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RESUMÉ OF THE REGIONAL GEOLOGY OF THE GRAND COULEE AREA, WASHINGTON

By

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Introduction

The following is a resumé of the geology of central eastern Washington. It has been written mainly to summarize current knowledge of the regional geology of the Grand Coulee damsite. Staatz, who has mapped one of the principal structures near the dam, is the principal author; Morris has also prepared some sections and has combined the various parts into a single document.

_/ Report was written in 1973.

Physiography

Grand Coulee Dam lies on the boundary between two physiographic provinces: the Columbia Plateau to the south and the Okanogan Highlands to the north. The Columbia and Spokane Rivers originally excised their channels along the northern margin of the Columbia River lava flows, which mantle the plateau. Twenty-some miles northeast of Grand Coulee Dam the Columbia River re-cut its channel through the Columbia River lava flows when its original channel was dammed by ice in Pleistocene time. The old channel is now in part filled with glacial debris and contains Goose Lake, Omak Lake, and the lower part of the Okanogan River.

The Columbia Plateau is a vast treeless area that has a very gentle slope to the southwest. In detail, it consists of small undulating hills cut here and there by shallow south- and southwest-trending valleys. This area owes its topographic character to being underlain by a thick sequence of layered basaltic flows, which, near the center of the plateau, are as much as 5,000 feet thick. These rocks taper to zero thickness on the older rocks near the margins of the plateau (Newcomb, 1961, p. A2). The tops of the flows give the principal form to the plateau. The flows are for the most part covered with dunes of windblown loess.

Large wheat farms cover much of this loess. During glacial times the ice-dammed Columbia River overflowed its southern bank in many places, cutting through the loess and forming shallow valleys or coulees in the underlying basalt.

The Okanogan Highlands is a jumble of mountains having no particular trend. The moderately undulating upland surfaces are cut by deep valleys.

The upland surfaces are commonly well rounded and represent a fairly mature stage of erosion; the major stream valleys are steep sided and represent a youthful stage of erosion. The land has been elevated since the more mature highlands were eroded, and a second cycle of erosion has started with the cutting of deep valleys. The western part of the area is not as rugged as the central and eastern parts, and has broader valleys and gently sloped hills. Local relief is as much as 5,700 feet (Pardee, 1918, p. 14). Except for the glacial deposits, rocks underlying the Okanogan Highlands are older than the basalts of the Columbia Plateau. They are also more diverse in character and are more complicated structurally.

Geologic history

The geologic history of this area is best seen in the Okanogan Highlands, because the Columbia River basalts conceal most of the underlying rocks in the Columbia Plateau. The oldest rock unit found within 40 miles of Grand Coulee Dam is a sequence of metasedimentary rocks and greenstone, which Pardee (1918, p. 20) called the Covada Group. In the Bald Knob quadrangle, 22 to 37 miles north of the dam, the following metasedimentary rocks were noted: phyllite, quartzite, graywacke, shale, limestone, and mica-quartz schist (Staatz, 1964, p. F8). Farther north, near the town of Republic, chert, conglomerate, and marble were also reported (Muessig, 1967, p. 24-26). Fossils collected from these marbles were Permian in age (Muessig, 1967, p. 21-24). The Covada Group has been intruded by several large igneous bodies and covered by at least one major extrusion. Hence, exposures of the Covada Group rocks are widely scattered. Outcrops of this group decrease southward and westward, and it is probable that the Covada is not exposed within 5 miles of the dam.

The oldest major intrusive is diorite, a large body of which is exposed 10 to 20 miles northeast of Coulee Dam on either side of the Sanpoil River. This rock consists principally of plagioclase, hornblende, and biotite. In places it grades into a quartz diorite. The rock is intruded by dikes of Tertiary volcanics and by Cretaceous quartz monzonite (Staatz, 1964, p. F23).

The most widespread rock types are massive intrusives that range in composition from quartz monzonite to quartz diorite. These rocks cover a large area, and extend to within 6 miles of the Canadian border (Parker and Calkins, 1964, pl. 1). These are the rocks which Pardee (1918, p. 30) called the Colville granite batholith, and they are exposed over at least 1,000 square miles in the Colville Indian Reservation. They are of importance not only because of the large area in which they occur, but also they are the rocks that form the foundation of Grand Coulee Dam. These rocks were all originally considered to be Cretaceous in age by Pardee (1918, p. 33-34), but more recent work north of Republic, Washington, by Muessig (1967, pl. 1) and by Parker and Calkins (1964, p. 41, 59-60) has shown that some of the granitic rocks are of Cretaceous and some are of Tertiary age. The rocks of the two ages are identical in hand specimen, and thus distinguishing the two intrusives is difficult. Dikes of Tertiary rhyodacite are older than the quartz monzonite of Tertiary age, and therefore, if a quartz monzonite is intruded by rhyodacite, the monzonite is probably Cretaceous in age. A small quartz monzonite body of definite Tertiary age occurs in the old Park City mining district, about 25 miles north of the dam. This pluton metamorphoses the adjacent Tertiary volcanics. Two ages of intrusive granitic rock also occur in the Nespelem mining district, 15 miles north of the dam (Pardee, 1918, p. 61), and in the foundation of the dam itself (Irwin, 1938, p. 1632), where dikes of a fine-grained porphyritic granodioritic rock, as much as several hundred feet thick, intrude a coarse-grained quartz monzonite. The greater part of the granitic rocks is of Cretaceous age, but here and there dikes and plutons of similar rocks of Tertiary age occur.

The first volcanic rocks deposited in this area lie in a northeasterly trending belt extending from 3 miles north of the town of Curlew to south of Owhi Lake, a distance exceeding 53 miles. A smaller north-south belt, some 10 miles long, occurs along the Sanpoil River near Keller. These rocks were deposited in Eocene(?) to Oligocene time and consist of a basal tuffaceous unit, which is in part water laid (O'Brien Creek Formation), overlain by a thick sequence of rhyodacite and quartz latite flows with some interbedded tuffs (Sanpoil Volcanics). Many dikes and small intrusives of rhyodacite and quartz latite (Scatter Creek Rhyodacite) were intruded at the same time. These rocks were formed earlier, were of a different composition, and came from a different source than the basalts that underlie the Columbia Plateau. The Columbia Plateau rocks are a thick sequence of layered lava flows of basalt and basic andesite, ranging in thickness north of the Columbia River from about 1,000 feet to less than 50 feet. They thin out northward as successively higher beds overlap one another. South of the river they thicken to more than 5,000 feet, toward the center of the basin. The Columbia River basalts were extruded in Miocene and Pliocene(?) time.

