BM 2141
Cedar
N A T I O N
Spider Lake Shelter
Spider Lake
Tb
Rock Peak
3370
Rock
F O R E S T
River
Creek
35
36



Le Bar
Ridge
Creek
2000
2500
1500
1000
6
5
BM 605
Le Bar Guard Sta
Brown
RESTRICTED
I O N A L
BM 585
BM 939
BM 1062
Intermount Guard Sta
Brown Cr. Campground
Gibbons
11
12
1589
Dennie Ahl Hill
VABM 2004
Peak
3370
3006
2602
2525
2125
Harp
South
Fork
16
15
14
13
984
823
Rock
Creek
1696
Gaging Sta
R E S T
2000
2558
2029
956
21
22
23
24
Grisdale Hill
VABM
1511
Flat
1304
2513
1534
28
27
26
25
770
873
Vincent
Camp 3
Cabin
Nicklund Creek
1942
786
32
33
34
35
36
Lake West
Skokomish
Vance
Fir
2535
Bounda

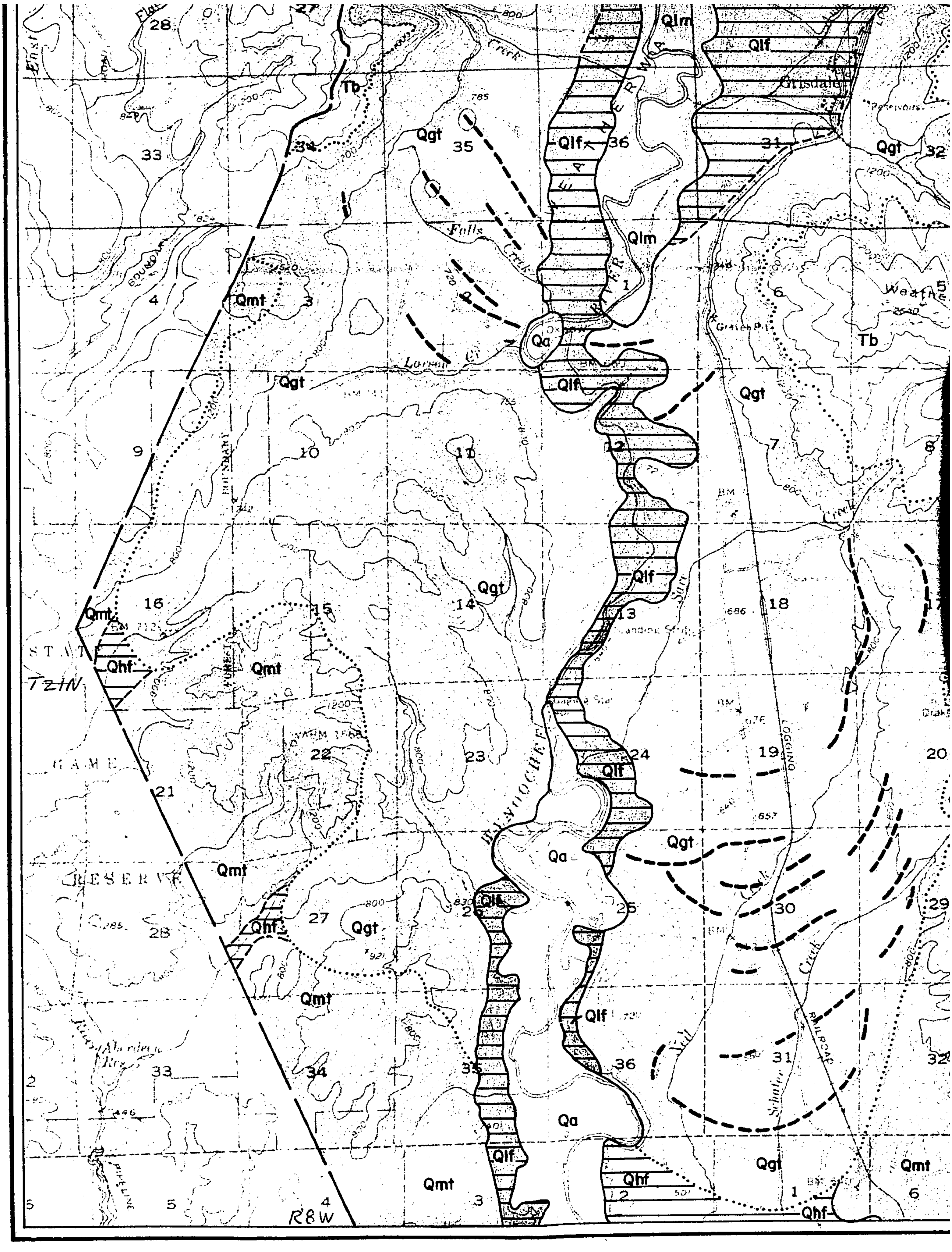


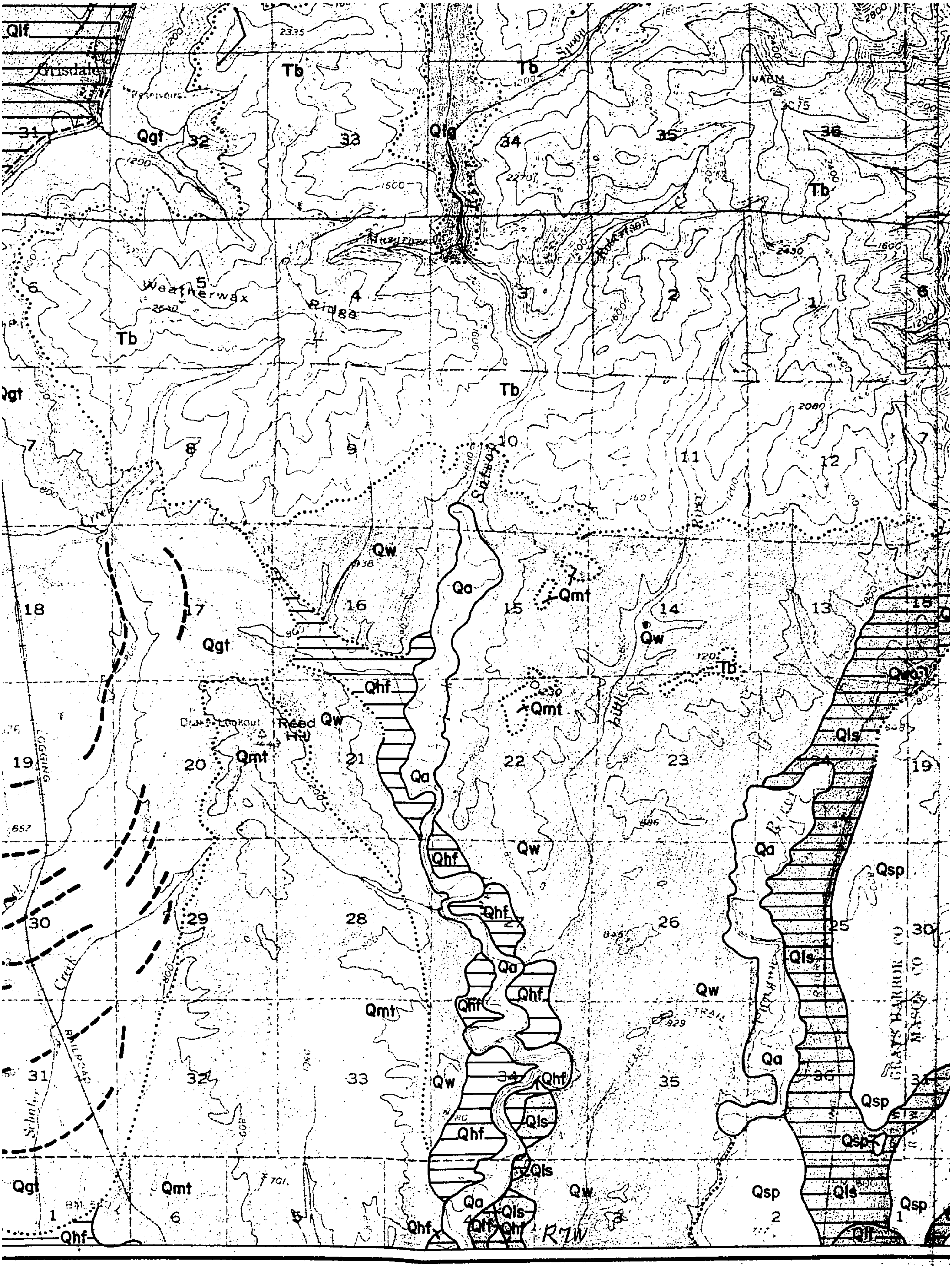
Ridge
CUSHMAN
Cushman Hill
Dow Mtn
BM 890
Lake Standstill
Dam
BM 748
BM 1062
McTaggert Cr
Gibbons Cr
Deer Meadow Creek
O N F
Gaging Sta
Nordby
Dennie Ahl Hill
VABM 2004
FOREST BOUNDARY
Frigid Cr
Fork
Camp 3
Lake West
Skokomish
RESTRICTED ROAD
Boundary
N
EXPLANAT
Landforms
Deposits
QUATERNARY
Holocene
Qa
Alluv
Pleistocene
Qvm
Vasho
Qvr
Vasho
Qvt
Vash
Qlf
Low
Qgt
Grisd
Qhf
High
Qlg
Depo
Qlm
Depo
incluc
Qd
Spoo
Qls
Late
Qsp
Salm
Lobe
Qms
Middl
of th



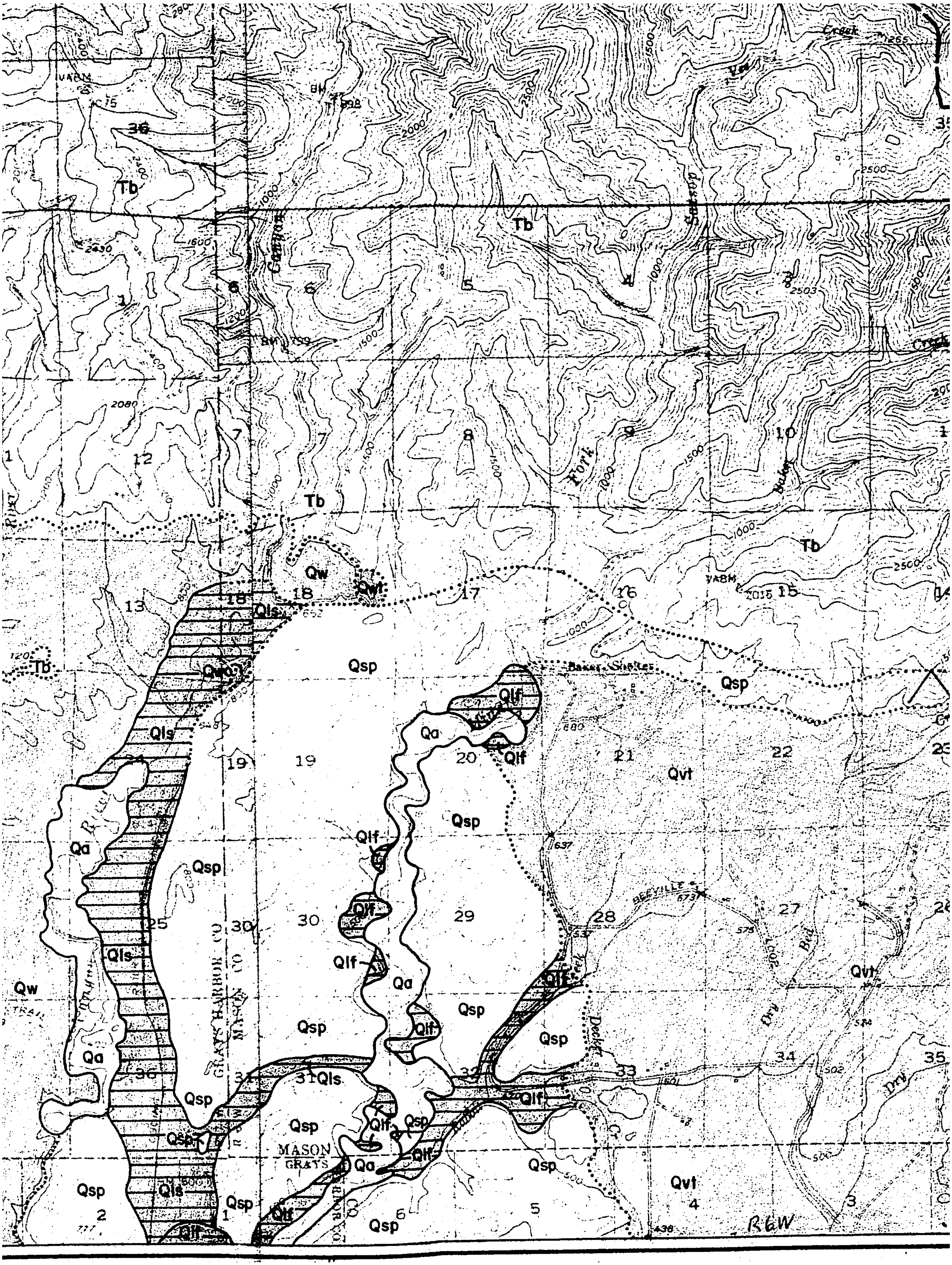
EXPLANATION

		Landforms	Deposits	
QUATERNARY	Holocene		Qa	Alluvium
	Pleistocene	Qvm		Vashon morainal topography
		Qvr		Vashon recessional meltwater channels
			Qvt	Vashon till and undifferentiated drift
		Qlf		Low Fraser terraces, outwash plains, and meltwater channels
			Qgt	Grisdale till and undifferentiated drift
		Qhf		High Fraser terraces
			Qlg	Deposits of lakes dammed up by Grisdale ice
			Qlm	Deposits of lakes dammed up by moraines (mostly Grisdale); includes some Holocene alluvium
			Qd	Spoon Creek diamicton
		Qls		Late Salmon Springs terraces and meltwater channels
			Qsp	Salmon Springs till and undifferentiated drift of the Puget Lobe; includes much bedrock
		Qms		Middle Salmon Springs terraces (associated with the maximum of the Puget Lobe)

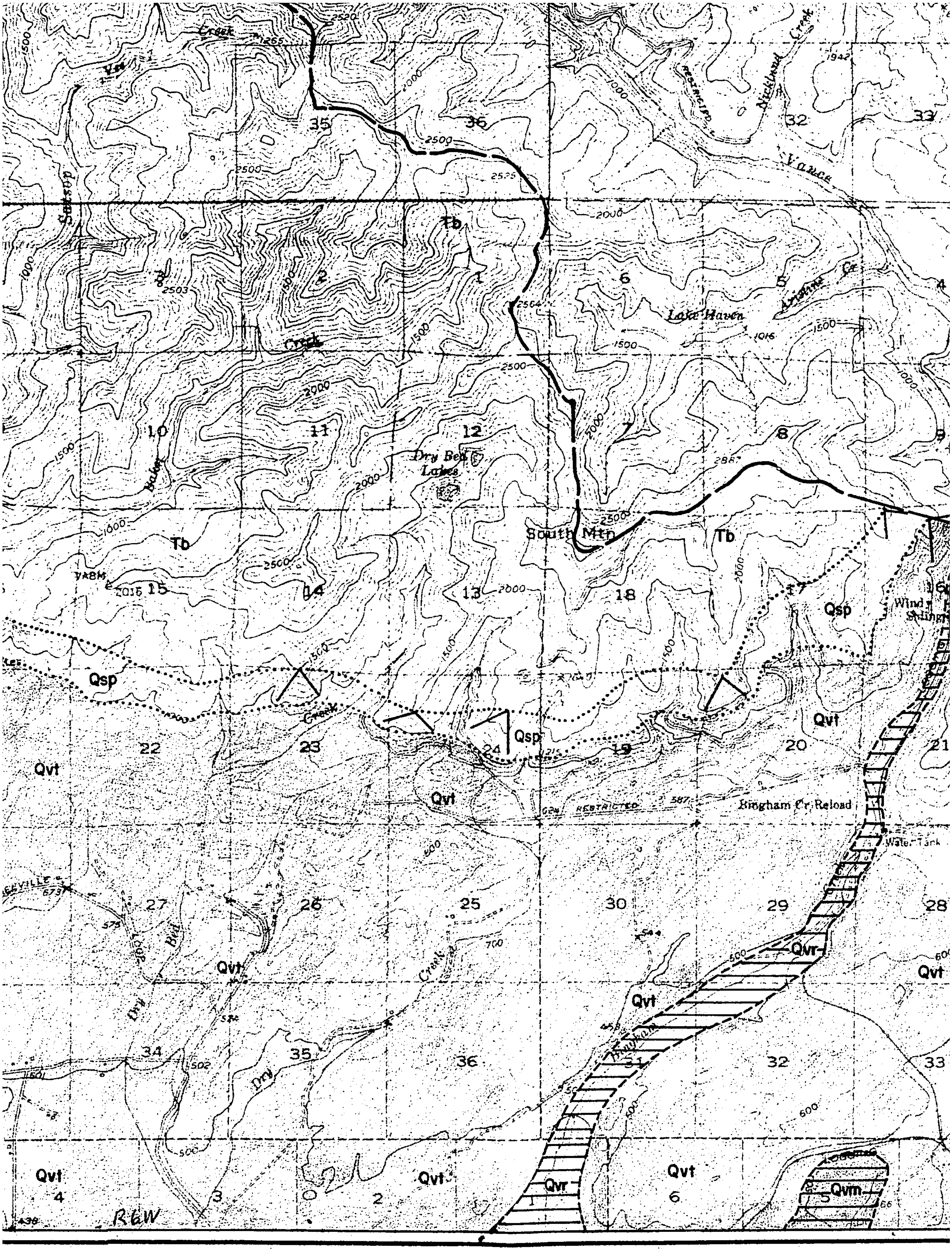

Qlm
Qlf
Tb
Grisdale
Qgt
Falls Creek
Qmt
Qa
Larson Cr
Weathe
Qhf
T21N
STATE
GAME
RESERVE
WYNOOCHEE
Satsop
Schafer Creek
Vail
LOGGING
RAILROAD
R8W



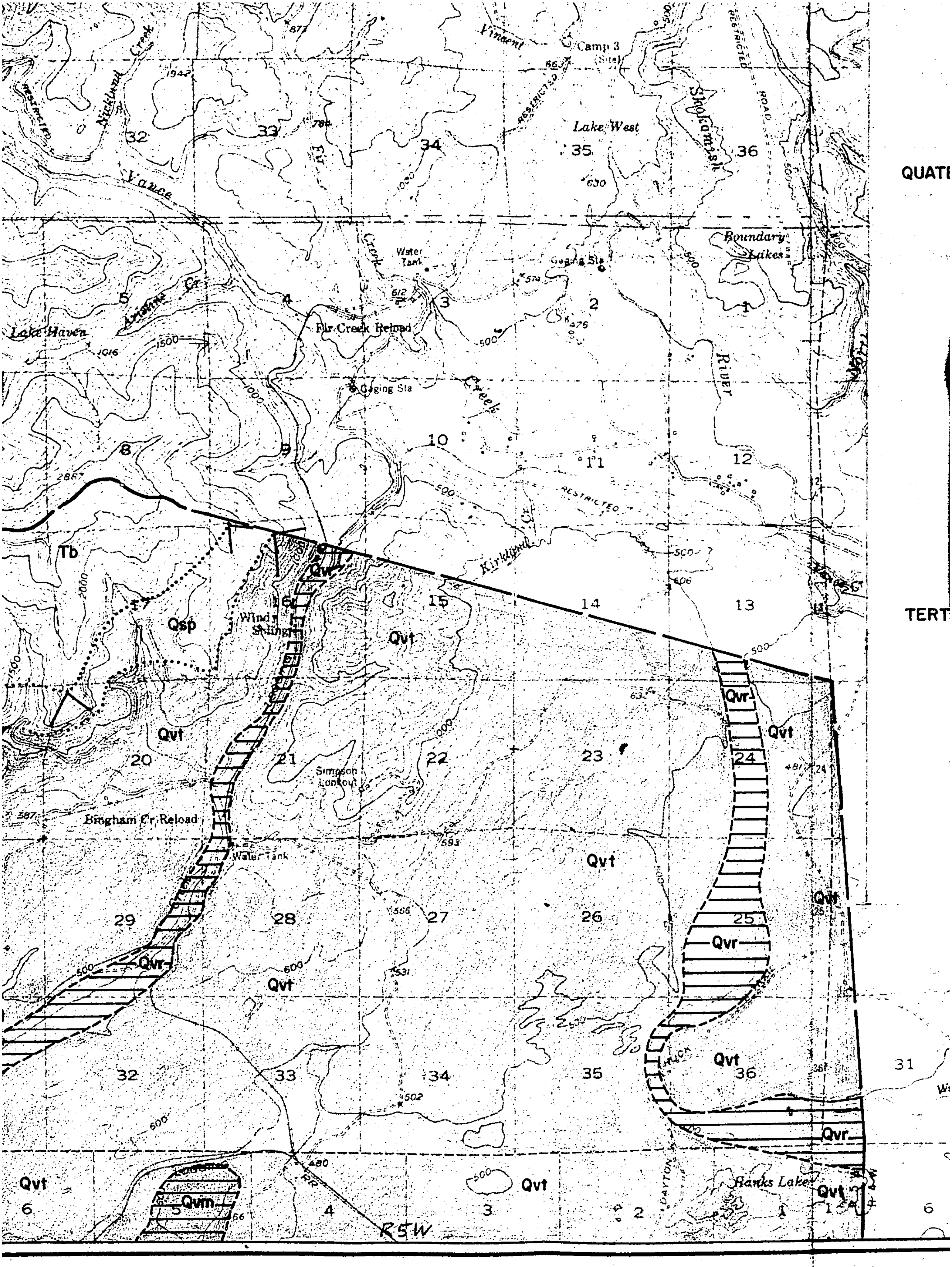
Qlf
Grisdale
Tb
Qgt
Qls
Weatherwax
Ridge
Musgrove Cr.
Satsop
Qw
Qa
Qmt
Qhf
Drake Lookout
Reed Hill
River
Little
Qsp
Schafer
Creek
LOGGING
RAILROAD
TRAIL
GRAYS HARBOR CO
MASON CO
R7W



Tb
Qw
Qwt
Qls
Qsp
Qlf
Qa
Qvt
GRAYS HARBOR CO
MASON CO
MASON
GRAYS
Baker Shelter
Fork
Creek
Dry
R6W



Creek
35
36
32
33
Vance
Tb
2
1
6
5
4
Lake Haven
Creek
10
11
12
7
8
9
Dry Bed Lakes
South Mtn
Tb
Tb
15
14
13
18
17
16
Qsp
Qsp
Qsp
Qvt
22
23
24
19
20
21
Qvt
Qvt
Bingham Cr Reload
Water Tank
27
26
25
30
29
28
Qvr
Qvt
Qvt
Qvt
34
35
36
31
32
33
Qvt
Qvt
Qvt
Qvr
Qvm
4
3
2
1
6
5
R6W



QUATI
TERT
Vincent
Camp 3
Lake West
Vance
Nicklund Creek
Fir
Creek
Boundary Lakes
Water Tank
Gaging Sta
Fir Creek Reload
Lake Haven
River
Kirkland
RESTRICTED
Windy Stingier
Tb
Qsp
Qvr
Qvt
Qvm
Simpson Lookout
Bingham Cr Reload
Water Tank
Hanks Lake
R5W
32
33
34
35
36
5
4
3
2
1
8
9
10
11
12
17
16
15
14
13
20
21
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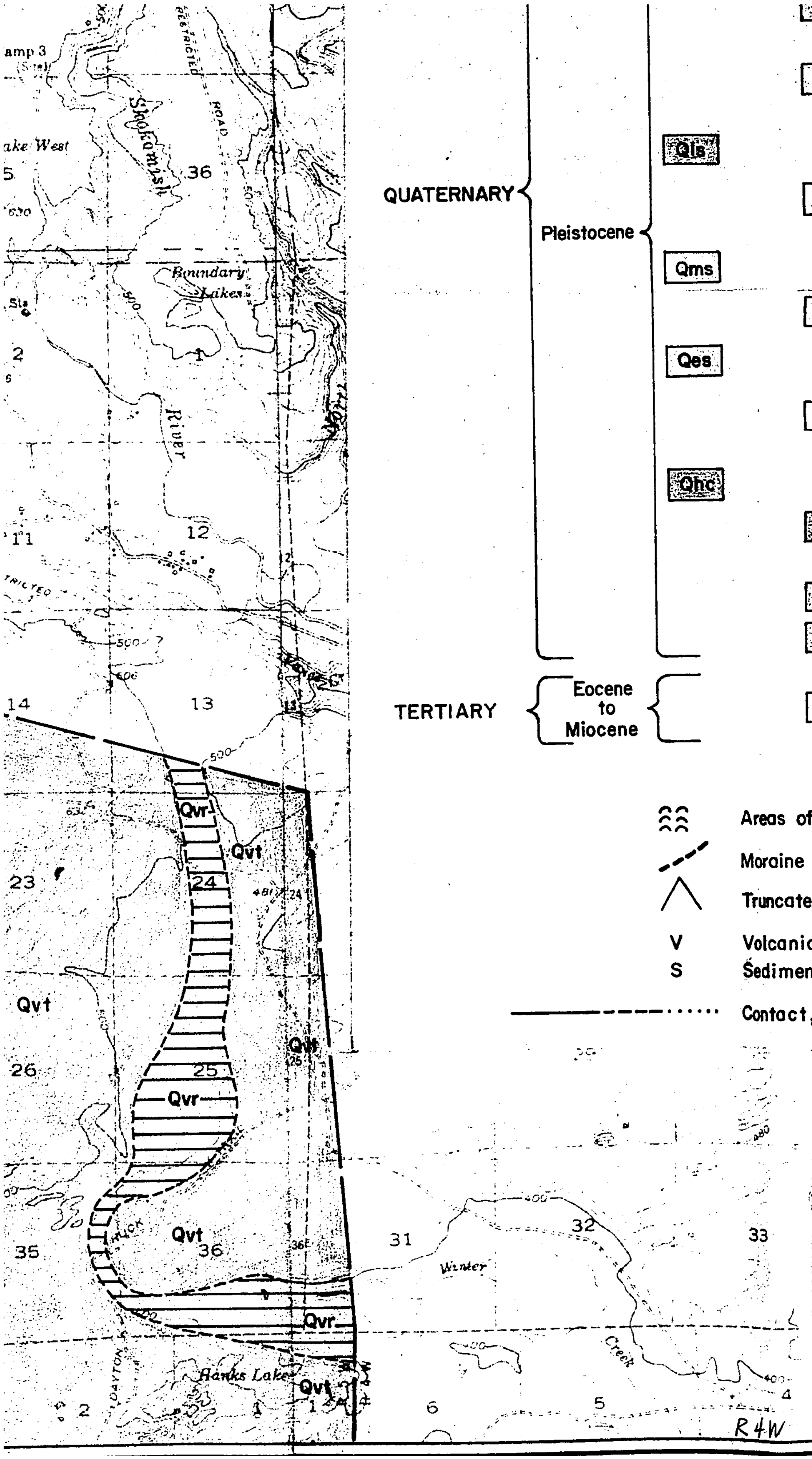


QUATERNARY	Pleistocene		Qdh	includes some Hol
			Qd	Spoon Creek diar
		Qls		Late Salmon Spri
			Qsp	Salmon Springs Lobe; includes n
		Qms		Middle Salmon S of the Puget Lob
			Qmt	Mobray till and u
		Qes		Early Salmon Spr of Mobray ice)
			Qw	Weatherwax For
		Qhc		Helm Creek terr
			Qht	Helm Creek (?) t
			Qwo	Wedekind Creek
			Qwt	Wedekind Creek
TERTIARY	Eocene to Miocene		Tb	Bedrock

Areas of Ford mounds on Vashon terrace

Moraine crests of the Wynoochee glacie

Truncated spur (top of chevron at apex

V Volcanic rock } outcrops in driftles
S Sedimentary rock

Contact, dashed where approximate, do

Plate I. SURFICI
SOUTH-CE

Drafted

Base from

			Qlm	Deposits of lakes dammed up by moraines (mostly Grisdale); includes some Holocene alluvium
			Qd	Spoon Creek diamicton
		Qls		Late Salmon Springs terraces and meltwater channels
[QUATE]RNARY	Pleistocene		Qsp	Salmon Springs till and undifferentiated drift of the Puget Lobe; includes much bedrock
		Qms		Middle Salmon Springs terraces (associated with the maximum of the Puget Lobe)
			Qmt	Mobray till and undifferentiated drift
		Qes		Early Salmon Springs terraces (associated with the maximum of Mobray ice)
			Qw	Weatherwax Formation (deposits of Glacial Lake Weatherwax)
		Qhc		Helm Creek terraces
			Qht	Helm Creek (?) till
			Qwo	Wedekind Creek outwash (?)
			Qwt	Wedekind Creek (?) till
[TERT]IARY	Eocene to Miocene		Tb	Bedrock

Areas of Ford mounds on Vashon terraces

Moraine crests of the Wynoochee glacier

Truncated spur (top of chevron at apex of spur)

V Volcanic rock
S Sedimentary rock
} outcrops in driftless areas south of the Olympic Mountains

Contact, dashed where approximate, dotted where indefinite or inferred

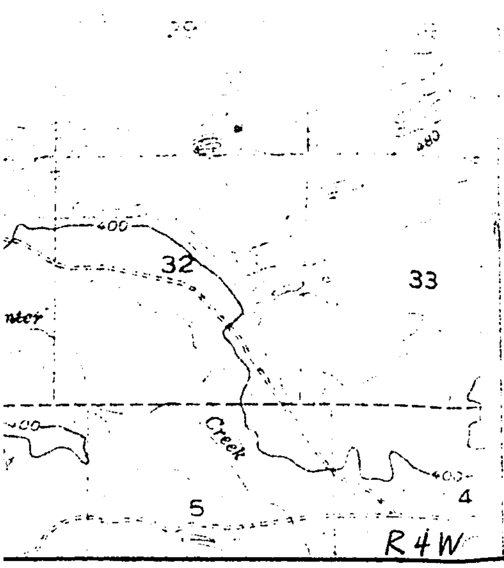


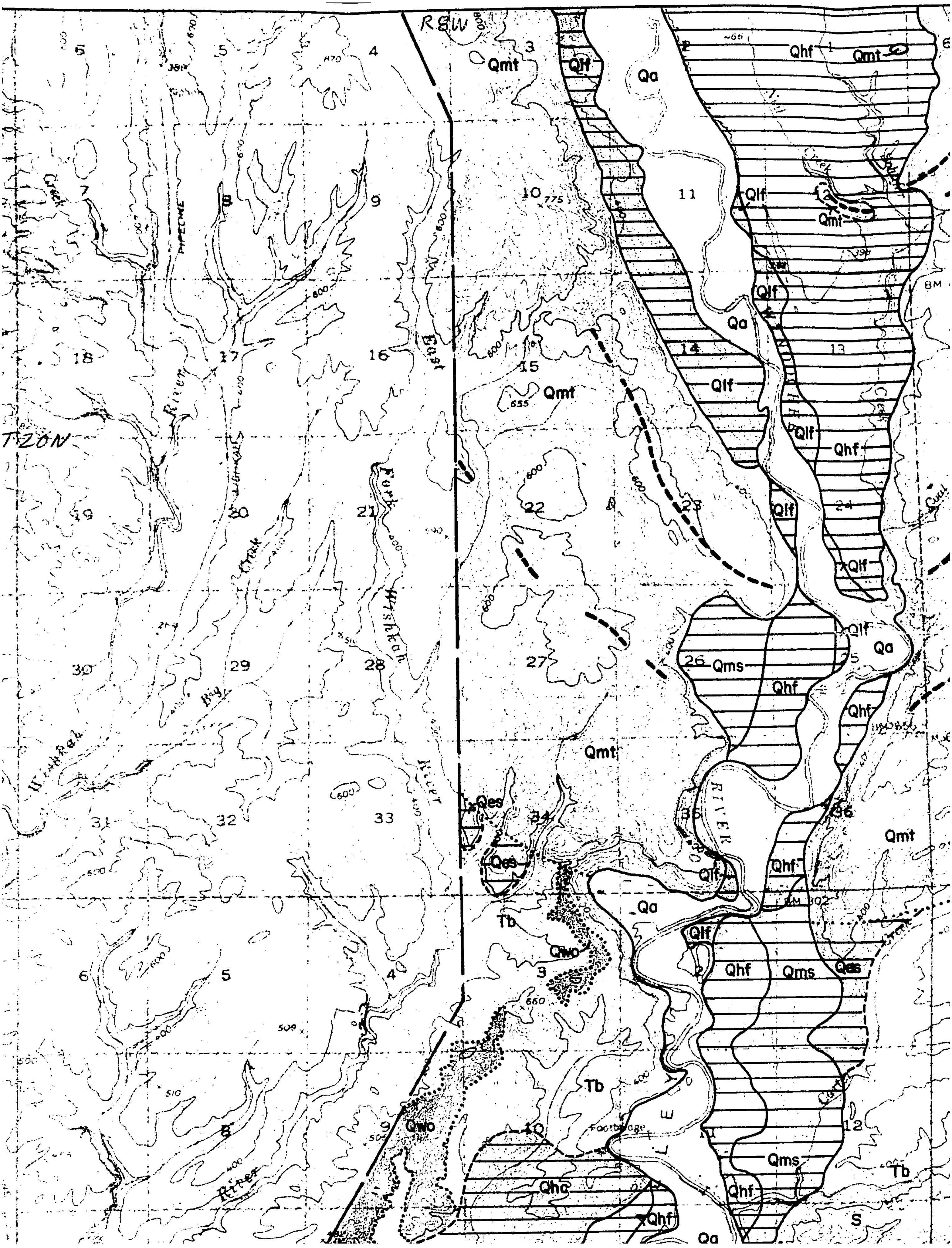
Plate I. SURFICIAL GEOLOGY OF THE SOUTH-CENTRAL OLYMPIC PENINSULA, WASHINGTON (northern portion)

SCALE 1:48,000

R. J. CARSON 1970

Drafted by J.C. MILHOLLIN, Cartographer

Base from U.S. Geological Survey topographical maps


R6W
Qmt
Qlf
Qa
Qhf
Qms
Qes
Qwo
Qhc
Tb
East Fork Wishkah River
Big Creek
Wishkah River
RIVER
Footbridge
BM 302
TZON
1
3
4
5
6
7
9
10
11
13
14
15
16
17
18
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23
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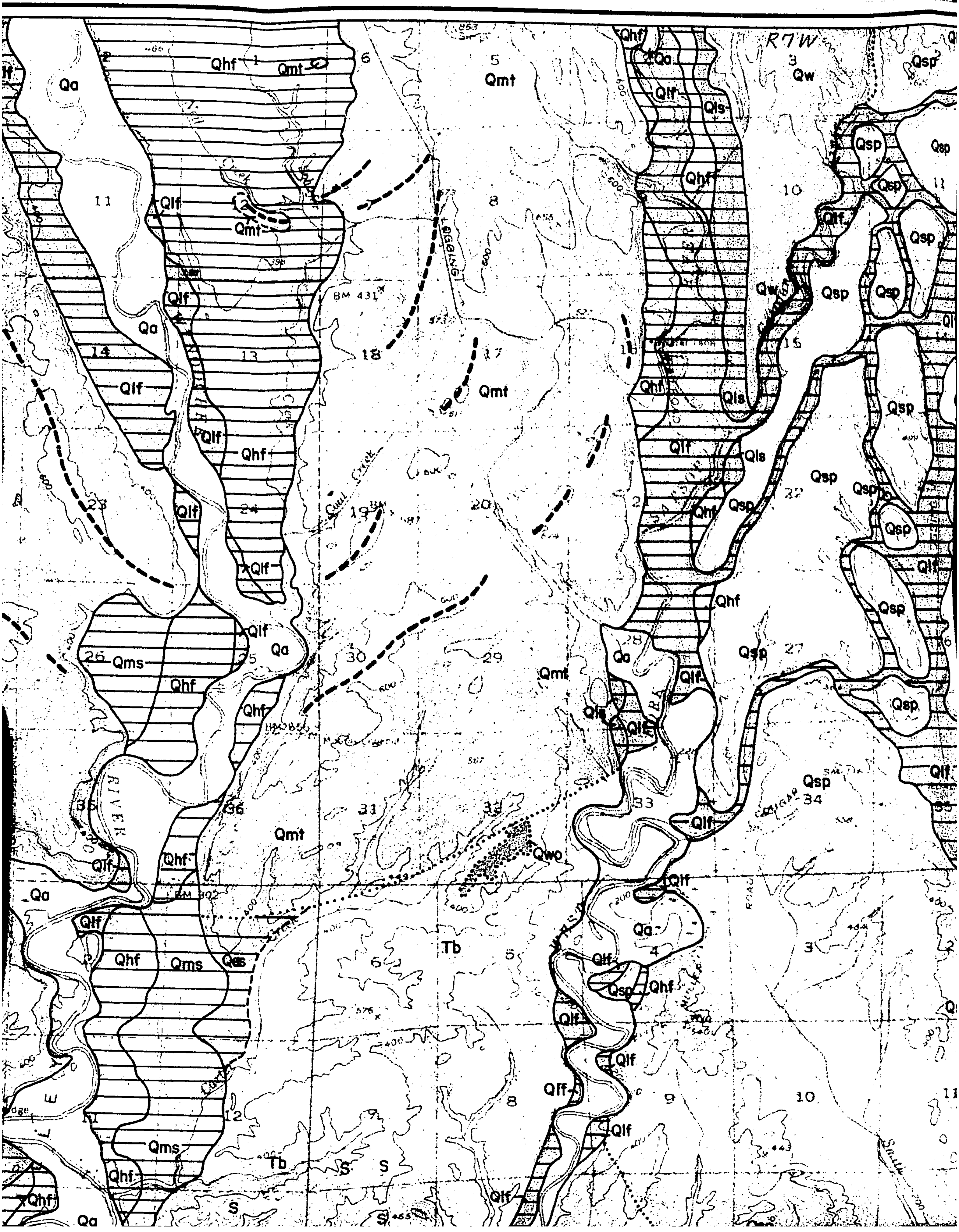
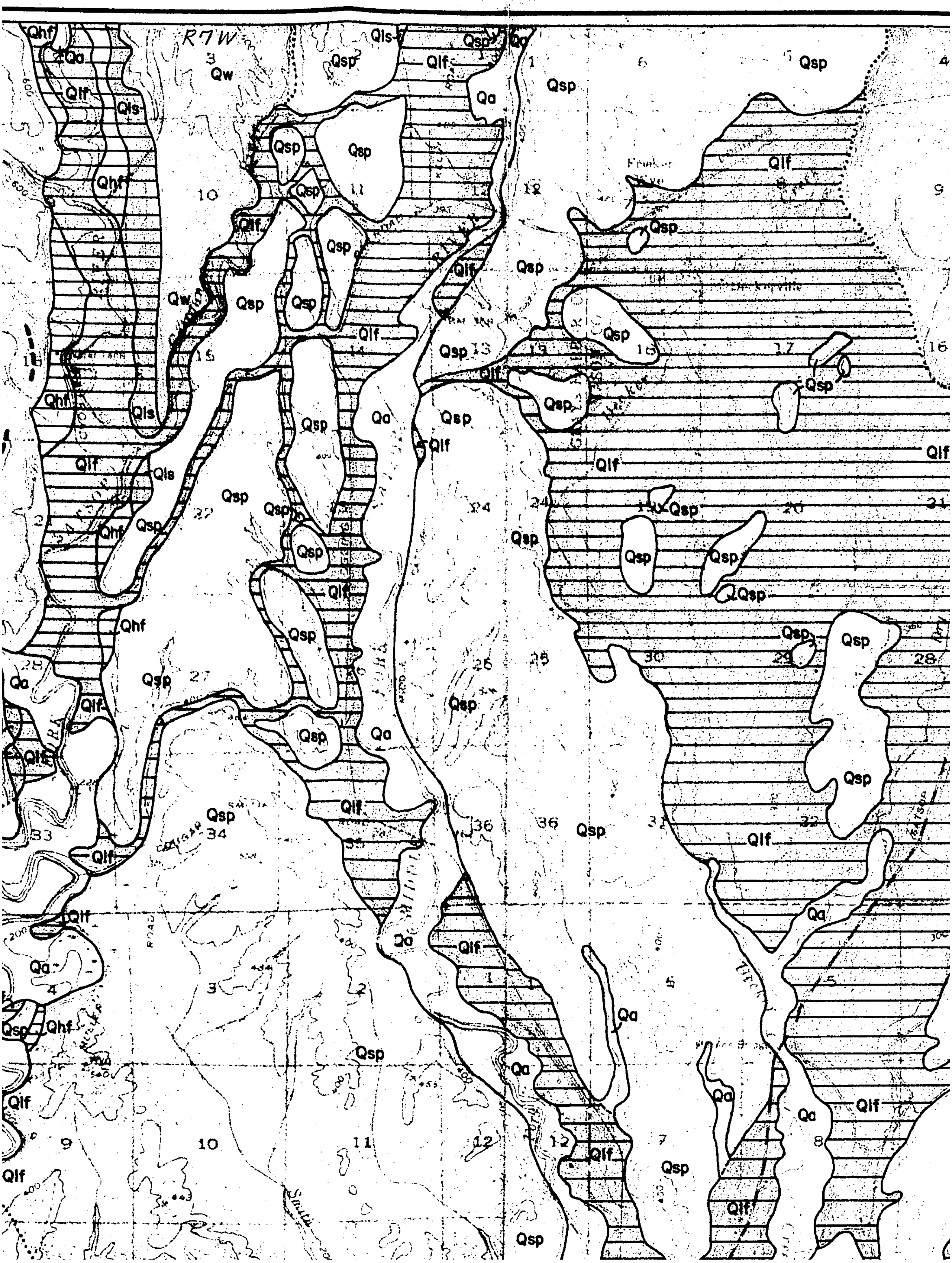
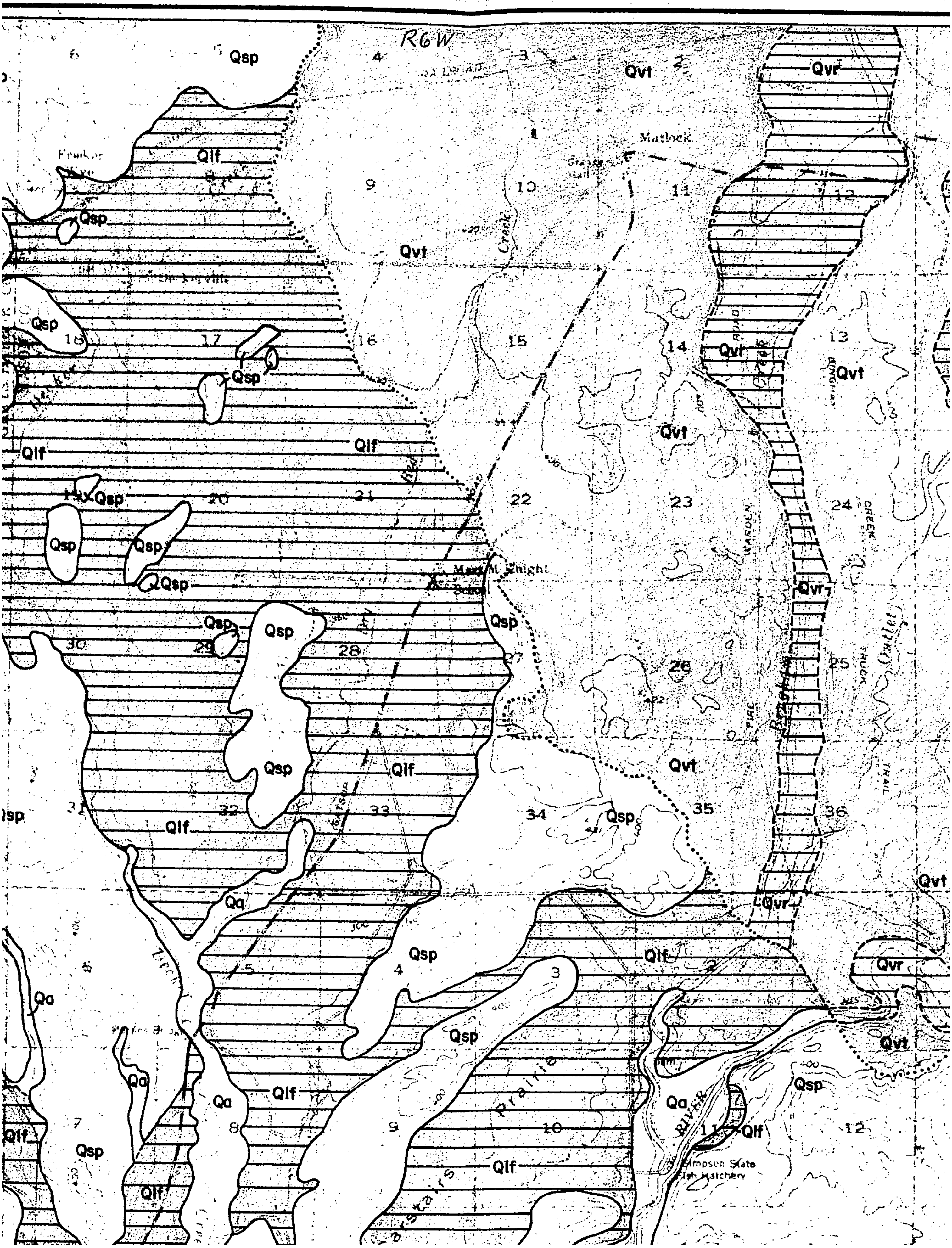
34
35
36
12
S

