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# A GEOLOGIC RECONNAISSANCE OF CLARK AND JEFFERSON AND PARTS OF BUTTE, CUSTER, FREMONT, LEMHI, AND MADISON COUNTIES, IDAHO.

By

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# PREFACE

The report herewith covers a brief and striking reconnaissance of a large area in that portion of the state of Idaho adjacent to the corner which is bounded on the east by the state of Wyoming and on the north by the state of Montana.

Although the project itself has a definite economic basis, the most significant results will probably be found to lie in the realm of structural geology. This does not mean, however, that the report is devoid of major economic significance for as the great English scientist John Tyndall once said - "The science of today is the practice of tomorrow", and if the rather bold hypothesis of the "Snake River Downwarp" put forward by Professor Kirkham, together with his tentative analysis of the fault system in the sediments north of the Plains, should be confirmed by further detailed work, then this rather modest publication will become a major one indeed in the annals of the geologic history of Idaho.

Francis A. Thomson,
Secretary, Idaho Bureau of Mines
and Geology.

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# INTRODUCTION.

## PURPOSE OF THE INVESTIGATION.

Previous to this investigation, local rumors concerning the presence in Clark County of oil and coal resulted in requests from the region for a geological examination of this county by the Idaho Bureau of Mines and Geology.

The writer was commissioned to make this examination and entered the field on July 20, 1925, with Norman R. White, a student in the School of Mines, as assistant. The purpose of the investigation was to search for oil, coal, phosphate, and other non-metallic resources as well as to make observations which would provide data for a geologic map of the area. It was hoped, also, that a study of the sediments and structure north and northwest of the Snake River Plain might result in a correlation with formations and structural features lying south and eastward of the Plain.

The entire project was of necessity conducted as a rapid reconnaissance.

The area mapped, which was 65 miles wide and 120 miles long, contains 167 townships. The work was prosecuted by means of auto camp outfit, by horses and on foot.

Temporary headquarters were established at Dubois, Arco, Mackay, Howe, and at Sheridan and Medicine Lodge creeks, and work was projected from each base. The plan of attack was to traverse the valleys and to cross and recross the ranges, by auto, on horseback, or on foot, as necessity demanded.

Geological mapping was facilitated by Forest Service topography of a few townships in the eastern part of the Targhee National Forest. Drainage lines on the Lemhi National Forest map, together with section and township corners, served as the only available guides to location of formation boundaries in the western part of the area, and the latter, consequently, have only sketch value. The lava desert area was crossed everywhere that a road was available and visits were made to nearly all of the cones shown. These were only approximately located by rudimentary triangulation and intersectioning with a compass.

The party left the field on September 13, 1925, and this completed the field examination except for five additional days spent in the area by the writer in August, 1926. A winter's study of the geollected field data suggested structural possibilities in the area which were confirmed when re-visited. The field geology was of necessity collected on several maps of varying scales, significance, and degrees of accuracy, and the geology of the area was not assembled until compilation was accomplished in the office.

The following brief bibliography represents, as far as is known, the chief publications which embrace any part of the area. The explanatory notes in parentheses are appended by the writer. References to publications throughout the following pages are made by the serial numbers assigned to the publications listed.


(1) BRYAN, L. L., and STEARNS, H. T., Preliminary report on the water resources of the Mud Lake Basin, Idaho, U. S. Geol. Survey in cooperation with G. L. O., and Idaho Bureau of Mines and Geol. mimeographed Bull., June 1922. (The central third of the area is represented. No geologic maps, but some excellent structure sections of the Snake River basalt are presented. Work done in 1921.)

(2) CONDIT, D. Dale, Relations of late Paleozoic and early Mesozoic formations of southwestern Montana and adjacent parts of Wyoming: U. S. Geol. Survey, Prof. Paper 120, pp. 111-122, 1918. (A brief reconnaissance along the eastern crest of the Centennial Range is represented. No geologic map, but a structure section is represented. Work done in 1916.)

(3) _______, Oil shale in western Montana, southeastern Idaho, and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 711, pp. 15-40, 1919. (A reconnaissance of Centennial Range, chiefly in Montana, is represented. Map shows outcrop of Permian in eastern part of area and no other geology. Work done in 1918.)

(4) HAYDEN, F. V., Eleventh Ann. Report of the Survey of the territories, 1879. (About 12 townships in extreme southeast are shown on reconnaissance geologic map. Work done in 1877.)

(5) KIRKHAM, Virgil R. D., A geologic reconnaissance of parts of Butte. Clark, Custer, Fremont, Jefferson, Madison, and Lemhi counties, Idaho. Idaho Bureau of Mines and Geology Press Bull., Sept., 1925. (Summary of entire area. No geologic map presented. Work done in 1925.)

(6) LEE, Willis T., STONE, Ralph W., GALE, Hoyt S., and others: Guidebook of the Western United States, Part B. The Overland route with a side trip to Yellowstone Park: U. S. Geol. Survey 612, pp. 136-148, 1915. (About 10 townships in southeastern part of area are represented. No geologic maps presented. Work done in 1914.)

(7) MANSFIELD, G. R., Coal in eastern Idaho: U. S. Geol. Survey Bull. 716 pp. 123-153, 1920. (Eastern third of the area is represented. Reconnaissance geologic map presented. Work done in 1917.)

(8) RUSSELL, Israel, C., Geology and water resources of the Snake River plains of Idaho, U. S. Geol. Survey Bull. 199, 1902. (Eastern and southeastern half of area represented. Reconnaissance map showing only Snake River basalt is presented. Work done in 1901.)

(9) SCHULTZ, Alfred Reginald, A Geologic reconnaissance for phosphate and coal in southeastern Idaho and western Wyoming, U. S. Geol. Survey Bull. 680, 1918. (A few townships in the extreme southeastern portion are represented. Reconnaissance geologic map presented. Work done in 1911 and 1912.)

(10) STEARNS, H. T., and BRYAN, L. L., Preliminary report on the geology and water resources of the Mud Lake Basin, Idaho, U. S. Geol. Survey Water Supply Paper 560-D in cooperation with G. L. O. and Idaho Bureau of Mines and Geology, 1925. (Eastern half of the area represented. No geologic map or sections presented. Work done in 1921 and 1922.)

(11) STEARNS, H. T., Volcanism in the Mud Lake area, Idaho, Am. Jour. Sci., Vol. 11, pp. 353-363, April, 1926. (Eastern three-fifths of area represented. Small reconnaissance geologic map presented. Work presumably done in 1921, 1922 and later.)

(12) UMPLEBY, Joseph B., Geology and Ore Deposits of the Mackay region, Idaho, U. S. Geol. Survey Prof. Paper 97, 1917. (Northwestern and western part of area is represented. Reconnaissance geologic map and detailed maps of small areas are presented. Work done in 1912.)

Aside from unavailable private reports, and unpublished and unavailable work done by the U. S. Geological Survey, the above list is believed to include substantially all geologic work done in the area.

## ACKNOWLEDGMENTS.

The writer takes pleasure in expressing appreciation of the courtesies extended by Messrs. H. R. Harn, D. T. Murphy, and R. W. Katerndahl, of Dubois, Idaho, and by Frank J. Hagenbarth, of Spencer, Idaho, in facilitating the work in the area and for use of maps, etc. Indebtedness is acknowledged to Alfred L. Anderson, Assistant Geologist, Idaho Bureau of Mines and Geology, for a petrographic study of some of the lavas described in this bulletin. Boundaries for some of the gravel and alluvium areas shown on the map were also taken from his unpublished field data. Thanks are due Dr. Francis A. Thomson, Dean of the School of Mines, University of Idaho, for valuable counsel in preparing the report and for a critical reading of the manuscript. The

writer is also grateful for the care and cooperation given by Vernon T. Otter in the drafting of maps accompanying this report. Able assistance was given in the field by Norman R. White. Photograph D. on Plate II has been borrowed from the U. S. Geological Survey.

## GEOGRAPHY.

### LOCATION.

The area examined and represented on the map contains 167 townships which lie in that part of eastern Idaho adjacent to the Idaho-Montana boundary as shown by the Index map on Plate IV. It lies between meridians 111° 38' and 114° 02' W. and parallels 43° 38' and 44° 34' N. The above mentioned area is approximately divided among six counties as follows: Clark county complete, 51 townships; Jefferson county complete, 32 townships; Butte county 32 townships; Custer county, 23 townships; Fremont county, 17 townships; Lemhi county, 4 townships; and Madison county, 8 townships. An area comprising approximately 28 townshipsllies in the Lemhi National Forest, about 13 townships are in the Targhee National Forest, and the remainder is public domain, or private or state land.

### DRAINAGE.

The entire area lies within the Snake River drainage. Snake River appears only within the southeastern part of the map where the northwestward flowing south fork of the Snake makes confluence with the southwestward flowing Henry's Fork. From this point, Snake River flows westward for a few miles and then in a southerly direction till it passes beyond the limits of the map.

The largest tributaries are Teton River, flowing west, and Sheridan Creek, flowing east into Henry's Fork.

Other large streams in the area contribute to the Snake River drainage but do not flow into it at the surface. All of these discharge into "sinks" except Camas Creek which empties into Mud Lake.

From Sheridan Creek, at the extreme eastern edge of the area, westward for more than a hundred miles beyond the area limits, no stream flows into Snake River from the northern side of the Plain. Snake River, in this part of the state, hugs the southern edge of the Plain. Consequently, each river or creek which would enter it would have to flow over arid lava rock for a distance of from 40 to 80 miles after it leaves its mountain valley. Desert evaporation, gravels, and cellularvesicular, and jointed lava conspire to entirely rob the stream of its water before it completes the journey. Many of the "sinks" are really intermittent lakes or playas which occupy depressions formed in the lavas by flows from surrounding lava cones and vents. A rather notably elevated area, formed by built-up lava extrusions, occupies the central parts of the Plain and thus separates the lateral depression along the southeast side of the Plain in which Snake River flows, and the similar depression which extends along the northwestern side of the Plain and in which the "sinks" are found. Many of the streams disappear beneath the edges of lava flows which have originated farther out in the Plain.

Some of the major streams which are lost in "sinks" are Big Lost River, Little Lost River, Birch, Medicine Lodge, Beaver, Warm Springs, and Blue creeks. Mud Lake and associated lakes which are virtually "sinks", receive water at the surface from Camas Creek and underground from some of the above mentioned streams. Some of these streams sink and reappear even during their course through the mountain canyons. Big Lost River, after leaving its mountain valley, strikes off across the Plain towards Snake River. About 10 miles out on the Plain it meets the higher lava area mentioned before and veers to the east for a distance of 10 miles. There it gradually swings northward for another 10 miles where it sinks to reappear after a few miles. It sinks again and rises to the surface again to flow for nearly 10 miles in a northeastern direction to where it finally disappears in the same major "sink" where Birch Creek loses itself. Thus, it flows eastward and northward for more than 50 miles over the basalt to find this depression after reaching the Plain. Little Lost River sinks upon reaching the Plain but much of its water probably contributes to the reappearance of Big Lost River in its journey to the "Big Sink." Many dry playas and old stream channels mark the courses that Big Lost River has used in other times. Major tributaries to Big Lost River are Willow, Lone Cedar, Pete, Upper Cedar, Lower Cedar, Pass, Sage, Alder, and Antelope creeks. Many minor creeks sink upon entering Big Lost River Valley. The chief tributaries of Little Lost River are Mahogany, Bell Mountain, Basinger, Deer, Cedar, Horse, Badger, Boulder, South, Wet, and Dry Creeks. It also has many tributaries that sink in the alluvial fans before reaching it. The only tributaries which reach Birch Creek are Eightmile, Skull, and Pass creeks. About 25 creeks disappear in the alluvial fans of this valley.

Medicine Lodge Creek has Warm, Irving, Fritz, Webber, Eddy, Middle Fork, and Indian creeks for its main tributaries. Beaver Creek is fed by Modoc, Idaho, Pleasant Valley, Miners, Stoddard, Dairy, Threemile, Rattlesnake, Corral, and Spring creeks; the chief tributaries of Camas Creek are Cottonwood, East Camas, and Spring creeks. Many streams flow from Big Bend Ridge, which lies on the eastern edge of the area, and sink at its base.

Five lakes constitute the Mud Lake group. These are Spring Lake, Jefferson Reservoir, Mud Lake, North Lake, and Hamer Lake. These stretch for 16 miles in an east and west direction and are readily located on the map in Jefferson county. According to Stearns[10] the maximum area of Mud Lake which is the largest of the group is 12,670 acres. It is said to have been as small as 2,500 acres before 1908, and as large as 14,200 acres in 1914[10]. According to the same source, Jefferson Reservoir has an area of 1354 acres, North Lake 1200 acres, Spring Lake 700 acres, and Hamer Lake 184 acres. Sheridan Creek reservoir lies in the northeastern part of Clark County and Mackay reservoir lies on the western edge of the area a few miles from the town of that name.

Another playa marks the site of extinct Market Lake, which lies north of Roberts in the southeastern part of Jefferson county.

Pahsimeroi River, Burnt, Sheep, and Gooseberry creeks drain northward into tributaries of Salmon River which enters the Snake many hundreds of miles to the northwestward.

## TOPOGRAPHY.

Four types of topography are represented in the area: (1) rugged mountainous provinces, made up of tilted, faulted, and folded sediments and early andesitic lavas, (2) gently sloping foothill-like areas made up of older gravels and later acidic lavas, which slope to the plains at a very low angle, (3) broad mountain valleys floored with later gravels and vast alluvial fans, and (4) the dominant feature of the region, the Snake River Plain.

The first type is represented by the Lost River Range which lies between Big Lost and Little Lost rivers, by Lemhi Range which is the next range to the east, and by Beaverhead Range which lies between Birch and Medicine Lodge creeks. These ranges are exceedingly rugged and serrated and are chiefly composed of limestone, dolomite, quartzite, shale, and schist. Minor quantities of soft lake beds and altered andesitie lavas make up some of their foothills. Each of these ranges has many characteristics similar to the others. They appear to have had a similar genesis, to contain many of the same formations, and to have undergone the same erosion cycles and physiographic history. They are notably parallel and are separated by basin-like valleys of similar width and each range strikes the Plain at a right angle. The ranges are also similar in their relief and in their major structural features. The highest known point in the area is Mt. McCaleb which reaches more than 11,500 feet above sea level. It is situated in Lost River Range which has 12 other peaks more than 11,000 in elevation within the area. The crest of this range is all above 10,000 feet except where passes cut through, dividing it into three sections. The highest part lies north of Pass Creek. The second section extends from Arco Pass north to Pass Creek, and the lowest part from Arco Pass south to the Plain. The valley bottom of Big Lost River to the west of this range is from 5,800 to 6,000 above sea level so that a vertical relief of about a mile is presented on the western side.

Lemhi, Range, which is an uncut unit, has two peaks within the area which extend above 11,000 feet and has its crest at an altitude of 10,000 feet. The valleys of Little Lost River and Birch Creek are mainly less than 6,000 feet above sea level and a relief similar to that of the Lost River Range exists here.

The Beaverhead Range also has many high peaks of altitudes similar to those mentioned in the other ranges. It is divided into east and west units with the re-entrants formed by Warm Springs Creek and Nicholia Creek on the north, giving it the appearance of a butterfly with one outstretched wing reaching to Birch Creek and the other one to Medicine Lodge Creek. The eastern wing is the highest and most rugged--its crest is above 10,000 feet, while the western wing is over 9,000 feet in elevation. Stratigraphically as well as topographically, these ranges pitch to the southeast where they plunge under the lavas which border the Plain.

No roads cross Lemhi or Beaverhead ranges, but three roads cross transversely the Lost River Range. At Double Springs Pass the elevation is 8,200 feet--at Pass Creek it is 7,500 feet and at Arco Pass approximately 7,200 feet.

That part of the Lost River Range included in this area is about 65 miles long and averages about 13 miles in width. About 45 miles of Lemhi Range is included. It has an average width of 9 miles. The Beaverhead Range projects only about 20 miles into the area and has an average width of about 15 miles.

The second topographic type is represented by most of the Centennial Range, by Big Bend Ridge which borders the area on the east, by the foothills of the Big Hole Range in the southeastern portion of the area and by Juniper Buttes, west of St. Anthony. This topographic type is made up of gently sloping lavas, chiefly rhyolite, trachyte and andesite with some basalt and interbedded lake sediments, ash and gravels. These lavas are late Tertiary in age and vary in thickness from place to place. They stretch in an uninterrupted fringe completely around the northwestern, northern, northeastern, eastern, and southeastern boundaries of the Snake River Plain. The head of the Plain area is not included on this map so the eastern and northeastern edges are not shown.

From the western point of Beaverhead Range to the mouth of Medicine Lodge Creek, the acid lavas dip gently southeastward to the Plain and ascend gradually almost to the Continental Divide. From Medicine Lodge Creek, eastward to beyond the limits of the map, they dip in a southerly direction and rise gently to the Continental Divide to arch over and dip northward into Montana, where they have been eroded from the crest of the Centennial Mountains. Tertiary gravels lie unconformably underneath them and Cretaceous or older sediments are also revealed in small areas. The latter formations, where exposed by erosion, invariably occupy relatively lower areas along the Divide. The higher peaks along the Divide are formed by the lavas which reach heights more than 10,000 feet above sea level.