During the Pliocene and continuing with probably decreasing intensity into the Pleistocene, the Columbia River basalts were folded and faulted along generally northwest-trending structural axes. The Pasco Basin, formed during this interval, was partly filled with gravel and sand of the early to middle Pleistocene Ringold Formation.

During Wisconsin time, giant piedmont glaciers covered the greater part of the Okanogan Highlands (Flint, 1935, p. 171-173). The ice front in the central Okanogan Highlands was irregularly lobate; one lobe lay across the Columbia River west of the present Coulee Dam (Flint, 1935, p. 189), and another lobe extended down the valley of the Sanpoil River to a little north of Keller (Pardee, 1918, p. 52). The ice front between these two lobes is imperfectly known but was probably very irregular. The ice covered not only the valleys but also most of the higher peaks. The area covered by ice was blanketed by a layer of glacial till. This till has been stripped off the steeper slopes by subsequent erosion, but most of the valleys and many of the flatter ridge tops are still covered. South of the glacier, many areas, and especially the valley of the Columbia River, received thick deposits of glacial outwash. The damming of the Columbia River west of Coulee Dam formed a large lake. Silt, sand, and clay formed thick deposits in the lake. The ice dam slowly melted in stages, and as the lake level lowered each stage was marked by a deposit of silt. Four prominent levels of terraces along the edge of the Columbia River mark the four principal levels of the old lake.

These silty terraces are particularly susceptible to landsliding. Jones (1961) has described many slides and relates most of them to the initial filling of the reservoir after construction; others have occurred since, during drawdown or refilling. No direct correlation of landslide occurrence was made to earthquakes. In the area downstream from Grand Coulee Dam, landsliding was more frequent after a large reduction in riverflow or after unusually long periods of above-normal precipitation.

Structure

Two large grabens, the Republic and the Chiwaukum, bounded by major faults, occur in eastern and central Washington. The proximity and trend of the Republic graben with respect to the Grand Coulee Dam make the consideration of the bounding faults pertinent to any discussion of the regional geology.

Republic graben

The Republic graben, which has been described in a brief summary article by Staatz (1960), is a large north-northeast-trending structure that has been mapped in considerable detail for 52 miles, from near the Canadian border to the south end of the Bald Knob quadrangle. The extent of the graben south of the Bald Knob quadrangle is not known. The graben, which is from 4 to 10.5 miles wide, is bounded by faults whose apparent displacement ranges from a few hundred feet or less to over 17,000 feet. Although the graben is a major geologic feature, it has remarkably little topographic expression. The Republic graben, due to its lack of topographic expression, its great breadth, and the thick cover of forest and glacial till, is an unimpressive feature when observed in the field. Hence, it was not recognized until the geology of the region was mapped in detail. The graben was discovered during the course of mapping three 15-minute quadrangles and parts of two others between 1956 and 1959. It was outlined by Parker and Calkins (1964, pl. 1) in the Curlew quadrangle, by Muessig (1967, pl. 1) in the Republic and Wauconda quadrangles, and by Staatz (1964, pl. 1; 1960, fig. 141.1) in the Bald Knob and Seventeenmile Mountain quadrangles.

The Republic graben is bounded on the northwest by the Scatter Creek fault zone and the Bacon Creek fault and on the southeast by the Sherman and several smaller unnamed faults. The Bacon Creek fault bounds the northwest side of the graben, from near the Canadian border to west of the town of Republic, where it joins the Scatter Creek fault zone, which extends to the south and consists of several faults having a braided pattern. Most of the faults are nearly vertical, but two of the faults in the Scatter Creek fault zone in the southern part of the mapped area dip from 35° to 70° to the southeast--toward the center of the graben. Movement along the faults is mainly dip slip, although a little strike slip has been noted. Movement along the Bacon Creek fault diminishes north of the Kettle River, and this fault terminates near the international border.

The history of formation of the Republic graben is closely tied to the eruption of the Eocene(?)-Oligocene volcanics, and hence the history of the graben is also that of these early volcanic rocks. The graben probably started to form in Eocene time with the development of small rifts. From these rifts were erupted pyroclastics that formed the O'Brien Creek Formation in the northern and central parts of the graben. Some of these rifts probably correspond to the position of later faults, but others near the center of the graben probably had little later movement. The number of rifts probably was greatest in the central part of the graben, because the Eocene(?) rocks are thickest here. The O'Brien Creek Formation thins to the south and disappears in the southern half of the Bald Knob quadrangle; this thinning suggests that volcanism started farther north. Soon after the O'Brien Creek strata were laid down, the first rhyodacite flows of the Sanpoil were extruded. These flows rose along the marginal rifts of the graben. The magma chamber from which the first flows and pyroclastics came probably underlay the central part of the graben, as this part of the graben was downwarped early in its history. As a result of the central downwarping, most of the flows extruded along the boundary faults flowed toward the center of the graben. As material from beneath the graben was extruded, the central graben block slowly sank. Flows interspersed with thin irregular layers of pyroclastics indicate a continued history of alternating quiescence and eruption. The volcanics are thickest in the central part of the graben and as much as 1,600 feet of rhyodacite has been exposed along the Sanpoil River. The boundary faults also in part served as conduits, and in places there are feeder dikes of rhyodacite. As noted previously, this volcanism ceased in Oligocene time. Movement on the faults may have continued after that time. Later erosion has beveled the horsts, and the volcanics are preserved only within the graben.

The graben faults have not been mapped south of the southern boundary of the Bald Knob quadrangle. The throw on the Sherman fault at its southern boundary, where the fault separates diorite from volcanics, may be well over 1,000 feet. The volcanics which fill the graben are exposed for 11 miles along the southern boundary of the quadrangle. Thus, the graben must extend well beyond the southern boundary of the quadrangle. Along the Columbia River, however, and for at least 5 miles to the north, the older volcanics are not present, although the faults may extend well beyond the present exposures of the older volcanics.

