SNAKE RIVER DOWNWARP[1]

VIRGIL R. D. KIRKHAM
Saginaw, Michigan

ABSTRACT

The history of the idea of subsidence and warping and the development of the idea of geosynclines and downwarps is reviewed, and a suggestion as to classification and definition of subsiding areas is made. Next is presented a review of the widely differing concepts held by many workers concerning the origin of the great arc-shaped depression called the Snake River plain which sweeps across the entire width of Idaho. The writer has accumulated evidence over a period of years which indicates clearly that the depression is a downwarp formed by gentle and very gradual subsidence. This great structure attains especial significance because it does not parallel the grain of the continent or the Rocky Mountain system, but, to the contrary, crosses the latter almost normal to its axis.

INTRODUCTION

The data and conclusions presented in the following pages are results of field work undertaken for the Idaho Bureau of Mines and Geology in executing economic investigations. The writer spent eight weeks of field work on parts of the area in 1920 and the main regional, stratigraphic, and structural implications were gained at that time. These were amply confirmed by subsequent more detailed work which constituted a week's work in November, 1921, a week's work in 1926, and four weeks in 1927. Finally, the earlier results were enriched and amplified by twelve weeks of detailed work on the map area in 1928. The bulk of the material presented herein has thus been under consideration by the writer for ten years.

ACKNOWLEDGMENTS

The writer acknowledges with appreciation aid from the Idaho Bureau of Mines and Geology which financed the field work for this paper. Courtesies also were extended the writer by Dr. Francis A. Thomson, president of the Montana School of Mines, former secretary of the Idaho Bureau of Mines and Geology; and Messrs. E. W. Ellis, A. W. Fahrenwald, and J. W. Finch who have since served as secretaries of that organization. Thanks are due also to several members of the Department of Geology, University of Chicago, for valu-

[1] This work was done in co-operation with the Idaho Bureau of Mines and Geology, and the results are published with the permission of the secretary.

able counsel and a careful reading and criticism of this manuscript. Able assistance was given in the field by Messrs. M. Melville Johnson, H. L. McKinley, and Clarence F. Myrene.

THE SNAKE RIVER DOWNWARP

This great structural depression extends in a broad crescent across southern Idaho from Yellowstone National Park to the map area of this report, which it crosses, and extends thence into Oregon for a distance of at least 25 miles (See Fig. 1). The name "Snake River Downwarp" was originally assigned to this depression by the writer[1] in January, 1927. Inasmuch as the origin of this great structural depression has been a matter of controversy for several years, a brief review of the ideas commonly held concerning downwarping are presented in the following pages, before presenting the evidence for considering this particular depression as a typical downwarp.

HISTORY OF THE "DOWNWARP" IDEA[2]

Strabo (born in 65 B.C.) appears to have first offered the idea that the lands have sunk and risen, assigning to vulcanism a large rôle in these movements. Celsius, in 1743, decided that areas in Scandinavia were subsiding. Although the idea was strongly opposed by many, Linnaeus supported him. When Leopold von Buch entered the lists, in 1802–07, supporting the idea by strong evidence, it became an orthodox conception. Von Buch apparently deserves the credit for establishing the idea of secular upheaval and subsidence. Bruslak, in 1803, argued that the Bay of Naples had subsided, and Prevost advanced evidence for crustal subsidences. Berzelius, in 1835, argued for subsidence as a common phenomenon, and Darwin, in 1839, brought forth subsidence to explain the coral islands of the Pacific. James D. Dana, in 1849, argued for elevation at the poles and subsidence at the equator.

Most of these earlier ideas of subsidence concerned areas chiefly submarine, vast in extent, and with indefinite boundaries. James

[1] Virgil R. D. Kirkham, "A Geologic Reconnaissance of Clark and Jefferson and Parts of Butte, Custer, Fremont, Lemhi, and Madison Counties, Idaho," *Ida. Bur. of Mines and Geol. Pamph. 19,* (January, 1927), p. 24.

[2] Thanks are due to Dr. George Otis Smith, former director of the U.S. Geol. Surv. for suggestions concerning sources of information on this subject.

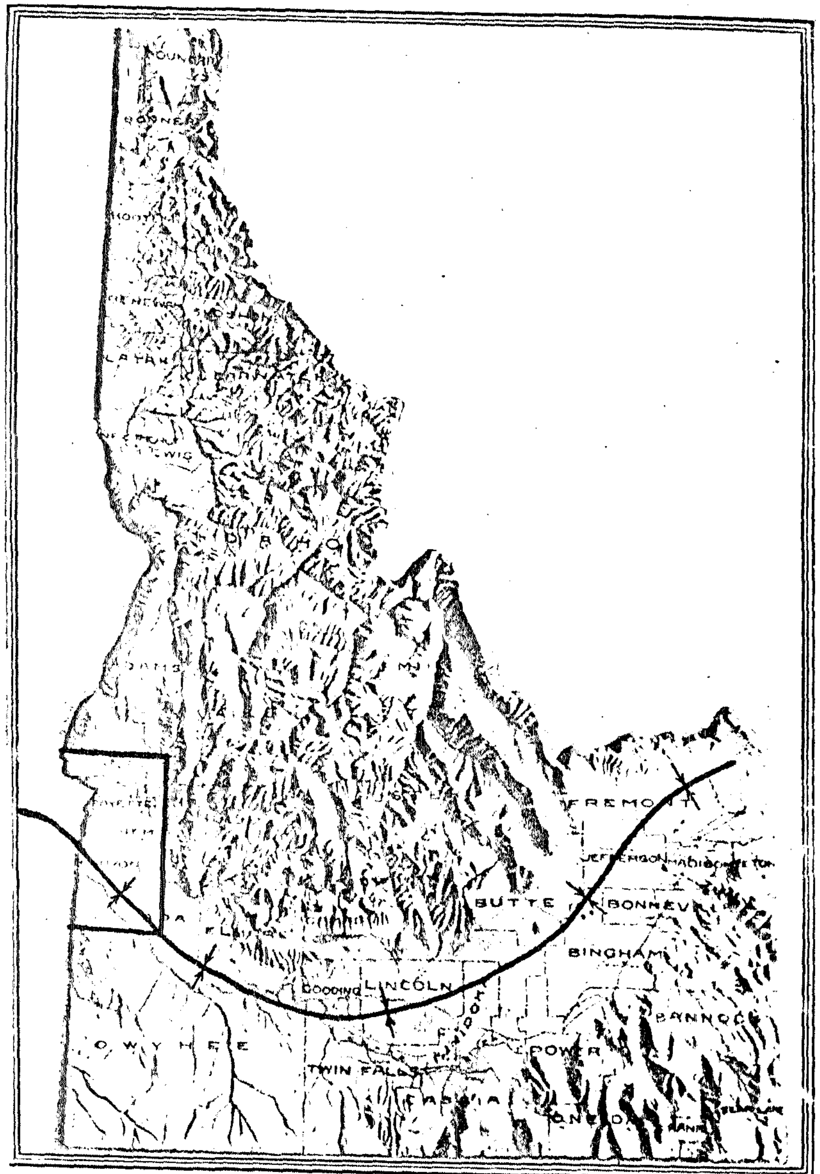

FIG. 1.—Index map showing position of map area in Idaho, and approximate position of axis of the Snake River downwarp.

