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TEMPERATURES IN THE LAVA BEDS OF EAST CENTRAL AND SOUTH CENTRAL OREGON.[1]

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ABSTRACT.

Temperature records of seven springs, seven flowing wells, and nine non-flowing wells are discussed briefly with reference to the hydrology and volcanology of the area.

The flat segments that appear on a number of the depth-temperature curves are supposed to be due to convection of water. In general, the source of the heat is attributed to the lava beds themselves, but the extraordinarily high temperatures at Lakeview may be due in addition to heat from the mountain mass or to an intrusive that penetrates the lava beds up to rather shallow depths from the surface of the ground.

INTRODUCTION.

The lava plateaus of Oregon and Washington east of the Cascade range are among the largest in the world. This paper deals with a narrow strip extending diagonally across the southern half of the lava-covered area in Oregon beginning at Vale in Malheur County and extending southwest and west through Harney, Lake, and Klamath counties. In this irregular strip, temperature tests have been made in two flowing wells, and one non-flowing well near Vale; one non-flowing well about 18 miles south of Burns; two flowing wells, two non-flowing wells and four springs near Lakeview; and three flowing wells, three hot springs and five non-flowing wells in the Bonanza-Klamath Falls area. The depths of the non-flowing wells range from 500 to 3870 feet. A few wells in the area remain to be tested.

GEOLOGY.

Detailed descriptions of the lava flows in Oregon are contained in publications by I. C. Russell, Waring, Washburne, Buwalda, R. J. Russell, Piper, Kirkham, and others (1). The following general description of the geology of the region has been kindly prepared for me by Dr. Eugene Callaghan, of the United States Geological Survey:

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[1] Approved for publication by the Director of the U. S. Geological Survey.

"The rocks are chiefly flows of basalts, andesites, and rhyolite interbedded with stratified volcanic tuffs and other volcanic ejecta which form porous beds of great thickness. Many of the lava flows spread out over wide areas, and successions of flows, together with layers of volcanic ejecta give the rocks of the region a stratified appearance. The basaltic layers tend to be glassy, compact and non-porous so that water does not readily pass through them. Some of the rhyolites are more porous, but the fragmental beds are by far the most porous.

Sedimentary rocks associated with volcanic rocks include conglomerate, sandstone, shale, clay, sand, and gravel, probably largely made up of igneous materials. Some of these strata contain fossil plants as well as vertebrate and invertebrate fossils. The age of the flows and associated sedimentary rocks has been determined as ranging from Miocene to the recent. Probably a large part of these rocks belong to the Pliocene.

In a broad way the geologic structure of this plateau region is relatively simple. There has been almost no folding but faults are numerous. The most prominent faults trend in a northerly direction as a continuation of the Basin-range type of faulting. Some blocks or parts of blocks have been uplifted above the general plateau surface, whereas others have been depressed to form the basins, many of which have been at one time or another occupied by lakes. Most of the uplifted blocks have been tilted, one side rising higher than the other, or one side even being depressed. Angles of dip are mostly less than 15°. Probably most of this movement took place before the latter part of the Pleistocene epoch, as the summits of high mountains such as the Steens Mountain, have been glaciated."

While this paper was being prepared for publication, Mr. Walter West, Klamath Falls, Oregon, kindly forwarded samples from an outcrop in a ravine about 12 miles from the Bonanza well (Fig. 6). Dr. J. B. Reeside, Jr., U. S. Geological Survey, reports that "the samples contain shells in a yellowish sandy matrix which are fragments of a gastropod close to *Amnicola* and of another belonging to the genus *Lanx*. Both are fresh water forms and probably of Tertiary age. No closer determination can be made."

Mr. West also forwarded about 60 churn drill samples from the Bonanza well (Fig. 6). Mr. Charles Milton, of the U. S. Geological Survey, on the basis of a preliminary examination of the samples states that the cuttings representing the formations drilled to a depth of 4365 feet, are all of basaltic lava.

SPRINGS.

In the course of making geothermal surveys in deep wells, tests were made also in a few springs and flowing wells that happened to be near at hand. The results of the tests in springs at Lakeview and Klamath Falls are tabulated in the accompanying table.

TABLE 1.

Temperatures in springs at Lakeview and Klamath Falls.

Name	*Town*	*Temperature* ° *F.*	° *C.*	*Remarks*
Hunter	Lakeview	196.3	91.3	3 miles north of Lakeview
Joyland Plunge	"	158.9	70.5	2½ miles south of Lakeview
Barry Farm	"	185.5	85.4	2½ miles south of Lakeview
Barry Farm	"	190.6	88.1	2½ miles south of Lakeview
None	Klamath Falls	187.6	86.4	100 feet north of White Pelican Hotel
Devil's Tea Pot	" "	182.9	83.9	East edge of town
Turner (Bonanza)	" "	149.5	65.3	W ½ NW ¼ sec. 10, T. 40 S., R. 13 E.

The thermometers were lowered to a depth of about five feet in Hunter's spring. The recorded temperatures for the remaining springs are too low as it was either impossible to lower the thermometers into the small vents from which the discharge occurred, or, the water was discharged into a large pool of much lower temperature than that of the spring water itself. Waring (1 d, page 45) records a temperature of 173° F. in three hot springs in the eastern edge of Goose Lake near Lakeview. Whether or not these three springs are the Joyland Plunge and the two springs on the Barry farm cannot be determined from his description of them.

FLOWING WELLS.

Table 2 contains the temperatures recorded in six flowing wells at Vale, Lakeview, Klamath Falls, and Bonanza.

TABLE 2. Temperatures of flowing wells.

Name	*Town*	*Temperature* ° *F.*	° *C.*	*Remarks*
Vale Naturium	Vale	199.5	93.1	300 feet from south bank of Malheur River; 400 feet from Malheur County State Bridge.
Vale Sanitarium	Vale	201.6	94.2	1000 feet east from Naturium; ¼ mile east from Malheur State Bridge.
None	Lakeview	199.5	93.1	Depth 5 feet. Near Hunter's Hotel.
None	Lakeview	199.8	93.2	Depth 7 feet. Same well.
Spring House	Lakeview	208.8	98.2	Cemented. Outlet about 5 feet above level of ground.
None	Klamath Falls	127.2	52.9	On three-cornered lot between Main and Division Streets.
None (Bonanza)	Klamath Falls	149.1	65.1	Depth 16 feet. 150 feet from Turner's Spring. W ½ NW ¼ sec. 10, T. 40 S., R. 13 E.

The two flowing wells at Vale are near the base of a basalt ridge. Each well is about 60 feet deep. On account of long discharge pipes, the observed temperature readings are too low.

The Lakeview wells are near the springs just described, about three miles north of the town. These wells are reported to have flowed as geysers and steam wells from a depth of about 300 feet. For several years past, one of the wells, Fig. 1, has discharged into the air to a height of 60 feet or more above the level of the ground. As the well is in the center of a large pool of water, accurate temperature readings were not attempted.

Agreement of the temperature in Turner's spring (149.5) with the temperature in the flowing well (149.1) at a distance of only 150 feet is to be expected, as the depth to the water bed is only 16 feet.