The Sherman fault, if projected along its line of strike in the Bald Knob quadrangle, would cross the Columbia River in the vicinity of Grand Coulee Dam. Thus, the chance that movement might have occurred along this fault in recent time is of considerable importance. As the geologic evidence indicates, the Sherman fault formed during a period of early Tertiary volcanic activity, and volcanism was directly responsible for much of its movement. This volcanism ceased in Oligocene time. Plots of earthquake epicenters since 1841 (John A. Blume and Associates, 1972), on fairly meager evidence, indicate little activity in this general area; except in the vicinity of Grand Coulee, none of the epicenters fall on the Sherman fault.

Methow River graben

A major structure in north-central Washington is a large graben whose center, for the greater part of its length, is occupied by the Methow River. The southeastern exposed end of this graben is 45 miles west of Grand Coulee Dam. From here it can be traced for at least 70 miles northwest to the Canadian border. The rocks within the graben for the most part are a thick sequence of interbedded plagioclase arkose and argillite of early Jurassic to Early Cretaceous age. This sequence is underlain by basaltic and andesitic volcanics (Staatz and others, 1971, p. 21-26). In the southeastern end of the graben occur gneisses and igneous rocks of probable Precambrian age. These rocks have been intruded by a number of quartz diorite, quartz monzonite, and granite plutons ranging in age from 86 to 46 million years (Tabor and others, 1968, p. C48). Rocks outside the graben are mainly igneous or metamorphosed igneous rocks of Jurassic or Cretaceous age (Staatz and others, 1971, p. 12-16).

The graben is bounded on the northeast by the Eightmile Creek fault and on the southwest by faults of the Ross Lake fault zone. Both faults have large throws. The Eightmile Creek fault has been traced in the United States for at least 50 miles. Movement on this fault probably started in the Upper Cretaceous and continued into the Tertiary. Near Island Mountain, along the northwestern part of this fault, an oval area of volcanic rocks overlies this fault with no apparent offset (Staatz and others, 1971, pl. 1). These volcanics are probably late Tertiary in age, and indicate that at least most of the movement on this part of the fault had ceased by the time the volcanics were deposited.

The Ross Lake fault zone has been traced in the United States for about 85 miles (Misch, 1966, p. 134). Two plutons, the Black Peak and Golden Horn batholiths, have been intruded in part along this fault zone. The youngest of these, the Golden Horn, has an age of about 46 million years (Tabor and others, 1968, p. C48). The trace of the Ross Lake fault zone has been found on either side of these plutons but has not been traced through them. Although this is suggestive that movement along these faults ceased prior to the intrusion of the igneous rocks, the evidence is not conclusive due to the difficulty in tracing faults through homogeneous igneous rocks.

Several faults have been mapped within the southeastern part of the graben (Huntting, 1961). Scattered earthquake epicenters reported in the 1930's, 1940's, and 1950's indicate some strain release either on these subsidiary faults or possibly on the boundary faults of the graben.

Chiwaukum graben

The Chiwaukum graben lies in central Washington on the east flank of the Cascade Mountains. It lies southwest of Lake Chelan, and its southeast corner is about 70 miles west-southwest of Grand Coulee Dam. This graben has a northwest trend and a maximum width of 13 miles. It has been traced for 52 miles, the northwestern part by Cater and Crowder (1967) and the rest by Willis (1953, fig. 1).

Most of the rocks in the floor of the graben are of the Swauk Formation. These rocks consist of 13,000 feet of interlayered arkose, shale, and conglomerate of Paleocene and Upper Cretaceous age (Willis, 1953, p. 791). Some older gneisses and schists and some Tertiary plutons are exposed in the northwestern part of the graben. The rocks bounding the graben on either side are mainly various types of schists, gneisses, and peridotite. At least some of these rocks are Precambrian in age. These older rocks have been intruded on the west side of the Chiwaukum graben by several quartz diorite plutons, ranging in age from Early Cretaceous to Tertiary.

The Chiwaukum graben is bounded on the northeast by the Entiat fault and on the west by the Leavenworth fault. Several major and minor structures lie within the graben; the most important are the Eagle Creek anticline and the associated Eagle Creek fault. The Entiat fault trends northwestward from the city of Wenatchee on the Columbia River. The scarp of this fault defines the west side of the Entiat Mountains, and has a maximum height of approximately 3,000 feet. The vertical displacement along this fault must exceed 16,000 feet (Willis, 1953, p. 792). The Leavenworth fault has a sinuous northwest to northerly trend. This fault is commonly marked by a well-developed breccia zone and drag folding in the adjacent Swauk Formation. Its attitude is near vertical. The vertical displacement is not known, but must exceed 10,000 feet. The Eagle Creek anticline, which lies within the graben, can be traced from southeast of the city of Wenatchee for 34 miles to the northwest. It is an asymmetrical open fold involving some 13,000 feet of Swauk strata. In three places along the crest of the anticline, older schists are exposed. The Eagle Creek fault lies along the northeast side of the anticline, where it bounds one side of the largest schist inlier. The Eagle Creek fault is parallel to both the Entiat fault and the Eagle Creek anticline and appears genetically related to the latter.

The faults and folds of the Chiwaukum graben are post-Swauk (Paleocene and Upper Cretaceous) and pre-Teanaway basalt (Lower to Middle Eocene) (Willis, 1953, p. 795-796). In the southwest corner of the graben, diabase dikes and sills cut the Swauk Formation, and diabase dikes occur in fault zones along the west border of the graben. South of the area, diabase dikes pass upward into flows of the Teanaway Basalts, which rest unconformably upon folded strata of the Swauk Formation. Although this evidence might suggest an end to movement on these structures, further deformation took place in Late Tertiary time along northwest-trending structures. A prominent uplift, the Badger Mountain syncline, and the adjacent Waterville syncline lie southeast of the Entiat Mountains; another northwesterly trending uplift, the Table Mountain anticline, lies southeast of the west side of the graben. These flexures are in the Columbia River Basalt, and indicate that movement continued along the southeast extension of the Chiwaukum graben after the major downfaulting to the northeast had largely subsided. Furthermore, numerous recorded earthquake epicenters with intensities of from III to VI northeast of Wenatchee suggest that strain-release along the Badger Mountain anticline and Waterville syncline is still continuing.