Hall, in 1857,[1] when discussing the origin of mountains, suggested a slightly different conception of subsiding areas, by saying, "Gradual accumulation of sedimentary masses in areas of subsidence must, on account of the altered equilibrium, give rise to folding and fracturing of the crust and consequently to mountain chains."

On the basis of this concept he outlined areas of subsidence whose boundaries and orientation were essentially similar to mountain chains. Babbage and Herschel had, however, in 1837, noted that areas of subsidence and deposition later became the sites of uplift.

Dana disagreed with Hall's concept of the origin of mountains but accepted his ideas on subsidence and consequent deposition. To the great trough-like hollows of subsidence and deposition he gave the name "geosynclinal." He advanced the idea that mountain systems arose from sediments accumulated in "geo-synclinals" and said, "As subsidence continues, the deeper strata are weakened by heat and pressure and readily tear assunder."

Dana, in 1863, defined "geoclinal" as follows[2]: "wider depressions lying between distant ranges of elevations were produced through a gentle bending of the earth's crust and these great valleys or depressions (like the Mississippi and Connecticut valleys) may be called 'geoclinal.' "

This represents his preliminary groping for a name to assign to certain types of subsiding, or warped, areas. In 1873, Dana[3] established the name "geosynclinal" for these downwarped areas. He said,[4] "The making of the Allegheny Range was carried forward at first through a long continued subsidence—a geosynclinal[5] (not a true synclinal).

That he considered it the same depression to which he had assigned the name "geoclinal," in 1863, is indicated by his calling the "Triassco-Jurassic region in the Connecticut Valley" a geosynclinal.

[1] An address before the American Association for the Advancement of Science.

[2] James D. Dana, *Manual of Geology*, 1st. ed. (1863), p. 722.

[3] James D. Dana, "On Some Results of the Earth's Contraction from Cooling, Including a Discussion of the Origin of Mountains and the Nature of the Earth's Interior," *Amer. Jour. Sci.*, 3d Series, Vol. V (1873), 423–43.

[4] *Ibid.*, p. 430.

[5] From the Greek—*earth* and *synclinal*, it being a bend in the earth's crust.

He also named the Green Mountain region as a one-time geosynclinal. He attributed the structure to "lateral thrust."

In 1895,[1] Dana altered the term to "geosyncline" and defined it. Ideas on geosynclines have gradually advanced through the succeeding years and the existence of such features has been generally accepted. Grabau,[2] in 1921, listed several geosynclines for each continent, and Schuchert,[3] in 1923, in his exhaustive paper on the subject, listed a large number for North America and argued for two types of geosynclines: simple and complicated, continental and mediterranean ("between continents"). In speaking of the continental type, he said,[4] "In North America the geosynclines all lie on the inner or continental side of the borderlands."

He also stated,[5] "Geosynclines, in the American sense, on the other hand, are long and narrow shallow-water *inland seas* lying wholly upon a continent."

European geologists consider the geosynclines as elongate oceans that are hemmed in by continents and typical "mediterraneans." Suess, Haug, and Ruedemann showed in their maps that some continental types link up with mediterranean types.

Hall's original conception confined the geosynclines to continents, but Dana,[6] in 1895, gave them a very elastic use. He said,

> That there were profound geosynclines over the oceanic basin during the later Tertiary and Quaternary is put beyond question. . . . . The Coral Island subsidence, announced by Darwin in 1839, recognized such geosynclines.

In the same text[7] he made two other applicable statements:

> *Rocky Mountain geosynclines*—local geosynclines, or subsidences, commenced over the summit regions of the mountains. The areas of the fresh-water lakes, referred to above, were the sinking areas; and the sinking went forward with concurrent deposition of beds, until the troughs contained strata of Eocene Tertiary 8,000 to 10,000 feet in thickness. . . . . After these Eocene basins ceased to subside, more eastern Miocene and Pliocene geosynclines formed.

[1] James D. Dana, "*Manual of Geology*, 4th ed. (1895), pp. 380, 385.

[2] A. W. Grabau, *Text Book of Geology* (1921).

[3] Charles Schuchert, "Sites and Nature of the North American Geosynclines," *Bull. Geol. Soc. of Am.*, Vol. XXXIV (June 30, 1923), pp. 151–230.

[4] *Ibid.*, p. 170.

[5] *Ibid.*, p. 195.

[6] *Manual of Geology* (1895) p. 937.

[7] *Ibid.*, p. 365.

And,

> The basin[1] of Lake Superior probably corresponds to a geosyncline as suggested by T. C. Chamberlin.

R. T. Chamberlin[2] believes that the word "geosyncline" should be chiefly applied to continental structures rather than oceanic or mediterranean, but that fore deeps are genetically similar. Many authorities from Dana down to R. T. Chamberlin, G. R. Mansfield, and Charles Schuchert, of the present time, assign the origin of these structures to lateral pressure. This is the most commonly accepted idea—excluding isostasists who explain all secular upheaval and subsidence by the well-known principles claimed for isostasy.

C. K. Leith[3] defined a geosyncline as follows, "A geosyncline is a gentle downwarping."

The use of the term "downwarp" and its relation to "geosyncline" should next be considered.

Bailey Willis,[4] in his book entitled *Geologic Structures*, said:

> Warped surfaces are usually broad and of moderate slopes. Thus, Hudson Bay, the Mississippian embayment, and the valley of California are typical broad downwarps. . . . .
>
> Downwarps of past ages are usually represented by the strata that accumulated in them. The Palezoic trough of the Appalachian Province, the Cretaceous trough of the Rocky Mountain region, the Mesozoic and early Tertiary trough that reached from the Alps to the Himalayas, were all great downwarps. Their bottoms subsided many thousands of feet and the depressions were filled with strata of corresponding thickness, ... great downwarps of this kind are called *geosynclines*. . . . .
>
> Smaller local upwarps and downwarps are of very general occurrence. The upwarps are recognized by rejuvenation of streams and other evidences of accelerated erosion, whereas the downwarps are basins in which sediments accumulate. . . . .
>
> Since the strata are usually laid down in basins that are continually deepening, the bottom layers of a deposit must themselves have subsided and been warped. They will have been tilted or have become basin shaped or trough-shaped, although the uppermost strata may be nearly flat. The strata of any series are therefore not strictly parallel. . . . .
>
> The broad type that is produced during the accumulation of sediments or as

[1] *Ibid.*, p. 106.

[2] Oral communication.

[3] *Structural Geology* (1923), p. 234.

[4] Willis, *Geologic Structures* (1929), p. 17.

a result of regional warping is due to vertical movements, to subsidences, or to uplifts. . . . . It is better to call the effects of warping *flexures* and to restrict the terms *folding* and *folds* to mechanical disturbances caused by compression.

In the first edition of the same book,[1] Willis said,

The term folding is broader than that of warping, which is a deflection due to vertical forces, and fold is more comprehensive than upwarp or downwarp.

Willis[2] in the 1929 edition, said:

Subsiding areas are the gathering places of sediments, both continental and marine, and the earlier deposits, in course of subsidence and in consequence of subsidence, become deeply buried under the later ones. It is demonstrable that the earlier beds were practically flat when deposited, that the thicknesses of the overlying strata vary greatly over the area of deposition, and that the upper surface was also practically flat during and at the close of the process of accumulation. There is, therefore, no escape from the conclusion that the older formations became flexed or warped during the progress of subsidence and in consequence of the vertical attraction of gravity. The structure thus developed is, by definition, an incompetent syncline. It is already well recognized as the "geosyncline" of Dana. It is not limited in occurrence to continental, marginal, or marine areas, and may be represented by the geosyncline of the Alps, by that of the Appalachians, by the basins of the Rocky Mountains, by the Valley of California, or by the Caribbean deep.