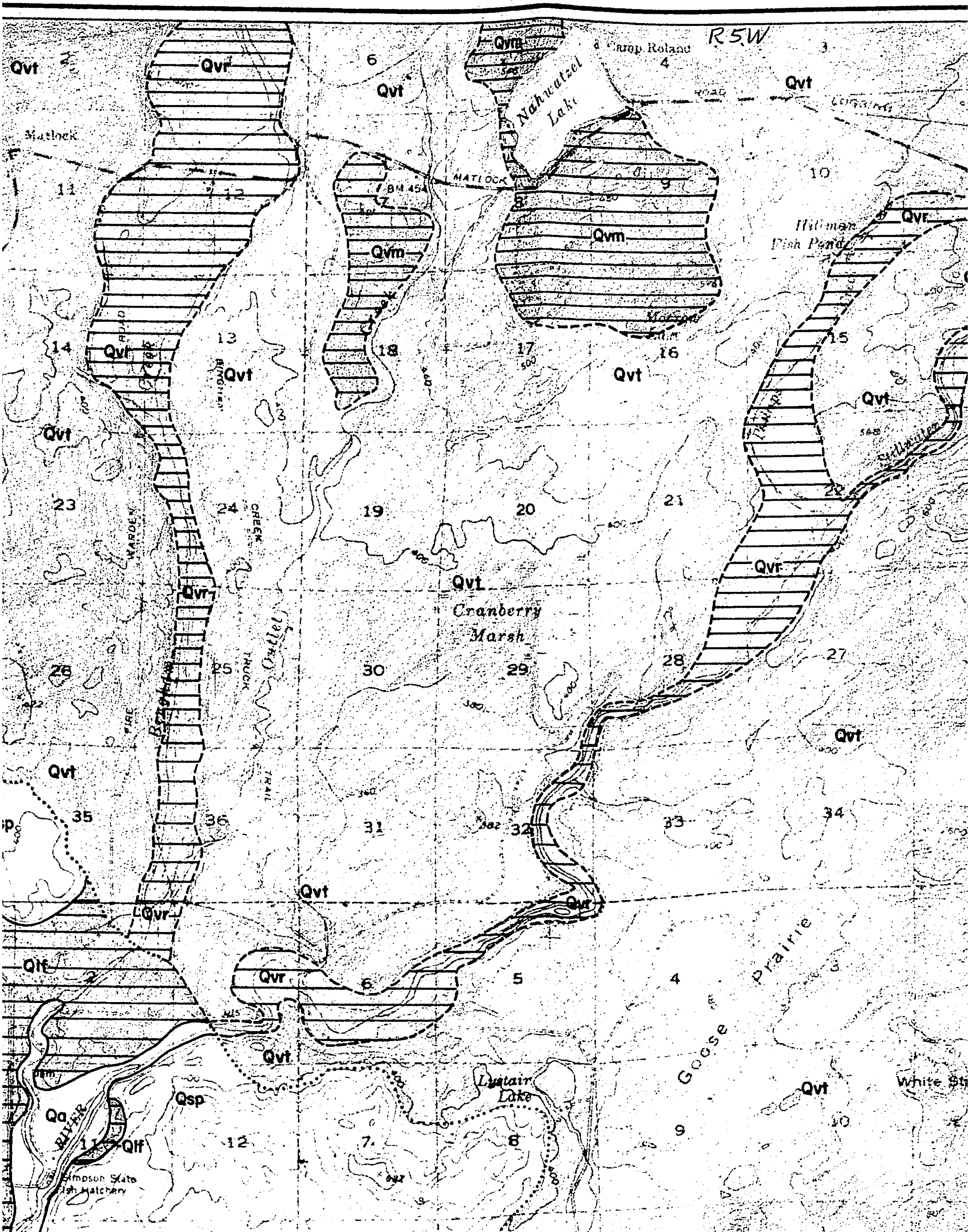

R7W
Qa
Qhf
Qlf
Qmt
Qms
Qls
Qw
Qsp
Qwo
Tb
BM 431
BM 302
RIVER
LOGGING
ROAD



R7W
Qhf
Qa
Qlf
Qls
Qw
Qsp
Qo



R6W
Qsp
Qvt
Qvr
Qlf
Qa
Matlock
Creek
Mary M. Knight School
FIRE
WARDEN
ROAD
CREEK
TRUCK
TRAIL
Outlet
RIVER
Prairie
Simpson State Fish Hatchery


R5W
Camp Roland
Nahwatzel Lake
Matlock
MATLOCK
BM 454
LOGGING ROAD
Hillman Fish Pond
Cranberry Marsh
Goose Prairie
Lystair Lake
RIVER
Simpson State Fish Hatchery
White St
Qvt
Qvr
Qvm
Qlf
Qa
Qsp
11
12
13
14
15
16
17
18
19
20
21
23
24
25
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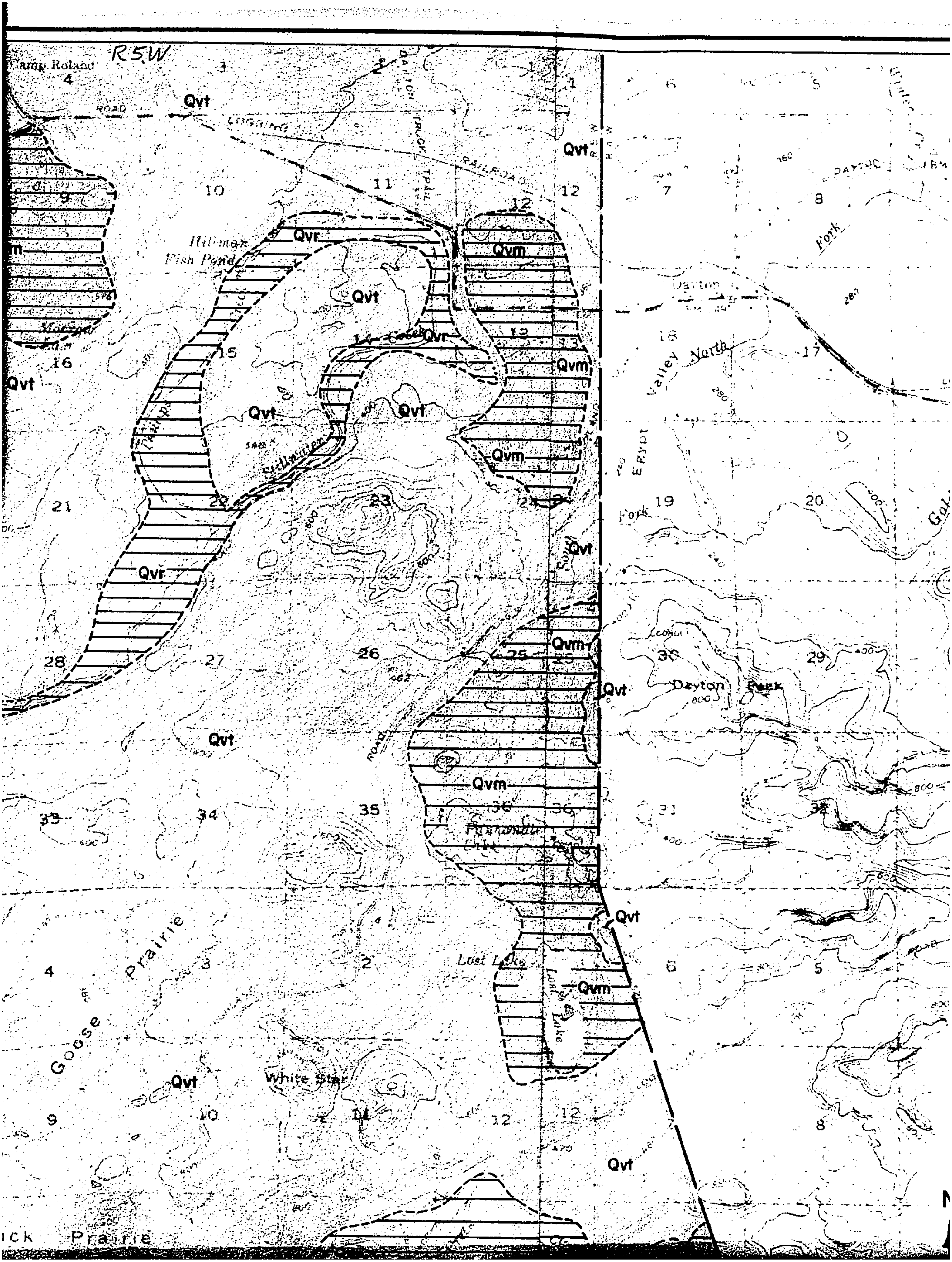
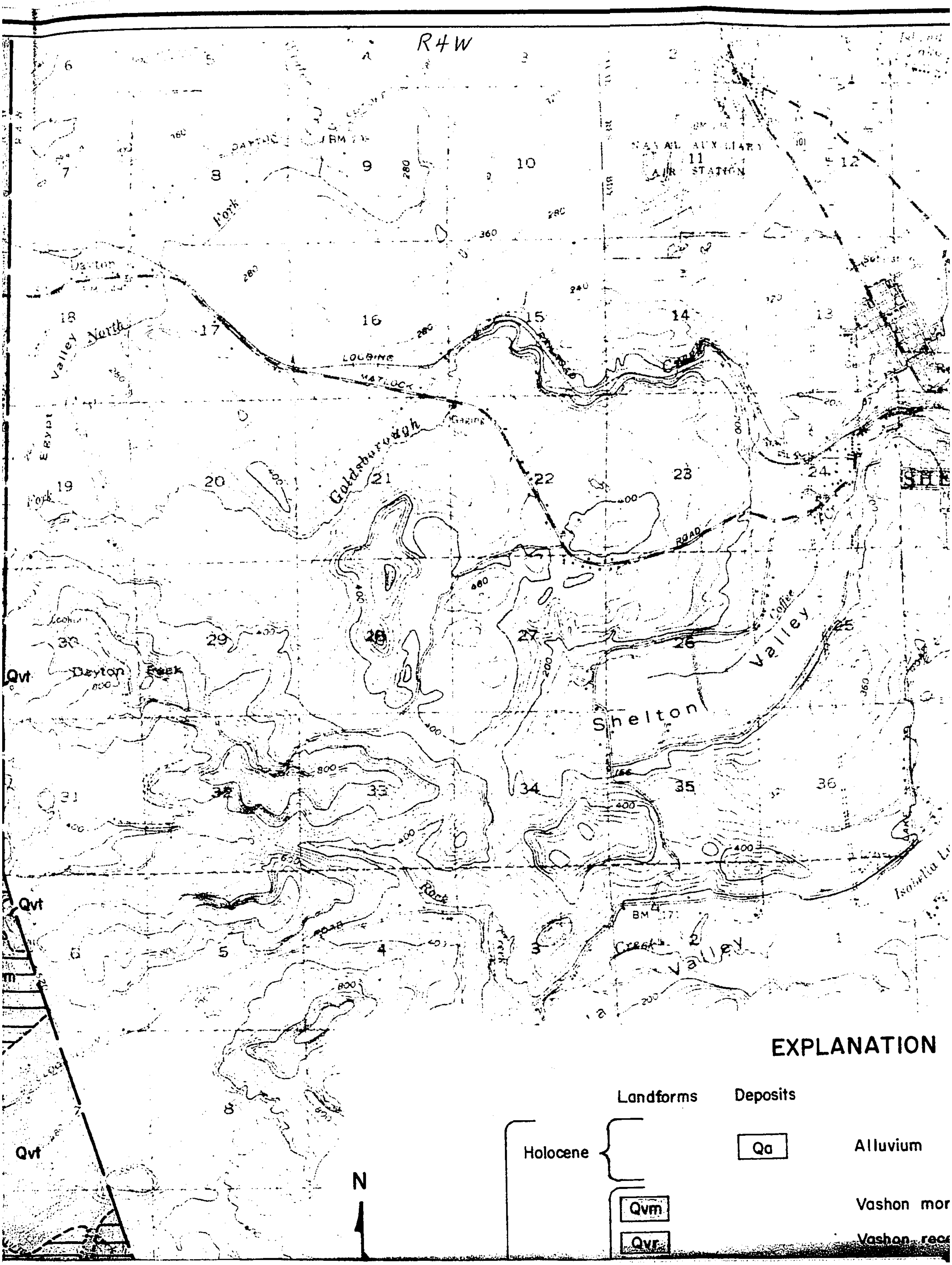
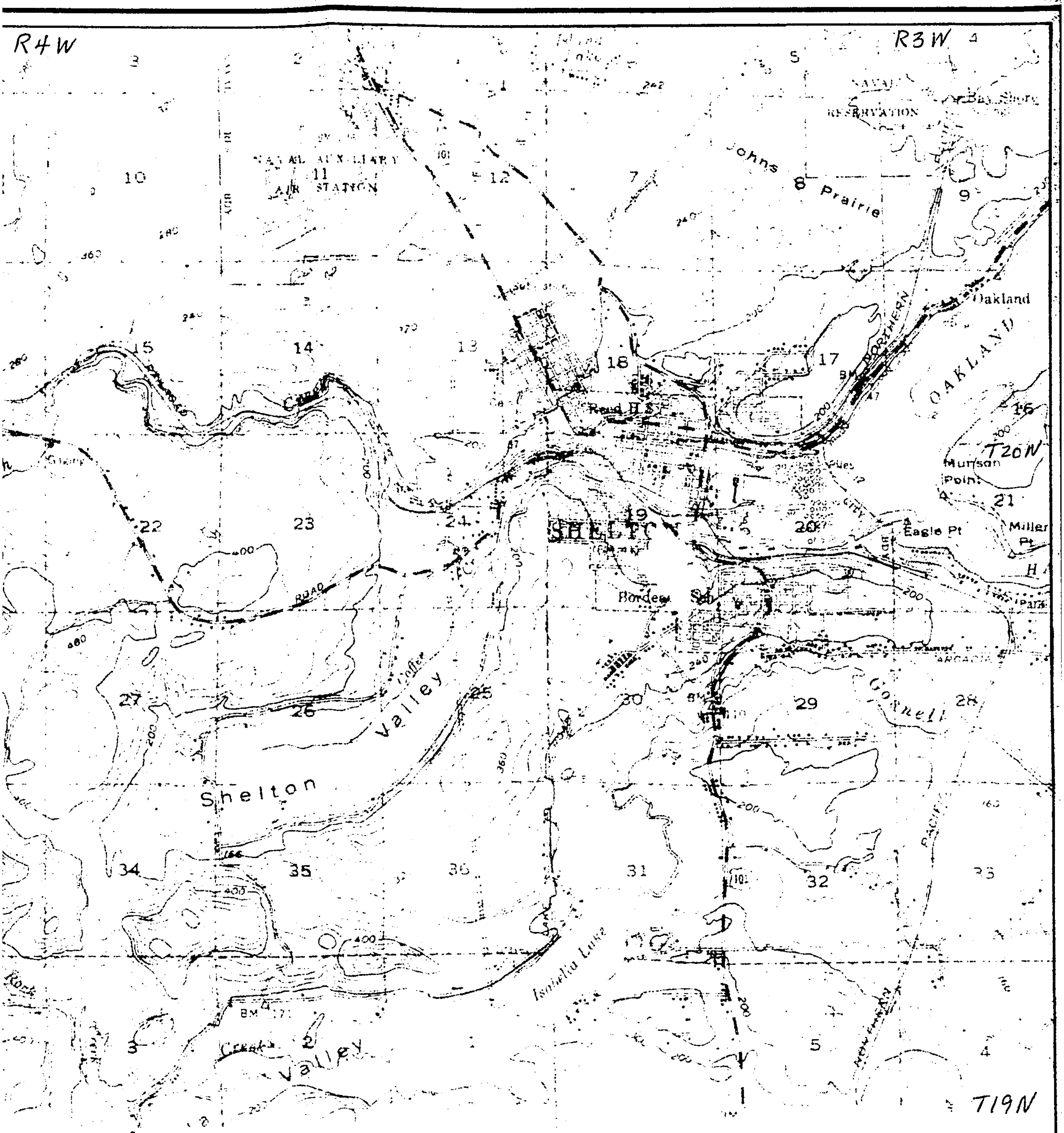
8
7
5
2
1



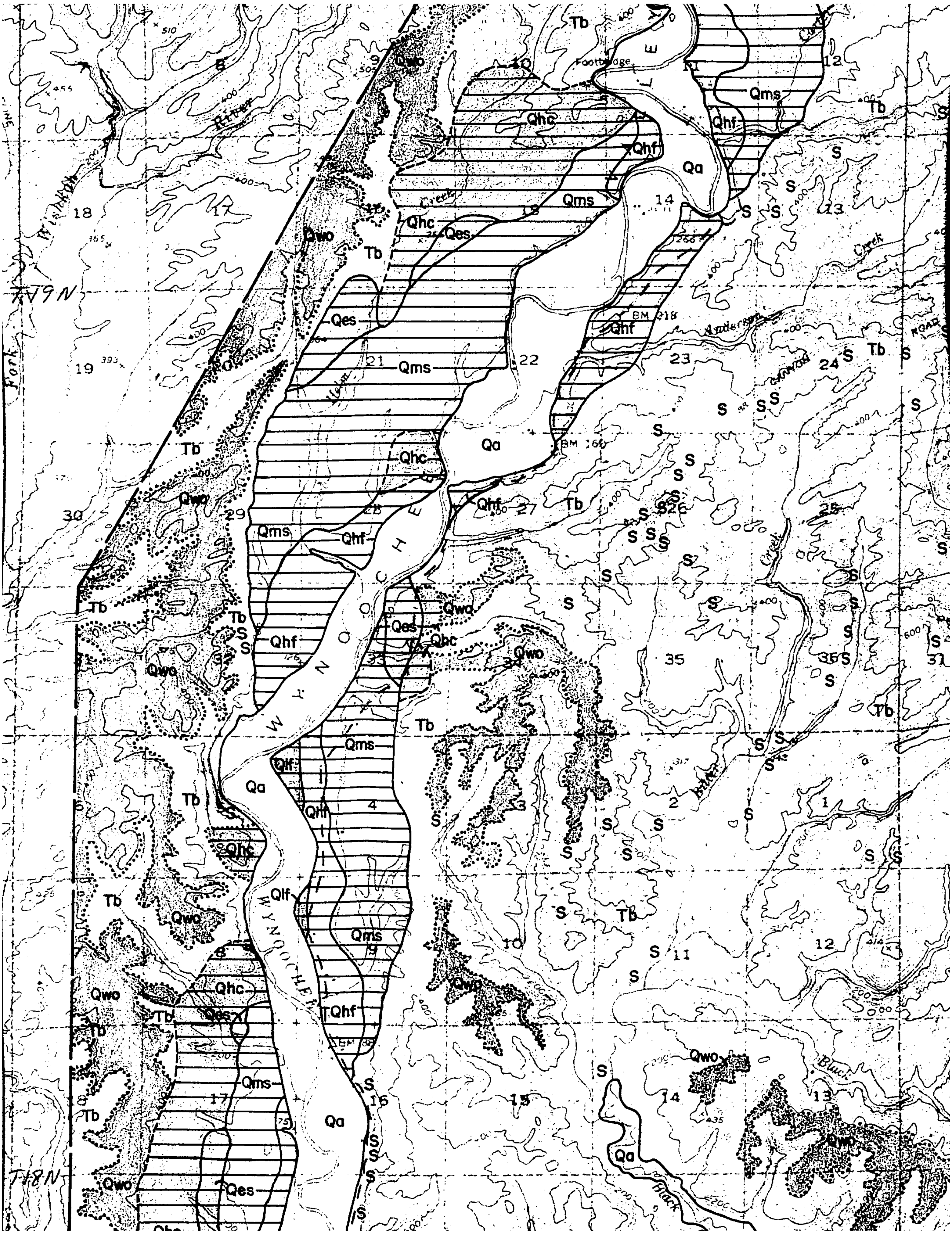
R5W
Camp Roland
LOGGING
RAILROAD
ROAD
TRUCK TRAIL
Qvt
Qvr
Qvm
Hillman Fish Pond
Dayton
Valley North Fork
Egypt
South
Fork
Dayton Peak
Lost Lake
Goose Prairie
White Star
Prairie


R4W
NAVAL AUXILIARY
AIR STATION
Dayton
Valley North
Fork
Goldsborough
Coffee
Valley
Shelton
Dayton Creek
Rock
Creek
Valley
Isabella
ROAD
Qvt
EXPLANATION
Landforms
Deposits
Holocene
Qa
Alluvium
Qvm
Vashon mor
Qvr
Vashon rece
N

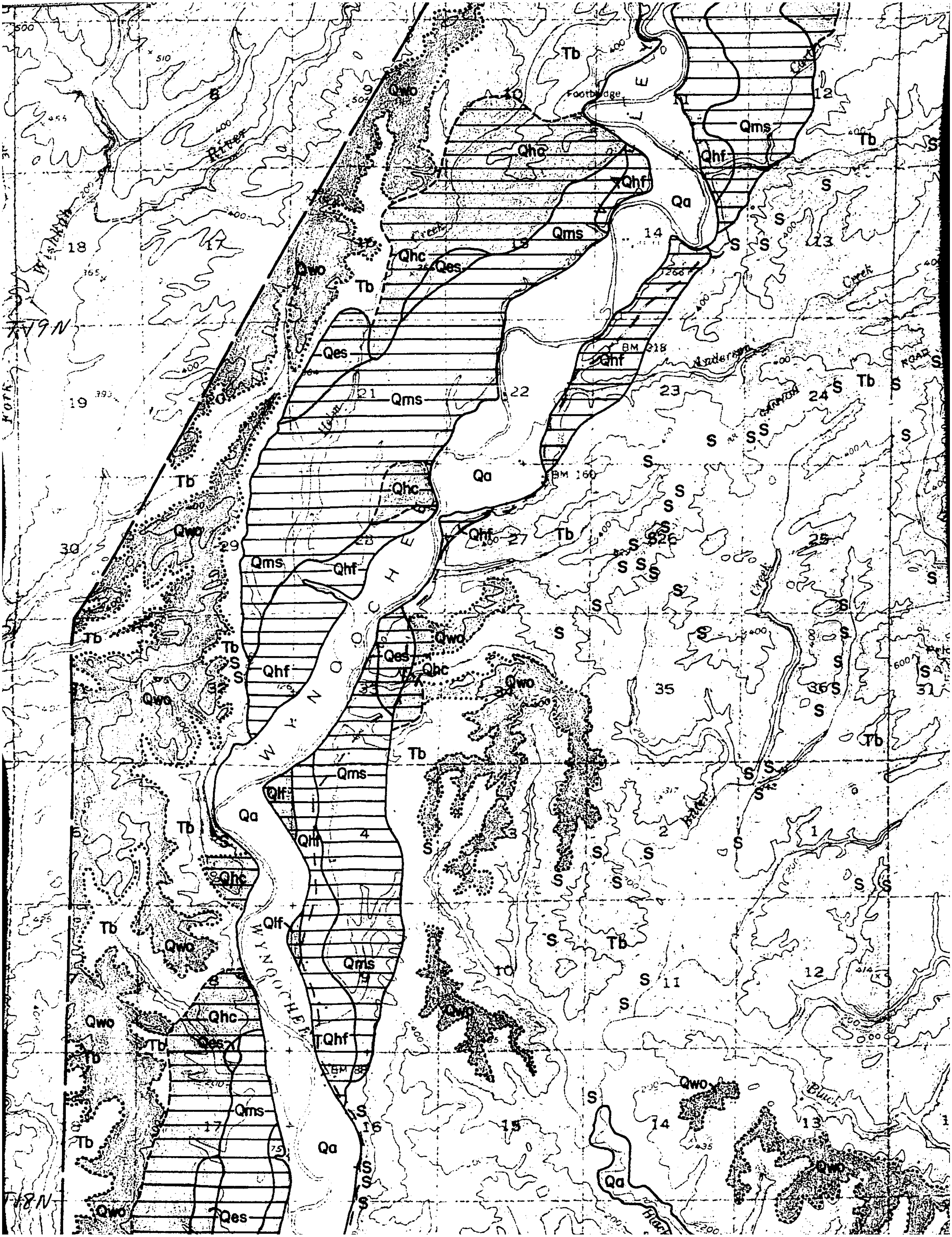


EXPLANATION

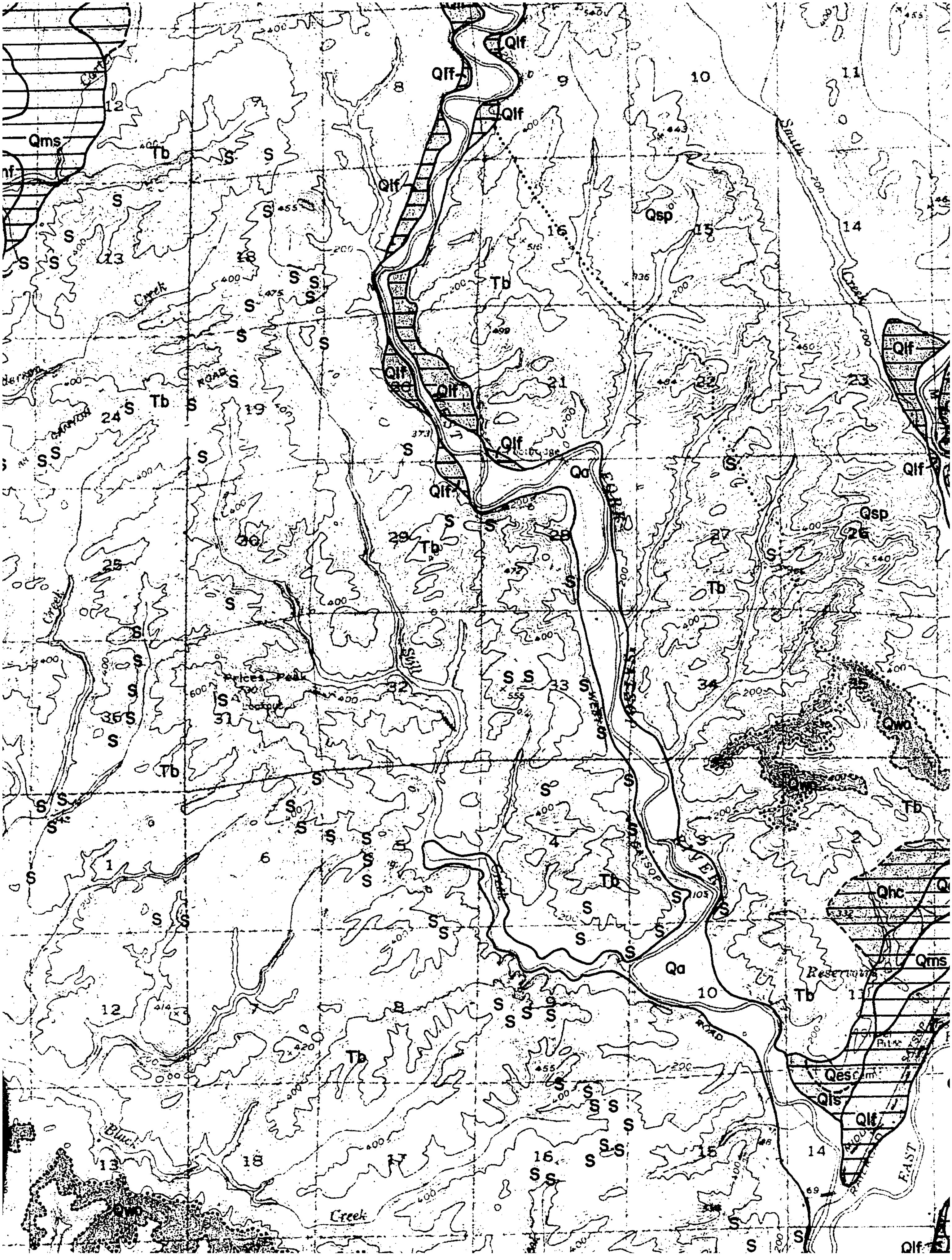
	Landforms	Deposits	
Holocene		Qa	Alluvium
	Qvm		Vashon morainal topography



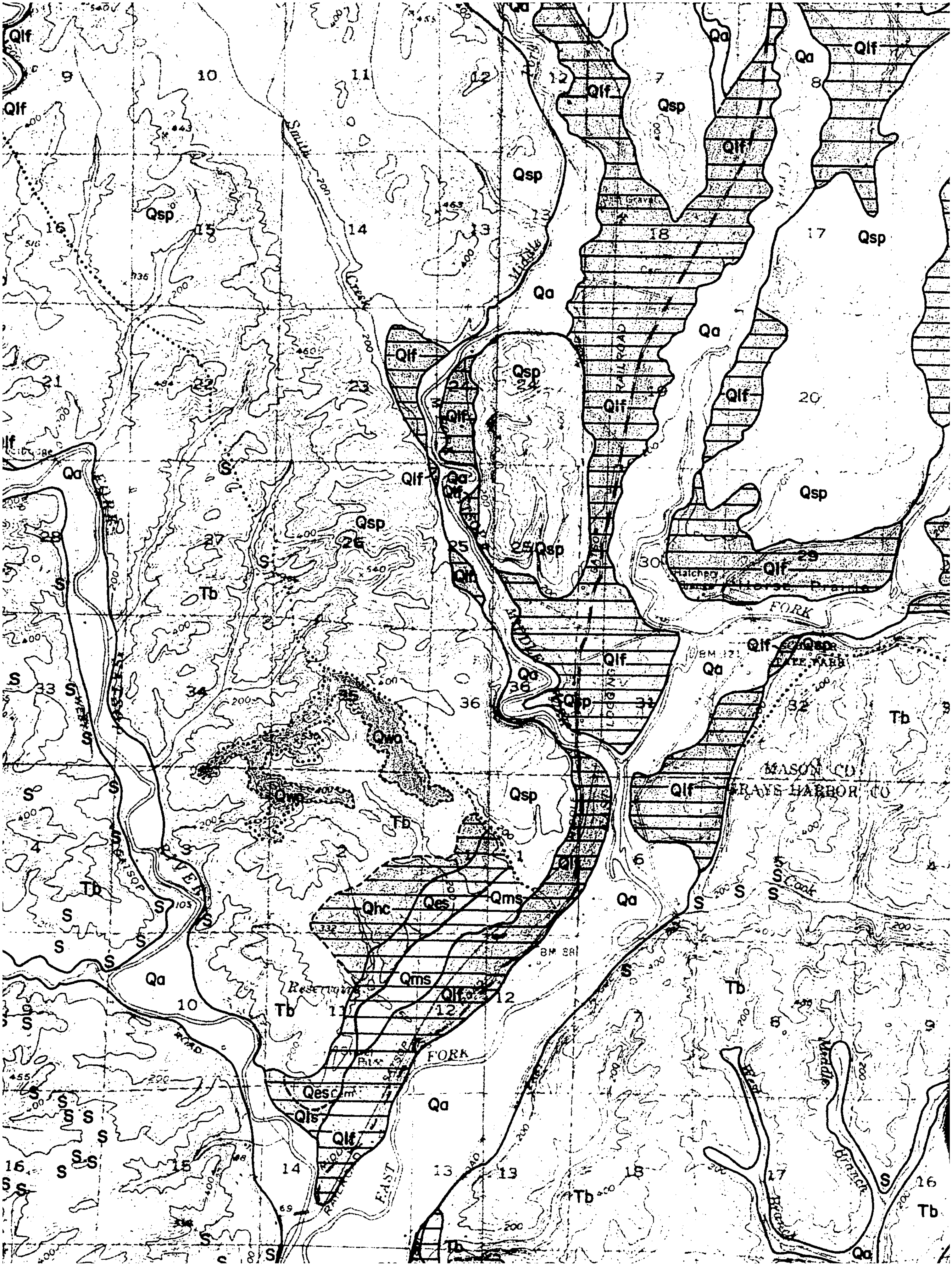
T19N
T18N
Footbridge
BM 218
BM 160
Anderson
Creek
River
Fork
WYNOOCHEE
Black
Qwo
Tb
Qhc
Qms
Qhf
Qa
Qes
Qlf
S



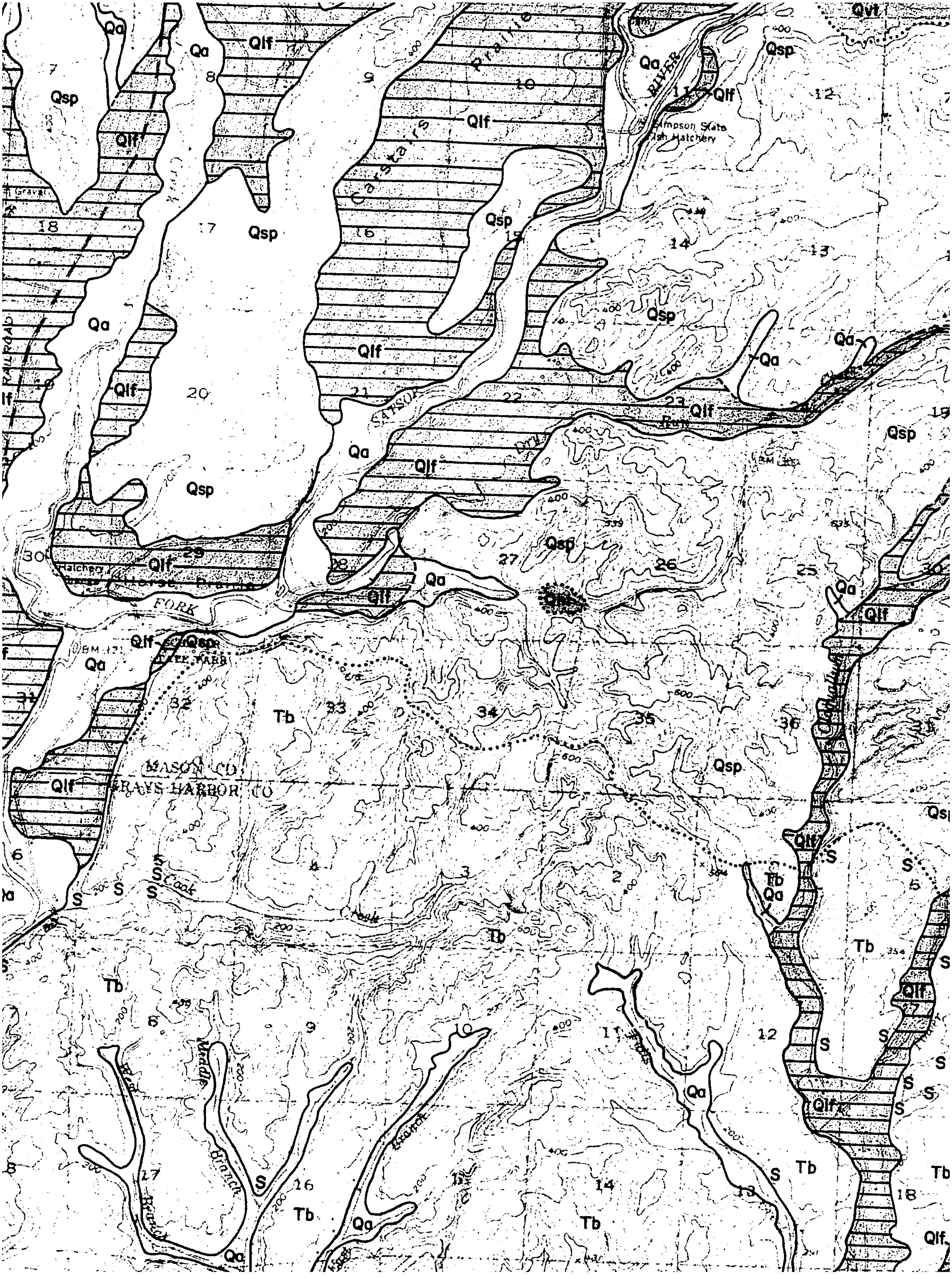
Footbridge
Tb
Qwo
Qhc
Qms
Qhf
Qa
Qes
Qlf
S
River
Creek
Anderson
Canyon
Black
ROAD
BM 218
BM 160
BM 88
WYNOOCHEE
T19N
T18N
Fork