The sides of these ranges are gentle slopes rather than precipitous cliffs such as are found in the ranges of the rough mountainous provinces. These gentle slopes do not appear to have been produced by peneplanation as suggested by Stearns,[11] but rather by gently dipping lavas. The slopes in general conform to the dip of the acidic series and interbedded ash, and sediments. Although erosion has roughened and modified the original surface so that it is no longer technically a dip slope, it virtually is one.

The third topographic type consists of broad-bottomed basin-like mountain valleys, illustrated by the valleys of Big Lost and Little Lost rivers and Birch Creek. These valleys are now chiefly occupied by stream gravels and alluvium but may be underlain by lake beds and old lavas. Big Lost River Valley is the longest, but it is narrower than the others. Its length in the area is 65 miles and its average width is five miles. At one place it is as narrow as three miles while at places it is eight miles across. It is also very narrow at its southern end. Vast overlapping piedmont alluvial fans reach more than half way across the valley from either side. The head of this valley in this area has an elevation of about 6,800 feet and where Big Lost River enters the Plain, the elevation is less than 5,900 feet above sea level. Some of the alluvial fans rise gradually to a point of 1,500 feet higher than their bases. The valley of Little Lost River is 55 miles long within this area and shows similar characteristics. The narrowest part of this valley is six miles across and this is at the southernmost extremity. Its average width is about eight miles and at some places it is more than 10 miles wide. Wet and Pahsimeroi creek valleys are also unusually wide. Little Lost River Valley is about 7,000 feet above sea level at the northern limit of the area and below 5,900 where the river enters the Plain province. Alluvial fans, stream gravels, and alluvium, as in Big Lost River, make up its floor. The fans here are generally less than 1,000 feet in height. Lake beds and early Tertiary andesitic lavas are known to underlie the gravels in parts of the depression.

About 35 miles of Birch Creek Valley lie in the area. At its narrowest part, near Kaufman, it is nearly six miles across. This point is about 10 miles from where the valley opens upon the Plain. Its average width is also eight miles and some places are eleven miles across. It also is 7,000 feet high at the limits of the mapped area and Birch Creek is less than 5,900 feet above sea level where it enters the Snake River Plain. Alluvial fans less than a thousand feet high, likewise flank the sides and cover its bottom.

Late Tertiary gravels, well consolidated, lie west of the stream in the northern extremity and the valley bottom, north of Kaufman, is also occupied by Late Tertiary Lavas somewhat distorted and chiefly andesitic or basic. Lavas and lake beds probably underlie in places the stream gravels and alluvium which now cover its bottom.

All of the depressions are undoubtedly structural and antecedent to the streams now occupying them. They all may be assumed to have a depth considerably in excess of that now represented. These valleys parallel the mountain ranges as well as each other and their present surface gradient plunges gradually to the Snake River Plain which they strike at a right angle to its edge.

The undisturbed Quaternary lava of the Plain does not form surface embayments in the valleys although older underlying lavas of the Plain very likely extend up these valleys for varying distances. The barren gentle alluvial slopes of these wide mountain valleys furnishes a striking contrast to the precipitous flanking mountain ranges.

The basalt-covered Snake River Plain area shown in the southeastern half of the map is only a small part of the Snake River Plain depression which sweeps across the southern half of Idaho into Oregon in a great crescent. The part of the Plain presented here, as well as those parts extending some distance east and west of the area limits, represents a great structural depression, probably a downwarp, which has since been filled with continental deposits and lava flows issuing from local craters and vents. The chief locus of the extrusive centers, now at the surface, is in the central portion of the Plain area and consequently the last extrusions have piled up the lava along the center, as has already been mentioned, so that the lowest parts of the Plain now lie near the flanking mountain provinces. The outpouring of lava, which has built up this Plain has been gradual and broken by intervals of quiet, accompanied by continental deposition. Perhaps 20 different ages of extrusion may now be differentiated by cones and flows showing at the surface. Many older extrusion records are undoubtedly buried beneath these later flows. Some of the older cones on the present surface may represent Pliocene basalts but nearly all, if not all, may be placed as Early to Late Quaternary. Temporary lakes and streams alternating with lava eruptions have formed a complicated and heterogeneous pattern of interbedded gravels, silts, and flows and interleaved flows from competing craters and vents.

The relatively flat surface of the Plain is now relieved by a great number of tuff, cinder, and lava cones, of varying dimensions, and by abrupt lava flow faces, by so-called pressure ridges and domes, by caverns, tunnels, and all the phenomena ordinarily accompanying a region of volcanic extrusions from local sources.

The Plain area has a relief from side to side of perhaps 600 feet because some of the gigantic gently-sloped lava cones rise several hundred feet above their base. These bases vary from a few hundred yards to several miles in diameter. The extreme eastern end of the Plain is the higher and has an elevation of about 6,300 feet. The Plain slopes gradually southwestward along its longer axis to nearly 4,800 feet at the southern and western limits of the map.

Juniper Buttes, composed of acidic tuffs and lava flows, represent either a swell or dome in the more acid Late Tertiary Lavas which underlie the still later basalts covering the present Plain surface, or an old volcano of large proportions, which was a source for those acid lavas, which remained an island in the basalt inundation. It rises by gentle slopes eight hundred feet above the basalt-covered Plain, which surrounds it at an elevation of about 5,400 feet.

At the extreme eastern edge of the area are the foothills of Big Bend Ridge which flanks the area on the east. It is an arch in the acidic Late Tertiary Lavas and is nearly 20 miles long by 8 miles wide. It also was an island in the basalt-covered basin and the isolated basalt flows now found on its surface are local and younger than most of the basalts at its base which surround it at an elevation of 5,400 feet on the south and southeastern slopes and at least 1,800 feet above the surrounding basalt Plain on its side of least relief.

South of the map limits a short distance are East Butte and Big Butte which represent the unsubmerged tops of great volcanoes which were imbedded in the basalt filled basin. Big Butte protrudes more than 2,350 feet above the surrounding basalt plains but East Butte is smaller and lower. Middle Butte, also outside the area, is a southeastward tilted monadnock of early or late Tertiary lava and is chiefly basalt and andesite.

## PHYSIOGRAPHIC HISTORY.

It has been shown that the three mountain ranges in the western part of the area have much in common. Their physiographic development also has been similar. Lost River Range differs from the other ranges by having two old valleys crossing it transversely. These valleys both extended south across the range and are now marked by early Tertiary lavas and in one case by lake beds. A minor range, which trends parallel to the other ranges, has not been mentioned before. It is represented by Hawley Mountain, the Donkey Hills, which lie northwest of Wet Creek and east of Pahsimeroi Creek, and the southern nose of a mountain mass which lies north of the headwaters of Little Lost River. A deep valley once cut through this minor range and ran south from the northern limits of the area, across where the southeastern end of the Donkey Hills shows the older lava, and then cut deeply across the larger Lost River Range near Pass Creek into the present Big Lost River Valley. This depression appears to have been six or seven miles across in places and was narrowest at the mouth of Pass Creek. What happened if it joined the present depression is conjectural but it may have extended southwestward toward Alder Creek, which lies west of the mapped area where another valley filled with early lavas reaches south to join the Plain. Its narrow width at Pass Creek may be evidence, on the contrary, for a northward flowing stream whose head was near the present mouth of Pass Creek. This early valley, extending from Pass Creek northward, is now filled largely with lavas and lake beds and must have been at least 30 miles long within the map area. A valley of similar nature lies east of Arco. It also crosses the range and runs north and south. It appears to have been about five miles wide and at least 20 miles long. What happens at its north end is concealed by gravels and alluvial fans. It is narrowest where it joins the Plain at its southern extremity and widens to the northward. Another old valley, paralleling the present river valleys, existed between Lost River Range and Donkey Hills! This headed into the Pass Creek Valley near the present head of Wet Creek altho a divide probably separated the antecedent of Pahsimeroi River and a northward flowing predecessor of Wet Creek. It is at present occupied by great thicknesses of early lava and late gravels. A tributary to it was also filled with lava and shows in the western edge of Donkey Hills. This valley was about 30 miles long, within the area, and was about five miles wide. These valleys, no doubt, were occupied by streams of considerable importance but were, it is believed, chiefly structural valleys. The evidence for this conclusion can only be suggested here and will be discussed under the section on structure. The stratigraphic relationships in Pass Creek make reasonably certain that overthrust faulting crosses the range in that vicinity. Another overthrust fault is evidenced on the east side of the Arco Pass region. Another overthrust fault separating Hawley Mountain from Lost River Range is believed to extend northwestward to separate the Cambrian of the Donkey Hills from the younger beds in Lost River Range to the westward. At the north edge of the map the ancient Cambrian (?) beds of Lemhi Range must be separated by faulting from the younger beds lying west of them. A continuous fault did not necessarily extend the full length of any one of these valleys but it seems likely that topographic gaps were made in the Lost River Range by large faults which influenced the early drainage of the area. This does not mean that all the structural adjustment in the area was pre-lava but that post-Carboniferous, (probably Cretaceous), movement had established some earlier structural lines along which movement was renewed in post-lava times. Both the lavas and lake beds are tilted at high angles and somewhat deformed indicating the strength of post-lava movement. It seems likely that the lower parts of the present valleys of Birch Creek, Little Lost and Big Lost Rivers also existed at the same time. The depressions occupied by these streams extend for equal or greater distances to the northwest where they are occupied by similar streams which flow into Salmon River. Each valley has a divide in the gravel-covered valley floor at an elevation of about 7,200 feet. The ranges extend to heights several thousands of feet above the sites where the present rivers are trickling streamlets with almost no erosive power. The present streams are not to be assigned credit for these valleys.

Insufficient evidence was gathered to permit a positive statement as to the direction of flow of the earlier streams, but it seems probably that early streams such as Lemhi and Pahsimeroi rivers which now flow northwestward had valley heads considerably farther south than the present divides.

The evidence suggests a northward-flowing stream which headed near the mouth of Pass Creek and flowed along the present course of Wet Creek past the southeastern end of the Donkey Hills and through the gap now occupied by Milk Creek. Another northward-flowing stream probably headed in wide valley lying between the Donkey Hills and Lost River Mountains in a manner similar to Pahsimeroi River. The lava-occupied valley, which lies on the west side of Donkey Hills, is so oriented as to have contributed to an old northward-flowing stream. The narrow valley north of Donkey Hills was a tributary to the old stream.

The narrow gap immediately east of Arco, may possibly be conceived as the head of another northward-flowing stream which flowed through the Arco Pass region and then northward up Little Lost River Valley and out at the Milk Creek depression. The old Pass Creek Stream would be a tributary of this larger stream. Other tributaries are indicated by the orientation of the re-entrants along the walls of Lost River and Lemhi ranges.

In Birch Creek Valley a northward-flowing stream probably headed west of Kaufman. Re-entrants in the valley walls indicate northerly-flowing tributaries. Southward-flowing streams occupied parts of Big Lost River Valley and the lower part of Little Lost River Valley northeast of Howe and Berenice. Another southward-flowing stream occupied the Birch Creek Valley, south of Kaufman.

The subsidence of the present Snake River Plain region, which lowered the south end of these valleys was accompanied by a complementary, nearly parallel, uplift to the north, which formed the east-west folds in the Centennial Mountains and probably continued in a general westerly direction across these ranges and valleys. Since Late Pliocene acid lavas took part in this movement the present stream arrangement probably represents the necessary adjustment which resulted from the new divide developed by this gently-arched, east-west fold. Undoubtedly much Early Tertiary and Late Tertiary Lavas and associated continental deposits have been eroded from the present valleys by the present southeastward-flowing streams.

Pleistocene alpine and cliff glaciers furnished much rock waste and debris which, at the time of glacial melting, appears to have been spread by torrential streams into great alluvial fans.

Evidence for a Tertiary peneplain surface may be found in the area by the similarity of the heights of the peaks in the various ranges. This peneplain was suggested by Umpleby[12*], but the evidence presented in the limited part of central Idaho represented here, seemed to the writer inconclusive and especially so regarding the age of the supposed base-levelling. If such a peneplain existed here, it was considerably warped and also broken by renewed faulting along earlier zones of weakness in Pliocene and possibly early Pleistocene time.

*Umpleby, Joseph B., an old erosion surface in Idaho; its age and value as a datum plane: Jour. Geol. Vol. XX, pp. 139-47, 1912, also Jour. Geol. Vol. XXI, pp, 224-31, 1913.

It is Umpleby's belief that the peneplain in this region was formed previous to the deposition of the lake beds in the valley of Wet Creek, and that these beds were deposited in a basin eroded after the peneplain had been developed. These Lake beds are contemporaneous with the later flows of the early andesitic lava series since the upper lava flows and lower lake bed and tuff members are interleaved and conformable. A Miocene age is given to these beds by Umpleby because he believes the lavas to possess a Miocene age, and he correlates these lake beds to similar ones in Lemhi Valley north of Birch Creek Valley, where Miocene leaf remains were identified.

The writer believes that the Miocene age of both Lemhi Valley and Wet Creek lake beds and tuffs may be questioned in the light of evidence contributed by a study of the Payette and associated formations of southwestern Idaho made by J. P. Buwalda in 1920. The writer accompanied Buwalda in the entire investigation, and is cognizant of his conclusions regarding the fossil record of those formations. Lindgren* considers the Payette as Miocene in age chiefly on evidence of fossil leaves. By the same method of determination, Umpleby assigns the same age to his lake beds, and thus the two formations, being similar in lithology and in relation ship to other formations, appear to be correlated.

Buwalda,** as the result of Mannalian fossil remains, assigns an age to the lower Payette of upper Miocene of lower Pliocene, and for the upper Payette (Poison Creek Formation of Buwalda***) a lower Pliocene age.

A corresponding change in age is not improbably necessary for Umpleby's lake beds, and should this surmise prove correct the age of the peneplain need not be so ancient as he contends.

At numerous places in southwestern Idaho, the writer has observed the Payette lying in fault valleys and structural depressions distinctly post-Payette in age. It seems likely that Payette lake beds were also deposited in erosion valleys or structural valleys which existed before peneplanation. Whether or not a peneplain existed before the deposition of the Payette, much evidence for peneplanation, after its deposition, surely exists in the mountainous area north of the Snake River Plain both in southwestern and southeastern Idaho.

Possibly an Early Tertiary peneplain existed which was succeeded by a Pliocene peneplain. If so, the earlier base-level was badly warped and faulted after the deposition of the lake bed sediments and then subjected to another base leveling which also affected the lake beds by excavating them except where they were protected by down-faulting and downwarping.

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* Lindgren, Waldemar, Boise Quadrangle, U. S. Geol. Folio 45, 1898.
** Buwalda, John P., The age of the Payette formation and the old erosion surface in Idaho. Science Vol. 60 No. 564, pp. 572-73, Dec. 19, 1924.
***Buwalda, John P., A Preliminary Reconnaissance of the gas and oil possibilities of southwestern and south-central Idaho. Idaho Bureau of Mines and Geol. Pamphlet 5, July 1923.

Evidence collected over several field seasons seems to point to the conclusion that the upper portion of the Snake River Plain, part of which is represented in this area, is the site of a great regional subsidence or downwarp.

A practically unbroken fringe of a series of lavas, chiefly acidic in nature, borders the Plain from the west wall of Birch Creek Valley, where it debouches on the Plain, eastward to the head of the Plain where it swings gradually southward and then westward on the southeastern border and extends across the end of the Blackfoot Range. Isolated remnants of the same lavas are found farther westward on both the north and south* side of the Plain.

These lavas, which project unconformably beneath the generally undisturbed younger basalt flows of the Plain, rise gently from this contact to a height varying from several hundred to a few thousand feet above the Plain.

Assuming a Pliocene age for the Late Tertiary Lavas, a pre-lava peneplain-like area must have existed over a wide region in order to have such a wide-spread relatively flat-lying series of these acid lavas which are consistently thin for their extent and notably similar in lithology over a vast region.

These Pliocene acidic lavas extruded from great volcanoes and small local craters must have had an appearance not unlike the present surface basalt flows of the Plain region. Sinking for several hundred miles along the long axis of the Plain caused the lavas and interbedded Salt Lake formation to dip gently inward to this axis.

Structural features and ranges, antecedent to the warping, which extended across this great area now covered with late basalt, were likewise affected and warped down. The warping in the middle area was accompanied by complementary uplift beyond the present Plain boundaries. The southern ends of Lost River, Lemhi, and Beaverhead ranges now plunge stratigraphically as well as topographically under the basalt lavas of the Plain. Similarly, the folded ranges south of the Plain, and outside the limits of this area, approach the Plain at a right angle and appear to plunge stratigraphically beneath it.

The complimentary, almost parallel, fold produced to the north of the Plain is expressed by the arch which makes up the crest of a large part of the Centennial Range. A continuation of its expression, as already stated, is probably the cause for the divide in the old valleys at the heads of Birch Creek, Little Lost, and Big Lost rivers, which flow southeast, and Lemhi and Pahsimeroi rivers, and Warm Springs Creek which flow northwestward into the Salmon. This divide approximates the point where the Lemhi, Lost River, and Beaverhead ranges begin to develop the stratigraphic plunge, to the Snake River Plain. Uplift, unaccompanied by much lateral movement or folding, is evident in the Big Hole, Caribou and Blackfoot ranges, although no evidence for another parallel arch cutting across the ranges to the south of the plain has

*Kirkham, Virgil R. D., Geology and Oil Possibilities of Bingham, Bonneville, and Caribou counties Idaho. Idaho Bureau of Mines and Geology Bulletin 8, September, 1924.

been seen by the writer.