The use of the word "warping" in a technical sense seems to have been established by W. M. Davis[3] in 1883, when he made free use of it in several papers. Davis, in 1898, so far as is known, was also the first to define "warping" or "warps" and to use these words as technical nouns or names for a definite type of structural feature. In his *Eighteenth Annual Report of the United States Geological Survey*, he defined warpings thus:[4]

Deformations of this class are not called "folds" because the dips are, as a rule, of moderate amount, and still more because it is not desired to imply that lateral compression, acting to produce folds after the manner ordinarily attributed to such a force, has had anything to do with the disturbance of the region.

On the next page he wrote an entire section on warps.[5]

Davis thus presented here a fundamental distinction between warping and folding, supported thirty-one years later by Willis, as

[1] *Ibid.*, (1923), p. 140. [2] *Ibid.* (1929), p. 258.

[3] *Science*, Vol. I (1883), pp. 304–5, 325–27, 356–57, 570.

[4] *U.S. Geol. Surv., Eighteenth Ann. Rept.*, Part II, p. 84. [5] *Ibid.*, p. 85.

quoted above. Davis thought the Connecticut Valley to be a "warp" and spoke of the "down-bending of the Triassic trough."[1] Dana, it will be remembered, mentioned this as one of his type geosynclines, as quoted above. Although Davis did not use the work "downwarping" or "downwarp," at this date, he spoke of "flat warping" and "down-bending" in describing what is now commonly called downwarping.

Daly,[2] in 1905, is believed to have been the first to use the word "downwarp" as a technical name for a type of structural feature. Washburne[3] called the Snake River depression "an almost imperceptible broad downwarp or syncline."

In 1918 Barrell,[4] said:

The recognition of *warping* as a major factor in the large structure of mountain systems, and the expression of that factor in the terms "geosyncline" and "geanticline" forms a notable advance in geologic thought. . . . . Since they are needed terms for the larger mountain structure and do not require a determination of the previous limits of upwarp and downwarp.

Buwalda,[5] in 1923, said, in referring to the map area:

This region is flanked on either side by rugged mountain ranges attaining an elevation of 9,000 feet and is believed to have been caused by a huge downwarping of the crescent-shaped area for a vertical distance of several hundred feet.

The writer,[6] in 1924, describing the map area, spoke of a "huge downwarping for a distance of several thousand feet," and Piper,[7] in 1924, said, "Downwarping and erosion of the series progressed into early Pleistocene time."

[1] *Ibid.*, p. 83.

[2] Reginald A. Daly, "The Accordance of Summit Levels among Alpine Mountains; The Fact and Its Significance," *Jour. Geol.* Vol. XIII (1905), pp. 105–25.

[3] C. W. Washburne, "Gas and Oil Prospects near Vale, Oregon and Payette, Idaho," *U.S. Geol. Surv. Bull. 431* (1909), pp. 26–35.

[4] Joseph Barrell, "A Century of Geology; The Growth of Knowledge of Earth Structure," *Amer. Jour. Sci.*, Vol. XLVI (1918), p. 162.

[5] J. P. Buwalda, "A Preliminary Reconnaissance of the Gas and Oil Possibilities of Southeastern and South Central Idaho," *Ida. Bur. of Mines and Geol. Pamph. 5* (1923), p. 2.

[6] Virgil R. D. Kirkham, "Oil Possibilities and Drilling Activities in South Idaho," *Ida. Eng.*, Vol. II, No. 1 (December, 1924), p. 11.

[7] Arthur M. Piper, "Geology and Water Resources of the Bruneau River Basin, Owyhee County, Idaho," *Ida. Bur. of Mines and Geol. Pamph. 11* (1924).

As has already been stated, the name "Snake River downwarp" was applied to the depression in a publication,[1] in January, 1927, and listed as a section heading for that paper. The writer believes this use, in a specific sense, is as fully justified as is the use of geosyncline for the Appalachian trough. The word "downwarping" has recently come into general use in papers by structural geologists and has been used extensively by R. T. Chamberlin, Bailey Willis, C. K. Leith, G. R. Mansfield, and others.

The writer suggests that subsiding areas, all of which may be genetically similar and products of secular subsidence, may be classified under four heads:

1. *Geosynclines*, located on continents, relatively lineal and narrow, generally marginal, progressive sinking, and deposition of marine shallow-water and terrestrial sediments. Type—Appalachian geosyncline.

2. *Mediterraneans*, located close to, and between contiguous continents, relatively irregular; deposition chiefly deep-sea rather than shallow-water sediments accumulating slowly. Type—Mediterranean Sea.

3. *Fore deeps*, located in oceans, relatively lineal and narrow, mostly marginal, deposition not shallow-water but deep-sea sediments accumulating slowly. Type—Tuscarora deep.

4. *Downwarps*: (*a*) Continental, located on continents, may have any orientation, relatively irregular or basin-shaped, progressive sinking and deposition of terrestrial sediments with or without extrusion or intrusion of lava sheets. Type—Snake River downwarp. (*b*) Oceanic, located in oceans far from continents, may have any orientation relatively irregular or basin-shaped, deposition slight, with or without extrusion of lava. Type—Cape Verde basin.

DEVELOPMENT OF THE "SUBSIDENCE" IDEA FOR THE SNAKE RIVER DOWNWARP

King,[2] in 1878, said:

> Severe crumpling, as already mentioned took place, and the mountainous country east from the eastern boundary of Pah-Ute Lake, which must have been on the meridian of 117°, became depressed so that the lake, at the beginning of

[1] *Ibid.*

[2] Clarence King, *U.S. Geol. Expl., Fortieth Par. Rept.*, Vol. 1 (1878), pp. 412, 413.

> the Pliocene deposition, stretched from the base of the Sierra Nevada to the base of the Wasatch, making a surface of eight degrees of longitude. The northward extension of this lake must have been far up the Upper Columbia River, while its southward extent is at present unknown. For this lake, occupying the whole breadth of the present Great Basin and parts of Idaho and Oregon, I propose the name Shoshone Lake.

Further on, he said:[1]

> The entire Great Basin area sank and became the receiver of the waters of an enormous lake, covering much of Nevada, Idaho, eastern Oregon and a part of California. The feature of general gentle subsidence and enlargement of lake areas is common to the eastern and western post-Miocene disturbance.

From these statements it is clear that the first geologist in the region recognized it as a depressed area and a site of extensive lacustrine deposition. In speaking of the tilted and warped attitudes of the beds in the area, he said further:[2]

> At the close of the Pliocene the last prominent dynamic events occurred. Both in the region of the eastern and western Pliocene lakes, wide areas were thrown into the attitude of inclined planes without either fault or fold. . . . . This wide inclined tilting of sheets was executed without a fault or a rupture.

These statements indicate that he believed the disturbance to be very gentle and not connected with faulting.

