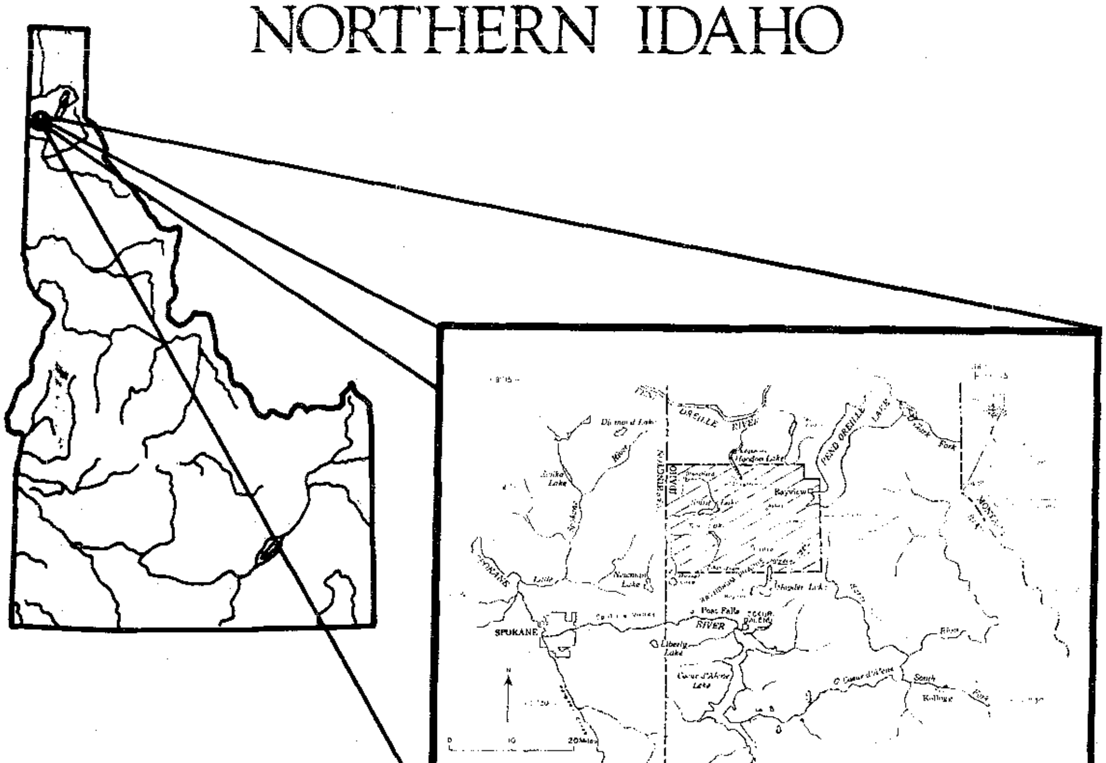
GROUND-WATER OCCURRENCE AND MOVEMENT IN THE ATHOL AREA AND THE NORTHERN RATHDRUM PRAIRIE, NORTHERN IDAHO



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GROUND–WATER OCCURRENCE AND MOVEMENT IN THE ATHOL AREA AND THE NORTHERN RATHDRUM PRAIRIE, NORTHERN IDAHO

by

R. E. Hammond

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ILLUSTRATIONS

GROUND–WATER OCCURRENCE AND MOVEMENT IN THE ATHOL AREA AND THE NORTHERN RATHDRUM PRAIRIE, NORTHERN IDAHO

by

R. E. Hammond

ABSTRACT

A highly permeable aquifer occupying the channel of ancestral Rathdrum River underlies the Spokane Valley of northeastern Washington and the Rathdrum Prairie and Athol areas of northern Idaho. Large quantities of water are pumped from the aquifer for irrigation, industrial, and municipal use. Natural discharge from the aquifer to the Spokane River is used for power generation.

New data from a geophysical survey (gravity), test drilling, and mass measurements of water levels in wells allow new interpretations of the ground-water movement beneath the Rathdrum Prairie and Athol areas of northern Idaho. Ground water in the aquifer moves from the Athol area to the northern Rathdrum Prairie through only two of three buried channels. A test well constructed in the principal (west) channel could not be completed because of difficulty in penetrating the extremely coarse boulder gravels encountered. For this reason, a quantitative estimate of flow through this channel could not be made. Estimates made by Pluhowski and Thomas (1968), suggest that about 200 million gallons per day flows through the two buried channels - the west channel and the Chilco channel. Of this amount, about 170 million gallons per day flows through the west channel and 30 million gallons per day through the Chilco channel. Flow through the middle channel is considered negligible because the bedrock bottom of the channel is above the water table. The west channel is filled at least partly with large, loose boulders. The Chilco channel is both smaller in cross-section than the west channel and is filled with less highly permeable material.

The amount of water contributed by Pend Orielle Lake could not be estimated from the data available. Use of ground water to date has had negligible effects on water levels in the study area.

INTRODUCTION

A highly permeable aquifer of sand, gravel and boulders underlies the Rathdrum Prairie-Athol area and the Spokane Valley of northern Idaho and northeastern Washington (fig. 1). Large quantities of water for irrigation, industrial, and municipal use are being pumped from the central and southwestern parts of this aquifer, and water that discharges from the southwestern part of the aquifer into the Spokane River is used to generate power. To date, the overall effects of these uses on the ground-water resource have been slight. However, in recent years, private and governmental agencies have been seeking to develop additional quantities of ground water in the southern part of the Rathdrum Prairie and in the Spokane Valley.

Several studies have indicated that large quantities of ground water flow from the Athol area toward the Rathdrum Prairie, and that this flow provides a significant part of the total ground-water supply for the Spokane Valley The amount of ground water entering Rathdrum Prairie from the north is, therefore, of concern to present and future water users and to those charged with administering the ground-water resources in these areas.

Purpose and Scope

In 1969, the U. S Geological Survey, in cooperation with the Idaho Department of Water Administration, began a study whose goal was to evaluate previous estimates of (1) the quantity of underflow moving toward the Rathdrum Prairie from the Athol area across a line extending about 6 miles northwestward from Chilco and (2) the quantity of water being recharged to the aquifer by Pend Oreille Lake.

Previous estimates of underflow, which were derived from a water budget for this area (Thomas 1963, and Pluhowski and Thomas 1968), indicate that about 200 to 300 mgd (million gallons per day) of underflow moves toward the northern Rathdrum Prairie. This included an estimated 30 to 130 mgd contribution from Pend Oreille Lake. Evaluation of these figures could be made either by collecting the large amounts of additional precipitation, evapotranspiration, and streamflow data needed to refine previous water budgets, an indirect method; or by gathering data on transmissibility, permeability, hydraulic gradient, and cross-sectional flow area, a more direct method. The decision was made to direct the study effort toward collecting the data needed to calculate the underflow directly.

To that end, a detailed geophysical (gravity) survey was made by the U. S. Geological Survey to define the configuration of the bedrock surface and to allow calculation of the thickness of fill in the west, middle, and Chilco channels. Three series of water-level measurements that were made in the few tens of wells in the area provided meaningful data on the depths to water. Also, drillers' logs of wells, a few gamma-ray logs, and drillers' reports of depths of wells and of bottom-hole materials were collected, and two test wells were drilled.