Monoclines

South and west of Grand Coulee Dam, two monoclines are shown on the structure map of the Columbia River basalt compiled by Newcomb (1970). The two are the Coulee and the Barker Canyon monoclines. The Coulee, which has a southwest trend, has been traced from just south of the Columbia River, about 9 miles east of Grand Coulee Dam, for 40 miles to a point about 9 miles east-southeast of Coulee City. The northeastern part of this structure is shown as an anticline. The Barker monocline starts with a southerly trend and then gradually changes to a southwesterly trend. This monocline, which has been noted (Newcomb, 1970) as far north as a point 3 miles south of the Columbia River and 12 miles northwest of Grand Coulee Dam, joins the Coulee monocline 4 miles northwest of Coulee City. Southwestward, the Coulee monocline apparently becomes the Beezley Hills anticline. The Coulee and Barker Canyon monoclines lie along the projection of the Republic graben. The trend of these monoclines, however, indicates that the projection of the graben's boundary faults would cut across these flexures, and hence the two are probably not related. To the south and west flexures and small faults are much more abundant in the Columbia Plateau (Newcomb, 1970). Grolier and Bingham (1971) mapped several faults and tightly folded, and in places faulted, anticlines in the central part of the Columbia Plateau. Farther south in the exposures of Columbia basalt bordering the Pasco Basin, anticlines are overturned and many are faulted along axial planes. This southward increase in structural complexity of the Columbia River basalts contrasts with the more subtle Barker Canyon and Coulee monoclines to the north. Recent microseismic monitoring has recorded many shallow moderate earthquakes in the Pasco Basin, which suggests that north-trending compressional forces are still active (M. Pitt, U.S. Geol. Survey, oral commun., 1973).

Lineation

Lineations, as seen in the field and on aerial photographs are due to differential erosion along faults and joints. Several sets of joints and small faults are known. The most prominent set has a north-northeast to northeast trend and a steep to vertical dip. This set of joints is regional, being found from near Republic, Washington to Grand Coulee Dam. This fracture direction is parallel or subparallel to the direction of movement in the large ice sheets that covered at least the northern three quarters of the area north of the dam. The glacial action helped excavate fractured rock along the joints and make them more obvious than they would have been if they were at a moderate angle to the glacier movement. These joints are common both in the granitic rocks and the older volcanics and may have a topographic expression visible on the 15-minute topographic sheets. Irwin (1938) reports them in the foundation of the Grand Coulee dam, where he notes that there has been slight movement on these joints. This movement is mainly horizontal with the east side moving south relative to the west side.

A second set of joints with a strike of west-northwest is well-developed near the dam site (Irwin, 1953, p. 1643), but is not so apparent farther north. The joints of this set dip 60° to 90° to the northeast, are generally shorter and less numerous than those with a northeasterly trend. The west-northwest trending fractures commonly have a little gouge along them and their relative movement is with the north side upward and to the east. In the dam foundation one of these fractures offsets a small basalt dike about 7 feet, and Irwin (1953, p. 1643-1644) believes that most movement along these fractures is post-Columbia River basalt (post-Miocene).

A third set of joints also occurs in the vicinity of Grand Coulee Dam. These joints are nearly flat lying and dip 5° to 15° to the south and southwest. They are undulatory and seldom extend for more than 20 feet. Near the surface they are spaced from 6 inches to 3 feet apart. Drilling to a depth of as much as 800 feet has indicated that these joints decrease in size and number with depth. Irwin (1953, p. 1645) believes that they are at least in part due to static relief of vertical pressure owing to the unroofing of the batholithic rocks by prebasalt erosion. Thus, their origin differs from that of the two sets of steeply dipping joints, which were caused by regional movements.

U.S. Geological Survey investigations in central Washington

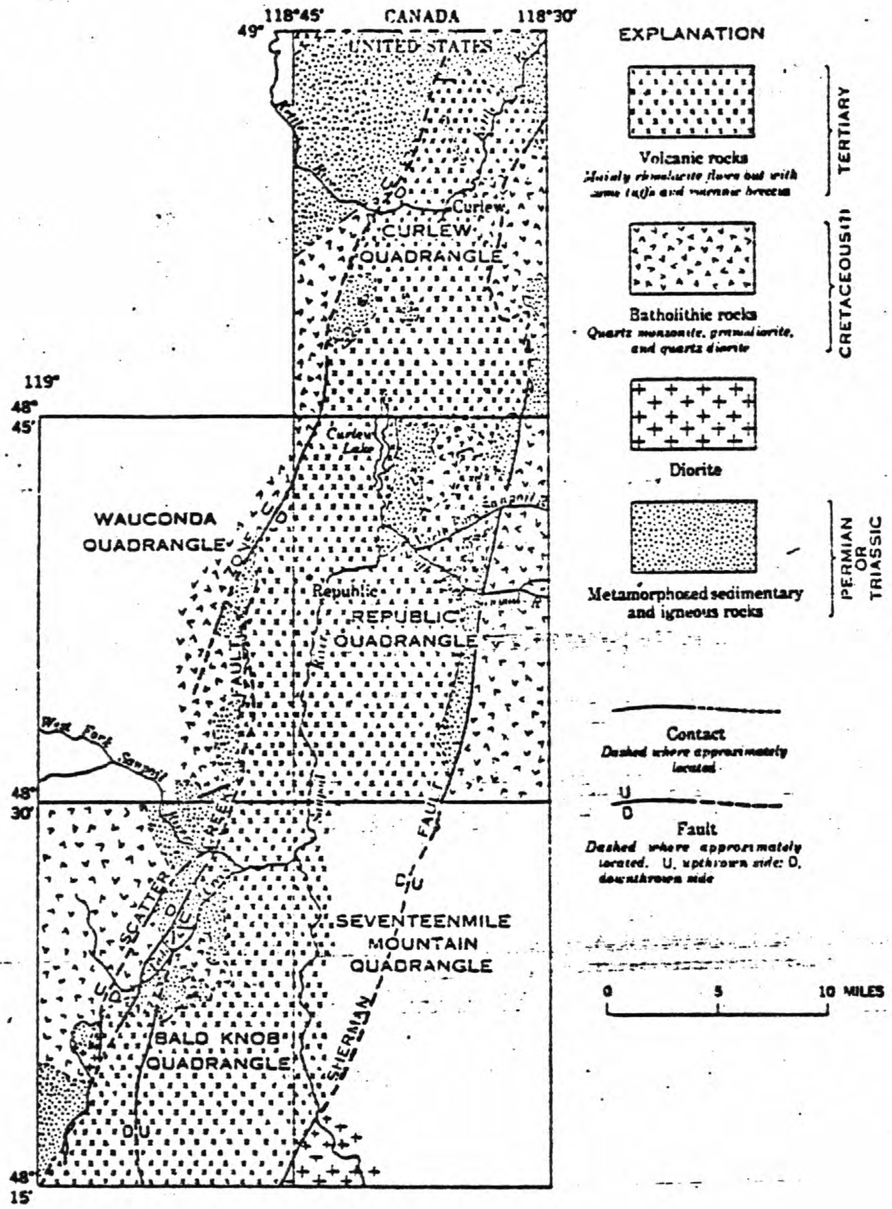
The U.S. Geological Survey has recently published two geologic maps of the Columbia Plateau. Miscellaneous Geologic Investigations Map I-587, by Newcomb (1970), is a regional map, while map I-589, by Grolier and Bingham (1971), covers the central part of the Columbia Plateau in greater detail. Index maps showing these areas are included at the end of the report. In addition to these completed projects, the USGS has several studies in progress. M. Pitt is studying the microseismicity of the Pasco Basin, D. Swanson is Project Chief of the Columbia River basalt petrology investigations, J. Savage and W. Kinoshita are doing laser beam trilateration surveys in the Pasco Basin, and regional tilt in the Pasco Basin is being analyzed by NCER.