Lindgren[3] described this depression thus:

> The Snake River Valley stretches across the whole width of southern Idaho in a broad curve opening toward the north and having a radius of 160 miles. The length of the valley from the base of the Tetons to Weiser, where the river enters into a narrow canyon, is over 400 miles, while its width ranges from 50 to 75 miles. Its total area being about 34,000 square miles. . . . . On both sides of this valley rise higher ranges, chiefly of granite in the lower valley, of granite and Paleozoic and Mesozoic rocks in the upper valley. The lower slopes of these ranges are often flanked by Tertiary lake deposits. The larger part of the valley is occupied by vast flows of basalt, frequently resting upon and covered by fluviatile and lacustrine accumulations contemporaneous with the flows. . . . .
>
> The mountains of older rocks surrounding the tectonic trough of the Snake River rise gradually, on the north side of the river. . . . .
>
> Before the beginning of the Neocene the chief features of the topography were outlined the broad uplift of the Boise Mountains and the depression of

[1] *Ibid.*, p. 756.

[2] *Ibid.*, pp. 757, 758.

[3] Waldemar Lindgren, "Mining Districts of the Idaho Basin and the Boise Ridge, Idaho," *U.S. Geol. Surv., Eighteenth Ann. Rept.*, Part III (1898), pp. 625–736.

Snake River Valley. The latter is not unlikely a sunken area separated by old fault lines from the mountains to the north. At that time the basalt flows and lake beds did not exist. . . . . Thus the time immediately preceding that from which the first records date was one first of uplift and subsidence; second, one of long-continued erosion, during which the Boise Mountains were dissected and the débris from the excavated canyons deposited in the basin of the Snake River Valley.

He made it clear that he believed the basin to have been formed by faulting before the basin beds were deposited in a lake which he called Lake Payette, whose highest level was placed at 4,200 feet because that was the highest point where he found lake-bed remnants. He believed the beds to have today essentially the positions and elevations of their deposition, regarding the slight dips noted at places in the lake beds as essentially initial dips, caused by deposition on a sharply sloping surface.[1] Lindgren,[2] in 1904, said:

During early Tertiary time the valley must have formed a broad and deep depression, north of which the mountains of central Idaho rose with an abrupt scarp, very probably due to faulting. Toward the south rose narrow, isolated mountains, like the Owyhee Range, with abrupt, deeply eroded outlines and with the general trend and character of the desert ranges of the Great Basin, of which, in fact, they are the most northerly outliers. The whole indicates an early Tertiary or pre-Tertiary fault differentiating the central Idaho mass from the area of fractured and dislocated blocks lying farther south. . . . . No lava flows had yet covered the eroded flanks of the granite mountains. . . . . It probably follows that a large part of this region has been depressed since the eruption of the lava, for the depth of the valley sediments near Weiser (elevation, 2,100 feet), as proved by borings, is more than 1,200 feet. . . . . Even assuming that the above figure represents the deepest point of the valley (which is not probable) it would place the bottom only 1,000 feet above sea level.

It is clear from the foregoing statement that Lindgren believed the depression to be due to faulting and to have been formed prior to the extrusion of the Columbia River basalts and deposition of any lake beds. Although, in 1898, he saw no evidence for disturbance or subsidence after the deposition of the lake beds, he recognized, by 1904, that subsidence on a small scale may have occurred.

[1] Waldemar Lindgren, "Description of the Boise Quadrangle," *U.S. Geol. Surv. Geol. Atlas Folio 45* (1898), p. 3.

[2] Lindgren, "Descriptions of the Silver City Quadrangles," *U.S. Geol. Atlas Folio 104* (1904), p. 1.

The writer[1] described the downwarp for much of its area in southeastern Idaho in January, 1927, as follows:

The great structural depression which lies in the southeastern half of the mapped area extends beyond the boundaries to the east and the southwest. It is now partly occupied by the Snake River lavas and the interbedded gravels and lake beds. The assumed axis of this trough extends from a point on the map edge directly south of Mud Lake northeasterly to Camas thence in the direction of Camas Creek northeastward. The Plain region at its widest part in the mapped area is about 50 miles across, not counting the wide valley reentrants. Its average width, in the area, measured at right angles to the axis, is nearly 45 miles.

As has been described under physiographic development, the outline and extent of this structural depression is marked by the Pliocene (?) acidic lavas (described under igneous rocks as Tertiary Late Lavas) and interbedded continental deposits.

These acidic lavas and associated interbedded continental sediments, as has already been mentioned, dip gently toward the edge of the plain, on all sides. Figs. 2 and 3 are sections showing the relationships existing from Medicine Lodge Creek to Henry's Fork along the northern edge. The structural relief here is often as much as 4,000 feet. In other parts of the plain area, especially along the east and southeast, the relations are the same but the relief is less (see photographs A and B, Plate I).

A slope of 4 to 5 degrees represents the angle of dip about the periphery of the Plain. At many places on the southeastern edge of the Plain the lava rises less than 2,000 feet above it on the noses of the ranges and to a lesser distance in the intervening structural valleys. How far these acid lavas continue their dip beneath the Snake River basalt is of course conjectural but in a structural valley whose average width is 45 miles a great vertical distance might be reached before flattening out takes place. To assume that the acidic series lies more than 2,000 feet deep in the center of the Plain, in this area, would not seem unreasonable. A distance twice this great is not unthinkable.

It is believed that the subsidence which took place in these relatively flatlying widespread acid lavas was accompanied by an upward tilting of the regions adjacent to the area. This expression to the north is represented by the Centennial Range geanticline or uplift whose axis parallels the topographic axis of the Centennial Range. It gradually dies out as it extends westward across the Beaverhead, Lemhi, and Lost River ranges and their intervening valleys.

Although upward movement was exerted southeast of the Plain, it was from several hundred to a few thousand feet less than that north of the Plain. Some

[1] Virgil R. D. Kirkham, "A Geological Reconnaissance of Clark and Jefferson and Parts of Butte, Custer, Fremont, Lemhi, and Madison Counties, Idaho," *Ida. Bur. of Mines and Geol. Pamph. 19* (January, 1927), pp. 24, 25, 26.

possible physiographic effects of the subsidence and complementary uplifts are discussed under the section on physiographic history.

It must be understood that in using the expression "downwarp" the writer does not mean to infer that minor faulting or small step-faults did not occur. It would seem a physical impossibility to move any widespread rigid sheet of material, which was so thin in comparison to its extent, without causing minor breaks and displacements.

Step-faults and slumpings of a few feet displacement should be abundant, but great block faults with several hundred feet displacement need not necessarily be assumed in this part of the Plain. No doubt, breaks of some magnitude occurred in the bottom of this depression. From these probably exuded the Snake River basalts along rifts now represented by chains of cones. These, however, at every place studied are more common near the center of the Plain than near the edges where they would be if great block faults formed the Plain borders. Only two hot springs lie within 25 miles of the Plain borders and these, located at Heise and Lidy Hot Springs, are associated with older major mountain faults which approach the Plain edge at a right angel.

In brief, the evidence, here as well as elsewhere, points overwhelmingly to a gently folded syncline of great proportions accompanied on either flank by a corresponding and complementary uplift. This appears to have been greatest to the north where an anticline much less in length and width was formed contemporaneously. The age of this movement was later than the Tertiary Late Lavas which are assigned a Pliocene (?) age on the strength of their relationship with the Salt Lake formation.

The writer,[1] in 1928, said, "the axes of the folds invariably plunge to the southeast down the flanks of the Snake River downwarp."