The downwarp is chiefly filled with lake beds in southwestern Idaho and eastern Oregon and these beds pass under the late basalts to the eastward. It is very likely that a considerable thickness of lake beds underlie the lava-covered Plain area in this region either interbedded with or underlying the lowest of the Quaternary flows. The lower Payette series lies conformably under a similar but thicker acid lava series in southwestern Idaho and eastern Oregon and it seems not improbable that a similar relationship may occur here. On the Centennial Range several thousand feet of consolidated and bedded gravels are exposed by erosion under this acid series of Late Tertiary Lavas. Lake beds, gravels, etc. possibly fill the great plunging valleys of Birch Creek and Little Lost River to great depths and project out under the basalts to join similar buried materials in the greater depression of the Plain.

## CLIMATE, SETTLEMENT, OCCUPATIONS, AND ACCESSIBILITY.

Differences in altitude and regional winds are the chief contributory reasons for a marked variation in the climate of the area.

Mackay, which lies in one of the valleys of the western part of the area, has an annual precipitation of 9.31 inches and an annual normal temperature of 41.4 degrees. At Arco the figures are 9.64 and 40.6, respectively. These stations may be classed as representative of conditions in the mountain valleys. Precipitation is much heavier on the intervening ranges, which are timbered on the northern and northeastern slopes, where snowfields lie for many months of the year. The higher peaks bear snow-filled cirques throughout the year. Snow is said to remain in the valleys only a few weeks yearly. January and May are the months of heaviest precipitation for the mountainous sections.

In the vicinity of Mud Lake,[10] on the lava desert of the Plain area, precipitation averages about 8.25 inches and the temperature about 38 degrees. At Camas,[10] to the northeast and slightly higher, the precipitation is 10.85 inches. At Sugar City, in the eastern edge of the area, the average yearly precipitation is 12.42 inches and the average yearly temperature is 41.2 degrees. Idaho Falls, outside the area and just south of Roberts, has an average yearly precipitation of 13.59 inches and an annual average temperature of 43.6 degrees. It is lower in altitude than most of the desert region in the mapped area.

At Spencer,[10] which lies at the northern edge of the Plain and at the base of the Centennial Range, the precipitation is 17.22 and the temperature similar to that of Arco. Kilgore[10] in the northeastern part of the area has a precipitation of 22.32 inches. These two towns are about 6,000 feet above sea level and have the highest annual precipitation and lowest annual temperatures of any places in the area exclusive of the mountain ranges and Big Bend Ridge. The eastern end of the Centennial Range is heavily timbered and is snow covered many months of the year.

The lava-covered Plain region has great yearly extremes of temperature ranging from 90 to 100 degrees in the summer to 30 to 40 degrees below zero in the winter.

The low precipitation of the western valleys is caused by the high mountain barriers which effect condensation and supersaturation on the ranges.

The largest town in the mapped area is Rexburg with a population of about 5,900. St. Anthony has 3,200 inhabitants and Rigby about 1700. Mackay has less than 900 inhabitants and Arco about 500.

Roberts, Dubois, Teton City, Sugar City, Ririe, Spencer, Hamer, Camas, Moore, and Darlington, are small towns with a few families and business houses. Post offices, schools, or stations and little else are represented by Howe, Berenice, Clyde, Leslie, Dickey, Chilly, Lost River, Sweet Sage, Reno, Winsper, Old Monteview, New Monteview, Small, Edie, Argora, Kilore, Idmont, Tenno, Jones, High Bridge, Wilford, Salem, Parker, Egin, Sunny Dell, Lewisville, Heise, Herbert, Menan, Level, Hawgood, Terreton, and Plano. Only a few of these latter names represent railroad points.

The more thickly settled agricultural regions are along Snake River in the southeast, along Big Lost River in the west, and around Mud Lake.

The occupations are varied. Mackay represents a mining and agricultural community. Spencer and Kilgore depend on livestock. The rest of the area is agricultural. The larger centers represent railroad shipping points in irrigated areas and the small ones are trading centers for dry farming regions. Little lumbering is done in the area and practically no manufacturing, except sugar refining.

The Oregon Short Line Railroad is the only rail transportation represented in the area. The main line extends from Pocatello, Idaho to Butte, Montana. It cuts across the area from north to south. Spencer, Dubois, and Roberts are the larger stations along this line. The Yellowstone Branch of this system leaves at Idaho Falls and extends to West Yellowstone, serving the Upper Snake River Plain. Rexburg, St. Anthony, and Rigby are the largest towns served by it in this area. The Mackay Branch, which leaves the main line at Blackfoot, serves Arco and Mackay.

A main gravelled highway follows the railway line from north to south. The Yellowstone Trail follows Snake River from Idaho Falls across the southeastern corner of the area. The Central Idaho Highway cuts westward from Sheridan Creek through Kilgore to Spencer, then to Dubois and west through Howe to Arco. The valleys of Big Lost and Little Lost rivers, and Birch Creek are arteries of travel toward the Salmon River and possess unimproved roads. Several roads cut across the desert. One of these cuts the desert from the mouth of Birch Creek to Camas, and one connects Birch Creek and Mud Lake. Another leads from Howe to Mud Lake, Hamer and Roberts, and still another connects Arco with Roberts. Arco, also, has desert roads connecting it with Idaho Falls and Blackfoot. Desert roads in the eastern part of the area connect St. Anthony with Kilgore and Spencer, and St. Anthony with Dubois. Of the desert roads, none except the Central Idaho Highway and the Mud Lake roads have water along their course. Many little-used desert roads wander aimlessly across the barren lava region and are used almost exclusively by sheep camp outfits, and live-stock men.

GEOLOGY.

STRATIGRAPHY.

In the attempt to give stratigraphic and age values to the great mass of Paleozoic sediments making up the western mountain ranges, the writer was guided by the lithologic descriptions of Umpleby[12] and Mansfield* and the paleontologic descriptions of Umpleby.

Previous experience with the stratigraphic section southeast of the plains was useful since some similarities appear to exist. Visits were made to the localities described and measured by Umpleby[12] and where fossil determinations were made by the U. S. Geological Survey. A few days were spent in becoming familiar with the lithology and sequence of these sections and then an attempt was made to allocate approximate ages to the various parts of the mountain masses. The boundaries of the variously aged groups, as shown on the map, are sketchy and inferred rather than traced and their chief value is to show the main formational relationships and to help indicate the probable major structural features of the region. The boundaries as well as the structure sections are highly generalized and do not undertake to show anything but the main form of the structural masses. The relationships near the major faults are fairly obvious and have a higher degree of accuracy. Vast numbers of small folds and faults were observed but not mapped. Thus in a section where a formation appears as a relatively gentle monocline several folds or faults of small displacement may occur, and the section undertakes to show only the general regional dip of the formation.

Faulting may likewise have brought small outcrops of older beds to the surface in a formation mapped as younger. Such occurrences were often too small to map and many, no doubt, were also undetected in this rapid reconnaissance.

Drainage was the chief guide to location on the base map and distances were generally estimated.

CAMBRIAN(?) SYSTEM.

The section first studied was at Wilbert, on the west side of the Lemhi Range at the head of Camp Creek. The age of these beds is questionable as no fossils have been found associated with them. They are tentatively assigned to the Cambrian purely on lithologic similarities and stratigraphic position.

Umpleby[12] describes the Wilbert section as follows:

> "The supposed Cambrian quartzites in the vicinity of Wilbert in the Lemhi Range, include four fairly distinct formations that are designated lower quartzite, shale, middle quartzite, and upper quartzite. The lower quartzite is a massively to semi-massively bedded white rock that has a wide range in texture but is, in most places, pebbly, containing subangular, pebbles of quartz as much as a quarter

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* Mansfield, G. R., Geography, geology and mineral resources of the Fort Hall Indian Reservation, Idaho, U. S. Geol. Survey Bull. 713, 1920.

of an inch across, firmly cemented by the finer siliceous material. The base is not exposed, but 200 feet of beds appear in the canyon side below the Wilbert mill.

A shale formation intricately folded in the vicinity of the mill but apparently about 150 feet thick, overlies the lower quartzite. The rock is greenish gray and has been so greatly compressed that it breaks readily into irregular plates with curved faces. Its metamorphism was accompanied by the development of considerable chlorite and sericite.

Above the shale formation is the middle quartzite, which, as exposed in nearly vertical beds along the canyon above the Wilbert mill, is 475 feet thick. The rock has a maroon color which contrasts sharply with the prevalent light grays of the other quartzite formations. The lower part of it is made up of thick beds, some of which are intricately cross-bedded, but the upper layers are thin and regularly stratified.

Overlying this formation is an assemblage of quartzite beds that were grouped and mapped as the upper quartzite. They are at least 800 feet thick although, as there is a strong fault on the east, their full thickness was probably not observed. The lowest beds consist of 25 feet of milky-white fine-grained quartzite, overlain by 6 feet of dark gray medium-grained quartzite, then 10 feet more of the milky-white variety, which grades into a brownish facies containing numerous annelid borings, the total to this horizon representing a thickness of about 170 feet. Above this lower group of beds is 80 feet of thin-bedded clear-white fine-grained quartzite, which from local evidence might be considered a distinct unit. This is overlain by 550 feet of massive quartzite beds of light-gray color and fine-grained texture."

The foregoing description fits much of the series of sediments ascribed to that age by the writer. In most instances the thicknesses appeared to be greater than those given by Umpleby.[12] Although, according to Umpleby, his section is faulted or eroded at both the top and the bottom, he measured a total of about 1625 feet. The writer would raise this figure to 2,000 feet at other localities.

A series of rocks assigned to the Algonkian system by Umpleby[12] lie next to the valley on the west side of the Lemhi Range. This band of rocks is about three miles wide at the edge of the area and diminishes to the south until it entirely disappears near Horse Creek. A study of the Cambrian, as it is traced north from Camp Creek to the same locality, shows these beds to be either the same or very similar. If they represent Algonkian rocks they appear to be conformable with members assigned tentatively to the Cambrian farther south. These rocks east of Milk Creek and in Cedar Creek and Sasinger Canyon are chiefly gray sericitic schist and gray and red quartzites and are no more metamorphosed than the Cambrian(?) farther south. The metamorphism, which is slight, may have been induced by the nearby major fault which is assumed to lie near their base.

Red, white and gray quartzites largely make up the Donkey Hills and a slice of the mountain mass west of Milk Creek. The Cambrian(?) series is believed to occupy the entire western side of the Lemhi Range from the edge of the area southward almost to Berenice. Its regional dip in this range is slightly north of east at varying angles where it lies apparently conformable under the Ordovician series of sediments.

A slice of red and gray quartzites thought to be up-faulted Cambrian is exposed surrounded by the Carboniferous series in the west wing of the Beaverhead Range in Skull Canyon.

This series is similar to the Cambrian series described by Mansfield* in the Fort Hall Indian Reservation southeast of the Snake River Plain. Red, purple and pink quartzites are fairly abundant throughout this region and may correspond to the Brigham quartzite (Middle and Lower Cambrian) of that region and the region farther south in Idaho and Utah. The chief difference between the two series seems to be in the absence of any limestone in the Cambrian of this region. Some of the limestone at present assigned to the overlying Ordovician should possibly be included here.

The presence of annelid trails and the apparently conformable relationship to the overlying Ordovician, coupled with the lithologic similarity to the Brigham quartzites are the only criteria for assigning to the beds a Cambrian age.

## ORDOVICIAN SYSTEM.

This series, as defined by Umpleby,[12] has three formations. At Elbow Canyon the lowest is made up of 1600 feet of fine-grained white quartzite. This is overlain by 420 feet of dark blue dolomite and 530 feet of white dolomite. The latter two formations, according to Umpleby,[12] contain Ordovician fossils.

This series is exposed along the western base of the Lost River Range from the northern edge of the area to a point east of Mackay. After a short break it appears again at the northern edge of Butte County and reaches south to a point east of Moore, where it is cut off by a fault. This series also appears for a short distance along the northern end of the east side of the range, where it extends south of Spring Hill mountain. The northern half of Hawley Mountain is made up of these beds as is also the western tip of the low ridge about five miles east of Arco. A band of these rocks extends along the entire west side of the Lemhi Range. Erosion along a subordinate fold in this range has exposed the Ordovician series along its eastern flank in several disconnected areas. A small area appears west of Milk Creek at the border of the map. The series was not recognized in that part of the Beaverhead Range represented here. However, the upper dolomitic members are so similar to the Carboniferous that they may be present in small areas where they were undetected.

*Mansfield, G. R., Geography, Geology and Mineral resources of the Fort Hall Indian Reservation, Idaho. U. S. Geol. Survey Bull. 713, 1920.

The white vitreous quartzite is tentatively correlated with the Swan Peak quartzite of southeastern Idaho. It is a conspicuous cliff-maker where gently tilted, and a ridge-maker where steeply inclined. It is much fractured due to structural movement, contains many minute cavities, and is iron stained in places.

The two dolomite members of this series are fossiliferous according to Umpleby[12] and are identified by characteristic Richmond fossils. They are correlated with the Fish Haven Dolomite, southeast of the Plain. The upper gray dolomite may very doubtfully be correlated with the laketown dolomite of southeastern Idaho and Utah which has been assigned to the Silurian system in that region.

## DEVONIAN SYSTEM.

More than 4,000 feet of beds assigned to this system by Umpleby,[12] are exposed at several places in the area. They lie conformably on the Ordovician beds of Fish Haven or Laketown(?) dolomite. The lower 2,000 feet are correlated with the Jefferson limestone and are made up of dark blue and gray colored massive dolomite. The upper 2,000 feet are chiefly brown shaly limestones which weather into smooth grassy slopes characteristic of the formation throughout the entire region. The uppermost 500 feet is another dark blue and gray dolomite with massive cliff-forming members. This dolomite contains red and brown shaly limestones which weather easily and stain the series giving it a color which serves as a convenient horizon marker. This limestone contains, according to Umpleby[12], fossils of Three Forks age. The top 2,000 feet of the Devonian is correlated with the Three Forks limestone of southeastern Idaho and Montana.

These beds make up the sides of the northern part of the Lost River Range and are exposed along the western flank of the southern portion. They are exposed in stream valleys on the eastern slope of the range and a narrow strip of them borders the eastern valley occupied by Arco pass near Horsethief Canyon.

Lemhi Range is capped by this series for most of its length, and small unidentified areas of dolomite probably occur in the Beaverhead Range, where erosion may have cut through the Carboniferous series.

## CARBONIFEROUS SERIES.

This series has the widest areal distribution of any of the Palezoic formations. A thickness of approximately 12,000 feet is assigned to this group of limestones. Umpleby's[12] section in the Joggle Canyon east of Mackay, shows 4,300 feet of Carboniferous beds at this point. His description is as follows:

> "The lower beds exposed are 1500 feet of thin-bedded, fine-grained, calcareous slate, which becomes somewhat thicker-bedded near the top. Conformably above these beds is 400 feet of buff and pale-maroon shale with a few thick beds of fossiliferous limestones near the base. Above the shale

beds is 200 feet of dark limestone in thin beds, which become thicker upward and lie beneath a medium-bedded limestone of distinctive reddish-buff and blue color. Above this limestone is 300 feet of massively bedded dark blue limestone, which grades upward 100 feet of buff sandstone, then follows 100 feet of clayey limestone which weathers a bright red. Above this, 1,050 feet of thick-bedded blue limestone remarkably free from partings along the bedding continues to the summit. Fossils were found only in the lower 200 feet."

At other places in the area from 2,000 to 4,000 feet of limestone, uniform in nature and of a dark blue color, occur in a position apparently above these highly colored horizon markers. The lower exposures of this uniform section generally show an unusually large number of chert bands. These chert masses make up from 20 to 30 per cent of the rock for several hundred feet of the section. They are well exposed on the ridge east of the mouth of Birch Creek.

According to Umpleby's[12] fossil determinations this series is chiefly upper Mississippian and would be correlated with the Brazer Limestone of other Rocky Mountain areas. The lowermost series may likewise be part of the Madison limestone which is so extensive in other regions.

More than 6,000 feet of conglomerate, sandstone, quartzite, and limestone, overlie the Mississippian series. The rocks are nearly all rusty brown sandstone and blue limestone. A heavy conglomerate apparently separates this series at places from the lower limestone. Umpleby[12] gives this group of beds a Pennsylvanian age. It would correlate easily with the Wells formation of other regions but for its immense thickness.

Only a small portion of these beds appear in the Lost River and Lemhi ranges. They show best in the Beaverhead Mountains, where they occupy the center of a great syncline along the axis of the range.

The Mississippian beds are best exposed along the crest and the southeastern slope of Lemhi Range. They appear again on the extreme outside flanks of the Beaverhead Range and at places within the range where they are exposed by erosion in deep canyons.