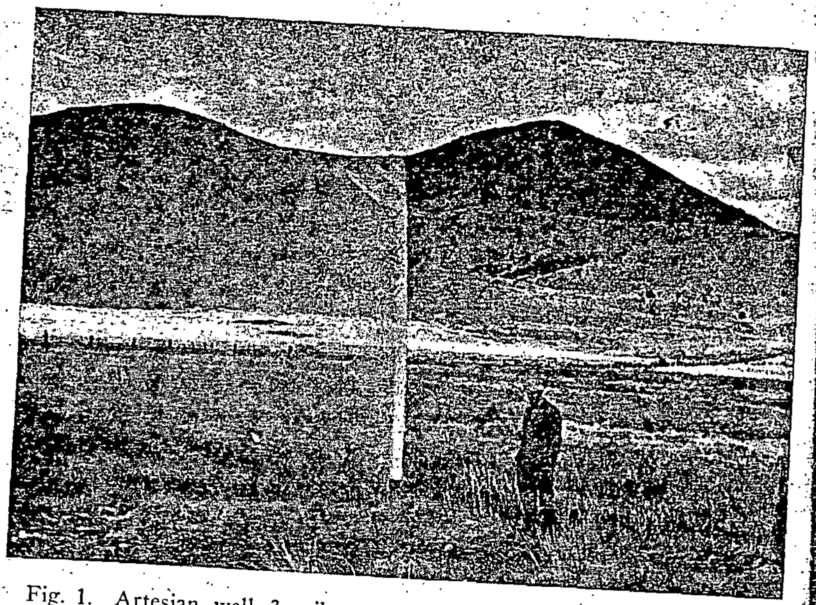

Fig. 1. Artesian well 3 miles north of Lakeview, Oregon. Photo by H. T. Stearns, Sept. 2, 1925.

In Table 3, the elevations have been taken from the volume on Climatological Data of the U. S. Weather Bureau, and the corresponding boiling point temperatures at that elevation have been interpolated from a table of my own (2). The interpolations show that the temperature of the water in the Spring House well is probably a few degrees above the boiling point at that elevation.

TABLE 3. Boiling point temperatures.

Location	*Elevation*		*Temperature*	
	Feet	*Meters*	° *F.*	° *C.*
Vale	2,234	681	208	97.8
Klamath Falls	4,100	1,250	204-205	95.6-96.1
Lakeview	4,950	1,509	203	95.0

NON-FLOWING WELLS.

In areas of thick sediments, the depth-temperature curves are usually smooth and uniform, showing a slight increase

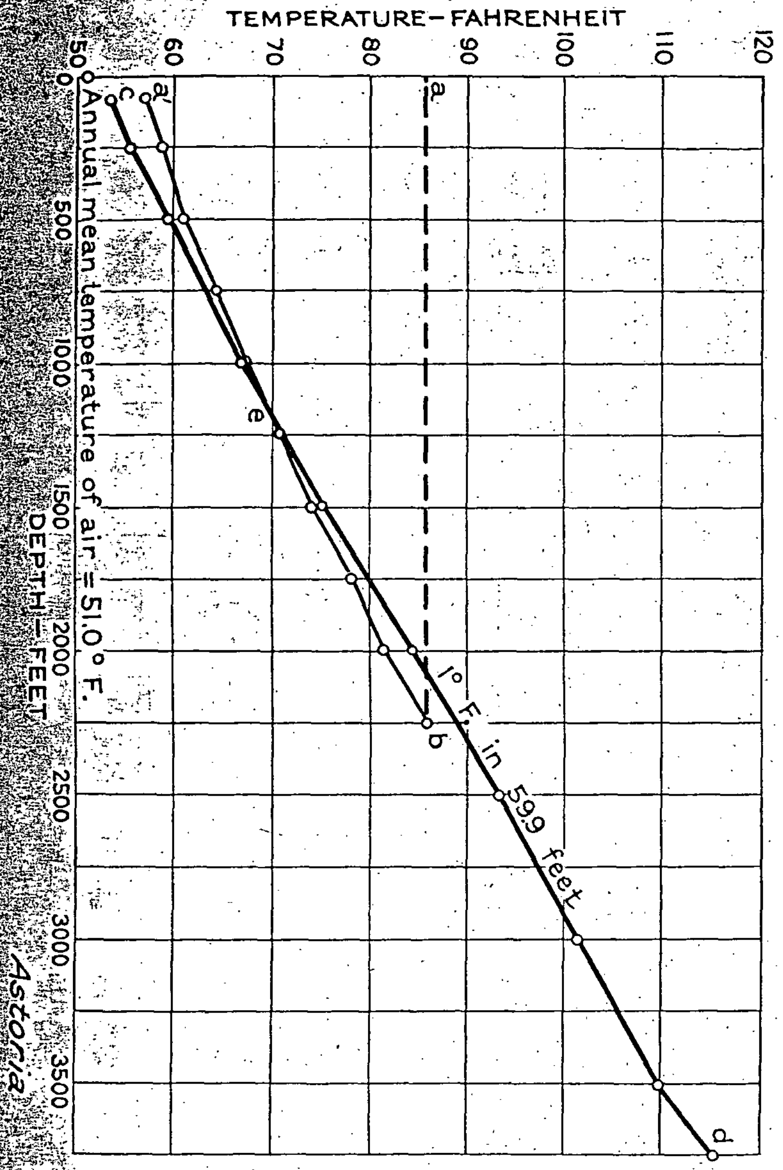

Fig. 2. Lower Columbia Oil and Gas Company. Chew Ranch No. 1. Sec. 25, T.8N., R.10W., Clatsop County, Oregon. (Astoria.) a'eb. Small flow of gas through water. Observations made in the Summer of 1921. Depth a little more than 2250 feet. ced. No gas. True rock temperature curve. Observations made in the Summer of 1922. ab. Upper limit of temperature in the flowing well.

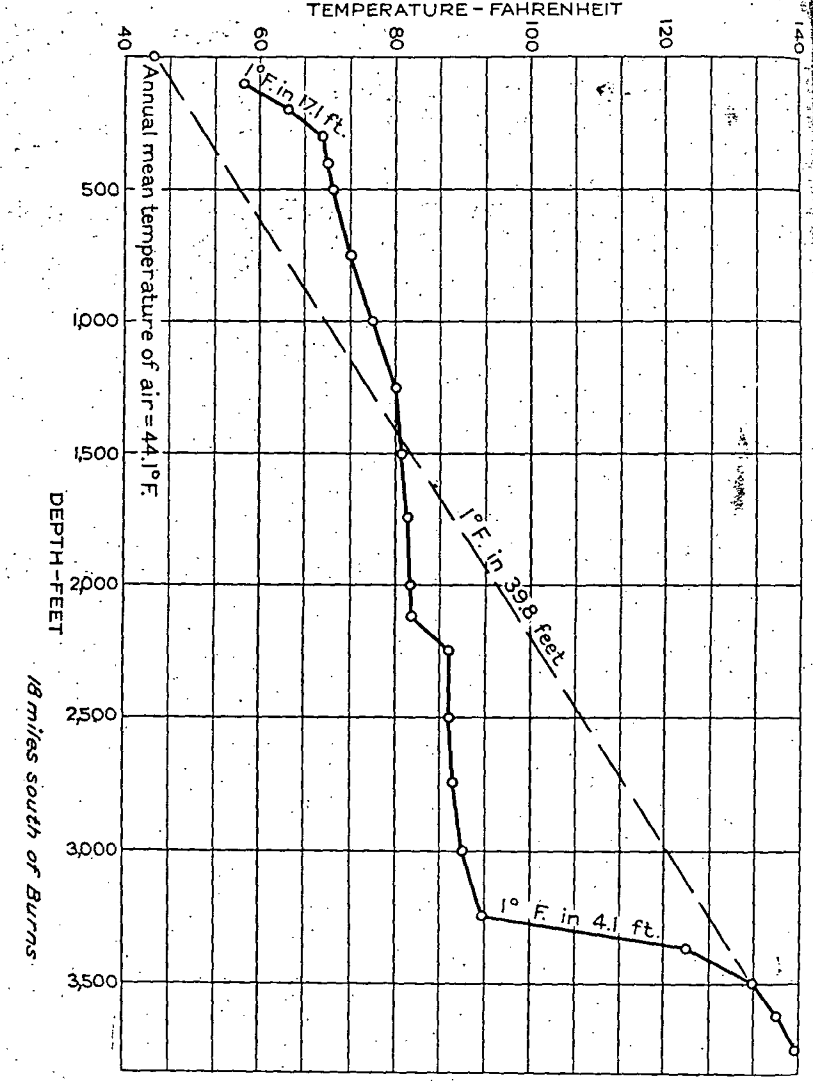

Fig. 3. Central Oregon Oil and Gas Company. U. S. Government Land No. 1. Sec. 19, T.26S., R.30E., Harney County, Oregon. (Burns.)