Bryan,[2] in 1929, said:

> The first earth movement recorded in this area is the slight deformation that arched a ridge prior to the deposition of the Payette and Idaho formations. It seems likely that the production of this ridge was only a minor feature of a much larger disturbance by which the Snake River region on the north was carried below the volcanic plateaus on the south. Certainly at Ontario, 30 miles north of this area, the thickness of the Payette and Idaho formations is more than 4,000 feet, as shown by the log of a deep well, and only 8 miles north a well 1,140 feet deep has been drilled without striking the basalt. . . . This structure also is only one of the minor results of the greater movement by which the Snake River Basin was carried below the plateaus of southeastern Oregon and southern Idaho.

[1] Virgil R. D. Kirkham, "A Brief Preliminary Report on the Possibilities of an Underground Water Supply for the City of Weiser, Idaho," *Ida. Bur. of Mines and Geol. Pamph. 29* (June, 1928).

[2] Kirk Bryan, "Geology of Reservoir and Dam Sites with a Report on the Owyhee Irrigation Project, Oregon," *U.S. Geol. Serv., Water-supply Paper 597 A* (January, 1929) p. 56.

The Payette beds of which he speaks are included in the Idaho beds of the writer in a recent paper.[1]

A review of all the publications describing this depression shows that in 1878 King,[2] as a result of his hurried reconnaissance of this region, believed that the area had subsided without violence, developing gentle dips in the lavas and the lake beds.

Lindgren, in 1898[3] and 1904,[4] conceived the basin to have been formed by a series of immense faults previous to the deposition of the lake beds and lavas. He believed that uplift to the north was as effective as the downfaulting in creating the present relief. Dips in the basin lake beds were regarded as depositional. He thought the mountains to the north were separated from the basin by an abrupt scarp. This misconception was due to the fact that the relatively soft, dipping basin-beds have been truncated during two periods of lateral planation, and the tilted and uplifted granite surface to the north now presents a notable relief, visible at great distances. Actually, however, this "abrupt scarp" has a slope to the basin beds of about 8°, and the truncated basin beds and lava flows, before erosion, rested on this surface as shown in a previous paper on physiographic history.[5]

The Owyhee Mountains, whatever may be the structure in the older rocks, now represent an anticline or arch in the Columbia River lavas and the Owyhee rhyolite which dip away from its axis into the downwarp on the north and northeast and also to the southwest, and northwest. This indicates anything but basin-range structure, and no basin ranges lie within the map area.

Lindgren[6] later revised his opinion to include some depression after the deposition of the lake beds and extrusion of the lava.

[1] Virgil R. D. Kirkham, "Revision of the Payette and Idaho Formations," *Jour. Geol.*, Vol. XXXIX, No. 3 (1931), pp. 193–230.

[2] King, *op. cit.*

[3] Lindgren, "Mining Districts of the Idaho Basin and the Boise Ridge Idaho," *op. cit.*, pp. 625, 3.

[4] Lindgren, "Descriptions of the Silver City Quadrangles," *op. cit.*, p. 1.

[5] Virgil R. D. Kirkham, "Old Erosion Surfaces in Southwestern Idaho," *Jour. Geol.*, Vol. XXXVIII (1930), pp. 653–58.

[6] Waldemar Lindgren, and N. F. Drake, "Descriptions of the Nampa Quadrangle," *U.S. Geol. Surv., Geol. Atlas Folio 103* (1904).

of Upper Miocene or Lower Pliocene age, the terrestrial Idaho formation of Pliocene and Pleistocene age, the terrestrial Upper Mesa formation of Pleistocene age, the Snake River basalt of Pleistocene age, and the terrestrial Lower Mesa formation of Pleistocene age.

In southern and southeastern Idaho, the Columbia River basalt is absent. The Salt Lake formation commonly described as of Pliocene (?) age lies in the same position in relation to the rhyolite as does the Payette formation in southwestern Idaho, and, although no definitive flora or fauna from it has as yet been determined, it may eventually prove to be contemporaneous with the Payette formation. The extensive rhyolite series of southern and eastern Idaho which takes part in the downwarp is the same for the most part as the Owyhee rhyolite of southwestern Idaho. The Idaho formation overlying this rhyolite extends as far east as Buhl. Several isolated deposits of gravels and clays which overlie the rhyolite and which underlie, or are interbedded with, the Snake River basalt may be contemporaneous with the Idaho formation in southeastern Idaho. The Snake River basalt in southeastern Idaho is chiefly Pleistocene in age, but some of the lower flows, which are now buried, may be Pliocene in age.

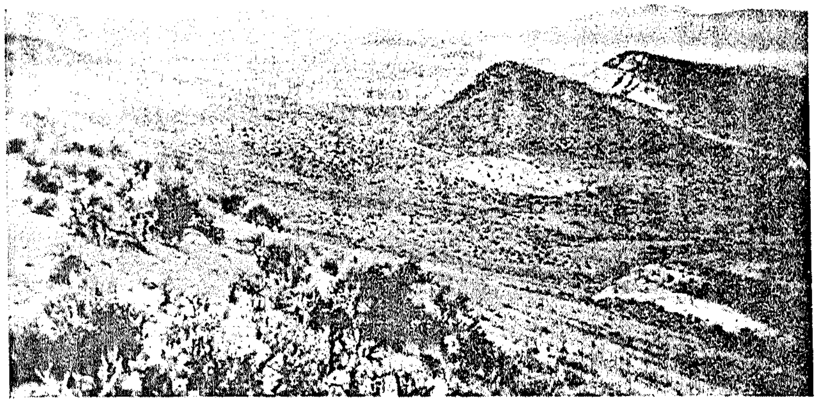

FIG. 2.—Looking southeast along the strike of the Idaho lake beds which dip southwest to the downwarp axis near Alkali Creek on the north side of the downwarp.

The evidence, much of which has been given in detail in a former paper[1] consists of tilted or dipping lava flows and lake beds (see Figs. 2, 3, 4, 5, and 6). In the map area (see Fig. 6) the Columbia River basalt lies on both sides of the downwarp and dips toward the

FIG. 3.—Idaho lake beds dipping gently to the downwarp axis from the south side. These are characteristic of the upper members.

FIG. 4.—Idaho beds in the Weiser quadrangle dipping southwest to the axis of the downwarp.

[1] Virgil R. D. Kirkham, "Revision of the Payette and Idaho formations," *op. cit.*

axis (see Figs. 7, 5, 8, 6, 9). The Owyhee rhyolite lies on both sides of the downwarp and dips toward the axis also (see Figs. 7, 8, 6). The Payette formation lies on both sides of the downwarp and dips toward the axis (see Figs. 7, 8, 6). The Idaho formation lies in the present basin area and the lowermost members dip toward the axis (see Figs. 7, 8, 6 and Figs. 4, 10). Higher members dip toward the downwarp axis at lower angles and so on (see Fig. 2) until the upper members in the central part of the basin lie in an

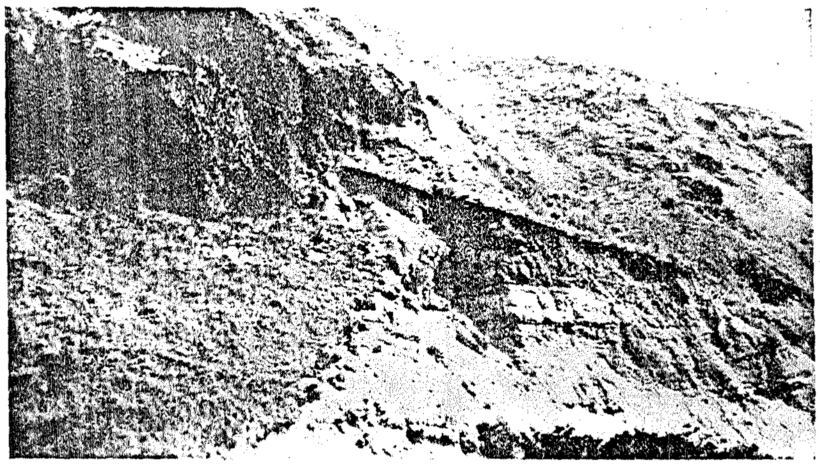

FIG. 5.—Payette beds under the upper series of Columbia River basalt in Linson Valley.

