Geologic Factors That Control the Occurrence and Availability of Ground Water in the Fort Rock Basin Lake County, Oregon

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Prepared in cooperation with the Oregon State Engineer

Geologic Factors That Control the Occurrence and Availability of Ground Water in the Fort Rock Basin Lake County, Oregon

By E. R. HAMPTON

HYDROLOGY OF VOLCANIC-ROCK TERRANES

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GEOLOGIC FACTORS THAT CONTROL THE OCCURRENCE AND AVAILABILITY OF GROUND WATER IN THE FORT ROCK BASIN, LAKE COUNTY, OREGON

By E. R. HAMPTON

ABSTRACT

The Fort Rock Basin, in south-central Oregon, is a high plateau area of interior drainage comprising about 1,500 square miles. The precipitation is sparse—less than 10 inches per year on the basin floor—and the growing season is less than 100 days. Consequently, the ready availability of ample water for irrigation is a requisite for successful farming in the area.

Three perennial streams enter the southwestern part of the basin and provide water for irrigation and stock supplies for that part of the basin. In the rest of the basin, water for irrigation, stock, and domestic supplies is obtained from wells.

Geologic structural features, consisting mainly of broad, gentle folds and predominantly northward-trending faults, largely control the depth and areal distribution of the water-bearing rock units. Thus, the availability of ground water in any particular part of the basin is directly related to the geologic structure and the rock units present.

The rock units mapped in the basin range in age from Pliocene to Recent and are from oldest to youngest as follows: Picture Rock Basalt, volcanic rocks of intermediate composition, Fort Rock Formation, Hayes Butte Basalt, Peyerl Tuff, Paulina Basalt, unconsolidated deposits, and younger basalt. Of these units, the volcanic rocks of intermediate composition, Peyerl Tuff, and young basalt yield little or no water to wells; the other units yield small to large quantities of ground water where they are saturated. Yields as great as 4,000 gallons per minute are obtained from wells tapping the Picture Rock Basalt.

The more productive aquifers yield water of good quality, but a few wells tapping poorly productive zones in the Fort Rock Formation yield moderately saline water. Pumpage in 1960 was about 12,000 acre-feet—about one-tenth the estimated average annual recharge of 125,000 acre-feet.

Long-term water-level fluctuations lag about 10 years behind the recorded long-term precipitation fluctuations. This fact indicates that most of the ground-water recharge occurs on the sloping flanks of the basin and that the water requires years to move to the areas of discharge in the central part of the basin or to adjacent lower basins. Pumping withdrawals apparently do not materially affect the long-term fluctuations; this lack of influence indicates that considerable additional ground water is available for irrigation and other uses.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The Fort Rock Basin, in northern Lake County, Oreg., consists of high desert plains and the mountain slopes that surround them. Some hay and grain crops are raised near the edges of the valley plains, although the climate is cool and dry and the growing season short. The dry climate and short growing season make irrigation necessary for the production of economic yields of most crops. Surface water is available for irrigation only in the Silver Lake area. In other parts of the basin irrigation water must be obtained from wells.

About 100 irrigation wells were being used in the area during 1960 and additional wells were being drilled. The lack of information on the rock materials underlying the basin has hampered prediction of the well-drilling conditions and the water-bearing character of the rocks at any locality, although the position of the water table is fairly well known. Thus most wells, being largely exploratory, have been unduly costly and a considerable number have been unsuccessful, either because of improper well construction or because permeable water-bearing rocks were not present.

The objectives of this investigation are: (1) to obtain information on the extent, structure, and water-bearing characteristics of the rock units underlying the area, (2) to determine the control of these geologic factors on the occurrence, availability, and chemical quality of the ground water for the area as a whole and for specific subareas, (3) to make these data available to persons concerned with development or management of the ground-water resources of this and similar upland basins.

This study was made by the Geological Survey in financial cooperation with the Oregon State Engineer. The fieldwork was done under the direction of R. C. Newcomb, former district geologist in charge of ground-water investigations in Oregon; this report was prepared under the direction of B. L. Foxworthy, who succeeded Mr. Newcomb. Reconnaissance and detailed reconnaissance-geologic mapping was done intermittently during the summer and fall months of 1956–58 by G. M. Hogenson. Similar work was done by the author during September 1958 and the latter part of April 1959. The geology was mapped on aerial photographs, if available, and transferred to planimetric maps. Records of wells were obtained from drillers' and owners' reports to the Oregon State Engineer, from field inventory, and from data previously compiled by Trauger (1950).

LOCATION AND EXTENT OF THE AREA

The Fort Rock Basin is in northern Lake County in central Oregon (fig. 1). It is a topographic basin of interior drainage that includes the high plains commonly known as the Silver Lake-Thorne Lake Valley, Christmas Lake Valley, Fort Rock Valley and slopes adjacent to those plains (fig. 2). The basin is about 1,500 square miles in area, about 50 miles long (east-west), and about 30 miles wide.

PREVIOUS INVESTIGATIONS

Early investigations of the general geology of south central Oregon were made by Russell (1884, p. 431–464) and Waring (1908). Waring's report included a generalized geologic map that covered much of Lake County including the Fort Rock Basin, and a reconnaissance topographic map of the area.

The only previous hydrologic study describing this area was made by Trauger (1950). His work included the collection and compilation of records of wells, springs, ground-water levels, and chemical quality of ground water and the compilation of a reconnaissance geologic map of Lake County.

Previous investigations of areas adjacent to the Fort Rock Basin include a study of the geology and ground-water conditions of the Klamath River basin (southeast of this area) by Newcomb and Hart (1958), a brief discussion of the geology of the Glass Buttes (about 30

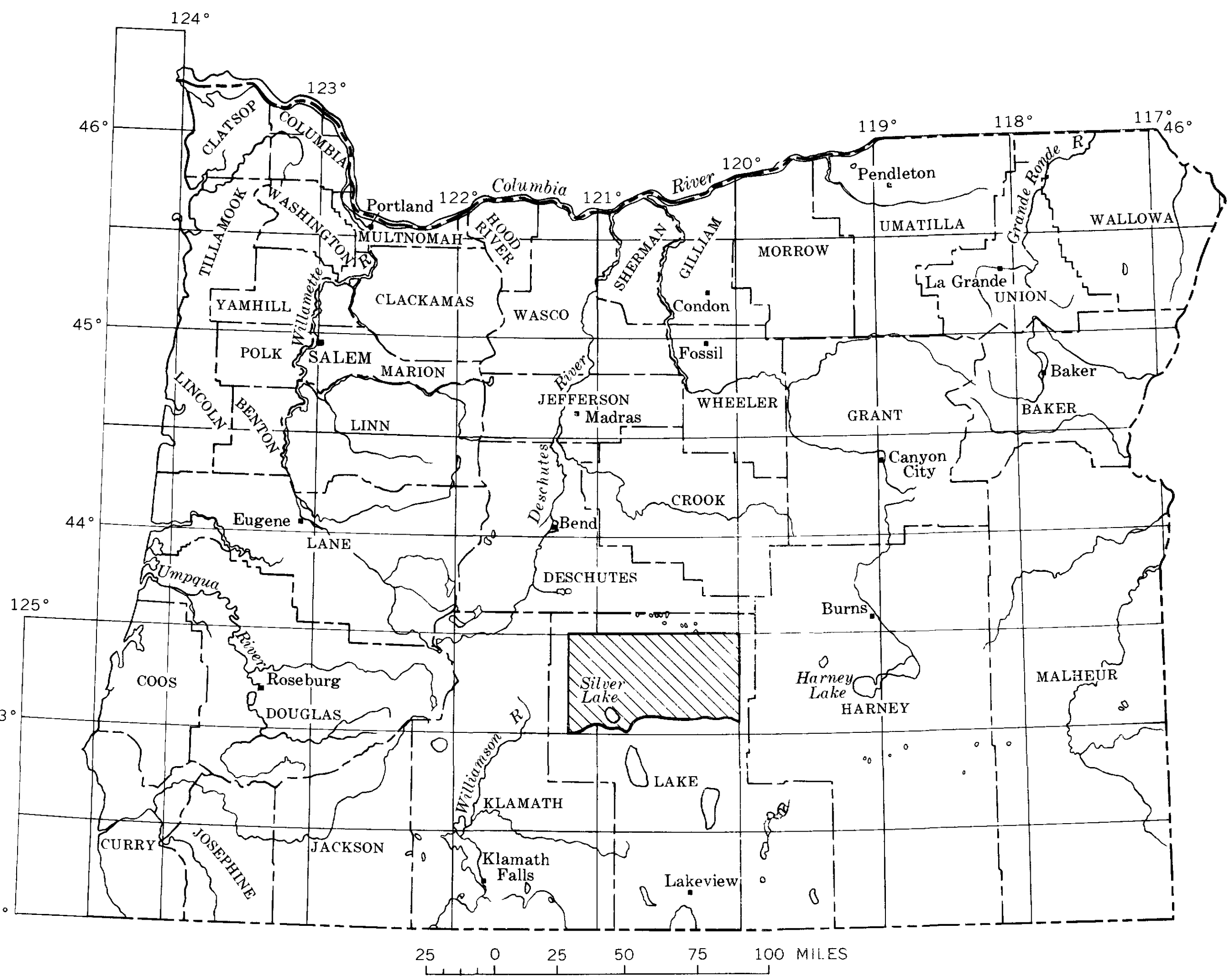


FIGURE 1.—Map of Oregon showing the area of this investigation.

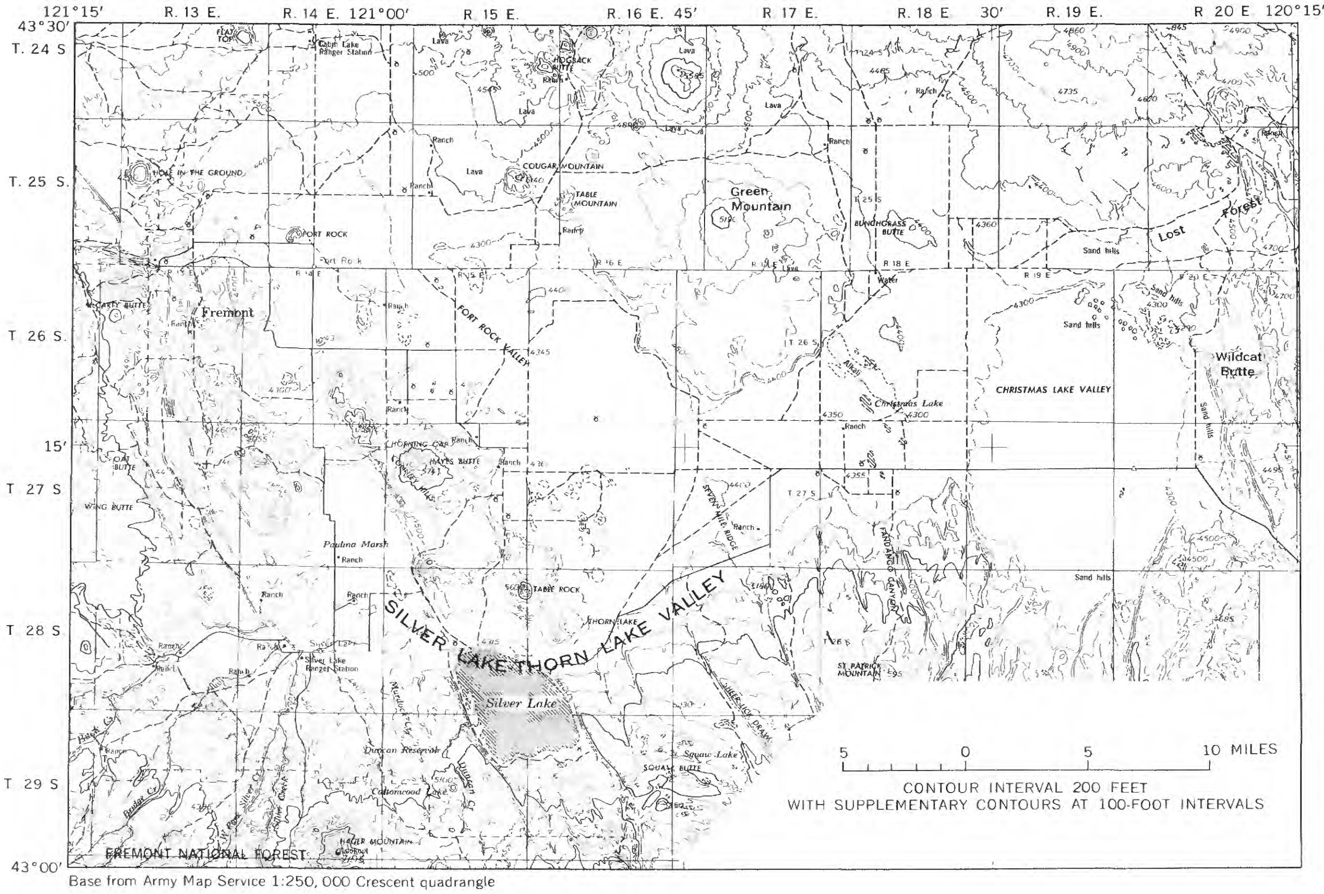


Figure 2.—Map of the Fort Rock Basin, Lake County, Oreg., showing general features in the area studied.

miles northeast of the Fort Rock Basin) by Waters (1927), and a detailed description of the Newberry Volcano (about 30 miles northwest of Fort Rock) by Williams (1935).

ACKNOWLEDGMENTS

The U.S. Soil Conservation Service office in Silver Lake, Oreg., supplied many of the aerial photographs used to aid field mapping. Base maps of the area were furnished by the U.S. Forest Service and the Oregon State Highway Department.

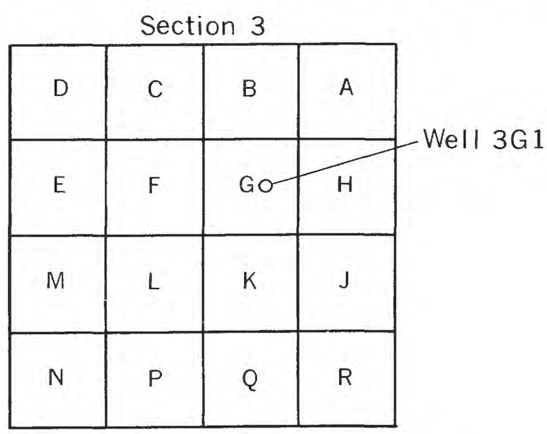
WELL-NUMBERING SYSTEM

Wells discussed in this report are designated by symbols that indicate their location according to the rectangular system of land division. In the symbol 29/13–3G1, for example, the part preceding the hyphen indicates the township and range (T. 29 S., R. 13 E.) south and east of the Willamette base line and meridian. As shown in the diagram (at right), the first number after the hyphen indicates the section (sec. 3) and the letter (G) indicates a 40-acre subdivision of the section. The final digit is the serial number of the well within that 40-acre tract. Thus, well 29/13–3G1 is in SW¼NE¼ sec. 3, T. 29 S., R. 13 E., and is the first well in the tract to be listed.

GEOGRAPHY

CLIMATE

The basin has an arid climate and receives on the average less than 10 inches precipitation annually (fig. 8). Because of the high altitude, early morning frost can be expected during any month of the year, and the average growing season is a little less than 100 days.



CULTURE AND INDUSTRY

About 300 people live within the area. The only centers of population are the hamlets of Silver Lake and Fort Rock.

The area is served by State Highway 31, which traverses its western and southern border, as well as by many roads and trails that are passable except during the wettest or snowiest times of the year. Throughout most of the year the mountainous areas that border the basin are accessible via narrow, rocky jeep trails.

Larger commercial centers nearest the basin are Bend and Lakeview, 70 miles northwest of and about 75 miles southeast of the town of Silver Lake, respectively.

Agriculture is the main occupation in the Fort Rock Basin, and the principal products of the area are livestock, small grains, and hay. Some pine timber from the mountains south of Silver Lake is sawed at mills at Silver Lake and at Klamath Falls, about 75 miles southwest of Silver Lake. The tourist industry is also an important source of income for the people of the small commercial centers of Silver Lake and Fort Rock.

LANDFORMS AND DRAINAGE

The Fort Rock Basin and adjacent upland areas are within the Great Basin section of the Basin and Range physiographic province (Fenneman, 1931, p. 326–395). Physiographic features typical of the northern Great Basin, as well as transition features associated with the Columbia Plateaus physiographic province, are represented within the area.