in the gradient as the depth increases; that is, the curves are convex toward the depth-axis as shown by curve (cd), Fig. 2. In the lava flows of Oregon, however, where observations have been made, the curves are smooth and uniform for short distances only; in general, they are characterized by very abrupt changes in the vertical, resembling a series of steps in which very flat and very steep segments of the curve intersect sharply at a point. Curves of this kind are shown in Figs. 3, 4, 5, 6, and 7. Curves 8, 9A, 9B, and 11 represent curves of the uniform type over the short distances represented by the observations.

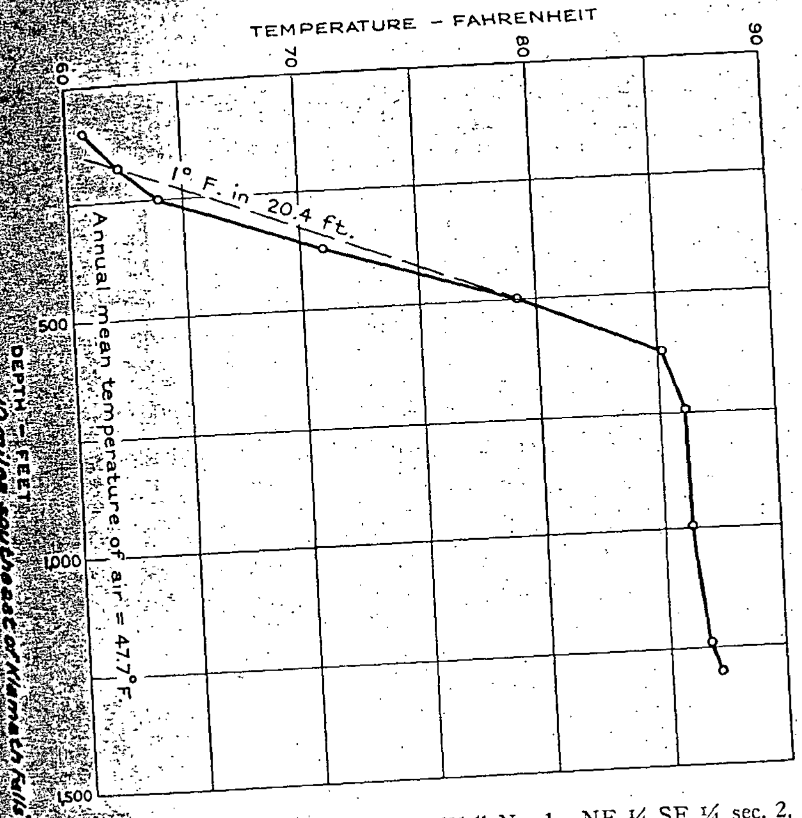

Fig. 4. Klamath Falls Oil Company. Well No. 1. NE ¼ SE ¼ sec. 2, T.40S., R.10E., Klamath County, Oregon. (Klamath Falls.)

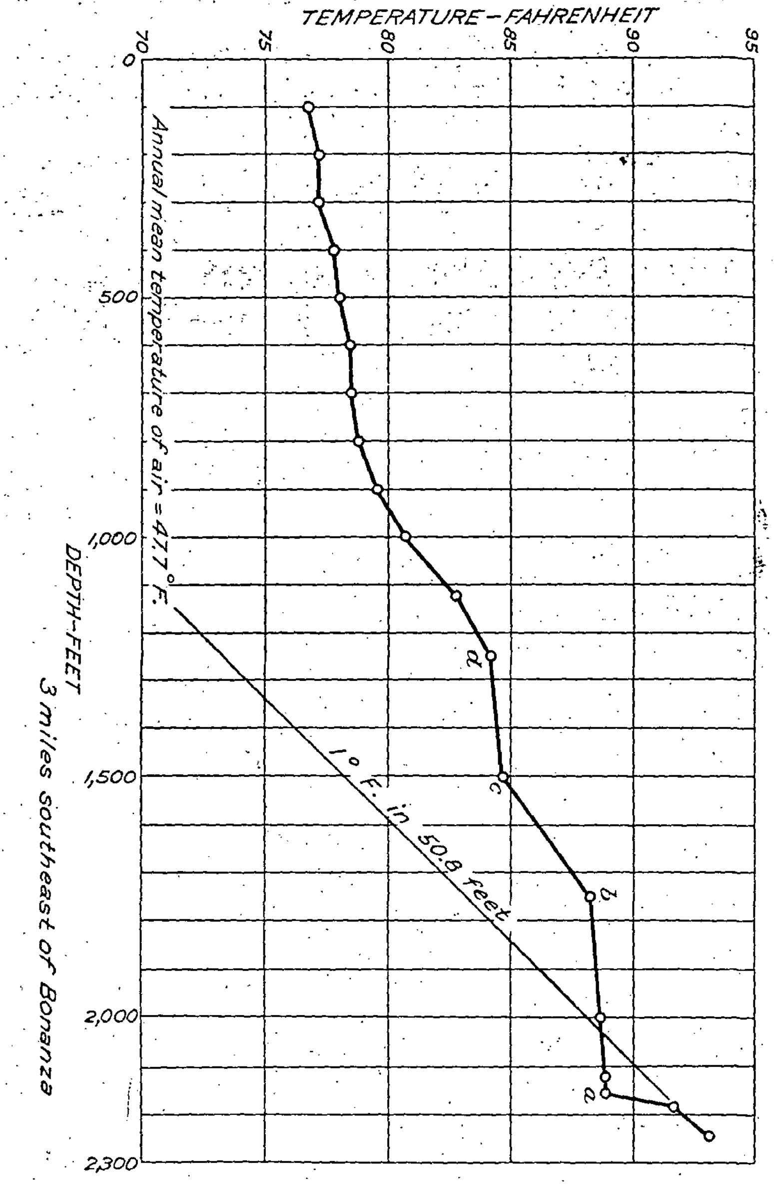

Fig. 5. Yonna Valley No. 1. SW ¼ NW ¼ sec. 13, T.39S., R.11E., Klamath County, Oregon. (Klamath Falls-Bonanza.) About 100 feet from ridge of basalt. 1200 feet of 8 inch casing. Flowing water reported to come from 1300 feet.