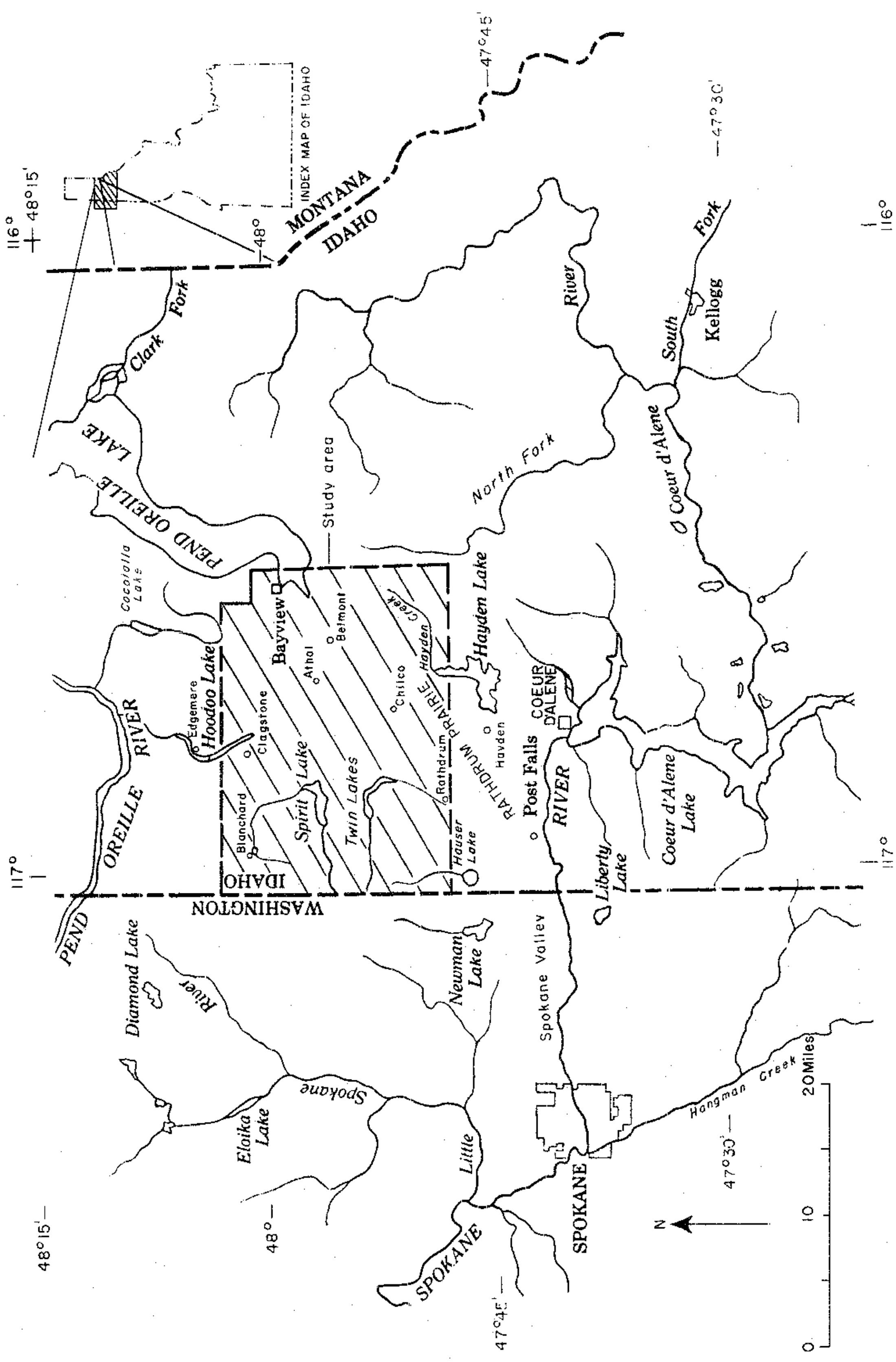

FIGURE 1. Regional index map showing location of study area.

However, owing to extreme aquifer characteristics, difficult drilling conditions, and the scarcity of wells, (explained later in this report), the data were not sufficient to calculate directly the amount of ground water being contributed to the northern Rathdrum Prairie. However, even though the objectives of this study were not met, the new information collected and the interpretations presented in this report should be of use to the ground-water users of the area.

In sum, the investigation produced new information on the thickness and configuration of the fill overlying bedrock, ruled out the middle channel as a conduit for ground water, yielded a new water-table map that shows depths to water and indicates directions of movement, indicated the position of a ground-water divide, and implied that the west channel is underlain by materials of exceptionally high water-bearing capacity.

Physiographic Features

The region of primary interest to this report includes parts of Bonner and Kootenai Counties, Idaho. The major topographic features in this region are the alluvium-filled valleys, which make up the lowlands, and the bordering mountainous highlands. The topographic break between the highlands and lowlands is generally abrupt.

The highlands to the west and north of the region are part of the Selkirk Mountains and to the east are part of the Coeur d'Alene Mountains. The rugged relief and well-established drainage systems that characterize the mountainous terrain of the highlands are the result of differential erosion of the bedrock. In this report, Round Mountain and the Chilco ridge are classed as highlands.

The lowlands have a flat to rolling topography and, because of the permeable composition of the underlying material, have no established surface drainage. Most of the streams flowing off the highlands onto the lowlands disappear in a short distance and little, if any, surface runoff is generated in the lowlands. The lowland area immediately south of line A-A′ through Round Mountain and Chilco ridge (fig. 3) is herein called the northern Rathdrum Prairie. North of this line the lowland areas are collectively referred to as the Athol area. Round Mountain and the Chilco ridge rise several hundred feet above the surrounding lowland. These two features divide the surrounding lowlands into three channels, namely, the west channel, middle channel, and Chilco channel (fig. 3).

Well-Numbering System

The well-numbering system used by the Geological Survey in Idaho indicates the location of wells within the official rectangular subdivision of the public lands, with reference to the Boise base line and meridian. The first two segments of the number designate the township and range. The third segment gives the section number, followed by three letters and a numeral, which indicate the quarter section, the 40-acre tract, the 10-acre tract, and the serial number of the well within the tract, respectively. Quarter sections are lettered a, b, c, and d in counterclockwise order from the northeast quarter of each section (fig. 2). Within the quarter sections, 40-acre and 10-acre tracts are lettered in the same manner. Well 53N-4W-28cab1 is in the NW¼NE¼SW¼ sec. 28, T. 53 N., R. 4 W., and was the first well inventoried in that tract.

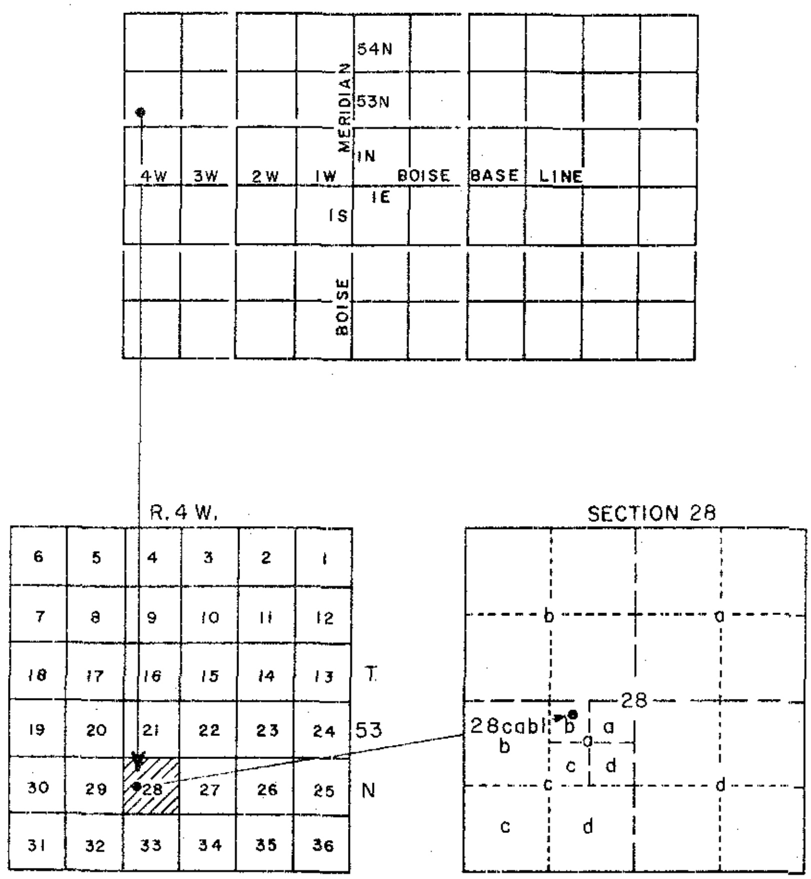

FIGURE 2. Diagram showing well-numbering system.