The landforms of the Fort Rock Basin fall in two categories—those associated with the basin floor and those associated with the mountain uplands. The basin floor has an altitude of about 4,300 feet, and the mountainous parts of the drainage basin that are included within this report rise to altitudes exceeding 5,900 feet; thus the maximum relief within the area is about 1,600 feet. The drainage of the basin is internal, and only three of the streams—Buck, Silver, and Bridge Creeks—are perennial. The channels of the other creeks in the uplands are dry most of each year.

BASIN FLOOR

Topographic features on the plains of the basin are the result of four main processes—water deposition, wave action, wind action, and volcanism. The volcanic features are the most apparent because the local relief due to water, wave, and wind action rarely exceeds 50 feet. In contrast, eroded cinder cones and volcanic plugs rise as much as 200 feet above the general basin floor; these and smaller spatter cones dot the area near Fort Rock.

MOUNTAIN UPLANDS

The most striking topographic features of the mountain uplands that surround the basin are high fault scarps, block mountains, volcanic shields and cones, and slopes and surface features of the lava. Some examples of block mountains and fault scarps, features typical of the Great Basin type of physiography, occur along the southern border of the basin in the mountains that separate this basin from the adjacent Summer Lake basin to the south and along both the eastern and western borders of the basin. Gently sloping lava plains and lava shields, as well as cinder and lava cones, form the uplands to the north and west of the basin. The Connley Hills formed by Horning Bend and Hayes Butte, which are respectively an eroded lava cone and a composite lava shield, rise in the south-central part of the basin (fig. 3).

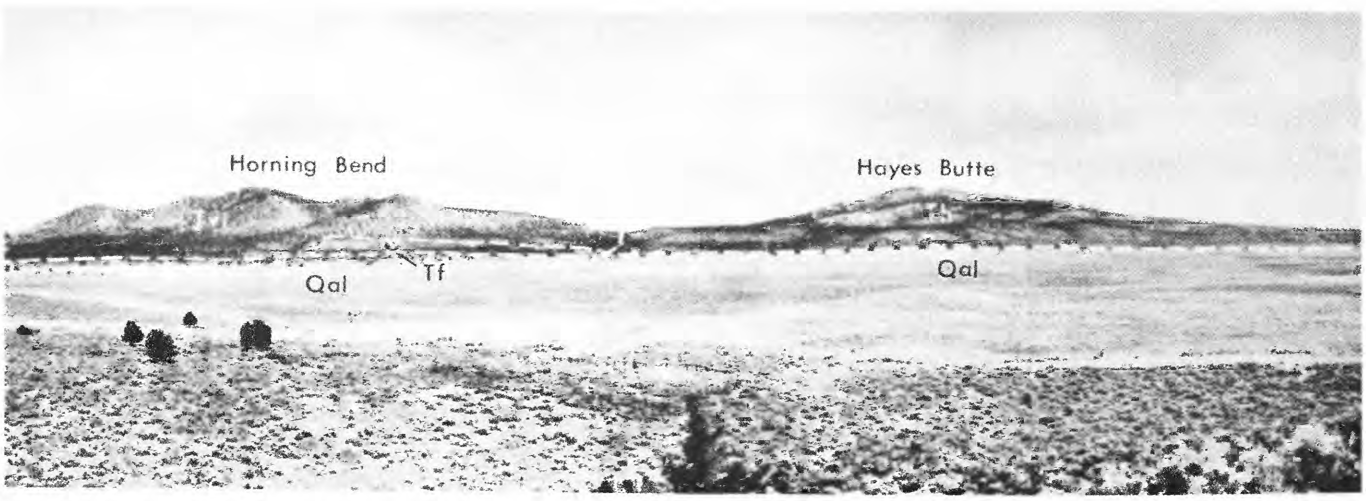


FIGURE 3.—Horning Bend and Hayes Butte as seen from the southwest. Dashed lines mark the approximate limits of the volcanic rocks of intermediate composition (Tvi), Fort Rock Formation (Tf), Hayes Butte Basalt (Th), and unconsolidated deposits (Qal).

GEOLOGY

GENERAL DESCRIPTION AND RELATIONSHIP OF ROCK UNITS

The rock units of the Fort Rock Basin range in age from Pliocene to Recent and, from oldest to youngest, are: Picture Rock Basalt, volcanic rocks of intermediate composition, Fort Rock Formation, Hayes Butte Basalt, Peyerl Tuff, Paulina Basalt, unconsolidated deposits, and younger basalt.

Some of these rock units intertongue and are in part equivalent in age, but are readily distinguishable on the basis of lithology. The intertonguing relationships are due mainly to the deposition of the volcanic and pyroclastic rocks from different centers of eruption or extrusion during overlapping periods of time. The general stratigraphic relationships of the units mapped in the area are shown in figure 4. The extent and relative positions of these units are shown on the geologic map and sections (pl. 1).

TERTIARY ROCKS

PICTURE ROCK BASALT

The oldest rock unit exposed in the area is a thick sequence of basaltic lava flows and interbedded pyroclastic materials herein named the Picture Rock Basalt. The unit is named for Picture Rock Pass, the pass between the Fort Rock and Summer Lake basins, where a great thickness of flows typical of the unit are exposed. An exposure in secs. 14 and 15, T. 29 S., R. 16 E., is hereby designated the type section. However, because not all the rock types found in this unit occur in this exposure, a second exposure in a fault scarp, about 6 miles south of Buffalo Wells, in sec. 8, T. 28 S., R. 20 E., is designated a reference section for this unit.

The Picture Rock Basalt underlies more than 150 square miles in the southern part of the mapped area (pl. 1). Layers of this basalt form the rather gentle plateau slopes and the abrupt escarpments of the uplands south and east of Silver Lake. Some excellent exposures of these rocks are in the scarps adjacent to Silver Lake. The Picture Rock Basalt also underlies large tracts south and east of the mapped area but has not been differentiated from other basaltic lavas in those tracts. Basalts of similar lithology of roughly equivalent age underlie vast areas of south-central Oregon. As yet, however, there is insufficient information to allow correlation of these similar basalts between the fault-bound basins in which they occur.

In contrast to younger lavas in the area, which generally have retained some of their initial surficial roughness, the surface of the Picture Rock Basalt forms uni-

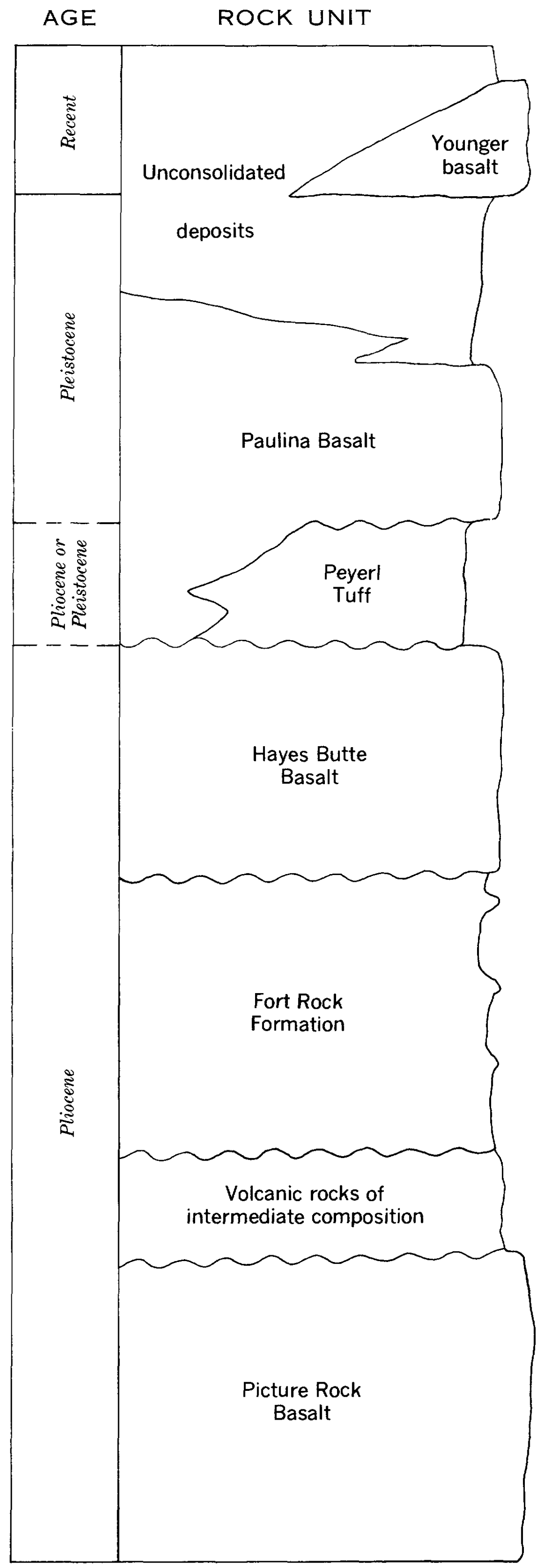


FIGURE 4.—Stratigraphic column showing the relationships of the rock units mapped in the Fort Rock Basin.

form and rather smooth slopes. A mantle of weathered basalt boulders, which average about 12 inches in diameter, is mixed with the thin soils derived from the Picture Rock Basalt. The soil developed on the basalt is very thin and rocky and is not suited for tillage.

The bottoms of most flows of the Picture Rock Basalt are somewhat scoriaceous, brecciated, and glassy. This thin basal zone may be permeable and may transmit water. The middle parts of the flows are massive and usually have very few vesicles or open cracks and joints. Some of the joint blocks of lava in the middle parts of the flows are as much as 5 feet in diameter. At most places, the upper parts of the flows are vesicular but relatively unbroken or are cindery and brecciated; thus they appear to be rather permeable. Because most flows are relatively thin (10–50 ft), the vesicular and cindery zones constitute a rather large part of their thickness. These zones, as well as the contraction joints, impart an overall fractured, pervious appearance to most exposures of the unit.

The basalt is dark gray, blue gray, or dark green gray on fresh exposures. The weathered rock is dark red brown or buff brown. The dark green-gray rock occurs near the base of some of the exposures; the color probably is caused by chlorite. Most of the basalt consists of a glassy or microcrystalline groundmass enclosing olivine crystals as much as 2 mm in diameter and plagioclase crystals as much as 6 mm.

The interbeds of pyroclastic and sedimentary materials within the Picture Bock Basalt are of typical character at the following reference section, measured by G. M. Hogenson at a fault scarp in the NE¼NW¼ sec. 8, T. 28 S., R. 20 E., at the east end of the basin floor, about 6 miles south of Buffalo Wells. Three-fourths of a mile farther south, along the same fault scarp, this interbed thickens to about 250 feet. There the sedimentary materials are of about the same composition as at the measured section but contain a thin flow of rhyolite.

Reference section of interbedded materials of the Picture Rock Basalt in NE¼NW¼ sec. 8, T. 28 S., R. 20 E.

	Feet
Picture Rock Basalt:	
9. Tuff, basaltic, yellow-gray-brown, bedded; contains pebbles of gray to black scoria and pumice; upper part covered by talus	5+
8. Conglomerate, pumiceous, light-gray, massively bedded; particles range from sand to cobble size, pebbles and cobbles predominate	10
7. Tuff (90 percent), yellow-brown (except in the lowest 3 ft, where the color grades to pinkish white); contains pebbles of white pumice and basaltic scoria; pumice fragments increase in size upward to cobble size at the top	25
6. Conglomerate, pumiceous, gray-white, crudely and massively bedded; maximum particle size 2 in	12

Reference section of interbedded materials of the Picture Rock Basalt in NE¼NW¼ sec. 8, T. 28 S., R. 20 E.—Con.

	Feet
Picture Rock Basalt—Continued	
5. Tuff, pumiceous, brownish-gray, finely to coarsely bedded; particles range from sand to pebble size; contains pebbles of glassy basaltic scoria as much as three-quarters of an inch in diameter	1.5
4. Conglomerate, pumiceous, white and gray, massive; maximum pebble size about 1 in	4
3. Sandstone, thinly bedded, fine- to coarse-grained	.5
2. Sandstone, granule conglomerate, tuffaceous, pumiceous; contains small pebbles of glassy basaltic scoria	22
1. Basalt	
Total	80+

This sedimentary section is capped by a flow of fine-grained glassy basalt containing sparse phenocrysts of feldspar as large as 2 mm in diameter. This capping flow is scoriaceous at the top and finely vesicular to dense near its base.

As previously stated, the pyroclastic rocks between the basalt flows of the Picture Rock Basalt at the eastern border of the area are as thick as 250 feet. The exposed thickness of the basalt at the eastern edge of Silver Lake exceeds 700 feet, and the unit may reach thicknesses greater than 1,000 feet. The individual flows of basaltic lava range in thickness from 10 to 50 feet.

After its deposition, the Picture Rock Basalt was deformed into broad folds and broken by numerous faults. The two cones that constitute the volcanic rocks of intermediate composition apparently erupted along faults in the Picture Rock Basalt; thus, the volcanic rocks of intermediate composition lie unconformably upon the Picture Rock Basalt. Because the Picture Rock Basalt is the oldest unit mapped in the area, its relation to underlying units is not known.

On the basis of its stratigraphic position below volcanic rocks of intermediate composition and the Fort Rock Formation (p. B10), and the degree of its deformation, the Picture Rock Basalt is tentatively assigned an early (?) Pliocene age. Its relation to similar basalts in other areas of eastern Oregon is not known.

The Picture Rock Basalt apparently erupted as a very fluid lava because each flow layer is widespread—5 to 10 square miles. The flows of this unit probably issued at high temperature from local vents or fissures.

The general water-bearing properties of the Picture Rock Basalt are good. The zones of greatest permeability are mainly along the tops and bottoms of the flows, but even the denser middle parts of the flows have some permeability. Individual flows are generally thin, and the cinder or scoria zones, which have high porosity and permeability, make up a large part of the total rock unit at some places. These cinder and scoria zones, where they are penetrated below the water table, yield large amounts of water to wells.

VOLCANIC ROCKS OF INTERMEDIATE COMPOSITION

The volcanic rocks of intermediate composition comprise two volcanic masses that unconformably overlie the Picture Rock Basalt. These masses form Horning Bend and Cougar Mountain, both lava cones.

Horning Bend (fig. 3) occupies about 6 square miles in secs. 23, 25–27, and 34–36, T. 26 S., R. 14 E., and secs. 1–3, T. 27 S., R. 14 E. Cougar Mountain covers about 1½ square miles in secs. 10, 11, 14, and 15, T. 25 S., R. 15 E.

Horning Bend is composed of a fine-grained andesite that is light blue gray to cream where unweathered and light buff where weathered. The andesite has closely spaced rectangular and platy joints, and few of the individual joint blocks are more than a few inches in diameter.

Cougar Mountain, in secs. 10, 11, 14, and 15, T. 25 S., R. 15 E., is composed of a fine-grained to glassy rock probably in the rhyodacite class of extrusive igneous rocks. It ranges in color from dark pink to bluish gray on fresh surfaces and is cream to buff on weathered surfaces. The rhyodacite is both massive and flowbanded. Where the rock is banded, wide bands of light pink or cream color generally alternate with very narrow dark bluish-gray bands. The rock has a rough and varied appearance owing to the presence of partly filled vugs, to variations in texture from spongy to glassy, and to variations in color. Figure 5 shows variations in the texture and color of the rhyodacite on the west side of Cougar Mountain, in SW¼NE¼ sec. 15, T. 25 S., R. 15 E. The vugs and vesicles are filled or partly filled by quartz crystals and amorphous silica. Iron oxide is present in some of the cavities, as are thin layers of clayey material.

FIGURE 5.—Rhyodacite on the west side of Cougar Mountain. The dark blotches are composed of shattered black obsidian; the light background is pink rhyodacite.

The obsidian on Cougar Mountain is mostly black, but some of it contains red streaks and nearly all the obsidian is transparent or translucent on thin edges. The obsidian lies in streaks within the rhyodacite, and there is a complete gradation from frothy fine-grained light-colored rhyodacite to dense obisidian. The dark color of the obsidian is apparently caused by microlites of magnetite because the rock is slightly magnetic.

The andesite and rhyodacite of this unit weather to form thin, rocky soil. The andesite weathers to small buff to gray blocks and forms a buff soil, whereas the rhyodacite weathers to thin flakes and forms a gray-brown soil that has fragments of glassy rhyodacite and obsidian dispersed through it.

The thicknesses of the rock masses forming Horning Bend and Cougar Mountain probably range from a few tens of feet to more than 1,000 feet. The thicker parts are at the central areas of the two eruptions. Horning Bend is the larger and the thicker of the two eruptive masses.