The well near Vale, Fig. 8, penetrates infusorial earth at the surface. This depth-temperature curve is slightly concave, but each of the other curves, Figs. 9A, 9B, and 11, particularly the last, shows the usual convexity found in wells in thick sedimentary deposits. Extension of the curves would probably

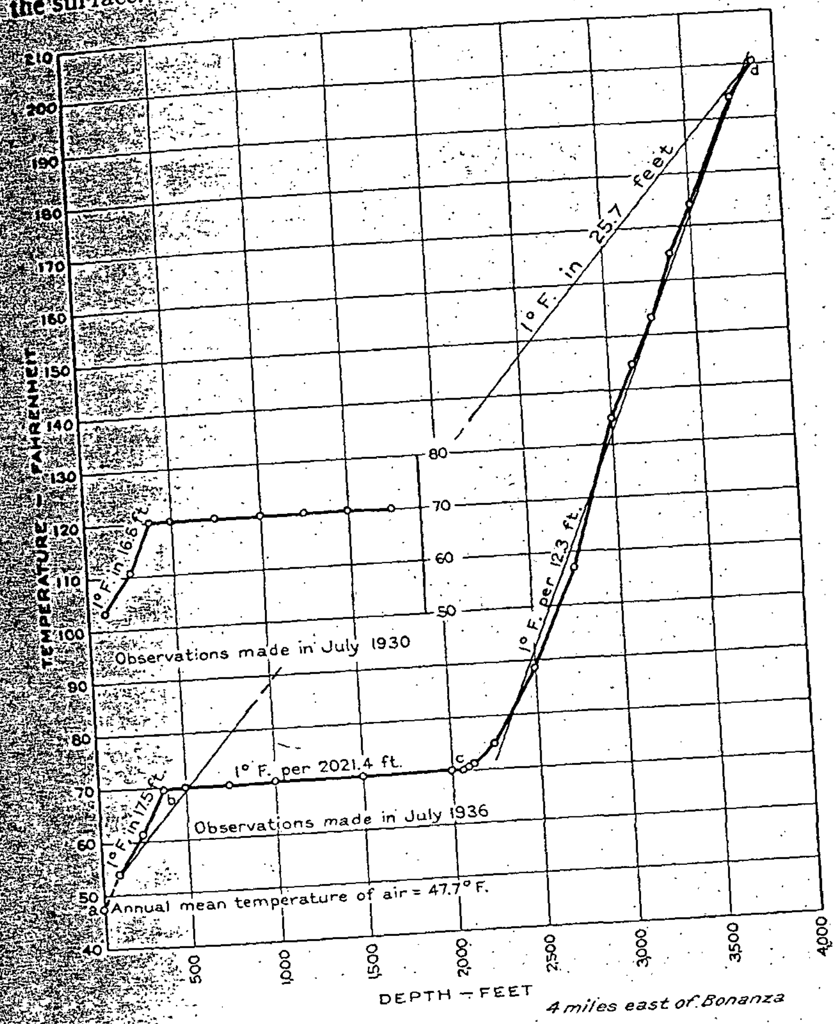

Fig. 6. The Langell Valley Oil Company. Well No. 1. NE corner, SW ¼ NE ¼, sec. 19, T.39S., R.12E., Klamath County, Oregon. (Bonanza.)

reveal abrupt changes in trend similar to those found in the deeper wells. Curve 10 represents the temperatures in a flowing well. The lower part of Curve 5 represents true rock temperatures, but, from 1300 feet to the surface, the temperatures of the rocks are obliterated by the flowing water.

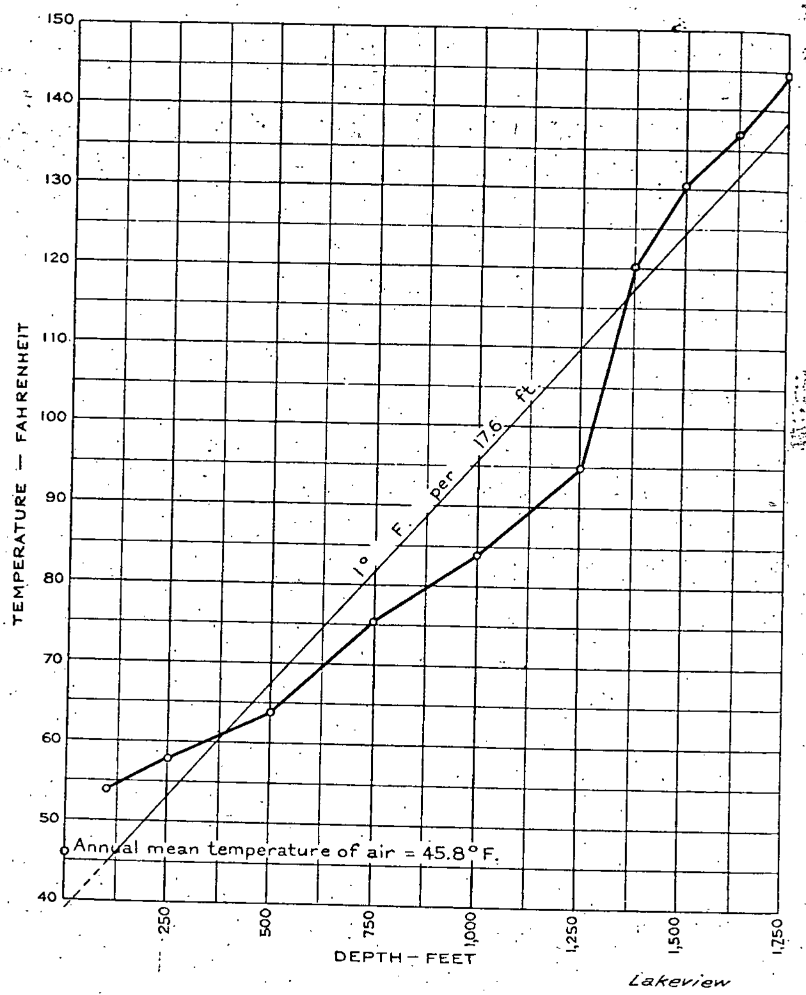

Fig. 7. Lakeview City well. In mouth of Bullard Canyon, Lakeview, Lake County, Oregon.

A question arises in regard to the extent of the horizontal area represented by an individual curve. On account of the great distances between the wells, it is difficult to make a comparison between them; however, Piper, Robinson, and Park, Jr., (1j) have made valuable progress in correlating water beds in Harney County with the steps in the depth-temperature curve of the Burns well (Fig. 3).

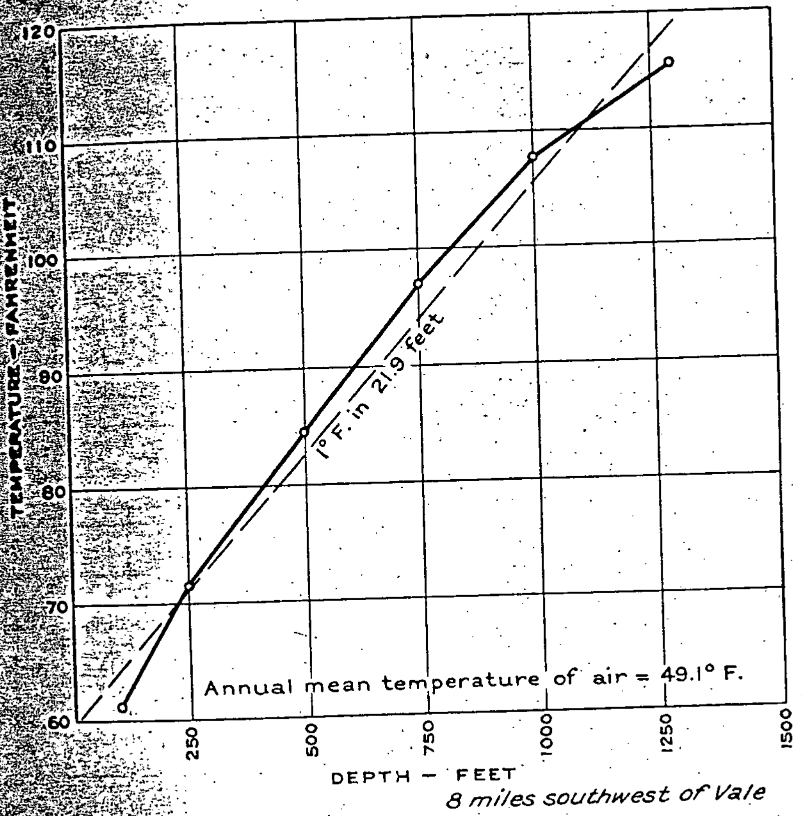

Fig. 8. Western Pacific Oil and Gas Company. Well No. 1. Sec. 19, T.19S., R.44E., Malheur County, Oregon. (Vale.)