East of Medicine Lodge Creek a series of limestones believed to be Mississippian are shoved up, as the upper lip of a great overthrust, above a series of Triassic conglomerates and limestones, which no doubt overlie Permian deposits.

Several chert exposures not unlike the Rex chert member of the Phosphoria formation were seen in the area north of Lidy Hot Springs where the Tertiary Late Lavas have been removed in isolated areas. Stearns[10] reports that the U. S. Geological Survey has identified Permian fossils from Medicine Lodge Creek. No Permian deposits were recognized in this area, although the Phosphoria formation in Montana has been traced by Condit[3] to the northern edge of the area. The writer believes the phosphate bearing Permian formation to be covered in the north part of Medicine Lodge basin by overthrust Mississippian limestones. Permian deposits were found on the crest of the Centennial Range, north of Sheridan Creek, where phosphate rock crops out. This location is referred to by Condit[2,3]. The Permian deposits at this place are less than 200 feet thick and are chiefly quartzite, chert and shale. About 2,000 feet of Pennsylvanian and Mississippian rocks occur below the Permian here and outcrop across the Montana line. The Pennsylvanian at this place appears to be only a few hundred feet thick.

It is doubtful if more than 2,500 feet of Carboniferous sediments is represented in the almost complete section exposed in Centennial Range. In the western part of the area a thickness of at least 12,000 feet is assumed for the Mississippian and Pennsylvanian members alone. This figure may be raised to 15,000 when detailed work is done or may be cut down if duplication by faulting is found where now undetected.

## TRIASSIC SYSTEM.

More than 3,000 feet of massive red conglomerate and thin limestone members is exposed in one small area on the map. These are in T. 13 N., R. 33 E., north of Irving Creek.

Fossils from this limestone according to Stearns[10] were identified by the U. S. Geological Survey as coming from the Thaynes formation of Lower Triassic age. That part of the series shown on the map dips to the southwest under the overthrust, eastwardly-dipping Mississippian limestone. This conglomerate is filled with an abundance of black chert, red quartzite and white quartzite pebbles, large quantities of limestone and dolomite fragments are also included in the red clay-like matrix.

About 1,000 feet of brown and bright red shale is exposed north of Sheridan Creek. The lower 300 feet of brown shale is tentatively correlated with the Woodside shale of southeastern Idaho, and the upper red shale with the Thaynes formation which contains red shale in other parts of Idaho.

These beds dip southward at a low angle ranging from 5 to 15 degrees.

## JURASSIC SYSTEM.

About 700 feet of sandstone and shale overlies the Triassic red beds north of Sheridan Creek. These have been tentatively assigned to the Jurassic and are probably to be correlated with the Ellis formation of Montana. They dip southwest at a low angle.

## CRETACEOUS SYSTEM.

Cretaceous beds of Frontier Age[7] are exposed in three isolated patches along the Centennial Range and Continental Divide where the overlying Tertiary gravels and lavas have been removed by erosion. About 3,000 feet of Frontier(?) and older Cretaceous formations are exposed in these areas. In the two easternmost exposures the beds dip at low angles to the southwest. They probably represent a continuous series because the beds at the head of Cottonwood Creek are assigned to the Frontier by Mansfield[7] and those north of Sheridan Creek appear to be the Wayan or Bear River formations which underlie the Frontier. The thickness of Cretaceous beds represented here in this monocline is possibly in excess of 6,000 or 7,000 feet. The Frontier beds are more disturbed near Humphrey and Modoc Creek where a few minor folds occur. These beds are almost entirely yellow and cream-colored sandstone and shale and contain occasional small seams of bituminous material. Some limestone members occur a few miles east of Humphrey.

TERTIARY SYSTEM.

Tertiary lake-beds occur at two places in the area. One group lies in Wet Creek basin west of Lost River Range and the other group is situated at the head of Medicine Lodge Creek and extend across the divide into Montana. As has been suggested under the discussion of the age of the central Idaho peneplain, the writer believes the age of these lake beds to be upper Miocene or lower Pliocene, comparable to the age assigned to the Payette of Poison Creek formations by Buwalda.*

In Medicine Lodge Creek the lake-beds dip to the southwest at angles of about 15 degrees. They are probably less than 1,000 feet thick and are made up of sandy shale, dark shale, lignite, sandstone, and conglomerate.

On Wet Creek the lake-beds dip northeast at steeper angles, generally more than 30 degrees. The series here is more than 2,000 feet thick of which about 1,500 feet is shale. Limestone, sandstone, conglomerate, lignite, and tuff, are all present in the section. The lower lake-bed members are here interleaved with the upper flows of the underlying and conformable tuffs and lavas of the Tertiary Early Lava series. The lake-beds in both places range from a brown to a creamy-yellow color and appear to differ in texture and material locally.

The Tertiarly gravels are of an age earlier than the Pliocene late acid lavas (called Tertiary Late Lavas in the section on igneous rocks) since they are overlain by members of that series wherever they were recognized. They may represent the Salt Lake formation. Two notable areas of these gravels are represented on the map. One area lies in the upper valley of Birch Creek. The other lies along the crest of the Centennial Range west of Humphrey and Spencer. In the latter area the gravels are steeply folded into a syncline, and possibly an anticline, and show a thickness of over 5,000 feet. They are consolidated and roughly stratified and are made up chiefly of black chert, and red, white, and pink quartzite pebbles. Practically no limestone pebbles occur in this formation. The pebbles range from 8 inches in diameter to minute sizes. These gravels also underlie the lava in places north of Kilgore and east of Humphrey where they are relatively thin.

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*Buwalda, John P., The age of the Payette formation and the old erosion surface in Idaho. Science Vol. 60, No. 564, pp. 572-73, Dec. 19, 1924.
__________, A preliminary reconnaissance of the gas and oil possibilities of southwestern and south-central Idaho. Idaho Bureau of Mines and Geology Pamphlet 5, July 1923.

Many other gravel deposits fill the intermontane valleys but nearly all of them are Quaternary to Recent at the surface. No doubt Late Pliocene gravels, which are younger than the Tertiary Late Lavas, lie in some of these valleys but are covered over with younger deposits.

The Salt Lake formation which is interleaved in this area with the Tertiary Late Lavas is described with that series.

## QUATERNARY SYSTEM.

Gravel and alluvium deposited by river, glaciers and in lakes are widespread over the area.

In the western mountain valleys, the gravels represent alluvial valley flats, alluvial fans and cones, and glacial moraines. Older gravels, cross-bedded and sorted, and probably of Pleistocene age are partially covered with late alluvial deposits. The pebbles are colored quartzite and black chert with some limestone.

The gravel and alluvium in the area west of Mud Lake extends to a depth of about 400 feet in many places as evidenced by well logs. This material is probably Pleistocene to Recent and chiefly represents deposits in a temporary lake of great extent. The gravels here are rhyolitic, quartzitic, and dolomitic pebbles. Loess and light clay soils extend over much of the older lava desert.

The present flood plain of Snake River is occupied by alluvium and the gravel deposits of an enormous alluvial fan or delta according to well logs; these gravels are about 300 feet deep near Rexburg and Ririe. They are underlain by basalt at shallow depths in many places. There appear to be two or more ages of alluvium in different parts of the area but they were not differentiated.

## STRUCTURE.

### GENERAL STRUCTURAL FEATURES.

The geologic structure of the area is complex and involves folds and faults of major proportions as well as uncounted minor irregularities. At least three periods of movement have affected the area. Much of the structure is masked by Tertiary and Quaternary gravels and lavas and only hypothetical conclusions can be arrived at in some cases.

The major folds of the region are the Snake River Plain geosyncline and the Centennial Mountains geanticline. Each of the mountain ranges of the area show folds of great persistence and size as well as myriads of small flexures. Four great regional faults were mapped in the area. Evidence points to their overthrust character. One of these, east of Medicine Lodge Creek, is overthrust to the east, as are the majority of faults in southeastern Idaho. The other three appear to be approximately parallel in altitude and are overthrust to the west. These faults, because of their westward overthrust nature, point to the development of two-sided wedge zones from compressional stresses and give added weight to the necessity for consideration of the major structural features of Idaho in the light of the diastrophic wedge-theory of R. T. Chamberlain* and his associates. The west side of the Beaverhead Range is probably bounded by still another fault of major proportions. This may also be an overthrust to the west, but insufficient evidence was collected to determine this fact. Many normal faults of various extent and displacement were observed, but only a few were mapped.

The traces of the faults and folds shown on the map are sketchy so far as accurate location is concerned, but the writer believes the relationships of the major masses are correctly delineated. Several notable angular undonformities are found in the Tertiary relations to Mesozoic and Palezoic sediments.

### SPECIAL STRUCTURAL FEATURES.

#### SNAKE RIVER DOWNWARP AND CENTENNIAL MOUNTAINS UPLIFT.

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 re-entrants. Its average width, in the area, measured at right angles to the axis, is nearly 45 miles.

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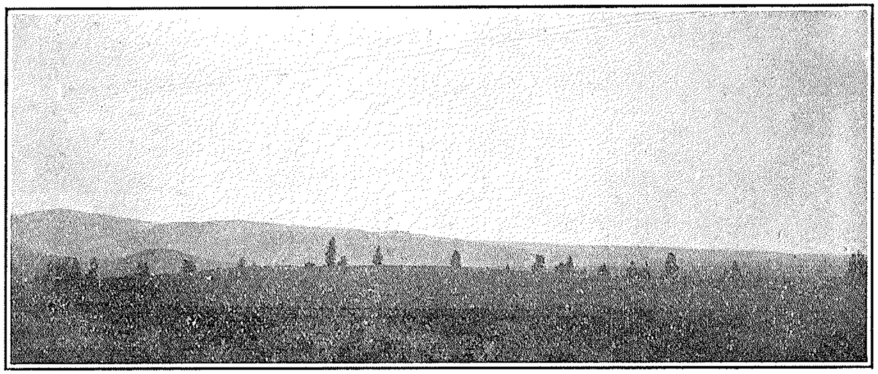
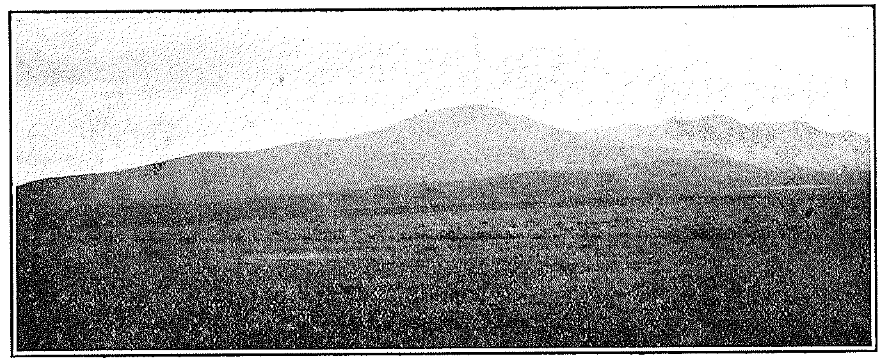
*1. Chamberlain, Rollin T., The Wedge Theory of Diastrophism, Jour. Geol. pp. 755-792, Vol. 33, 1925.

2. Flint, Richard Foster, A Brief View of Rocky Mountain Structure, Jour. Geol. pp. 410-431, Vol. 32, 1924.



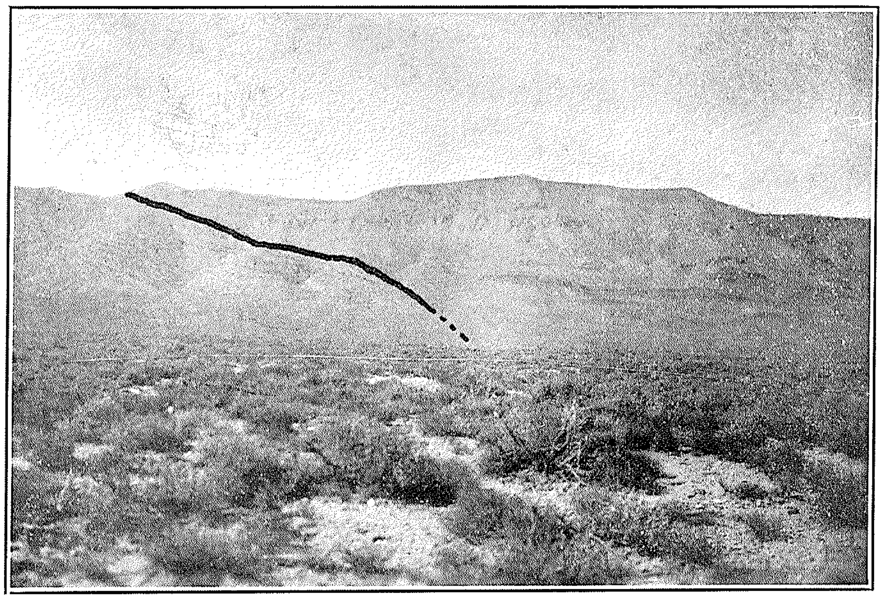
A.

A. Looking East. Acidic Tertiary Late Lava, on the north side of the Plain in middle distance, and horizon, dipping gently southward and disappearing under the Snake River Plain basalt. A basaltic cinder cone, perched on the older acid lava, shows in the extreme left middle distance. In the foreground, in front of the trees, is a small lava cone.



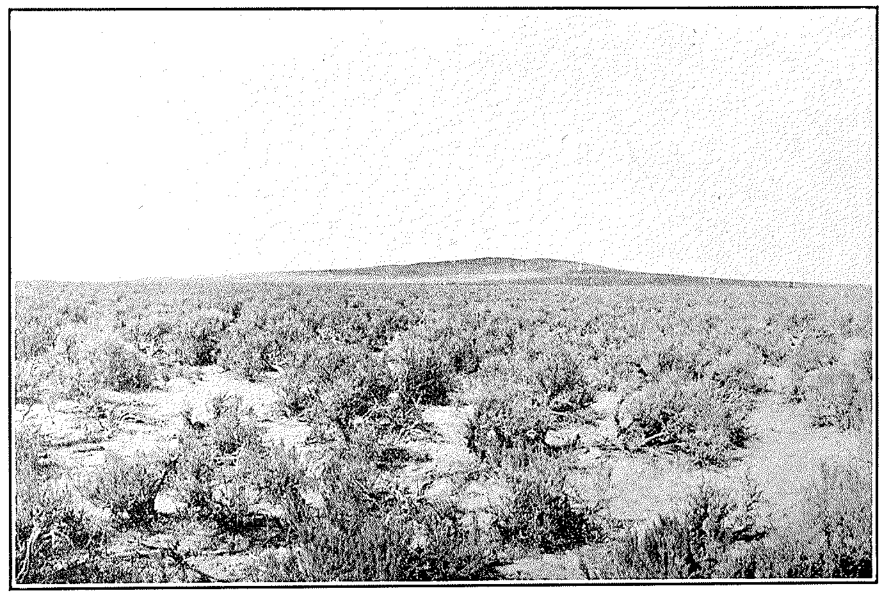
B.

B. Looking East. Acidic Tertiary Late Lava on the southeast side of the Plain on horizon dipping gently northward and northwestward to disappear under the Snake River Plain basalt. Alluvial fan of South Fork of Snake River in foreground and middle distance.



C.

C. Looking North. Carboniferous limestone which makes up the west wing of Beaverhead Range can be seen plunging stratigraphically and topographically beneath the Plain. This is the southeasternmost tip of the range. Note the angular unconformity delineated by the heavy black line between the limestone and the over-lying Tertiary Late Lavas which lie on the noses of these ranges and also dip to the Plain at a different angle.



D.

D. Looking North. Typical lava cone showing wide expanded base. This type of cone is more common in the western lava area.

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. Figures 2 and 3 are sections showing the relationships existing from Medicine Lodge Creek to Henry's Fork along the northern edge. The relief here is often as much as 4,000 feet. In other parts of the Plain area, expecially along the east and southeast, the relations are the same but the relief is less (See photographs A and B, Plate 1.).

These lavas dip towards the Plain at some places along the Continental Divide with a gradient of about 300 feet per mile. At other places as on Medicine Lodge Creek, this gradient is as low as 100 to 125 feet per mile.

A slope of four 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 congectrual but in a structural valley whose average width is 45 miles a great vertical distance might be reached before flattening out taks 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 flat-lying widespread acid lavas was accompanied by an isostatic 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.5

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

Minor warpings occurred at Big Bend Ridge after some of the Snake River basalt was erupted. At this place, the Snake River basalt is arched and eroded, in many places, to the underlying acidic series. The eminence at Juniper Buttes may represent a similar warping. Flows of basalt and lava caps and mesas are found on its higher points although no late source for them was observed. The great size of this acid mass compared to its lack in height makes it seem possible that this also is an arched-up area. (See photograph C Plate II.) Further data on its occurrence is also presented under the section on igneous geology. Other movements in the area are represented by faulting which has affected the late lavas. The most notable of these displacements lies northeast of Mud Lake. These later movements may be due, however, to settling rather than to regional movement.

It must be understood that in using the expression "downwarp", that 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 wide-spread 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 major mountain faults which approach the Plain edge at a right angle.

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.