Areas of concern regarding Grand Coulee damsite

Two major geologic structures are critical to the proper seismic analysis of Grand Coulee Dam: (1) the Sherman fault, and (2) the Coulee monocline.

According to Staatz (1964, 1960), the most recent movement on the Sherman fault is interpreted to be Miocene. The Sherman fault trends toward Grand Coulee damsite, where the granitic bedrock has a prominent set of fractures parallel to the fault. South of the dam, granitic bedrock is flooded by Banks Lake or lies buried beneath the lavas of the Columbia Plateau. The continuation of the Sherman fault or at least a zone of fracturing parallel to and along the projected trend of the fault has not been recognized nor searched for in detail in the Banks Lake area. Structurally, Banks Lake probably occupies a very subdued synclinal low between the Barker Canyon and Coulee monoclines. The glacial lake waters may have breached the lava plateau at this point because of a coincidence of a topographic low with the synclinal low. It could be additionally inferred that a zone of weakness caused by a zone of northeast-trending fractures permitted rapid channel scour of Grand Coulee. Because of the lack of detailed geologic mapping in the area, extending from Bald Knob south to and including Banks Lake, no definite correlation of this apparent structural relationship can be made. Seismic records also are meager in this area, but one earthquake was reported at Electric City in 1956 and, if of shallow depth, could be related to this structure.

The major limitations of the available data span the interval from Miocene to the present. There is insufficient knowledge of Pleistocene and Holocene deposits and their relationship to faults to dispell doubts of recent tectonic activity.



Geology in the Curlew quadrangle by Calkins, Parker, and Disbrow (1959); in the Republic and Wauconda quadrangles by Muessig and Quinlan (1959); and in the Bald Knob quadrangle by M. H. Staatz

FIGURE 7.—Generalized geologic map of the Republic graben.

Figure 1.--Generalized geologic map of the Republic graben, from U.S. Geological Survey Bulletin 1161-F.