Although not definitely known, it seems reasonable to interpret the segments of abrupt rise in the depth-temperature curve of the Burns well as being due to dense basalt, or compact clay, which is almost impervious to water while the flat portions of the curve, on the other hand, represent volcanic tuff or rhyolite which is sufficiently porous to permit of convection currents. Curves 4, 5, and 6 are additional remarkable examples of this type of lava bed structure. Alternative explanations are (1) convection currents limited to the well itself and (2) entrance of water into the well at one level and exit at another level. The hypothesis that the abrupt rise in the curves is due to dense basalt or compact clay seems to me the most probable. In fact, it is difficult to interpret the steps in the Yonna Valley curve, Fig. 5, in any other way, for it is improbable that there are two or more series of beds in the same well in which water enters the well in one stratum of the series and leaves at another stratum of the same series, as for example, that water should enter the well at (a) and leave at (b), and again, that water should enter at (c) and leave at (d) and so on; or, that water should enter the well in strata (a b) and leave in strata (c d). On the other hand, a horizontal movement of the water that tends to increase

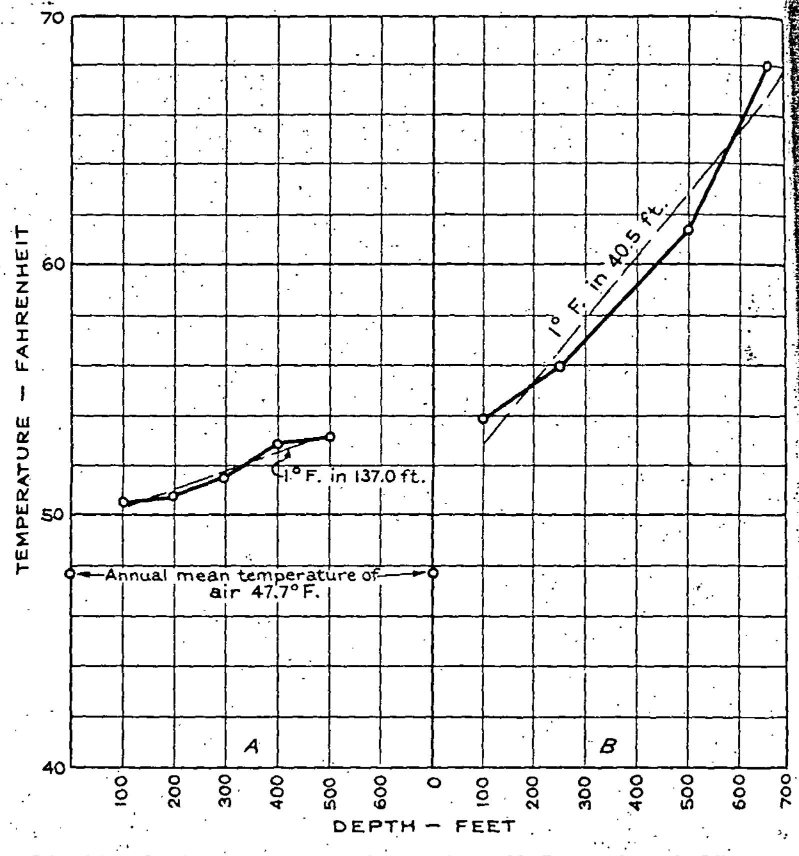

Fig. 9A. Oakland Well. NE ¼ SW ¼ sec. 19, T.38S., R.11E., Klamath County, Oregon. (Klamath Falls-Bonanza.)

Fig. 9B. The Crater Oil and Gas Co. Well No. 1. Klamath County, Oregon. (Near Merrill.)

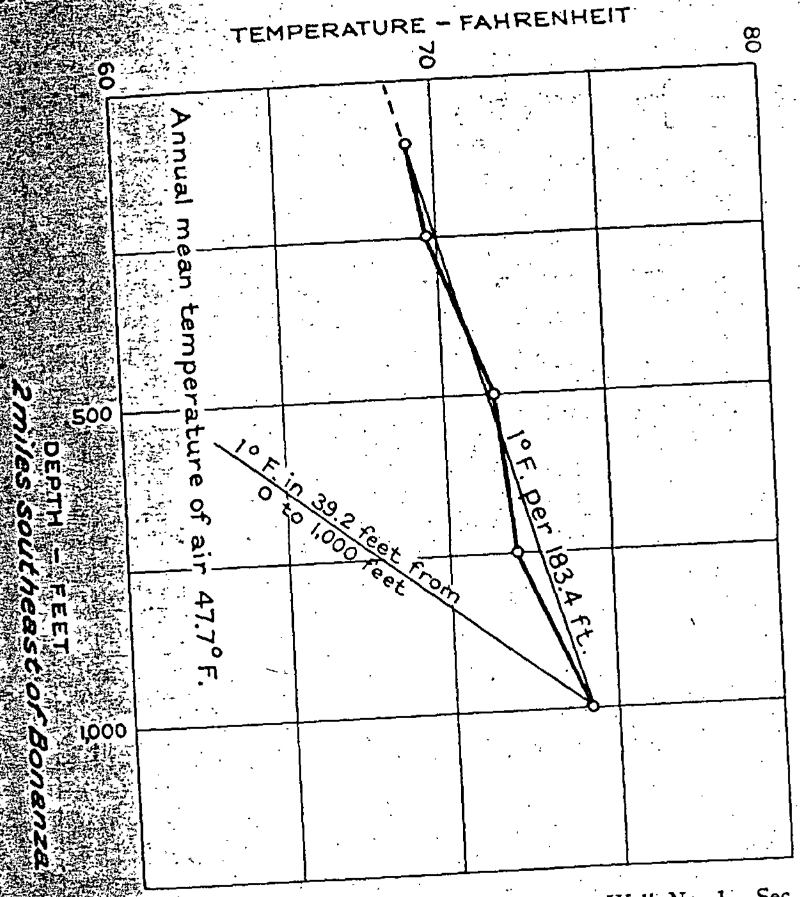

Fig. 10. The Yonna Valley Oil and Gas Company. Well No. 1. Sec. 14, T.39S., R.11½E., Klamath County, Oregon. (Dairy.) Near base of basalt ridge. Flowing well. Water reported to come from 550 and 935 feet.