almost horizontal position (see Figs. 7, 8). The Upper and Lower Mesa formations and the erosion flats upon which they lie dip at slight angles toward the downwarp axis, as described in a former paper.[1] All dips in the Idaho formation were secured by plane-table sections crossing the strike of the beds. These were carefully ascertained in order to detect the very gradual change of dip. The old pre-Columbia River basalt peneplain on the granite also dips toward the downwarp axis from each side of the plain, as previously described. That the lake beds were nearly horizontal when deposited is indicated by the bedding planes, ripple marks, and character of the cross-bedding. Thin, but widespread, ash beds, diatomite

[1] Virgil R. D. Kirkham, "Old Erosion Surfaces in Southwestern Idaho," *op. cit.*, pp. 652–63.

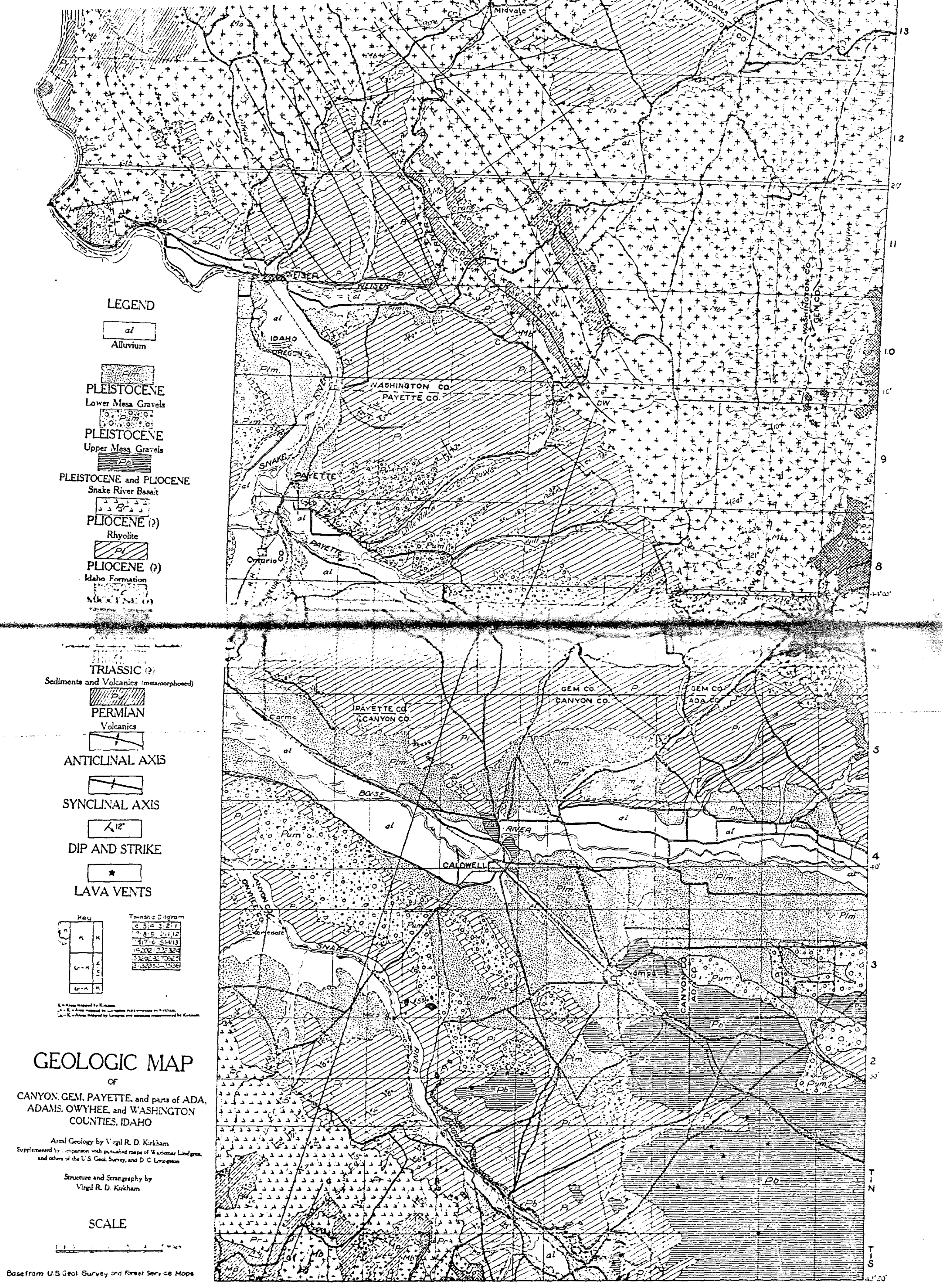
LEGEND
al
Alluvium
Plm
PLEISTOCENE
Lower Mesa Gravels
Pum
PLEISTOCENE
Upper Mesa Gravels
Pb
PLEISTOCENE and PLIOCENE
Snake River Basalt
PLIOCENE (?)
Rhyolite
Pi
PLIOCENE (?)
Idaho Formation
TRIASSIC (?)
Sediments and Volcanics (metamorphosed)
PERMIAN
Volcanics
ANTICLINAL AXIS
SYNCLINAL AXIS
DIP AND STRIKE
LAVA VENTS
Key
Township Diagram
GEOLOGIC MAP
OF
CANYON, GEM, PAYETTE, and parts of ADA, ADAMS, OWYHEE, and WASHINGTON COUNTIES, IDAHO
Areal Geology by Virgil R. D. Kirkham
Structure and Stratigraphy by Virgil R. D. Kirkham
SCALE
Base from U.S. Geol. Survey and Forest Service Maps
Midvale
WEISER
IDAHO
OREGON
WASHINGTON CO.
PAYETTE CO.
SNAKE
PAYETTE
Ontario
GEM CO.
CANYON CO.
ADA CO.
BOISE
RIVER
CALDWELL
Nampa
13
12
11
10
9
8
5
4
3
2
T 1 N
T 1 S

FIG. 6

beds, and carbonaceous seams deposited in flat-lying positions are now tilted at angles too high to be depositional.