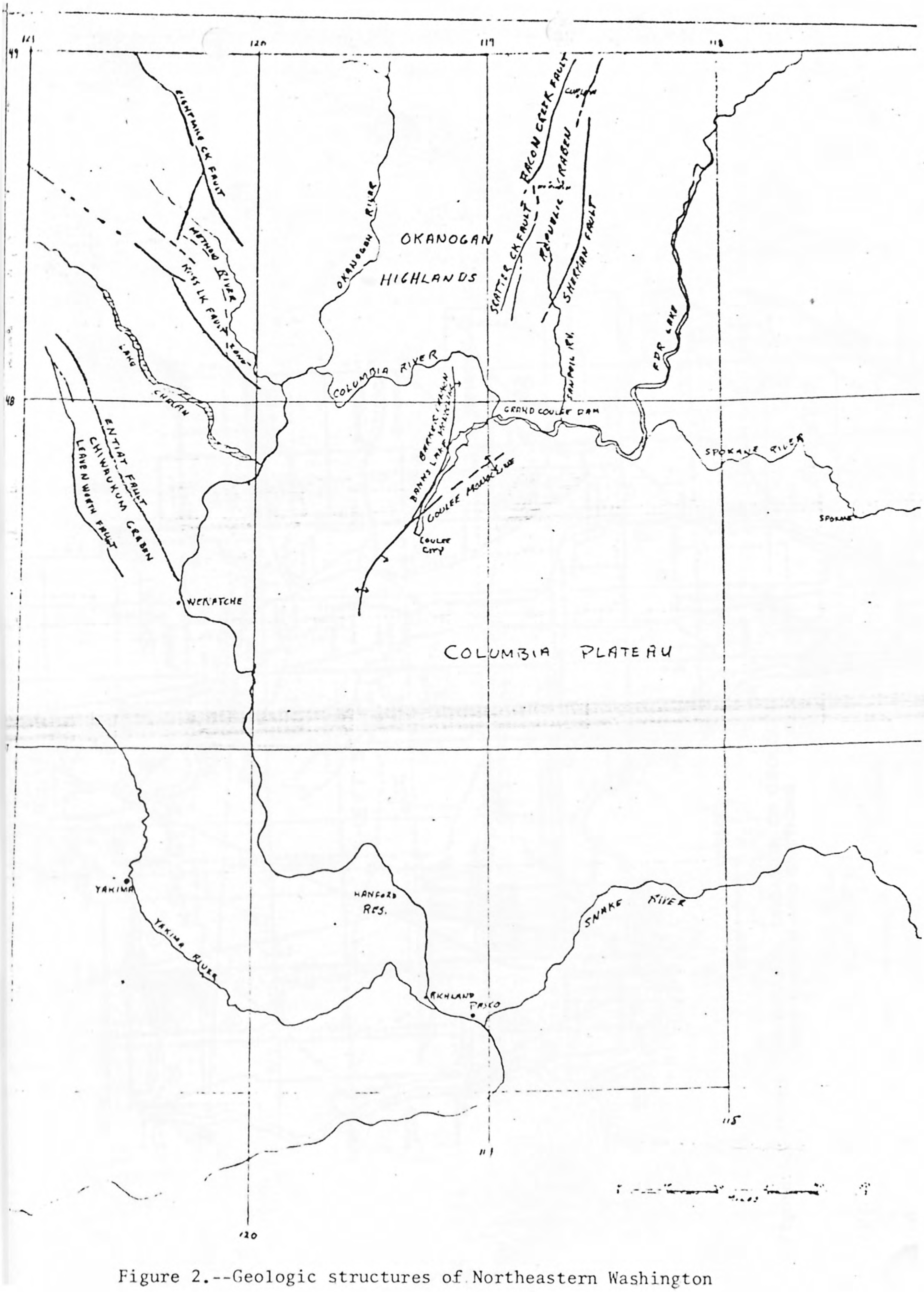


Figure 2.--Geologic structures of Northeastern Washington

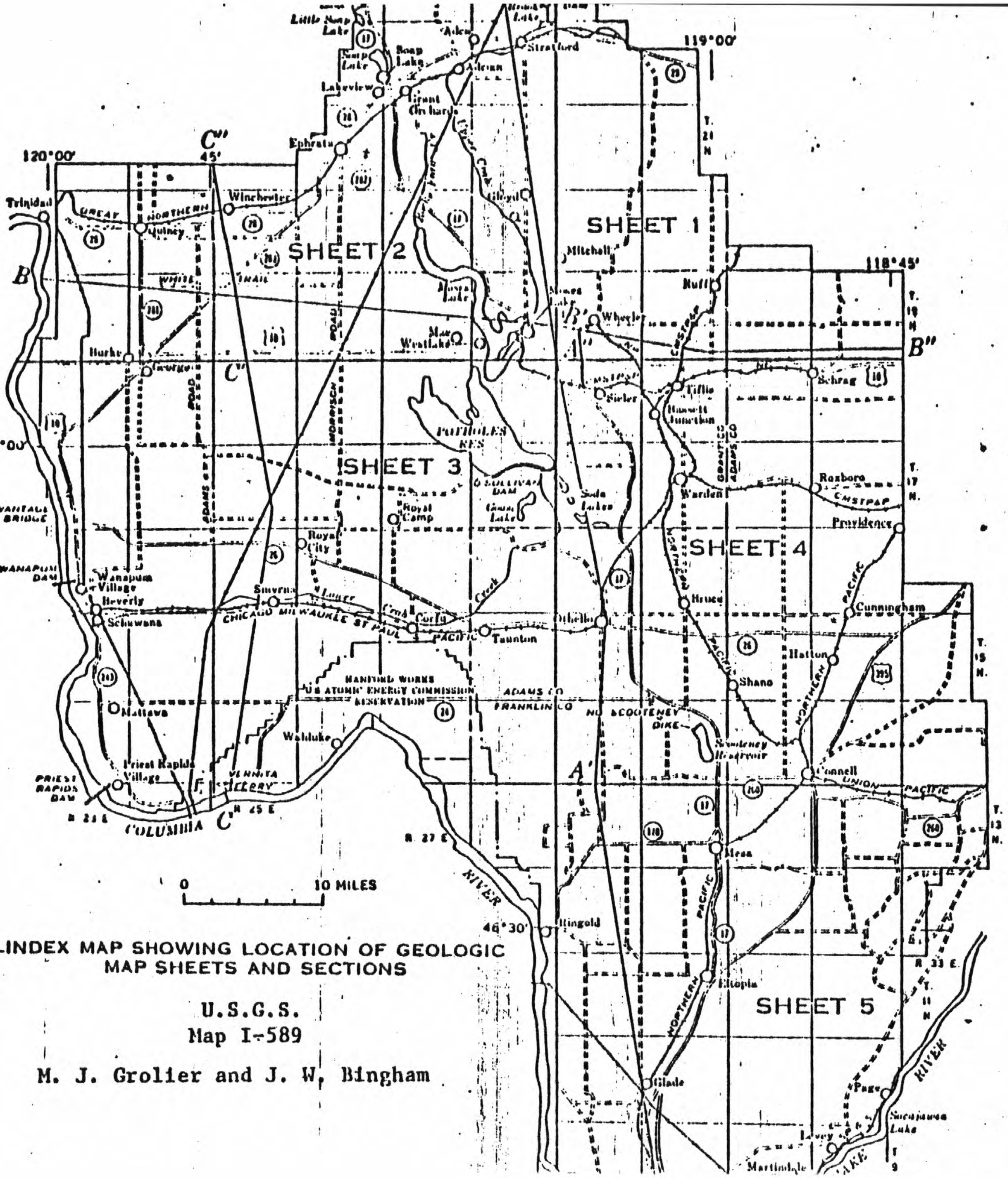
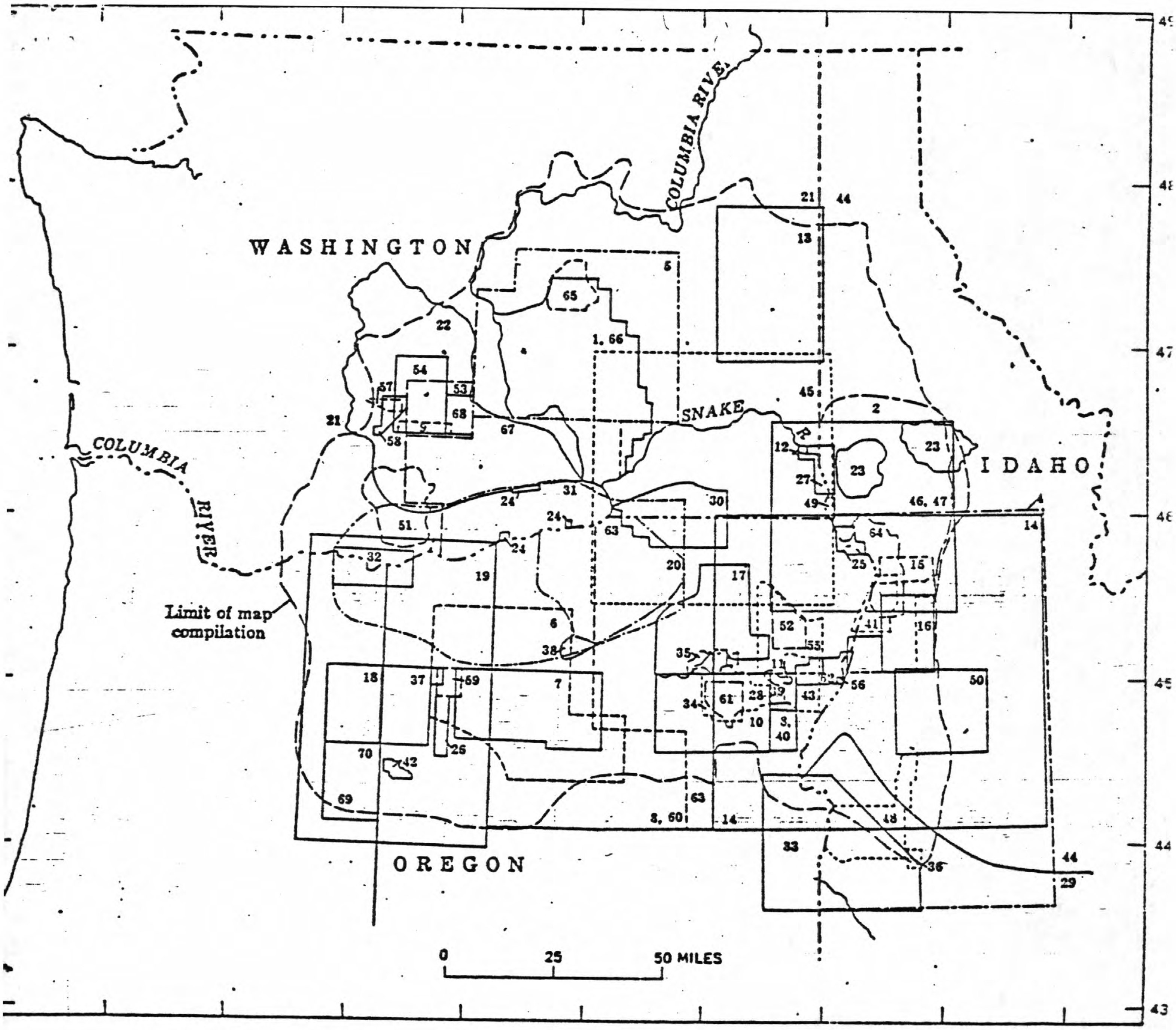