The volcanic rocks of intermediate composition that unconformably overlie the Picture Rock Basalt are unconformably overlain by the Fort Rock Formation at Horning Bend. Because the Fort Rock Formation near Cougar Mountain contains fragments of rhyodacite and obsidian identical with the rocks of that mountain, the rhyodacite of Cougar Mountain is probably also older than the Fort Rock Formation, and approximately equivalent in age and stratigraphic position to the andesite at Horning Bend.

Stratigraphic position alone suggests that the volcanic rocks of intermediate composition are probably of middle Pliocene age; they are tentatively so assigned herein. No correlations with named rock units of similar lithology in south-central Oregon are proposed at this time.

These volcanic rocks of intermediate composition erupted from central vents along the faults that cut the Picture Rock Basalt. Because the lavas were viscous, they did not spread out over large areas, as did the preceding flows of basalt, but formed relatively high, isolated cones. Both Horning Bend and Cougar Mountain have undergone minor faulting and have been strongly eroded.

No wells are known to obtain water from the volcanic rocks of intermediate composition.

FORT ROCK FORMATION

Unconformably overlying the volcanic rocks of intermediate composition and the Picture Rock Basalt is a sequence of volcanic and sedimentary materials herein named the Fort Rock Formation. The Fort Rock Formation is named for Fort Rock, a remnant of an eruptive center of this unit, which rises above the valley plains as a mesalike butte in secs. 29 and 30, T. 25 S., R. 13 E. in the western part of the area. Rocks of this unit are exposed over about 90 square miles of the basin, and much of the basin floor is underlain by this unit at shallow depths.

The areas where the Fort Rock Formation crops out are irregular and scattered (pl. 1), and there is no single exposure that is typical of the formation as a whole. Consequently, several reference sections at different localities are necessary to describe the formation adequately. One reference section that typifies the relationship of some of the pyroclastic rocks to sedimentary rocks is in NE¼SW¼ sec. 33, T. 27 S., R. 17 E., and is herein designated the type section. However, the thicknesses of the sedimentary materials of the formation are better represented by the drillers' logs of wells 28/15–14H1, 28/14–21Q2, 28/16–5Q1, 27/16–34L1, 27/17–27L1, 27/17–13A1, 27/19–19G1, 27/18–6F1, 27/18–12A1, 26/15–5C1, 26/15–6C2, 27/15–11R2, and 26/13–25R1 (table 1).

Rocks characteristic of the Fort Rock Formation are exposed in the following parts of the area:

1. Surrounding Table Rock Butte, in secs. 30–32, T. 27 S., R. 16 E.; secs. 5–8 and 17–20, T. 28 S., R. 16 E.; secs. 25 and 36, T. 27 S., R. 15 E.; secs. 1 and 12, T. 28 S., R. 15 E. (underlying about 11 sq mi).
2. At Seven Mile Ridge, in secs. 16, 17, 20, 21, 27, 28, and 32–35, T. 27 S., R. 17 E.; secs. 2–5 and 10–14, T. 28 S., R. 17 E. (underlying about 10 sq mi).
3. In the Fandango Canyon-St. Patrick Mountain area, where about 14 square miles are underlain by tuff, basaltic lapilli tuff, and intercalated basalt flows.

The Fort Rock Formation is composed principally of four rock types. They are, in order of abundance, tuff, diatomite, basaltic agglomerate, and basaltic lava.

The basalt and basaltic lapilli tuff are more resistant to erosion than are the ashy diatomite, diatomite, and fine-grained tuff. The more resistant masses of basaltic lapilli tuff remain as topographic highs such as Fort Rock and Seven Mile Ridge. Basalt and basaltic agglomerate are resistant caprock units for softer, less resistant ashy diatomite, diatomite, and fine-grained tuff.

A sandy light-brown soil is developed where basaltic lapilli tuff and fine-grained tuff are the principal rock types underlying the surface. A silty gray-brown or brown soil is developed where ashy diatomite and diatomite underlie the surface. Areas underlain principally by basaltic lapilli tuff, diatomite, and other relatively soft units, but also by one or more flows of basaltic agglomerate or basalt, are mantled by weathered basalt boulders and have much the same appearance as a weathered basalt flow.

The tuffs of the Fort Rock Formation include basaltic lapilli tuff and fine-grained tuff. Of these, the basaltic lapilli tuff is perhaps the most typical and most easily recognized rock of the Fort Rock Formation. It is yellow buff to dark gray brown or reddish brown. This rock occurs as bedded semiconsolidated tuff or welded tuff, or in massive nonbedded layers, probably derived from volcanic mudflows. The lapilli-sized particles in the rock are principally scoriaceous or cindery basalt, but at places the scoria or cinder lapilli are replaced by pumice lapilli and the rock is a pumice tuff. At those places, the pumice is generally light gray but rarely dark gray or black. The pumice fragments range in diameter from about ⅛ to ½ inch. Brick-red cinders and cinder tuffs occur at the top of the Fort Rock Formation in exposures in the northern part of the area. They range in texture and degree of induration from loose, friable cinders ⅛ to ¼ inch in diameter to finer grained baked strongly indurated tuff. They directly overlie yellow or buff basaltic lapilli tuff and unconformably underlie the Paulina Basalt.

One of the best exposures of basaltic lapilli tuff and diatomite is in NE¼SW¼ sec. 33, T. 27 S., R. 17 E., on the west side of Seven Mile Ridge. This section is designated the type section of the Fort Fock Formation because it is considered to be the most representative of the formation.

Type section of the Fort Rock Formation in NE¼SW¼ sec. 33, T. 27 S., R. 17 E.

	Feet
Fort Rock Formation:	
15. Mudflow, basaltic pumice, massive, buff-brown; fragments of basaltic scoria, pumice, and basalt commonly range from 3 in. to 1 ft in diameter; upper part of unit obscured by brush	37.8+
14. Mudflow, basaltic pumice, massive, buff-brown; fragments of basaltic scoria, pumice, and basalt range from 1 to 2 in. in diameter	6
13. Diatomite, cream to white; some bedding	12.3
12. Mudflow, basaltic, welded or cemented; tuff matrix is greenish gray buff; fragments of basaltic pumice ¼ to ½ in. in diameter make up 20 percent, medium to coarse sand-size fragments make up 50 percent of the rock	.7
11. Conglomerate, pumice, dark- to medium-gray, poorly cemented; fragments ¼ to 1 in. in diameter	.4
10. Sandstone, pumice, diatomaceous, fine- to medium-grained	.3
9. Sandstone, pumice, limonite cemented, rust-colored	.1
8. Diatomite, ashy, gray; upper 0.2 ft contains limonite layers	.8

Type section of the Fort Rock Formation in NE¼SW¼ sec. 33, T. 27 S., R. 17 E.—Con.

	Feet
7. Diatomite, white	1.1
6. Sandstone, basaltic, and limonite-cemented diatomaceous sandstone, gray to buff	.4
5. Diatomite, ashy, fine-grained, white	1.6
4. Sand, pumice, and limonite-cemented diatomite	.3
3. Diatomite, fine-grained, white to gray	5.2
2. Diatomite, sandy, limonite-cemented; sand grains of basalt constitute 20 percent of rock	.2
1. Diatomite, fine-grained, white; base covered by alluvium	2.4+
Total	69.6+

Where the tuff is composed entirely of fine particles, the rock is called fine-grained tuff. The fine-grained tuff is light gray to yellow gray and is composed of fine-grained glass and rock fragments. The tuff was deposited in water and is generally well bedded. The bedded tuff that crops out in NE¼SW¼, sec. 8, T. 26 S., R. 14 E., shown in figure 6, is typical of the Fort Rock formation. Some of the lighter colored tuff contains diatoms. The fine-grained tuff occurs both near and at great distances from the eruptive centers and is the predominant rock of the Fort Rock Formation at distance from the eruptive centers.

Diatomite and ashy diatomite occur in the Fort Rock Formation in the Table Rock Butte-Seven Mile Ridge district and are exposed in some of the dry washes there and elsewhere in the area. The diatomite is white or creamy white and is semicompact but friable. It is composed principally of the microscopic siliceous skeletons of fresh-water algae (diatoms) that were deposited in a lake or lakes during the time the Fort Rock Formation was being deposited. Even the purest diatomite contains some very fine volcanic ash packed tightly between the diatoms. The ashy diatomite is generally more consolidated and cemented than the diatomite and is usually light gray to white. The diatomite is massive (unbedded), but the ashy diatomite is thin to thick bedded at places. Both the ashy diatomite and the diatomite weather to a light gray-brown soil.

The basalt occurs as flows or agglomerate in layers about 5 to 15 feet thick and is dark gray to dark red brown on weathered surfaces and dark gray on fresh surfaces. The flows of this unit generally display columnar jointing and are vesicular at the top. Near two eruptive centers (Table Rock Butte and St. Patrick Mountain) vertical and near-vertical basalt dikes, 2 to 6 feet wide, penetrate the tuffs of the Fort Rock Formation. The agglomerates contain boulders of basalt, as much as 3 feet across, in a matrix of tuff and cinders. They are mostly coarse basaltic debris that accumulated near the eruptive sources, but at places they contain so

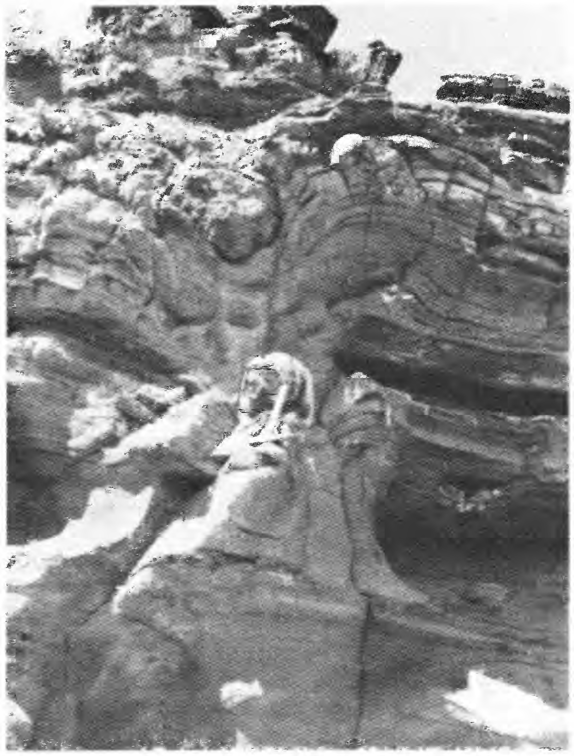


FIGURE 6.—Bedded tuff of the Fort Rock Formation. Note the deformation caused by the large boulders of basalt that apparently dropped on and sank into the finer grained materials before the latter were indurated.

much massive basalt that they are almost a flow breccia of the lava. The surface of a weathered agglomerate looks like the weathered surface of a basalt flow.

The component sedimentary beds and flows of this unit range in thickness from about 10 to 200 feet. As indicated from well logs, the total thickness of the unit, where it fills the graben in the Picture Rock Basalt at Thorne Lake, is about 1,000 feet. The various eruptive centers reach maximum elevations of about 1,000 feet above the basin floors, as at Table Rock.

The Fort Rock Formation unconformably overlies volcanic rocks of intermediate composition. It also unconformably overlies, much more extensively, the older Picture Rock Basalt. In turn, the Fort Rock Formation is unconformably overlain by the Hayes Butte Basalt and younger units.

On the basis of stratigraphic position, lithologic similarity to rocks in adjacent areas, and fossil evidence, the Fort Rock Formation is tentatively assigned a middle and late Pliocene age.

A sample of the diatomite from the bottom of the measured section, but stratigraphically near the top of the pyroclastic rocks of the formation, was examined by K. E. Lohman of the Geological Survey. He identified 28 species and varieties of diatoms, 7 of which are extinct. Those extinct species and varieties are:

Diploneis ostracoderum (Pantoesek)
Melosira cf. sp. A
solida Eulenstein
cf. *M. solida* Eulenstein
Opephora n. sp. B
Stephanodiscus carconensis Grunow
cf. *S. carconensis* Grunow

According to Lohman (written comm., 1959), some of these extinct species have geologic ranges restricted to the late Pliocene. This evidence strongly suggests a late Pliocene age for the enclosing materials.

The rocks of the Fort Rock Formation are very similar to those of the Yonna Formation (Newcomb, 1958, p. 41–48) of the Klamath Basin, farther south. The Yonna Formation is probably of middle Pliocene age, based on vertebrate fossil evidence. Also, the Fort Rock Formation is lithologically similar to parts of the Danforth Formation of the Harney Basin (Piper and others, 1939, p. 43–49); the Danforth was tentatively dated as Pliocene. Because of the similar lithologies and also similar stratigraphic positions, these units may be at least partly contemporaneous with the Fort Rock Formation. However, the fossil evidence for dating all these formations is scanty, and the regions between the described areas are as yet unmapped; therefore, it is considered inadvisable to propose any but the most tentative correlation at this time.

The materials of the Fort Rock Formation were erupted from volcanic centers within and bordering the area and deposited in the basins formed by the Picture Rock Basalt. The eruptive centers are on the faults that cut the underlying Picture Rock Basalt, and several are preserved today as eroded remnants of former large cinder cones. One of the larger and most spectacular of remnants of these cinder cones, in secs. 29 and 30, T. 25 S., R. 14 E., is called Fort Rock. Exposures there exhibit the bedding of the welded and cemented cinders near the center of the cone (fig. 7).

During the latest stages of some of the volcanoes of Fort Rock time, eruptions were progressively less explosive, and a higher percentage of basalt was extruded. As the eruptions stopped, basalt solidified in the craters. These crater fillings remain today as "caps" on the remnants of the volcanic cones. Both Table Rock Butte and St. Patrick Mountain are capped by remnants of such crater fillings, which from a distance look like parts of flows.

Of the Fort Rock Tuffs, some were laid down in water, whereas others appear to be the result of unreworked ash fall or volcanic muflow. Grain size in the respective pyroclastic units of the Fort Rock Formation generally decreases with the distance from the eruptive centers and sorting generally becomes better with distance. However, because some of the pyroclastic materials—for example, the pumice and cinders—are highly inflated and thus have low density, large particles of these inflated materials have been carried to places relatively distant from the eruptive centers. Accordingly, logs of wells 5 miles or more from the mapped eruptive centers show pumice and cinder particles as large as gravel size.

The various types of rock composing the Fort Rock Formation have greatly different water-yielding properties. In general, the finer grained tuffs and diatomite yield quantities of water adequate only for stock and domestic supply, whereas some of the coarser grained basaltic agglomerates, cinders, and basalt flows yield moderate to large quantities of water to wells. Over

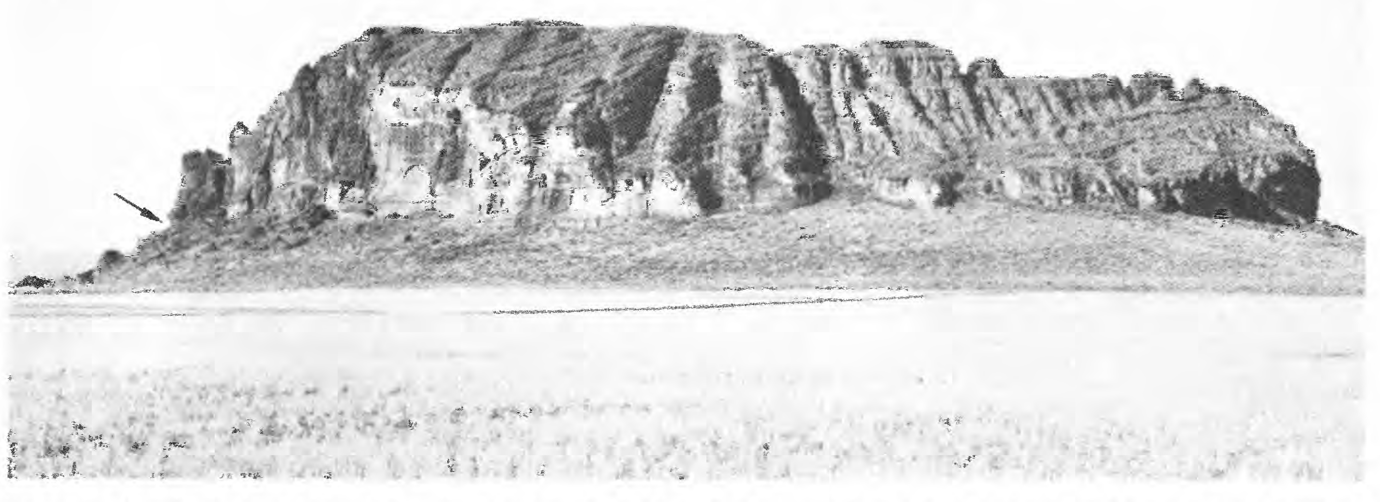


FIGURE 7.—Fort Rock viewed from the northeast. Note the bedding of the cemented cinders that dips toward the observer. Notch and bench at left edge (at arrow) are wave cut.

large tracts of the Fort Rock and Christmas Lake subareas, drillers report "black sand" and medium to coarse "pumice gravel" as productive water-yielding units. These coarse-grained deposits probably accumulated at distances of less than 2 miles from the eruptive centers. Closer to the eruptive centers, the sedimentary materials of the Fort Rock Formation are apparently poorly sorted and more tightly cemented, and thus yield only small to moderate quantities of water to wells. Likewise, at a distance of several miles from the eruptive center, the materials of this formation are better sorted and consist mainly of fine-grained materials of generally poor permeability.