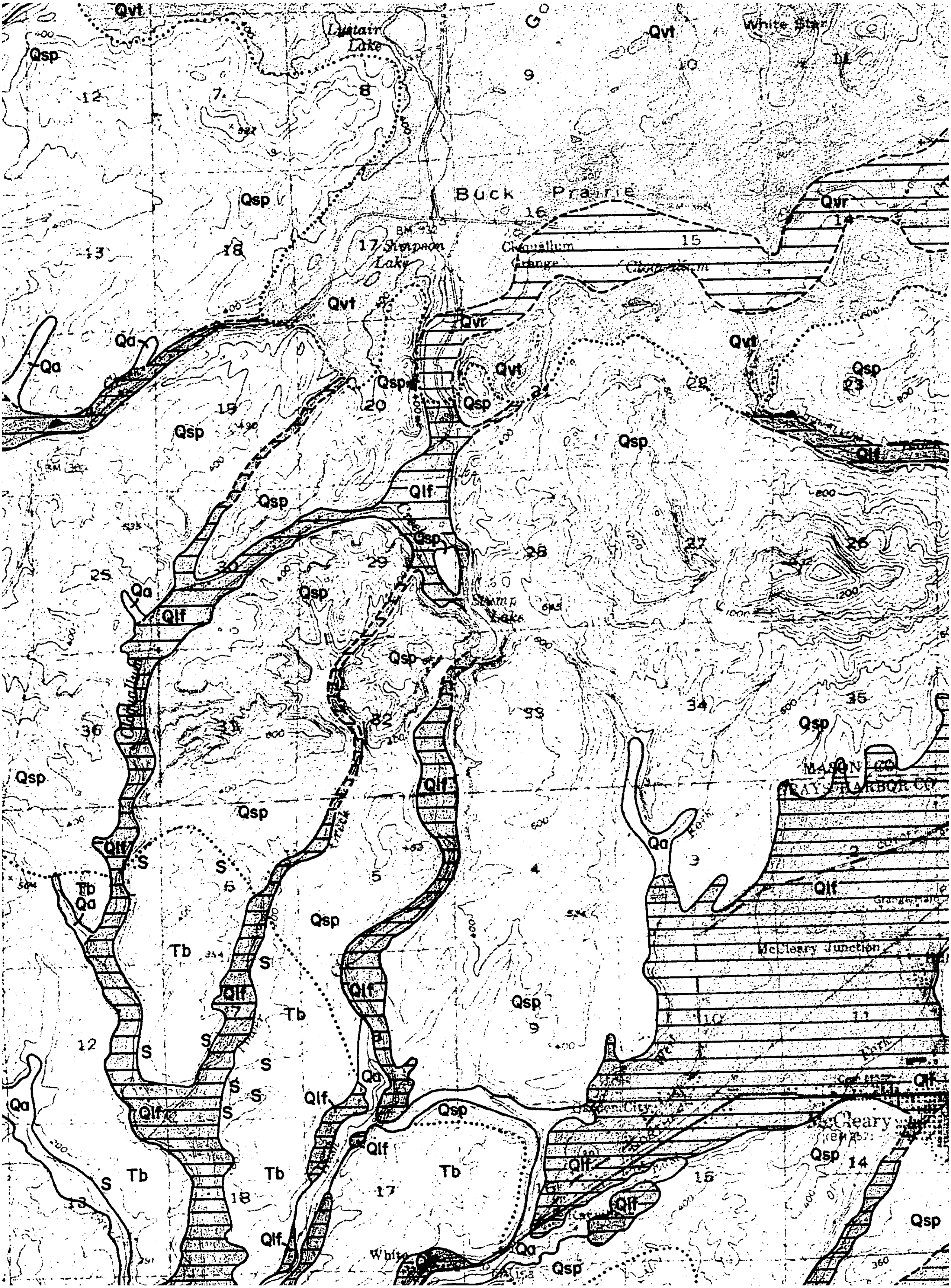
Qlf
Qms
Tb
S
Qsp
Qa
Qwa
Qhc
Qesc
Qls
Smith Creek
Creek
Prices Peak Lookout
ROAD
Reservoirs
EAST



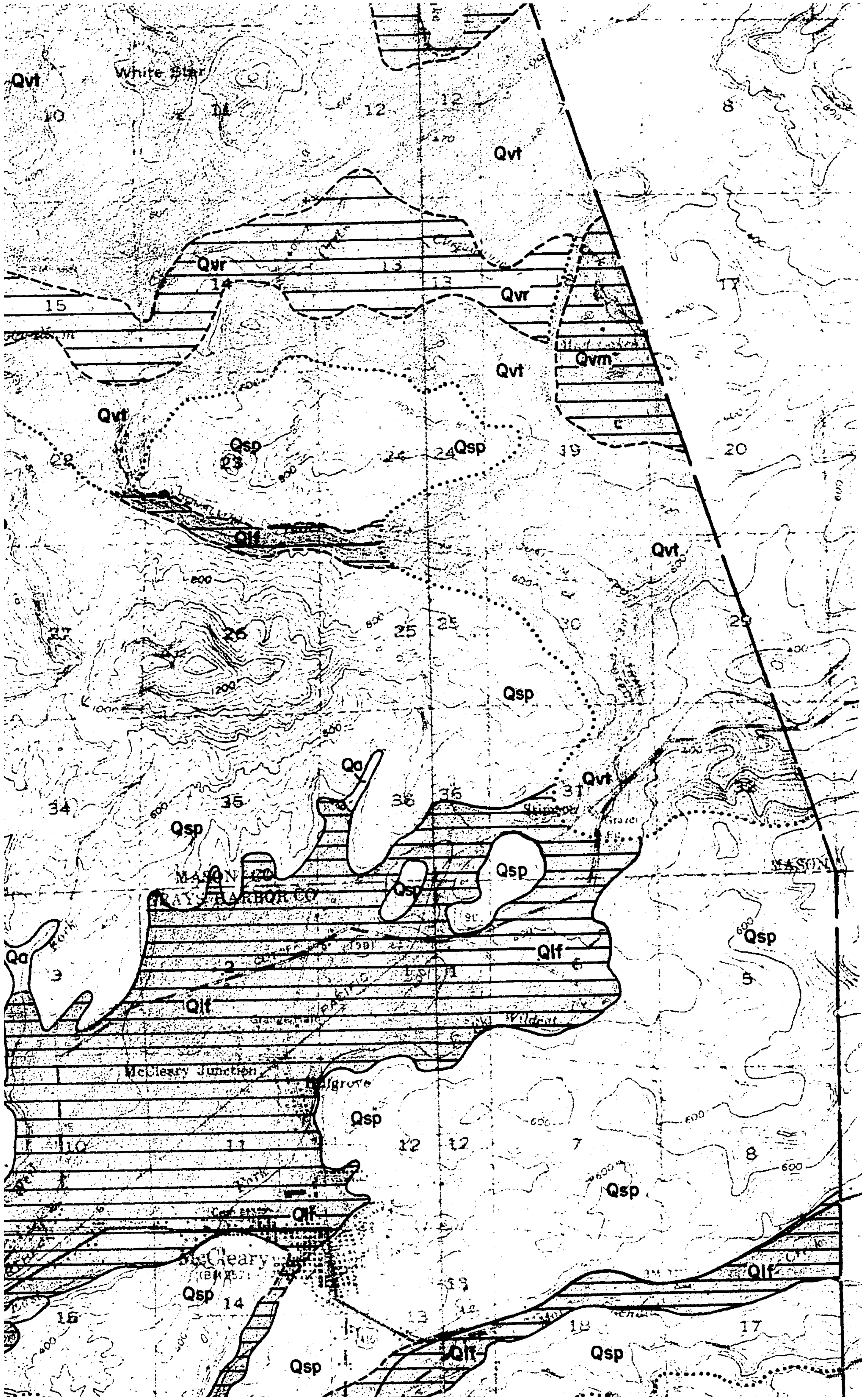
Qlf
Qa
Qsp
Tb
Qwo
Qhc
Qes
Qms
Qescm
Qls
S
Smith
Creek
Middle
FORK
EAST
FORK
MASON CO
GRAYS HARBOR CO
BM 321
BM 88
Reservoir
Cook



Qvt
Qa
Qsp
Qlf
Tb
S
RIVER
Simpson State Fish Hatchery
Carstairs Prairie
SATSOP
Dry Run
FORK
Hatchery
STATE PARK
MASON CO
GRAYS HARBOR CO
Cook Creek
RAILROAD
Middle Branch
Branch

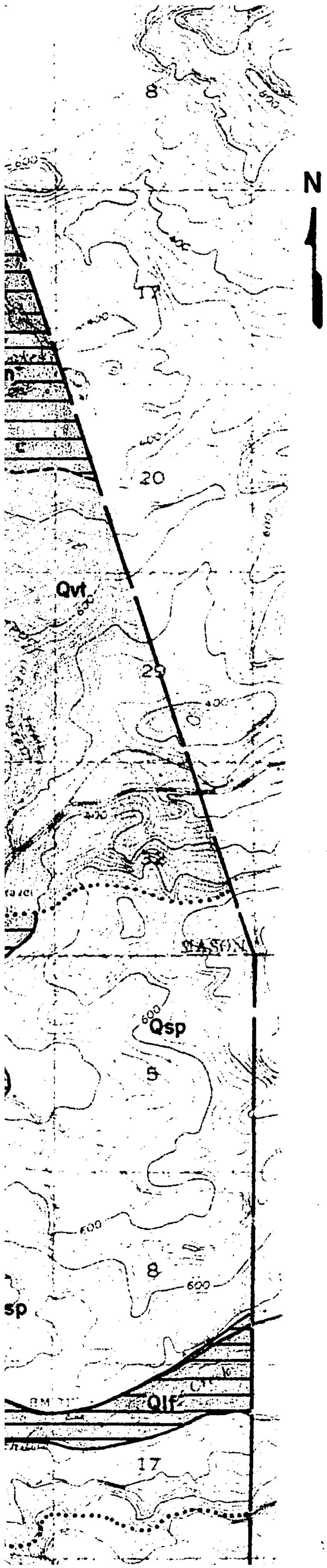


Qvt
Qsp
Lystair Lake
White Star
Buck Prairie
17 Simpson Lake
Cloquallum Grange
Qvr
Qa
Qlf
Stump Lake
MASON CO
GRAYS HARBOR CO
McCleary Junction
McCleary
Tb
S



QUATERNARY

TERTIARY



EXPLANATION

		Landforms	Deposits	
QUATERNARY	Holocene		Qa	Alluvium
	Pleistocene	Qvm		Vashon morainal topogra
		Qvr		Vashon recessional melt
			Qvt	Vashon till and undiffer
		Qlf		Low Fraser terraces, outv
			Qgt	Grisdale till and undiffer
		Qhf		High Fraser terraces
			Qlg	Deposits of lakes damm
			Qlm	Deposits of lakes damme includes some Holocene a
			Qd	Spoon Creek diamicton
		Qls		Late Salmon Springs terr
			Qsp	Salmon Springs till and u Lobe; includes much bed
		Qms		Middle Salmon Springs te of the Puget Lobe)
			Qmt	Mobray till and undiffere
		Qes		Early Salmon Springs terr of Mobray ice)
			Qw	Weatherwax Formation (
		Qhc		Helm Creek terraces
			Qht	Helm Creek (?) till
			Qwo	Wedekind Creek outwash
			Qwt	Wedekind Creek (?) till
TERTIARY	Eocene to Miocene		Tb	Bedrock

Areas of Ford mounds on Vashon terraces

Moraine crests of the Wynoochee glacier

Truncated spur (top of chevron at apex of spur)

V Volcanic rock } outcrops in driftless areas
S Sedimentary rock

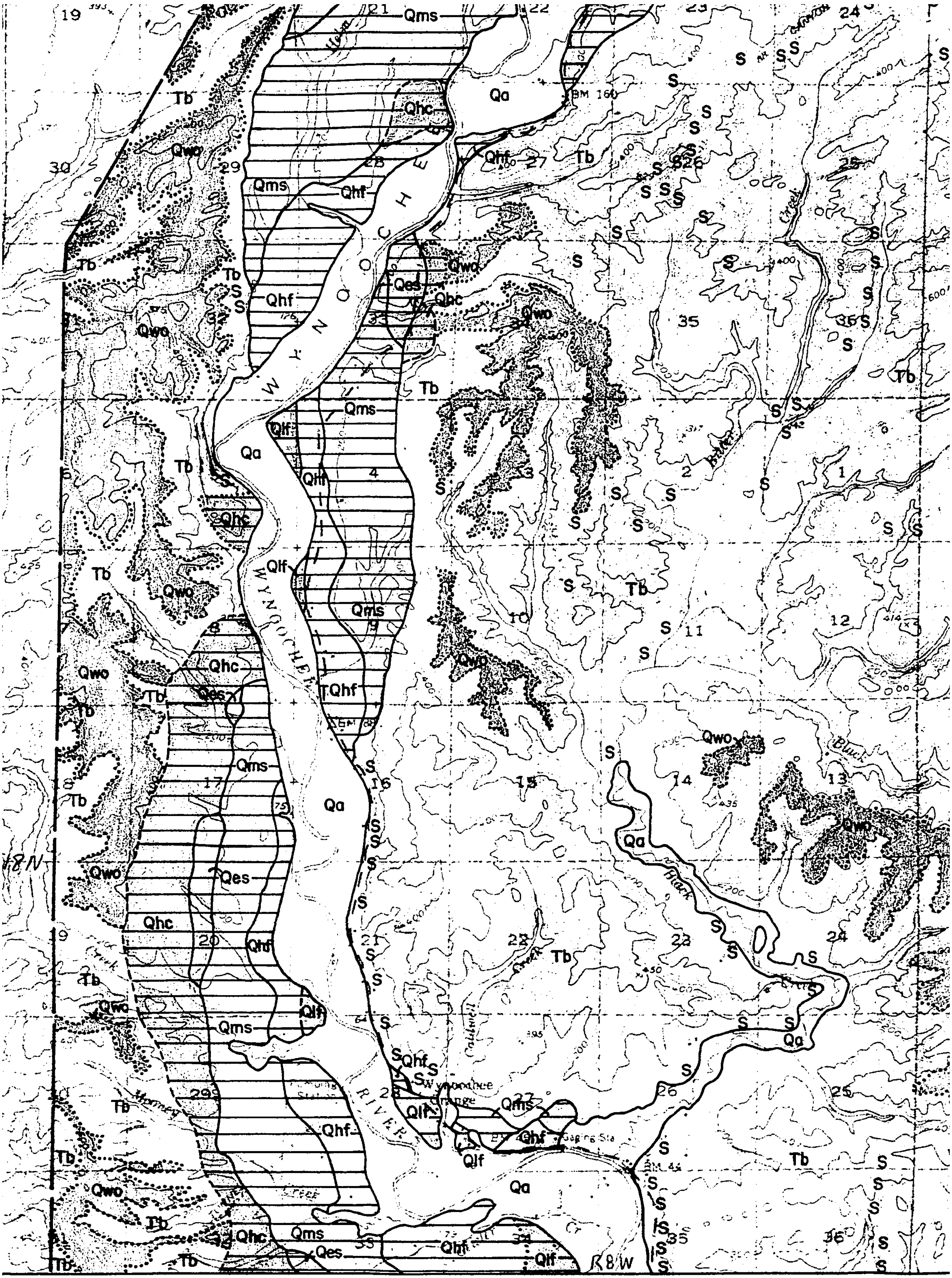
EXPLANATION

		Landforms	Deposits	
ERNARY	Holocene		Qa	Alluvium
	Pleistocene	Qvm		Vashon morainal topography
		Qvr		Vashon recessional meltwater channels
			Qvt	Vashon till and undifferentiated drift
		Qlf		Low Fraser terraces, outwash plains, and meltwater channels
			Qgt	Grisdale till and undifferentiated drift
		Qhf		High Fraser terraces
			Qlg	Deposits of lakes dammed up by Grisdale ice
			Qlm	Deposits of lakes dammed up by moraines (mostly Grisdale); includes some Holocene alluvium
			Qd	Spoon Creek diamicton
		Qls		Late Salmon Springs terraces and meltwater channels
			Qsp	Salmon Springs till and undifferentiated drift of the Puget Lobe; includes much bedrock
		Qms		Middle Salmon Springs terraces (associated with the maximum of the Puget Lobe)
			Qmt	Mobray till and undifferentiated drift
		Qes		Early Salmon Springs terraces (associated with the maximum of Mobray ice)
			Qw	Weatherwax Formation (deposits of Glacial Lake Weatherwax)
		Qhc		Helm Creek terraces
			Qht	Helm Creek (?) till
			Qwo	Wedekind Creek outwash (?)
			Qwt	Wedekind Creek (?) till
ARY	Eocene to Miocene		Tb	Bedrock

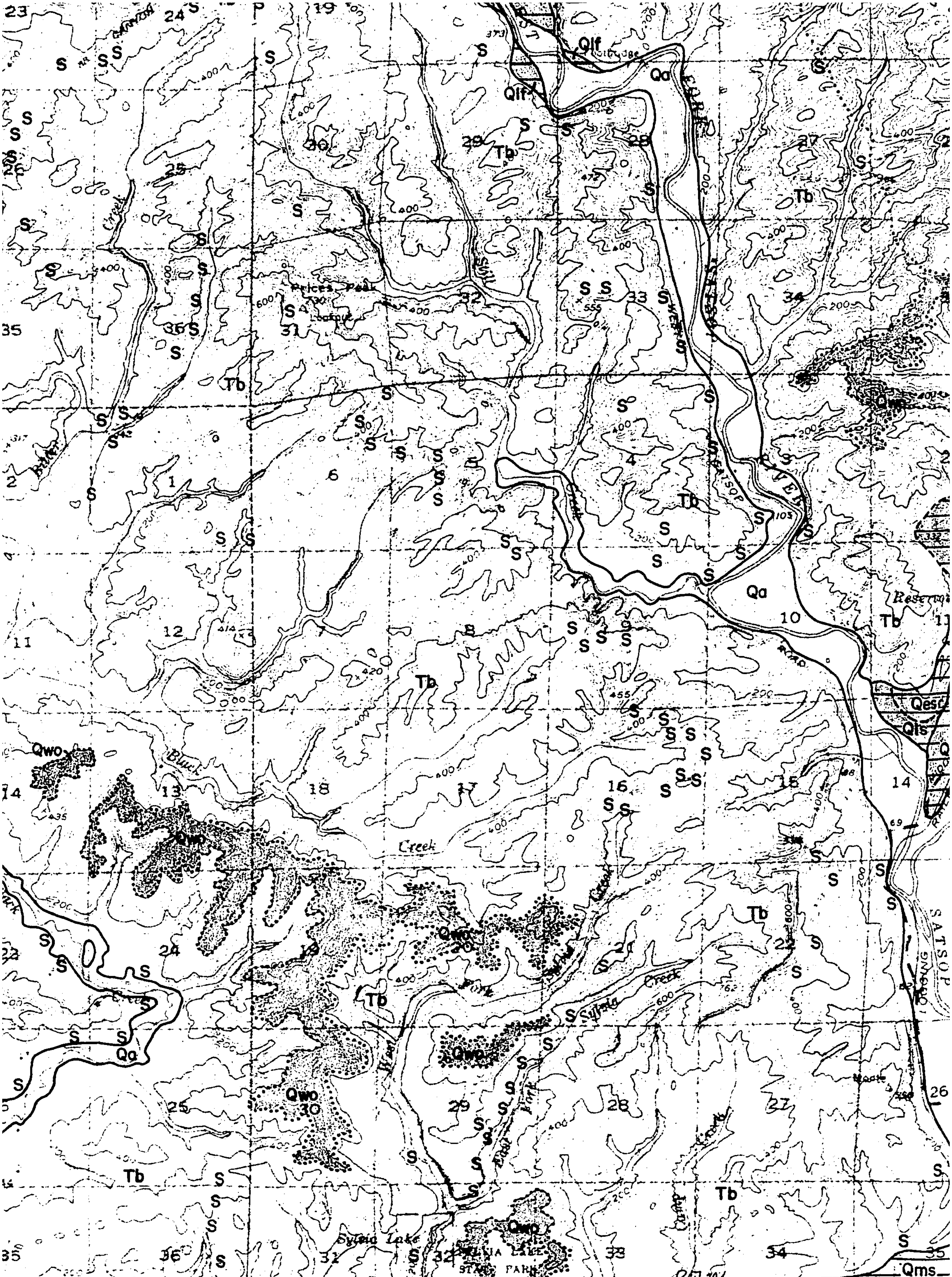
Areas of Ford mounds on Vashon terraces

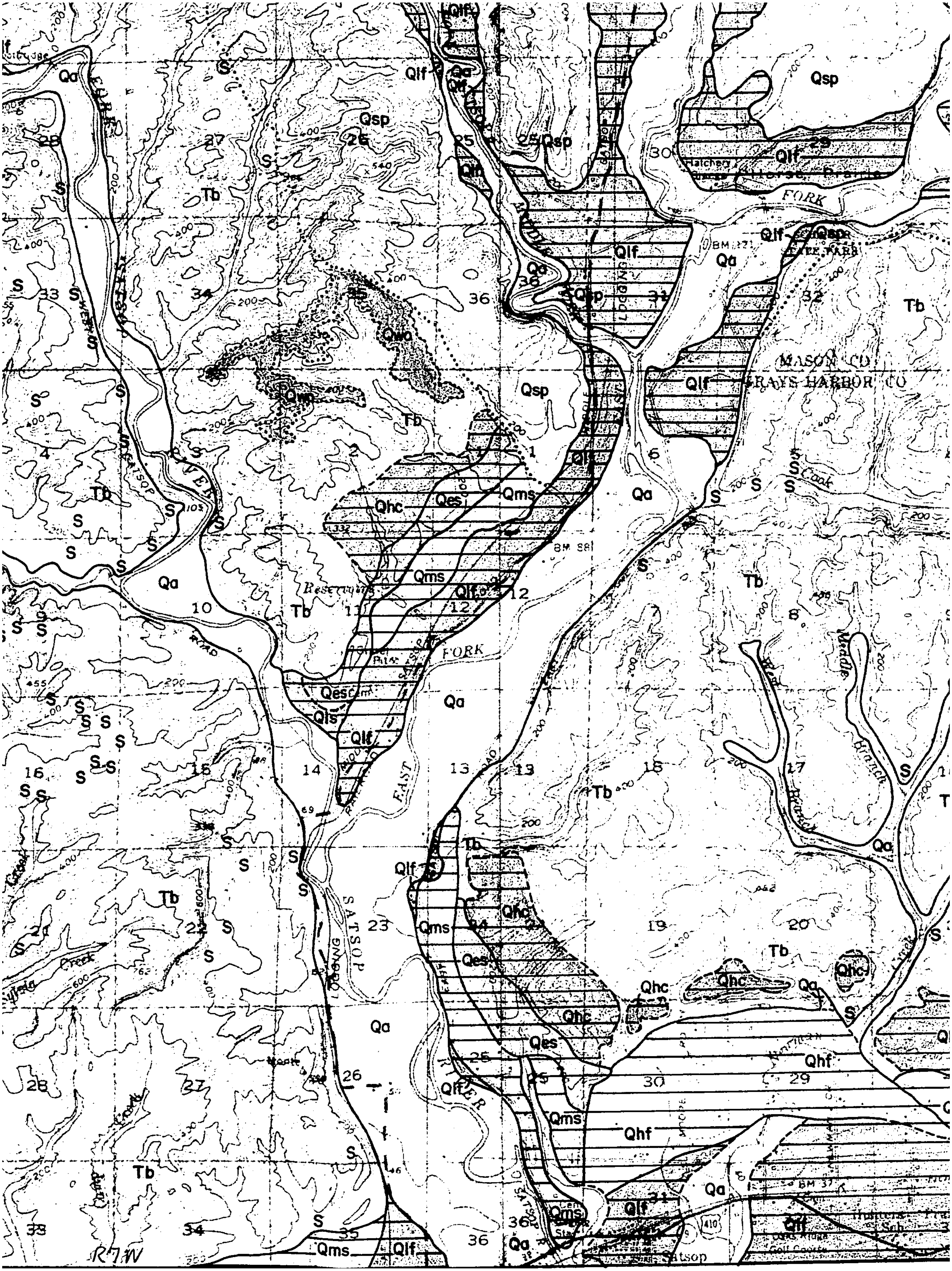
Moraine crests of the Wynoochee glacier

Truncated spur (top of chevron at apex of spur)

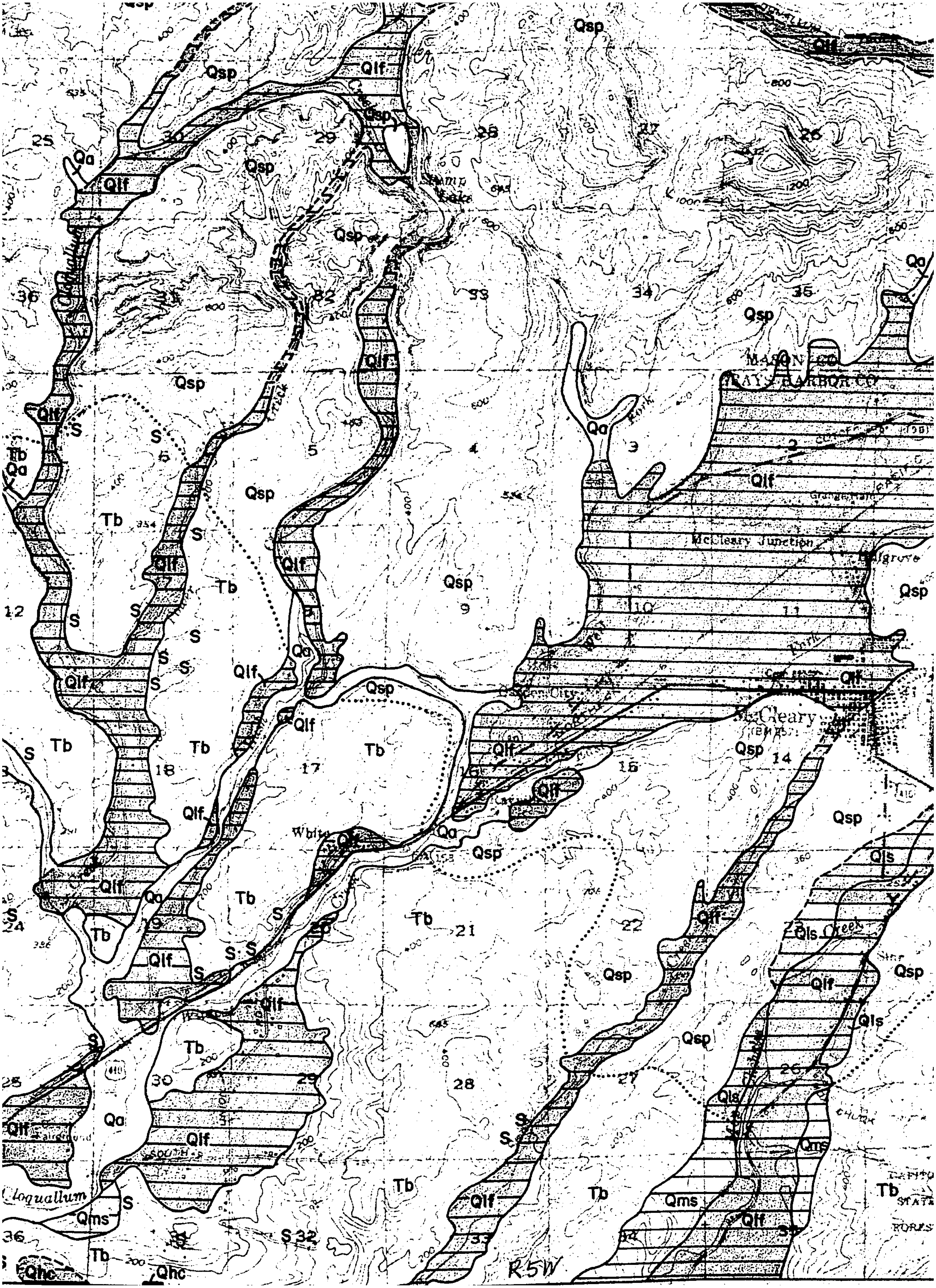


Qms
Qa
Qhc
Qhf
Qlf
Qes
Qwo
Tb
S
WYNOOCHEE
WYNOOCHEE
RIVER
Black
Creek
Baker
Cr
Wynoochee Grange
Gaging Sta
BM 160
18N
R8W


Qlf
Qa
Tb
S
Qwo
Qesc
Qls
Qms
Prices Peak
Lookout
Creek
Black
Sylvia Creek
Fork
Sylvia Lake
SATSOP
R7W


Qsp
Qlf
Qa
Tb
S
Qwa
Qhc
Qes
Qms
Qescam
Qls
Qhf
Qhc
MASON CO
GRAYS HARBOR CO
FORK
EAST
FORK
SATSOP
RIVER
Cook
Creek
Reservoir
Hatchery
STATE PARK
BM 88
BM 37
Satsop
410
R 7 W

Qsp
Qa
Qlf
Qsp
27
26
25
30
29
28
FORK
Qa
Qlf
Qlf
32
33
34
35
36
Tb
Qsp
MASON CO
GRAYS HARBOR CO
Qlf
6
3
2
S
Cook
Creek
Tb
Tb
Qa
12
Tb
8
9
10
11
Qa
Qlf
Branch
Branch
Branch
18
17
16
15
14
13
Tb
Tb
Qa
Qa
S
19
20
21
22
23
24
S
Tb
Tb
Tb
Qhc
Qhc
Qhc
Qa
Qa
Qhc
Qhf
30
29
28
27
26
25
Tb
Qhc
Qhc
Qms
Qhf
ns
Qlf
Qa
Cloquallum
Qms
Qa
Qlf
Qlf
Qlf
Qa
Qlf
36
Qhc
Satsop
R6W


Qsp
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Qa
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Qls
Qms
Qhc
MASON CO
GRAYS HARBOR CO
McCleary Junction
McCleary
Cloquallum
R5W
25
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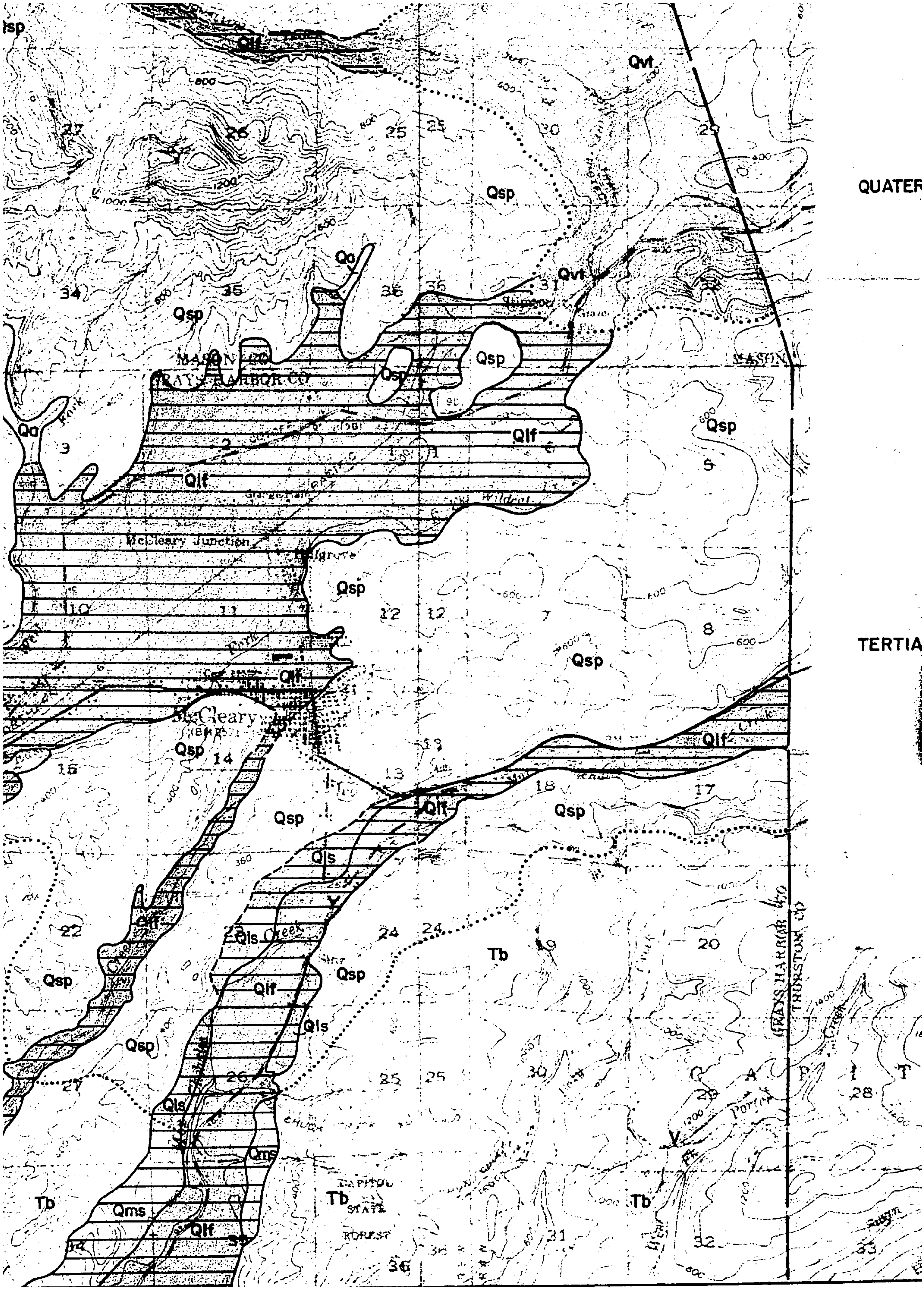
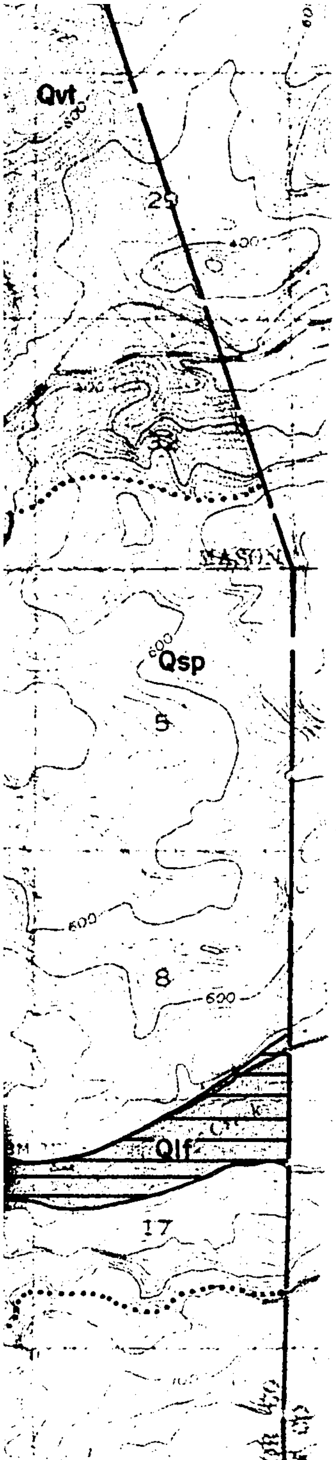

Qsp
Qlf
Qvt
Qa
Qsp
MASON CO
GRAYS HARBOR CO
McCleary Junction
McCleary
Qls
Qms
Tb
GRAYS HARBOR CO
THURSTON CO
CAPITOL STATE FOREST
QUATER
TERTIA



QUATERNARY	Pleistocene		Qlm	Deposits of lakes damm includes some Holocene
			Qd	Spoon Creek diamicton
		Qls		Late Salmon Springs ter
			Qsp	Salmon Springs till and Lobe; includes much be
		Qms		Middle Salmon Springs of the Puget Lobe)
			Qmt	Mobray till and undiffer
		Qes		Early Salmon Springs te of Mobray ice)
			Qw	Weatherwax Formation
		Qhc		Helm Creek terraces
			Qht	Helm Creek (?) till
			Qwo	Wedekind Creek outwas
			Qwt	Wedekind Creek (?) till
TERTIARY	Eocene to Miocene		Tb	Bedrock

Areas of Ford mounds on Vashon terraces

Moraine crests of the Wynoochee glacier

Truncated spur (top of chevron at apex of spur)

V Volcanic rock
S Sedimentary rock } outcrops in driftless areas

Contact, dashed where approximate, dotted wh

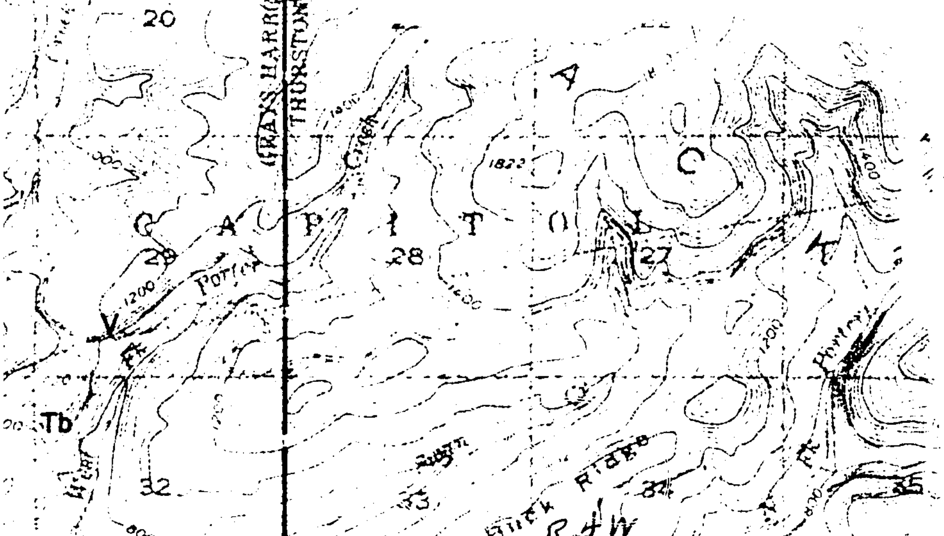


Plate I. SURFICIAL G
SOUTH-CENTRAL
WAS
(centr

SCAL

R.J. CA
Drafted by J.C.