Previous Investigations

There are many reports that pertain either directly or indirectly to the Rathdrum Prairie area and its ground-water system. Those cited herein are used to emphasize certain physical conditions or problems associated with the area of primary concern and do not represent the total number of reports covering this region. Generally speaking, the reports

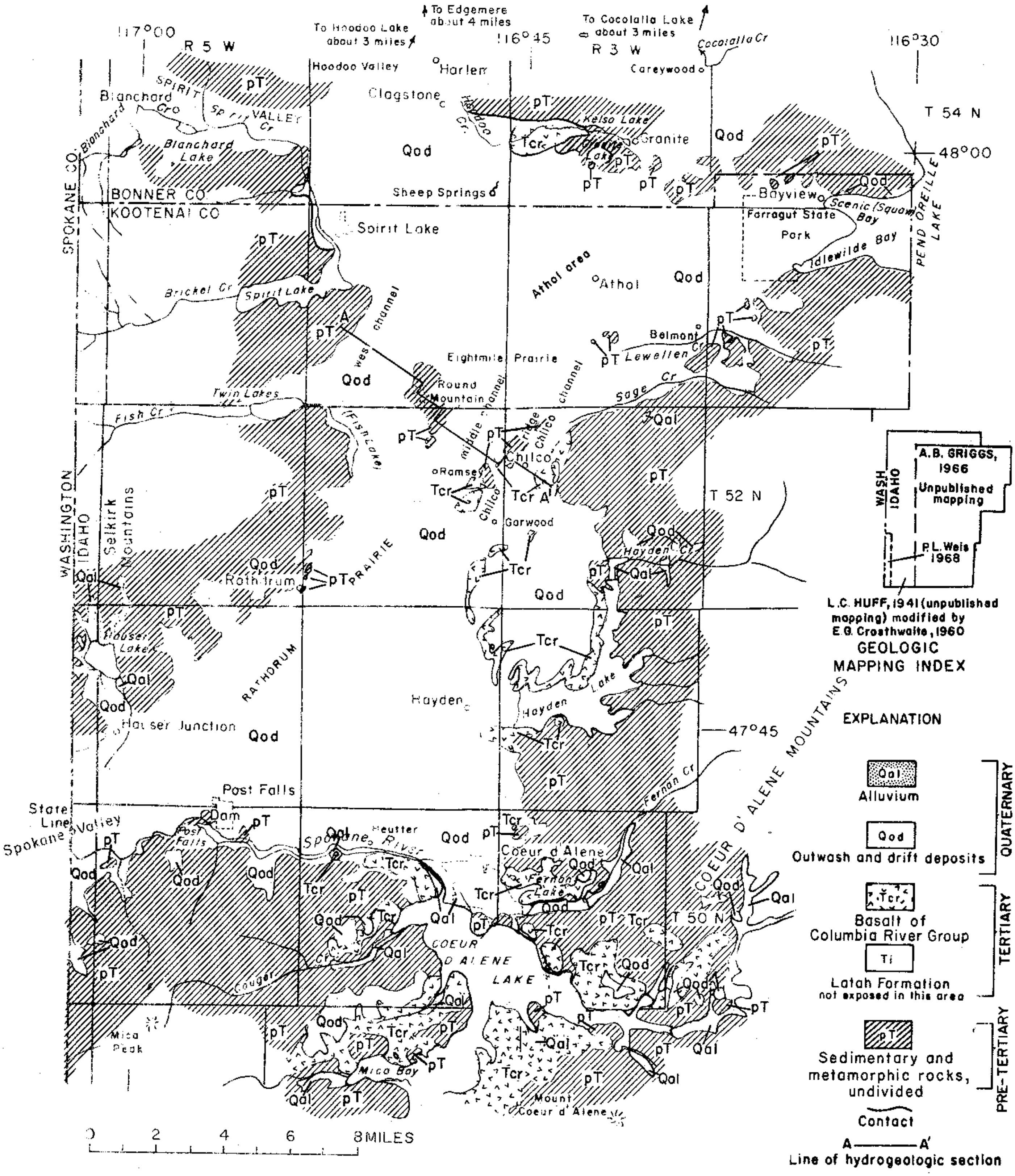

FIGURE 3. Generalized geologic map of the Rathdrum Prairie and adjacent area.

cited can be divided into two broad categories: (1) those describing the geologic events that created the physical makeup of the ground-water system; and (2) those describing the behavior of the ground-water system.

General comments on the pre-Quaternary geologic history of the region are contained in a report by Savage (1967) which describes the geology and mineral resources of Bonner County, Idaho. Of special interest in Savage's report is a discussion of "pre-basalt drainages," in particular, the "Rathdrum River" and its major tributaries which flowed through the Rathdrum Prairie area during the Tertiary Period. The Quaternary history of this region is discussed in a paper by Richmond, Fryxell, Neff, and Weis (1965). This report is a summary of previous publications and incorporates ideas and concepts that are still valid concerning glacial and flood events occurring in Pleistocene time. Of particular interest is a discussion of the creation of Lake Missoula and the catastrophic releases and flood paths of the lake waters, which were channeled through the Rathdrum Prairie area. The importance of glacial and flood deposits as ground-water aquifers and the extremely high permeabilities found in the area are discussed in publications by Simons and others (1953), Walker (1964), Savage (1967), and Piper and LaRocque (1944).

A water budget, which describes the source and amount of recharge to the ground-water system underlying the Rathdrum Prairie and the area around Athol, was presented in a paper by Pluhowski and Thomas (1968). The amount of water contributed to the ground-water system by Pend Oreille Lake was estimated by them to be 30 to 130 mgd; whereas, Simons and others (1953, p. 178) estimated the contribution from Pend Oreille Lake to range from 130 to 200 mgd.

GEOLOGIC UNITS AND THEIR WATER–BEARING CHARACTERISTICS

For purposes of this report, the geologic units of the study area are grouped into rocks of pre-Tertiary, Tertiary, and Quaternary age. The surficial distribution of the rock units is shown in figure 3.

Practically all the pre-Tertiary units are sedimentary formations that have been metamorphosed, intruded, and displaced by igneous rocks, and then eroded to form the ridges and valleys of the highlands in this region. These rocks constitute the bedrock found in wells. The rocks of Tertiary age are the lake deposits of the Latah Formation and the basalts of the Columbia River Group which are interbedded with the Latah Formation. Glaciers and catastrophic floods occurring in Pleistocene (Quaternary) time removed much of the Latah Formation and Columbia River basalt from the Rathdrum Prairie-Athol areas and deposited large quantities of alluvium consisting of varying mixtures of clay, sand, gravel and boulders.

The general configuration of the buried bedrock surface in the study area (fig. 5) was drawn using data obtained from geophysical and drillers' logs of wells and a detailed gravity survey (fig. 4). The configuration of the buried bedrock surface is not precisely defined below an altitude of about 2,000 feet above mean sea level, because few wells penetrate bedrock and because the very steep regional gravity gradient occurring in this general area makes interpretation of the gravity data difficult. Drilling of test hole No. 1 in the middle channel provided pertinent data on the depth to bedrock.