Most of the sedimentary beds of the Fort Rock Formation are somewhat friable but will generally stand unsupported in a well. Some uncased or improperly constructed wells obtain large quantities of water from medium to coarse basaltic sand but pump appreciable quantities of sand with the water.

HAYES BUTTE BASALT

One of the most widespread rock units in the Fort Rock Basin is the Hayes Butte Basalt, herein named for Hayes Butte, the basaltic lava cone pictured in figure 3. Besides Hayes Butte, whose crest is in sec. 8, T. 27 S., R. 15 E., the principal areas of occurrence are the upland area a few miles west of Hayes Butte, Table Mountain, Wildcat Butte, and most of the slope off Hager Mountain. About 190 square miles of the mapped area is underlain by this unit.

As with the other units of lava or pyroclastic materials, no one exposure is typical of the unit as a whole. However, typical exposures of Hayes Butte Basalt in all its phases, from scoria piles to rather orderly layered basalt flows can be observed at several localities on Hayes Butte. Therefore, Hayes Butte and its lava shield to the south, in T. 27 S., R. 15 E. and northern T. 28 S., R. 15 E., are herein designated the type locality of the unit.

The Hayes Butte Basalt weathers to a thin brown rocky soil. Scoria of this unit weathers more rapidly than glassy dense lava; thus, deeper less rocky soils are formed on the scoria. In general, soils derived exclusively from Hayes Butte Basalt are too rocky for cultivation. However, where scoria is mantled by thin layers of wind- or water-deposited silts and sands, the land has been cultivated.

Like the older and younger basalts in the area, the Hayes Butte Basalt is light to dark gray on fresh surfaces and reddish brown to dark gray brown on weathered surfaces. The texture of the rocks in this unit ranges from diktytaxitic lava and open frothy scoria to dense glassy ropy lava. Where individual flows are exposed in fault scarps, they display a thin scoriaceous, glassy, or brecciated base, a dense fine-grained center, and a vesicular to rubbly top zone, which may be as much as 5 feet thick. The dense centers of the flows generally are jointed vertically into polygonal columns. Most of the lava of the Hayes Butte is basaltic, but the composition of some of the light-gray and glassy rock may approach that of an andesite.

The systematic layering of lava flows ceases near the eruptive centers, where simple flows merge into chaotic piles of scoria, tuff, and blocky and ropy lava. The rough surfaces of the Hayes Butte Basalt eruptive centers are due primarily to the weathering of the uneven textured lava and volcanic ejecta, and not to the irregularities of the original flow structures as at younger eruptive centers of the Paulina Basalt and Recent volcanics.

The basalt flows of the Hayes Butte Basalt range in thickness from about 10 to 30 feet. The thickness of this unit, as measured from the peak of Hayes Butte, exceeds 1,300 feet. At most exposures this unit occurs as one or two basalt flows, whose combined thickness does not usually exceed 100 feet. The number of flows and, thus, the thickness increase west of Hayes Butte; about 150 feet of the unit is exposed in the fault scarp that bounds the northwestern part of Paulina Marsh.

The Hayes Butte Basalt unconformably overlies the Fort Rock Formation and the older volcanic rocks. It is overlain unconformably by the Peyerl Tuff and the Paulina Basalt and, locally, by some of the younger units.

Because of its stratigraphic position, the Hayes Butte Basalt is tentatively assigned to the late Pliocene, although it may conceivably range into the early Pleistocene. Some of the youngest Hayes Butte Basalt flows may be age equivalents of some of the older Paulina Basalt flows (p. B14), and are approximately equivalent to the "upper lava rocks" (Newcomb, p. 21, 1958) of the Klamath Basin.

The Hayes Butte Basalt was erupted from centralized areas, generally along one of the strong northwestward-trending fault zones. The larger cones, such as Hager Mountain and Hayes Butte, are each about 4 miles across; smaller cones are only a few hundred to a few thousand feet across at the base. Near most of the eruptive centers, the floods of lava flowed down slopes underlain by Fort Rock Formation or Picture Rock Basalt and formed sloping lava plains such as the one south of Hayes Butte.

The Hayes Butte Basalt has undergone some faulting. The displacement on the faults cutting this unit is less than 50 feet at most places, but displacements on some of the faults in T. 26 S., R. 13 E., exceed 100 feet.

The outcrops of the scoria and scoriaceous, brecciated zones at the top of individual flows appear to be highly permeable. If flows of Hayes Butte were penetrated by wells below the water table, they would probably yield large quantities of water. However, in the areas of existing wells, the Hayes Butte Basalt apparently does not extend below the water table, and where the Hayes Butte probably extends below the water table, as at the northwest end of Paulina Marsh, no deep wells have been drilled.

TERTIARY AND QUATERNARY ROCKS

PEYERL TUFF

Through about 10 square miles of the area, in the vicinity of Peyerl Ranch (sec. 10, T. 26 S., R. 13 E.), the Hayes Butte Basalt is unconformably overlain by a sequence of tuff, tuffaceous sandstone, and pumice conglomerate. This tuffaceous unit is herein named the Peyerl Tuff.

The unit is well exposed in the roadcut of State Highway 31 in sec. 31, T. 25 S., R. 13 E., which is herein designated the type section of the formation, and is also fairly well exposed at an erosional escarpment where crossed by a county road in sec. 28, T. 25 S., R. 13 E. The lithology of the unit is well described in the following section measured at the type section by G. M. Hogenson:

Type section of Peyerl Tuff measured along 1½-mile highway cut in sec. 31, T. 25 S., R. 13 E.

	Feet
Paulina Basalt:	
35. Basalt, forms rimrock	
Unconformity (?)	
Peyerl Tuff:	
34. Tuff, caprock, tannish-yellow or pink, rhyolitic, welded, platy; bottom 4–5 ft. gray pumiceous tuff, containing scattered fragments of pumice, lava, and obsidian; grades upward into platy, banded welded rhyolitic tuff; upper part of unit obscured by slumped blocks of Paulina Basalt	14+
33. Sandstone, reddish-brown, tuffaceous, rudely bedded; contains lenticular layers of lapilli and scattered pebbles of weathered pumice as large as 1 in. in diameter	3
32. Covered interval	18
31. Sandstone, reddish-brown, tuffaceous, massive; contains about 20 percent fragments of pumice and red and gray lava as large as 1 in. in diameter; scattered fragments of gray pumice up to 12 in. in diameter	8
30. Covered interval	11
29. Tuff, gray, pumiceous; about 75 percent is sand-size or smaller, 20 percent is gray and buff pumice less than 1 in. in diameter, and 5 percent is gray pumice fragments 1–10 in. in diameter	13
28. Covered interval	16

Type section of Peyerl Tuff measured along 1½-mile highway cut in sec. 31, T. 25 S., R. 13 E.—Con.

	Feet
Peyerl Tuff—Continued	
27. Sandstone, yellow-brown, tuffaceous, bedded; platy parting mostly slumped and covered	6
26. Pumice, yellow-brown, well-indurated (welded?); contains a few fragments of obsidian	4
25. Sandstone, tuffaceous, reddish-brown to yellowish brown; contains scattered fragments and pebbles of gray pumice	7
24. Covered interval	8
23. Sandstone, tuffaceous, yellow-brown, massive; contains scattered small fragments and pebbles of gray to tan pumice	2
22. Sandstone, tuffaceous, gray, crossbedded and lenticular; contains gravel of fragmental gray pumice	3
21. Tuff, sandy, reddish- or yellowish-brown, thinly bedded; cemented in part with iron oxide	2
20. Tuff, sandy, red, massive; speckled with scattered small fragments of white and gray pumice	3
19. Mostly covered; one slumped outcrop of dark-gray sandy tuff	10
18. Tuff, sandy, light-reddish to yellowish-brown; contains scattered fragments of pumice	2.4
17. Conglomerate, sandy, gray to brown; composed of crossbedded pumice	1.5
16. Sandstone and conglomerate, tuffaceous, lenticular; lenses as much as 50 ft long and 12 in. thick; appear fairly well sorted but all layers contain scattered pebbles and small cobbles of pumice	8
15. Sandstone and conglomerate, tuffaceous, light-gray to light-brown; pebbles are gray pumice; lenses as thick as 12 in., the thicker ones being crossbedded or containing smaller lenses; most pumice fragments less than 2 in. across, but some as much as 6 in	3.1
14. Sandstone, tuffaceous, gravelly, pink-gray, unsorted; gravel particles are subangular to well-rounded gray pumice	.5
13. Claystone and sandstone, tan, pink, and yellow-brown, in layers ¼ to 1 in. thick; contains a few pebbles of gray pumice less than 2 in. in diameter	.4
12. Sandstone, tuffaceous, fine-grained, pinkish-gray; contains a few pumice shards as much as half an inch in diameter	.4
11. Sandstone, fine- to coarse-grained, bedded, lenticular, poorly indurated; contains lenticular beds of fine-grained gravel	1.7
10. Gravel, unsorted, sandy tuff matrix; contains subrounded to rounded gray pumice, pea sized to 2 in. in diameter	.4
9. Conglomerate, sandy, and shale; lenticular layers, shaley partings one-eighth of an inch thick, conglomerate layers as much as 5 in. thick; gravel particles of angular to subrounded gray pumice	.8

Type section of Peyerl Tuff measured along 1½-mile highway cut in sec. 31, T. 25 S., R. 13 E.—Con.

	Feet
Peyerl Tuff—Continued	
8. Tuff, fine-grained, sandy, gray-brown; contains some grit-sized angular particles of gray or red lava and pumice as much as 1 in. in diameter	0.8
7. Covered interval	2
6. Tuff, sandy, grayish-brown, speckled with angular to subrounded fragments, half an inch in diameter, of light-gray to tan pumice	2
5. Covered internal	15
4. Tuff, gray, reddish-brown, in upper 12 ft; glassy matrix contains fragments of pumice, some fragments of dark scoria and black obsidian; most fragments less than 1 in. in diameter, some as much as 3 in	35
3. Covered interval	14.5
2. Tuff, pebbly, white to tan, lenticular, crossbedded; white where ashy tuff and pumice predominate; some lenses as thick as 12 in	6
1. Tuff, dark-reddish-brown, cemented with iron oxide; contains 50 percent pebbles; gravel and grit composed of white pumice, black or gray scoria, and gray lava; most fragments less than three quarters of an inch in diameter; base not exposed	4+
Total	226.5+

Another reference section of this unit, measured at the aforementioned scarp in sec. 28, T. 25 S., R. 13 E., includes two locally distinctive and fairly extensive beds that are useful as mapping horizons but that were not present at the type section. These are a layer of reddish-brown sandy silt directly underlying the caprock of welded rhyolitic tuff, and a 30-foot-thick bed of dark-brown welded tuff about 110 to 140 feet below the caprock welded tuff. The exposure at this scarp, which is about 2 miles east of the type locality, also shows the lithologic diversity in the unit within short distances.

Section of Peyerl Tuff where a county road crosses an erosional escarpment in center part of sec. 28, T. 25 S., R. 13 E.

	Feet
Peyerl Tuff:	
8. Tuff, caprock, tannish-pink, rhyolitic, welded, platy parting; contains drawnout fragments of lava of an intermediate composition; top of unit eroded	5+
7. Silt, brownish-red, sandy, tuffaceous, massive; contains scattered particles of white tuff, black obsidian, and gray lava	11.5
6. Conglomerate, reddish-brown, moderately indurated; sandy tuffaceous matrix; subrounded pebbles as much as 1½ in. in diameter but most less than ½ in.; composed of basaltic scoria, pumice, and light-gray lava	.5
5. Sandstone, reddish-brown, tuffaceous, silty, moderately indurated, massive; contains some particles of lava and pumice as large as 3 in. in diameter	7
4. Covered by slope wash	33
3. Breccia, tuffaceous, light- to dark-brown; about 60 percent composed of matrix of coarse tuff and basaltic lapilli, remainder cobble- and boulder-sized pieces of rounded to angular basalt scoria and pumice as large as 12 in. in diameter	6
2. Covered interval	52
1. Tuff, welded, chocolate brown; contains angular fragments of lava, black pumice, and frothy glass as large as 1½ in. in diameter; base not exposed	30+
Total	145+

The foregoing data show that, although this unit has a diversity of rock types, it is composed mostly of tuffaceous, pumiceous volcanic materials of intermediate composition, most of which were waterlaid. The tuffs of this formation weather rapidly to form a sandy to clayey reddish- to tannish-brown soil. The welded tuff caprock and welded tuffs within the unit are moderately resistant and weather less rapidly. All the rocks constituting the Peyerl Tuff are less resistant than the overlying Paulina Basalt, which forms a rimrock over the Peyerl at several localities.

As shown in the sections just described, individual beds of this unit range in thickness from a few inches to about 30 feet. The total exposed thickness of the unit at the type section is about 227 feet, and the thickness recorded in the drillers' log of the nearby well 26/13-4B1 is 160 feet. This well apparently entered the tuff at a stratigraphic horizon nearly equal to the base of the measured section at the type section; therefore, the total thickness of the Peyerl Tuff near the type section may be 400 feet.

The Peyerl Tuff unconformably overlies the Hayes Butte Basalt, is unconformably overlain by flows of Paulina Basalt, and is in part contemporaneous with the lower part of the Paulina Basalt. The relationship of the tuff to other units is shown on the geologic cross section *A–A′* (pl. 1).

Because of its stratigraphic position, the Peyerl Tuff is considered to be of latest Pliocene or early Pleistocene age. No correlations with units in adjacent areas are suggested at this time.

The Peyerl Tuff was deposited in a rather small basin on the western edge of the present Fort Rock Basin. The sources of the Peyerl materials probably were rather small explosive-type eruptive centers located west of the present-day areas of outcrop. Most of the beds of the unit are waterlaid, although some appear to be of mudflow origin. The rhyolitic tuff at the top of the unit may have been deposited by a glowing cloud, because much of the upper part of this bed is welded. The Peyerl Tuff has undergone minor faulting but shows few traces of folding of the nearly flat-lying beds.

Records of a few wells drilled and dug into this formation indicate that the regional water table lies below its base; thus, the water-transmitting characteristics of this unit are unknown.

PAULINA BASALT

Unconformably overlying the Peyerl Tuff is the Paulina Basalt, which is the main lithologic unit underlying the area that borders the northern part of the basin. This unit is herein named for the Paulina Mountains, which are northwest of and adjacent to the Fort Rock Basin. These mountains include many of the eruptive centers for the Paulina flows. The unit underlies about 370 square miles of the mapped area. The unit occurs as intertonguing flows from a number of low shield volcanoes, many of which lie to the north of the Fort Rock Basin. The type area of the Paulina Basalt is herein designated as secs. 1 and 2, 11 and 12, T. 26 S., R. 16 E., where five overlapping flows from possibly three different sources are exposed.

Because the older flows of the Paulina have weathered longest, they have smoother surfaces than the younger flows. Most of the flows are only moderately weathered and have a very thin residual soil cover. The soil is light brown and very rocky. At some places tillable windblown soil overlies the basalt to depths of several feet.

The Paulina Basalt is dark reddish brown on weathered surfaces and dark gray on fresh surfaces. It has the diktytaxitic texture common to many Pliocene and Pleistocene basaltic lavas. The flows are usually brecciated slightly on the bottom, dense in the middle, and brecciated and scoriaceous on the top, although there is some local variation of this sequence. Most flows are somewhat vesicular throughout, but especially so in the top 2 to 4 feet. The basalt is separated into either polygonal or irregular blocks by joints that are relatively widely spaced in the dense centers of the flows.