Base from U.S.Geolo

		Qlm	Deposits of lakes dammed up by moraines (mostly Grisdale); includes some Holocene alluvium
		Qd	Spoon Creek diamicton
	Qls		Late Salmon Springs terraces and meltwater channels
:NARY	Pleistocene	Qsp	Salmon Springs till and undifferentiated drift of the Puget Lobe; includes much bedrock
	Qms		Middle Salmon Springs terraces (associated with the maximum of the Puget Lobe)
		Qmt	Mobray till and undifferentiated drift
	Qes		Early Salmon Springs terraces (associated with the maximum of Mobray ice)
		Qw	Weatherwax Formation (deposits of Glacial Lake Weatherwax)
	Qhc		Helm Creek terraces
		Qht	Helm Creek (?) till
		Qwo	Wedekind Creek outwash (?)
		Qwt	Wedekind Creek (?) till
:RY	Eocene to Miocene	Tb	Bedrock

Areas of Ford mounds on Vashon terraces

Moraine crests of the Wynoochee glacier

Truncated spur (top of chevron at apex of spur)

V Volcanic rock
S Sedimentary rock
} outcrops in driftless areas south of the Olympic Mountains

Contact, dashed where approximate, dotted where indefinite or inferred

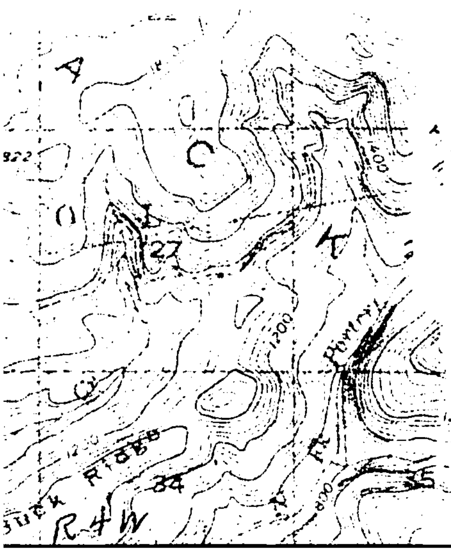


Plate I. SURFICIAL GEOLOGY OF THE SOUTH-CENTRAL OLYMPIC PENINSULA, WASHINGTON

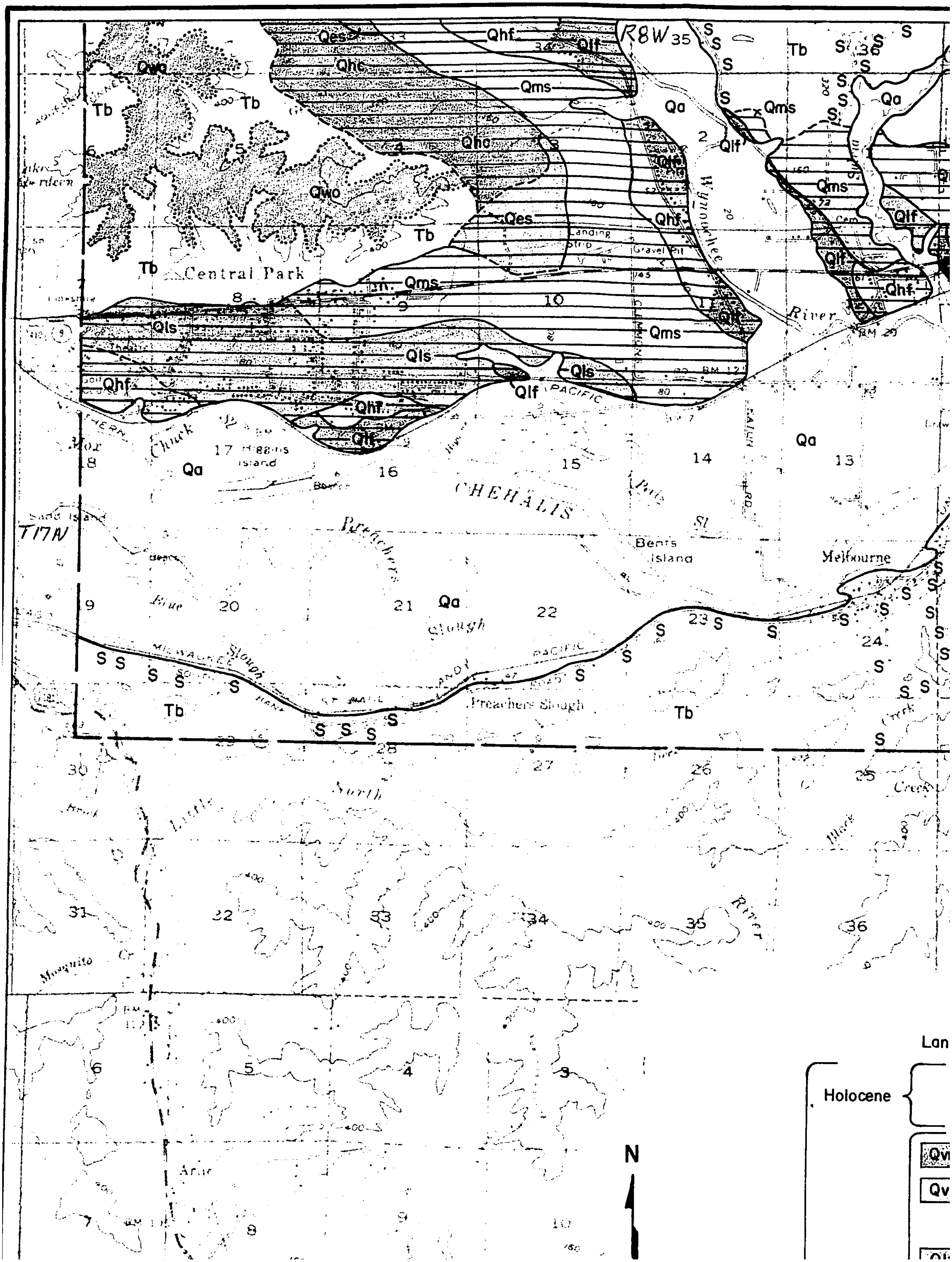
(central portion)

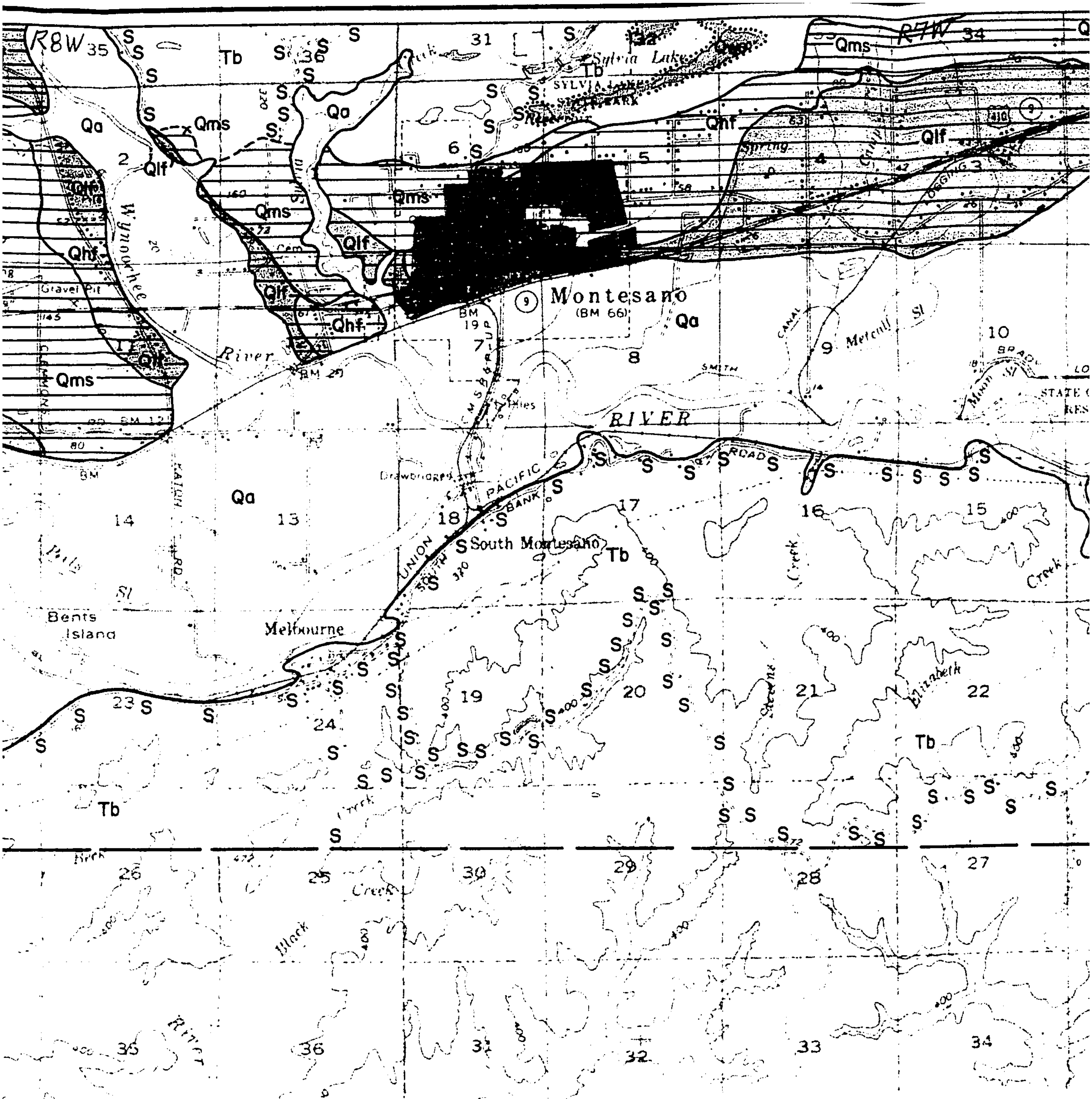
SCALE 1:48,000

R.J. CARSON 1970

Drafted by J.C. MILHOLLIN, Cartographer

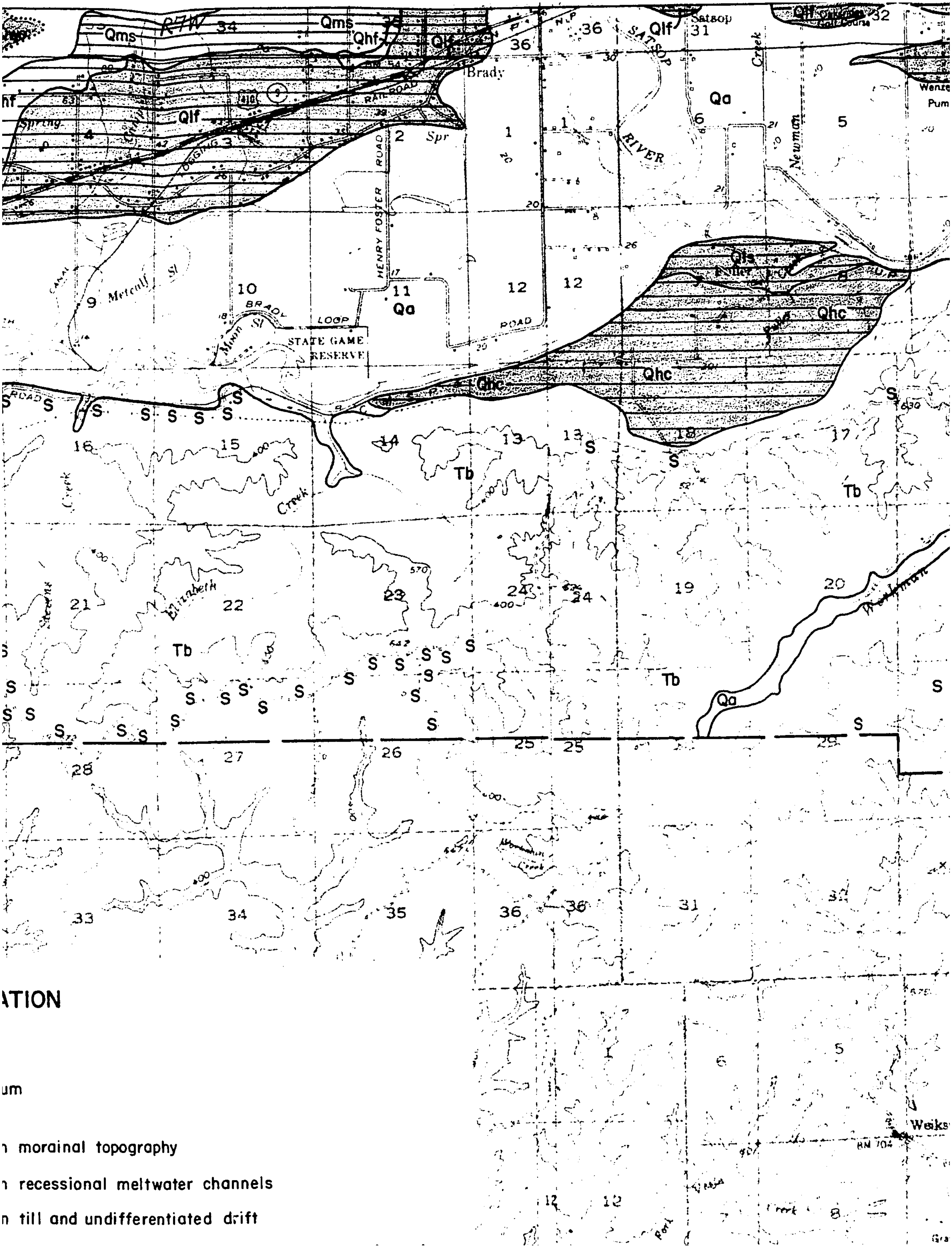
Base from U.S. Geological Survey topographical maps


R8W
T17N
Qes
Qhc
Qhf
Qlf
Qms
Qwo
Tb
Qa
Qes
Qls
Central Park
Wynoochee
River
Landing Strip
Gravel Pit
PACIFIC
NORTHERN
Chuck
Higgins Island
CHEHALIS
Preachers
Bents Island
Melbourne
Blue
Slough
MILWAUKEE
Preachers Slough
Sand Island
North
Little
Black
River
Creek
Mosquito
Cr
Arie
N
Lan
Holocene
Qv



EXPLANATION

	Landforms	Deposits	
Holocene		Qa	Alluvium
	Qvm		Vashon morainal topography
	Qvr		Vashon recessional meltwater channels
		Qvt	Vashon till and undifferentiated drift
	Qlf		Low Fraser terraces, outwash plains, and meltw



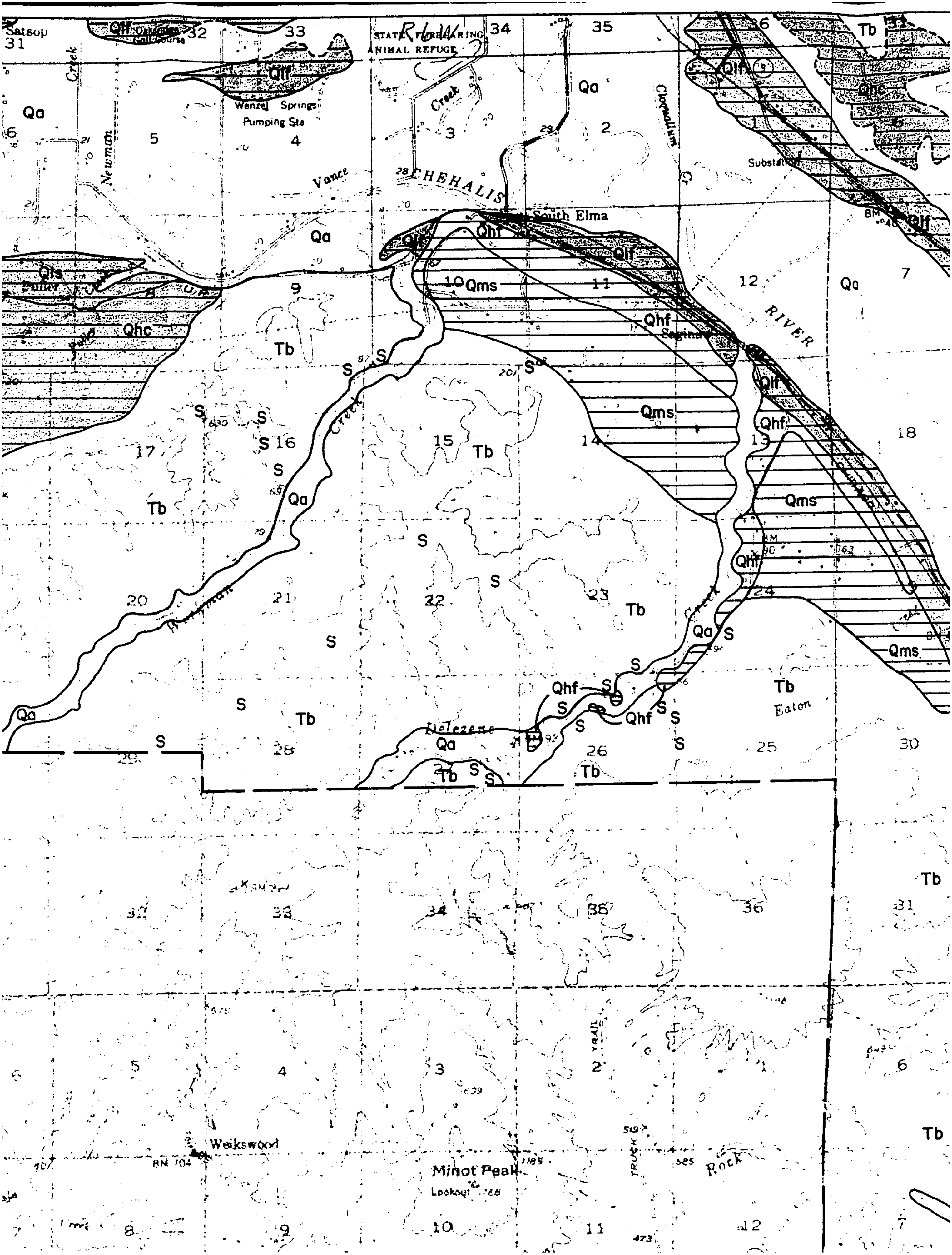
ATION

um

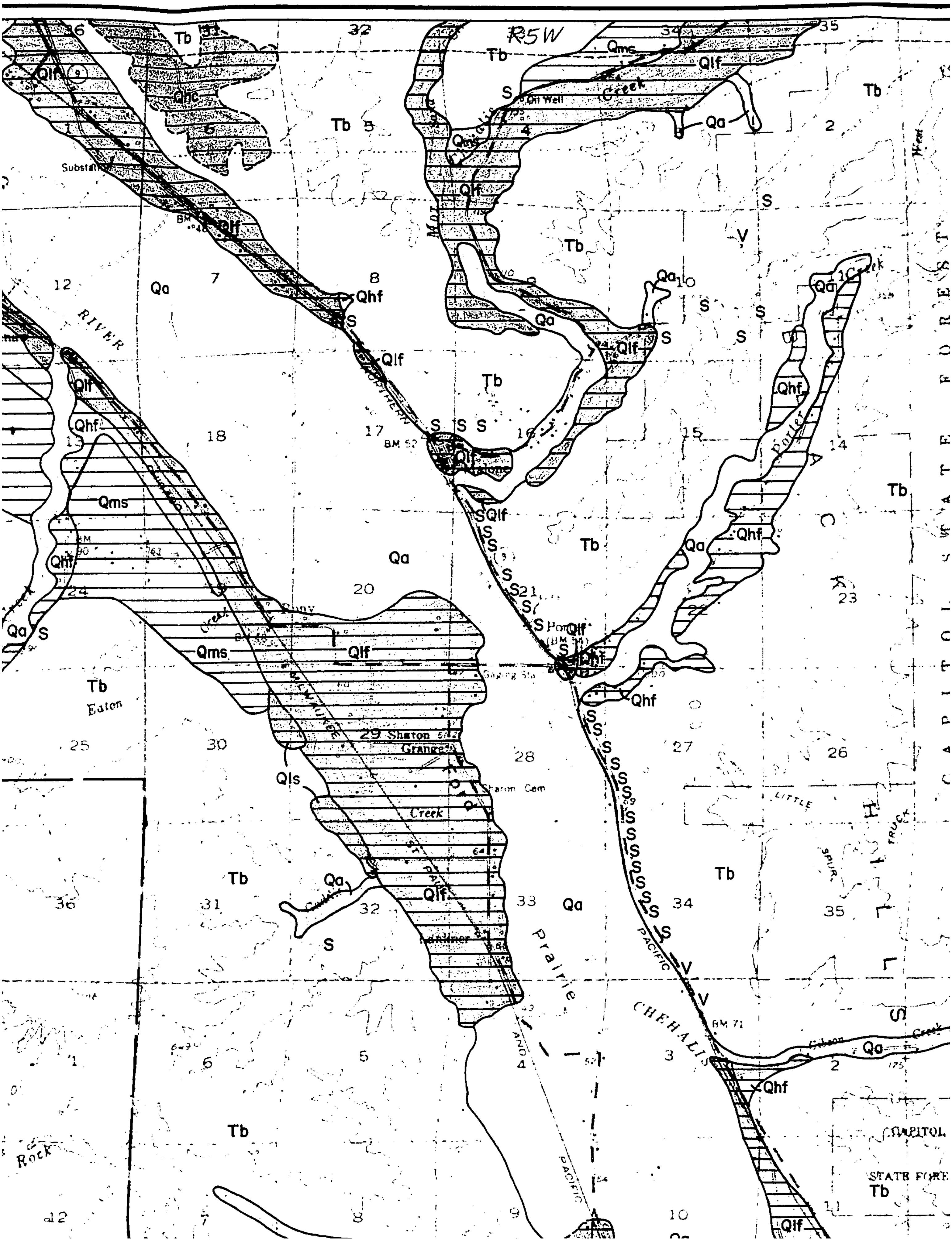
n morainal topography

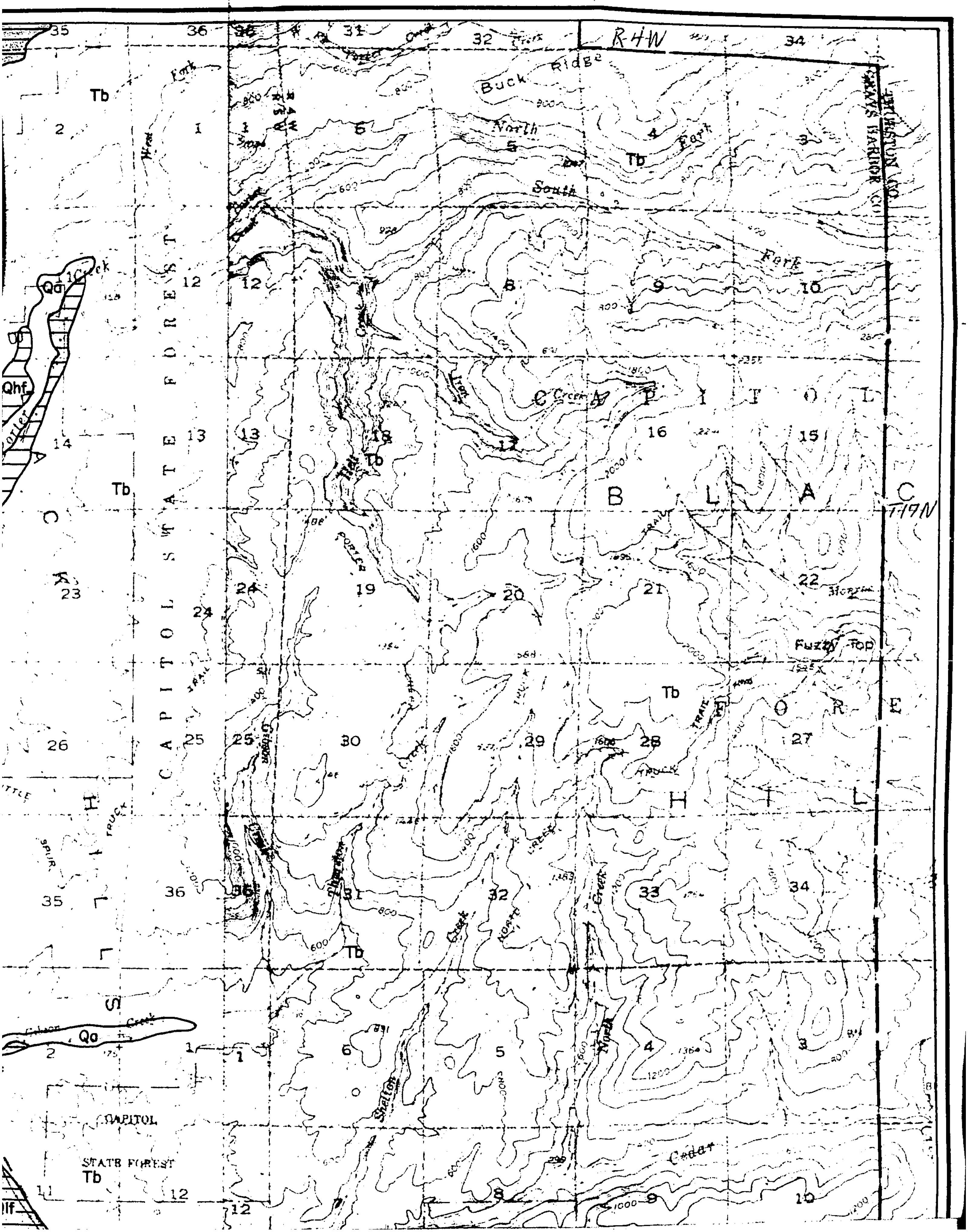
n recessional meltwater channels

n till and undifferentiated drift

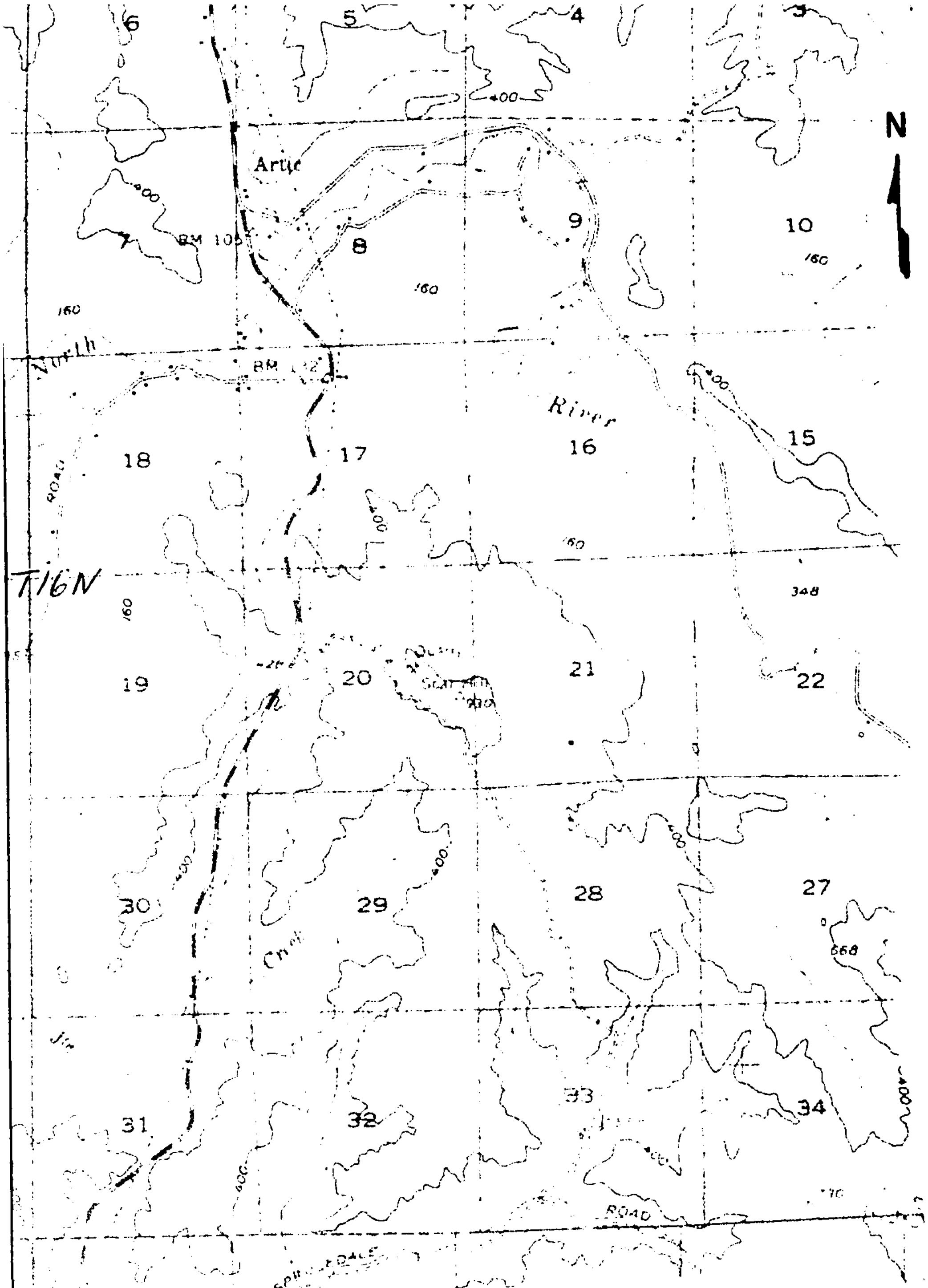


Satsop
Qlf
Oakridge Golf Course
STATE GAME REFUGE
Gravel Pit
Wenzel Springs Pumping Sta
Creek
Newman
Vance
CHEHALIS
RIVER
South Elma
Satsop
Saginaw
Substation
Qa
Qlf
Qls
Qhc
Qhf
Qms
Tb
S
Eaton
Delezene
Weikswood
Minot Peak
Lookout
TRAIL
TRUCK
Rock


R5W
Tb
Qlf
Qhc
Qms
Oil Well
Creek
Qa
Substation
BM 46
RIVER
Qhf
NORTHERN
BM 52
Porter
Qms
BM 90
Creek
Eaton
Qls
Sharon
Grange
Sharon Cem
MILWAUKEE
ST PAUL
Gaging Sta
Prairie
PACIFIC
CHEHALIS
BM 71
Gibson
LITTLE
SPUR
TRUCK
CAPITOL STATE FOREST
CAPITOL
STATE FORE
Rock
AND



R4W
T17N
Buck Ridge
North Fork
South Fork
Tb
Qa
Qhf
CAPITOL STATE FOREST
C A P I T O L
B L A C
H I L L
F O R E
Fuzzy Top
THURSTON CO.
GRAYS HARBOR CO.
Iron Creek
Porter
Shelton
Cedar
Gibson Creek
TRAIL
TRUCK
CAPITOL
STATE FOREST



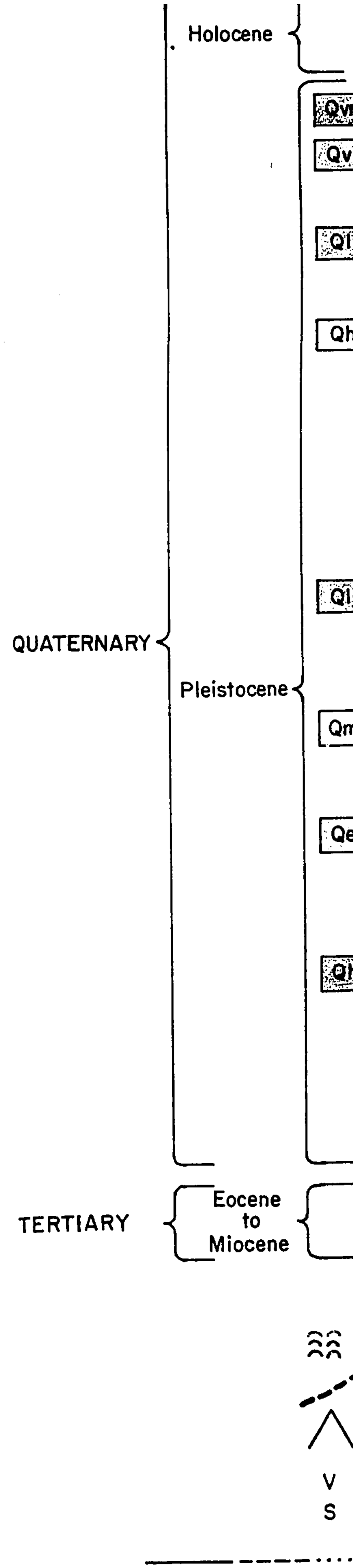


Plate I. SURFICIAL GEOLOGY OF THE SOUTH-CENTRAL OLYMPIC PENINSULA, WASHINGTON

(southern portion)

SCALE 1:48,000

R.J. CARSON 1970

Drafted by J.C. MILHOLLIN, Cartographer

Base from U.S. Geological Survey topographical maps

QUATERNARY	Holocene	Qa	Alluvium
	Pleistocene	Qvm	Vashon morainal topography
		Qvr	Vashon recessional meltwater channels
		Qvt	Vashon till and undifferentiated drift
		Qlf	Low Fraser terraces, outwash plains, and meltwater ch
		Qgt	Grisdale till and undifferentiated drift
		Qhf	High Fraser terraces
		Qlg	Deposits of lakes dammed up by Grisdale ice
		Qlm	Deposits of lakes dammed up by moraines (mostly Gri includes some Holocene alluvium
		Qd	Spoon Creek diamicton
		Qls	Late Salmon Springs terraces and meltwater channels
		Qsp	Salmon Springs till and undifferentiated drift of the Lobe; includes much bedrock
		Qms	Middle Salmon Springs terraces (associated with the m of the Puget Lobe)
		Qmt	Mobray till and undifferentiated drift
		Qes	Early Salmon Springs terraces (associated with the mc of Mobray ice)
		Qw	Weatherwax Formation (deposits of Glacial Lake Wea
		Qhc	Helm Creek terraces
		Qht	Helm Creek (?) till
		Qwo	Wedekind Creek outwash (?)
		Qwt	Wedekind Creek (?) till
TERTIARY	Eocene to Miocene	Tb	Bedrock

Areas of Ford mounds on Vashon terraces

Moraine crests of the Wynoochee glacier

Truncated spur (top of chevron at apex of spur)

V Volcanic rock
S Sedimentary rock
} outcrops in driftless areas south of the Olympic Mountains

Contact, dashed where approximate, dotted where indefinite or inferred

s

d meltwater channels

t

sdale ice

nes (mostly Grisdale);

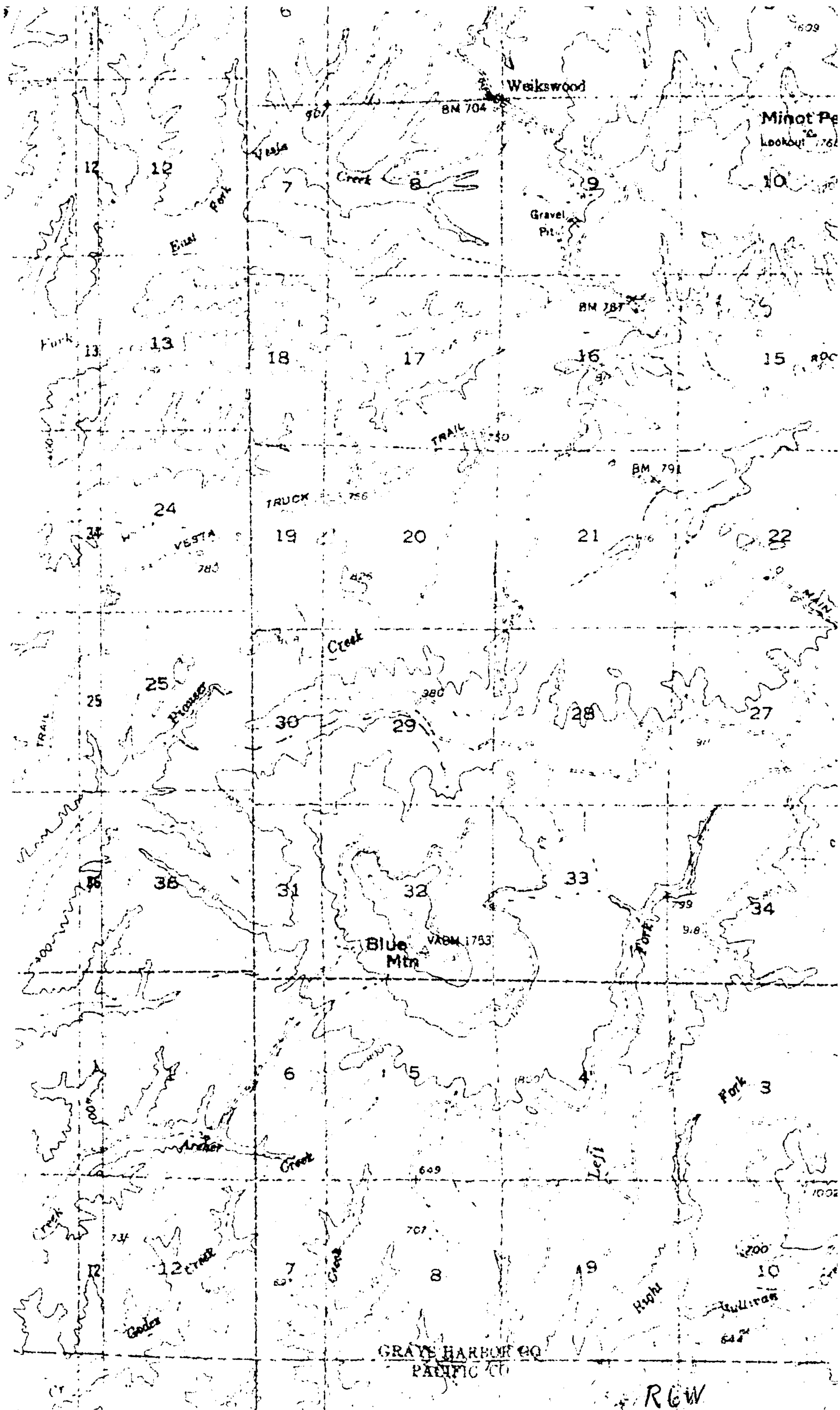
water channels

ed drift of the Puget

ated with the maximum

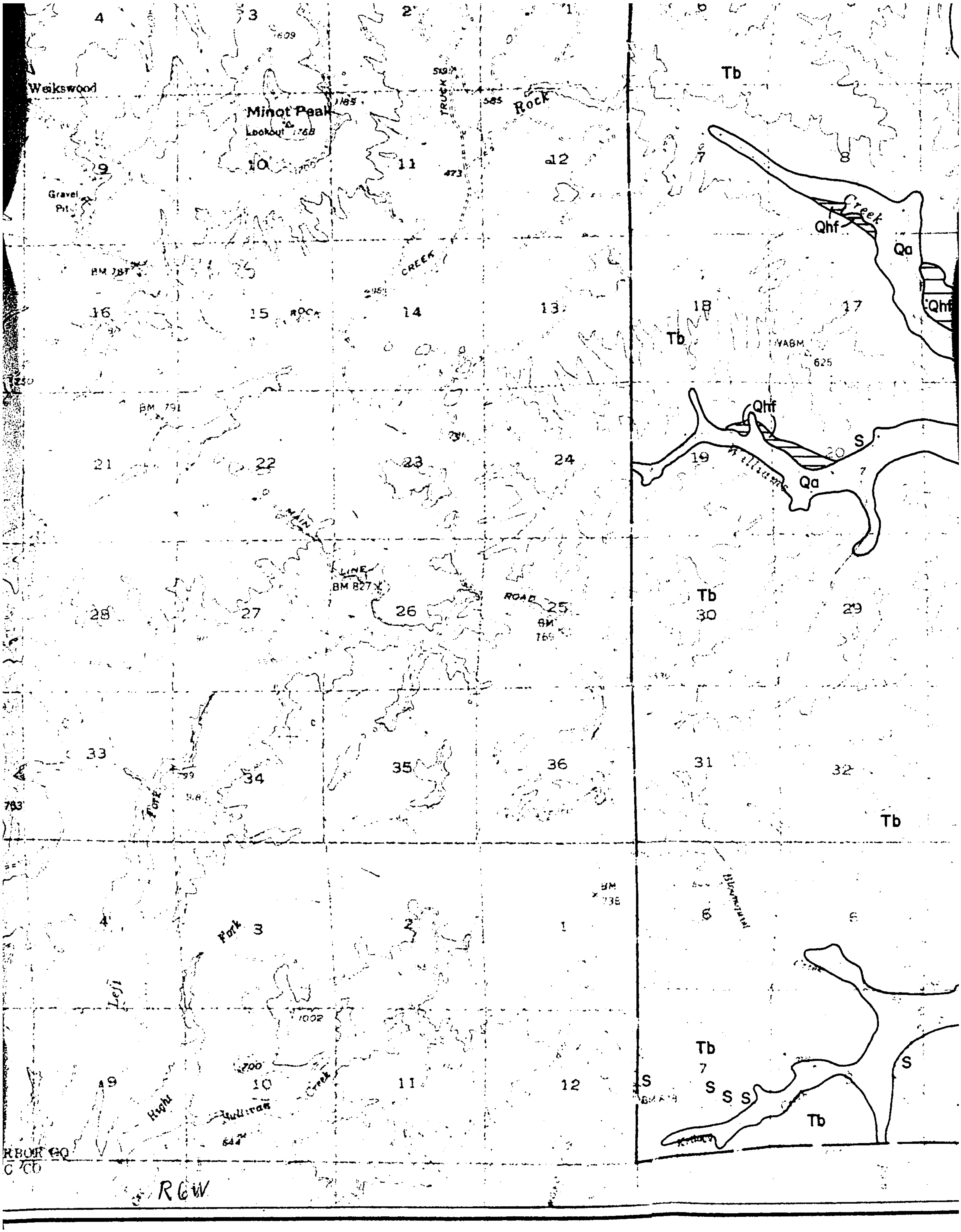
ted with the maximum

lacial Lake Weatherwax)



Dlympic Mountains

or inferred



Weikswood
Minot Peak
Lookout
Gravel Pit
Rock
CREEK
ROCK
TRUCK
MAIN LINE ROAD
BM 827
BM 791
BM 787
BM 769
BM 738
YABM 625
Tb
Qa
Qhf
S
Creek
Williams
Fork
Left
Right
Fork
Creek
R6W
4
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2
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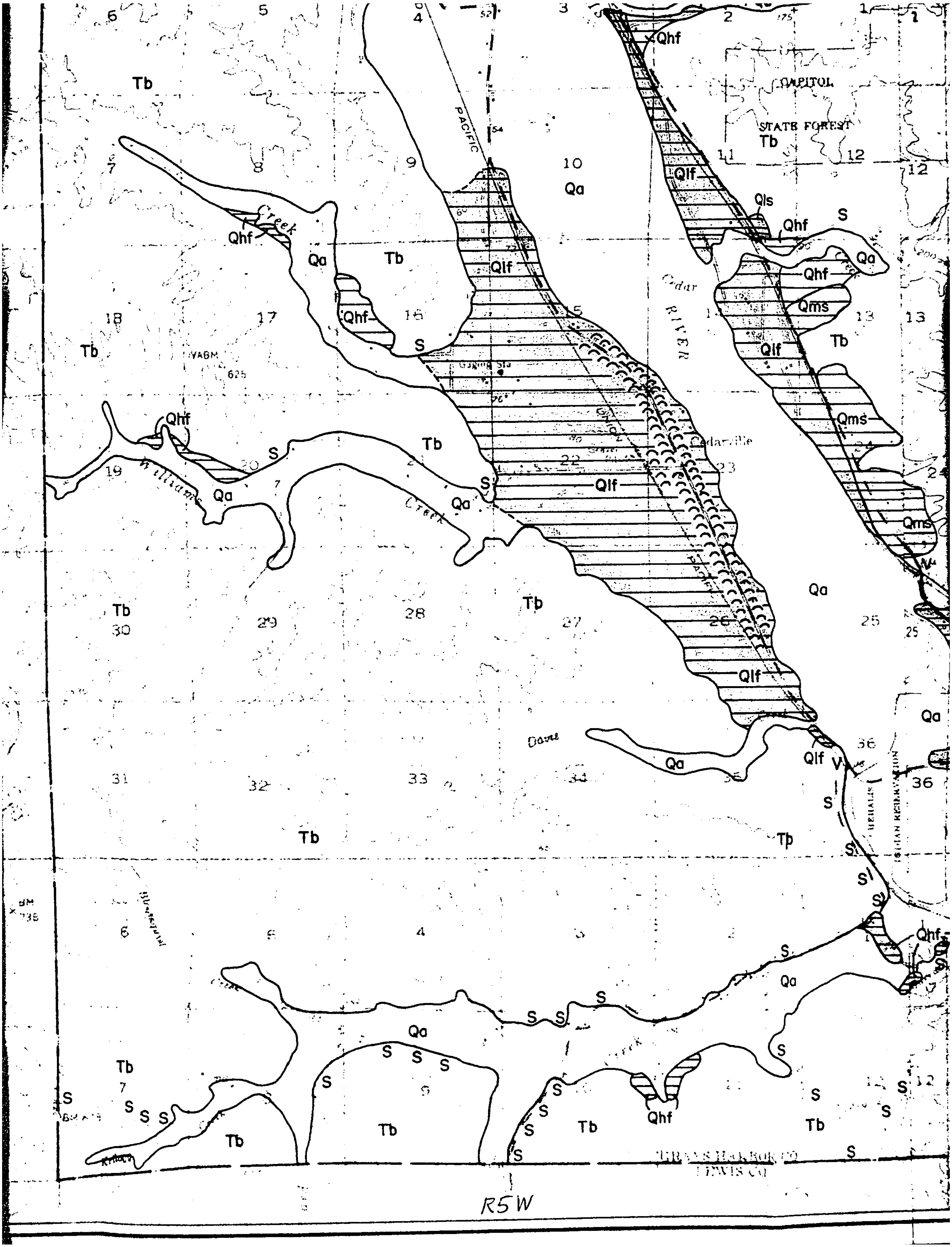
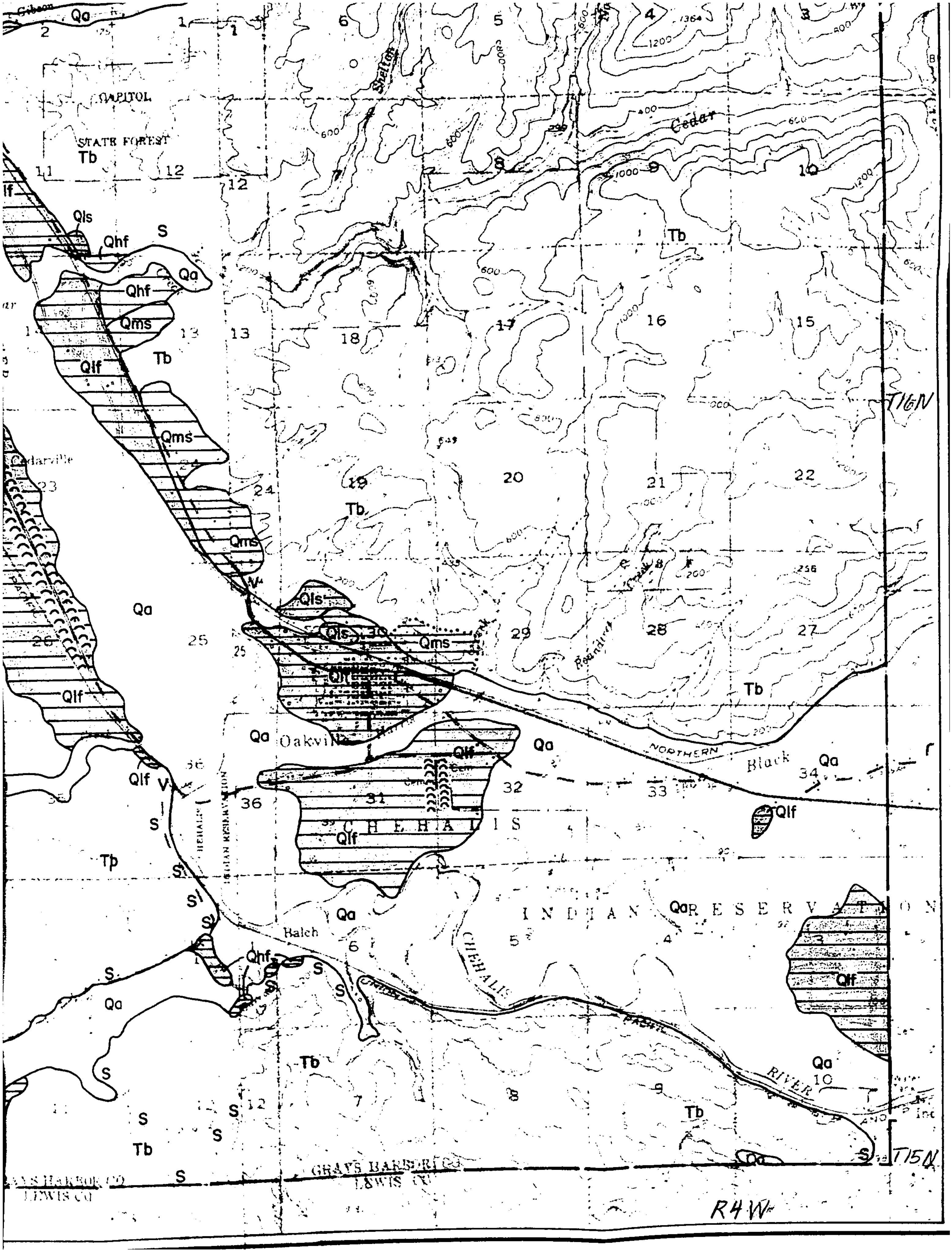
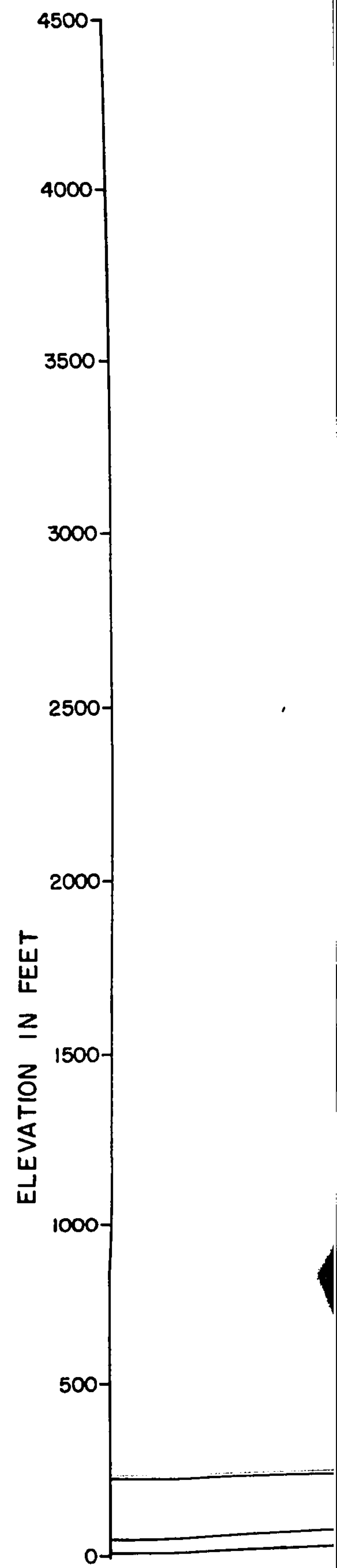