## MEDICINE LODGE OVERTHRUST FAULT.

This overthrust fault was first noted where Carboniferous limestone beds, whose lithology caused them to be assigned to a Mississippian age, were found overlying a vast thickness of red conglomerate and thin interbedded limestones which dip in an opposite direction. The fault was traced in both directions along its strike from Irving Creek, which is a branch of Medicine Lodge Creek, and found to extend for many miles into Montana where its possible extension may be found in the overthrust fault west of Dillon. Figure 9 of the structure sections represents, by a generalized sketch, the conditions here. The fault has Mississippian (?) limestone, which dips east and northeast, on the western overthrust side. The underthrust or east side is occupied by beds assigned by Stearns[10] to the Lower Triassic.

To the southeast the fault disappears under the Tertiary Late Lavas which are apparently unbroken by it. The vertical throw at this place is probably not less than 10,000 feet and the horizontal overthrust several times that much.

South and southeast of the Plain in Idaho and Utah occurs the Bannock Overthrust, a fault of tremendous extent and proportions. This was first described in 1912.*

* Richards, R. W., and Mansfield, G. R., The Bannock Overthrust: A major fault in southeastern Idaho and northeastern Utah; Jour. Geol. Vol. 20, pp. 681-707, 1912.

Further work by geologists of the U. S. Geological Survey and expecially by Mansfield* has furnished further information regarding it.

The overthrust is credited by those writers with a length of more than 270 miles and a horizontal displacement of from 12 to 35 miles. The thrust is to the northeastward. The underlying block is generally composed of folded Mesozoic rocks somewhat less resistant than the Paleozoic rocks which generally make up the more competent overlying block. In some places the overthrust constitutes a single fault plane but more commonly it is branched and shows as many as six distinguishable branches in some localities.

From previously published investigations, its farthest north trace southeast of the Plain is shown to lie in the Blackfoot Mountains where they disappear under the acid Tertiary Late Lavas which in turn plunge under the Plain. This point lies approximately 23 miles due south of Rigby.

At this point the plane of the fault, where it cuts the surface, has a general strike of about N. 20 W. It seems in the highest degree improbable that this vast fault abruptly ceases here. The strike given above, when projected across the lava desert, passes north of Mud Lake and strikes the north side of the Plain in the vicinity where the Medicine Lodge fault appears from beneath the acid lavas and extends across the Divide into Montana. A fault[10] of considerable magnitude lies along the north shore of Mud Lake and may represent recent movement along the possibly underlying Bannock overthrust.

In the Blackfoot mountains Carboniferous beds are thrust eastward over the Triassic and younger beds. At that place the Carboniferous beds dip west and southwest and the Mesozoic beds dip to the northeast. Thus, the same stratigraphic relationships exist where the Bannock overthrust last appears and where the Medicine Lodge overthrust first appears.

All the evidence points to the probability of the Medicine Lodge fault, which extends into Montana, being an extension of the Bannock fault southeast of the plains.

## THE LOST RIVER OVERTHRUST FAULT.

The Lost River overthrust with the Hawley Mountain overthrust, and the Lemhi overthrust is of importance inasmuch as it offers an explanation of the fomration of these ranges and valleys different from that heretofore proposed. These faults are also notable because they differ from the major overthrusts of southeastern Idaho in the direction of the thrust. These valleys and ranges have, previous to this investigation, been called products of "Basin Range faulting". But Basin Range faulting is generally conceded to be predominantly of the horst and graben type, and represent expressions of vertical, rather than horizontal, forces, whereas the juxtaposition of the various stratigraphic

*1. Mansfield, G. R., Types of Rocky Mountain Structure in southeastern Idaho: Jour. Geol. Vol. 29, No. 5 pp. 442-468, 1921.
2. ______________, Structure of the Rocky Mountains in Idaho and Montana: Geol. Soc. of Am. Bull. Vol. 34, pp. 263-284, 1923.
3. Richards, R. W., and Mansfield, G. R., Geology of the Phosphate deposits northeast of Georgetown, Ida.: U. S. Geol. Survey Bull. 577, 1914.

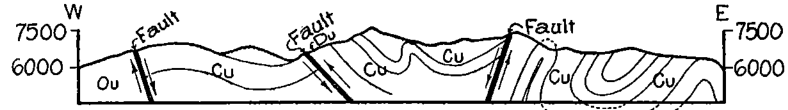



Fig. 1 – Section across extreme Southeast end of Lost River Range East of Arco.

1 0 1 2 3 Miles

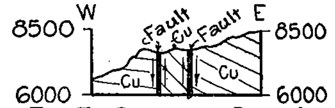



Fig. 7 - Section in Beaverhead Range East of Kaufman.

2 0 2 4 Miles

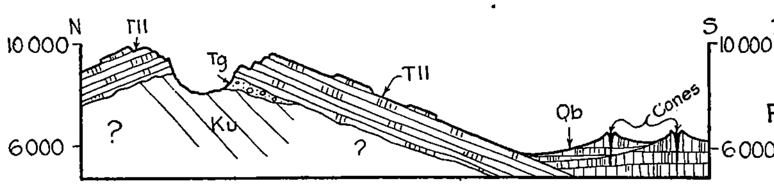



Fig. 2.- Section across Centennial Range East of Humphrey.

2 0 2 4 Miles

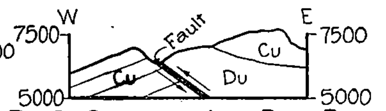



Fig. 8 - Section in Lost River Range East of Moore.

2 0 2 4 Miles

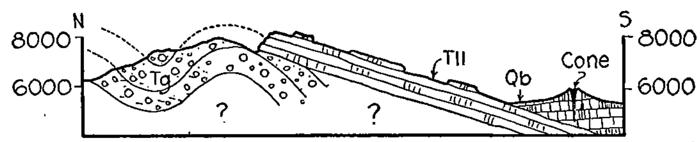



Fig. 3.- Section across Centennial Range West of Humphrey.

2 0 2 4 Miles

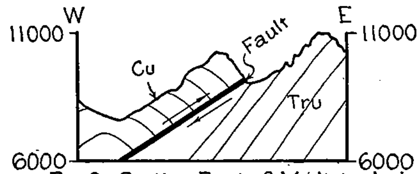



Fig. 9 - Section East of Medicinelodge Creek North of Irving Creek.

2 0 2 4 Miles

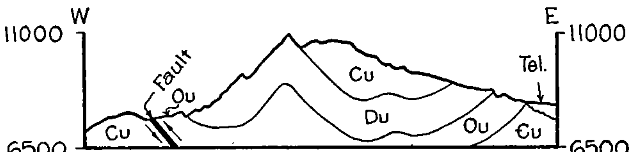



Fig. 4 - Section across Lost River Range North of Double Springs Pass.

2 0 2 4 Miles

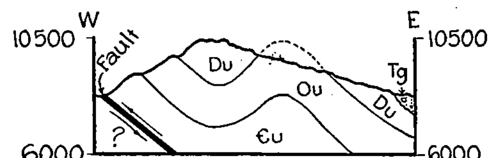



Fig. 10.- Section across Lemhi Range East of Basinger Canyon.

2 0 2 4 Miles

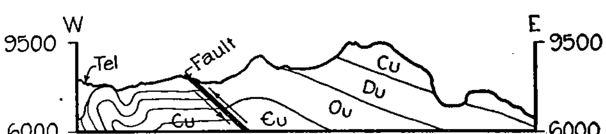



Fig. 5.- Section across Lost River Range from Pass Creek Eastward to Little Lost River Valley.

2 0 2 4 Miles

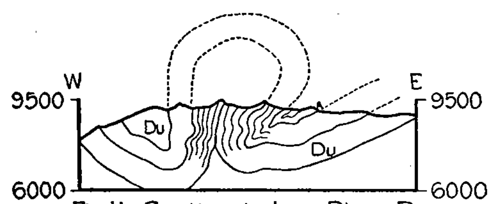



Fig. 11.- Section in Lost River Range East of Mackay.

0 ½ 1 Mile

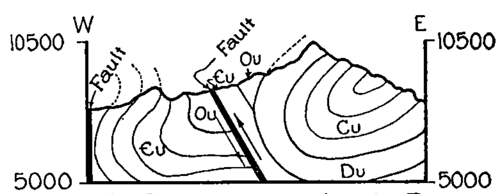



Fig. 6.- Section across Lemhi Range North of Bernice.

2 0 2 4 Miles

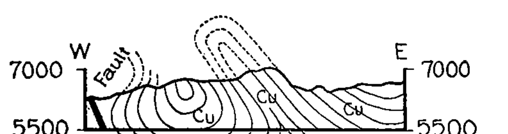



Fig. 12.- Section across Foothills West of Howe.

0 ½ 1 Mile

Qb-Quaternary Basalt Tel-Tertiary Early Lavas Ku-Cretaceous Undiff. Cu-Carboniferous Undiff. Ou-Ordovician Undiff.
Tll-Tertiary Late Lavas Tg-Tertiary Gravels Tru-Triassic Undiff. Du-Devonian Undiff. €u-Cambrian Undiff.

GENERALIZED STRUCTURE SECTIONS OF THE AREA series and the regional tilt of the mountain slices in this area point conclusively to an overthrust origin. Many minor folds along major monoclines show also the overthrusting forces. Overturned folds, products of both overthrusting and underthrusting, are abundant.

Figures 11 and 12 are presented as examples of the complex minor folding which may take place in one formation which appears on the map as an area without dip or structure symbols. Only regional dips are given on the map except in a few cases where it was convenient.to secure more detail. Consistently the older beds appear on the western sides of these tilted blocks and the younger beds appear only on the eastern sides of the mountain masses. The relations are evidently not those of "Basin Range faulting".

The Lost River overthrust extends northwestward from a point east of Arco beyond the mapped area. Its relationships are obvious and can be studied at three places. The best sections are east of Moore and north of Dickey. At the north end, Ordovician strata are thrust westward over Carboniferous strata; east of Moore, Ordovician and Devonian strata have been thrust over the Carboniferous beds; and east of Arco, Devonian beds overlie Carboniferous strata. A stratigraphic throw of several thousand feet is evident at each place but the fault plane is thought to be much steeper than some of the southeastern Idaho faults. The angle of this fault is assumed to be above 40 degrees.

The fault is inferred from Moore northwestward to its outcrop at Sheep Creek because the rocks west of the valley are without exception Carboniferous while those to the east are older.

The rock slice, which constitutes Lost River Range, tilts to the east and northeast although it is folded into anticlines and synclines. Figures 5 and 8 of the structure sections shows this strikingly. Figure 4 represents the relationships at the northern end of the range and the middle fault shown in Figure 1 represents the Lost River overthrust. This fault appears to have had at least two branches with important proportions and far-reaching effects. These split the range into three units and shoved each unit north as well as west upon that unit lying northwest of it.

One fault called the Pass Creek fault cuts the range east of Pass Creek and disappears under the lake beds. This fault shows in Figure 4 and thrusts an Ordovician anticline over a steeply overturned Carboniferous fold.

The branch fault which leads north through Arco Pass and Briggs Canyon is inferred because of the eastward-dipping Devonian on one side of the valley and the younger Carboniferous on the west side of the valley also dipping eastward under it.

## THE HAWLEY MOUNTAIN OVERTHRUST FAULT.

The Donkey Hills made up of Cambrian (?) quartzite dipping northeast apparently overlie Devonian strata which appear at a much lower elevation to the west across the lava filled valley. At Hawley Mountains, however, the Ordovician and Devonian Beds which conformably overlie the Cambrian are thrust over the Carboniferous limestone of

Lost River Range. The trace of the fault is assumed from there south to Howe and lies somewhere near the course of Little Lost River.

The stratigraphic throw and horizontal displacement of this fault are similar to those of the Lost River overthrust.

## THE LEMHI OVERTHRUST FAULT.

This fault is thought to lie along the western base of the Lemhi Range. At the north Cambrian or older beds, tilted to the east, outcrop much higher in elevation than do the eastward-dipping Devonian beds west of them. The same is true east of the Hawley Mountains, and north of Howe where the Cambrian appears to overlie the Carboniferous beds which dip to the east on the opposite side of the valley. The stratigraphic displacement would be greater at this point than on either of the other westward overthrusts. Figure 10 shows the altitude of the strata in the north end of the Lemhi Range and Figure 6 suggests a solution to the highly complicated folding at the south end of the range. A fairly continuous syncline extends along the axis of this range. It is flanked on the east for a few miles by a low anticline. The whole slice, however, cants to the northeast. The syncline is greatly overturned at the south end. This explains the discrepancies in the dip which show in the Carboniferous and Devonian strata northeast of Berenice.

## IGNEOUS GEOLOGY.

### MODES OF OCCURRENCE.

### CONES AND CRATERS*.

Several types of cones, craters and vents were found in the lava desert region of the Plain. The most common type in the mapped area are lava cones. These broad-based gentle-sloped eminences vary greatly in their dimensions from cones a few hundred yards across the base of their meager flows to cones whose diameters are more than ten miles. (See photograph D, Plate I.) Several of these cones cover areas equivalent to two or three townships, although their vertical range may be less than 400 feet. The lava which forms these cones appears to have been very fluid. The cones nearly always show some sort of crater-like depression at their summits, and here also appears a more scoriaceous or pumiceous type of red-colored lava. The lava cones appear to have been extruded quietly and rapidly from relatively small vents. Lava cones resist erosion more successfully than other types and this, with their frequency of occurrence, makes them chiefly responsible for the building up of the Plain area.

Next to lava cones, cinder cones are the most numerous type found in the area. These are of a very different shape and are more obviously the result of volcanic phenomena. They are nearly all grouped in the eastern part of the lava area. Their rounded haystack-like summits are generally considerably higher and are very short-based compared to the lava cones. Usually only a few hundred yards across, they sometimes rise 400 to 500 feet above the surrounding lava. Their slopes are generally grassy, but otherwise barren, and they exhibit more notable craters than do the lava cones.

Driblet cones of small dimensions are, generally, found oriented so as to suggest a fissure vent in a few places.

Tuff cones are located in the southeastern part of the area. They appear to be much older than the other surface lavas of the Plain area and probably should not be classed with the Quaternary extrusions. They are known as the Market Lake Craters or Menan Buttes, and have been described in considerable detail by other writers.[4, 8, 10, 11.] They are several hundred feet high and have craters several hundred yards across. Their slopes are made up of a variety of ash and lapilli.

All, except the lava cones, are explosive types that cover relatively small areas.

Two gently sloping grass-covered acidic tuff cones were identified in the area. These were about 500 feet high and about 500 yards across the base. In both cases, these cones arose from the acidic lava fringe, which borders the Plain area. One, Indian Creek Butte, lies northeast of the mouth of Medicine Lodge Creek. The other lies southeast of Rexburg. Several other cones of the same nature have been examined in the vicinity, but outside the limits of the area. These cones sit on a tilted base and are to be found tilting to the Plain. (See photograph A, Plate II.) It is assumed that at one

* For a more detailed account of such occurrences in this region the reader is referred to 8 and 11, of the Bibliography.

time they were built up perpendicular to the originally horizontal acidic lavas and that the subsequent tilting of these lavas toward the Plain likewise affected them.

Juniper Buttes, an eminence chiefly made up of acidic lavas and tuffs, has been called an old acidic cone or volcano by former writers[7, 10] on this area. It may also be the site of a local uplift. Basalts, which show no local source, cover much of its area, and dip quaquaversally from its sides. In its center lies a wide crater-like area, but no such variety of material is found here as is found on Big Butte and East Butte south of the area, with which such a volcano must be compared. No scoria, pumice, as lapilli was observed in the"Crater". The pitch of the outward dipping lava is gentle and, of course, could be either a lava flow slope from a crater or that produced by a gentle swell. Big Bend Ridge,indisputably an arched-up area, lies nearby. In the cases of Big Butte and East Butte, the nature of the lavas and their attitudes are such that there is only one solution.

If Juniper Buttes represent an old crater, as some evidence would indicate, it was of tremendous size and can be grouped with Big Butte and East Butte as sources for much of the widespread acidic series, which underlies the Plain basalt. In some of the deeper parts of the downwarp are probably several volcanoes rising from lower ground or of less height than East and Big Buttes, whose flanks and summits lie below the surface level of the late basalt.

## LAVA FLOWS[8, 10].

### TERTIARY EARLY LAVAS.

These are represented in this area only in the western mountain valleys. The old valley which extends northward along the east side of Lost River Range, contains the greatest area of this lava series. The old northward-reaching valley east of Arco contains about 60 square miles of this series. A few small buttes at the south end of the Beaverhead Range, represent erosional remnants of these flows. The north side of Wet Creek Valley shows an exposure of a few square miles as also does the west wall of Milk Creek. These lavas, in all cases, occupy old structural and erosion-developed valleys, and were not observed to occur as mesas, buttes, cappings or erosion remnants on the higher mountain regions. It is consequently believed that they occupied only the lower depressions of an ancient topography. They were undoubtedly more widespread than their present outcrop shows. Much of their extent lies buried beneath later gravel deposits of an alluvial or lake bed origin, and large areas have surely been removed by ice and stream erosion of Pliocene to present age.