As shown in a former paper,[1] the dips indicate a thickness of more than 18,000 feet of Idaho formation alone; beneath these beds lies

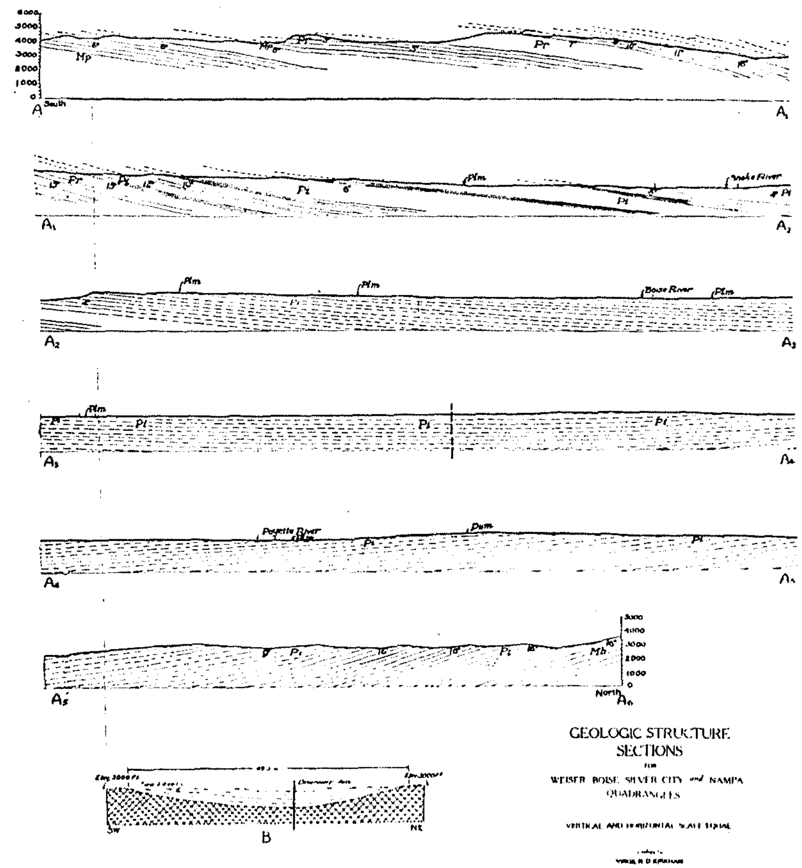

FIG. 7.—*Mp* is the Payette formation, *Pr* is the rhyolite series, *Pi* is the Idaho formation, *Plm* is the Lower Mesa formation, and *Pum* is the Upper Mesa formation. *Mb* is Columbia River basalt.

the Owyhee rhyolite which is over 1,900 feet thick at places south of the plain and 700 feet thick north of the plain. Underlying the rhyolite is a variable thickness of Columbia River basalt which averages 2,000 feet in thickness south of the plain and attains thicknesses

[1] "Revision of the Payette and Idaho formations."

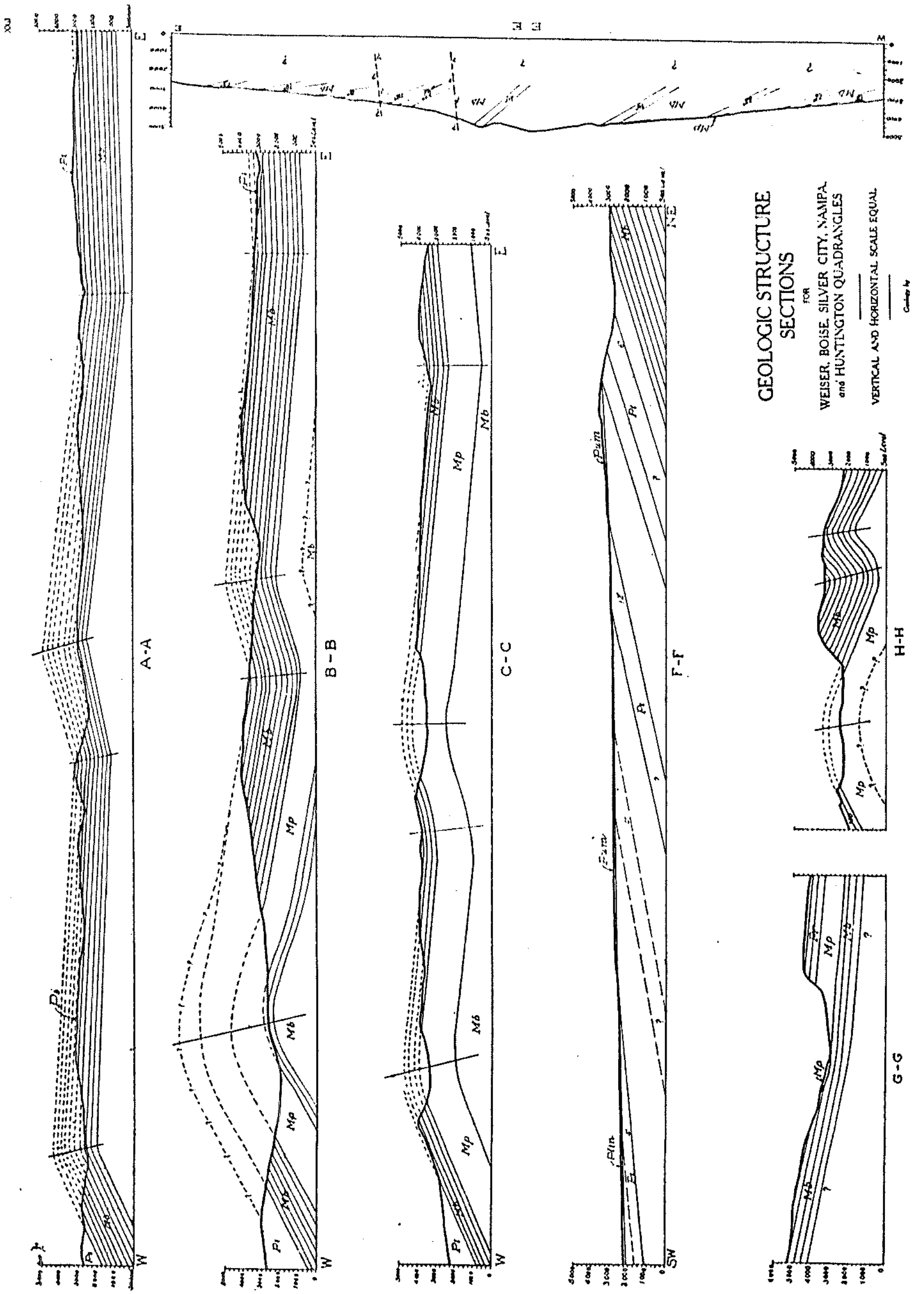

FIG. 8.—*Mb* is Columbia River basalt, *Pi* is Idaho formation, *Pum* is the Upper Mesa formation, *Plm* is the Lower Mesa forma-

much greater north of the plain; interbedded with this are 900 or 1,000 feet of Payette formation (see Figs. 11, 5, 12, 9).

That these formations extend beneath the plain's area is strongly suggested by their presence on both sides and their relations to each

FIG. 9.—Looking north on Little Squaw Creek at the Owyhee rhyolite overlying the Payette lake beds in the middle, and Columbia River basalt underlying the Payette in the foreground.

FIG. 10.—Idaho beds in the Nampa quadrangle overlying the rhyolite and dipping toward the downwarp axis to the northeast. Note the irregular surface of the rhyolite projecting through the lake beds.

other and the Idaho formation. The sections of Owyhee rhyolite and Columbia River basalt, exposed on each side, have suffered much erosion before and since the deposition of the Idaho and may not represent their original thicknesses. A compilation of these thicknesses suggests that the pre-Columbia River basalt peneplain may have been downwarped to a point between 19,000 and 21,000 feet below sea level. A well at Ontario, Oregon, actually passes

FIG. 11.—Payette beds dipping under the Owyhee rhyolite cap toward the downwarp. The small patch of rhyolite on the right has slumped from the main mass.