In gross texture the surfaces of the various flows range from moderately rough to very rough; the roughness is due almost entirely to the original flow structures, such as pressure ridges, ropy flow surfaces, and blocky breccia.

Individual flows of the Paulina Basalt range in thickness from about 5 to 20 feet. When extruded, the lava apparently was only moderately fluid; hence, great variations in the thickness of any one flow are common. The total thickness of the unit is not known but probably exceeds 1,000 feet near eruptive centers.

The Paulina Basalt unconformably overlies the Peyerl Tuff and, where the Peyerl is absent, the Hayes Butte Basalt. It is unconformably overlain by younger basalt and by unconsolidated deposits.

The general period of volcanic activity in the Paulina Mountains, during which the Paulina Basalt was extruded, may have extended in time from late Pliocene to Recent. The earliest lava flows in the Paulina Mountains (which underlie the flows mapped as Paulina Basalt) probably are equivalent in age to part of the Hayes Butte Basalt. The latest flows in those mountains, which are equivalent to the flows herein described under "Younger basalt," are Recent in age. The Paulina Basalt, as designated herein, is tentatively assigned to the latest Pliocene(?) and Pleistocene ages. No correlation with basaltic units of this general age range in other parts of eastern Oregon is suggested at this time.

The Paulina Mountains constitute the principal center of eruption of the unit. The Paulina Basalt exposed in the Fort Rock Basin was erupted from centers oriented along the northward-trending fault zones that are within or adjacent to the northern part of the basin. A typical example of one of these centers is Bunch Grass Butte, a low volcanic shield in the northeastern part of the basin. Green Mountain is another, although larger and steeper, volcanic shield in the north-central part of the basin. Flows of the Paulina Basalt have undergone minor faulting; displacements along the faults seldom exceed 20 to 50 feet, and in most places are 5 to 10 feet.

In outcrop the Paulina Basalt appears to have good vertical and horizontal permeability, and wells that have penetrated this unit below the water table yield large quantities of good-quality water.

QUATERNARY ROCKS

UNCONSOLIDATED DEPOSITS

The surficial sedimentary materials that overlie the older volcanic and sedimentary rocks throughout the Fort Rock Basin are grouped together in this report as unconsolidated deposits. Included in the unconsolidated deposits are: lakebed deposits and associated terrace, spit, bar, and deltaic deposits of Pleistocene age; and stream-valley alluvium, playa deposists, and windblown sand and silt of Recent age. Because the materials of this unit form only a thin cover over the older rocks in most of the basin area, and thus do not extend below the water table, they are, with the exception of the large masses of dune sand, mapped as a geologic unit on plate 1. The various deposits in this unit are described in some detail in the following paragraphs.

LAKEBED AND TERRACE DEPOSITS

The lakebed and terrace deposits are in part contemporaneous with, and in part unconformably overlie, the Paulina Basalt. These sedimentary deposits probably range in age from early to late in the Pleistocene Epoch. They accumulated in a large lake that occupied the bottom of the Fort Rock Basin during the times of greater precipitation and lesser evaporation that occurred during parts of the Pleistocene.

At places along the borders of the valley plains, deposits of this unit overlie each of the older units described in this report. A thin layer of fine-grained material was laid down over the entire area covered by the Pleistocene-age lake and now underlies the valley plains. The highest level at which the lake stood was about 4,500 feet in altitude, but this level apparently was mantained only briefly. One of the high levels maintained for a longer time is that from about 4,450 to 4,400 feet. At about the 4,400-foot level around the edges of the basin are wave-cut terraces, wave-built terraces, spits, and bars, which are shoreline evidence of this lake stage. The material underlying the wave-built terraces consists of sand and gravel. The spits and bars are composed of materials similar to, although somewhat finer grained than, the deposits underlying the terraces.

Fine-grained lacustrine, or lake, deposits—consisting of clay, silt, sand, volcanic detritus, and diatomaceous earth—mantle the former lakebed. Obsidian chips ranging from pebble to cobble size are widespread over the surface of these lacustrine deposits in the Christmas Lake and Fort Rock Valleys. Because the lacustrine deposits are uniformly fine grained, it is unlikely that heavy fragments of obsidian were incorporated within these sediments over a major part of the basin. One obvious source of the obsidian is the obsidian-bearing basaltic lapilli tuff of the Fort Rock Formation, which underlies large areas in the Christmas Lake and Fort Rock Valleys. Weathering of this tuff apparently loosened the resistant obsidian chips, and, where only a foot or two of lacustrine deposits overlies the tuff, the obsidian has been heaved by frost action to the surface. In some places where obsidian chips form a virtual pavement on the windswept surface of the lacustrine deposits, there are signs of former arrowhead manufacturing.

In outcrop, the lacustrine deposits underlying the terraces and the bars or spits range in color from dark gray brown to light gray or light brown. The color depends mostly on the color of the component cobbles and pebbles, but also on the degree to which these pebbles have been coated by the cream to gray caliche that is characteristic of this region. The cobbles and pebbles in these deposits consist of basalt, welded tuff, and other resistant rock that is available in the immediate vicinity of any particular reach of terrace. The grit, sand, and finer particles consist of rock fragments and pumice.

The clay, silt, and sand-sized particles constituting the lakebed sediments are light gray and light brown and are thinly bedded. The particles consist of fine-grained volcanic detritus and diatoms.

The deposits that underlie the terraces, bars, and spits of the Pleistocene lake deposits are virtually unweathered. The fine-grained lacustrine deposits of the old lakebed also are only slightly weathered, although large volumes of these deposits have been eroded away by wind and rain. The finer grained lacustrine deposits constitute the soil and subsoil of much of the farmed land in the Fort Rock Basin and are recorded as soil in most well logs.

DELTA DEPOSITS

In the parts of the basin where streams entered the Pleistocene-age lake, deposits of gravel, sand, silt, and clay-sized materials were laid down in the form of deltas. Remnants of these deltas are present around the southern edge of Paulina Marsh, at the mouths or along the lower reaches of the present-day streams. Silver and Bridge Creeks are separated in their lower reaches by a remnant of a delta that remains as a low terrace of bedded medium-sized gravel and sand, and the lower course of Buck Creek has valley walls of unconsolidated deltaic gravel and sand. Fine-grained, crossbedded, and deformed delta deposits occur along the lower reaches of Murdock Creek, about 3 miles west of the western edge of Silver Lake.

DUNE SAND

The wind-laid sands have been derived principally from the Pleistocene lakebed deposits. They form dunes that extend over wide areas in the Fort Rock Basin. High dunes of moving sand cover about 23 square miles in the area east of the playa known as Christmas Lake (pl. 1). Lower dunes, now nearly stabilized, are widespread in the basin.

The sand particles in the dunes consist of volcanic glass, fragments of diatoms, pumice, and basalt. The dunes are light tan to cream tan.

The dune sand is moderately permeable, and thus more readily permits the infiltration of water than do the more consolidated rocks in the area. In many places where dune sand overlies a less permeable rock, such as tuff or basalt, a zone of perched ground water is contained in the sand above the water table by the less pervious rock. A prime example of the occurrence of such a zone of perched ground water is found at Lost Forest, at the east side of the Fort Rock Basin, where about 10 feet of dune sand overlies tight clay-mantled basalt, which perches or retards the downward movement of ground water in the bottom part of the sand. This thin zone of perched ground water is the source of water for the pine trees of Lost Forest and is also tapped by one or two stock wells.

The dune sand, like the scraggly surfaced young lavas, is important in routing infiltrating water underground, where it may escape evaporation and transpiration and thus may reach the regional ground-water body.

STREAM-VALLEY ALLUVIUM

The channels and flood plains of the lower reaches of Silver, Buck, and Bridge Creeks and of many of the intermittent streams and arroyos are underlain by thin deposits of sand, gravel, and rock rubble; the meadows in the uplands along these creeks are underlain by fine-grained surficial deposits. These sedimentary deposits, of Recent age, constitute the small amounts of stream-valley aluvium. They underlie about 1½ square miles in the area.

The gravel in the stream-valley alluvium is composed of basalt, volcanic cinders, and pumice. The sand is generally composed of volcanic glass or particles of basalt and pumice. The clay and silt are the products of weathering of the upland soils and reworked materials from older fine-grained sedimentary and pyroclastic rocks.

The coarser grained stream-valley alluvium yields moderate quantities of water to wells. One well dug into this material is known to supply water for a farmstead. The total depth of the alluvium at that well (28/13–14K2) is 10 feet. Most of the alluvium lies above the level of the channels that carry the meager summer streamflow; hence, the alluvium is generally drained during part of the year and does not supply water to wells perennially.

YOUNGER BASALT

The youngest basaltic lava flows and cinder cones exposed in the northern Fort Rock Basin are included in the unit designated younger basalt. Lavas of this unit underlie about 15 square miles of the mapped area along the northern border of the basin.

The most recent flows are in secs. 22, 23, 26–28, and 33–35, T. 25 S., R. 17 E., and secs. 1, 2, 11, and 12, T. 26 S., R. 17 E. Associated with these flows are four cinder cones that are alined along a northwest-striking fault (pl. 1).

The younger basalt is virtually unweathered. The earliest flows of this unit have somewhat smoother surfaces than the latest flows, but all flows have very rough, scraggly surfaces and are black to reddish black—evidence that the minerals in the rock have not undergone much chemical breakdown.

Most rocks included in this unit are basaltic lavas; some, however, are basaltic cinders that form cones both within or distant from the central areas of eruption. The younger basalt flows are composed of dark-gray to black vesicular lava.

The flows possess almost all their original flow structures. Most of the lava examined is blocky, broken vesicular lava that is in part loosely imbedded in less shattered vesicular lava. The surface of each flow shows lateral variations from rough, scraggly heaps of broken lava blocks to solid ropy lava.

Cinder cones of this unit are composed of inflated granular loose reddish-brown to black basalt.

The total thickness of the various young lava flows ranges from about 5 to 50 feet. The centers of eruption and the piles of cinders are as much as 200 feet thick.

The younger basalt was deposited on the surface formed by the overlapping basaltic shields of the Paulina Basalt. The rocks of the unit represent the youngest lava flows in this basin and are considered to be of Recent age. This unit has the same mode of origin as the Paulina Basalt—that is, moderately to highly liquid lava was erupted from central areas and spread out over the preexisting landscape in circular masses, as shown on plate 1.

Because all the younger basalts are above the regional water table, they are not aquifers in the Fort Rock Basin. These basalts appear to be highly permeable; therefore, they may be important as inlets by which precipitation can be carried underground to the underlying older basalts and other water-bearing rocks.

GEOLOGIC STRUCTURE

The Fort Rock Basin is a compound structural depression that was formed by deformation at various intervals from middle Tertiary to Quaternary time. The topography and drainage of the basin are intimately related to the geological structure, as are the occurrences and thicknesses of some of the rock units. To understand the occurrence and availability of ground water in the area, it was necessary to determine the sequence of structural events—such as folding, faulting, and subsequent eruption along faults—and the effects that these events had on the surface extent and subsurface continuation of the water-bearing units.

FOLDS

Although there are several major folds within the Fort Rock Basin, the axis of only one, the St. Patrick anticline on the southern edge of the basin, can be depicted with reasonable accuracy on the geologic map.

The axis of this fold is approximately as shown on the map, although the fold is broken by many cross faults. The Fort Rock-Christmas Lake Valley is probably a broad downwarp (syncline), the north limb of which may extend beyond the area of this study. On the south side of this valley the general northward inclination of the rock layers is clearly evident, but on the north side, rocks that presumably would show a southward dip are covered by the Paulina Basalt.

The St. Patrick anticline is named after St. Patrick Mountain—a vent that had contributed volcanic material to the Fort Rock Formation—which is the highest peak on the arch. The axis of the anticline follows an arcuate course from Picture Rock Pass east-northeast to St. Patrick Mountain, then trends southeast to the vicinity of Sheep Rock (pl. 1). The anticline is slightly asymmetrical; the rock layers of the northern limb dip 2°–5° N. and those of the southern limb dip 7°–10° S. The rock units involved in this upwarp are the Picture Rock Basalt and older underlying units that are not exposed in the Fort Rock Basin.

The folding which depressed some of the water-yielding units to depths below the present-day basin floor provides a favorable setting for the occurrence of artesian (confined) ground water, as noted by Waring (1908, p. 58–59). Although no flowing wells have been reported to date (1962), the driller's record of water levels in well 27/16–34L1 (table 1) indicates that the fine-grained materials of the Fort Rock Formation and the center parts of the Picture Rock Basalt flows act somewhat as confining layers for the water in the permeable parts of these units. Thus, despite the fact that in some parts of the basin the water-yielding units have been folded to considerable depths below the present basin floor, the water in those units will rise in wells to levels that permit economic pumping for irrigation.

FAULTS

The most important structural elements of the Fort Rock Basin are the northward-trending faults. Those observed were all normal faults. The northward-trending system of faults apparently developed simultaneously with the folds, presumably starting in early or middle Pliocene time. Movement along the faults has occurred intermittently throughout the period from early or middle Pliocene to Recent time, whereas the folding apparently ceased with the deformation of the Picture Rock Basalt. Each rock unit younger than the Picture Rock Basalt is cut by faults but apparently has been subject to little, if any, warping.

The vents and eruptive centers of volcanic units younger than the Picture Rock Basalt are alined along fault zones; thus the areal distribution of the younger units is partly controlled by the early faulting. Similarly, the variations in the thickness of the more extensive units, especially the Fort Rock Formation, are controlled by the locations of the horsts (uplifted blocks) and grabens (downdropped blocks) formed by faulting of the Picture Rock Basalt.

Most major faults in the Fort Rock Basin strike northwest, but some that cut the Picture Rock and Hayes Butte Basalts in the southeastern part of the basin strike due northeast or north. Vertical displacements are greatest along the older faults that do not affect units younger than the Picture Rock Basalt. Vertical displacements at different places range from a few feet to about 800 feet along those older faults. The displacements are smaller along faults in the succeeding units and rarely exceed about 100 feet along faults cutting units younger than the Picture Rock Basalt.

A few minor faults in the Fort Rock Basin intersect the northward-striking faults at nearly right angles. The vertical displacement along these east-west faults is generally less than 50 feet but at places exceeds 100 feet.

In regard to ground-water occurrence and development, the main importance of the faults is their role in depressing or elevating the various water-bearing rock units. So far as is known, the broken rock of the fault zones in the Fort Rock Basin does not form effective barriers to the horizontal movement of water in the lava rocks as do fault-breccia zones at other places in the Northwestern United States (Newcomb, 1961). Rather, the fault zones at many places in the Fort Rock Basin probably provide avenues for vertical movement and interchange of the ground water across the less permeable strata; however, the narrow zones of fault breccia should be avoided in selecting sites of wells because the shattered rock may require excessive casing, may involve difficult drilling, and will generally have somewhat poorer water-bearing characteristics than the parent rock.

GROUND WATER

INFILTRATION AND RECHARGE

The ground water in the Fort Rock Basin, as in most areas, is derived from the infiltration of precipitation in the area. Most of the water that percolates downward to the ground-water body passes through the permeable lavas that form the flanks of the basin. Some water also infiltrates to the ground-water body from the streams that discharge into Paulina Marsh. The amount of recharge, or replenishment, of the ground-water body varies widely from year to year, depending mostly on the total precipitation in the area. Probably very little precipitation reaches the ground-water body during periods of below-average precipitation.

DISCHARGE

There is a continual drain on the ground-water body in the Fort Rock Basin from pumping, evapotranspiration (the combined effects of evaporation and transpiration by plants), and probably subsurface outflow beyond the area. The quantities of water discharged by each of the modes just mentioned are not known, but in order of magnitude are probably: (1) subsurface outflow, (2) evapotranspiration, and (3) pumping.

Subsurface outflow possibly occurs in two directions—to the Deschutes River drainage system and to the closed basin of Summer Lake. Additional, refined data on the surface elevations at the wells, together with available data on ground-water levels, might allow determination of the main directions of movement of ground water.

Because the water table is moderately deep throughout much of the area, the discharge of ground water by evapotranspiration is probably not large for the whole area. Evapotranspiration is greatest in the vicinities of Paulina Marsh and Silver Lake, where the water table is generally at or near the surface and where there are dense stands of water-loving plants. Evapotranspiration also may be great at Lost Forest, where perched ground water is discharged by transpiration of the pine trees.

Pumping from wells in 1960 accounted for only a relatively minor part of the discharge of ground water in the area. The amounts pumped and the potential supply available for pumping are discussed subsequently in this report.