Gamma-ray logs made in several wells indicate that the sands and gravels have a relatively low level of gamma-ray activity, that sands and gravels with some clay have a slightly higher level, and that a relatively high level of activity is measured as bedrock is penetrated (see middle-channel well log, fig. 8, as a selected representation of gamma-ray logs in the area). Thus, gamma-ray logs, where available, provided a ready method of identifying depths to bedrock in wells. Drillers' logs were also useful in determining depths to bedrock and types of materials penetrated. Study of drillers' logs and cuttings obtained from wells indicates that the alluvial fill of the lowlands is derived predominantly from bedrock of nearby highlands.

Pre-Tertiary Rocks

The rocks of pre-Tertiary age are those gneisses and schists which are older than the Belt Supergroup, the argillites and siltites of the Belt Supergroup of Precambrian age, and the limestones and quartzites of Cambrian age. Locally, all these rocks have been intruded by granitic rocks of Cretaceous age. Generally, these rocks have very low permeabilities and act as an impervious basement which underlies the entire area.

Beneath the lowlands, the buried bedrock surface has the shape of a deep river valley (fig. 5). The relief of this buried surface may be as great as that of the exposed bedrock surface in the highlands. Round Mountain, Chilco ridge, and other outcrops are the exposed tops of hills and ridges that are partially buried beneath basalt and sedimentary deposits of a younger age.

Tertiary Rocks

The rocks of Tertiary age are the Latah Formation and the Columbia River Group. Prior to emplacement of the Columbia River basalt in mid-Tertiary time, the bottom of the buried river valley, as outlined by the 1,000-foot contour in figure 5, was occupied by the Clark Fork River or "Rathdrum River" (Savage, 1967). During the Tertiary Period, basalt flows of the Columbia River Group originated in and spread northeastward from the Columbia Plateau. As some of these flows flooded the lowlands to the north and east of the Columbia Plateau, they dammed drainageways, including the "Rathdrum River," and thereby created lakes in which the sand, silt, and clay beds of the Latah Formation were deposited. Initially, the basalt flows did not extend into the study area and a relatively thick section of the Latah Formation was deposited in the lakes. Later, outpourings of basalt overrode the early Latah deposits and again disrupted the drainage. Repeated outpourings of basalt and deposition of sediments produced the alternating sequence of basalts and lake sediments penetrated by many wells. The extent to which basalts invaded the lowlands is indicated by their occurrence west of Granite, east of Chilco, and along Hayden and Coeur d'Alene Lakes (fig. 3). Much of the basalt and the Latah Formation were removed by subsequent glaciation and glacial-flood waters.

Yields of water to wells penetrating the basalts and the Latah Formation vary considerably within short distances. Generally, yields range from virtually none to quantities sufficient for domestic purposes. Because the basalts are typically quite dense and have low permeability, only those wells which penetrate fractures or interflow contact zones below the water table yield significant quantities of water. Similarly, the Latah Formation contains a preponderance of relatively impermeable clay beds and only those wells which penetrate one or more of the few saturated sand or gravel beds in the formation yield significant quantities of water. In general, the basalts and the Latah Formation, like the pre-Tertiary bedrock, serve as barriers to the movement of ground water.

Quaternary Rocks

The several advances and recessions of lobes of the Cordilleran ice sheet during the Quaternary Period modified preexisting surface features and the surficial materials of the lowlands. Erosion by the advancing ice lobes deepened valleys, smoothed off valley walls, and not only removed much of the basalt and the Latah Formation but also removed large quantities of older rock. The erosion did not occur uniformly, however, as is indicated by the presence of basalt on Chilco ridge and the reported occurrence of basalt and the Latah Formation at depth beneath the Eightmile Prairie.

Much of the material eroded by the ice was deposited as till, as poorly sorted sand and gravel by glacial meltwater streams, or as silt and clay in glacial lakes. A clay layer noted by drillers in wells east of Spirit Lake was probably deposited in a glacially-dammed lake because outwash gravels both overlie and underlie the clay. Other fairly thick deposits of clay occur in the Chilco channel. These clays, which are overlain by outwash gravels and underlain by bedrock (Chilco channel, fig. 8), may be either glacial-lake deposits or a part of the Latah Formation.

Ice dams creating large glacial lakes were formed during the general advances and recessions of ice lobes into Idaho and Montana. The sudden breaching of some of these ice dams, in particular the dam behind which glacial Lake Missoula in Montana was formed, caused immense catastrophic floods that passed over the lowlands (Richmond, Fryxell, Neff, and Weiss, 1965). These floods modified, in some places to a considerable degree, the preexisting topography and either re-sorted, redeposited, or removed preexisting glacial deposits. The water-cut bluffs between Bayview and Granite and south of Round Mountain, and the giant ripple marks east of Spirit Lake are some of the more spectacular features produced by these floods (P. L. Weis, oral commun., 1970). Another major effect of the floods was the removal of much of the finer material (clay, silt, and sand) from preexisting tills and outwash deposits. As a result, beds of coarse material that ranges in size from fine gravel to boulders several feet in diameter occur deep in the subsurface throughout the lowland area. These deposits are highly permeable and, where saturated, constitute the principal aquifers of the lowlands.

GROUND–WATER OCCURRENCE AND MOVEMENT

The ground water in the poorly sorted to well-sorted silt, sand, gravel, and boulder beds of Pleistocene age in the Rathdrum Prairie-Athol area occurs under water-table conditions. Yields from wells which penetrate the regional ground-water body range from several gallons per minute to several thousand gallons per minute and the yields are almost entirely dependent on manner of construction. Locally, small amounts of ground water are also found in rocks of pre-Tertiary and Tertiary ages, usually in fractures or in the weathered zone on the upper surface of the bedrock.

The ground water beneath the Rathdrum Prairie-Athol area is derived from the infiltration of precipitation on the lowlands, from the downward percolation of runoff from the peripheral highlands, and by seepage from lakes on or adjacent to the lowlands.

In the area of Athol, ground water flows west-southwestward through the alluvium-filled valley of the ancestral "Rathdrum River." To the north and west of Athol, the flow is from Spirit Valley to Hoodoo Valley then south to join the west-southwestward flow from Athol. The combined flow then moves south through the west channel to the northern Rathdrum Prairie (fig. 6). Ground water flow from Pend Oreille Lake toward Athol is variable because the observed hydraulic gradient toward well 53N-2W-9aad1 from the lake during the period December 1969 to August 1970 ranged from 2 feet per mile to 0.5 foot per mile. However, when the lake level declines below the adjacent water table, an apparent ground-water mound (divide) is formed in the vicinity of Farragut State Park. At such times, ground water may even flow toward the lake from a distance of at least one-third of a mile and possibly several miles from the shoreline (Nace, and others, unpublished data in files of U. S. Geological Survey).

Well control for the contours on the water table (fig. 6) is sparse. Interpretations based on those contours must be made cautiously and accepted as tentative. But their configuration, if reasonably accurate, is instructive, especially as seen with reference to the bedrock surface inferred from the gravity survey (fig. 5). The bedrock contours suggest that the main channel of the ancient "Rathdrum River" extended westward from modern-day Pend Oreille Lake toward Spirit Lake, then turned southward passing through what is now called the west channel between Twin Lakes and Round Mountain. The inference (fig. 5) is that the ancient channel bed is about 1,100 feet below the present water-table.

The water-table contours (fig. 6) imply a flat gradient perhaps 1 foot per mile, from Pend Oreille Lake westward to near Athol where the gradient steepens to more than 6 feet per mile and swings southwestward for about 3 miles. Thence, southward through west channel to near Rathdrum, the gradient flattens again to about 3 feet per mile.