Tb
Qa
Qhf
Qlf
Qls
Qms
S
CAPITOL
STATE FOREST
PACIFIC
Cedar
RIVER
Cedarville
Williams
Creek
Dave
YABM
625
GRAYS HARBOR CO
LEWIS CO
R5W



CAPITOL
STATE FOREST
Cedarville
Oakville
CHEHALIS
INDIAN RESERVATION
Balch
CHEHALIS
RIVER
NORTHERN
PACIFIC
Cedar
Black
Qa
Qls
Qhf
Qms
Qlf
Tb
Tp
S
GRAYS HARBOR CO
LEWIS CO
T16N
T15N
R4W


4500
4000
3500
3000
2500
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1500
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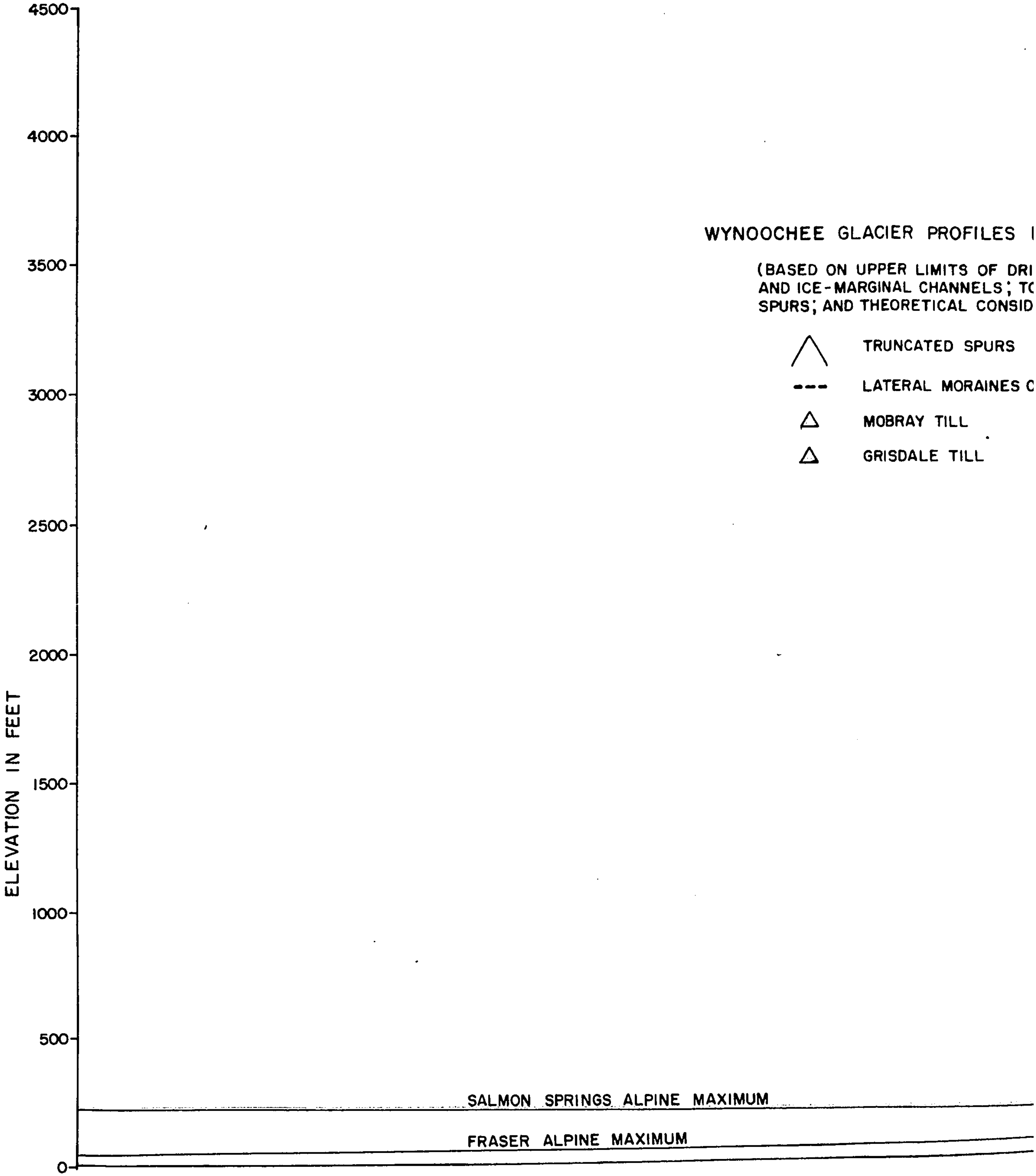
500
0
ELEVATION IN FEET


4500
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0
ELEVATION IN FEET
WYNOOCHEE GLACIER PROFILES I
(BASED ON UPPER LIMITS OF DRI
AND ICE-MARGINAL CHANNELS; TC
SPURS; AND THEORETICAL CONSID
TRUNCATED SPURS
LATERAL MORAINES C
MOBRAY TILL
GRISDALE TILL
SALMON SPRINGS ALPINE MAXIMUM
FRASER ALPINE MAXIMUM

WYNOOCHEE GLACIER PROFILES FOR MOBRAY AND GRISDALE ICE

(BASED ON UPPER LIMITS OF DRIFT, MORAINES, AND ICE-MARGINAL CHANNELS; TOPS OF TRUNCATED SPURS; AND THEORETICAL CONSIDERATIONS)

/\ TRUNCATED SPURS

--- LATERAL MORAINES OR ICE-MARGINAL CHANNELS

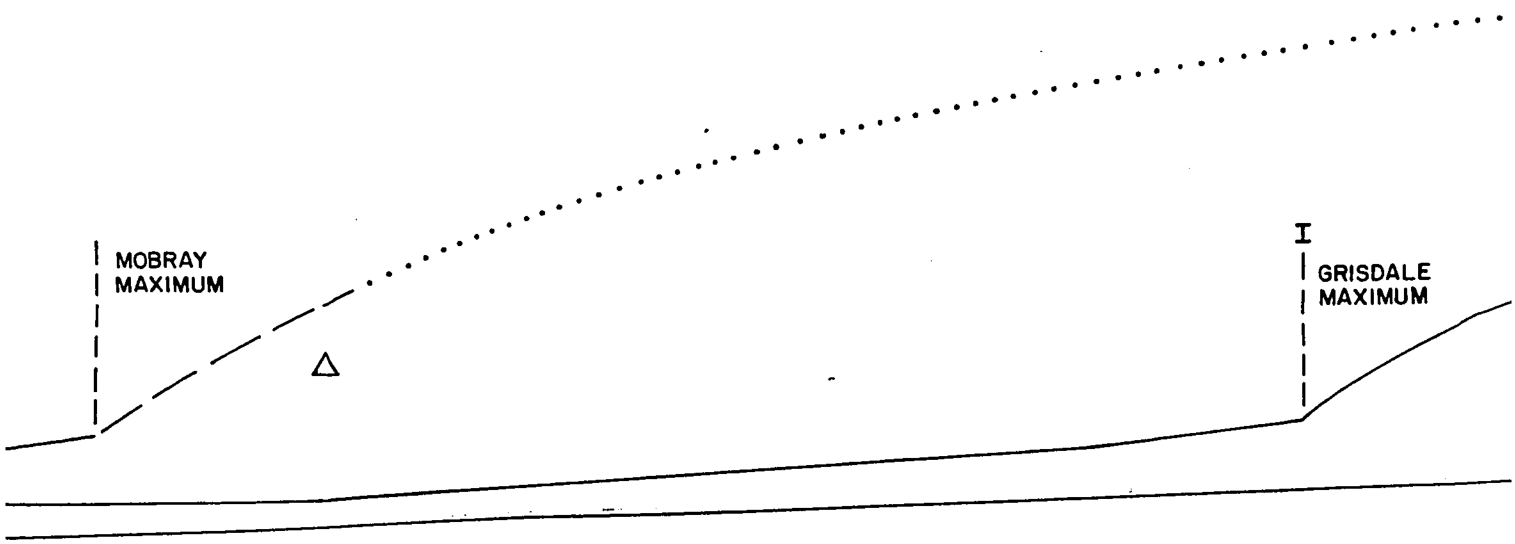
△ MOBRAY TILL

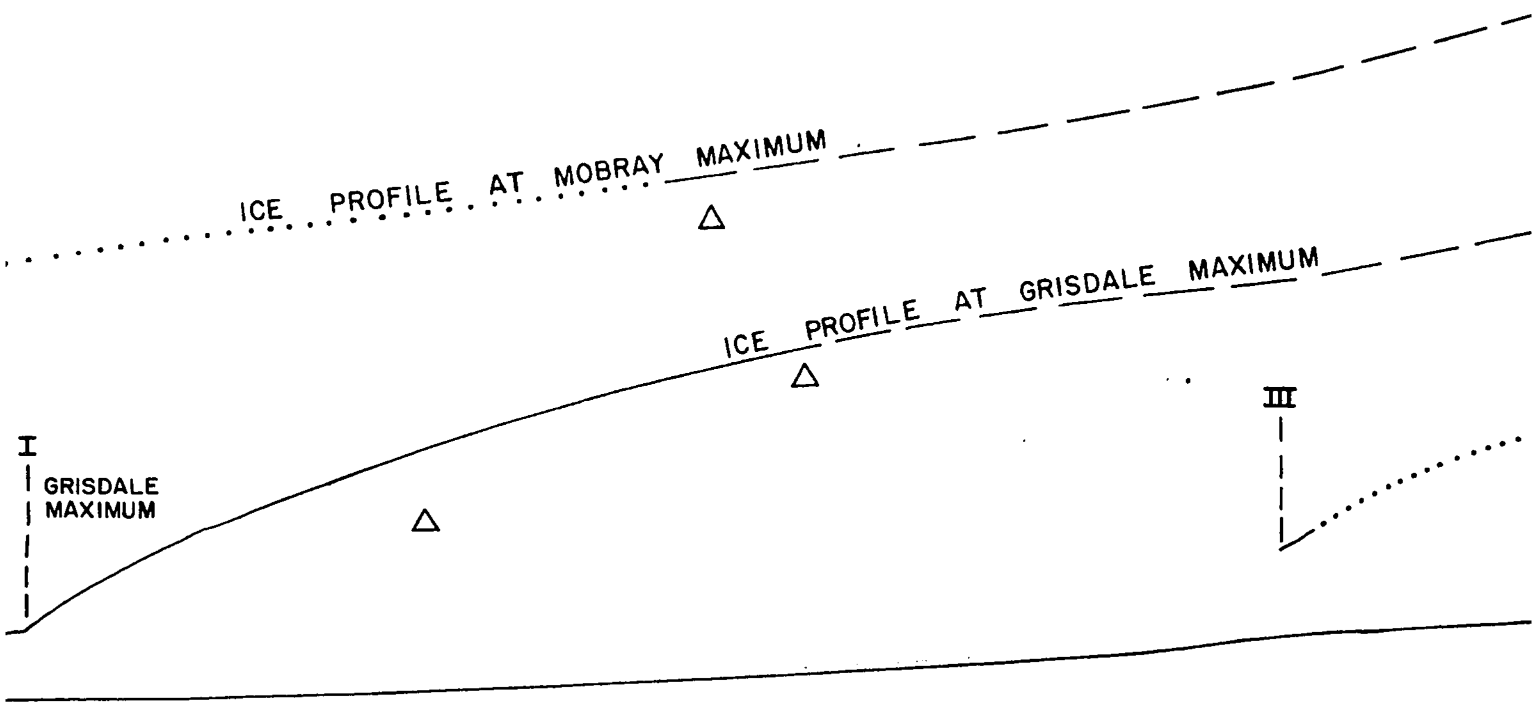
△ GRISDALE TILL

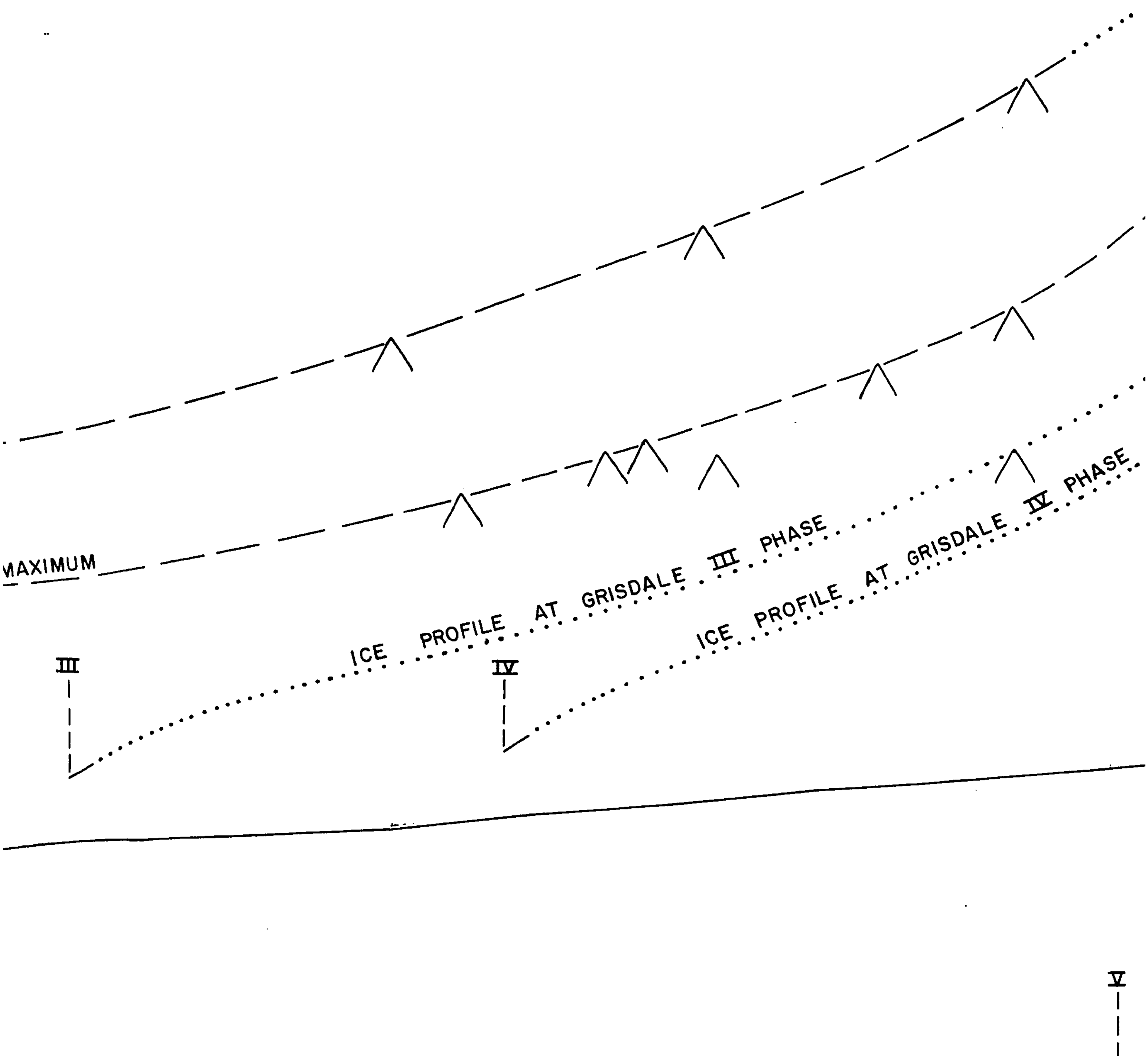
PINE MAXIMUM

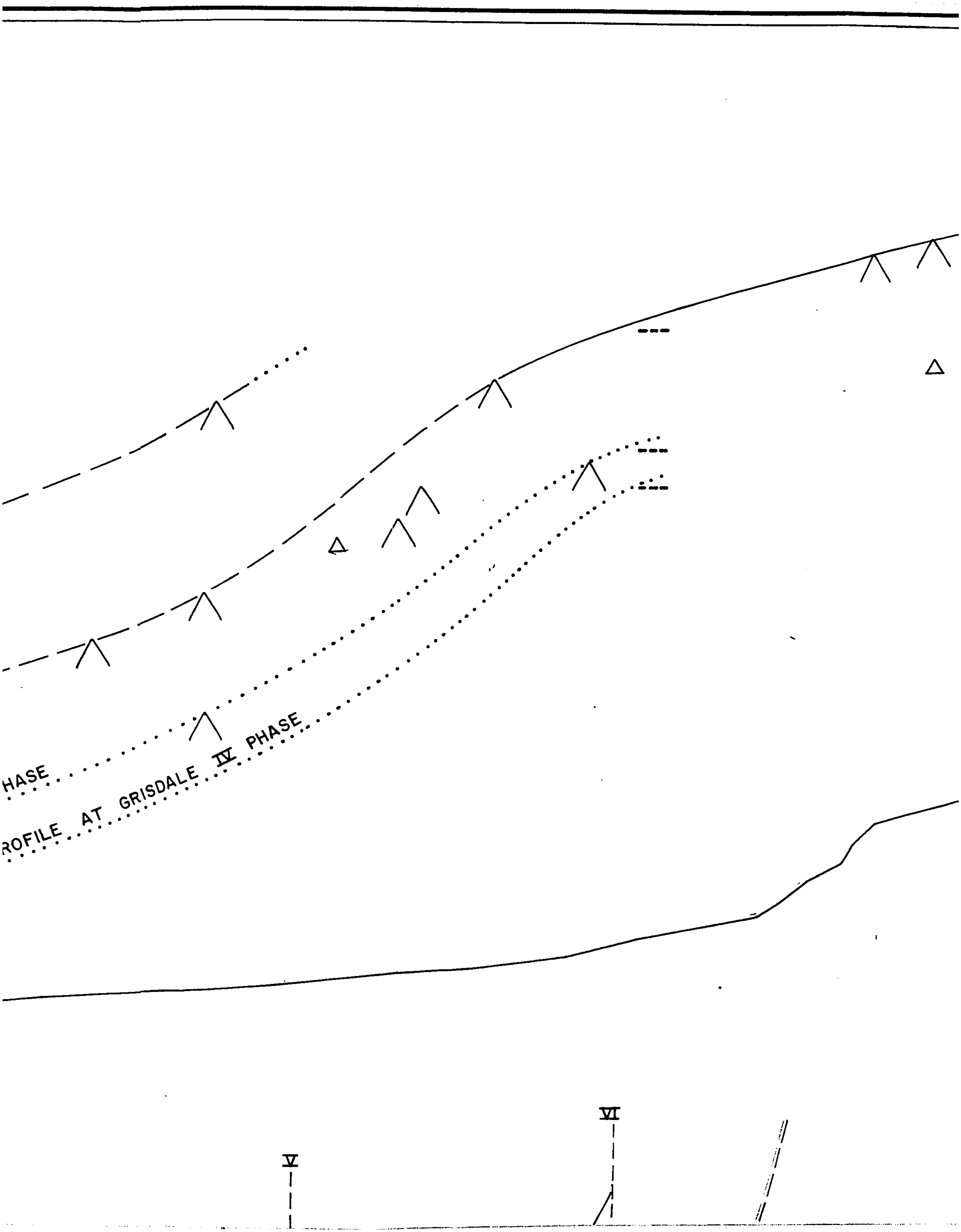
IMUM


MOBRAY
MAXIMUM

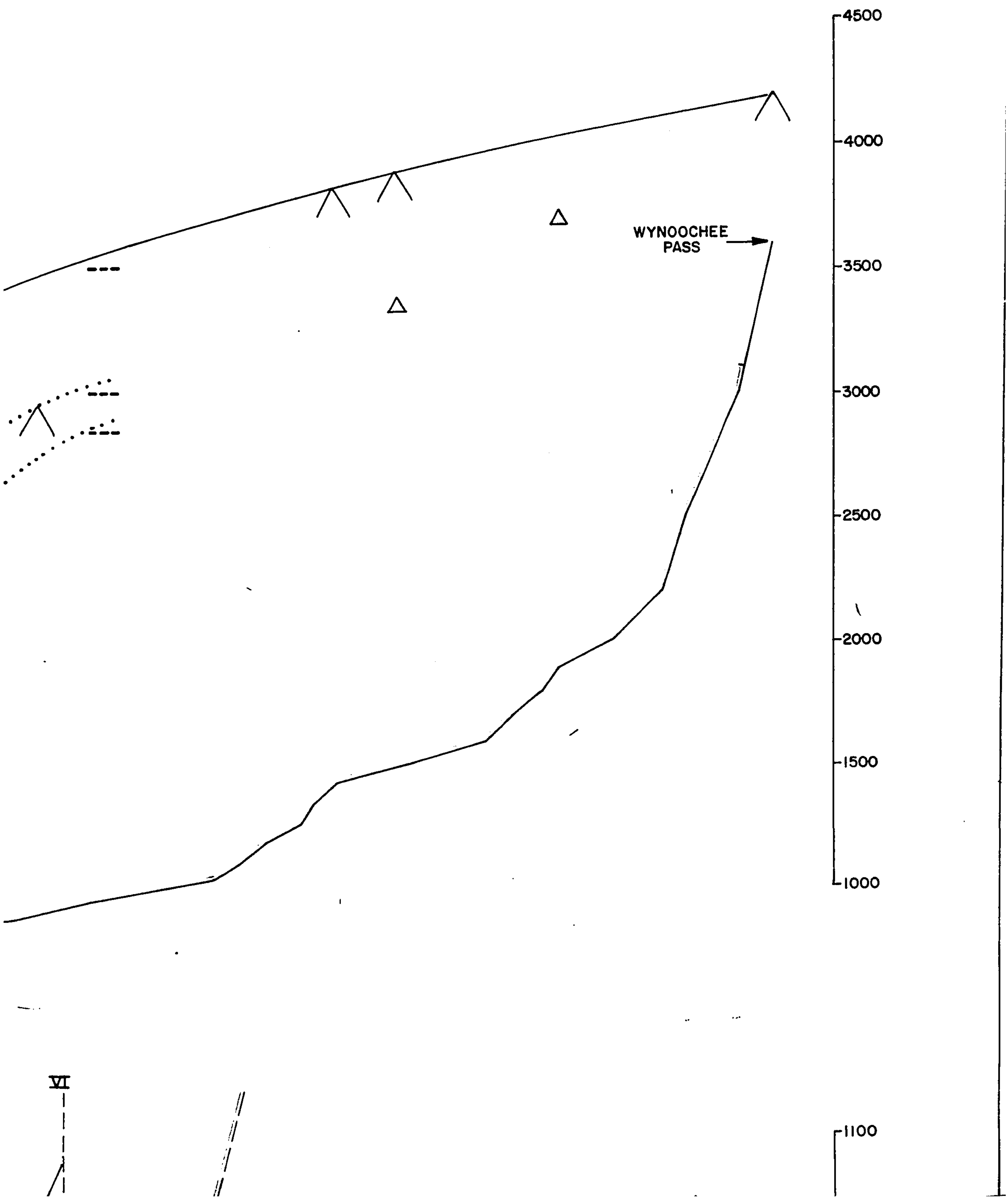

MOBRAY
MAXIMUM
GRISDALE
MAXIMUM

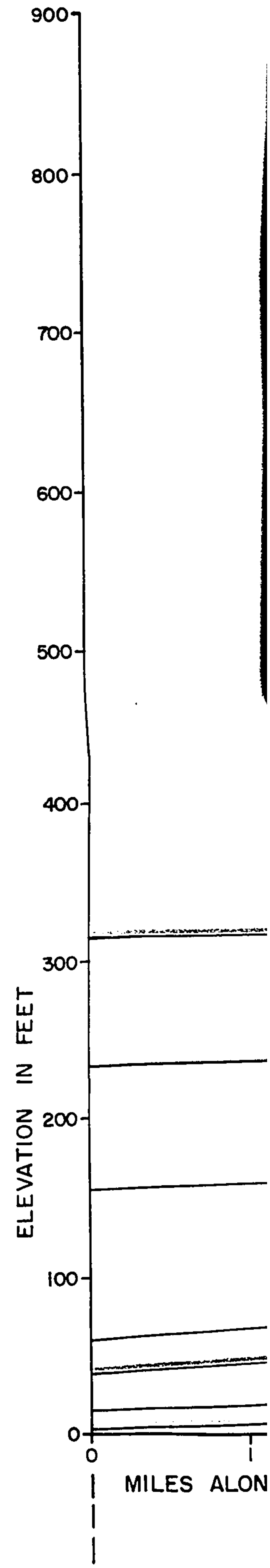

ICE PROFILE AT MOBRAY MAXIMUM
ICE PROFILE AT GRISDALE MAXIMUM
I
GRISDALE MAXIMUM
III


MAXIMUM
ICE PROFILE AT GRISDALE III PHASE
ICE PROFILE AT GRISDALE IV PHASE
III
IV
V



HASE
ROFILE AT GRISDALE IV PHASE
V
VI


4500
4000
WYNOOCHEE PASS
3500
3000
2500
2000
1500
1000
VI
1100



900
800
700
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400
300
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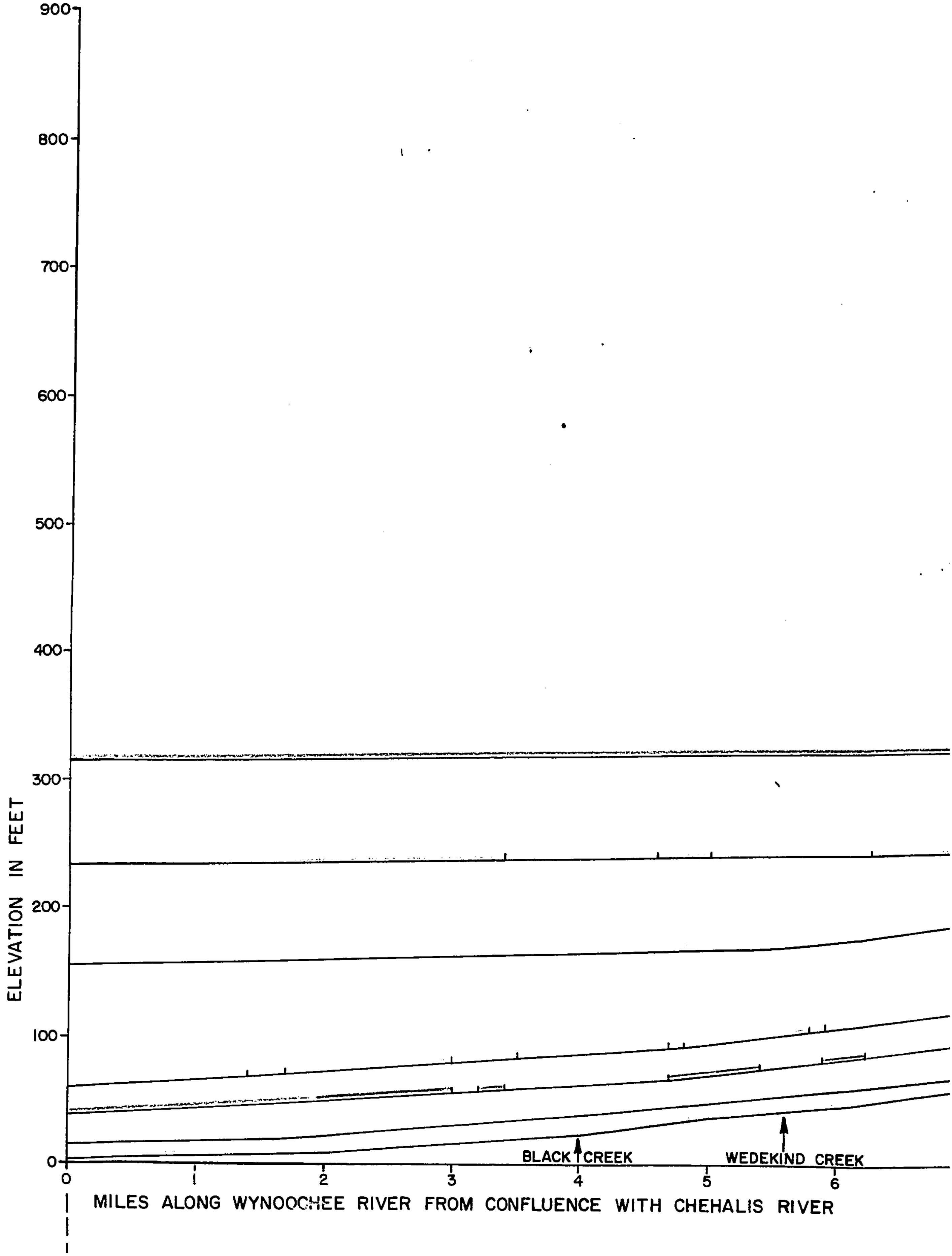
100
0
ELEVATION IN FEET
0
1
MILES ALON


900
800
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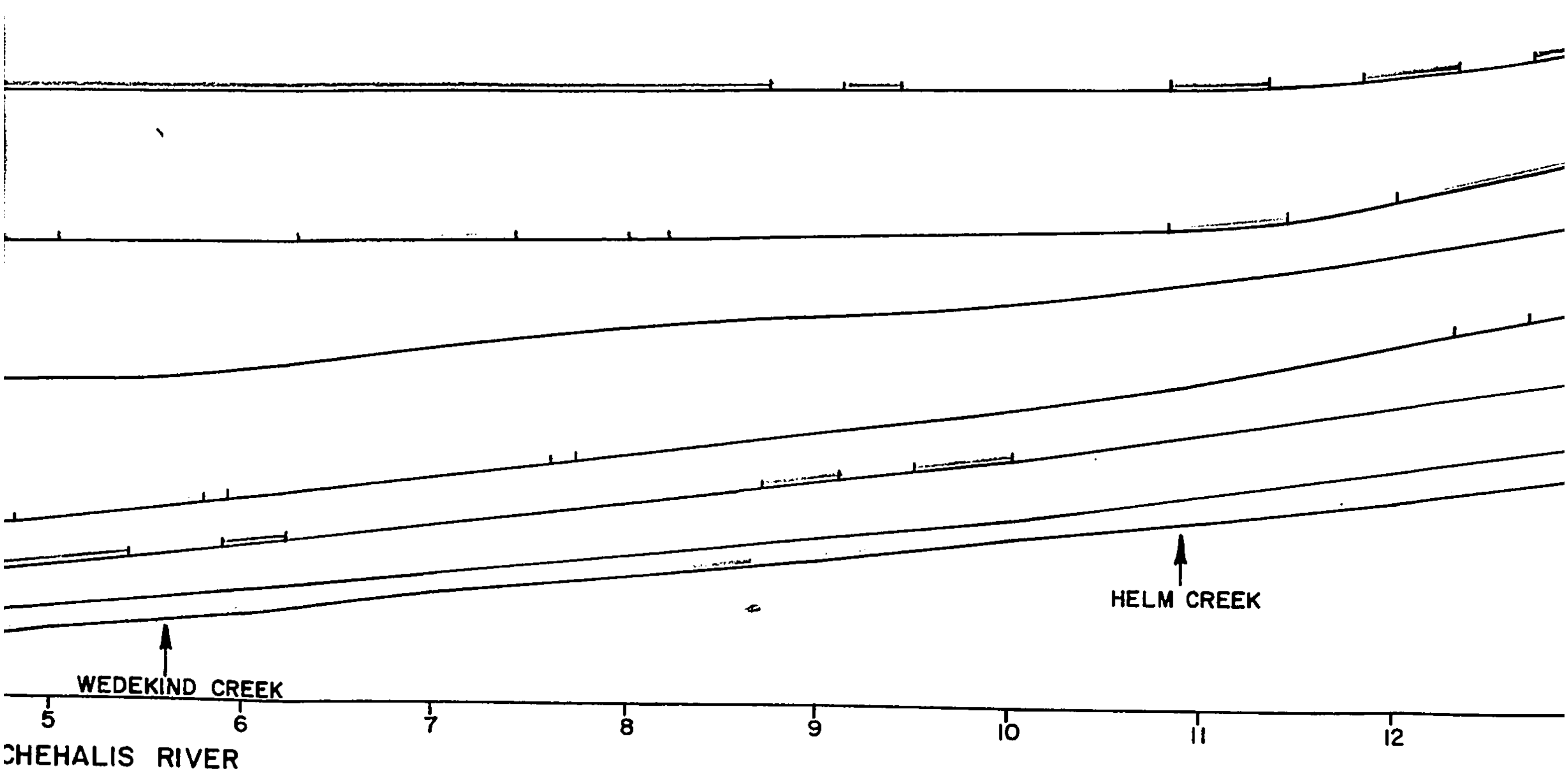
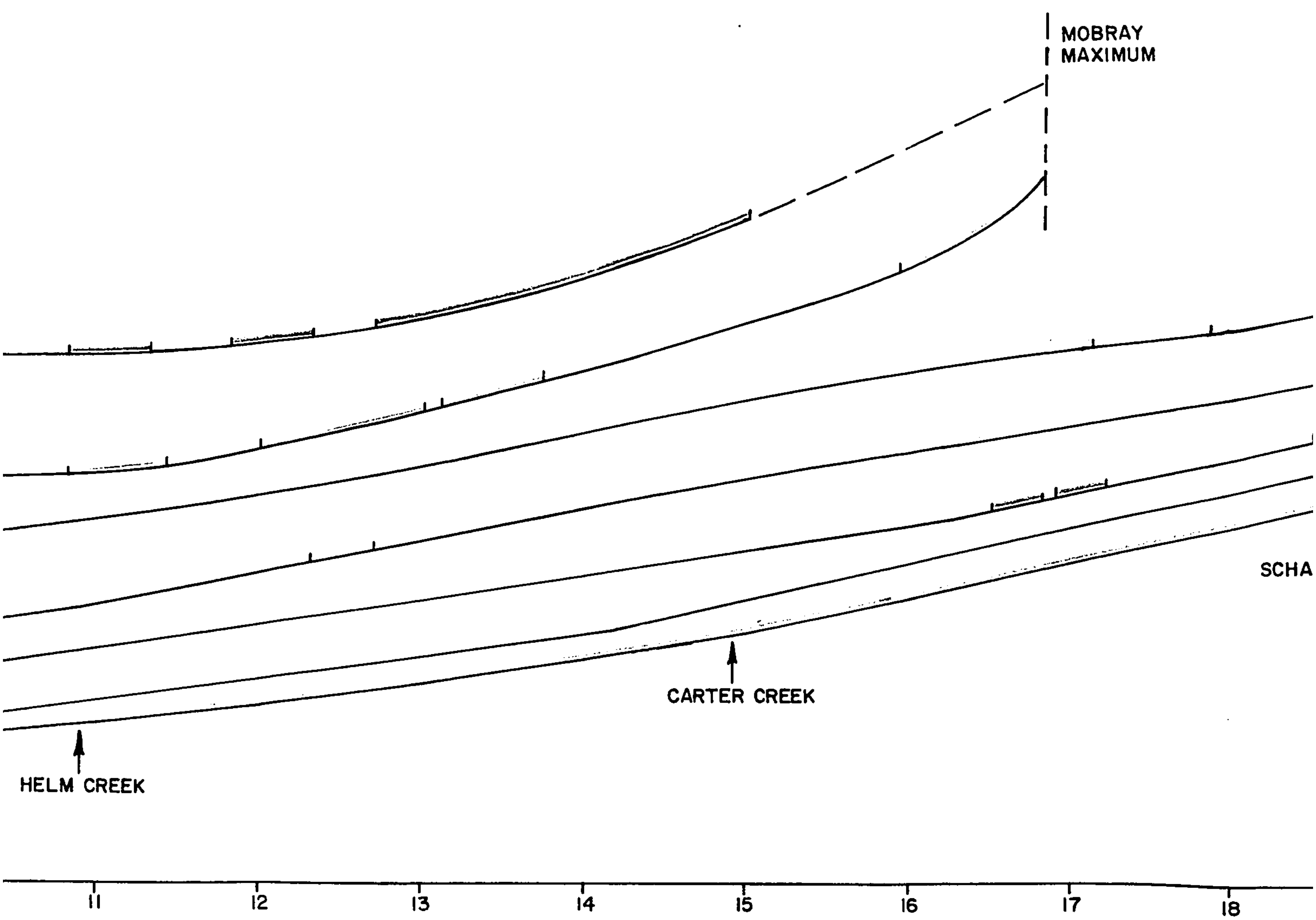
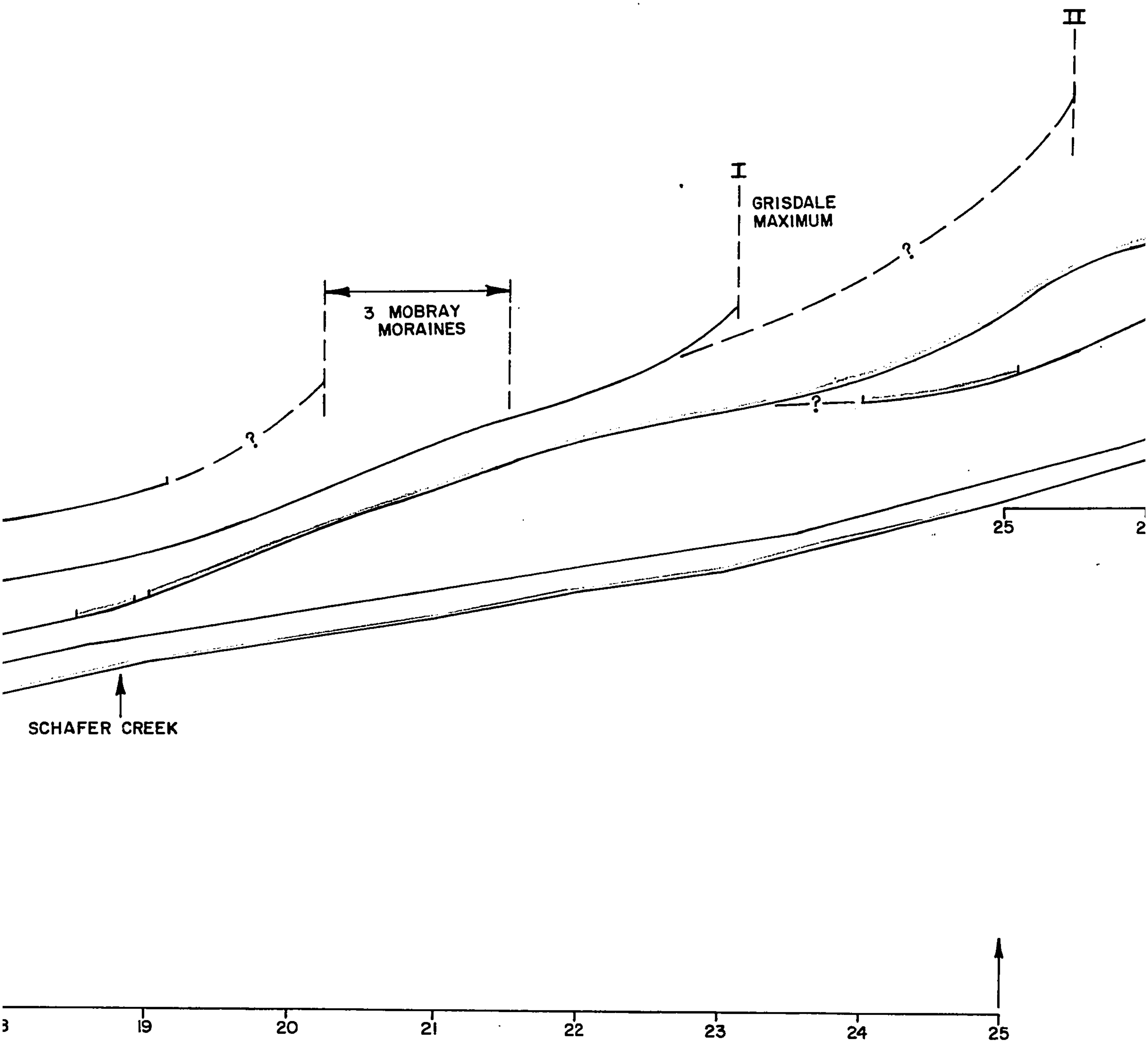
400
300
200
100
0
ELEVATION IN FEET
0
1
2
3
4
5
6
BLACK CREEK
WEDEKIND CREEK
MILES ALONG WYNOOCHEE RIVER FROM CONFLUENCE WITH CHEHALIS RIVER