WATER-LEVEL FLUCTUATIONS

When discharge exceeds recharge, the volume of ground water in storage decreases, and water levels in wells decline; when recharge exceeds discharge, levels rise. Thus, there is a definite relationship between the amount of precipitation and the fluctuations of the ground-water levels in the area.

Seasonal fluctuations of the water levels in wells in the area are slight and result from pumping wells or from the irrigation of fields near the wells. The major fluctuations of water levels are due to the long-term trends in precipitation.

The long-term fluctuations of ground-water levels in a large part, if not all, of the Fort Rock Basin for the period 1932–60 are in general represented by the levels measured in well 27/15–4G1. The well is drilled 257 feet deep and 16 to 8 inches in diameter and taps the basalt(?) of the Fort Rock Formation. The hydrograph of the well is shown on figure 8 together with graphs of the annual precipitation and cumulative departure from a long-term average near Fremont.

A comparison of the hydrograph of well 27/15–4G1 and the graph of the cumulative departure shows that the long-term water-level fluctuations apparently lag about 10 years behind the long-term precipitation trend. Levels in nine other wells in the area measured for various intervals during the period 1932–60 show the same general long-term trend. As the hydrograph in figure 8 shows, the water level at the end of 1960 may have been near the end of a long-term rise or at the beginning of a period of general decline.

CHEMICAL QUALITY OF THE GROUND WATER

The chemical quality of the ground water in the Fort Rock Basin, as determined by analyses of nine samples,

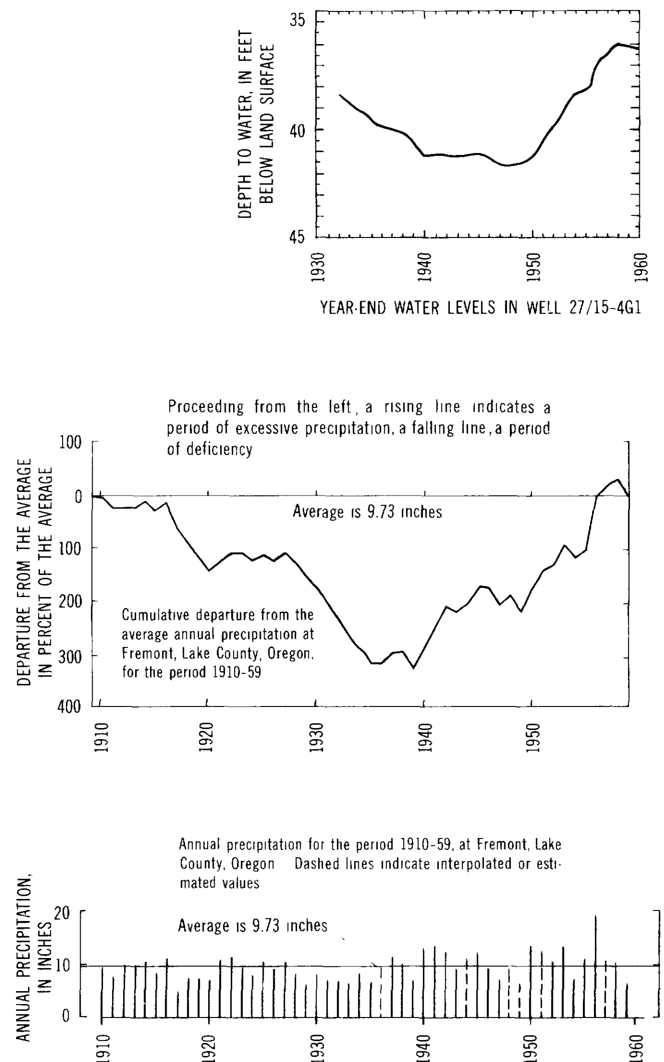


FIGURE 8.—Annual precipitation and cumulative departure from the average precipitation at Fremont, Oreg., for the period 1910–59, and hydrograph of year-end water levels in well 27/15–4G1.

ranged from moderately good to excellent for most purposes (table 2). Hardness of water ranged from 44 to 277 ppm (parts per million), chloride content from 1.0 to 121 ppm, and dissolved solids from 128 to 729 ppm.

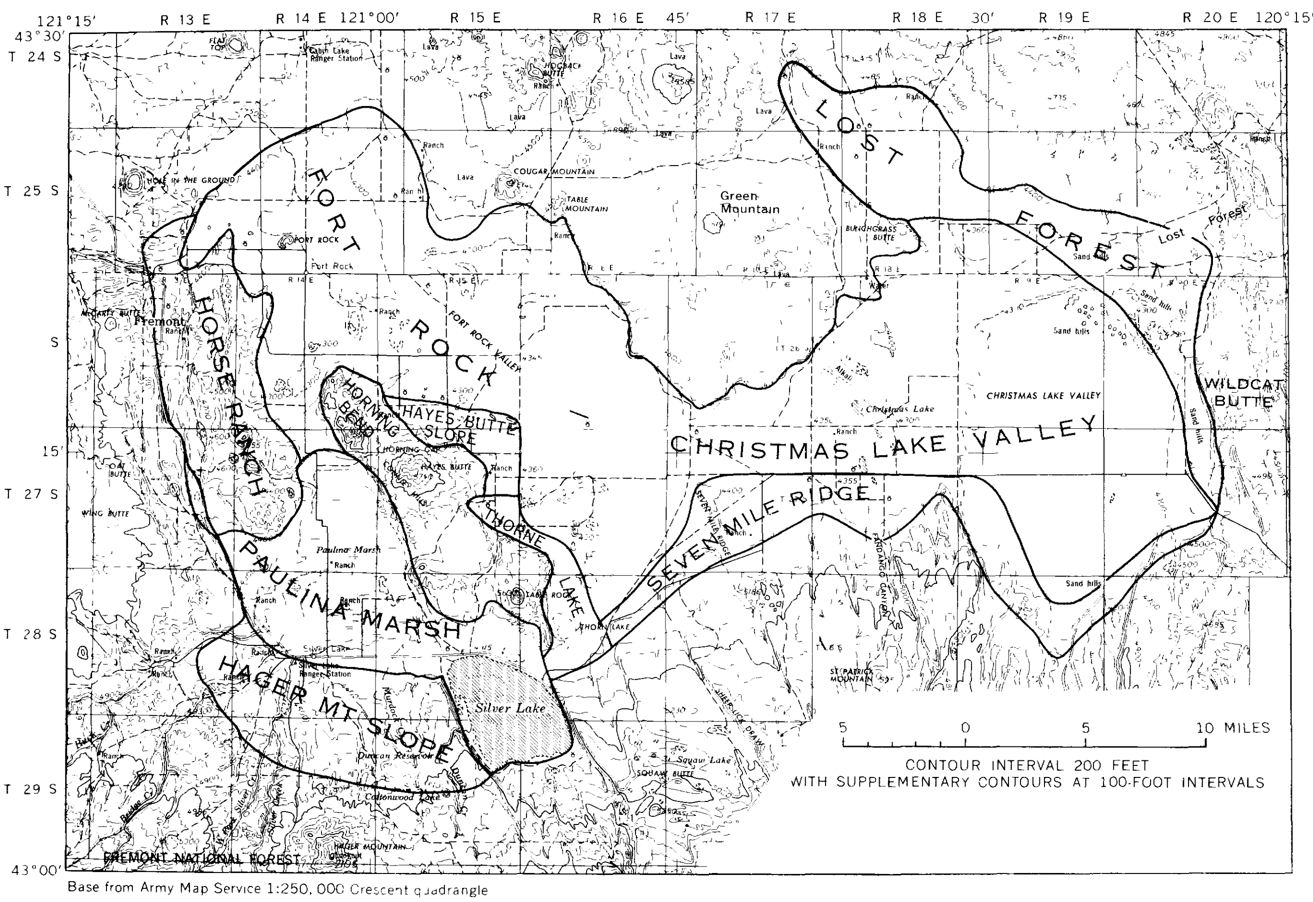
A small amount of boron is required for plant growth; however, a slightly larger amount is harmful to many plants. The water from well 26/15–33A1 contains 2.1 ppm, the largest amount of boron in any of the samples analyzed. That amount is considered unsuitable for plants that are sensitive to boron and may be harmful to some semitolerant crops, such as small grains and potatoes (Wilcox, 1948, p. 5, and table 2), that are suited to the Fort Rock Basin. Considering the few samples analyzed, the occurrence of boron in a concentration exceeding 2 ppm suggests that some of the more saline waters in the basin may contain even greater amounts of this constituent. Thus, any ground water that is developed for irrigation use and that is suspected of containing a substantial concentration of dissolved minerals should be tested for boron concentration.

OCCURRENCE IN SUBAREAS OF THE FORT ROCK BASIN

The principal aquifers, or water-bearing rock units, and their water-yielding character have been discussed briefly in the preceding section on "Geology." The most productive are the basaltic flow rocks and the coarse-grained pyroclastic rocks. Because the number, position, and extent of these aquifers varies widely from place to place in the Fort Rock Basin, a better understanding of the hydrologic conditions in specific subareas can be obtained if these subareas are discussed separately.

The part of the Fort Rock Basin that includes most of the arable land has been separated into eight subareas in this report. These subareas, whose locations are shown on figure 9, are herein designated as follows: Hager Mountain slope, Paulina Marsh subarea, Thorne Lake subarea, Seven Mile Ridge subarea, Lost Forest subarea, Fort Rock-Christmas Lake Valley, Hayes Butte slope, and Horse Ranch subarea.

The principal development of ground water in the Fort Rock-Christmas Lake Valley, the Seven Mile



Base from Army Map Service 1:250, 000 Crescent quadrangle

FIGURE 9.—Map of Fort Rock Basin, showing principal ground-water subareas.

Ridge subarea, the Thorne Lake subarea, and the Hayes Butte slope is for irrigation. Two ranches in the Paulina Marsh subarea also are irrigated from wells (fig. 10). The occurrence of ground water in the subareas that are presently developed and the potential aquifers that are probably present in the other subareas are described below.

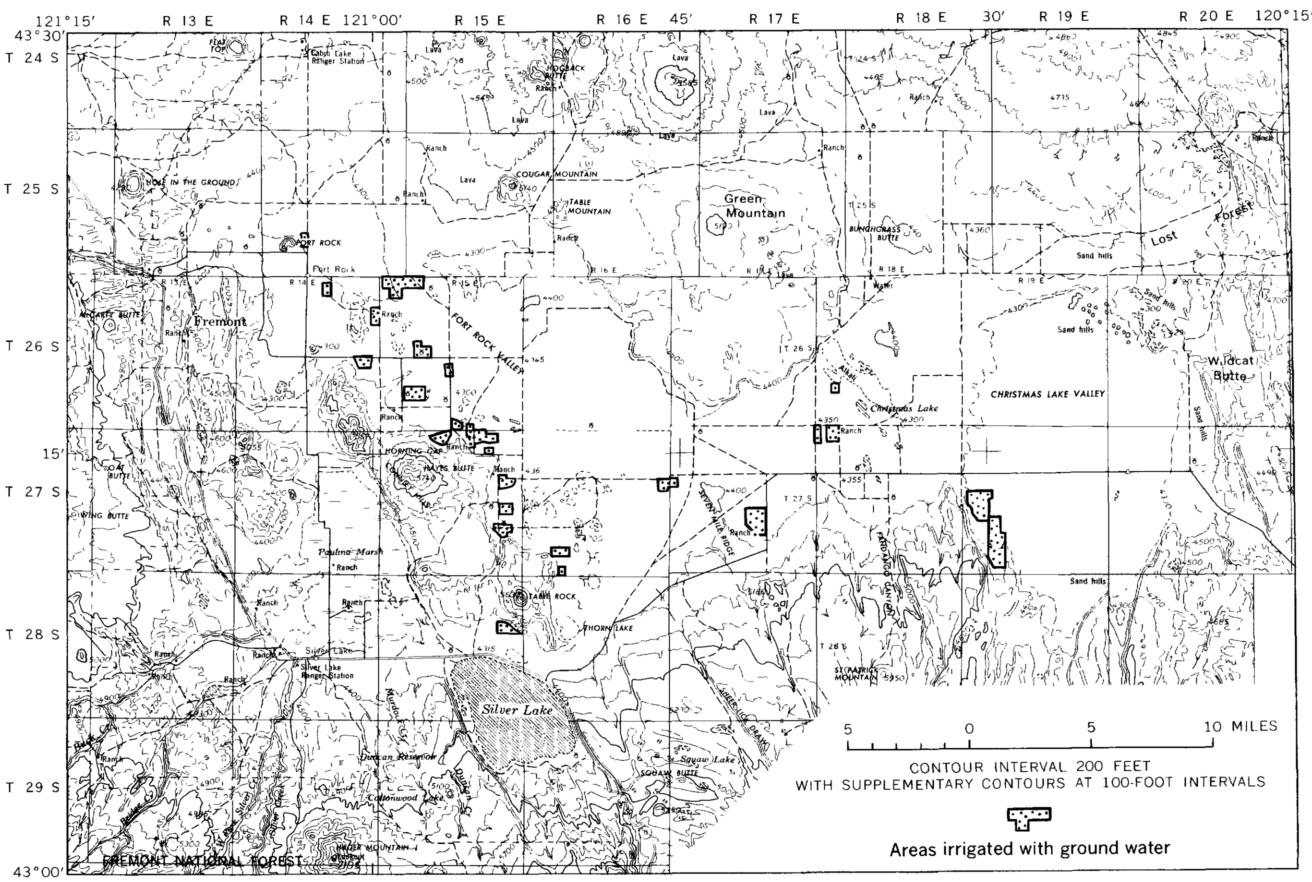
HAGER MOUNTAIN SLOPE

The region between Buck Creek, the southern and western edges of Silver Lake, the southern edge of the valley plain of Paulina Marsh, and the steep slopes of Hager Mountain is included in the subarea called Hager Mountain slope. The geologic units underlying this subarea are the Picture Rock Basalt, Fort Rock Formation, Hayes Butte Basalt, and unconsolidated delta deposits and alluvium. Of these, the Picture Rock Basalt and the unconsolidated deposits have yielded water to wells. Because most of the tillable land in this subarea is irrigated by surface water, only a few attempts have been made to obtain supplies of ground water adequate for irrigation. Most of the domestic water supplies in this subarea are obtained from shallow dug or drilled wells or from springs.

A record is available from only one deep well (28/14–27L1) in the subarea. This well was drilled to a total depth of 480 feet (table 1). The driller reported that this well penetrated basalt (Picture Rock Basalt) from 24 to 480 feet below the land surface. As this well was drilled, the static water level stood about 55 or 60 feet below the land surface until a depth of 150 feet was reached. At the 150-foot depth, the static level dropped to 89 feet below the land surface. The yield of this well at a depth of 143 feet was about 30 gpm (gallons per minute); its yield at the final depth was not determined.

The shallow wells in this subarea seldom exceed 50 feet in depth. They obtain perched water from the Quaternary alluvium of upland meadows or stream valleys. The yields of these wells are small because the aquifers supplying them are not extensive nor very productive.

The Picture Rock Basalt, which passes beneath the lowland at the north side of this subarea, where the only tillable land occurs, is probably the best potential source of ground water for irrigation in this subarea. At other places, the Picture Rock yields large quantities of water to wells.



Base from Army Map Service 1:250,000 Crescent quadrangle

FIGURE 10.—Map of Fort Rock Basin, showing areas irrigated from wells in 1960.

Because few wells have been drilled in this subarea, the water-yielding character of the Fort Rock Formation and Hayes Butte Basalt have not been tested. If the Hayes Butte Basalt extends below the water table and is penetrated by wells, it might also yield moderate to large quantities of water. The Fort Rock Formation is probably either absent, occurs above the water table, or is too thin to yield appreciable amounts of water to wells in this subarea.

In this subarea, as in other parts of the Fort Rock Basin, the altitude at which any rock unit or aquifer may be struck during drilling varies considerably from place to place, owing to the initial dips or subsequent folding of the rock units and to displacement by faulting.

PAULINA MARSH SUBAREA

The part of the Fort Rock Basin occupied by Silver Lake, Paulina Marsh, and adjacent low-lying areas is included in the Paulina Marsh subarea. This subarea is underlain by unconsolidated alluvial and delta deposits, Hayes Butte Basalt, materials of the Fort Rock Formation, and Picture Rock Basalt.

The delta deposits, Fort Rock Formation, and Picture Rock Basalt have been tapped by wells. Most of the wells have been dug or drilled to shallow depths into the delta deposits or Fort Rock Formation and yield quantities of water adequate only for domestic and stock supply. Several irrigation wells tap the Fort Rock Formation and Picture Rock Basalt at places where surface water is not available for irrigation.