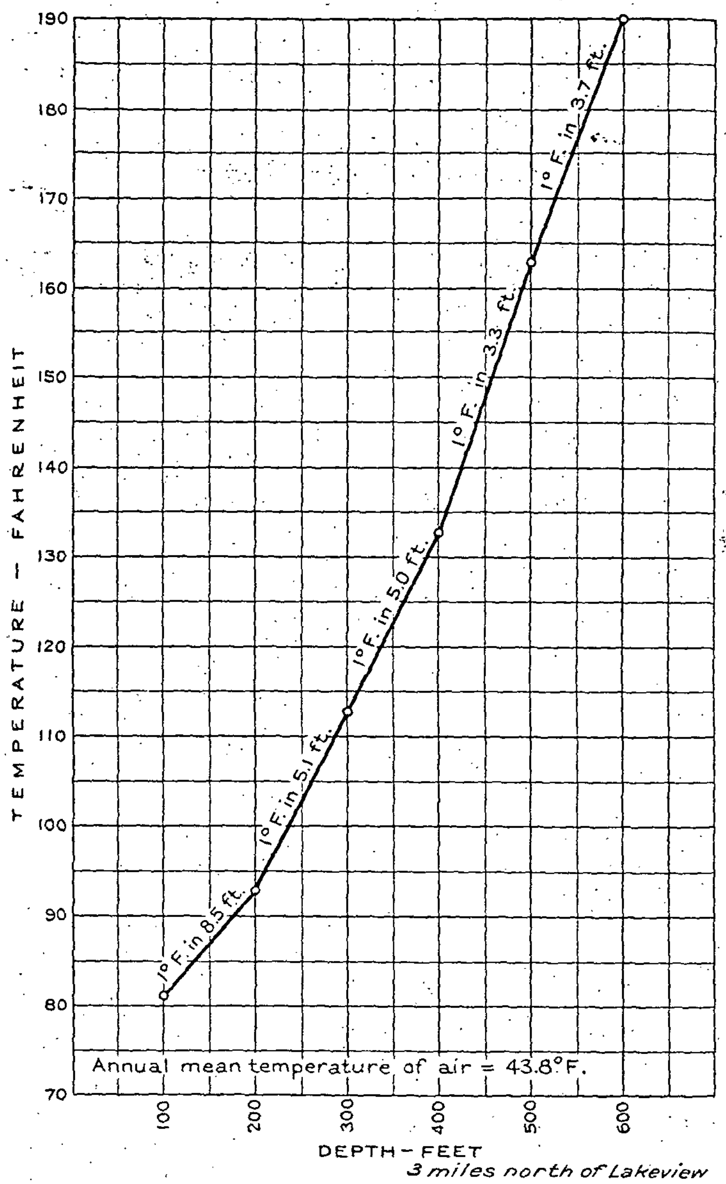

Fig. 11. H. A. Utley deep well. About 3 miles north of Lakeview, Lake County, Oregon. See Fig. 13.

convection currents within the beds is an important possibility; and, furthermore, flat segments of the kind found in the lava bed temperature curves have never been found in sedimentary rocks except in two or three instances in which it is practically a certainty that the wells penetrated water beds having a thickness of something like 100 or 150 feet.

Another striking feature of some of the lava-bed types of curve is to be noted. On each figure, where possible, there has been plotted the annual mean temperature of the air interpolated from the volume of Climatological Data of the U. S. Weather Bureau. Extension of the curves of Figs. 3, 6, 7, 8, 9A, 9B, backward until they intersect the line of zero depth so as to obtain the annual mean temperature of the rock just beneath the surface of the ground shows that the temperatures of the surface rocks have been gradually reduced from the temperature of molten rock (approximately 1000° C., 1832° F.) to a temperature that approximates closely to the annual mean temperature of the air for the locality. Curve 5 is an exception. Here the flowing water, possibly from a depth of about 1300 feet, heats the upper part of the well to such an extent that the excess of water temperature at the mouth of the well over annual mean air temperature amounts to about 30° F. instead of the usual difference varying from about 1 to 3 or 4° Fahrenheit. Likewise, flows of water that are reported to come from depths of 550 and 935 feet cause an increase of about 18° F. at the mouth of the Dairy well, Fig. 10. Another marked exception is to be found in the Lakeview well, Fig. 11. Here the difference amounts to something like 20° F., and as this well is not a flowing well, it shows clearly, even at a depth of 100 feet, that the well is located in a high temperature area. This important fact could have been discovered by making temperature tests in shallow wells at depths, possibly not exceeding five or ten feet.

In the Bonanza well, Fig. 6, there is an interval of 1750 feet, from 375 to 2125 feet, throughout which the temperature rises at the extraordinary rate of only 1° F. in 2021 feet. That this peculiar temperature distribution is not an accidental result is shown by comparison of the two sets of observations, the first of which was made in July, 1930, when the well had reached a depth of a little more than 1750 feet, while the second set of observations was made six years later after approximately 2100 feet had been added to the depth of the well.

When the Bonanza well had reached a depth of 3870 feet, the accumulated gas flow was sufficient to permit of burning while the bailer was being removed from the upper part of the well. The sharp angular trends in the depth-temperature curve prove conclusively that this gas did not sensibly affect the temperature in the upper levels of the well. Water has been standing in this well at a depth of about 15 feet for a period of more than six years.

Kirkham (1 k) believes that the gases in the lava beds result from decomposition of organic matter in thin sedimentary strata of lake bed origin. His conclusions are based on analyses of gases from the Rattlesnake Hills area near Benton City, Washington, and the Weiser-Payette area in western Idaho. Typical analyses from the latter area are as follows:

	Percentages			
Carbon dioxide	1.11	0.2	4.63	2.05
Oxygen	0.08	0.4	0.13	0.16
Methane	72.9	72.4	67.62	0.00
Ethane	25.18	26.9	12.21	1.41
Nitrogen	0.01	0.1	15.41	96.38

Some of the analyses showed a trace of helium. In the Rattlesnake Hills area the highest known percentages of gaseous constituents were methane, 95.77; ethane, 13.1; nitrogen, 21.8; oxygen, 3.4; and carbon dioxide, 2.6 per cent.

HYPOTHETICAL SOURCES OF HEAT AND WATER IN HOT SPRING AREAS.

The hypothesis that the heat source of many hot spring areas has its origin in gaseous emanations, chiefly superheated steam exhaled from intrusives at unknown depths, is elaborated in great detail by Doctors Allen, Day, and Fenner[3] in the reports of their extensive researches on hot springs and geysers in California and Wyoming. Fundamental among their conclusions are the following:

1. Superheated magmatic steam prevents water from either the upper or lower levels from coming into contact with the hot magma (3, pages 507, 508, . . . ; 3b, page 90 . . . ; 3c, pages 225, 311; 3e).

2. Steam superheated at the surface has remained superheated throughout its passage from the magma to the surface (3, page 39).

3. Heat cannot be supplied in sufficient quantities by conduction through the rocks (3, pages 40-42, 507, . . .).

4. Certain volcanic substances, chiefly arsenic and boron, besides carbon dioxide, hydrogen, methane, nitrogen, argon, and less frequently, hydrogen sulphide, characterize the emanations from hot magmas (3, foot-note page 32; pages 38, 91, 507, . . .; 3d, page 95).

That these conditions are to be found in intruded areas of comparatively recent date, the Valley of Ten Thousand Smokes, for example, cannot be denied; nor, can it be denied that, in the course of time, the discharge of water cannot be continued other than by means of hydrostatic pressure and gas pressure. The effect on the temperatures caused by a very small flow of gas, just sufficient to lift the water over the top of the casing, is illustrated by the two depth-temperature curves of the Astoria well, Fig. 2. One point only on the true depth-temperature curve (c d) remains unchanged: below this point (e) the effects of expansion exceed the effects of the movement of the fluids in the well, but above this point, the conditions are reversed and the observed temperatures of the moving fluids are too high.