Figure 3.--INDEX MAP SHOWING LOCATION OF GEOLOGIC MAP SHEETS AND SECTIONS

U.S.G.S.
Map I-589

M. J. Grolier and J. W. Bingham



Index map of Columbia Plateau showing references to geologic reports (from Newcomb 1970)

Figure 4.--Index map of Columbia Plateau, from U.S. Geological Survey Miscellaneous Geological Investigations Map I-587.

INDEX TO GEOLOGIC MAPPING

NOTE: Numbers refer to serial numbering of published sources of information. Limits of areas are not shown where they follow state boundaries or major rivers

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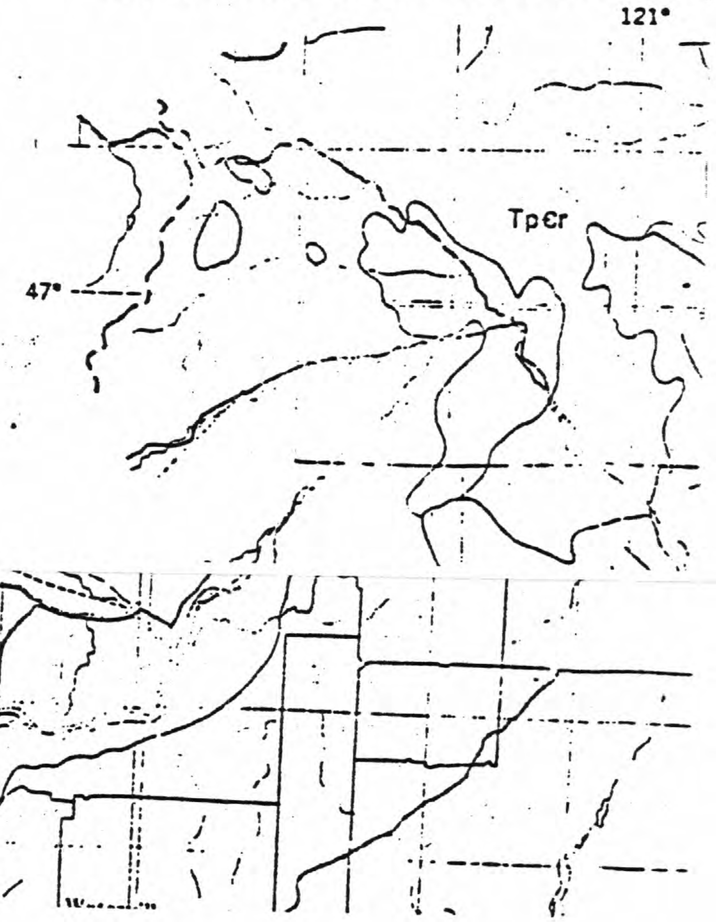