Well 28/15–14H1 is representative of irrigation wells drilled into the Picture Rock Basalt. The driller's log shows that the basalt was entered at a depth of 452 feet (alt 3,923 ft) and penetrated to a depth of 520 feet. The yield of this well is reportedly more than 1,000 gpm with only a few feet of drawdown.

In well 28/15–14Q1, which is about half a mile south of well 28/15–14H1, Picture Rock Basalt was entered at a depth of 613 feet (alt 3,702 ft), or at an altitude 221 feet lower than that of well 28/15–14H1. This evidence indicates the large variation in depth of the water-bearing units within relatively short distances and suggests a vertical displacement of more than 200 feet between the two wells.

Well 28/14–21Q2 is representative of some of the wells that tap the Fort Rock Formation. The driller's log of this well shows that the Fort Rock Formation was entered at a depth of 18 feet and that several beds of cinders and gravel, any of which may be potential water-yielding zones, occur at depths ranging from 145 to 240 feet below the land surface. This well yielded 154 gpm with 11 feet of drawdown after 4 hours of pumping, and its water is reportedly free of sand. Unlike most wells, either shallow or deep, that were drilled into the alluvium and the Fort Rock Formation in the Paulina Marsh subarea and near Silver Lake, this well has a factory-perforated liner in the interval from 180 to 240 feet below the surface. The slots in the liner are machine cut, $\frac{1}{8}$ x $1\frac{1}{2}$ inches in size and, like a well screen, hold back the larger size loose materials in the aquifer while allowing the ground water to enter the well.

THORNE LAKE SUBAREA

An irregular, elongate lowland area extending north from Silver Lake and lying east and north of Table Rock is herein designated the Thorne Lake subarea (fig. 9).

The geologic units underlying this subarea are unconsolidated deposits, materials of the Fort Rock Formation, and Picture Rock Basalt. The principal water-yielding units in the subarea are the Fort Rock Formation and Picture Rock Basalt. As indicated on plate 1, the Picture Rock Basalt along the southern border of the subarea dips beneath the unconsolidated deposits and Fort Rock Formation at angles ranging from 1° to 4°. The Picture Rock Basalt is cut by the northwestward-trending faults whose vertical displacements range from a few to more than 200 feet. Thus, the depth to the Picture Rock Basalt at any particular place in the Thorne Lake subarea is contingent upon the dip of the basalt, the distance from the outcropping basalt, and the amount and direction of vertical movement on the particular fault block that underlies that place. The logs of some wells in the subarea show a sharp difference in the depth to basalt for wells drilled a quarter of a mile apart and thus indicate the continuation of faults in the Picture Rock Basalt at depth.

The Fort Rock beds in this subarea consist of diatomite and tightly to moderately consolidated tuffs. In the part of this subarea adjacent to Table Rock (an eruptive center for the Fort Rock Formation), the sedimentary and pyroclastic materials of the Fort Rock Formation are generally poorly sorted, tightly cemented, and poorly permeable. The driller's log of well 28/16–5Q1 (table 1) shows the diversity of the materials in that part of the subarea and indicates that the depth to the Picture Rock Basalt is 718 feet. The static water level in that well was 43 feet below the land surface when the well was 608 feet deep, and 29 feet when the well was completed at a 764-foot depth. The well is reported to yield 140 gpm; no record of the drawdown at this pumping rate is available.

Well 27/16–34L1, about 3 miles northeast of well 28/16–5Q1, penetrated a thick section of diatomite before entering the Picture Rock Basalt at a depth of 675 feet. A comparison of the driller's log of that well with the log of well 28/16–5Q1 shows the typical increase in the proportions of diatomite and other fine-grained material in the Fort Rock Formation with distance from the Fort Rock eruptive centers.

Wells finished in the Fort Rock Formation that underlies the southern part of the Thorne Lake subarea yield small to moderate quantities of water, but none drilled to date (1960) are considered adequate for irrigation supplies.

SEVEN MILE RIDGE SUBAREA

The part of the area that extends generally from the Thorne Lake subarea to the eastern edge of the basin and which includes Seven Mile Ridge, the lower slope of Picture Rock Ridge, and some of the lowland near the southern edge of Christmas Lake Valley is herein called the Seven Mile Ridge subarea (fig. 9). The geologic units underlying this subarea are unconsolidated deposits, in the Fort Rock Formation, and the Picture Rock Basalt.

The aquifers tapped by wells in this subarea are the Fort Rock Formation and Picture Rock Basalt. As in the Thorne Lake subarea, the depth to the water-yielding Picture Rock Basalt at any place in this subarea depends on the distance from the outcropping basalt, the dip of the basalt, and the amount and direction of vertical displacement on individual fault blocks within the basalt.

The Picture Rock Basalt in Seven Mile Ridge subarea is found at shallower depths than in the Thorne Lake subarea and is generally highly permeable.

The driller's log of well 27/17–27L1 shows the Picture Rock Basalt to be overlain by 60 feet of soil and materials of the Fort Rock Formation. The basalt was penetrated to a depth of 195 feet, at which depth the drill bit reportedly dropped into a 25-foot-deep cavern (probably a lava tube). This well yielded 4,800 gpm with 40 feet of drawdown and 2,500 gpm with 13 feet of drawdown, from the Picture Rock Basalt.

Several shallower wells have been dug or drilled into the Fort Rock Formation and furnish moderate quantities of water. Well 27/17–13A1 penetrated alternating beds of diatomite and sand of this formation to a depth of 116 feet and yielded 30 gpm with 20 feet of drawdown after 3 hours of pumping.

Several wells in the eastern part of the Seven Mile Ridge subarea near Viewpoint Ranch have been tested at about 2,500 gpm with drawdown ranging from 4 to 15 feet. Well 27/19–19G1, which obtains its water from the Picture Rock Basalt, is typical of these wells.

LOST FOREST SUBAREA

The northeastern and eastern border areas of the Fort Rock Basin constitute the Lost Forest subarea (fig 9). This subarea ranges in width from about 1½ miles at Buffalo Wells to about 5 miles near Peters Creek sink (pl. 1).

The principal aquifers of this subarea are dune sand, Paulina Basalt, Hayes Butte Basalt, and Fort Rock Formation. These units have been tapped by wells and have yielded some water. Wells in the southern part of this subarea tap materials of the Fort Rock Formation, those in the northwestern part tap the dune sand and possibly the Hayes Butte Basalt, and those in the northwestern part tap the Paulina Basalt.

One of the few wells in the subarea that was intended for irrigation supply is well 25/18–5C1. This well taps the Paulina Basalt and was reported to yield about 400 gpm, a quantity considered inadequate by the owner. The driller reported that the water was "lost" when the well was drilled to a depth of nearly 200 feet; the well was then plugged with cement to a depth of 115 feet. The water level in that well is not known, but static levels in two other wells about three-quarters of a mile west of well 25/18–5C1 and at about the same altitude stood at about 50 feet below the land surface in October 1948.

No logs of the wells in the southern part of this subarea are available, but records of water levels are. The water level in several wells in the Buffalo Wells area (pl. 1) stood about 35 feet below the level of the valley plain in October 1948.

FORT ROCK-CHRISTMAS LAKE VALLEY

The Fort Rock-Christmas Lake Valley constitutes the largest subarea in the Fort Rock Basin. This subarea is a flat, nearly featureless plain, extends eastward about 40 miles from near Fort Rock, and ranges in width from 4 to about 12 miles.

The two principal aquifers in this subarea are the Paulina Basalt, which at places underlies and elsewhere forms the northern border of the subarea, and the Fort Rock Formation, which underlies the greatest part of the subarea. The Picture Rock Basalt underlies the area at depth, and is tapped by at least one well.

The aquifers of the Fort Rock Formation occur throughout the subarea and consist largely of basaltic and pumice sand, basaltic agglomerate, and lava flows. Well 27/18–6F1, which penetrated mostly beds of sand, gravel, and tuff, and a thick layer of diatomite, is representative of wells drilled into the Fort Rock Formation in the central Christmas Lake Valley. That well reportedly yielded 375 gpm with 45 feet of drawdown after 8 hours of pumping.

Well 27/18–12A1, about 6 miles east of well –6F1, was drilled through the Fort Rock Formation and into the Picture Rock Basalt (table 1). This well yielded

1,300 gpm with 54 feet of drawdown after 4 hours of pumping.

Wells in the Fort Rock Valley have penetrated and obtained water from several thin lava flows within the Fort Rock Formation, as shown in the driller's log of well 26/15-5C1. This well reportedly yielded 2,000 gpm with 25 feet of drawdown after 2 hours of pumping.

Well 26/15-6C2, about three-fourths of a mile west of well 26/15-5C1, is another large-yield well that taps the Fort Rock Formation. This well apparently penetrated nearly the same sequence of materials as well 26/15-5C1 and reportedly yielded 1,000 gpm with 27 feet of drawdown after 8 hours of pumping.

HAYES BUTTE SLOPE

The lower slopes on the northeast side of Hayes Butte constitute the subarea herein called the Hayes Butte slope. The subarea is an L-shaped strip about 7 miles long and 1½-2 miles wide and includes about 15 square miles.

The principal aquifers in the area are agglomerate, cinder, and basalt flows of the Fort Rock Formation. The Hayes Butte Basalt is at the surface at the southern and western borders of this subarea, and underlies part of the subarea at shallow depths beneath unconsolidated deposits. The Fort Rock Formation occurs at depth and is tapped by wells scattered throughout the subarea.

Well 27/15-2P1 is representative of wells that have been drilled through the Hayes Butte Basalt and obtain water from the Fort Rock Formation. This well is 79 feet deep, and was tested at a yield of 1,250 gpm with a drawdown of 3 feet after 1 hour of pumping. Well 27/15-11R2, another large-yield well, about 1 mile southeast of 27/15-2P1, penetrated unconsolidated deposits, the Hayes Butte Basalt, and the Fort Rock Formation to a total depth of about 90 feet. It obtains water from cinder beds of the Fort Rock Formation.

HORSE RANCH SUBAREA

The part of the Fort Rock Basin south of Hole-in-the-Ground, west of the Fort Rock Valley floor, generally east of State Highway 31, and north of Paulina Marsh is called the Horse Ranch subarea. This subarea is characterized by fault-block uplands, small eruptive centers, and small closed basins. The tracts of arable land in this region are relatively small, and no irrigation wells were known to exist as of 1960. The principal aquifers in the subarea—the Hayes Butte Basalt and the Fort Rock Formation—are tapped only by domestic and stock wells.

Wells 26/13-4B1 and 26/13-15H1 are representative of those wells in the subarea that obtain water from the Hayes Butte Basalt (table 1). Well 26/13-25R1 was drilled through the Hayes Butte Basalt and obtains its water from the Fort Rock Formation. No data are available on the yields of these or other wells in this subarea; therefore, the water-yielding character of the local aquifers is unknown.

POTENTIAL FOR ADDITIONAL DEVELOPMENT

Because of the lack of perennial surface-water supplies in most of the area, any additional water supplies that are developed in the Fort Rock Basin must come largely from ground-water sources. By far the greatest demand for ground water, in the future as at present, will be for irrigation. However, substantial increases in the use of ground water for irrigation would probably be accompanied by some increase in demands for domestic and stock supplies.

As is indicated by figure 10, only about 6,000 acres of the land within the Fort Rock Basin was irrigated with water from wells in 1960. The discussions of the subareas included descriptions of most of the more productive irrigation wells in the subareas as of 1960, and three of the subareas had no wells used for irrigation supply. However, a few wells intended for irrigation supply have been drilled in the area each year during this investigation, and prospecting for ground water for irrigation is expected to continue in the future.

The water levels in wells tapping the more productive aquifers are not greatly affected by the present-day pumping withdrawals but apparently fluctuate chiefly in response to long-term changes in recharge from precipitation (fig. 8). The failure of the pumpage to cause a noticeable general decline in ground-water levels indicates that only a small part of the total ground water available for withdrawal is currently being used.

In a brief report appraising the ground-water supplies available for irrigation in the area, Newcomb (1953, p. 5) estimated that the recharge from precipitation was about 125,000 acre-feet per year. He further estimated that 50,000 acre-feet of ground water was transpired by vegetation, leaving about 75,000 acre-feet to discharge from the basin by other means, principally by subsurface outflow. The 75,000 acre-feet could be considered as the maximum increment of the average annual recharge that is available to supply water pumped for irrigation or other purposes. The amount of water pumped during 1960 is estimated to be only 12,000 acre-feet.

The aforementioned estimates indicate that roughly one-tenth of the ground water that is replenished naturally each year was pumped during 1960 and that as much as 60,000 acre-feet of additional water could be pumped annually without overdraft of the ground-water supplies if the subsurface outflow could be salvaged completely. Moreover, the amount pumped might be increased if part of the evapotranspiration could be salvaged for beneficial use. Thus, at the 1960 rate of development, the amount of additional ground water that is available for withdrawal in the basin will probably exceed the demand for many years. However, any plans for the large-scale withdrawal of additional ground water from the area should provide for spacing of the wells to minimize interference (mutual drawdown) among the wells. In addition, periodic measurements of ground-water levels should be continued to provide early warning of overdraft that may develop in the future.

All the subareas are underlain by aquifers that will yield quantities of water adequate for substantial irrigation supplies. In some, such as in parts of the Thorne Lake subarea, the most productive aquifers occur at depths greater than 1,000 feet; thus, construction and development of wells capable of yielding quantities of water adequate for irrigation at those places would be costly. In other subareas, such as the Fort Rock-Christmas Lake Valley, wells require proper construction and development to obtain optimum yields of sand-free water.

The local occurrence of ground water containing greater amounts of dissolved minerals than are desirable for some purposes (p. B19) indicates that the chemical quality, as well as the quantity, may be critical in the future development of additional ground-water supplies in the Fort Rock Basin.

WELL CONSTRUCTION

Most of the wells in the Fort Rock Basin have been drilled with percussion (cable-tool or churn) drills, although a few have been dug, driven, or bored. The older wells usually have only a few feet of casing, regardless of the materials penetrated. As a result, some of the wells that obtain water directly from sand or that pass through sand and tap agglomerate or basalt aquifers yield large amounts of sand with the water. The sand causes undue wear on pump parts and clogs sprinklers and transmission pipes. Although some of the newer wells have enough casing to prevent to a large extent the "quicksand" layers from sloughing into the well, some sand is produced from the uncased water-yielding part of the wells. One well is cased with a machine-perforated liner in the water-bearing sand and grit zone; this liner not only effectively prevents sloughing of the aquifer materials into the well but permits free passage of water into the well.

Several moderately high yield wells in the basin have been abandoned for irrigation use because of excessive sand. Those wells probably could have been developed into adequate sand-free irrigation wells if a properly sized screen or perforated liner had been installed in the aquifer material, and the wells had then been adequately developed. The size of the openings in the screen or perforations in the liner is selected on the basis of grain-size analyses of the aquifer sand, sampled during drilling. After the screen or perforated liner is installed, the well is developed, usually by surging or by intermittent pumping at a high rate. During proper developing, most of the fine-grained material adjacent to the well comes through the openings into the well and thus is removed, leaving a natural pack around the casing before the well is put into use. Adequate development of a well having screen or perforated liner not only eliminates or materially reduces the entrance of sand later, but also improves the yield of the well by increasing the permeability of the aquifer materials adjacent to the well.

TABLE 1.—*Drillers' logs of selected wells in the Fort Rock Basin, Lake County, Oreg.*

Data collected from drillers or owners, or from reports submitted to the State Engineer. Altitudes determined approximately by barometric leveling. All depths given in feet below land surface at well. Tentative stratigraphic designations are by the author.