Taking into account all of the factors of the problem considered in the preceding discussion, it seems to me that three periods of development which may overlap one another, more or less, are possible:

1. High pressure superheated magmatic steam that reaches the surface as superheated steam.

2. High pressure superheated magmatic steam that is converted into water in transit to the surface; and, possibly, also, high pressure-temperature water direct from the magma. The latter hypothesis is a controverted question at the present time.[4]

3. Conduction of heat through magmas and adjacent rocks.

Fig. 6 serves to illustrate the first case. Disregarding the plotted depths and temperatures, the line (c d) can be assumed to represent the temperature in a magma from which superheated steam at high pressure is escaping into porous or fractured rocks (b c) above the magma. The strata (b c) can be several hundred feet in thickness, and, as shown in Fig. 6, in extreme cases, that segment of the depth-temperature curve

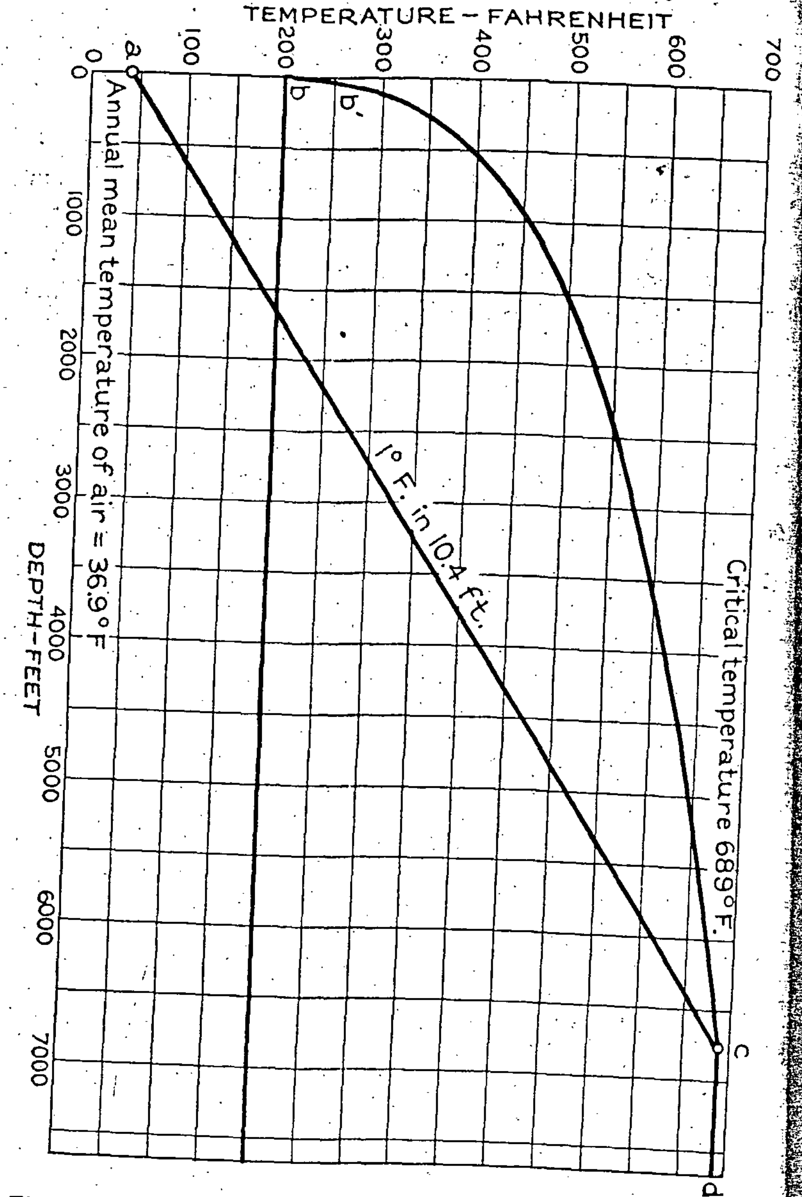

Fig. 12. Theoretical boiling point and depth of water column for an assumed boiling temperature of 200° F. (93.3° C.) at a ground elevation of 6632 feet (2021 meters). (Reference 2. Pages 203 and 223.)

represented by (b c) may be almost parallel to the depth axis. The line (a b) represents the temperature in a stratum of moderate thickness in which the temperatures may increase very rapidly. These strata may carry seepage water from the surface drainage and they may carry also water beds whose intakes are at remote distances from the hot spring area. Both super-heated and saturated steam, carrying both meteoric and juvenile waters are assumed to escape through various conduits in these strata.

In the second period of development, the water is brought to the surface through changes in density, the lifting power of a small volume of gas, and hydrostatic pressure which seems to be a possibility in many hot spring areas. The ascending waters would be converted into steam when the temperature and pressure in the water column are represented by a point above the line bb'cd, Fig. 12. The activity of the hot waters would be greatly accentuated by release at depth into a cavern, or at the surface, if the hydrostatic head (or steam pressure) is greater than that represented by a column of water just reaching to the surface of the ground. Much of the sputtering observed in many springs is apparently due to a release from only a few feet of head, or a few pounds of steam pressure. This reduction in head and steam pressure is apparently the result of clogged passage ways. Reference to Fig. 12 shows that the temperature near the surface of the ground rises very rapidly for small changes in head, so it is to be expected that the temperature of the escaping fluid would be a few degrees above the boiling point of water at that elevation. The excess of fluid temperature at the mouth of a well (or the surface of a spring) over the boiling point temperature at that elevation depends, among other things, on the velocity of discharge. Experiment shows that the excess temperature depends also on the rate at which heat is supplied to the boiling water. The latter phenomenon is known as superheat.[5]

Stage 3 represents the last step in the history of hot spring activity. A flow resulting from differences in density, possibly no gas or at most only a very small flow of gas, and hydrostatic pressure would continue the process until the temperature of the escaping spring water is reduced to its minimum value, that is, the annual mean temperature of the air at the location. In the early part of stage 3, water in transit to the surface of the ground might be converted into steam by release of pressure as in Case 2.

POSSIBLE SOURCES OF HEAT AND WATER IN THE LAVA-BEDS OF SOUTHEASTERN OREGON.

The H. A. Utley well, Fig. 11, is located on the mountain side at an estimated elevation of 500 or 600 feet above the level of Goose Lake plain, d, Figs. 13 and 14. Water is standing in the well at a depth of 190 feet from the surface of the ground. The top of the casing stands at the level of the ground, so that surface drainage is a possibility. The other wells together with the springs are located on Goose Lake plain as shown at a, b, c in Figs. 13 and 14. These wells are reported to have a depth of 300 feet.