The sequence just described suggests the possibility that something in the subsurface materially impedes ground-water flow near Athol. As the bedrock-configuration map (fig. 5) shows no constriction in the walls or floor of the buried channel, the reasonable inference is that flow is hindered by a change toward finer grain size of the channel fill, hence lessened transmissibility, at least with respect to the transmissibility that prevails southwestward from areas about 3 miles west of Athol. The rather flat gradient through the west channel and on toward Rathdrum implies the presence of highly permeable materials in the aquifers, an inference that is supported by known high permeabilities southward beneath Rathdrum Prairie.

The problem of underground flow from Pend Oreille Lake to the Rathdrum Prairie is unresolvable with the existing data. At no time, during this investigation, was any well in the study area equipped with a pump, or operating on a pumping regimen, that would allow making any sort of tests that would have yielded useful indications of aquifer characteristics in areas of inferred high permeability. In consequence, it was impossible to make quantitative estimates of discharge from the Pend Oreille Lake or through the aquifer system from direct observations.

In Spirit Valley, the ground water moves eastward at a gradient of about 10 feet per mile toward the southern part of Hoodoo Valley and merges with the water table there. The water table in the southern part of Hoodoo Valley is very shallow and is represented by the surfaces of several small lakes and swamps in the valley. Although the surficial drainage in that area is to the north, Walker (1964) surmised that a ground-water divide may exist near Edgemere, and thus, south of this point ground water would move southward. Conclusive data with which to verify this assumption are lacking, but the sparse data available indicate that a southward gradient of about 25 feet per mile may exist south of Hoodoo Valley. The water-level contours in this area (fig. 6) were drawn on the assumption that the shallow water table in the southern part of Hoodoo Valley is not perched. If the direction of ground-water movement implied by the map is correct, then the ground water moving southward from Hoodoo Valley merges and flows southward with ground water moving westward from the vicinity of Athol.

East of Spirit Lake and south of Hoodoo Valley, a water body is perched on a clay layer of Pleistocene age. The thickness of the saturated zone appears to be about 5 to 10 feet. This perched water is the source of Sheep Springs. At Sheep Springs, the perched water table is about 200 feet above the regional water table shown in figure 6. The gradient and the areal distribution of the perched water table are not known.

From the vicinity of Belmont, ground water is assumed to migrate southwestward to the Chilco channel. The inferred location of a bedrock divide just north of Belmont is shown in figure 6. Well data are almost completely lacking, but ground water in the vicinity of Belmont is assumed to occur in Pleistocene deposits overlying the bedrock surface. The configuration of the buried bedrock surface probably significantly influences the direction of ground-water movement in this sub-area, as well as the thickness of saturated alluvial material. Relative altitudes of the water table at Chilco and the surface of Pend Oreille Lake indicate that no lake water flows through Chilco channel.

FLOW THROUGH THE THREE CHANNELS

Previous investigations have assumed that Round Mountain, Chilco ridge, and the highlands to the east and west confine the southward movement of ground water from the Athol area into northern Rathdrum Prairie to the three small, alluvium-filled, west, middle, and Chilco channels.

The locations of test holes 1 and 2 in the middle and west channels, respectively, were selected to provide the data necessary for flow calculations to be made. Test hole No. 1 (52N-4W-11aab1) was drilled to 285 feet below land surface in the middle channel (fig. 7) and pre-Tertiary bedrock was first penetrated at 254 feet. Only a trace of water was found in the bedrock at 278 feet (see fig. 8 for drillers' log). For that reason, it is unlikely that flow of any consequence occurs in the middle channel. Test hole No. 2 (53N-4W-28cab1) was drilled to 448 feet below land surface in the west channel (fig. 7) and the water table was found to be at 408 feet (see fig. 8 for drillers' log). The location of the Chilco channel part of the hydrogeologic section was selected so as to pass through an existing well (52N-3W-7dcal, fig. 7) for which a drillers' log of the materials penetrated was available (fig. 8).

Flow Through the West Channel

Difficult drilling conditions at test hole No. 2 (53N-4W-28cab1) prevented completion of the work needed to provide a direct determination of transmissibility for the west channel

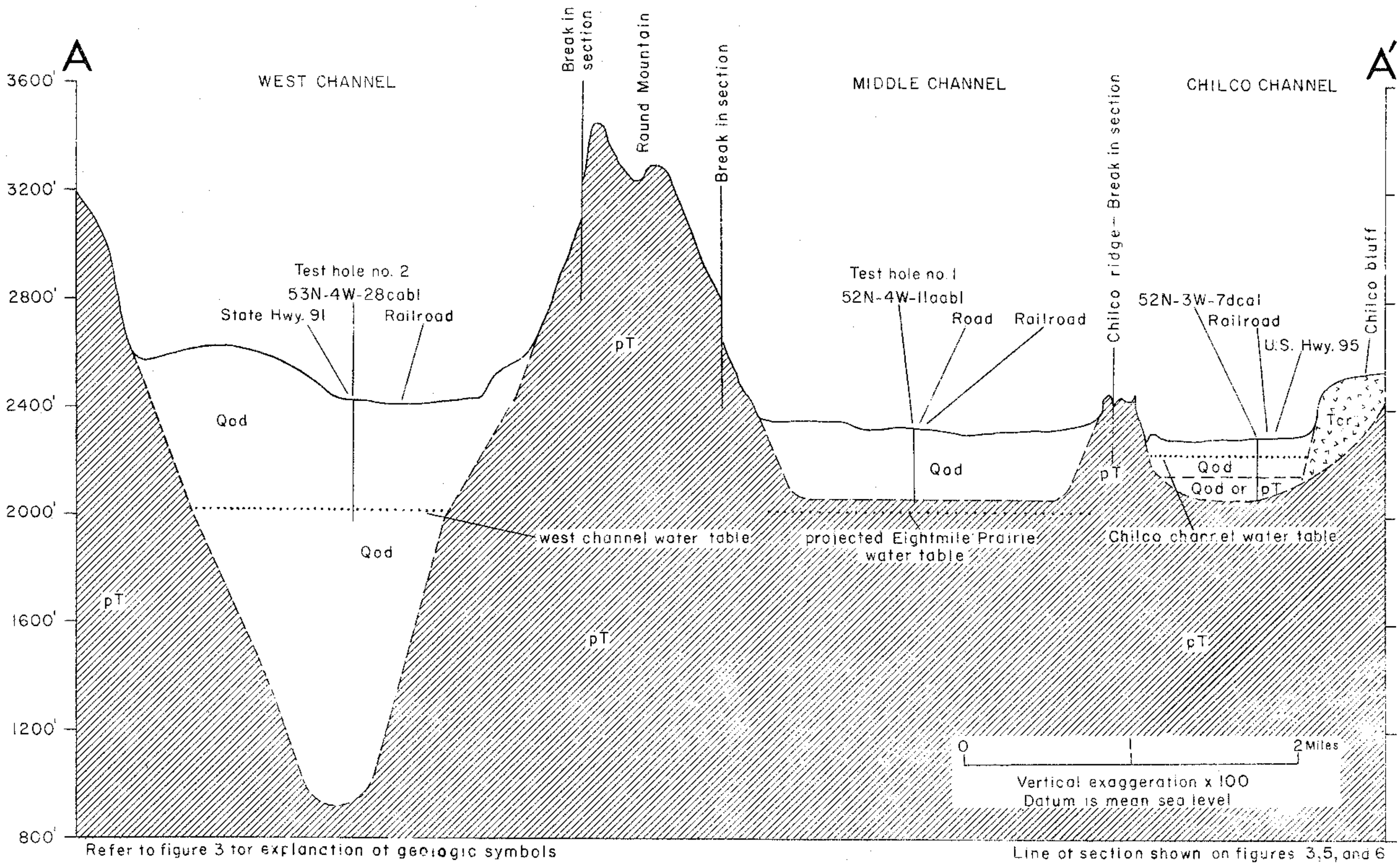

FIGURE 7. Hydrogeologic section A-A′, through the west, middle, and Chilco channels.