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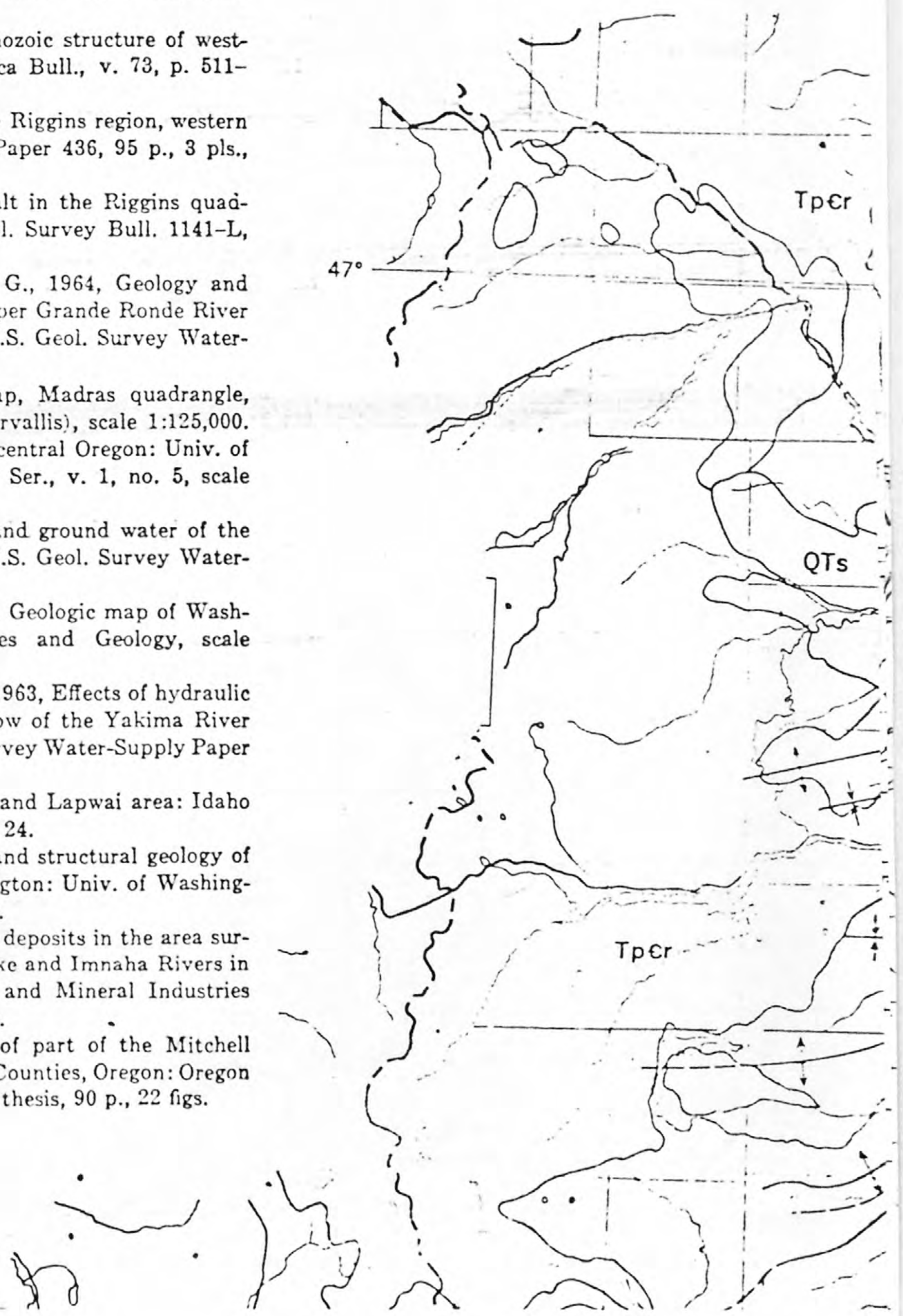

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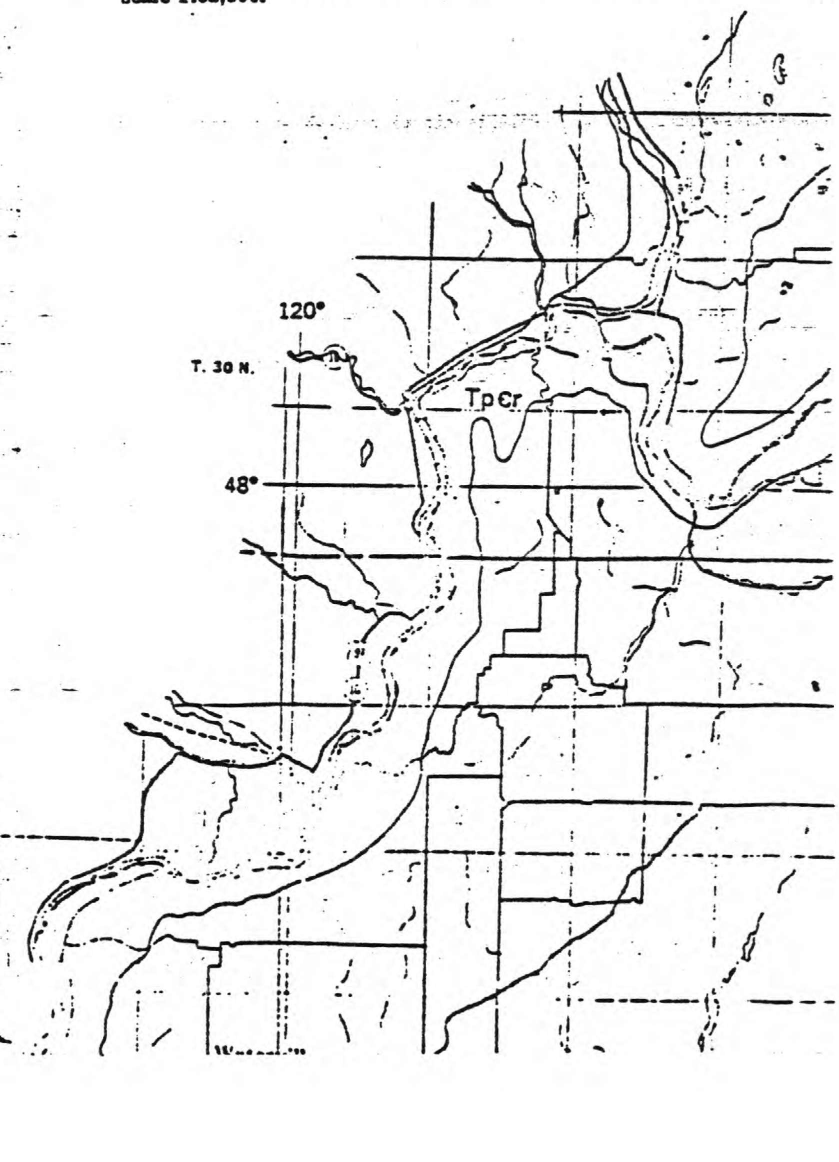

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This map was compiled to show the areas in which geologic structure favors the accumulation and storage of ground water in the basalt of the Columbia River Group of Miocene and Pliocene age. Published and unpublished sources of data were used, supplemented in places by field reconnaissance. In addition to folds and faults in the basalt, the map includes a few structures in rocks older than the basalt, where those structures affect the position and water-bearing capabilities of the nearby basalt.

Most of the known folds that show structural relief of more than 100 feet and faults that have more than 50 feet displacement are included. In zones of close and complex deformation, minor structures have been omitted for lack of space or have been generalized. Except in the area south of the Ochoco anticline, where faults and fractures were plotted from aerial photographs without ground checking, nondisplacement breaks of the extension-fracture type, sometimes called regional joints, have been omitted.

The structures that displace the basalt are geologically youthful, Pliocene and Quaternary in age. Most of the anticlines are tectonic mountains, and the synclines are tectonic valleys.