Although no detailed study was made of these lavas, it was noted that many of the flows were separated by explosively formed members such as ash and tuff, which represent a good share of the thickness of the series. The upper lava members are interleaved and conformable with the lower members of the lake beds in Wet Creek basin. This relationship offers, so far as is known, the only evidence as to their probable age. At all places where observed, they appeared to have been moderately tilted and disturbed. They have been notably altered and weathered and present an appearance of age. The series as exposed in this area is given a minimum thickness of 3,000 feet by Umpleby.[12] No attempt to verify this was made by the writer. In the field these rocks were classified as basalts, andesites, trachytes, or rhyolites and related tuffs, which was Umpleby's[12] classification. In describing a typical occurrence, Umpleby[12] says the rock

> "is a grayish-black rock, studded with many bright needles of hornblende. In it the phenocrysts exceed the ground mass slightly in area. The ground mass is microcrystalline and is composed principally of minute crystals of feldspar. The phenocrysts comprise hornblende, oligoclase, andesine, a little biotite, and much less magnetite and apatite. Another specimen from the same vicinity is pale lavender and contains noteworthy amounts both of hornblende and biotite, along with feldspar, in a fine-grained to glassy ground mass. The feldspars are approximately oligoclase-andesine in composition and exceed hornblende, which in turn is somewhat greater than biotite in amount. The area of the ground mass greatly exceeds that of the phenocrysts."

A rhyolite exposed east of Arco, he describes as

> "a light-gray rock that carries small crystals of feldspar, biotite, and quartz, embedded in dense material, some of which shows flow lines."

He describes another rock which he terms "an olivine-free basalt", as belonging to the series east of Arco. The writer believes that the latter may belong to the Tertiary Late Lavas, rather than to this older series.

Several specimens classified in the field as andesites or latites, by the writer, when petrographically studied, were given the name of hornblende rhyolite porphyry by Mr. Alfred L. Anderson, who made the petrographic analysis. A representative analysis of a specimen selected eight miles east of Mackay is described here. This rock borders on a latite, but the inferred presence of sufficient quartz and the lack of sufficient plagioclase places the rock just within the rhyolite group. The rock is dense, greenish porphritic, much like a dike rock, with a liberal sprinkling of black hornblende crystals, tabular in outline, and as long as one-fourth inch and as wide as one-eighth inch. Andesine feldspar crystals generally dull in appearance, are even more abundant. All are embedded in a greenish ground-mass.

Under the microscope, the phenocrysts are seen to be embedded in a microspherulitic ground mass, composed of about 57 per cent orthoclase and 18 per cent quartz (inferred). The color is brownish probably due to the presence of minute grains of hematite. Similar grains of magnetite are present. About 20 per cent of the rock is made up of lath-like andesine crystals which as a rule show partially resorbed and rounded outlines. Carlsbad, combined with polysynthetic twinning, is abundant. The hornblende, representing about five per cent of the rock, appears as euhedral laths showing strong greenish-brown pleochroism. Large quantities of magnetite border the hornblende which has an unusually high iron content.

Many of the rocks called andesites are true andesites and these, with the type just described, are the most abundant flows in the series. A generally red tinge shows in the whole series and may be ascribed to hematite.

It is difficult to say what is the extent of the flows inasmuch as a source for any of them was not recognized. Various flows, however, must have had dimensions of at least 15 to 20 miles in one direction and some of them show thicknesses of more than 100 feet. Their actual number is unknown, but more than 20 different flows of this older lava are believed to be exposed at various places.

## TERTIARY LATE LAVAS.

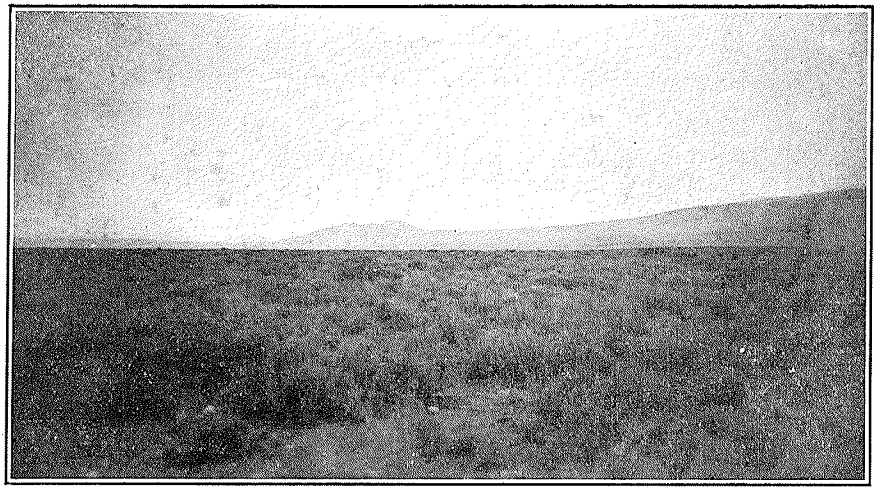
As has already been suggested, this lava series, once widespread at the surface, now outcrops as a ragged fringe bordering the Snake River lava where it has been left unburied, or it shows where recent erosion has cut through the younger basalt and revealed it in stream canyons. It also appears in arched-up areas where it was never completely covered with basalt or where the basalt has been almost entirely removed by erosion.

On the northwestern side of the Plain area, the farthest west exposure of this lava appears at the southern tip of Lemhi Range where it joins the basalt lava plains. At this place only a relatively small erosional remnant remains. It contains basalts, andesites, trachytes, and rhyolite, which dip beneath the Quaternary basalt.

This upper edge of this series has been eroded away by Birch Creek although it probably extends across the mouth of the valley underneath the overburden of gravels and later basalt.

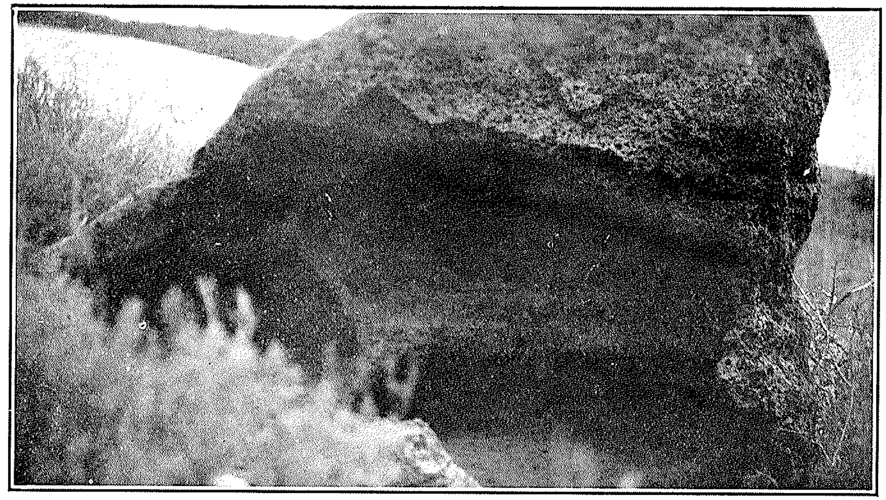
East of Birch Creek, where the south end of the west wing of Beaverhead Range protects them, (See photograph C, Plate I.) they appear again and extend without a break around the northeast and north side of the Plain, eastward until they pass off the mapped area. They occupy re-entrants in Warm Springs and Blue Creek valleys and reach almost to the head of the wide depression occupied by Medicine Lodge Creek and its tributaries. From the north-south pass which crosses the Centennial Range, they extend eastward and in many places extend northward over the range into Montana. Where they are eroded through, they reveal underlying Tertiary gravels or Cretaceous and older sediments. Outside the area this fringe swings around at the true head of the Snake River Plain and occurs on the eastern and southeastern side from where it proceeds southwestward, paralleling the long axis of the Plain. On this side also it appears on the noses of the ranges (See photograph B, Plate I.) and extends into the structural valleys which lie between the ranges for many miles*

* Kirkham, Virgil R. D., Geology and Oil Possibilities of Bingham, Bonneville, and Caribou counties, Idaho: Bureau of Mines and Geology Bull. 8, 1924.



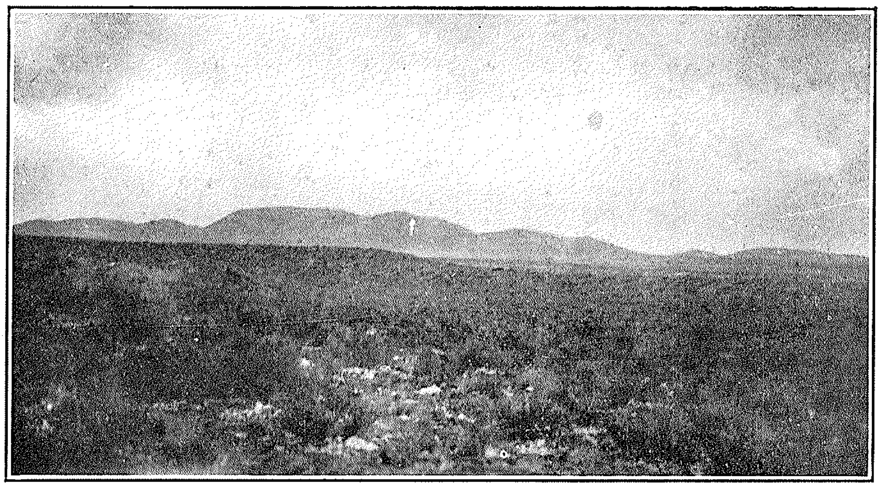
A.

A. Looking East. The dim horizon shows Tertiary Late Lava at the north edge of the plain, dipping gently southward and southeastward to disappear under the Snake River Plain basalt which makes up the foreground. In the center of the picture rises an old acidic cone perpendicular to the acidic lava series on which it sits, but tilted toward the Plain.



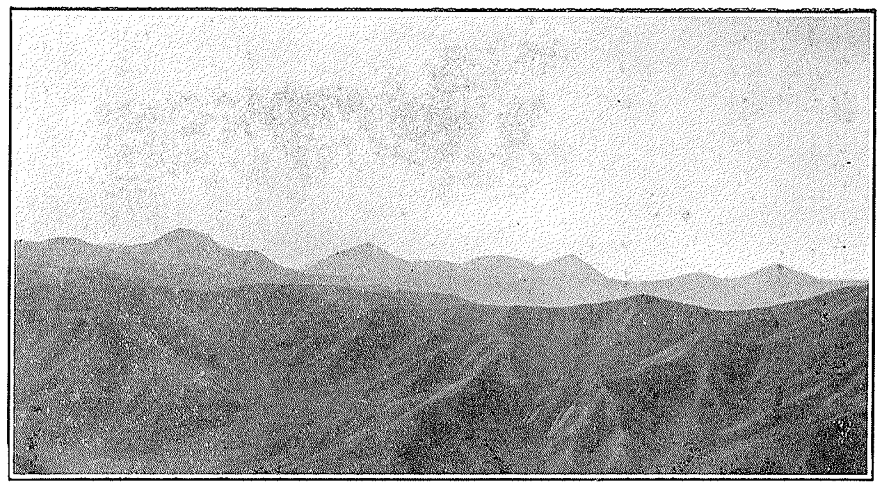
B.

B. The vesicular nature of the trachytes and rhyolites is typified by this boulder. These vesicles, several feet in diameter as shown in the lower part of the boulder, are characteristic of one wide-spread flow in the Tertiary Late Lava.



C.

C. Looking South. Juniper Buttes make up the sky-line. Note the low elevation compared to the lateral extent which reaches beyond the edges of the photograph. If this is an old volcano, its proportions and characteristics are vastly different from those of Big and East buttes. The lava on its slope dips gently to the surrounding Plain.



D.

D. Looking West. Standing on the Continental Divide several miles west of Humphrey. In the foreground lie thousands of feet of stratified Tertiary gravel. The highest peak on the left of the horizon is made up of southwestward dipping Triassic conglomerate and limestone.

These lavas characteristically dip towards the long axis of the Plain on all sides with angles of two or three degrees up to 10 degrees. This dip is often the surface slope and nearly always approximates it. Erosion in the canyon of Henry's Fork, east of the area covered by this map, exposes these acidic lavas as lying beneath the basalt for several miles. Big Bend Ridge, a gentle arch in the upper end of the Plain, exposes them over an area of more than 100 square milex. Lavas and tuffs of this nature are again exposed, further south and far out in the Plain, at Juniper Buttes. Similar exposures are represented by the old volcanoes, Big Butte and East Butte outside the area. Acid lavas are uncovered by erosion for several miles in Snake River Canyon at Shoshone Falls. All of these occurrences offer persuasive evidence for believing that a widespread sheet of acid lavas now extends, or formerly extended, under the later basalts which partly fill up the present depression.

This fringe at its farther south points is often represented by mesa-like caps which are erosional remnants on some of the higher peaks.* This blanket-like series of acid lavas seems to have had a much greater extent than do the present wide-spread late basalts of the Upper Snake River Plain. Interbedded with this series, there is found in many places bedded continental deposits which are conformable and tilt, as do the lavas, toward the axis of the Snake River Plain downwarp. The formation described and called the Salt Lake Formation, by Mansfield**, is given, tentatively, a Pliocene age. The conformable relationship of this formation and the lava series has been previously described for some of the area south of the Plain, by the writer.* The tilted ashbeds, tuffs, conglomerate, limestone, etc. which make up this formation, convince the investigator that the conformable lavas which lie above and below the series are not flow slopes like the slopes of the great broad-based cones of later basalt to be observed out in the Plain. At the Continental Divide, in the Centennial Range, the same flows which pass over the range at an elevation of 10,000 feet, pass under the Plain basalt flows at an elevation of about 6,000 feet. The difference in elevation is nearly as great on the ranges south and southeast of the Plain, but is less towards Yellowstone National Park on the east.

Since this much difference in elevation exists above the present basalt lava of the Plain, a considerable relief must be allowed for, with the extension of this series under the Plain.

Sections made in the area and at various points outside the mapped area, show that the series is generally made up of basal flows of basalt and andesite, with trachytes, latites, and rhyolites constituting the upper flows. Interbedded with these lavas occurs ash beds, fresh water limestone, clay, shale, sandstone, and conglomerate, which are called the Salt Lake Formation, southeast of this area.

A section on Snake River, southeast of Heise and off the mapped area, showed at the base calcareous conglomerate of the Salt Lake formation, thickness unknown. This was overlain by 35 feet of latite.

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* Kirkham, Virgil R. D., Ibid.

** Mansfield, G. R., The Wasatch and Salt Lake formations of southeastern Idaho: Am. Jour. Sci. Vol. 50 pp. 54-64, July, 1920.

This in turn is overlain by 25 feet of black to dark green vesicular basalt. Next comes 55 feet of pink rhyolitic tuff and agglomerate; above this occurs 100 feet of a conglomeratic deposit cemented by pink volcanic ash in some places and by travertine spring deposits in other localities. Rounded pebbles of variegated country rocks are found within this matrix. Succeeding this is a red trachyte, a red andesite, and a gray rhyolite. This section is about 250 feet thick. Over it all rests Snake River Basalt.

West of Warm Springs Creek, more than half the section is old basalt, but a few flows of andesite and rhyolite, separated by acidic tuff, make up the top of the series. At this place, much of the upper part is eroded leaving a fairly large area of the older basic material exposed.

In the canyon of Medicine Lodge Creek, one basalt and several andesites make up the base of the column. On the gentle sloping benches bordering this creek, appear higher uneroded flows of trachyte and rhyolite which apparently top the series here. Near Humphrey the upper acid series has been eroded to a lower basalt member but the overlying flows appear in the foothills lying to either side of the pass.

Most of the Centennial Range is covered at the surface with rhyolites and trachytes. The lower lying andesites are exposed mainly in the stream valleys and cliffs.

Rhyolites, and trachytes are exposed at the surface on Big Bend Ridge and Juniper Buttes. No andesites of this series appear here, perhaps because of insufficient erosion. Southeast of St. Anthony and Rexburg, the andesites and old basalt are uncovered at several places in the stream valleys.

The following descriptions of rocks collected from sections in this area are based on petrographic analysis made by Alfred L. Anderson. They are designed to represent typical occurrences, over a wide area.

An olivine basalt, which forms the base of the series near Humphrey, appears at several places in this area and southeast of it. Several acid flows overlie it. It is highly porphyritic. This is a distinguishing field characteristic. The phenocryst are masses of plagioclase crystals arranged in groups or rosettes. The lath-like individual crystals of these aggregates are glassy-appearing and show multiple twinning. The masses are from one half to one inch in diameter with laths of proportionate dimensions. These masses are generally in cavernous parts of the rock suggesting that after the crystals assumed their position, the surrounding liquid magma was drained off. The ground mass appears dense and non-vesicular but shows on close examination a minutely porous structure. This rock is black and a dark greenish tint is imparted by the presence of olivine.

Under the microscope, large augite masses are also revealed. They are more abundant even than the plagioclase phenocrysts. These two kinds of phenocrysts make up about five per cent of the rock.

The ground mass is holocrystalline with the feldspar of the same generation as the pnehocrysts. An ophitictexture is represented by the interlocked and interwrapped augite and feldspar crystals. The poikilitic character of the augite shows clearly that it is the youngest mineral. The rock is composed of approximately 30 per cent labradorite, 58 per cent augite, eight per cent magnetite and four per cent olivine. Apatite is an important accessory mineral. The magnetite occurs in two generations and the olivine was the first mineral to form.