FIG. 12.—Looking northeast at the Payette formation in the Silver City quadrangle, dipping northeast under the Owyhee rhyolite which caps it.

through the Idaho formation to a point 2,300 feet below sea level and has not entered the Owyhee rhyolite which should lie below. Under this should be the Payette formation and the Columbia River

basalt. If the well should enter rhyolite at once, which is unlikely, and these formations are present with thicknesses comparable to those now exposed on the flanks, the minimum depth at Ontario, to the granite peneplain, would be over 7,000 feet below sea level. Although terrestrial deposits are now accumulating in regions below the present sea level, as in Death Valley, California, it seems unlikely that accumulations such as those represented by the great thicknesses of the Payette and Idaho formations could have been formed in such a situation. It is reasonable to infer that the present position of these formations, far below sea level, is due to subsidence which, in this case, occurred by downwarping.

In all parts of the downwarp the lavas dip toward the axis as they do in the map area. This area, however, affords evidence, because of the continuous deposition of the lake-bed and terrestrial sediments, of the steady and progressive sinking of the area. In the regions where the lavas welled forth rapidly with great time intervals between extrusions, the downwarping is equally obvious, but no measure of its progress is at hand. Thus in eastern Idaho the rhyolite is notably tilted, but the intervening time interval before the extrusion of the Snake River lava was apparently so great that the latter overlies the rhyolite at most places with angular unconformity. This may not be true of earlier flows now buried, but the present surface flows at the edge of the basin are practically horizontal and abut against the warped rhyolite dip slopes.

Outside the map area the rhyolite and the interbedded or underlying Salt Lake formation of Pliocene (?) possibly Upper Miocene (?) age are the key formations indicating the downwarping. These were certainly deposited and extruded nearly horizontally and now lie in an unbroken fringe around the northeast, east, southeast, and south flanks of the downwarp. The rhyolite and interbedded Salt Lake formation dip toward the downwarp axis at angles varying from 5° to 20°.

The acidic lava series called "Tertiary Late Lavas," originally had a widespread occurrence and extended over the Snake River, Caribou, Blackfoot, Goose Creek, and Sublette ranges and many others as well. These ranges have been notably uplifted vertically since the extrusions of these flows and the lava now dips away from the tectonic axes. These ranges are folded anticlinoria and thrust fault slices which form definite, nearly parallel, units of the Rocky Mountain structure. The age of the folding is chiefly post-Lower Cretaceous,[1] and most of the thrust-faulting is certainly pre-Eocene. During Pliocene times these ranges were tilted and now plunge below the acid lavas and Snake River basalt, where the downwarp crosses them. The acidic lava on these ranges is found at elevations as high as 8,800 feet. The same flows dip under the basalt of the plain in a distance of less than 10 miles at an elevation of 4,500 feet above sea level. The acidic lava extends far up the synclinal depressions parallel to the tectonic axes of the mountains. At several places it extends 20 miles farther back from the basalt of the plain than it does on the summits of the ranges from which most of it has been removed by erosion. Whether in troughs between ranges or on the noses, the acidic lava always dips under the basalt of the plains. Erosion by the South Fork and North Fork of Snake River shows that it underlies the basalt far out in the plain. That the dip of the acidic lava is not the angle of flow is indicated by the interbedded sediments and tuffs and ash beds of the Salt Lake formation which were deposited nearly horizontally but now dip concordantly with the rhyolite.

Evidence that the rhyolite underlies the basin-filling of Snake River basalt is found at many places where the Snake River has cut through the basalt, as at Shoshone Falls, Big Falls, or American Falls.

From Birch Creek to a point west of Hailey, on the north side of the downwarp, occur a series of ranges of thrust slice-blocks such as Beaverhead, Lemhi, and Lost River ranges. These ranges, like those on the south, intersect the downwarp at a high angle and like them, plunge beneath the rhyolite which, in turn, dips under the basalt of the plain. The acidic lava fringe has been removed by stream erosion from the valleys between the ranges, but remnants still remain on the nose of each range. At some places the plunge of the range reaches an angle of 7°. This amount of tilting is similar to that recorded by the peneplain on the granite in the map area;

[1] Virgil R. D. Kirkham, "Geology and Oil Possibilities of Bingham, Bonneville and Caribou Counties, Idaho" *Ida. Bur. of Mines and Geol. Bull. 8* (1924).

It is thus clear that the downwarp crosses the tectonic axes of the main ranges of the Rocky Mountains in southeastern Idaho. These ranges have been tilted bodily, and now plunge to the downwarp axis from each side.

Another curious proof of the warping exists in southeastern Idaho. More than a dozen old cones, from which the rhyolite was extruded, still exist on the tilted rhyolite slope which surrounds the downwarp. As one would expect, all of these cones now stand perpendicular to their warped base and markedly tilt toward the valley. For further substantiating details concerning the evidence outside the map area the reader is referred to several former papers of the writer.[1]

CAUSE OF DOWNWARPING

That the downwarp is a result of vertical subsidence due to deep-seated flowage or adjustment of magma rather than a result of compressive forces, is strongly supported by the fact that the downwarp, for half of its length, is superimposed on the westernmost ranges of the Rocky Mountain system in a direction practically normal to their tectonic axes. Proof of this superimposition lies in the fact that great overthrust faults, anticlinoria, and tectonic axes all plunge beneath the downwarp axis on each side.

Subsidence due to the removal of underlying supporting elements, could have accomplished this phenomenon, but it hardly seems conceivable that compressive forces, applied normal to the downwarp axis and parallel to the tectonic axes, would not have been expressed in arching or vast lateral or strike movements along the planes of the long and essentially parallel overthrust faults rather than in subsidence.

At no place along the downwarp was the warping initiated until after the extrusion of the thick and widespread Columbia River basalt series and the equally widespread but less thick series of acidic flows called the Tertiary Late Lavas.

It seems possible that the extrusion of both of these lava series over the area now occupied by the downwarp and adjacent areas may have caused a diminution of the underlying support of a considerable area which resulted in the initiation of subsidence. The

[1] *Bull. 8*, and *Pamphs. 16 and 19*, *Ida. Bur. of Mines and Geol.*, Moscow, Idaho.

accumulation of sediments and lavas in this incipient depression undoubtedly contributed to further subsidence, as did other factors.

SUMMARY

The widespread, relatively thin sheet of rhyolite lava called "Tertiary Late Lava" and represented by the Owyhee rhyolite in the map area, is everywhere affected by the downwarp or the uplift in the adjacent regions. The Rocky Mountain ranges on either side of the downwarp plunge toward the downwarp axis which crosses them normal to their tectonic axes. In the western part of the downwarp, thousands of feet of sediments collected gradually with the continued sinking. In the eastern part were extruded great thicknesses of Snake River basalt, which partially filled the depression.

The downwarp being apparently a region of structural weakness probably has faults or rifts in its bottom and sides. At some places the smooth, warped dip slopes are broken by small discontinuous faults; these usually are expressed in lavas underlain by soft, relatively unconsolidated lake beds and result from compaction, slumping, and spalling, and are technically landslides. No faults approaching the magnitude of those of the Basin Ranges or the north and south fault-block ranges, which occur north and south of the downwarp in Idaho, occur, bounding the plains area, as postulated by Lindgren and Russell. Stratigraphic and structural units and physiographic surfaces have been correlated with certainty across the downwarp and this indicates their probable existence below the present plain surface at great depths.