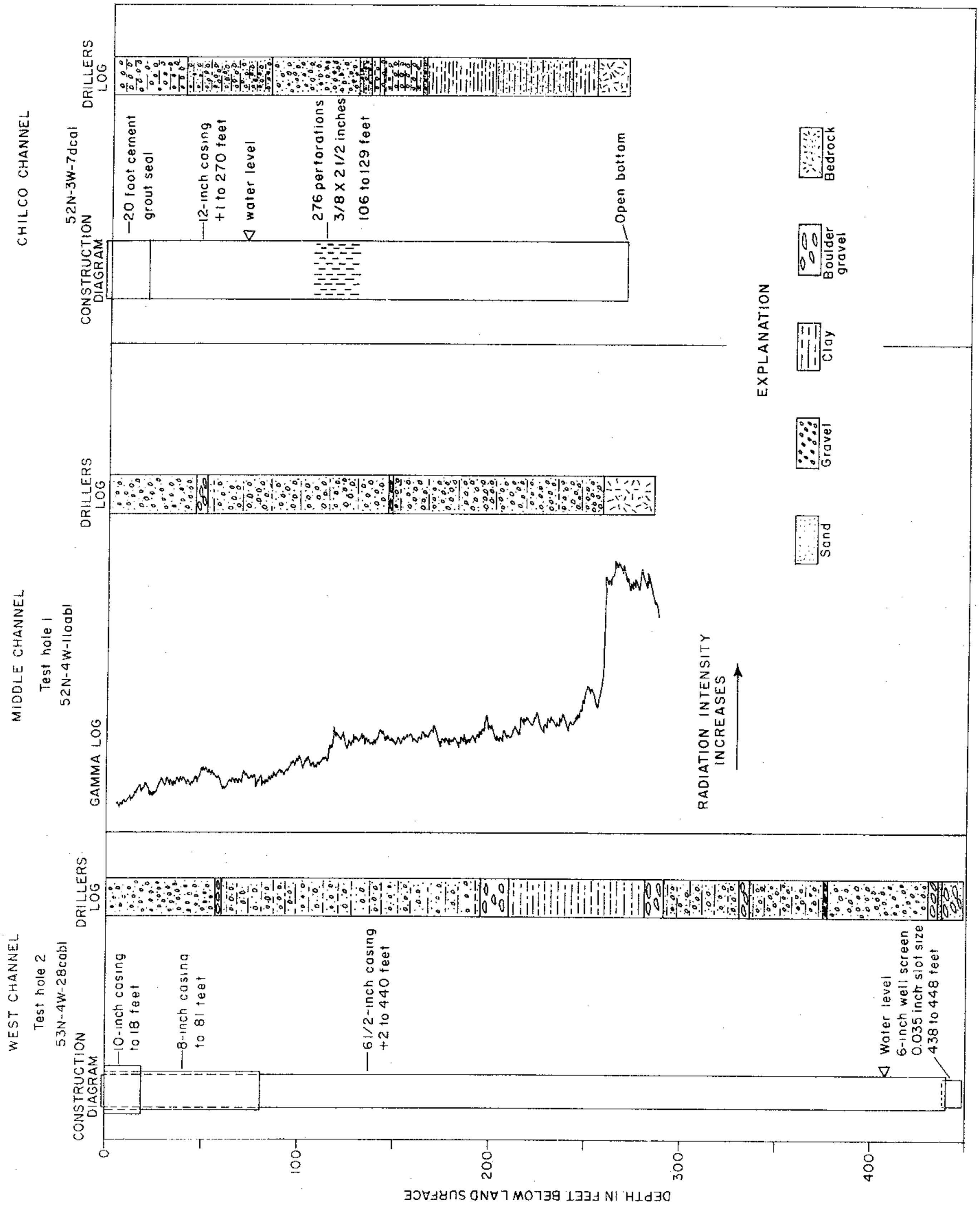

FIGURE 8. Diagrams showing logs of wells in hydrogeologic section.

The flow (Q) through the west channel is estimated by the author to be about 170 mgd based on data and computations by Pluhowski and Thomas (1968). The 170 mgd (which may be too high) includes an arbitrary estimate of 30 mgd seepage from Pend Oreille Lake; 50 mgd from Blanchard Creek and Spirit Valley; 60 mgd from Brickel Creek and Spirit Lake; and 30 mgd from the lowlands in the Athol area, excluding the area south of the bedrock divide near Belmont and Spirit Valley. From figure 7, the average effective width (L) of the saturated part of the hydrogeologic section of the west channel was estimated to be 5,000 feet. The hydraulic gradient was calculated to be about 2 feet/mile (0.0004 ft/ft) using the water-level contours in figure 6.

Using the formula Q = TIL where Q = flow in gallons per day, I = water-table gradient in feet per feet, and L = average width of cross section in feet, a coefficient of transmissibility (T) of about 90 mgd/ft was calculated. This value appears to be large when compared with the coefficients of transmissibility of many aquifers. However, four pumping tests made near the Washington-Idaho State line indicate that the coefficient of transmissibility for the aquifer underlying that part of the Rathdrum Prairie must be greater than 10 mgd/ft (M. J. Mundorff, written commun., 1955). The residual drawdown values obtained in these four aquifer tests were so small that firm coefficients of transmissibility could not be computed. That test area was downstream from the west channel and aquifer materials there are probably finer and, therefore, less permeable than in the west channel. It is reasonable to assume, therefore, that the coefficients of transmissibility in the west channel are greater than those near the Washington-Idaho State line.

During glacial times, the breaching of ice dams in upstream areas released flood waters that passed through the area and, in particular, through the west channel. These flood waters undoubtedly scoured out the alluvial filled valleys to some significant depth, and, as indicated by drillers' logs of wells, deposited thick sections of boulders and very coarse gravels containing few fines. Persons digging wells into these deposits reportedly noted large voids between boulders occurring above and near the water table. Materials such as this are noted for very large coefficients of transmissibility.

A further evaluation of the reasonableness of the large coefficient of transmissibility can be made in terms of the expected permeability of these materials. The coefficient of permeability of an aquifer, expressed in gpd/ft^2 (gallons per day per foot squared), is equal to the coefficient of transmissibility divided by the thickness of the aquifer. Assuming an aquifer thickness of 1,000 feet in the west channel (fig. 7), the permeability would then be 90,000 gpd/ft^2. In light of the permeability values given by Wenzel (1942, p. 13), as much as 90,000 gpd/ft^2 for gravels, the value calculated for the boulder gravels known to occur in the west channel appears reasonable.

Present data do not allow further evaluation of the volumetric estimates of Pluhowski and Thomas. However, it may be reiterated that most of the flow in the study area, from whatever sources, must move through the west channel toward Rathdrum Prairie.

Flow Through the Middle Channel

The hydrogeologic section across the "middle channel" apparently crosses the high part of a buried saddle between the northern Rathdrum Prairie and the Eightmile Prairie (fig. 7) and has a relatively flat bottom with steep sides. Geophysical data and well logs indicate that depths to bedrock apparently increase to the north and south of the saddle.

The altitude of the bottom of the saddle, as evidenced by the log of test hole No. 1, is sufficiently high above the regional ground-water table to prevent movement of ground water through the overlying material. Such small amounts of water as may leak through cracks and fissures in the bedrock are probably insignificant in comparison to the flow through the west and Chilco channels. Thus, the total ground-water flow through the middle channel is assumed to be zero. This is of particular interest as prior investigators have assumed that most of the ground water from the Athol area moved to the southwest through this channel.