Materials	Thickness (feet)	Depth (feet)
Well 25/18-5C1		
[ZX Ranch. Alt 4,400 ft. Drilled by Frank Skillings, 1959. Depth 115 ft; 18-in. casing to 8 ft. Pumped 400 gpm]		
Clay, sandy	5	5
Paulina Basalt:		
Basalt	63	68
Cinders, red	4	72
Basalt	43	115
Well 26/13-4B1		
[Sam Olmstead. Alt 4,488 ft. Dug by W. E. McCallum and owner, 1910 and 1932. Depth 220 ft; 3-in. casing to 198 ft; static water level 201 ft, 1932]		
Peyerl Tuff:		
Gravel	10	10
Clay, red, bricklike (tuff?)	50	60
Rock fragments, loose	15	75
Basalt(?)	30	105
Pumice tuff(?)	15	120
Tuff	40	160
Hayes Butte Basalt:		
Basalt, porous, fractured	60	220
Well 26/13-15H1		
[U.S. Soil Conservation Service. Alt 4,480 ft. Dug by W. L. Dehne, 1914. Depth 200 ft; 48-in. casing; static water level 184 ft, 1914]		
Soil	8	8
Peyerl Tuff:		
Basalt(?)	8	16
Diatomite	30	46
Pumice tuff	30	76
Sandstone, tuffaceous, contains basaltic lapilli	104	180
Hayes Butte Basalt:		
Basalt	20	200

TABLE 1.—*Drillers' logs of selected wells in the Fort Rock Basin, Lake County, Oreg.*—Continued

Materials	Thickness (feet)	Depth (feet)
Well 26/13-25R1		
[W. J. Mattis. Alt 4,460 ft. Drilled by Sam Olmstead, 1940. Depth 180 ft; 6-in. casing to 60 ft and 4-in. casing to 180 ft; static water level 160 ft, 1940]		
Hayes Butte Basalt:		
Boulders (weathered basalt)	30	30
Basalt, black	70	100
Fort Rock Formation:		
Tuff, yellow	20	120
Agglomerate, basaltic	30	150
Tuff, red and gray	30	180
Well 26/15-5C1		
[Ed Turner. Alt 4,315 ft. Drilled by Frank Skillings, 1957. Depth 361 ft; 12-in. casing to 123 ft; static water level 32 ft, Apr. 23, 1957. Pumped 2,000 gpm for 2 hr., drawdown 25 ft]		
Fort Rock Formation:		
Clay, sandy	28	28
Sand, fine	4	32
Clay, gray (diatomite?)	11	43
Sand, black	5	48
Clay, gray (diatomite?)	14	62
Clay, yellow (tuff?)	66	128
Clay, gray, dark (ashy diatomite?)	18	146
Clay, black, rotten	3	149
Rock, gray, hard (welded tuff?)	27	176
Clay, brown (tuff?)	64	240
Lava	20	260
Clay, brown (tuff?)	12	272
Lava	15	287
Rock, gray, hard (lava?)	21	308
Lava, porous	48	356
Rock, gray	5	361
Well 26/15-6C2		
[A. E. Albertsen. Alt 4,310 ft. Drilled by Claude Shafer, 1956. Depth 317 ft; 16-in. casing to 36 ft and 12-in. casing to 119 ft. Pumped 1,000 gpm for 8 hr, drawdown 27 ft]		
Soil	4	4
Fort Rock Formation:		
Gravel, pea-size	4	8
Silt, sandy	24	32
Clay	8	40
Sand, loose, black	13	53
Clay	14	67
Sand, loose, black	9	76
Clay	4	80
Sand, black, with clay (cinder tuff)	17	97
Sandstone, hard (tuff?)	4	101
Tuff	69	170
Tuff, sand layers	26	196
Tuff	24	220
Lava and "sand"	14	234
Tuff	11	245
Lava	20	265
Tuff	5	270
Gravel; streaks of sand and clay	47	317

TABLE 1.—*Drillers' logs of selected wells in the Fort Rock Basin, Lake County, Oreg.*—Continued

Materials	Thickness (feet)	Depth (feet)
Well 27/15-2P1		
[Edwin Eskalin. Alt 4,320 ft. Drilled by owner, 1935. Depth 79 ft; 12-in. casing to 12 ft; static water level 27.1 ft, Oct. 25, 1948. Pumped 1,250 gpm for 1 hr, drawdown 3 ft]		
Unconsolidated deposits:		
Soil, sandy	6	6
Sandstone, gray, medium-grained (hardpan?)	6	12
Hayes Butte Basalt:		
Basalt, black, dense	15	27
Fort Rock Formation:		
Pumice, soft	18	45
Cinders and lava, alternating layers	29	74
Cinders, black, coarse, caving	5	79
Well 27/15-11R2		
[Jess Miles. Alt 4,350 ft. Drilled by Edwin Eskalin, 1947. Depth 90.5 ft; 12-in. casing to 9 ft; static water level 46.5 ft, Oct. 21, 1948]		
Soil, sandy	2. 5	2. 5
Unconsolidated deposits:		
Gravel, sandy	6	8. 5
Hayes Butte Basalt:		
Lava, red, porous	38	46. 5
Fort Rock Formation:		
Cinders, red, and black gravel	25. 5	72
Ash, white, "packed"	. 5	72. 5
Cinders, red	3	75. 5
Gravel, cemented	. 5	76
Gravel, coarse, rounded, and sand	2	78
Cinders, red	6	84
Lava, porous, red (welded tuff?)	3	87
Cinders, red, and gravel	2	89
Gravel, coarse, loose	1. 5	90. 5
Well 27/16-34L1		
[Mallett estate. Alt 4,330 ft. Drilled by Floyd Nicholson, 1957. Depth 828 ft; 12-in. casing to 10 ft; static water level 24 ft, 1957. Pumped 400 gpm for 2 hr, drawdown 97 ft]		
Soil	6	6
"Hardpan" (caliche in soil?)	2	8
Fort Rock Formation:		
Diatomaceous earth	282	290
Sand, gray, water-bearing; yield 5 gpm; static water level 70 ft	12	302
Diatomaceous earth	373	675
Picture Rock Basalt:		
Basalt, broken; static water level 47 ft at 675-ft depth	43	718
Basalt, hard, gray; some water at 730- to 731-ft depth; static water level 37 ft	46	764
Basalt, gray, and pumice; static water level 32 ft	5	769
Basalt, broken black; water at 782- to 784-ft depths; static water level 29 ft, total yield 400 gpm	22	791
Basalt, hard	23	814
Basalt, broken; static water level 24 ft, total yield 600 gpm	6	820
Basalt, hard	8	828

TABLE 1.—*Drillers' logs of selected wells in the Fort Rock Basin, Lake County, Oreg.*—Continued

Well 27/17-13A1

[Jack Gillette. Alt 4,320 ft. Drilled by Floyd Nicholson, 1957. Depth 116 ft; 12-in. casing to 18 ft; static water level 20 ft, 1957. Pumped 30 gpm for 3 hr, drawdown 20 ft]

Materials	Thickness (feet)	Depth (feet)
Soil	5	5
Fort Rock Formation:		
Clay	2	7
Diatomaceous earth	67	74
Sand, rock	1	75
Diatomaceous earth	27	102
Sand, gray, and rock	10	112
Diatomaceous earth	4	116

Well 27/17-27L1

[H. Wahl. Alt 4,355 ft. Drilled by Pat McGinley, 1952. Depth 220 ft; 16-in. casing to 77 ft; static water level 42.2 ft, June 18, 1952. Pumped 4,800 gpm for 6 hr, drawdown 40 ft]

Materials	Thickness (feet)	Depth (feet)
Fort Rock Formation:		
Soil and soft clay	14	14
Clay, hard, yellow (tuff)	14	28
Clay, blue (diatomite?)	20	48
Sand, hard, fine-grained; some water	12	60
Picture Rock Basalt:		
Rock, lava, medium-hard	15	75
Rock, lava, medium to hard	10	85
Rock, lava, firm	45	130
Rock, lava, soft	9	139
Sand, water-bearing (cinders?)	2	141
Rock, lava, hard	20	161
Rock, lava, soft	10	171
Rock, lava, hard, bluish-colored	5	176
Rock, lava, soft, caving	6	182
Rock, lava, hard	13	195
Cavern (in basalt)	25	220

Well 27/18-6F1

[Robert Morehouse. Alt 4,320 ft. Drilled by S. Munnerlyn, 1958. Depth 425 ft; 12-in. casing to 20 ft; static water level 25 ft, June 9, 1958. Pumped 375 gpm for 8 hr, drawdown 45 ft]

Materials	Thickness (feet)	Depth (feet)
Soil	5	5
Fort Rock Formation:		
"Hardpan"	5	10
Clay, yellow (tuff?)	32	42
Sand, water-bearing (pumice sand?)	5	47
Clay, blue (diatomite?)	33	80
Clay, yellow (tuff?)	79	159
Gravel, coarse	11	170
Clay, blue (diatomite?)	20	190
Gravel	10	200
Rock, hard, gray	10	210
Clay, blue (diatomite?)	215	425

Well 27/18-12A1

[J. A. Pettus. Alt 4,320 ft. Drilled by Frank Skillings, 1960. Depth 287 ft; 14-in. casing to 11½ ft; static water level 20 ft, June 1960. Pumped 1,300 gpm for 4 hr, drawdown 54 ft]

Materials	Thickness (feet)	Depth (feet)
Fort Rock Formation:		
Clay, sandy	34	34
Clay (diatomite?)	113	147
Pumice sand, water-bearing	11	158
Picture Rock Basalt:		
Basalt	110	268
Cinders, gray	19	287

TABLE 1.—*Drillers' logs of selected wells in the Fort Rock Basin, Lake County, Oreg.*—Continued

Well 27/19-19G1

[View Point Ranch, Inc. Alt 4,340 ft. Drilled by Frank Skillings, 1958. Depth 314 ft; 16-in. casing to 10 ft; static water level about 40 ft, 1959. Pumped 2,400 gpm for 8 hr, drawdown 13 ft]

Materials	Thickness (feet)	Depth (feet)
Unconsolidated deposits and Fort Rock Formation:		
Clay, sandy	57	57
Fort Rock Formation:		
Sand, coarse, pumice	6	63
Clay, sandy	19	82
Rock, gray	15	97
Rock, lava, soft	7	104
Clay, dark-gray	20	124
Cinders, gray (pumice)	6	130
Clay, gray	58	178
Picture Rock Basalt:		
Rock, gray	46	224
Cinders, gray and red	10	234
Basalt	50	284
Cinders	30	314

Well 28/14-21Q2

[U.S. Forest Service. Alt 4,380 ft. Drilled by R. Hartley, 1958. Depth 240 ft; 8-in. casing to 240 ft, perforated liner from 180 to 240 ft; static water level 74.5 ft, Dec. 14, 1958. Pumped 154 gpm for 4 hr, drawdown 11 ft]

Materials	Thickness (feet)	Depth (feet)
Unconsolidated deposits:		
Gravel, cemented	18	18
Fort Rock Formation:		
Sandstone, brown	22	40
Chalk, blue (diatomite?)	33	73
Rock, lava, black	21	94
Chalk, blue (diatomite?)	51	145
Gravel, small	1	146
Sandstone, red (cinders?)	28	174
Clay and cinders, sandy, red	46	220
Cinders, red clay, water	20	240

Well 28/14-27L1

[Duane Crane. Alt 4,380 ft. Drilled by Floyd Nicholson, 1957. Depth 480 ft; 12-in. casing; static water level 89 ft, 1957[

Materials	Thickness (feet)	Depth (feet)
Unconsolidated deposits and Fort Rock Formation:		
Silt, sand, and rubble	24	24
Picture Rock Basalt:		
Basalt, gray	18	42
Basalt, black	18	60
Basalt, black, hard, with ashy breaks	420	480

Well 28/15-14H1

[A. E. Albertsen. Alt. 4,375 ft. Drilled by Pat McGinley, 1955. Depth 520 ft; 16-in. casing to 342 ft; static water level 67 ft, 1955]

Materials	Thickness (feet)	Depth (feet)
Unconsolidated deposits:		
Sand and gravel	7	7
Hayes Butte Basalt:		
Rock, lava, hard, dark	21	28
Fort Rock Formation:		
Sand (lapilli tuff?); first water at 67 ft	217	245
Chalk, rotten (diatomite?)	207	452
Picture Rock Basalt:		
Rock, lava, broken	25	477
Rock, lava, red	18	495
Rock, lava, soft, red	4	499
Rock, lava, firm, red	9	508
Cinders, dark	2	510
Rock, lava, hard, black	10	520

TABLE 1.—*Drillers' logs of selected wells in the Fort Rock Basin, Lake County, Oreg.*—Continued

Materials	Thickness (feet)	Depth (feet)
Well 28/15-14Q1		
[A. E. Albertsen. Alt 4,315 ft. Drilled by Frank Skillings, 1957. Depth 646 ft; 12-in. casing to 336 ft: static water level 20 ft, Nov. 21, 1957. Pumped 1,600 gpm for 4 hr, drawdown 35 ft]		
Unconsolidated deposits and Fort Rock Formation:		
Sand and clay	18	18
Sand, loose	6	24
Fort Rock Formation:		
Sand and clay	52	76
Shale (tuff)	13	89
Sand and clay	129	218
Sand, fine	114	312
Shale (tuff)	28	340
Clay (diatomite)	273	613
Picture Rock Basalt:		
Basalt, black	14	627
Cinders, red	7	634
Rock, lava	8	642
Rock, gray	4	646
Well 28/16-5Q1		
[Claude Shafer. Alt 4,320 ft. Drilled by owner, 1957. Depth 764 ft; 12-in. casing to 6 ft, 12-in. well diameter to 715 ft, 8-in. well diameter to 764 ft; static water level 29 ft, 1957. Pumped 140 gpm]		
Soil	6	6
Fort Rock Formation:		
Sand, medium-hard	25	31
Clay, blue, with layers of rock	41	72
Rock, lava (welded tuff?)	43	115
Tuff	50	165
Sand and pumice	15	180
Tuff	51	231
Rock, lava (welded tuff?)	9	240
Tuff	38	278
Pumice and rock	35	313
Rock, very hard	2	315
Sandstone, gray	50	365
Pumice	5	370
Rock, lava, hard (welded tuff?)	80	450
Tuff	20	470
Rock, lava	39	509
Tuff	2	511
Lava, soft; water rose 5 ft in well	15	526
Tuff	4	530
Rock, lava, hard; water level 43 ft at 608-ft depth	80	610
Cinders, red	5	615
Clay, gray	10	625
Clay, brown	35	660
Pumice, water-bearing	8	668
Clay	2	670
Lava, soft, cinders and sand streaks	40	710
Clay, brown to red, green pumice	8	718
Picture Rock Basalt:		
Lava, brown, broken	9	727
Basalt	37	764

TABLE 2.—*Chemical analyses of water from wells in the Fort Rock Basin, Lake County, Oreg.*

[Use: D, domestic; Irr, irrigation; PS, public supply; S, Stock. Analyses by U.S. Geol. Survey unless otherwise indicated. Results are given in parts per million unless otherwise indicated]

Well	Owner	Use	Depth of well (feet)	Aquifer	Date of collection	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue at 180°C	Hardness: As $CaCO_3$	Hardness: Noncarbonate, as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH
26/15-33A1	M. Y. Parks	Irr	200	Fort Rock Formation.	4-26-61	----	45	------	------	36	19	84	7.9	191	103	68	0.4	0.2	2.1	460	468	170	14	725	7.6
27/14-35M1	Maude Kittridge & Sons.	D, S	61.3	Fort Rock(?) Formation.	2-18-50	50	51	0.72	0.00	17	17	20	5.6	184	1.0	1.0	.2	3.2	.01	207	188	112	0	285	7.5
27/15-4G1	M. Y. Parks	Irr, D, S	257	Fort Rock Formation.	10-24-48	62	54	[1].04	<.2	31	21	176	15	330	115	121	.6	4.3	.8	701	690	164	0	1,100	8.1
24N1	Ralph Webber	Irr	351	do	12-3-48	50	45	[1].52	.4	8.4	5.7	16	1.9	92	2.9	2.2	.2	.2	.02	128	125	44	0	145	8.1
27/17-5E1	Chewaucan Land & Cattle Co.	S	206	do	10-12-48	52	44	[1].29	<.2	9.4	14	92	7.7	210	90	12	.4	8.5	.06	382	368	81	0	555	7.5
27L1 [2]	Mr. Wahl	Irr	220	Picture Rock Basalt.	1-10-52	----	16	.80	------	15	9.7	35	------	140	24	11	------	------	.10	180	------	78	0	------	7.0
27/18-18D1	Rolly Hardin	S	45	Fort Rock Formation.	10-19-48	----	53	[1]1.3	<.2	45	40	120	14	194	302	54	.3	5.4	.08	729	736	277	118	1,070	7.3
28/14-21Q2	U.S. Forest Service.	D, PS	240	do	12-12-58	----	43	.07	------	14	7.7	10	2.8	107	4.4	1.5	.1	.5	------	137	133	66	0	177	8.2
22L2	Ray Hohstadt	D	34	Unconsolidated deposits.	2-18-50	48	53	.95	.00	13	9.8	13	4.8	94	9.0	8.0	.2	8.8	.00	166	160	73	0	210	7.4

[1] Total iron; other values indicate iron in solution at time of sample collection. [2] Anaylsis by Twining Laboratories, Fresno, Calif.

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