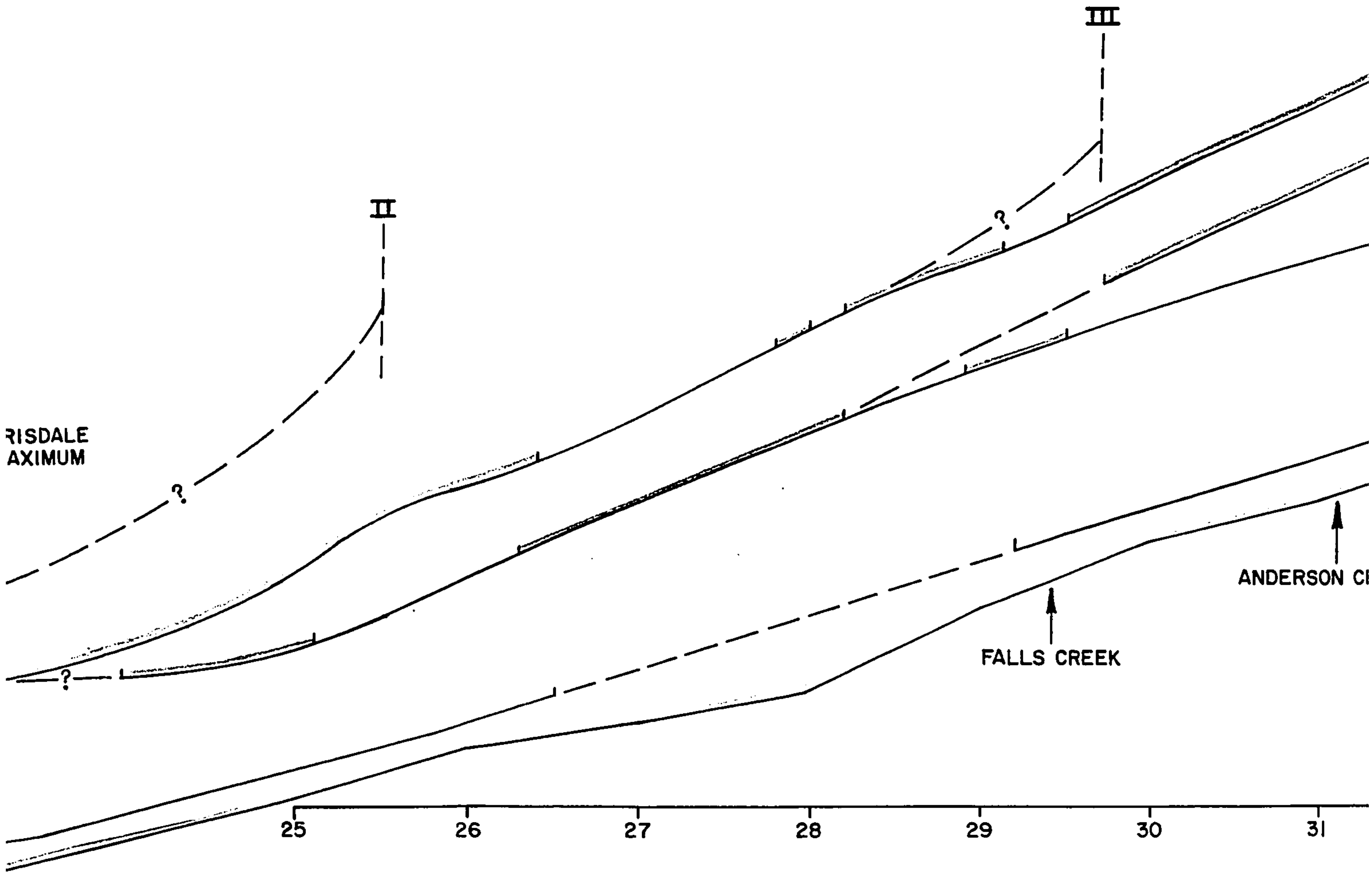


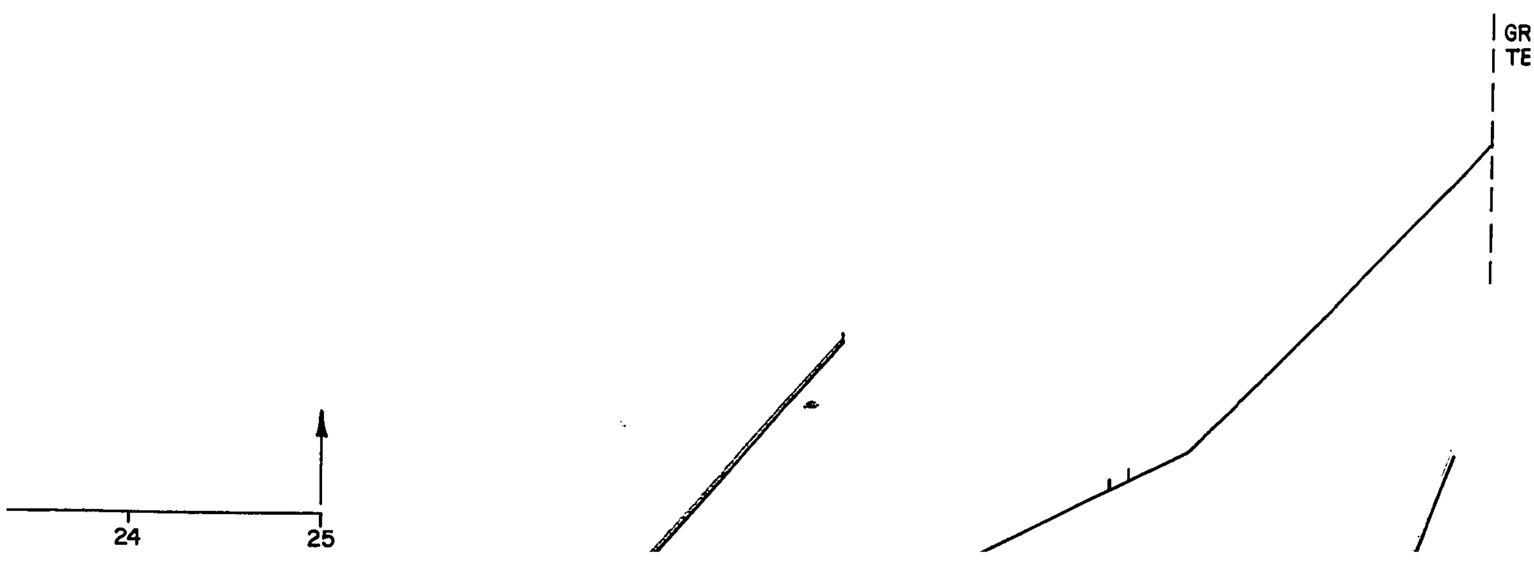
HELM CREEK
WEDEKIND CREEK
5
6
7
8
9
10
11
12
CHEHALIS RIVER


MOBRAY MAXIMUM
SCHA
CARTER CREEK
HELM CREEK
11
12
13
14
15
16
17
18



II
I
GRISDALE
MAXIMUM
3 MOBRAY
MORAINES
?
?
?
25
2
SCHAFER CREEK
19
20
21
22
23
24
25


III
II
RISDALE
AXIMUM
?
?
?
ANDERSON C
FALLS CREEK
25
26
27
28
29
30
31


GR
TE
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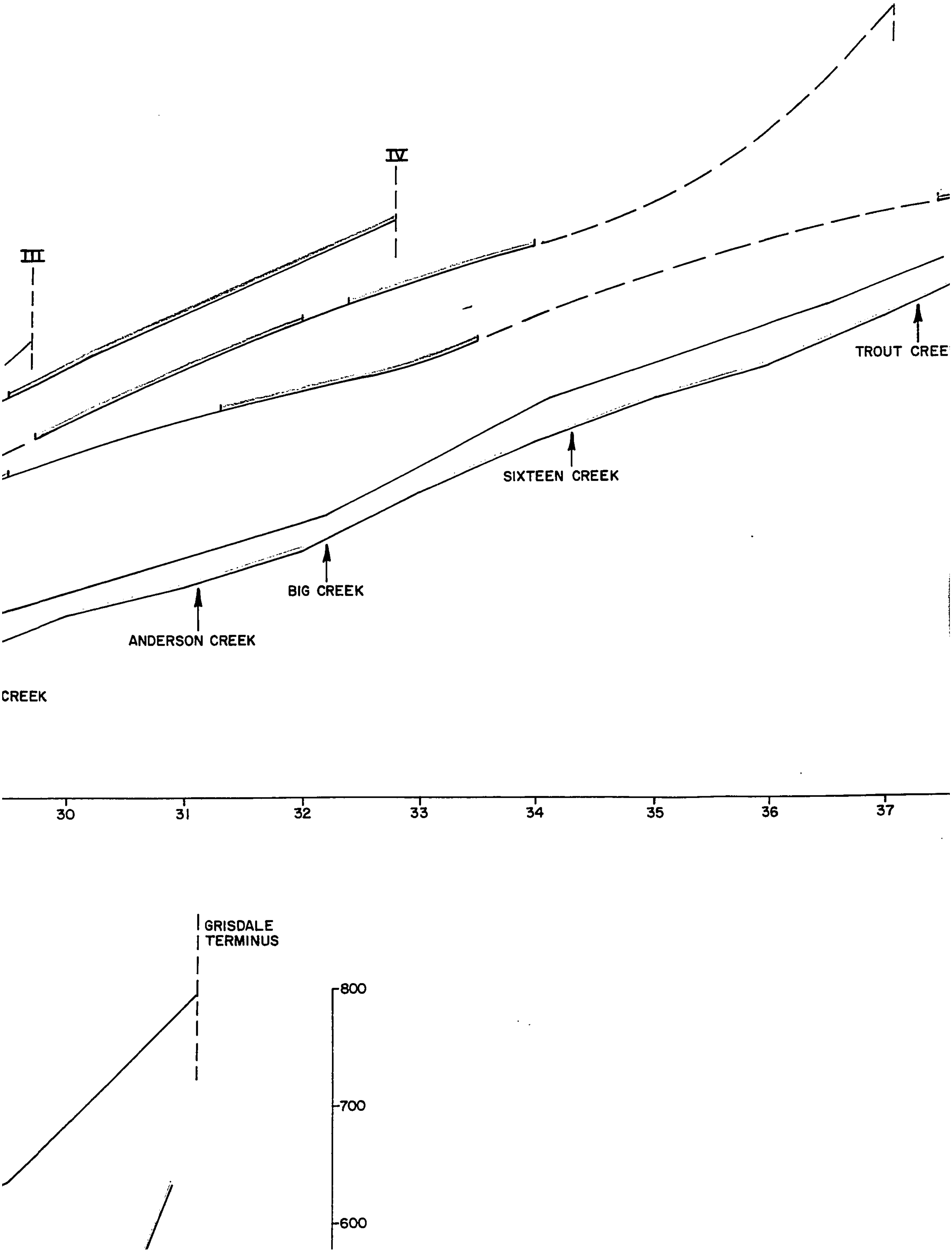
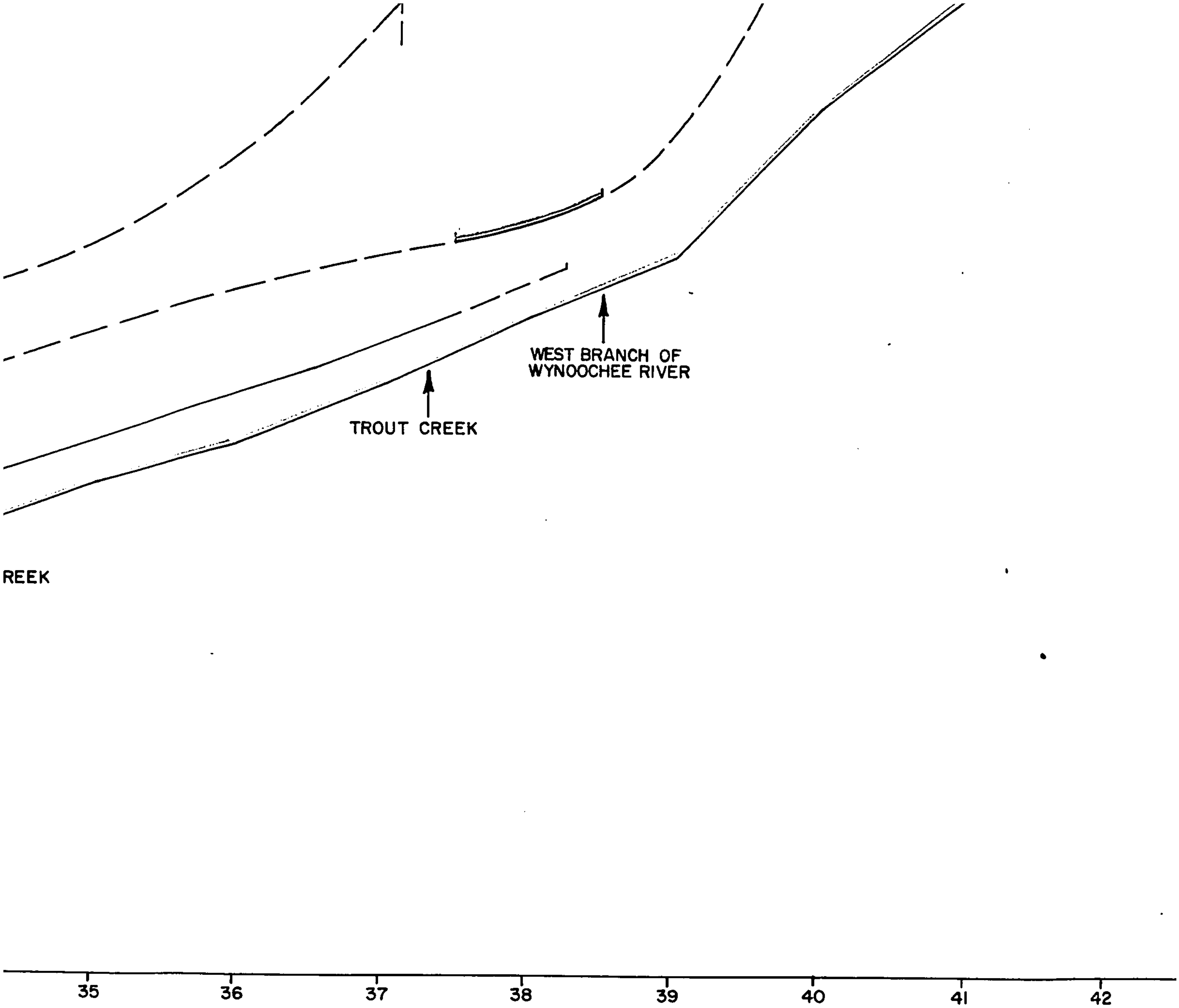
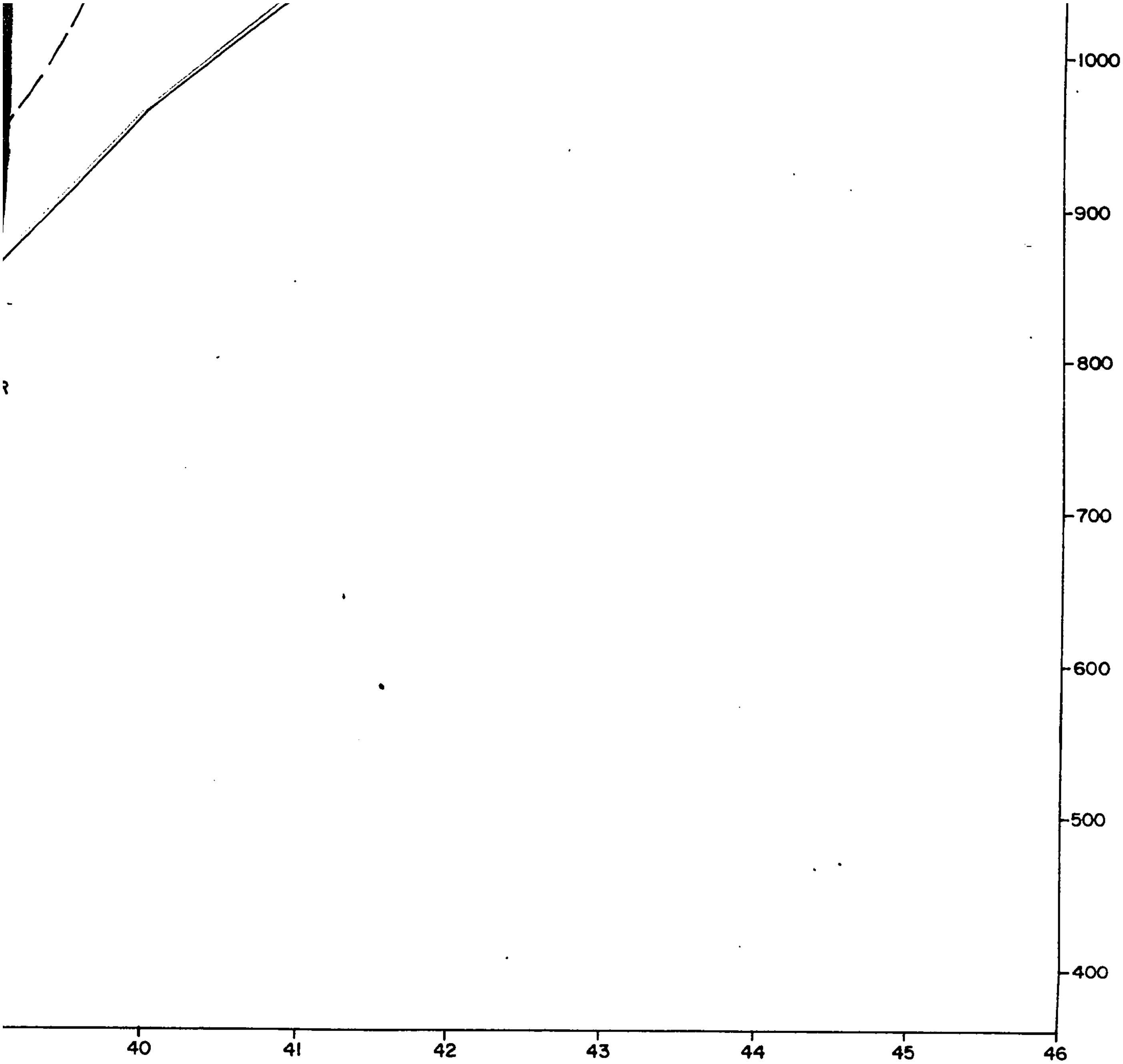

III
IV
TROUT CREE
SIXTEEN CREEK
BIG CREEK
ANDERSON CREEK
CREEK
30
31
32
33
34
35
36
37
GRISDALE
TERMINUS
800
700
600


WEST BRANCH OF
WYNOOCHEE RIVER
TROUT CREEK
REEK
35
36
37
38
39
40
41
42


1000
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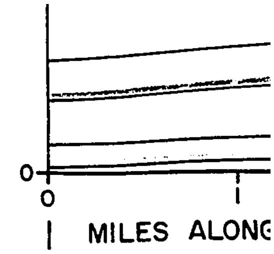
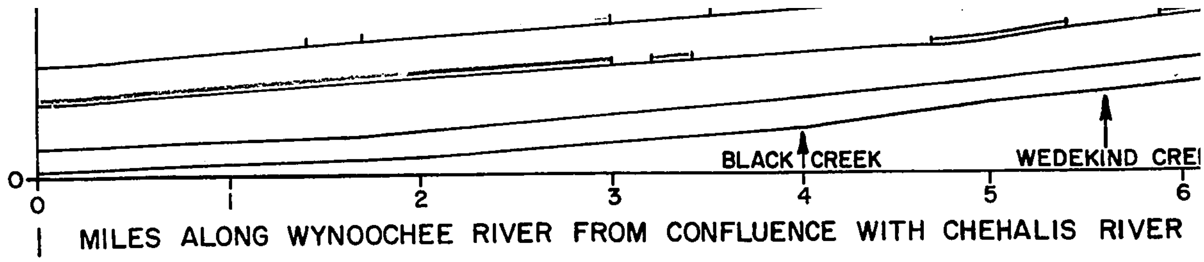

0
0
MILES ALONG


BLACK CREEK
WEDEKIND CRE
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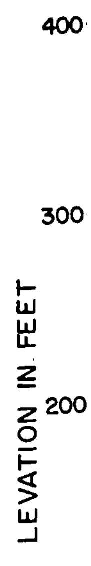
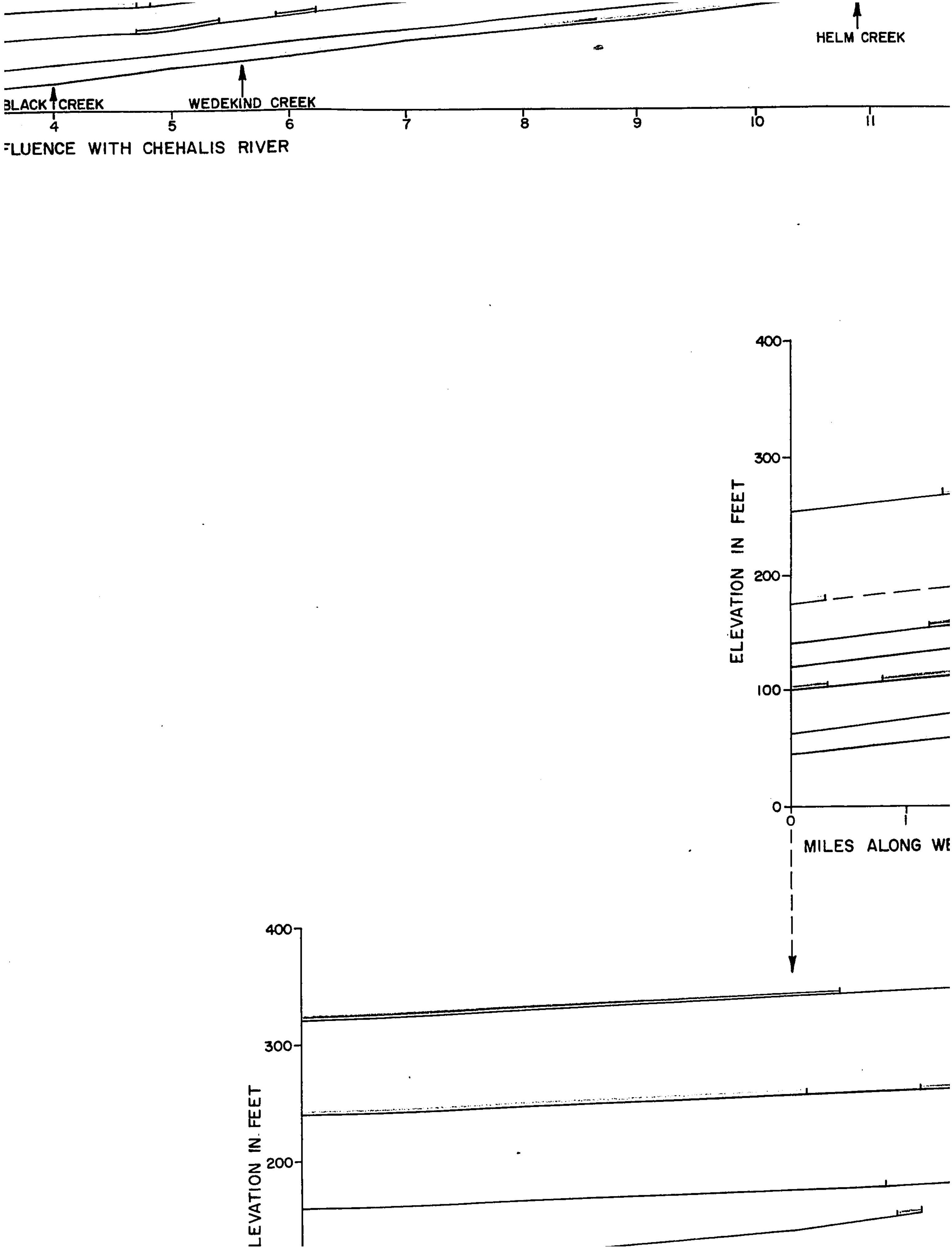
6
MILES ALONG WYNOOCHEE RIVER FROM CONFLUENCE WITH CHEHALIS RIVER


400
300
200
LEVATION IN FEET


HELM CREEK
BLACK CREEK
WEDEKIND CREEK
4
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6
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8
9
10
11
FLUENCE WITH CHEHALIS RIVER
400
300
200
100
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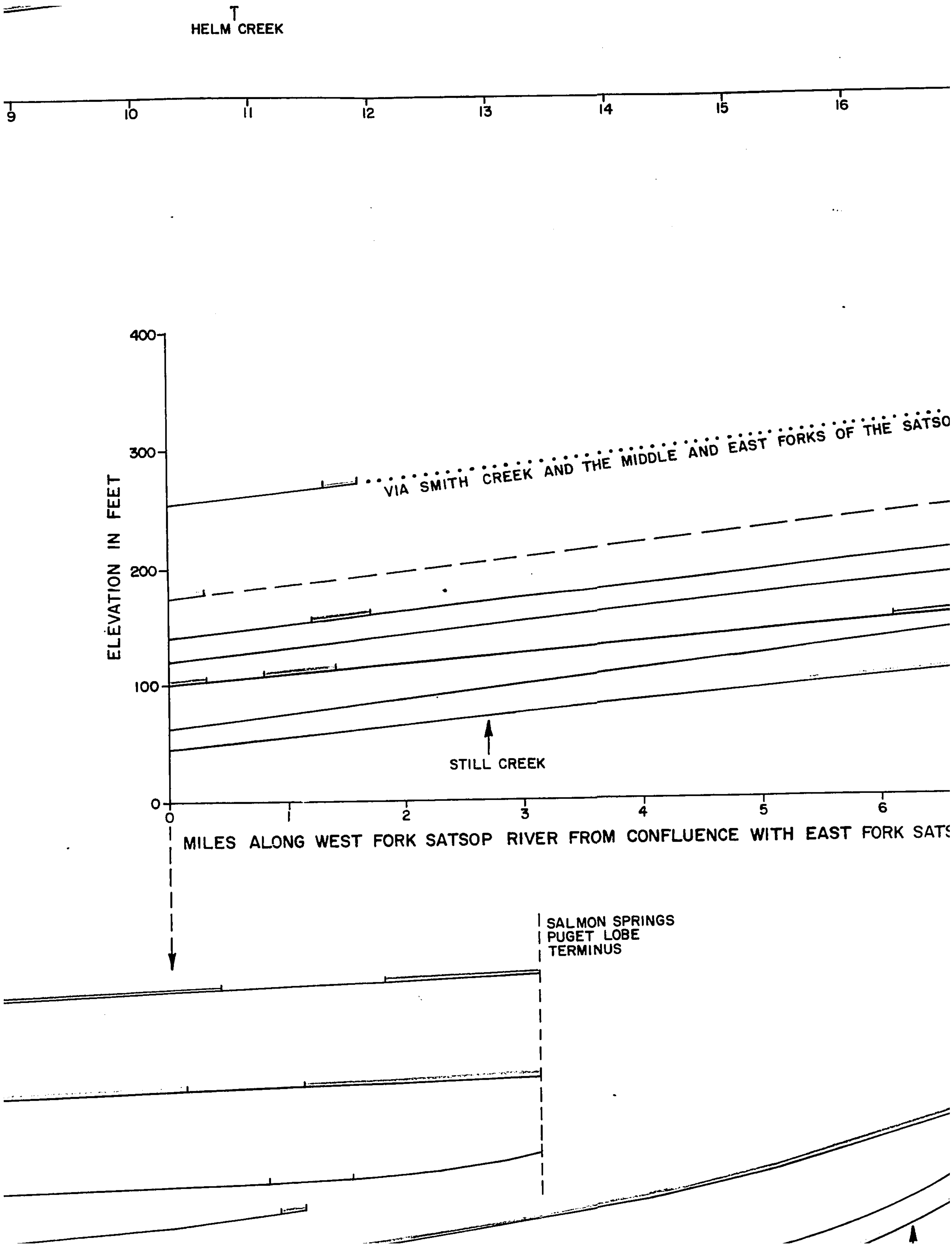
1
ELEVATION IN FEET
MILES ALONG WE
400
300
200
LEVATION IN FEET


HELM CREEK
9
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400
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ELEVATION IN FEET
VIA SMITH CREEK AND THE MIDDLE AND EAST FORKS OF THE SATSO
STILL CREEK
0
1
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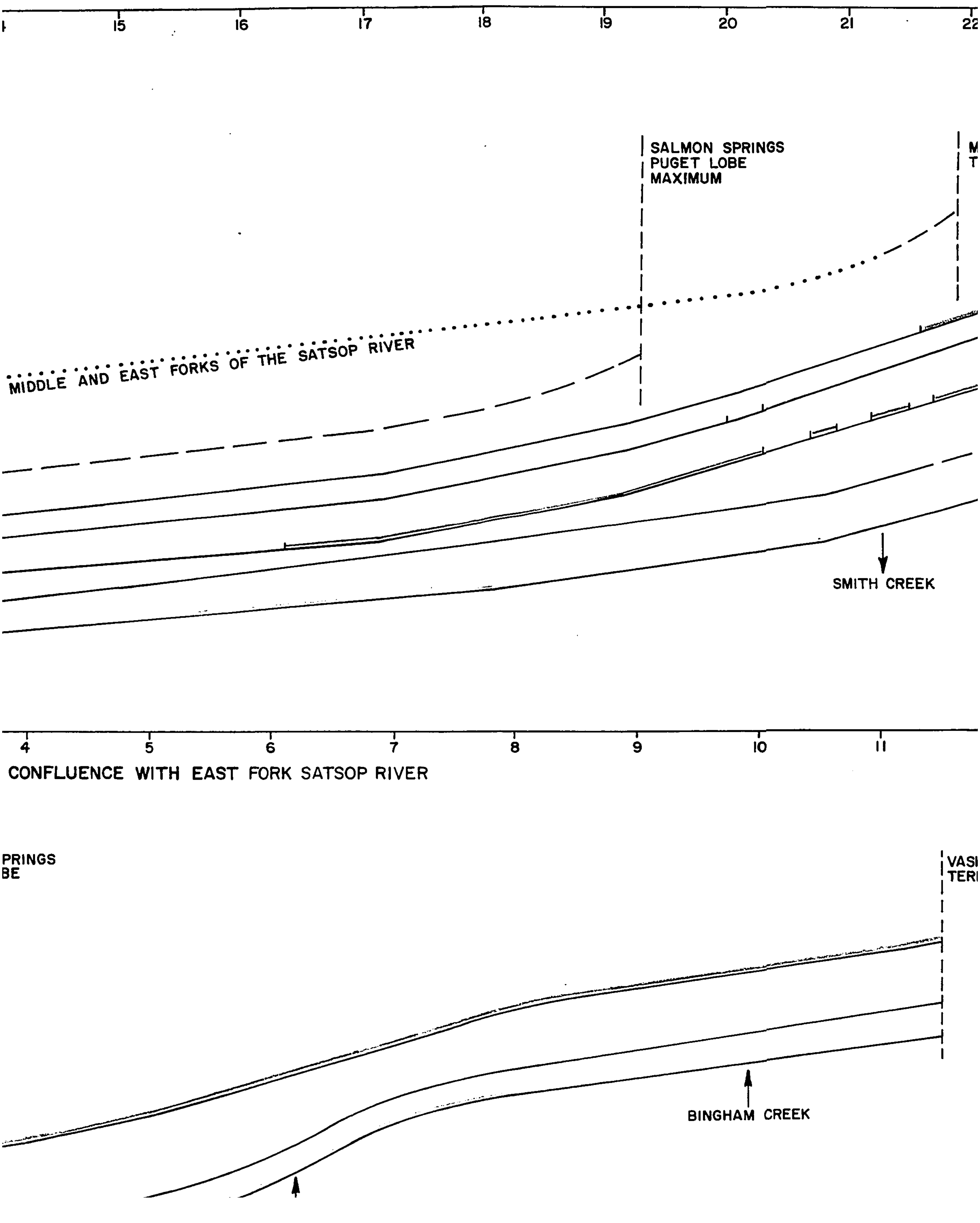
5
6
MILES ALONG WEST FORK SATSOP RIVER FROM CONFLUENCE WITH EAST FORK SATS
SALMON SPRINGS
PUGET LOBE
TERMINUS



15
16
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20
21
SALMON SPRINGS
PUGET LOBE
MAXIMUM
MIDDLE AND EAST FORKS OF THE SATSOP RIVER
SMITH CREEK
4
5
6
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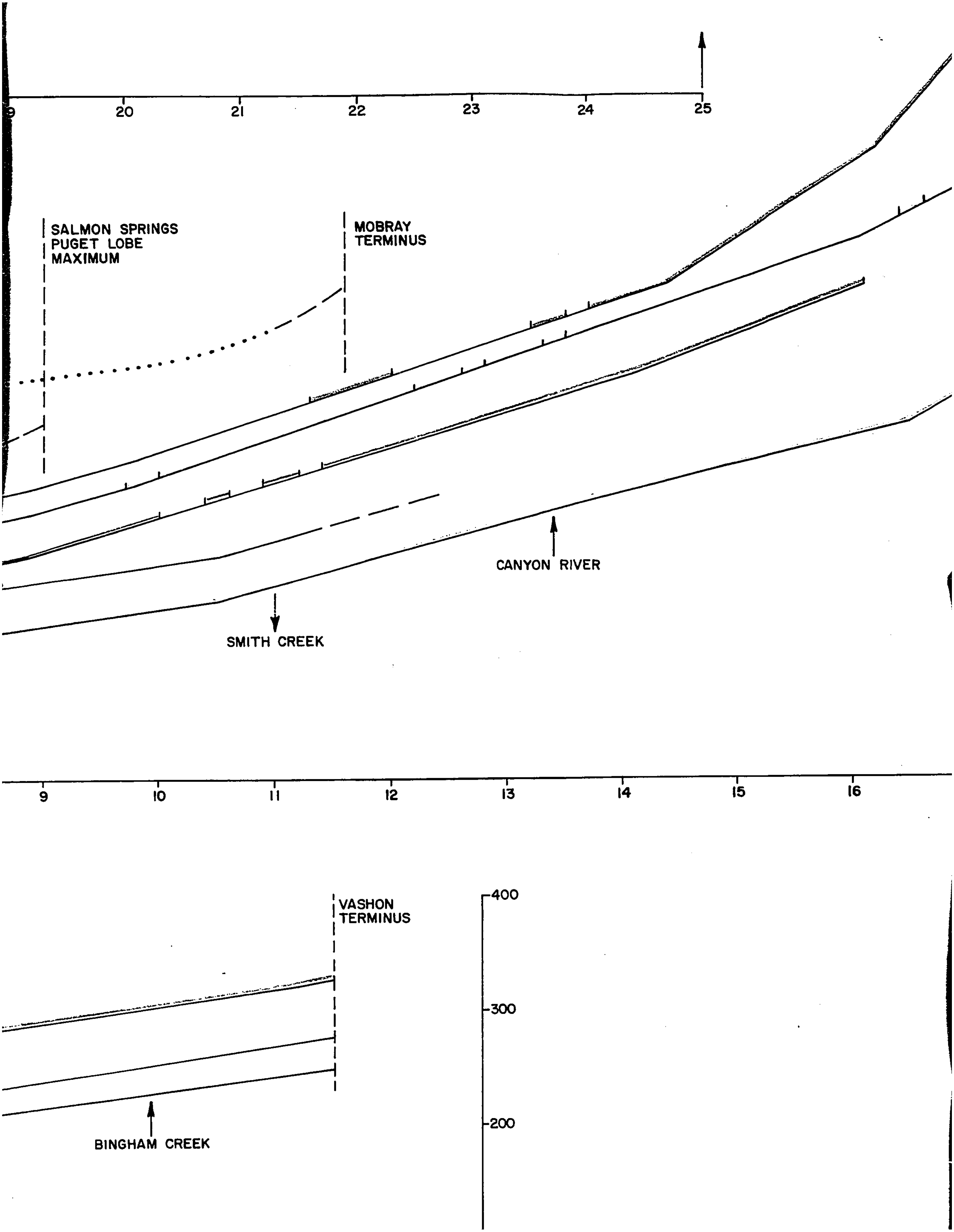
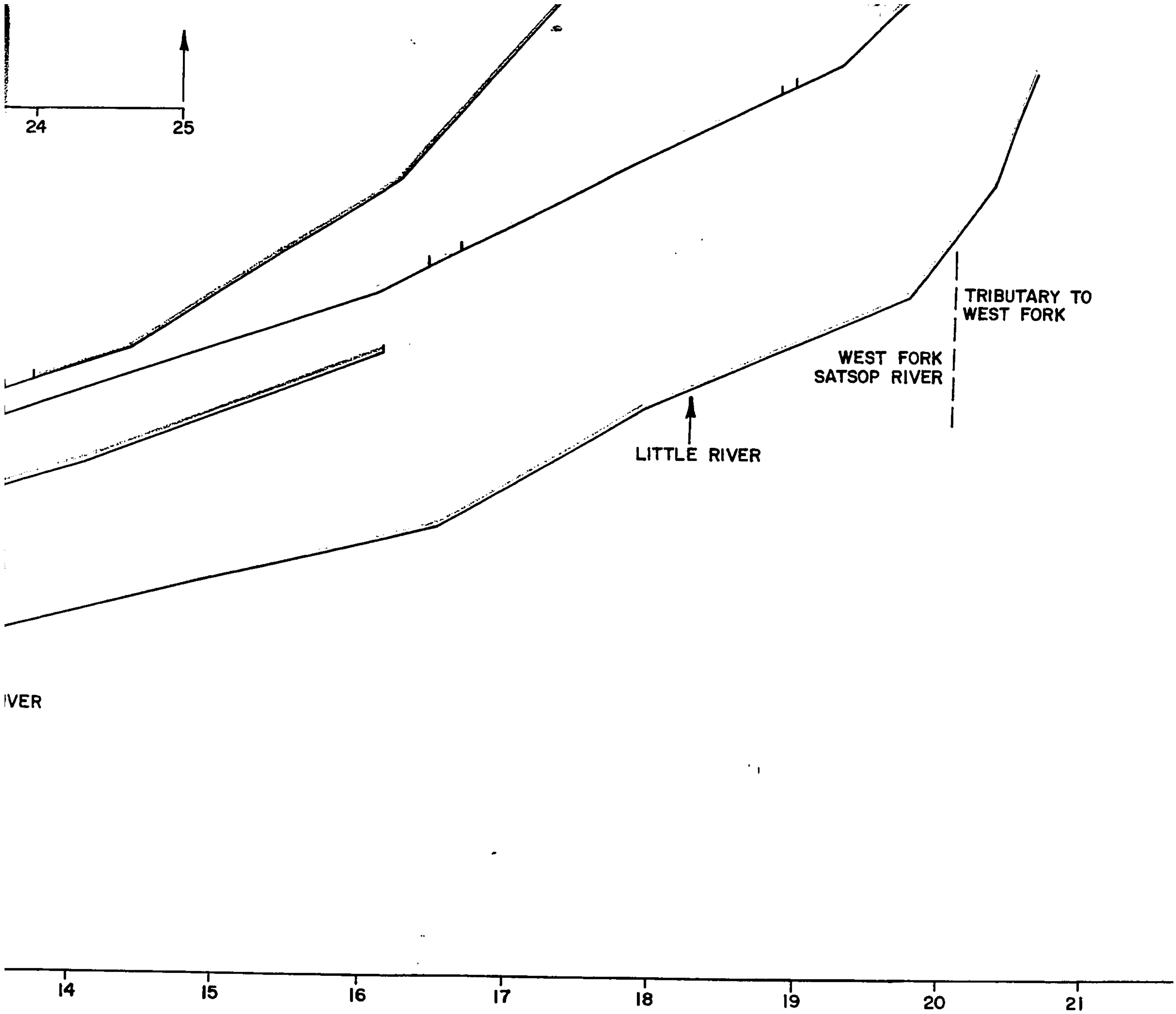
9
10
11
CONFLUENCE WITH EAST FORK SATSOP RIVER
BINGHAM CREEK