Another basalt, typical of those higher in the series and interleaved with the more acidic flows, is dark gray in color and slightly vesicular. The vesicles vary from one-sixteenth to one-half inch in diameter. This basalt is non-porphyritic. It is a dense stoney basalt of a pale greenish tint given by olivine. The minute labradorite crystals occupy less than one per cent of this rock. The ground mass is ophitic, and crystalline without glass. Augite makes up 60 per cent of the rock and lies in formless masses between the acid labradorite laths. Magnetite of two generations comprises eight per cent of the rock and rounded olivine grains form less than four per cent. Olivine crystallized first, then plagioclase, then magnetite, followed by augite and more magnetite. The plagioclase of the ground mass is of the same generation as the few small phenocrysts, the laths of labradorite are twinned polysynthetically. Apatite is an important accessory mineral.

An andesite in the series is a dull red color which distinguishes it in the field from the light pink, gray, and lavender rhyolites and trachytes. This rock is porphyritic, but the plagioclase and amphibole crystals are small and infrequent. The rock is minutely vesicular. Andesine-labradorite and augite phenocrysts make up eight per cent of the rock. They are embedded in a cryptocrystalline ground mass of pilotaxitic structure made up of minute andesine laths in fluidal lines with much magnetite and a reddish subtranslucent, non-pleochroic mineral which colors the rock. It is assumed to have been derived from augite. Tabular crystals of augite with reddish borders of the mineral just mentioned are abundant. The plagioclase laths are twinned several times and show zonal extinction. The minute andesine crystals of the groundmass are twinned once and packed closely together or separated by magnetite or the red unnamed mineral which occupies half of the groundmass.

One rhyolite characteristic of the acid types of this series is pale lavender to mauve in color. A layered fluidal structure is caused by alternating deep lavender dense and stony bands, and cream color porous bands of feldspar and quartz. Glassy phenocrysts of oligoclase are present in both bands. More crystalline quartz occurs in this type of rock than in the other acidic types. It is generally in lense-like seams in the light colored porous bands. Biotite is recognizable. About 90 per cent of the rock is a microspherulitic ground mass estimated to contain 66 per cent orthoclase and 22 per cent quartz. Phenocrysts of oligoclase polysynthetically twinned make up two per cent. The cream colored bands of quartz and feldspar make up eight per cent of the rock. The orthoclase formed first and is surrounded by anhedral quartz. It appears that the lava cooled very rapidly permitting a mecrospherulitic mass to form with cavities and vesicles filled with aqueous solution of orthoclase and quartz, residual juices, to crystallize slowly. Biotite constitutes two per cent of the mass, but was originally more abundant. Hematite developed from the biotite gives the rock its color. Magnetite makes up two per cent of the total.

The trachytic type of rhyolite, the most common in the series, contains no observable quartz. The rock is dense, slightly porphyritic, and of a pinkish, cream or lavender color, with faint fluidal structure. The rock rings like phonolite when struck. Infrequent phenocrysts of dull white oligoclase comprise less than one per cent of the mass. Altered hornblende crystals are accessory.

The ground mass is eutaxitic and cryptocrystalline, and apparently chiefly orthoclase. The texture is that of a rhyolite, and, although quartz could not be identified, its presence is inferred from this texture. This rock also has lenses filled with orthoclase probably crystallized from a slowly cooling solution in cavities of a quickly chilled magma. Magnetite and hematite are unimportant accessories.

Another trachytic type of rhyolite is darker lavender with more pronounced fluidal structure. The weathered lava possesses knotty seams, and ridges in high relief, like the bark of yellow pine. It also rings when struck. Its phenocrysts are orthoclase and sanidine. No quartz is observable and the rock is less acid than the preceding one. Nevertheless, it is called rhyolite because of the texture.

A dark gray rhyolite which is generally present in the area is highly vesicular. The cavities are often several inches along and an inch across. Flow structure is dominant, and fine lines of lavender alternate with black glassy bands. Sanidine crystals are abundant. They are glassy and lath-like forms, and the fuidal lines curve around them. They comprise four per cent of the rock and are characterized by a notable cleavage. The seams and cavities in this rock are lined with subhedral orthoclase crystals indicating that after the main mass had quickly cooled these cavities retained aqueous solutions which crystallized slowly. Hematite has formed from hornblende. No quartz is observable but the texture is that of a rhyolite.

A latite porphyry little different from the other types described, contains more hornblende due perhaps to slower cooling conditions. The color is lavender but no flow lines show. About 80 per cent of the phenocrysts are andesine and 20 per cent hornblende. The ground mass is 55 per cent orthoclase, 5 per cent quartz and the rest glass. Magnetite, hematite, and biotite are accessories and the hornblende is rich in iron.

The Tertiary Late Lavas appear to have occurred in wide-spread flows, many of which were observed to have areas of at least 100 square miles. Along the entire Centennial Range, only one source was recognized. This was Indian Creek Butte, north of Small.

If the Juniper Buttes eminence represents an old volcano, perhaps much of this area received lava from that source. If no other intervening volcano exists beneath the Snake River basalt, then acidic lava flows from this source may have extended for 50 miles. Fissure eruptions now concealed by later undisturbed basalts may have contributed great areas of this lava.

Flows in the eastern part of the area undoubtedly belong to the widespread westward-extending sheets of Yellowstone National Park.

It may be that a great part of the lava in the area owes its origin to this source. Southeast of the Snake River Plain about a dozen old, but relatively small acidic lava and tuff cones have been recognized. These, of course, would suggest a manner of distribution of the acid lavas very similar to that of the Snake River basalt. Six flows with an average thickness of less than 50 feet each, were noted at several places in this series.

## QUATERNARY AND PLIOCENE(?) LAVAS.

This type of lava rock, commonly called the Snake River basalt, appears everywhere as the surface lava in the Plain area. At some places it is covered with an overburden of gravel or soil and at others it has been eroded so as to reveal lower lying lavas of another series.

The basalt does not extend as embayments in the valleys, as has been said of this area. No Snake River basalt extends into the valleys north, northeast, or northwest of the Plain.

Basalt flows do, however, occupy some of the valleys which enter the Plain from the southeast. These valleys lie outside the mapped area and in all instances the basalt does not represent embayments, but flows which have originated in the upper part of the valley and flowed towards the Plain. At some places the flow joined the basalt of the Plain and at other places failed to reach that far. This valley basalt, because of its lithology and relationship to the under-lying formations, is assigned the same age as the lava in the Plain.

Most of the cones have volcanic necks of diabase, and the craters contain much scoria, but the flows vary greatly in texture from fine-grained stoney rock, to vesicular and porphyritic types. The basalt is generally a heavy dark gray to black rock which contains varying amounts of olivine, magnetite, and labradorite. No specimen can be described which is typical of any great area. More than 100 different flows of about 20 different ages were noted. At no place was a flow more than 15 miles long or covering an area greater than 125 square miles, seen in the Snake River basalt area. A few lava cones have extruded flows covering areas from 75 to 100 miles in area. The greater number, however, are much smaller and represent only a few square miles. The thickest flows observed, were no more than 50 feet and most of them appear to be much less in thickness. At no place were widespread lava sheets, similar to those of the Columbia River lava, recognized. A possibility exists that earlier and basal flows may have been extruded from fissures and were more widespread than those showing at the present surface.

## NON-METALLIC RESOURCES.

### OIL POSSIBILITIES.

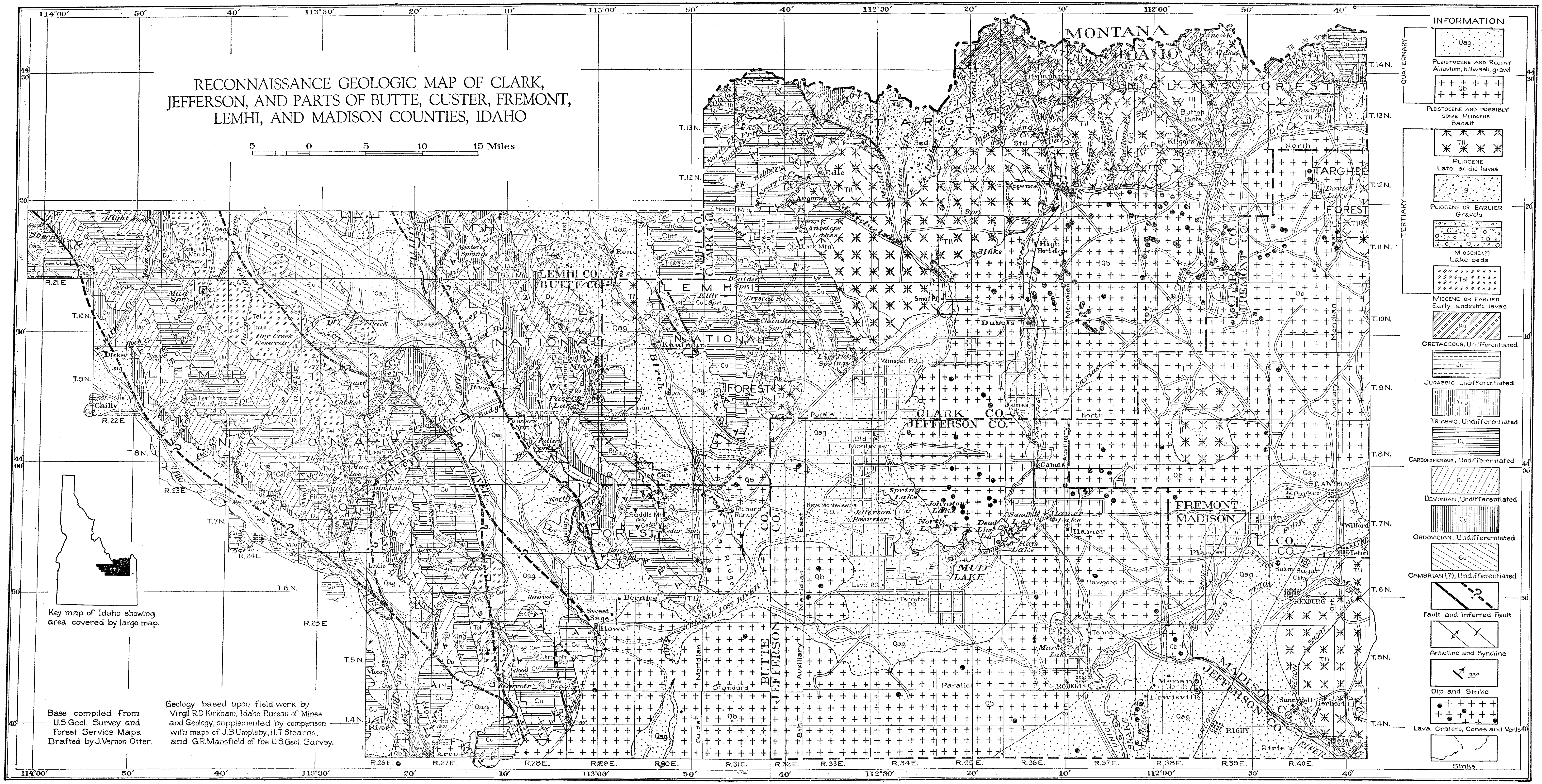
Areas suspected of oil-bearing possibilities by the laymen of the locality proved to be unfavorable. A few areas, however, north of the Plain and near the Montana Boundary in Clark County are occupied by sedimentary beds of Cretaceous age. A formation exposed at two localities, by erosion of the older lavas, is believed to be the Frontier of Upper Cretaceous age. It appears lithologically and stratigraphically to be the same formation which is exposed at the surface in Teton Basin. Fossil evidence at the latter place has classified that formation as Frontier.

The Frontier is the formation that produces petroleum in many fields of Wyoming, Colorado and Montana. It is now producing a notable gas flow at the wells drilling for oil in Teton Basin. Because of this record any area where the Frontier formation is present deserves examination for oil bearing possibilities. Neither the structure or nature of the older Palezoic sediments as observed in most places, were considered favorable for petroleum production. However, considering the interest recently shown in the Pennsylvanian in adjoining states, this formation may justify further detailed examination.

Geologists recognize some nine controlling factors for commercial accumulation of oil. They are:

1. Presence of sedimentary rocks of marine origin.
2. Absence of intense metamorphism or deformation.
3. Presence of an organic source for oil.
4. Presence of a porous reservois or containing rock.
5. Presence of a suitable cover or impervious capping.
6. Presence of a suitable structure for trapping oil.
7. Presence or absence of water in reservoir rock.
8. Presence of closure.
9. Presence of a sufficiently large drainage area.

Measuring the area by these standards, Mesozoic sedimentary rocks of marine origin, that are not metamorphosed, are present. They contain a coal bed and seams of carbonaceous material and shales which could be construed as a possible source horizon for oil. Porous reservoir rocks and suitable cappings are present. The presence of a suitable structure and one with closure is more uncertain. Eroded lava has exposed one gently folded anticline, in the area on Modoc Creek and Beaver Creek, but lava covering over the ends fails to reveal whether closure is present to trap the oil. Another fold appears to be present but only what may possibly be the probable west limb of the anticline is revealed. Lava masks the rest of it so that its proportions or outlines are too problematical to risk testing unless the westernmost structure should produce petroleum. For neither of these structures is the drainage area definitely known, although for the western one, which is most exposed, it appears to be large enough to satisfy the demands. Samples of sandstone having the field appearance of saturated sands were taken from both structures and subjected to laboratory analysis with negative results. The absence of surface indications is, however, not necessarily a disadvantage to the area.


RECONNAISSANCE GEOLOGIC MAP OF CLARK, JEFFERSON, AND PARTS OF BUTTE, CUSTER, FREMONT, LEMHI, AND MADISON COUNTIES, IDAHO
5 0 5 10 15 Miles
INFORMATION
QUATERNARY
Pleistocene and Recent Alluvium, hillwash, gravel
Pleistocene and possibly some Pliocene Basalt
TERTIARY
Pliocene Late acidic lavas
Pliocene or Earlier Gravels
Miocene (?) Lake beds
Miocene or Earlier Early andesitic lavas
Cretaceous, Undifferentiated
Jurassic, Undifferentiated
Triassic, Undifferentiated
Carboniferous, Undifferentiated
Devonian, Undifferentiated
Ordovician, Undifferentiated
Cambrian (?), Undifferentiated
Fault and Inferred Fault
Anticline and Syncline
Dip and Strike
Lava Craters, Cones and Vents
Sinks
Key map of Idaho showing area covered by large map.
Base compiled from U.S. Geol. Survey and Forest Service Maps. Drafted by J. Vernon Otter.
Geology based upon field work by Virgil R.D. Kirkham, Idaho Bureau of Mines and Geology, supplemented by comparison with maps of J.B. Umpleby, H.T. Stearns, and G.R. Mansfield of the U.S. Geol. Survey.
MONTANA
IDAHO
TARGHEE NATIONAL FOREST
LEMHI NATIONAL FOREST
CLARK CO.
JEFFERSON CO.
FREMONT CO.
MADISON CO.
MUD LAKE
Dubois
Spencer
Hamer
Mackay
Arco
Howe
Rigby
Rexburg
St. Anthony

Owing to the lack of a clearly defined structure, the writer cannot enthusiastically recommend drilling in this area unless oil is produced from this formation at Teton Basin.

The region is, however, within a petroliferous province and has rocks representing petroleogenic epochs. If oil is found in nearby areas, where investigations are now proceeding, the sedimentary column of this area, especially the Mesozoic and Carboniferous beds, will justify detailed examination.

## COAL POSSIBILITIES.

Carbonaceous material was found at many places in the area.

Many seams of dark, shiny, carbonaceous shales were found in the Devonian and Carboniferous beds in the western part of the area. Analyses showed that none of these beds could be classified as coal or fuel. Lignite beds were found in the Tertiary lake-beds in Wet Creek. These also proved valueless as coal. Many reported coal areas were examined but with the exception of the Cretaceous areas along the crest of the Centennial Range the search was fruitless. In the latter region Cretaceous sandstone, shale, and limestone, thought to be the Frontier formation, carry small coal seams. This formation contains at least 20 notable seams of coal in the Teton Basin and is a producing commercial coal in several areas in Wyoming. The largest seam examined is one described by Mansfield[7] in 1921. In a five foot section, located in the S. E. 1/4, Sec. 11, T. 14 N., R. 38 E., on Cottonwood Creek, he[7] gives the following measurements:

| | Ft. | In. |
|---|---|---|
| Clay, gray, grades upward into sandstone | | 6 |
| Coal, sheared and slickensided; pinches out eastward | | 6 |
| Clay, gray | | 6 |
| Coal ~~Clay~~, hard, dense | 2, | 8 |
| Clay, black, partly bone | | 7 |
| Clay, gray | | 3 |
| | 5. | 0 |

This seam widens in a few hundred yards to 36 inches of good sound coal. Analyses made by the U. S. Geological Survey and other reputable sources show an ash content averaging below 10 per cent, a low moisture content, and a fixed carbon percentage of about 55. At some places on the seam this percentage is closer to 50. The volatile matter ranges between 30 and 40 per cent. In heating value this coal averages well above 12,000 British thermal units and as a whole compares very favorably as a fuel with the good bituminous coals of Utah, Wyoming, and other Rocky Mountain states.