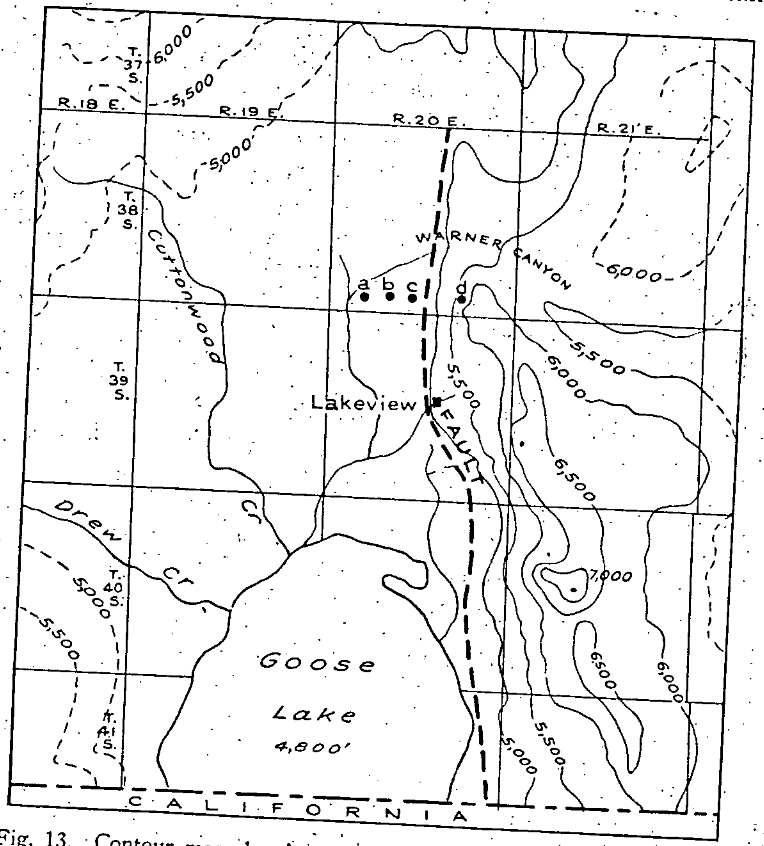

Fig. 13. Contour map showing approximate location of wells and springs north of Lakeview. (Waring Id.)

The relation of the H. A. Utley well to the wells and springs in the Goose Lake valley suggests a hydrostatic system which has its origin in the mountain ridge and its storage reservoir beneath a clay bed or some other compact stratum at a depth of about 300 feet beneath the level of Goose Lake plain. Extension of the depth-temperature curve of the Utley well to the level of the water bed beneath the plain, a distance of

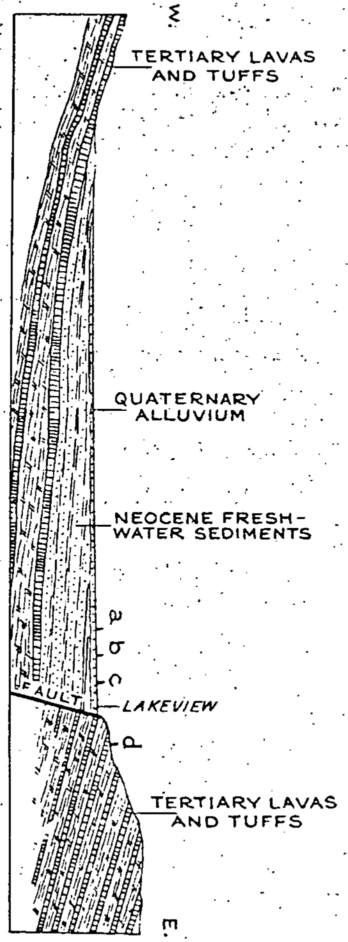

Fig. 14. Generalized sketch section from west to east through Lakeview, Oregon. Distance about 15 miles. Vertical scale greatly exaggerated. (Buwalda, lg. Page 34.)

about 300 feet, shows that the water at this depth may have a temperature of possibly 280 or 300° F., hence, there seems to be nothing inconsistent in the hypothesis that both the heat and the water have their origin, chiefly, in the mountain ridge; unless perhaps the fault shown in Figs. 13 and 14 should prevent the flow of hot water from the base of the mountain to the water bed beneath the plain. Waring, however, did not consider it probable that the fault would interfere with the movement of the water. Instead, he held the view that several hot springs along the eastern side of the Goose Lake basin are supplied by water that rises along the fault; and, taking into account the facts of evaporation and water supply, he concludes that Goose Lake itself is supplied largely from this underground source. However, Doctor Callaghan informs me that the lake has evidently gone dry several times according to local reports, so that the lake level must be to a large extent dependent on run-off.

If the heat source is the lava beds immediately beneath the hot springs and flowing wells, the depth-temperature curve of the Lakeview City well, Fig. 7, three miles to the south and located at the entrance of Bullard Canyon into the Goose Lake basin, shows that a temperature of 240° F. would probably be reached at a depth of 3500 or 4000 feet. Assuming a moderately rapid rise of the water to the surface of the ground as a result chiefly of hydrostatic flow, possibly along the fault plane, a heat source of this kind would be sufficient to explain the comparatively small discharge of hot water from the Lakeview wells and springs. Other hypotheses consist in assuming that heat is obtained by conduction, by exudation of high-temperature water, or by exhalation of superheated steam from a shallow or deep-seated intrusive within the lava beds themselves.

SOME FINAL CONSIDERATIONS.

A final and definite decision in regard to the source of the heat and water in the wells and springs of southeastern Oregon does not seem to be possible at present. As ordinary chemical analyses do not reveal the presence of magmatic water in a sample, it is hardly to be expected that such analyses, if made, would add very much to our information on the subject. The same is true of analyses of gas samples. An analysis would probably show a rather high percentage of methane, as was actually found by the U. S. Bureau of Mines (1 g, page 35) in the Carter well about nine miles southwest of Lakeview. The depth of the well was 370 feet, about the same as those at Lakeview. This analysis shows a methane content of 73.5 per cent, which, however, is believed to be of organic rather than magmatic origin.

The hypothesis that the hot water is obtained by percolation to lower levels through the mountain mass is confronted with the fact that the strata incline away from the Goose Lake plain (Fig. 14). This difficulty, however, is not insurmountable, for fractures in the strata would permit the water to flow toward the plain.

Residual heat from the lava beds in the plain is another possibility.

Exceptionally hot spots like that at Lakeview may be due perhaps to unequal cooling of the lava flows or to intrusives that have penetrated the lava beds either beneath or adjacent to the high-temperature area.

REFERENCES.

1. Russell, I. C.: A geological reconnaissance in southern Oregon. U. S. G. S. Fourth Ann. Rept., 431-464, 1882-3.

a. ————: Notes on the geology of southwestern Idaho and southeastern Oregon. U. S. G. S. Bull. 217, 1903.

b. ————: Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon. U. S. G. S. Water Supply and Irrigation Paper 78, 1903.

c. ————: Preliminary report on the geology and water resources of central Oregon. U. S. G. S. Bull. 252, 1905.

d. Waring, G. A.: Geology and water resources of a portion of south-central Oregon. U. S. G. S. Water Supply Paper 220, 1908.

e. ————: Geology and water resources of the Harney Basin region, Oregon. U. S. G. S. Water Supply Paper 231, 1909.

f. Washburne, C. W.: Gas and oil prospects near Vale, Oregon, and Payette, Idaho. U. S. G. S. Bull. 431, 26-55, 1909.

g. Buwalda, J. P.: Report on oil and gas possibilites of eastern Oregon. The Mineral Resources of Oregon. The Oregon Bureau of Mines, 3, 3-47, July 1921.

h. Gilbert, G. K.: Studies of Basin-Range structure. U. S. G. S. Prof. Paper 153, 1928.

i. Russell, R. J.: Basin Range structure and stratigraphy of the Warner Range northeastern California. Calif. Univ., Dept. Geol. Sciences, Bull. 17, 387-496, Nov. 8, 1928.

j. Piper, A. M., and Robinson, T. W.: Ground water for irrigation in the Harney Basin, Oregon. U. S. G. S. Press Notice 55497. Aug. 11, 1931.

Piper, A. M., Robinson, T. W., and Park, Jr., C. F.: Geology and ground-water resources of the Harney Basin, Oregon. U. S. G. S. In the press.