20
21
22
23
24
25
SALMON SPRINGS
PUGET LOBE
MAXIMUM
MOBRAY
TERMINUS
CANYON RIVER
SMITH CREEK
9
10
11
12
13
14
15
16
VASHON
TERMINUS
400
300
200
BINGHAM CREEK



24
25
TRIBUTARY TO WEST FORK
WEST FORK SATSOP RIVER
LITTLE RIVER
IVER
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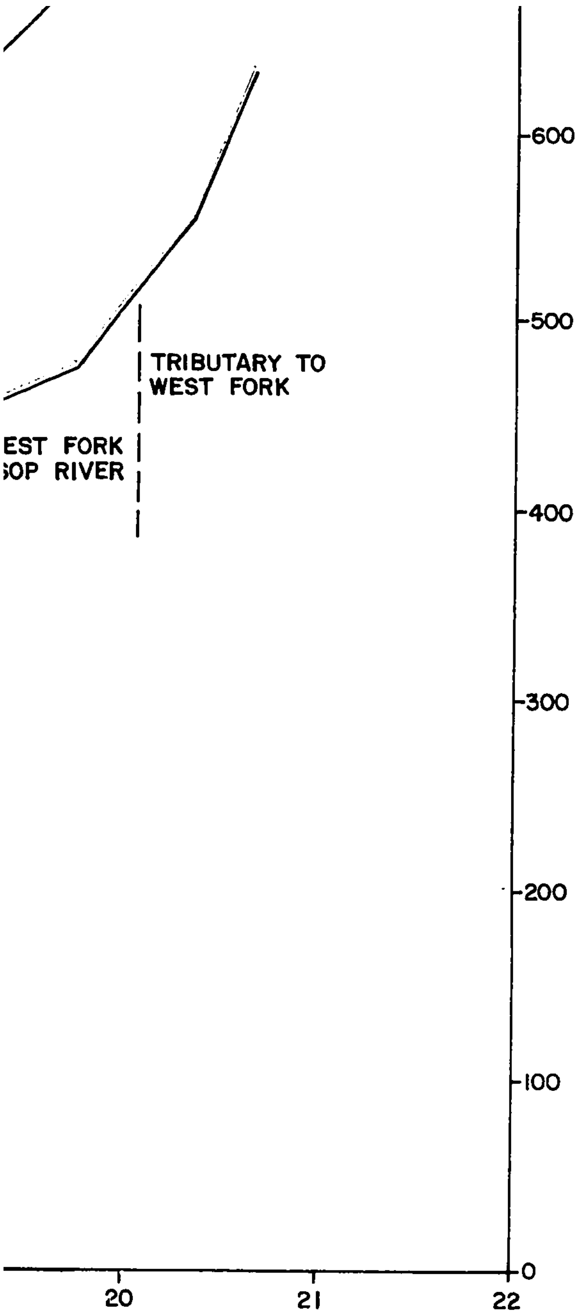
17
18
19
20
21


600
500
TRIBUTARY TO WEST FORK
EST FORK
;OP RIVER
400
300
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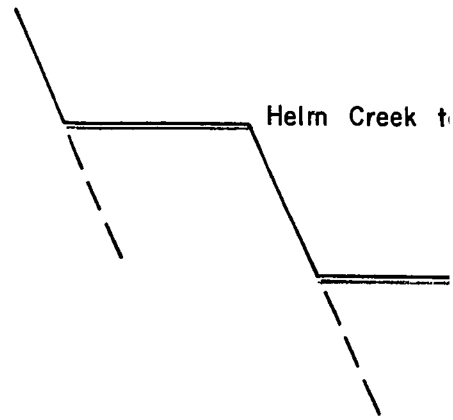
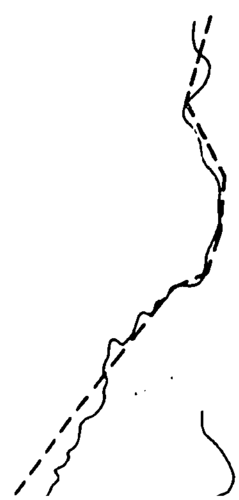
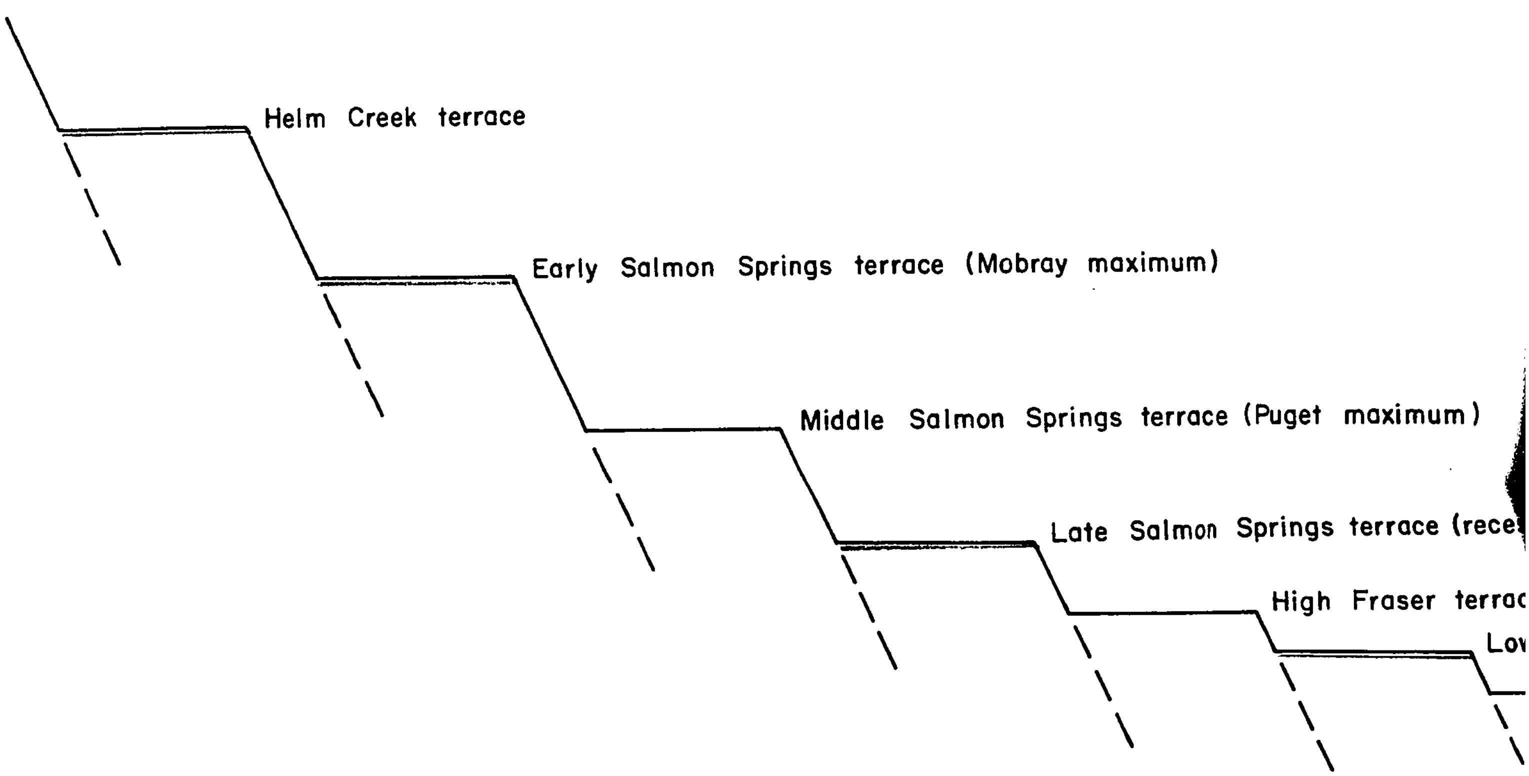
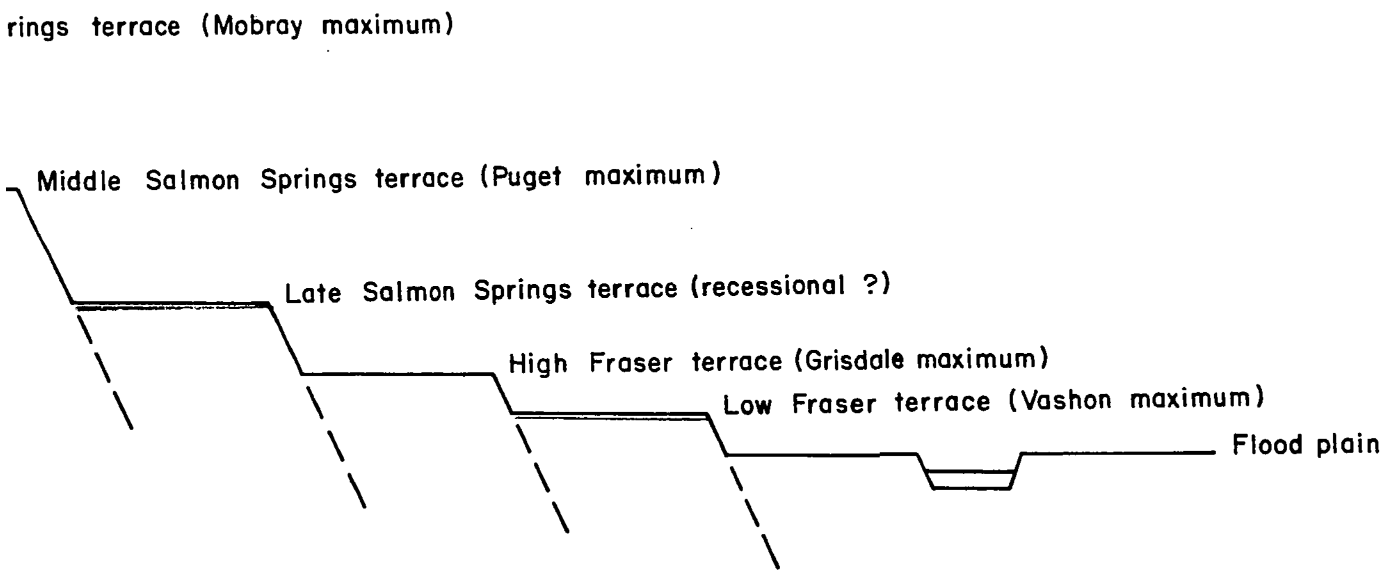
100
0
20
21
22


Helm Creek t

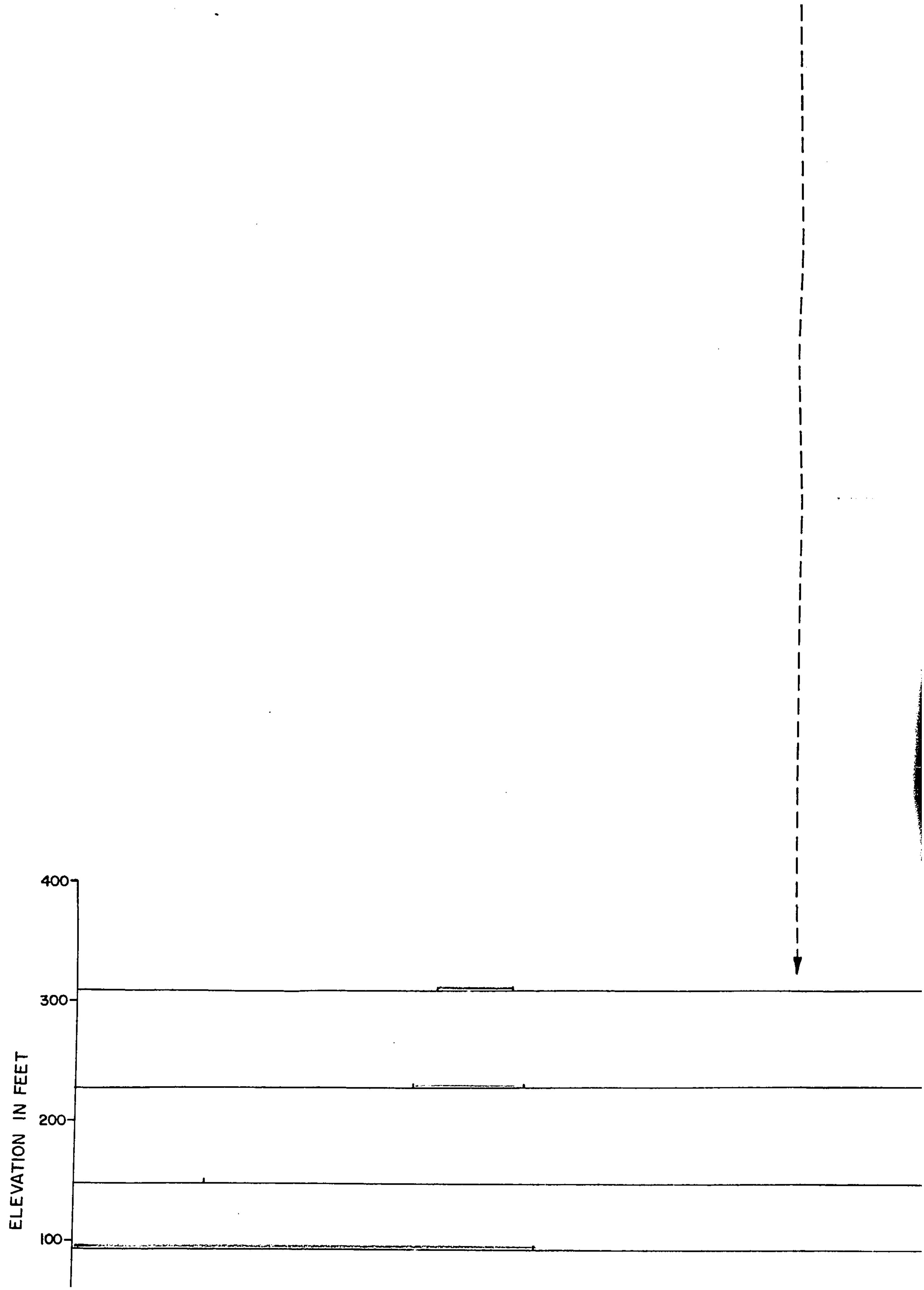


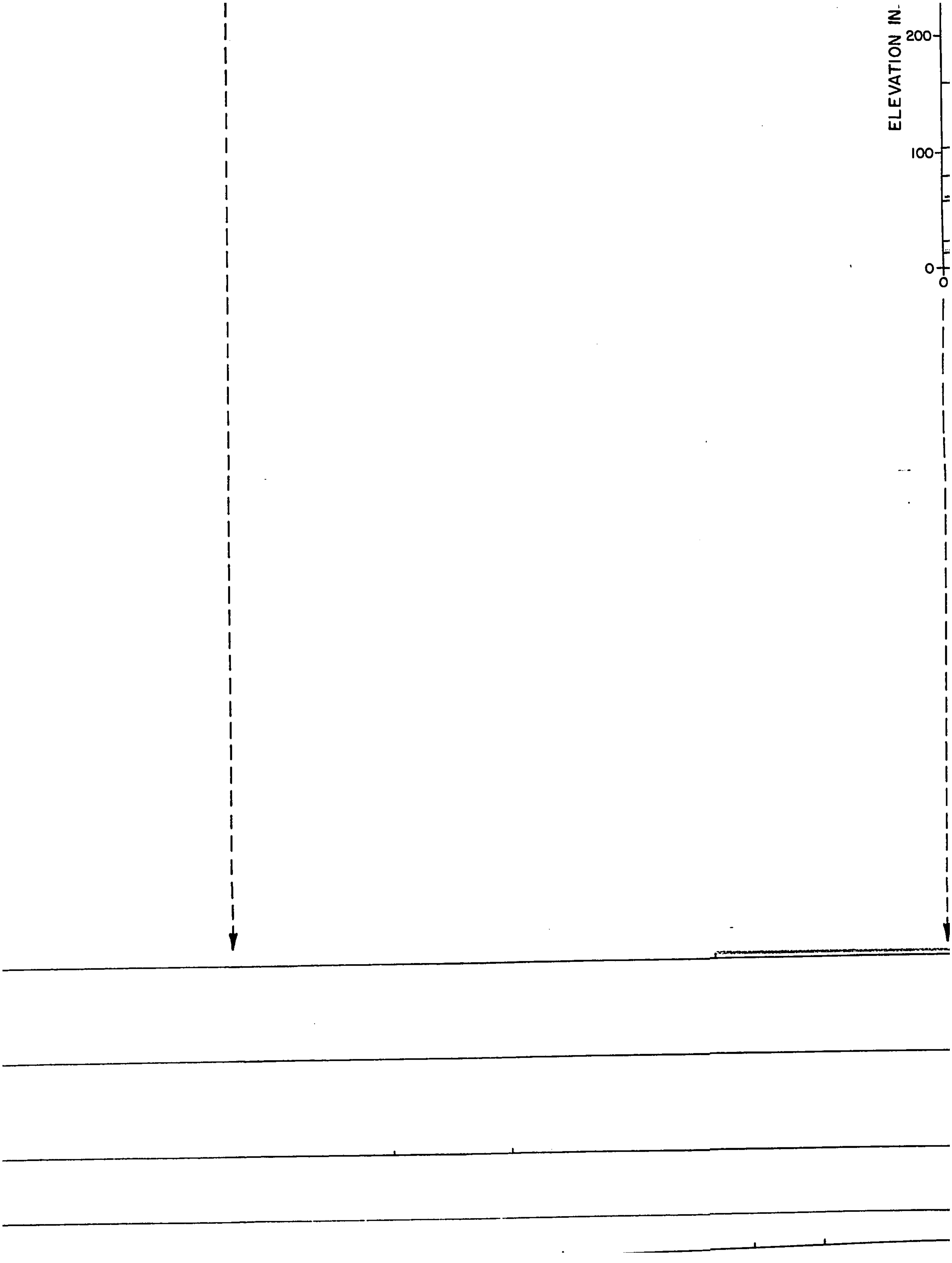


KEY TO TERRACES

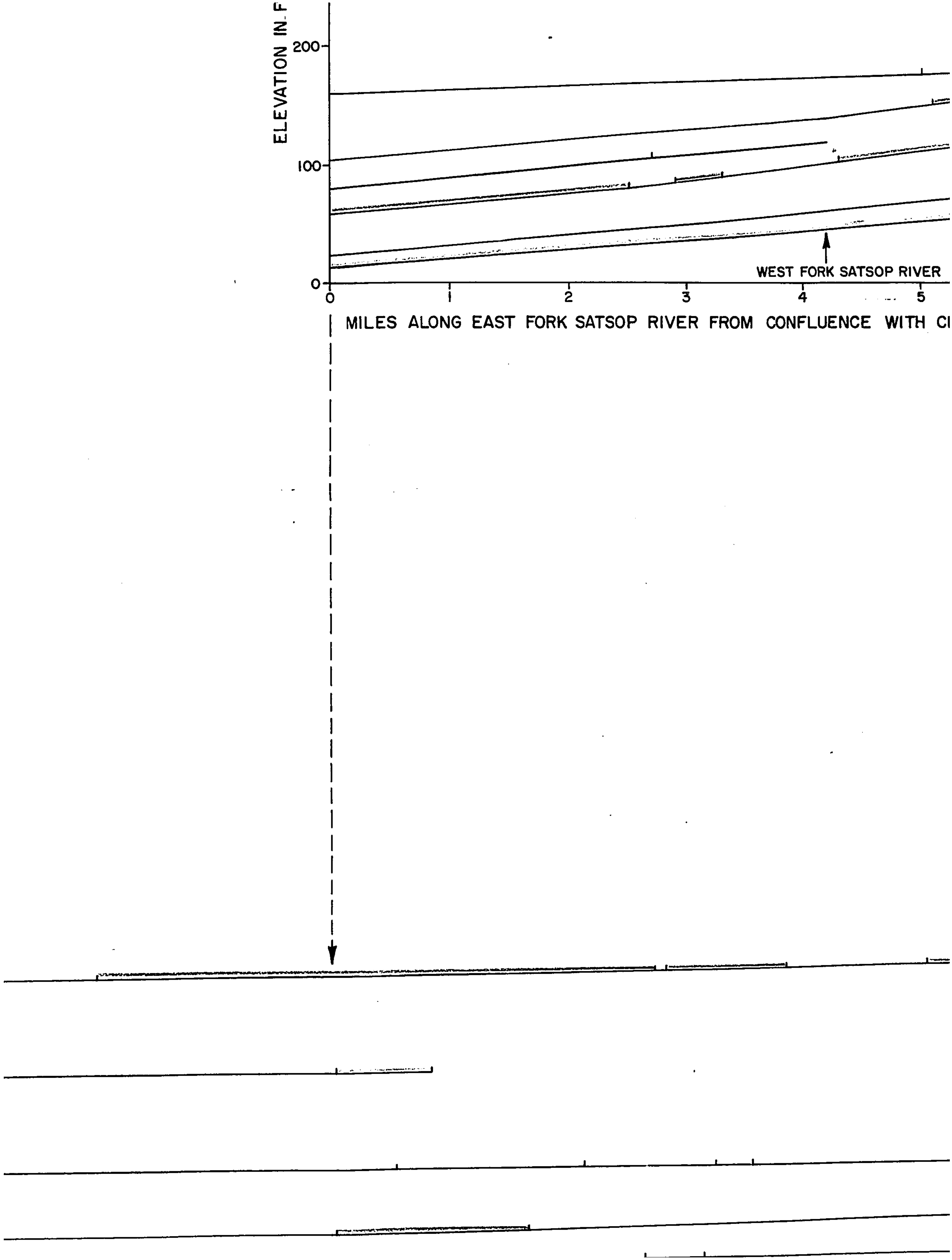

rings terrace (Mobray maximum)
Middle Salmon Springs terrace (Puget maximum)
Late Salmon Springs terrace (recessional ?)
High Fraser terrace (Grisdale maximum)
Low Fraser terrace (Vashon maximum)
Flood plain

TO TERRACES

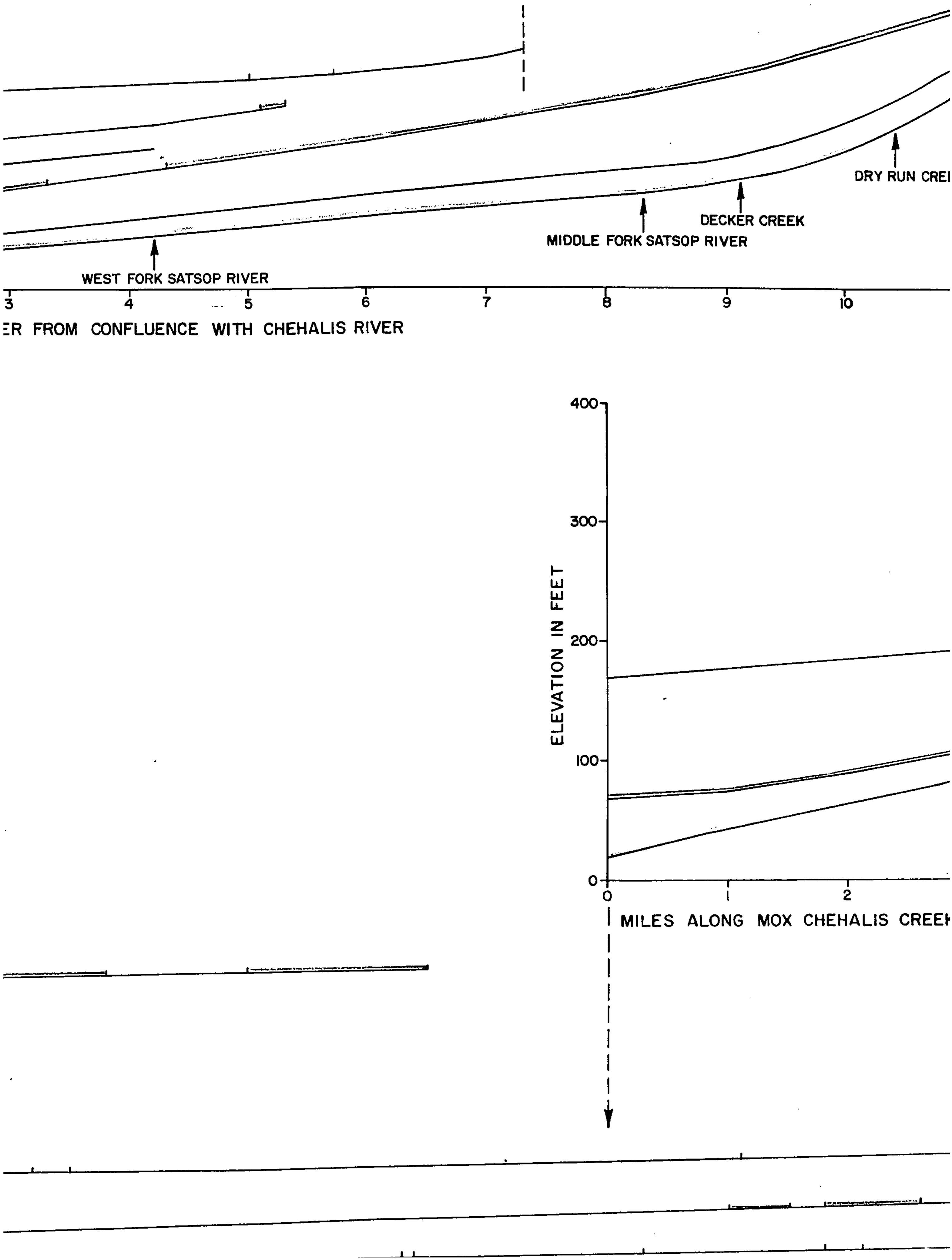

400
300
200
100
ELEVATION IN FEET



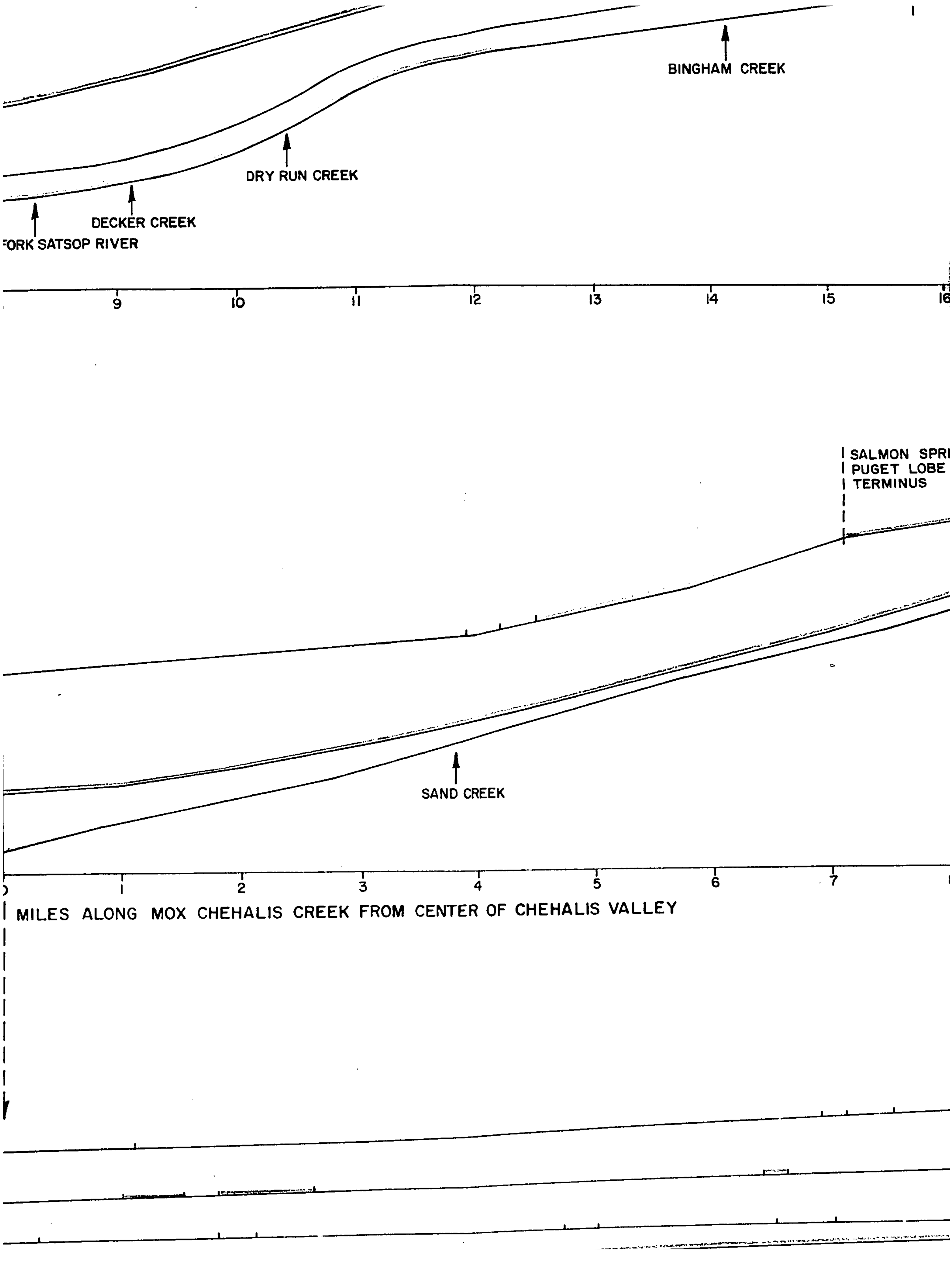
ELEVATION IN
200
100
0
0



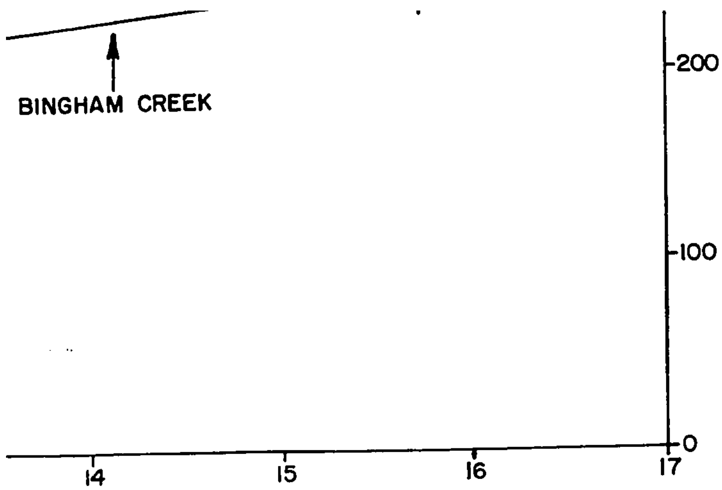
ELEVATION IN F
200
100
0
0
1
2
3
4
5
WEST FORK SATSOP RIVER
MILES ALONG EAST FORK SATSOP RIVER FROM CONFLUENCE WITH C



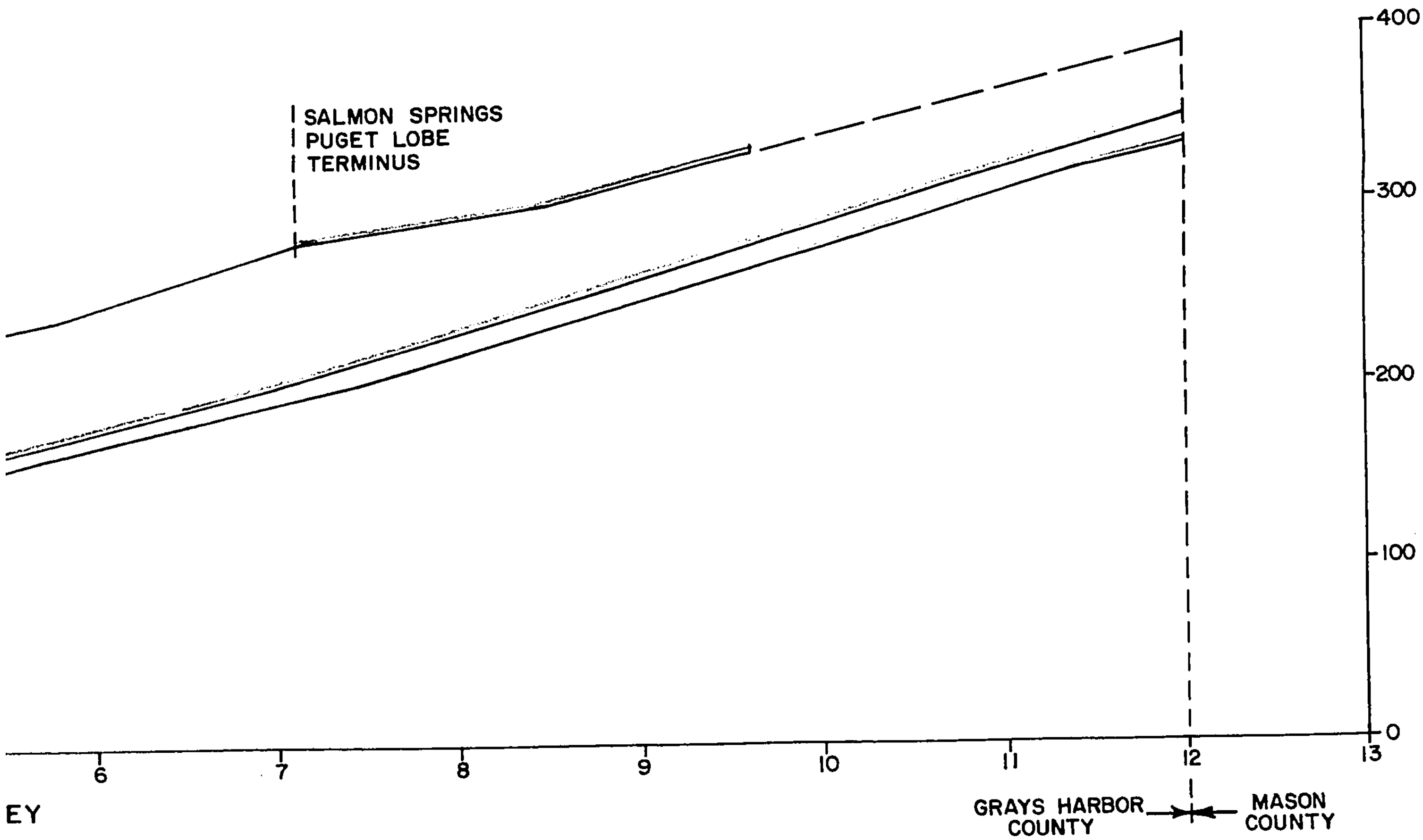
WEST FORK SATSOP RIVER
MIDDLE FORK SATSOP RIVER
DECKER CREEK
DRY RUN CREI
3
4
5
6
7
8
9
10
ER FROM CONFLUENCE WITH CHEHALIS RIVER
400
300
200
100
0
ELEVATION IN FEET
0
1
2
MILES ALONG MOX CHEHALIS CREEK



BINGHAM CREEK
DRY RUN CREEK
DECKER CREEK
FORK SATSOP RIVER
9
10
11
12
13
14
15
SALMON SPRI
PUGET LOBE
TERMINUS
SAND CREEK
1
2
3
4
5
6
7
MILES ALONG MOX CHEHALIS CREEK FROM CENTER OF CHEHALIS VALLEY

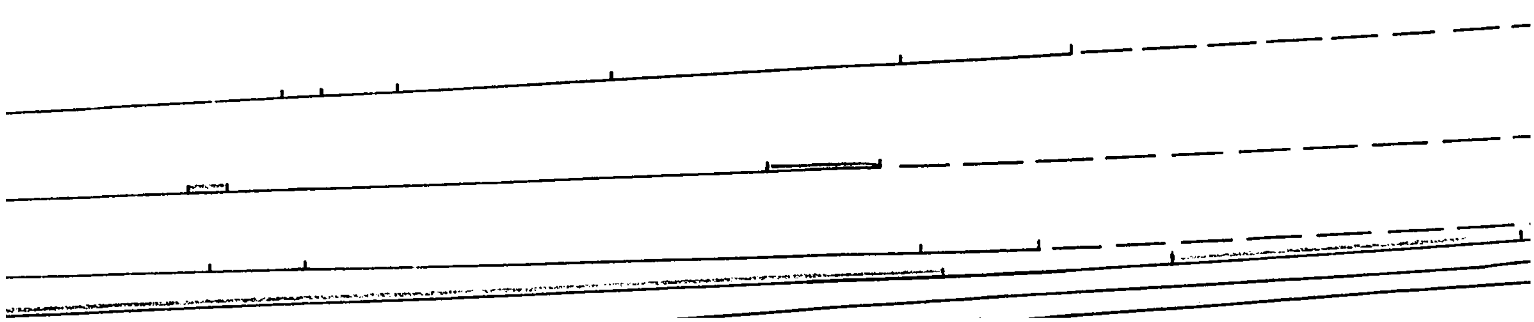


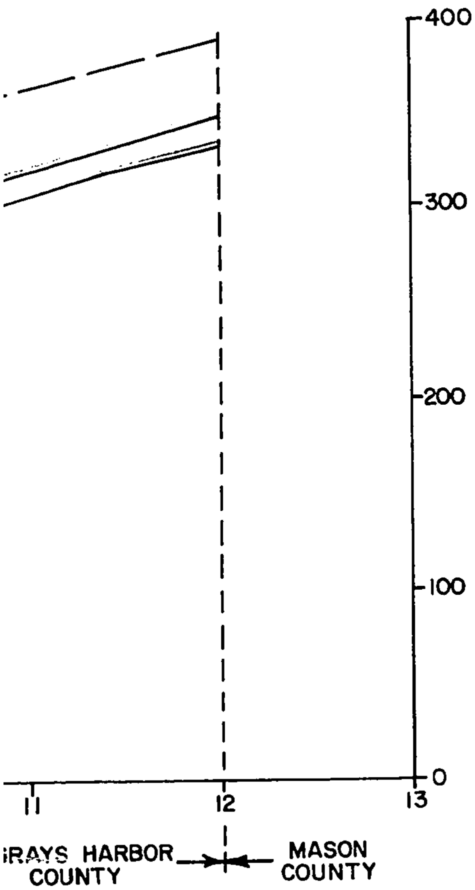
BINGHAM CREEK
200
100
0
14
15
16
17

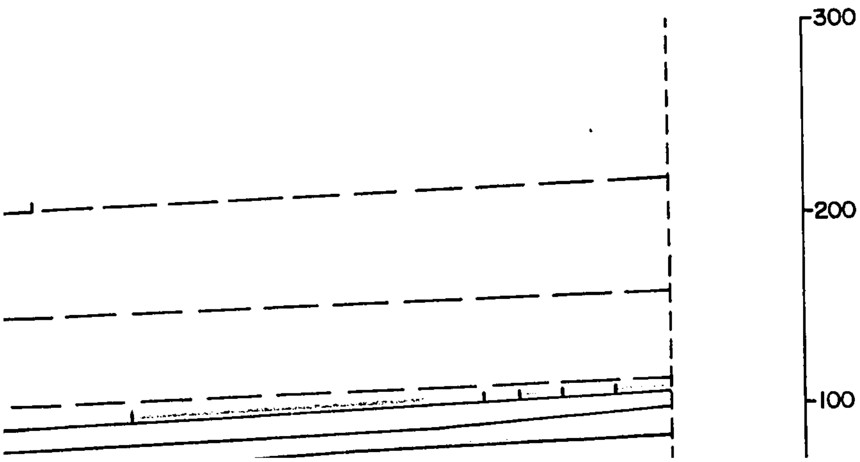


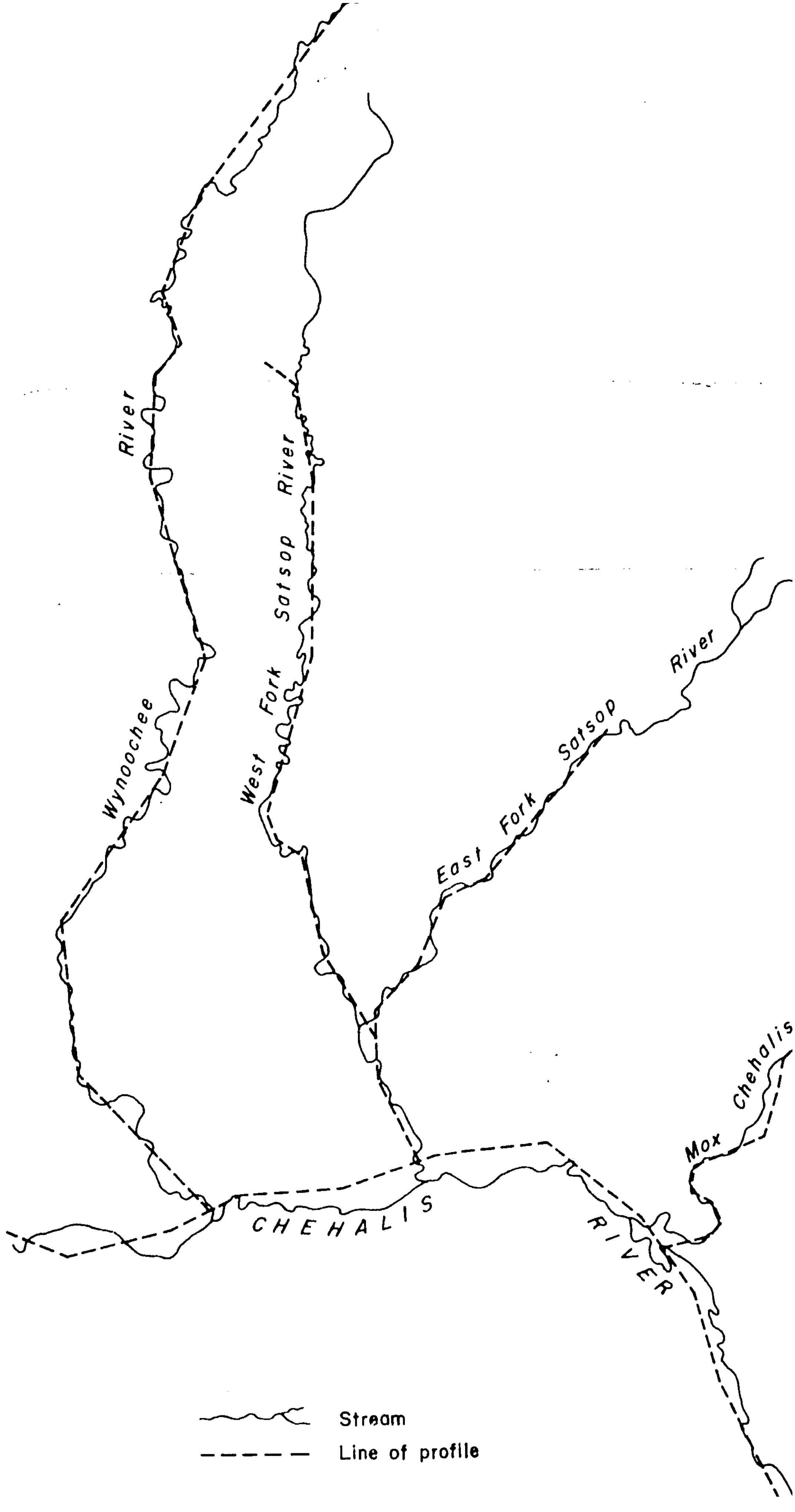
SALMON SPRINGS
PUGET LOBE
TERMINUS
400
300
200
100
0
6
7
8
9
10
11
12
13
GRAYS HARBOR COUNTY
MASON COUNTY