Flow Through the Chilco Channel

Aquifer characteristics in the Chilco channel were estimated using the same technique as employed for the west channel. The Chilco channel is assumed to have a flat-bottomed, steep-sided configuration smiliar to that of the middle channel (fig. 7) but with a water-table altitude considerably higher than the west or middle channels. The steep channel walls attest to the fact that the channel has been scoured to some extent by ice. Below the water-bearing zones are impermeable clays of undetermined age; thus, it cannot be assumed that either ice or floods removed all the pre-Pleistocene deposits overlying the bedrock in the channel.

Well 52N-3W-7dca1, which penetrated to bedrock (figs. 7 and 8), is the only source of information on the lithology of the water-bearing zones in the Chilco channel. For purposes of this report, it is assumed that the lithology of the water-bearing zones at the well is representative of conditions across the entire Chilco channel section. The drillers' log (fig. 8) reported four water-bearing zones separated by impermeable layers of clay or clay and sand. The total saturated thickness of the four water-bearing zones is 67 feet, based on the position of the water table in the summer of 1970.

The average width of the section (L) at the depth of the water-bearing zones is about 5,000 feet and the water-table gradient (I) is 0.0095 ft/ft (about 50 feet per mile). The flow (Q) is assumed to be 30 mgd from unpublished data and unpublished computations made by Pluhowski and Thomas (written commun., 1968). Using the formula $Q = TIL$, a coefficient of transmissibility of about 630,000 gpd/ft was calculated for these deposits. The permeability (P) is equal to the coefficient of transmissibility divided by the thickness and is about 9,400 gpd/ft^2. This value falls within the range of permeabilities given by Wenzel

(1942, p. 13), and is approximately equal to the value given by Johnson (1963, p. 32) for very fine gravel. The coefficient of transmissibility is much lower than that calculated from the aquifer tests performed near the Washington-Idaho State line or the value estimated in the west channel. On the basis of drillers' logs, this lower T value could be expected because the aquifer is thinner and the water-bearing materials in the Chilco channel are finer grained than the material near the State line or in the west channel.

CONCLUSIONS

Previous investigators estimated that approximately 200 mgd of ground water flowed southwestward from the Athol area (Pluhowski and Thomas, 1968) through three channels -- the west, middle, and Chilco channels -- into the northern Rathdrum Prairie and that most of this flow was through the middle channel (Nace, R. L. and others, unpublished data in files of USGS). Data collected from test holes and other wells and a geophysical survey made as a part of this study show that most of this water flows through the west channel, and that a smaller amount flows through the Chilco channel. Also, because the buried bedrock floor in the middle channel is above the regional water table, flow through the middle channel is virtually zero.

Estimated values of 170 mgd and 30 mgd for flow through the west and Chilco channels, respectively, could not be verified because of a lack of data. Previous estimates of a 30 to 130 mgd contribution from Pend Oreille Lake could neither be refined or verfied. Computed values of transmissibility based on the above estimates are reasonable.

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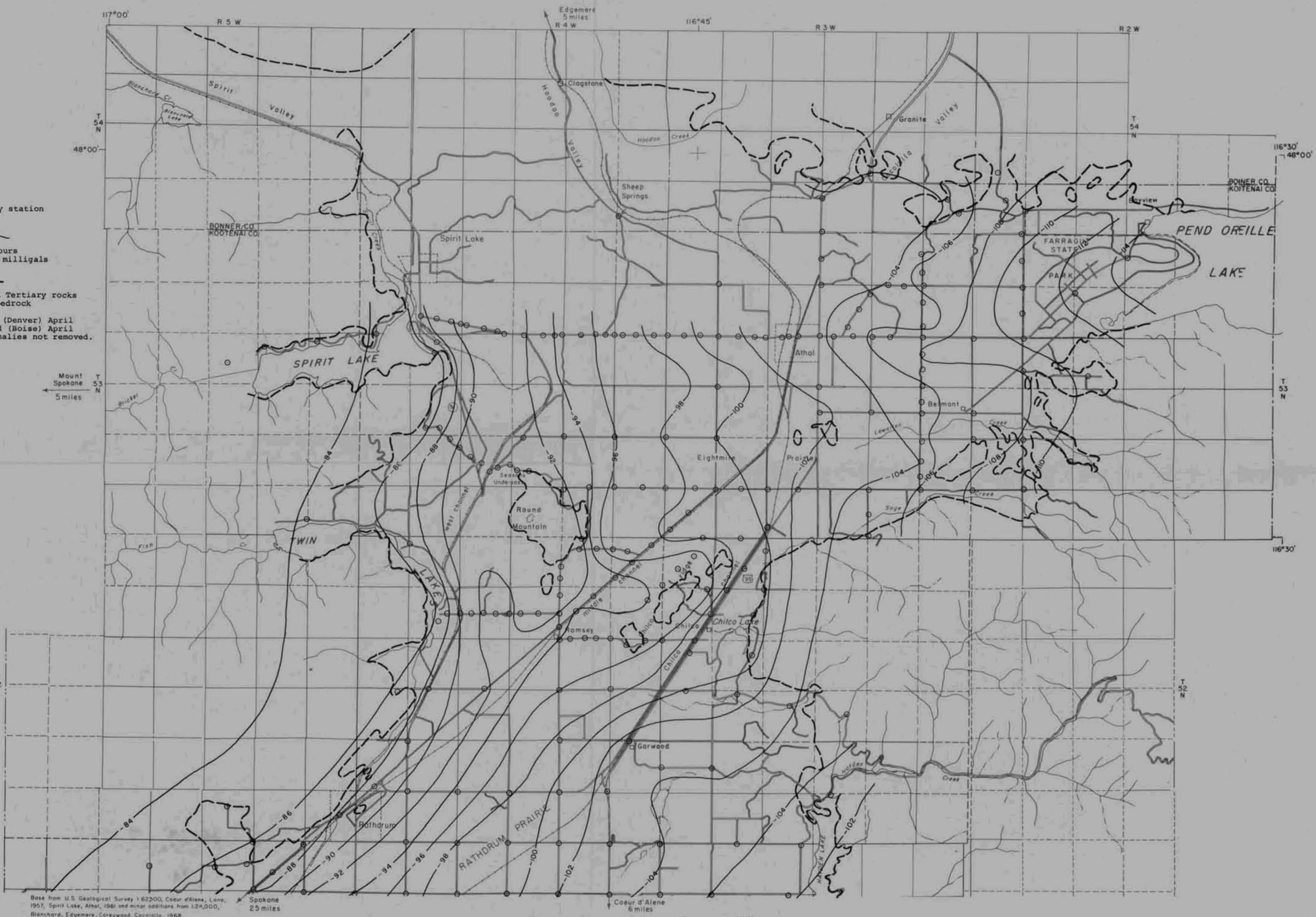

EXPLANATION

⊙
Location of gravity station

—-100—
Milligals contours
Contour interval 2 milligals

— — —
Contact of Quaternary and Tertiary rocks with pre-Tertiary bedrock

Map prepared by D. Peterson (Denver) April 1971, modified by R. Hammond (Boise) April 1971: Regional gravity anomalies not removed.

FIGURE 4.--MAP SHOWING BOUGUER ANOMALY CONTOURS.

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EXPLANATION

—3000— Exposed pre-Tertiary bedrock surface contour from topographic maps

—1500— Buried pre-Tertiary bedrock surface contour inferred from well data and gravity survey

Contact of Quaternary and Tertiary rocks with pre-Tertiary bedrock

—2000— Contour of bottom of Pend Oreille Lake

Contour interval 500 feet
Datum is mean sea level

A—A' Line of hydrogeologic section

Subsurface bedrock contours prepared by D. Peterson (Denver) April 1971, modified by R. Hammond (Boise) April 1971.