The seam dips to the southwest at angles ranging from 15 to 20 degrees, and appears to lie in the east limb of a wide and gently folded syncline. Its strike is from 65 to 80 degrees west of north and the clay bed and "blossom" extend for nearly four miles. It disappears under rhyolite of the Tertiary Late Lavas to the southeast and passes over the Continental Divide into Montana. Exploration may prove that this seam extends into Centennial Valley, where it would be located if found, many miles nearer the railroad and at an elevation two or three thousand feet lower than here.

This coal, although an excellent fuel, is so handicapped by location and accessibility as to be valueless to the region. Only a few tons are mined yearly and hauled down the trail to supply the school at Kilgore. The distance to Spencer, the nearest rail shipping point, by road, is more than 35 miles. The present coal prospect, which is accessible only from the Idaho side, lies on the very crest of the range, nearly two thousand feet above Kilgore. Although the seam could be opened up at a lower elevation it would be no more accessible than now because of the drainage of the area.

Realizing that this seam, as exposed, is valueless to the community, the writer spent some time endeavoring to find a recurrence of this or some similar seam in the region west of this and nearer rail transportation. Similar beds appear again in what possibly may be the west limb of a syncline which outcrops in a "window" in the acid lavas, in the vicinity of Pete Creek, tributary of Camas Creek. In a two days search of this region, commercial coal was not found although small seams of carbonaceous material developed an occasional "blossom". These beds outcrop again in another "window", where the Oregon Short Line Railroad, and the main Pocatello to Butte highway cross the divide. This region lies in an air line about 16 miles west of where the three-foot vein of coal dips to the southwest.

If that vein, or a similar vein, were discovered here it would be commercial coal chiefly, because of its strategic situation on the Continental Divide with easy haulage in both directions to, at present, coalless regions. It has been stated authoritatively that more than 75 per cent of the north-bound freight which goes over this Divide is coal destined for Beaverhead Valley and Butte.

Prospecting by the inhabitants of the region around Humphrey, instigated and directed by the writer, revealed some carbonaceous seams of excellent coal of only a few inches in width. Up to date, this prospecting has been only surface scratching, and no attempt to systematically examine the area has been made. Because of the prevalence of carbonaceous material throughout these beds, and their strategic position, the writer believes that considerable detailed prospecting is justified.

## CLAY RESOURCES.

Various clays, formed from decomposed lavas and loess and which are suitable for ordinary brick and tile, are abundant in the region. An important and less common clay, rather notable in its properties, also occurs in this region. It is called Bentonite and because of its extraordinary absorptive quality, and other characteristics which make its uses manifold, it has a higher commercial value than the average clays. This clay is developed by the alteration and decomposition of acidic, ash, tuff, or lava. The physical and chemical reactions, agencies, and processes, which are necessary to produce this certain kind of clay rather than some other, are at present still not fully understood. Associated with the Tertiary Late Lavas in this region, as well as in nearby localities, are various sediments tentatively assigned to the Salt Lake formation. It is in this interbedded formation that the bentonite occurs. At two places in the region it is perhaps accessible and could be developed. Near the railroad south of Mackay it is very pure and white. Because of a masking overburden of gravels its extent at this place is unknown. Its nearness to transportation justifies an investigation. About 15 miles from the railway west of Dubois is an enormous tonnage of this material underlying a fresh water limestone. At this place the outcrop is several hundred feet long and probably averages 15 feet thick. The bentonite here, which is, of course, impure at the weathered soil-covered surface, seems to be pure enough for commercial uses and has a soapy yellow color. The haulage problem for this deposit at present is a handicap which will probably null its value. Prospecting in the acidic lava-covered regions near the railway is almost certain to discover other deposits of this unusual clay.

## PHOSPHATE POSSIBILITIES.

Numerous samples were collected from formations suspected of containing tricalcium phosphate. Analyses showed that several carbonaceous shales collected from formations of different ages carried low percentages of phosphate of lime. Although the Permian aged formation, called the Phosphoria, which contains nearly all of the commercial phosphate of Idaho and the western field, was sought for with diligence, it was observed at only one place in the area. This place, at the crest of the Centennial Range, was visited and described by Condit.[2,3] In describing the phosphatic shales which are contained in the Phosphoria formation at this place, he gives the following measurements:[3]

| | |
|---|---|
| Cherty shale | 8 feet |
| Shale, black, bony | 4 " |
| Phosphatic rock, gray, oolitic | 8 inches |
| Sandstone and shale | ---- |

He found the black shale to contain 6 gallons of shale oil per ton, but the whole series has a low phosphatic content and is not commercial.

In a publication, issued after the field work on this problem was finished, Permian fossils were reported by Stearns[10] to have been found on Medicine Lodge Creek.

Commercial phosphatic shales of the Phosphoria were found north of this area about 2 miles from the Idaho line, but the formation was not traced into the area boundaries. It was anticipated that phosphate rock would be found in the vicinity of Medicine Lodge Creek, but a fairly diligent search was fruitless. The carbonaceous members of the Pennsylvanian which bear commercial phosphate rock in other regions may be present in this area but analyses of the samples collected revealed no commercial phosphate rock. The writer believes, nevertheless, that commercial phosphate rock will yet be found in the mapped region, when a detailed study is made of the areal geology, because areas both of Permian and Pennsylvanian rocks, undetected in this reconnaissance, very probably outcrop in such a region where the Carboniferous series is so widespread.

## WATER RESOURCES*

In a region so arid as is most of this area, water is one of the

* A more adequate description of the water resources of the region is found in 1 and 10 of the bibliography.

most valuable mineral resources. Every major stream in the area which lies in either the Plain area or the mountain valleys is used for irrigation or power.

Irrigation in Birch Creek and Big and Little Lost Rivers has robbed the Plain of an extensive playa, or lake similar to the present Mud Lake, and left in its place a "sink", but irrigation has also compensated by developing in a similar old "sink" the present Mud Lake from water which comes from the eastern irrigated regions. According to Stearns,[10] Mud Lake is increasing in volume each year and the supply for irrigation is thus augmented. The water resources of a small part of the area are described by Meinzer*.

To the writer it seems that the hope of the water situation is to tap the underground flows of Medicine Lodge, and Birch creeks and Big and Little Lost rivers, which can be found underlying the vast alluvium and gravel covered area, west, northwest, and south, of Mud Lake. Some of the lost water from Medicine Lodge Creek no doubt contributes to Spring Lake and others of the Mud Lake group but most of it goes farther west and south.

At the north end of the alluvium and gravel district are several thousand acres of fertile soil which can be watered from pumped wells with depths less than 25 feet. Farther south and west, the depths of the wells would gradually increase to perhaps as much as 500 feet. With proper technical precautions, the flow from each well, where efficient supervision and apparatus exists, would be sufficient to irrigate a half section of land. Lines for electrical power would have to be extended only a few miles to serve 25,000 acres adequately.

Should rail transportation connect Birch Creek Valley with the Oregon Short Line Railroad, pumping projects in this region may meet with success.

Two hot spring centers which, as yet, have value only as natatoriums, are in the region. Both Springs have temperatures of about 120 degrees Fahrenheit and large flows. The three springs at Lidy Hot Springs are located on a north-south fault which plunges under the Plain. They are almost entirely undeveloped. They lie on the new Central Idaho-Yellowstone Highway, and offer great tourist, and recreational and health possibilities. Heise Hot Springs lie across the Snake River from a scenic canyon drive which follows the River south to Wyoming. These springs are also associated with a large fault which follows the river valley for several miles before it plunges under the Snake River basalt. These are destined to be popular resorts with the increase of tourist traffic on this thoroughfare.

BUILDING STONE RESOURCES.

The gray, pink, white, lavender, and mauve rhyolite, trachyte, and tuff of the Tertiary Late Lava series are widely used for building stone in the Upper Snake River Plain. These beautiful stones are quarried at many places and are easily extracted and dressed. Their pastel shades make pleasing colors and the stone is very popular. A black shiny tuff,

* Meinzer, Oscar E. Ground water in Pahsimeroi Valley, Idaho. Idaho Bureau of Mines and Geol. Pamphlet 9, February, 1924.

chiefly glass, is quarried for building purposes at Menan Buttes and Market Lake Craters. It is often used as a trimming stone in rich contrast to the delicately shaded lighter blocks. Every town along the southeast side of the Plain has its local quarries so that rail shipment is rarely necessary. In many of these towns, three-fourths of the business and public buildings are made from this material. Many residences are constructed from it, as well as all the foundations. It is also very popular for chimney and fireplace stone and in its variety of colors it achieves an effect difficult to excel. This material is one of the most important mineral resources of the area and could readily be expanded into a widely used product by advertising and organization. Transportation, which is the usual obstacle to the production and marketing of building stone in Idaho, is readily available.

These acidic lava flows and tuffs probably lead all other building stones in the state in popularity, abundance, and ease of extraction and dressing. Their only drawback may lie in their softness and lack of compressive strength, which may limit their use to smaller buildings.

## ROAD MATERIAL RESOURCES.

According to the conclusions of Alfred L. Anderson, Assistant Geologist, Idaho Bureau of Mines and Geology, set forth in an unpublished report on the road materials of southeastern Idaho, there are, in this area, abundant gravels of almost every variety and size, large deposits of cinders, and an unlimited and complex variety of lava rocks, all of which are easily accessible. Clay for binder is discussed elsewhere in this report. Gravels are found in the alluvium and gravel-marked areas on the maps. Cinders are found in the slopes of many of the cones of the area, and the lava rocks occupy considerably more than half of the surface area.

## SUMMARY AND CONCLUSIONS.

The area examined in the eight weeks reconnaissance comprises about 167 townships which make up all of Clark and Jefferson counties and large parts of Butte, Custer and Fremont counties, and small areas of Lemhi and Madison counties. The extremities of the area lie in Townships 4 to 14 N., and Ranges 20 to 41 E. Important railway points within the mapped area are Rexburg, St. Anthony, Rigby, Dubois, Spencer, Camas, and Hamer in the eastern part and Mackay and Arco to the west.

The entire area lies within the Snake River drainage. Unusual features which mark the drainage is the presence of a large number of "lost" rivers, and sinking streams. The "sinks" in which these streams disappear are large flat playas which are lakes in some years and are dry for parts of other years. Mud Lake is such a sink, which has recently been gaining water from irrigation. Other sinks are losing water by the same cause.

Four types of topography are represented in the area. These are (1), rugged mountainous provinces, represented by the western ranges, (2), gently sloping foothill-like areas composed of gravels and gently sloping acid lavas which make up the slopes surrounding the Plain, (3), broad mountain valleys, floored with gravel, which are found in the western part of the area, and (4), the dominant feature of the region, the basalt-covered Snake River Plain. Interrupted by lava and tuff cones, and interlacing flows , this great plain slopes gradually along its longer axis from a height of more than 6,300 feet towards its head, to 4,800 feet where it leaves the mapped area. Its relief from side to side is about 600 feet with the lowest portion along the borders, where the lakes and streams are located.

The mountainous area which borders the Plain on the north and west is rough and rugged, and represents alternations of parallel mountain ranges and stream valleys. The altitude of each valley varies from 7,000 to 5,800 feet above sea level and many points in the ranges reach heights in excess of 11,000 feet. Mt. McCaleb is believed to be the highest known point and has an elevation of 11,525 feet. These valleys and ranges trend in northwesterly and southeasterly directions.

At their southeastern extremity the valleys merge with the Snake River Plain, and the mountain ranges plunge beneath the flat lying lava of the Plain. The important ranges in the area are Lost River Range, Lemhi Range, Beaverhead Range and the Centennial Mountains.

Important water bodies appearing in the area are Mud Lake, Henry's Fork, and South Fork of Snake River, Big Lost River, Little Lost River, Birch, Medicine Lodge Creek, Beaver and Camas creeks. Of those enumerated, the latter creek and Snake River are the only streams which do not lose themselves on the desert before reaching another water body. Parts of the Targhee and Lemhi National Forests lie in the area and their acreage as well as much land adjacent to their boundaries is chiefly used by live stock producers. A few irrigation projects and occasional dry farms in the valleys are the only arable lands.

Peneplanation appears to have developed over the area in pre-Pliocene or early Pliocene times. The existence of northward flowing streams before the late Pliocene in most of the western mountain valleys is suggested by persuasive evidence. In the late Pliocene a large regional subsidence, now marked by the Snake River Plain, was accompanied by a gentle complementary arch to the north which disturbed this earlier drainage and set up new drainage in these valleys similar to that at present.

The sedimentary column of the area includes a large number of important and well-known formations reaching a thickness of about 36,000 feet and comprises sediments of Cambrian (?). Ordovician, Devonian, Carboniferous, Triassic, Jurassic, Cretaceous, Tertiary, and Quaternary ages.

An attempt has been made to identify, correlate, and segregate these formations throughout the entire area and their main masses are indicated by sketch boundaries.

The igneous geology of the region is represented by a variety of volcanic and extrusive occurrences. A large number of lava and cinder cones and their associated phenomena dot the plain and three lava series, distinct in age, are found in different parts of the area. One series represents early Tertiary lavas chiefly of andesitic type, another series of about Pliocene (?) age are chiefly acid but contain basalts and andesites, and the third group are chiefly Quaternary (possibly some Pliocene (?) ) basalts. The first two have been folded and faulted more than the third series which is relatively undisturbed.

The Snake River Plain is the greatest structural feature of the region. It is believed to constitute in this area a gentle downwarp or subsidence which was at least 50 miles wide and at least 150 miles long. The acidic Pliocene (?) lava flows which were poured out over a relatively flat surface, and over a wide area, before subsidence, now may be found pitching to the long axis of the great syncline from each side and around the east end. They disappear under later basaltic flat-lying lavas and are covered at every place except along the edges of the downwarp, or where erosion has revealed them.

Four overthrust faults of great magnitude lie in the western mountainous area.

One overthrust fault with an eastward thrust which brings Carboniferous formations into a position overlying younger Triassic sediments was mapped near Medicine Lodge Creek. This is believed by the writer to be a northern extension of the notable Bannock overthrust which plunges beneath the lava covered Plain on its southeast, with almost identical relations where last visible. The fault extends southerly from that point for a distance of 275 miles. The writer's assumption extends the probable length of this fault yet another 100 miles.

The Lost River, Hawley Mountain, and Lemhi overthrust faults differ in having westward thrusts. The overthrust slice, in each case, makes the range for which the fault is named. Several thousand feet of vertical displacement and much more horizontal displacement are represented by these faults. The mountain masses are canted to the northeast and are completely folded and faulted on a smaller scale.

Monoclinal and gently folded structures were found in the Cretaceous sediments of the Centennial Mountains but each of these was partly concealed by overlying lavas. Areas suspected of oil bearing possibilities by the laymen of the locality proved to be unfavorable. A few areas, however, north of the Plain near the Montana state line in Clark County are not unfavorable. They contain beds which have produced petroleum at other localities and have several of the factors thought to be necessary for favorable prospecting areas. Poorly delineated structures, which are partly concealed by lava, preclude recommendations for a test until these beds or similar ones have proven productive in nearby areas.

An examination was made for phosphate and although some shales revealed a low phosphate content, none were found within the area which had commercial value even had they been easily accessible.

A three-foot exposure of good coal crops out on the state line at the head of Cottonwood Creek in the Centennial Mountains. A futile attempt has been made to mine this for local use, but the rugged topography and attendant difficulty of transportation has discouraged development. The seam appears to be in the east limb of a wide and gently folded syncline. Several days spent in searching for a possible exposed western limb closer to rail transportation were fruitless. Many other areas and samples were examined for coal but without favorable results. Prospecting in the vicinity of Humphrey appears justified.

A commercial grade of bentonite, a peculiar type of clay with extraordinary absorptive qualities, was found at two localities in the area. One is near the railway in the vicinity of Mackay, the other is more remote and lies west of Dubois.

The chief water resource not as yet utilized, is the lost flow of Birch and Medicine Lodge creeks and Big and Little Lost rivers. Wells drilled in the alluvium and gravel covered "sink" areas should produce sufficient water for irrigation. Several thousand acres might thus be claimed if marketing conditions were improved.

Building stone, distinguished for its variety of color, abundance, ease of extraction and dressing, is easily accessible and represents one of the most important mineral resources of the region. It offers considerable opportunity for exploitation.

Various excellent road materials occur in abundance. In general, it may be said that no startling finds of non-metallic mineral resources resulted from the field examination. Considerable value, however, probably was derived from the data collected which served to round out a fuller understanding of physiographic, stratigraphic, and structural development of this part of the state and the Rocky Mountains. Some new conceptions were necessary to explain the evidence.

No endeavor was made to study in detail the rather extensive and well-known metalliferous resources in the northwestern portion of the area inasmuch as the time for study was quite limited and as this portion of the area has been studied by the U. S. Geological Survey, and is covered in the following publications by Joseph B. Umpleby: Geology and Ore Deposits of the Mackay region, Idaho. U. S. Geol. Survey Prof. Paper 97, 1917, to which reference should be made by persons interested in the metallic mineral resources of the area.