EY




400
300
200
100
0
11
12
13
RAYS HARBOR COUNTY
MASON COUNTY


300
200
100


Wynoochee River
West Fork Satsop River
East Fork Satsop River
Mox Chehalis
CHEHALIS RIVER
Stream
Line of profile

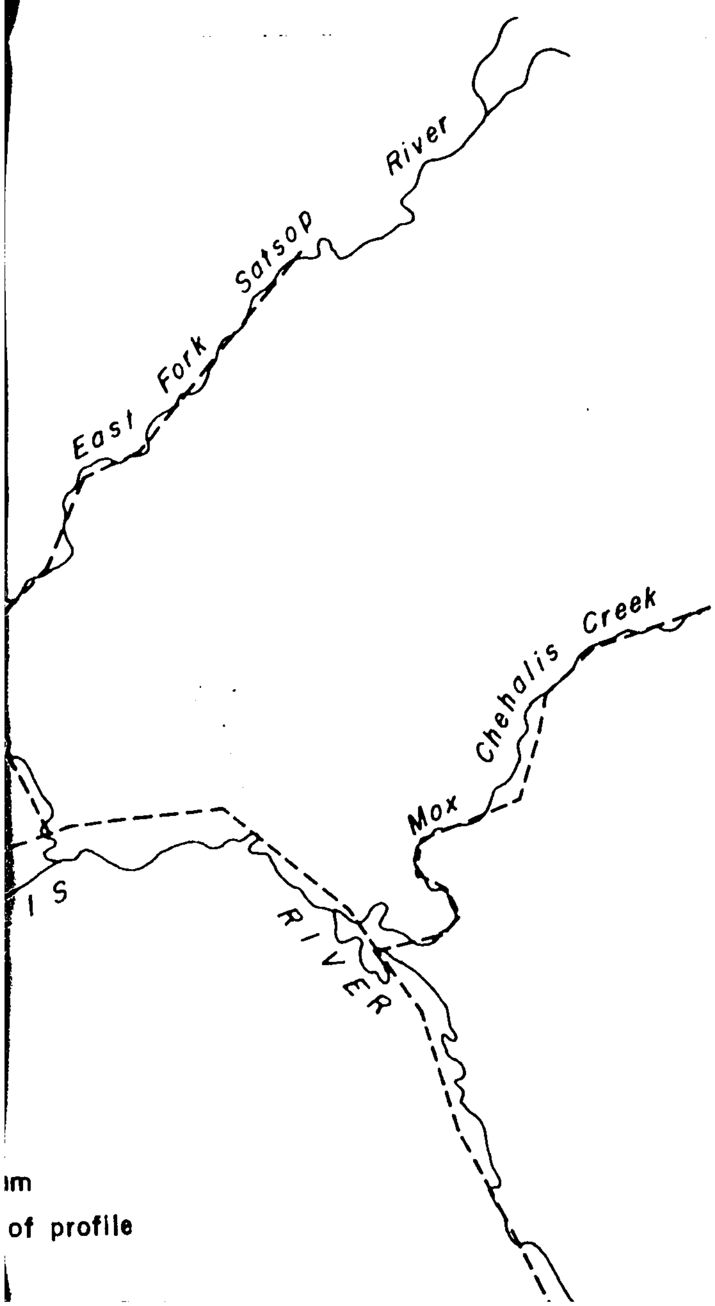
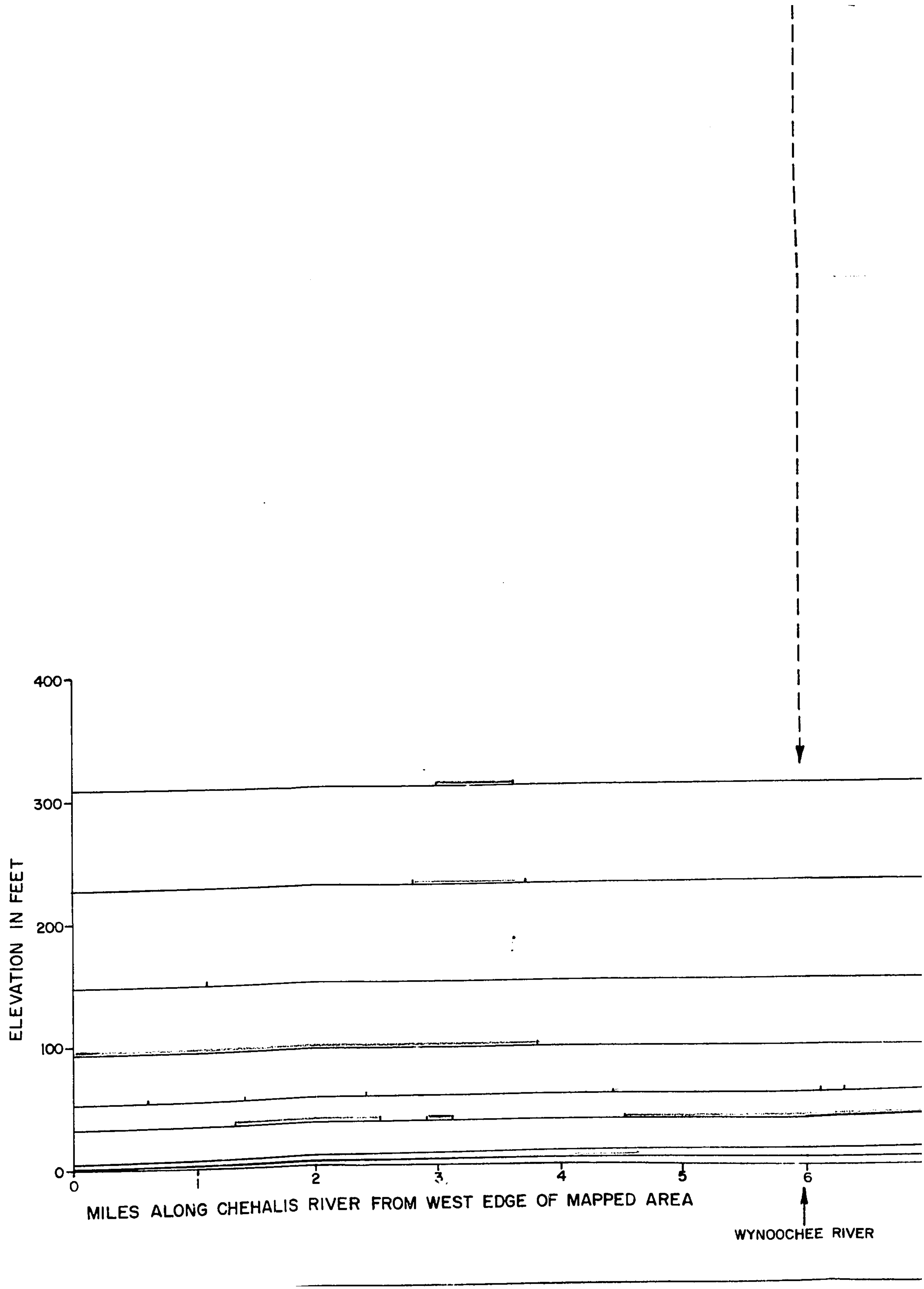
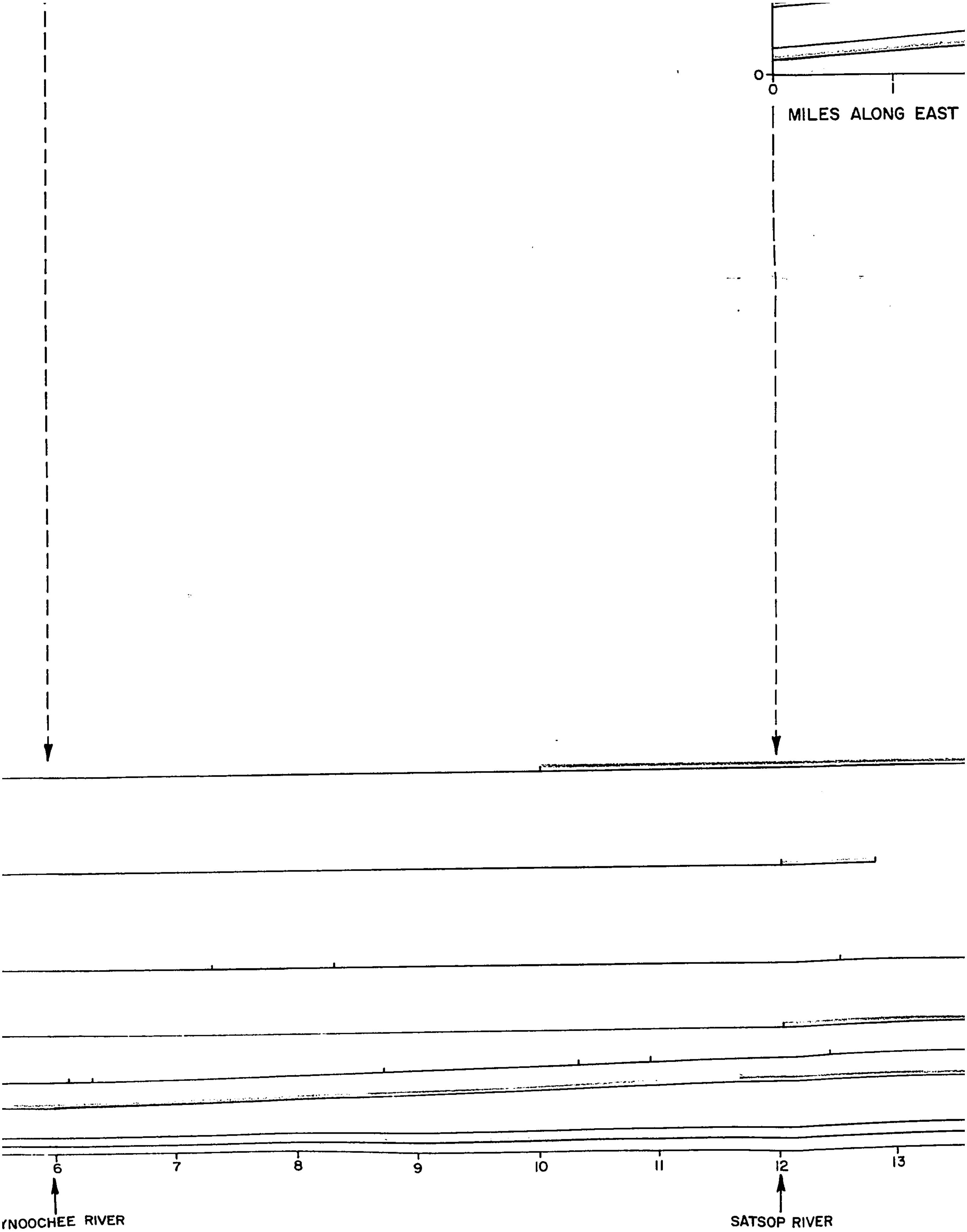


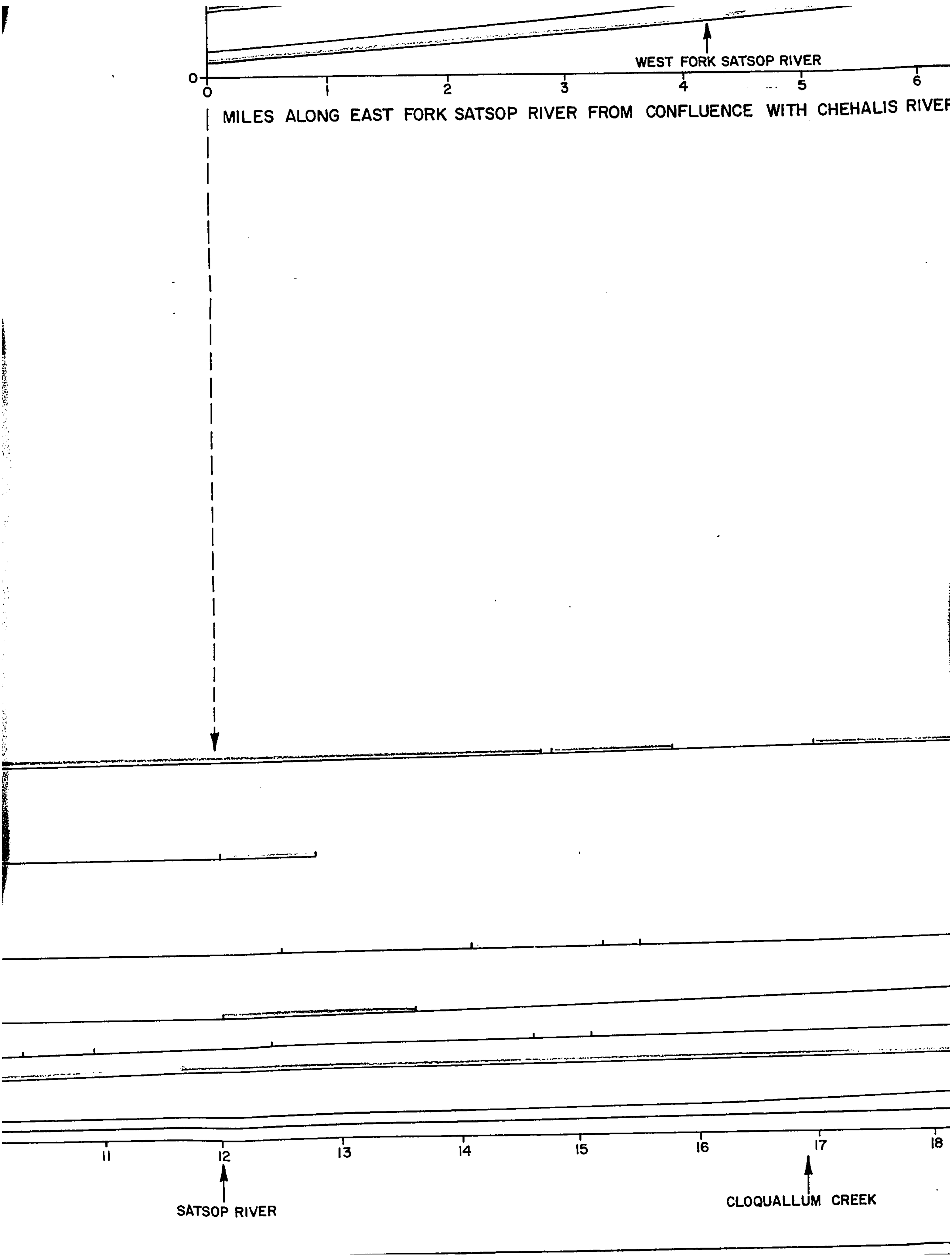
Plate II. TERRACE
ALONG SE
SOUTH-C
WASHINGT

Plate II. TERRACE AND GLACIER PROFILES ALONG SELECTED RIVERS OF THE SOUTH-CENTRAL OLYMPIC PENINSULA, WASHINGTON

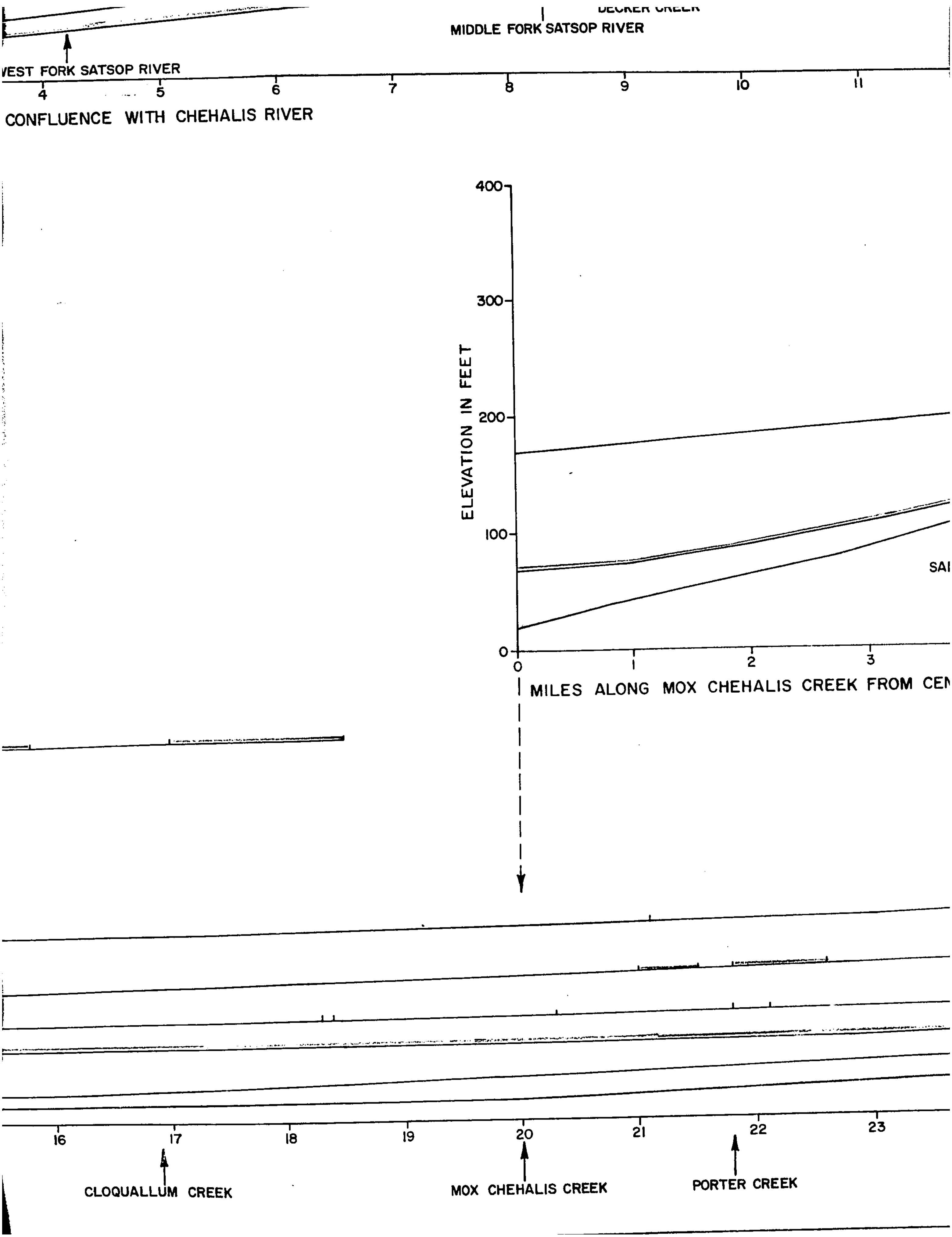

400
300
200
100
0
ELEVATION IN FEET
0
1
2
3
4
5
6
MILES ALONG CHEHALIS RIVER FROM WEST EDGE OF MAPPED AREA
WYNOOCHEE RIVER

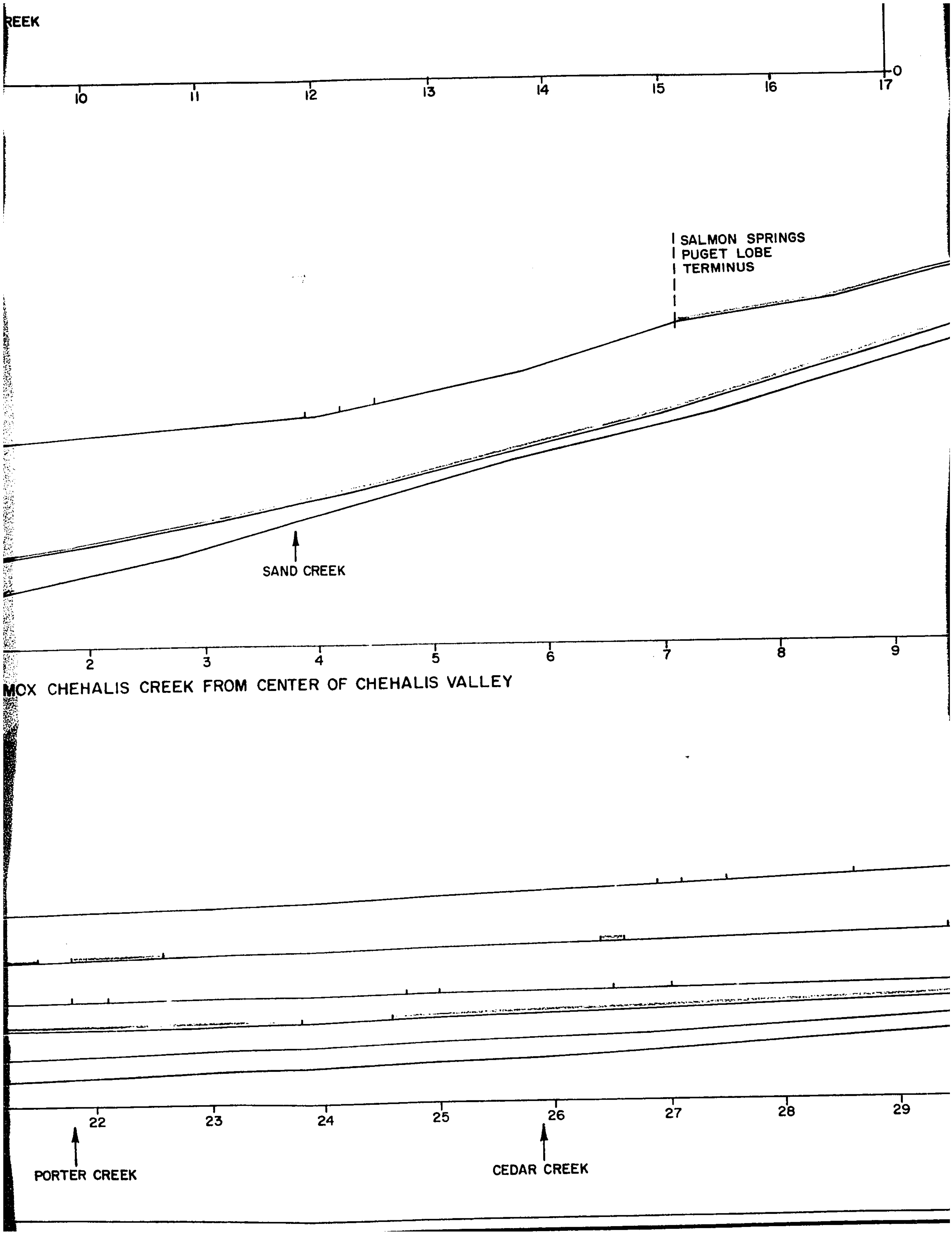


0
0
MILES ALONG EAST
6
7
8
9
10
11
12
13
YNOOCHEE RIVER
SATSOP RIVER

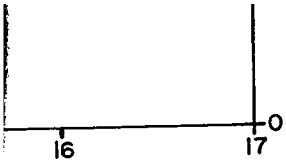


WEST FORK SATSOP RIVER
0
0
1
2
3
4
5
6
MILES ALONG EAST FORK SATSOP RIVER FROM CONFLUENCE WITH CHEHALIS RIVER
11
12
13
14
15
16
17
18
SATSOP RIVER
CLOQUALLUM CREEK

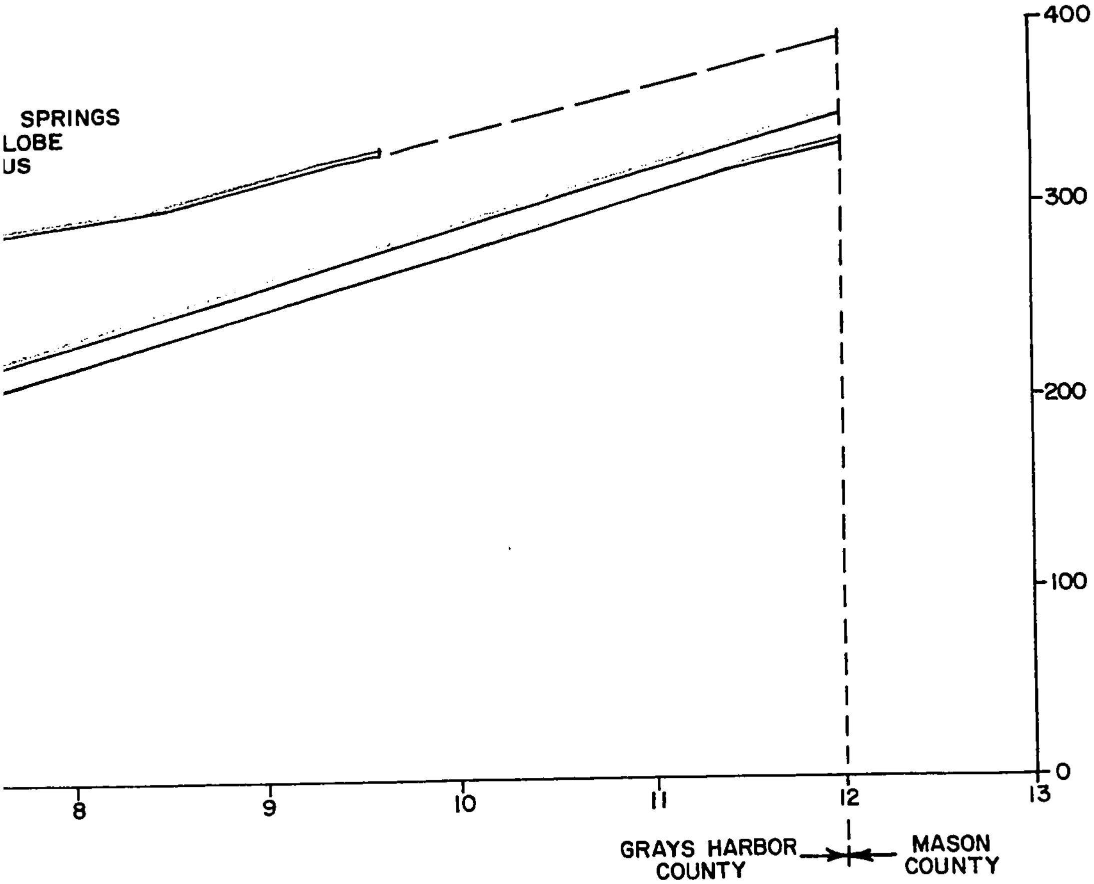

DECKER CREEK
MIDDLE FORK SATSOP RIVER
WEST FORK SATSOP RIVER
4
5
6
7
8
9
10
11
CONFLUENCE WITH CHEHALIS RIVER
400
300
200
100
0
ELEVATION IN FEET
SA
0
1
2
3
MILES ALONG MOX CHEHALIS CREEK FROM CE
16
17
18
19
20
21
22
23
CLOQUALLUM CREEK
MOX CHEHALIS CREEK
PORTER CREEK



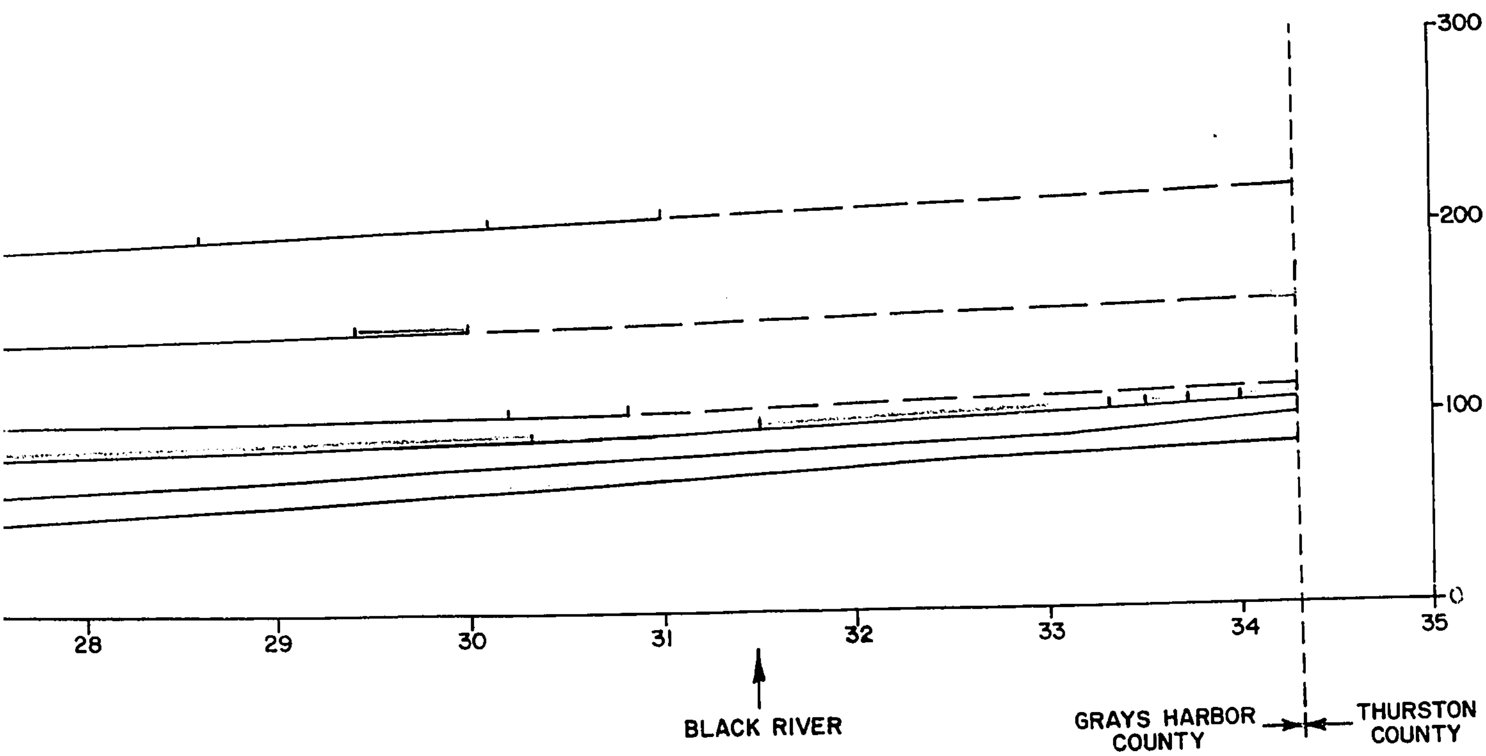
REEK
0
10
11
12
13
14
15
16
17
SALMON SPRINGS
PUGET LOBE
TERMINUS
SAND CREEK
2
3
4
5
6
7
8
9
MOX CHEHALIS CREEK FROM CENTER OF CHEHALIS VALLEY
22
23
24
25
26
27
28
29
PORTER CREEK
CEDAR CREEK



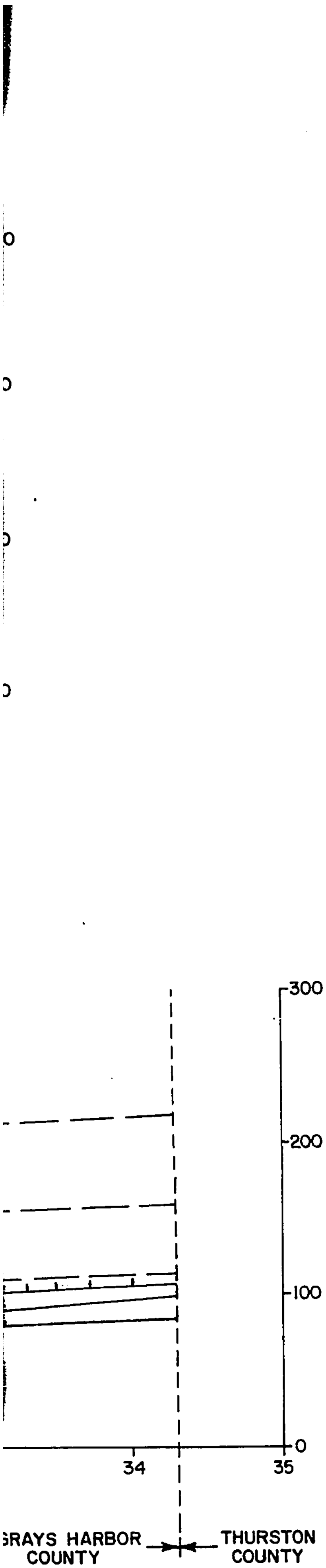
0
16
17

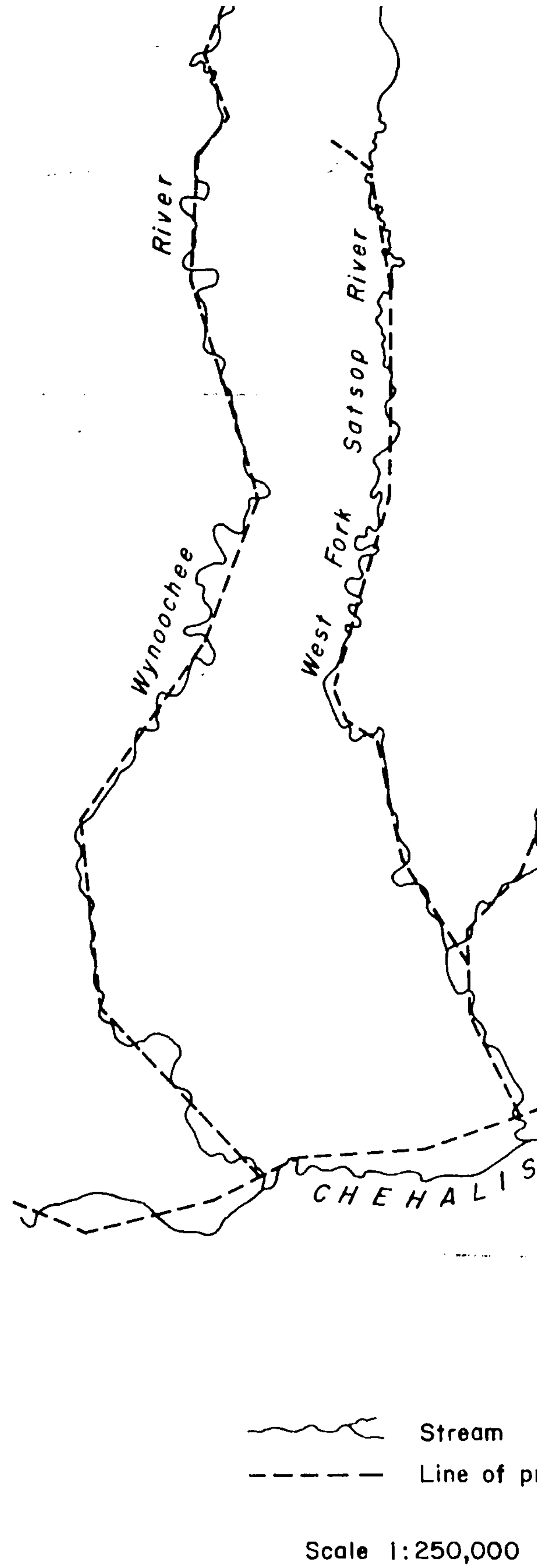


SPRINGS
LOBE
US
400
300
200
100
0
8
9
10
11
12
13
GRAYS HARBOR COUNTY
MASON COUNTY

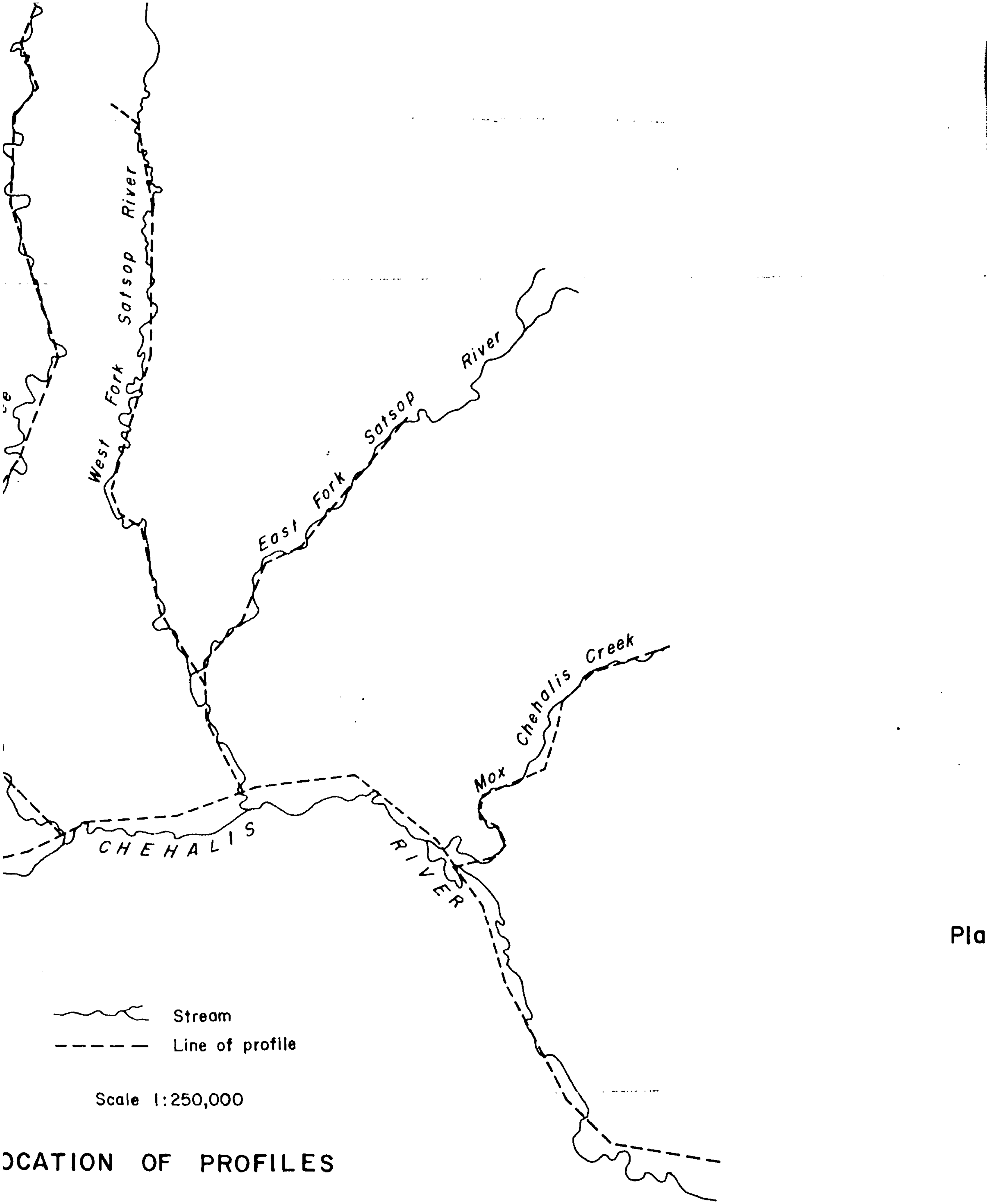


300
200
100
0
28
29
30
31
32
33
34
35
BLACK RIVER
GRAYS HARBOR COUNTY
THURSTON COUNTY





LOCATION OF PRO



OCATION OF PROFILES

Pla

Plate II. TERRACE AND GLACIER PROFILES ALONG SELECTED RIVERS OF THE SOUTH-CENTRAL OLYMPIC PENINSULA, WASHINGTON

R.J. CARSON 1970

Drawn by J.C. MILHOLLIN Cartographer