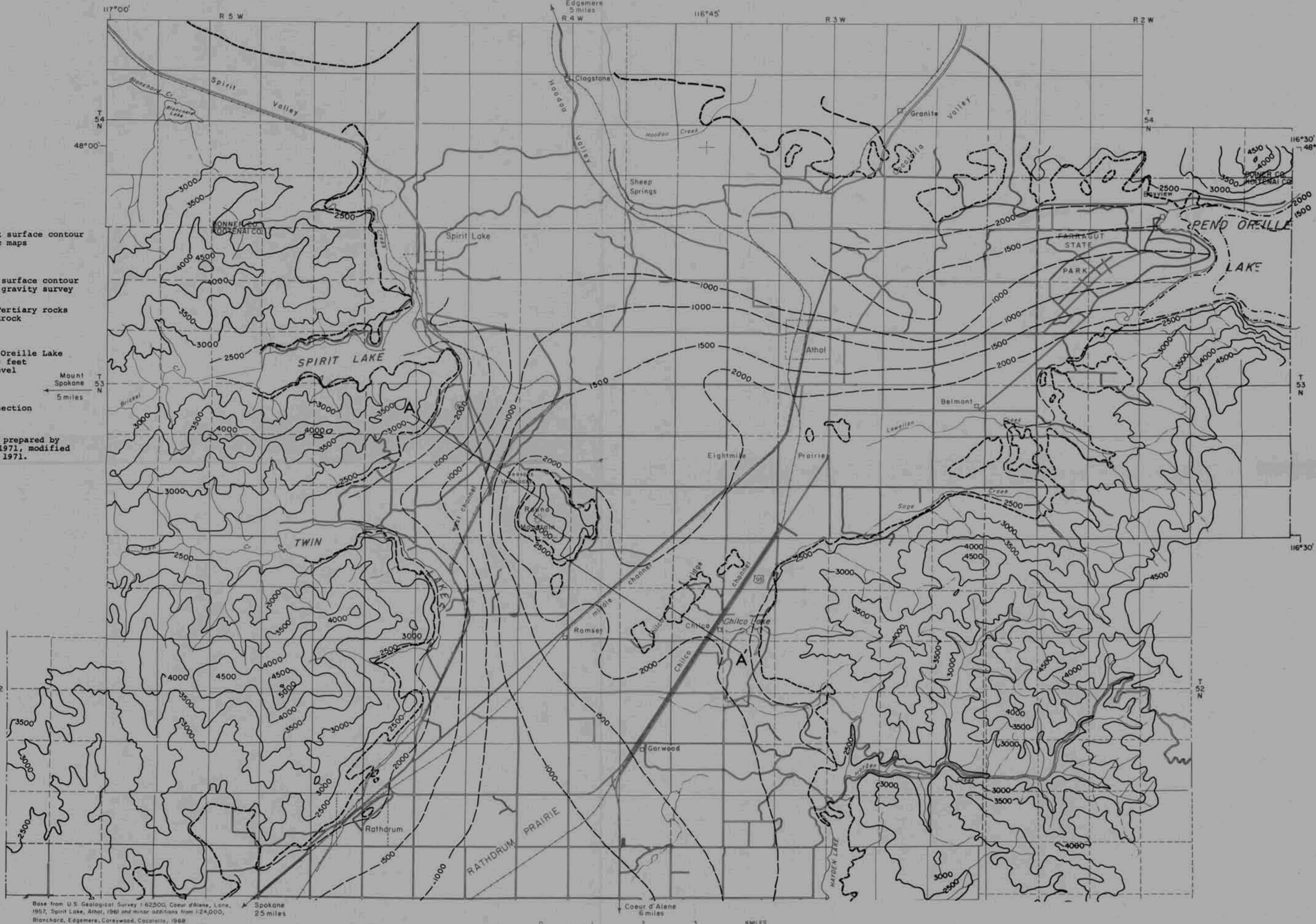

FIGURE 5.--MAP SHOWING ALTITUDE OF EXPOSED AND BURIED BEDROCK SURFACES.

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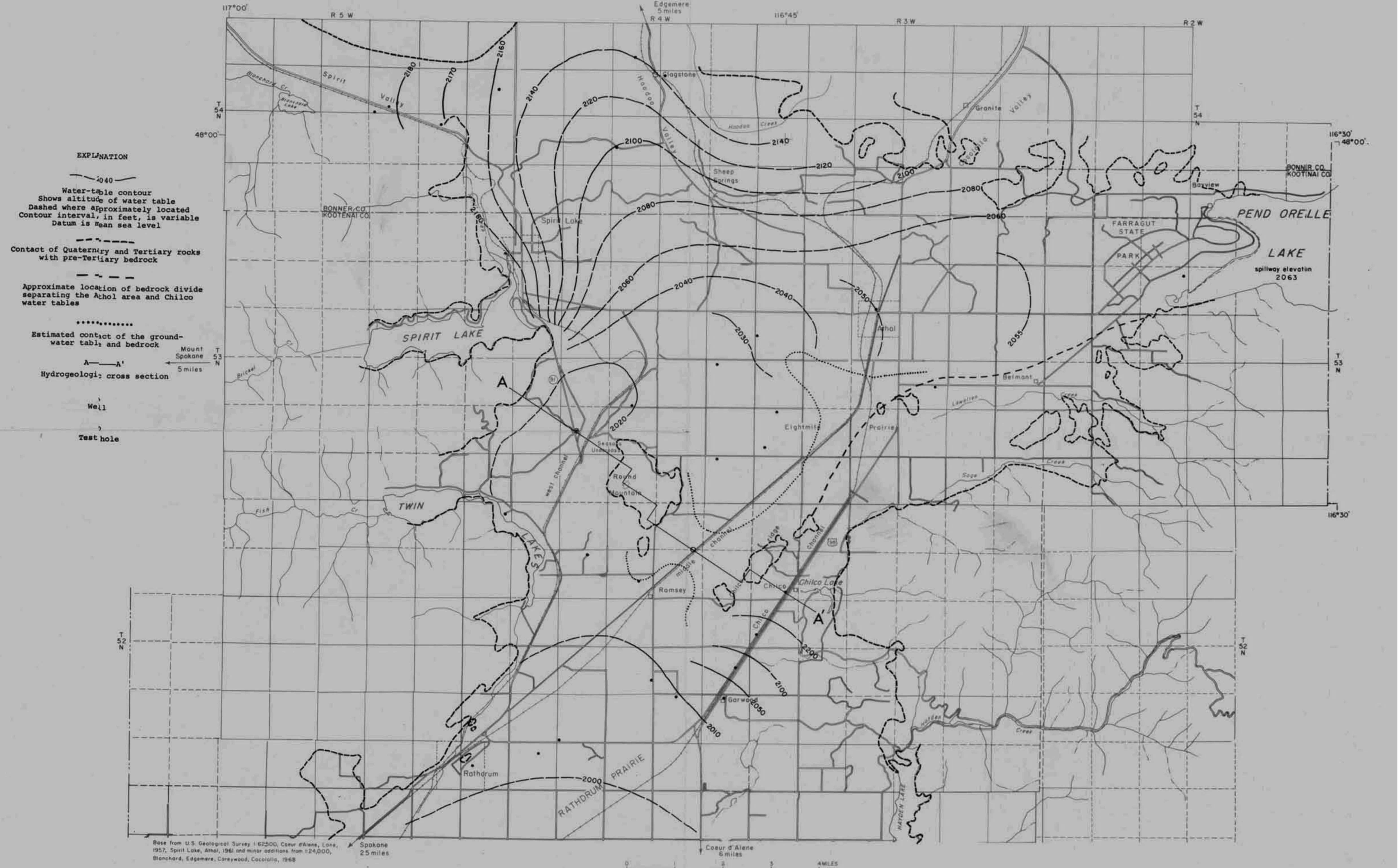

FIGURE 6.--MAP SHOWING WATER-LEVEL CONTOURS IN THE STUDY AREA, SUMMER 1970.